July 14, 2011

Developing a Diverse Conservation Portfolio for Bonneville Cutthroat Trout

Executive Summary

Ensuring the long term persistence of native cutthroat trout in an era of rapid environmental change due to global warming, spread of invasive species, and other factors, requires a diverse conservation portfolio that spreads the risk of loss in an uncertain future across a variety of habitats, populations and management approaches. Rangewide diversity for native trout includes genetic integrity, life history diversity, and geographic (or ecological) diversity. A management portfolio that includes multiple examples of these elements of diversity and large patches of interconnected habitat for resiliency provides a 'no regrets approach' for reducing the threat of biodiversity loss due to climate change. The 3-R framework (Schafer and Stein 2000) provides a structure for describing existing levels of diversity for a subspecies:

- **Representation** – saving existing elements of diversity;
- **Resiliency** – having sufficiently large populations and intact habitats to facilitate recovery from large disturbances and rapid environmental change;
- **Redundancy** – saving enough different populations so that some can be lost without jeopardizing the subspecies.

<u>Conservation Portfolio for Bonneville Cutthroat Trout</u>

Conservation populations of Bonneville cutthroat trout occupy 30% of their historical stream habitat. Although the Bear River and Northern Bonneville basins support some large interconnected populations, many of the populations outside of these strongholds have been fragmented by dams and water diversions or isolated above instream barriers to protect them from nonnative species. Climate change, particularly wild fire and drought, nonnative species, and energy and water development projects are the greatest threats to remaining populations.

Representation:

- Genetic integrity – 70% of conservation populations are genetically pure. However, only 25% of these populations meet the minimum criteria for long-term persistence.
- Life history diversity – 85% of the conservation populations no longer support a migratory life history form. Bear River and Northern Bonneville are the only basins that still contain migratory populations.
- Geographic diversity –39 disjunct peripheral populations remain, occupying less than 15% of the historical peripheral habitat. The average extent for these populations is less than 5 km.

Resiliency: 26 populations (16%) are classified as resilient, six of which function as metapopulations with a migratory life history. Four of the metapopulations are found in the Bear River basin. Of the 26 resilient populations, just eight are classified as genetically pure while another 12 are of mixed stock where both hybridized and pure fish coexist within a population.

Redundancy: Less than 35% of the conservation populations satisfy the persistence and genetics criteria for contributing to the redundancy portion of the portfolio. Eight of the 20 sub-basins currently occupied meet portfolio objectives while six no longer contain any populations. The Bear River and Northern Bonneville basins meet the goal of supporting at least one metapopulation.

<u>Conservation Priorities</u>

Securing and diversifying the existing portfolio for Bonneville cutthroat trout requires a diversity of management approaches. The security of the resilient populations in the Bear River and Northern Bonneville basin can be increased with habitat protection and restoration strategies and control of nonnative species. In the West Desert and Southern Bonneville basins the management emphasis is on building redundancy by increasing the size and extent of existing populations where the habitat is available as well as replicating these populations into other suitable habitats.

Developing a Diverse Conservation Portfolio for Western Native Trout

A fundamental goal of conservation is to protect and restore biodiversity. Biologically rich communities are better able to withstand disturbance and swings in environmental conditions that would destabilize communities dominated by few species or populations. The ability of diverse natural systems to maintain their function and productivity in the face of rapid environmental change has been termed the 'portfolio effect,' a concept analogous to the desire among financial managers to maintain a diverse economic portfolio as a hedge on uncertain futures (Figge 2004). For natural resources, increasing the biological diversity within a management portfolio decreases the risk of widespread subspecies decline. Furthermore, increasing the variety of approaches to population management also helps spread future risk. These concepts are applicable to entire ecosystems as well as individual species or subspecies (Schindler et al. 2010).

The portfolio for western native trout historically included a variety of life history strategies and genetic diversity that enabled them to occupy a wide range of habitats and adapt to changing environmental conditions. Today, the loss and degradation of habitat from land conversion, resource development, demand for water and spread of invasive species has homogenized the portfolio for many species and subspecies. All of the native trout have declined dramatically from their historical ranges and many are listed as endangered or threatened species or are candidates for listing. This situation is further exacerbated by rapid global warming which is likely to have significant negative impacts on most native salmonids (Haak et al. 2010a; Mote et al. 2003), particularly those that have lost substantial amounts of their historical diversity. Not only will rising air temperatures increase the temperatures of lakes and streams, but also the frequency and intensity of disturbances such as flooding, drought and wildfire (Poff 2002; Williams et al. 2009; Haak et al. 2010a). Populations containing migratory individuals have the ability to occupy varying habitats as environmental conditions change. The ability of fluvial or adfluvial fish to connect subpopulations helps spread risk across dynamic landscapes (Rieman et al. 2000). Isolated populations have lost these abilities.

Restoring a diverse conservation portfolio for western native trout requires the inclusion of at least some proportion of the life history, habitat, genetic, and population diversity that has allowed these fishes to succeed and persist over time despite disturbances and changes to their environment. Diversity is preferred whereas the reliance on one life history form, habitat type or management approach should be avoided. The concept can be illustrated in the use of instream barriers to isolate native trout from downstream nonnative species. On the one hand, isolation of populations may provide the best available protection from displacement by or hybridization with nonnative trout, but at the same time, isolation of small populations will increase their vulnerability to extirpation from disturbance (Fausch et al. 2009). Therefore, a diverse portfolio would include some populations isolated above barriers and others maintained in larger, more interconnected stream systems.

In order to provide a structure to describe existing and potential future levels of diversity within a conservation portfolio, we adopt the 3-R framework of **Representation** (protecting/restoring diversity), **Resilience** (having sufficiently large populations and intact habitats to facilitate recovery from rapid environmental change), and **Redundancy** (saving enough different populations so that some can be lost without jeopardizing the species) (Shaffer and Stein 2000). The US Fish and Wildlife Service adopted these principles in developing recovery plans for listed species (Carroll et al. 2006). Therefore, proactive adoption of this strategy might preclude the need to list additional native trout as threatened or endangered species.

Table 1 provides a more complete description of the application of the 3-R framework to native trout. Representation encompasses three population attributes important to diversification of the subspecies' portfolio: genetic purity, life history, and geography. Each of these elements are quantified based on the number of conservation populations that are genetically pure, exhibit a migratory life history form (fluvial or adfluvial), or occupy a unique geographic region as indicated by the presence of peripheral populations.

Resilience in the portfolio is quantified based on the presence of strongholds or metapopulations, applying criteria on stream habitat extent and patch size from Hilderbrand and Kershner (2000) and Rieman et al. (2007). Redundancy provides a spatial hedge against losses by securing multiple populations within each sub-basin of the historical range. In order for a population to count towards redundancy it must satisfy criteria for both genetic purity and persistence. The genetic purity standard allows for some introgression (up to 10%) while the determination of persistence applies criteria on occupied habitat extent, patch size and population density from Hilderbrand and Kershner (2000) and Rieman et al. (2007).

Management Goal	Objectives	Indicators of Success
Representation	1. Conservation of genetic diversity 2. Protection and restoration of life history diversity 3. Protection of geographic (ecological) diversity	1a. Presence of genetically pure populations 2a. Presence of all life histories that were present historically 3a. Presence of peripheral populations
Resilience	1. Protect/restore strongholds 2. Protect/restore metapopulations	1a. Occupied stream habitat exceeds 27.8 km and habitat patch size exceeds 10,000 ha 2a. Occupied stream habitat supports migratory life history and exceeds 50 km and habitat patch size exceeds 25,000 ha
Redundancy	1. Protect multiple populations within each sub-basin	1a 10 replicate populations within each sub-basin, or 1b. 5 persistent populations within each sub-basin, or 1c. 2 or more strongholds within each sub-basin, or 1d. 1 metapopulation within each sub-basin 2. 1 metapopulation within each river basin

Table 1. Goals, objectives, and indicators of success in the conservation of western native trout.

Hilderbrand and Kershner (2000) have provided quantifiable criteria for the amount of habitat needed to maintain populations large enough to reduce the risk of demographic and genetic collapse. A general conservation goal is to maintain an effective population size of at least 500 interbreeding adults, which for inland trout equates to a census population size of approximately 2,500 individuals greater than or equal to 75 mm total length (Hilderbrand and Kershner 2000). For small stream populations containing low densities of cutthroat trout, Hilderbrand and Kershner (2000) determined that 27.8 km of habitat was necessary to meet the effective population size of 500. Table 2 provides the criteria used for determining population persistence as it applies to the 3-R framework. Populations that meet any of the four combinations of patch size, habitat extent, and population density are considered persistent for the purposes of this analysis.

Patch Size (ha)	Stream Habitat (km)	Population Density (Fish > 150 mm TL)
>=5,000	>= 13.9	Any
< 5,000	>= 27.8	Any
< 5,000	13.9 – 27.8	Moderate 31-93 fish/km
Any	9.3 – 13.9	High > 93 fish/km

Table 2. Minimum criteria for determining population persistence. Population density categories are constrained by density ranges reported in the rangewide status assessment (May and Albeke, 2005, 2008) for individuals 150 mm or longer total length (TL).

Rieman et al. (2007) is applied for the determination of sub-basin goals for redundancy based on their assumption that vulnerability is related to size and number of habitat patches. A minimum of five non-networked populations that meet our persistence criteria or two stronghold populations or one metapopulation are required within each sub-basin to satisfy the objectives for redundancy. Our analyses based on population size and extent reflect requirements for persistence from a demographic perspective. However, we also recognize that increases in habitat quality and/or quantity will help to ensure the long-term viability of populations and subspecies as a whole (i.e. incorporating ecological and adaptive processes, see Fausch et al. 2006 and McElhany et al. 2000) by reducing the vulnerability of these populations to loss from environmental disturbance.

For arid regions that do not have adequate available or potential habitat to meet Hildebrand and Kershner's (2000) habitat length criterion, we have developed a modified indicator for meeting redundancy. In these areas we retain the goal of an effective population size of 500 interbreeding adults (or 2,500 total population size for fish greater than or equal to 75 mm TL, or 1,250 total population size for fish greater than or equal to 150 mm TL) but eliminate the habitat requirement. For these "replicate populations" we establish a goal of 10 populations per sub-basin to meet redundancy requirements. This increased number of populations recognizes their reduced conservation value relative to populations that meet both population size and habitat length criteria. This modified goal would apply only in areas characterized by reduced habitat availability, such as sub-basins containing only disjunct populations (Haak et al. 2010b).

Although the following analyses use the most recent rangewide population data available (May and Albeke (2005, 2008), local population conditions may exist that are not reflected in our assessment. Therefore, it is important that the results of our analyses are considered in conjunction with more detailed knowledge of local conditions to devise the most appropriate strategy.

Applying the 3-R Framework to Bonneville Cutthroat Trout

Our application of the 3-R framework uses a hierarchy of geographic scales to analyze current conditions and establish measurable goals for development of the conservation portfolio. Figure 1 shows the historical range of Bonneville cutthroat trout to illustrate the relative size of each geographic unit used in our assessment. Conservation populations are the building blocks of the portfolio while sub-basins and basins are used to set conservation goals that ensure the presence of viable populations across the full extent of the historical range.

Figure 2 shows the current and historical distributions of Bonneville cutthroat trout at the subwatershed scale. May and Albeke (2005, 2008) identified over 4,000 km of occupied stream habitat, including 167 conservation populations in 3,356 km of that habitat based on important genetic and/or life history traits. Three of these populations were reintroduced in Nevada outside of the historical range and were not included in the following analyses. The remaining 164 conservation populations are the focus of this report.

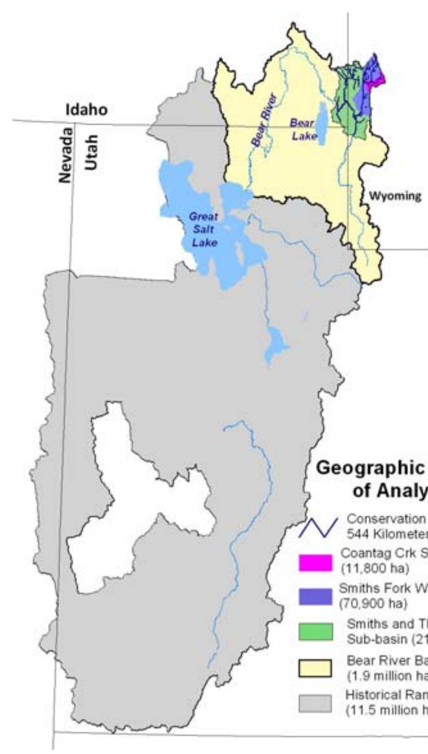

Figure 1. Geographic scales used in development of the Bonneville cutthroat trout conservation portfolio.

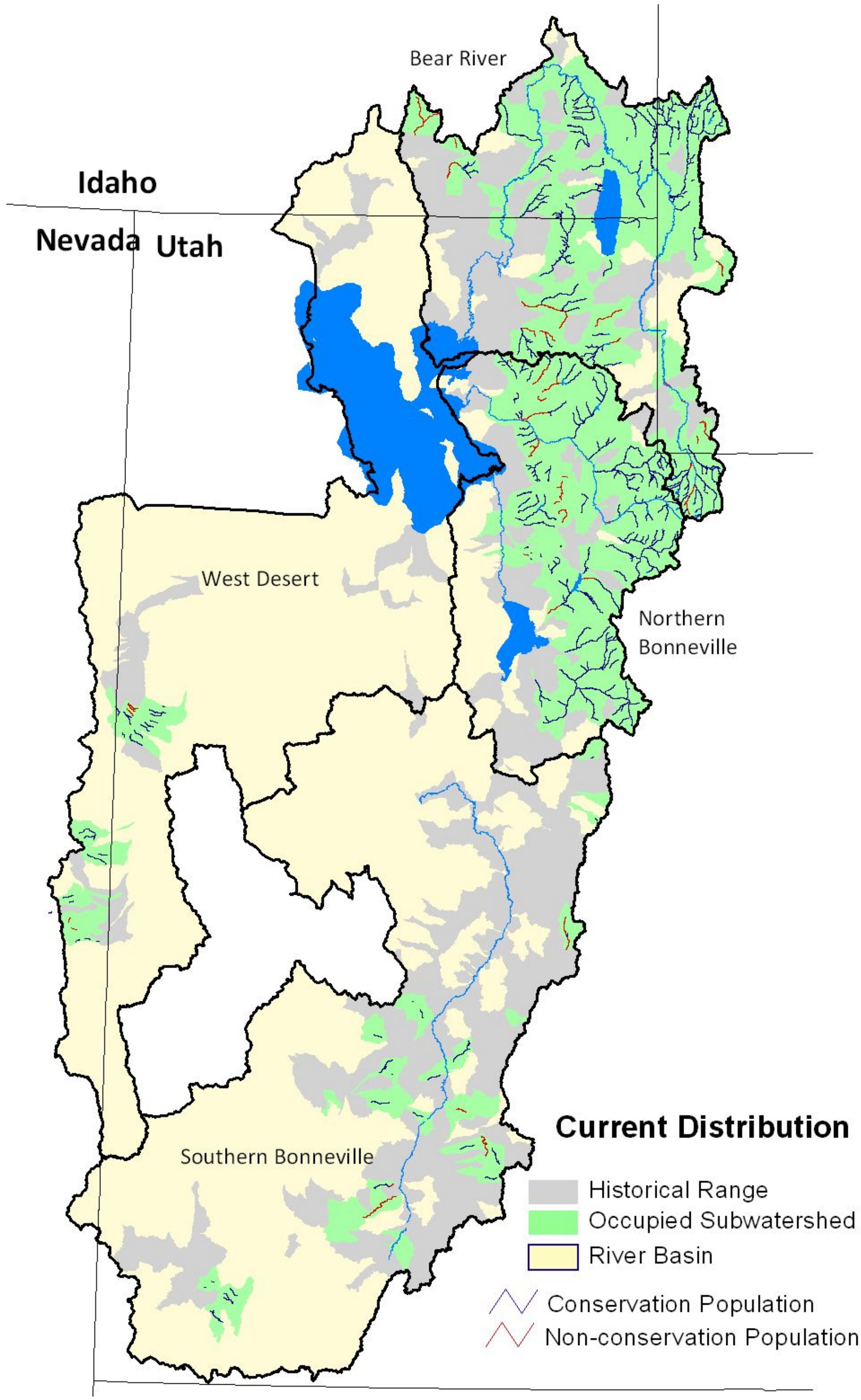

Figure 1. Distribution of Bonneville cutthroat trout: 1800's and 2008. Historical range is shown in gray while currently occupied subwatersheds are in green. Conservation populations (blue lines) occur in 216 of the 269 occupied subwatersheds.

Representation

The representation component of the portfolio addresses within species diversity through the conservation and restoration of the following three population attributes:

- Genetic integrity;
- Life history diversity;
- Geographic diversity.

Our assessment of representation is based on population data on genetics, and life history from May and Albeke (2005, 2008) and on an analysis of peripheral populations from Haak et al. (2010b).

Genetic Integrity

Hybridization with nonnative salmonids, particularly rainbow trout, is the greatest threat to the genetic integrity of Bonneville cutthroat. Figure 3 shows the results of our analysis of genetic integrity. Populations are classified as genetically unaltered if they are 99% pure through-out 80% or more of their occupied habitat (green on map). They are classified as hybridized if 80% or more of the occupied habitat contains fish that are less than 90% pure (dark red on map). In situations where both pure and hybridized individuals are found within different reaches of a single population and neither occupies more than 80% of the habitat, the entire population is classified as 'mixed' (red on map).

70% of the populations are classified as genetically pure, many of which are found in isolated habitats where less than 25% satisfy the minimum criteria for long-term persistence. The Nounan reach of the Bear River supports the most extensive genetically pure population remaining (218 km) while the Chalk Creek population in the Northern Bonneville basin has the second largest extent (179 km). All but two of the populations in the West Desert and Southern Bonneville basins are genetically pure but only five satisfy our criteria for long-term persistence.

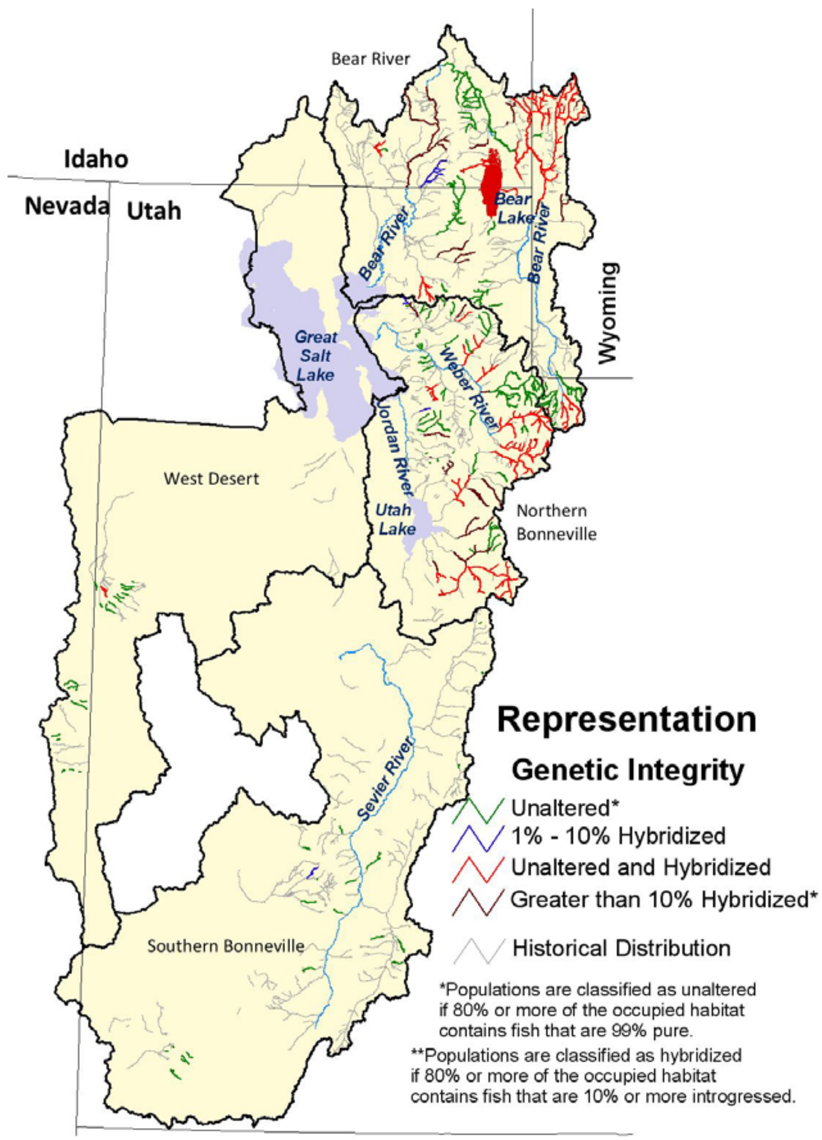

Figure 3. Representation: genetic integrity. Of the 164 conservation populations, 127 are genetically unaltered and occupy 1380 km of habitat.

Life History Diversity

Historically, Bonneville cutthroat trout exhibited a variety of behavioral strategies that enabled them to exploit different habitats including small streams, larger rivers and lakes. Migratory life history forms were well represented as individuals could move among subpopulations and habitats to support different life stages. Adfluvial and fluvial life history forms move to lakes or large rivers, respectively, for food and growth before returning to their natal tributary streams for spawning while the resident form spends the entire life cycle in smaller stream systems. Fragmentation of habitat from man-made structures such as diversions, dams and culverts and a management strategy of isolation above barriers for protection from nonnative species have separated formerly migratory populations from their feeding and growing habitats. This has resulted in a disproportionate number of resident populations and the loss of evolutionary potential for adaptation to environmental change. These isolated populations are at greater risk of extinction since they have lost their ability to move in response to disturbance events such as floods and wild fires and are unable to recolonize disturbed habitats once they have recovered.

Figure 4 shows the results of our analysis of life history diversity. The Bear River and Northern Bonneville basins contain a total of 24 migratory populations: 14 fluvial, 8 adfluvial and two that support both migratory forms. Historically the Southern Bonneville basin likely supported fluvial populations in the mainstem of the Sevier River. Currently populations are isolated in small tributary streams and no longer have access to the larger river system. The West Desert also supports only the resident form although this is likely consistent with historical conditions in these truncated drainages. However, many of the remaining populations occupy more limited extents in these streams than they did historically due to water diversions, instream barriers, and habitat degradation.

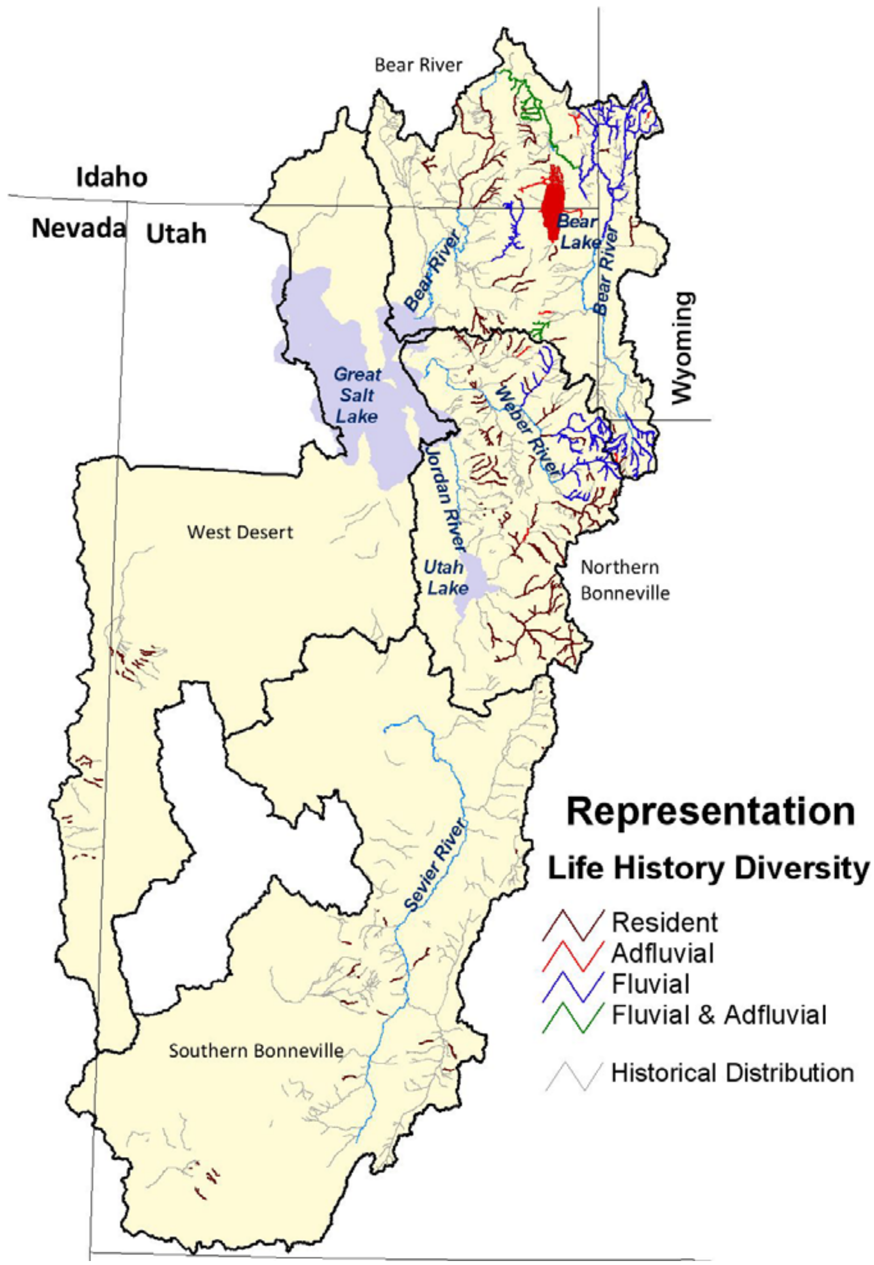

Figure 4. Representation: life history diversity. 24 populations support a migratory life history form: 14 fluvial, 8 adfluvial, and 2 that support both.

Geographic Diversity

Bonneville cutthroat trout have evolved in a variety of habitats ranging from the high desert in eastern Nevada and western Utah to the forested mountains around the Idaho, Utah, and Wyoming border. Preserving the local genetic diversity and adaptations required to persist across these varied landscapes is an important objective of the Representation strategy. In this assessment we use peripheral populations as an indicator of geographic diversity.

Peripheral populations are those found at the geographic edge of a species' range. They have a high conservation value due to their potential for unique genetic adaptations that have allowed them to occupy marginal habitats at the limits of environmental suitability for a species (Hampe and Petit 2005). Our rangewide assessment of peripheral populations for native cutthroat trout distinguishes between continuous peripheral and disjunct peripheral populations (see analysis details in Haak et al. 2010b). Disjunct populations are those that are separated from the core such that genetic interactions are precluded while continuous populations occupy the outer edge of a species' range. For the purposes of this portfolio, both types are of equal conservation value.

Historically, disjunct populations of Bonneville cutthroat trout occupied over 1,300 km of habitat in the West Desert and Southern Bonneville basins outside of the Sevier River drainage (Haak et al. 2010b). Figure 5 shows remaining disjunct peripheral populations (there were no continuous peripheral populations historically). Twenty-nine are found in the West Desert and another 10 remain in the Southern Bonneville basin. Together these populations occupy 194 km of habitat, less than 15% of their historical distribution. All but two of these disjunct populations are genetically pure but with an average extent of just 5 km they are highly vulnerable to disturbance events.

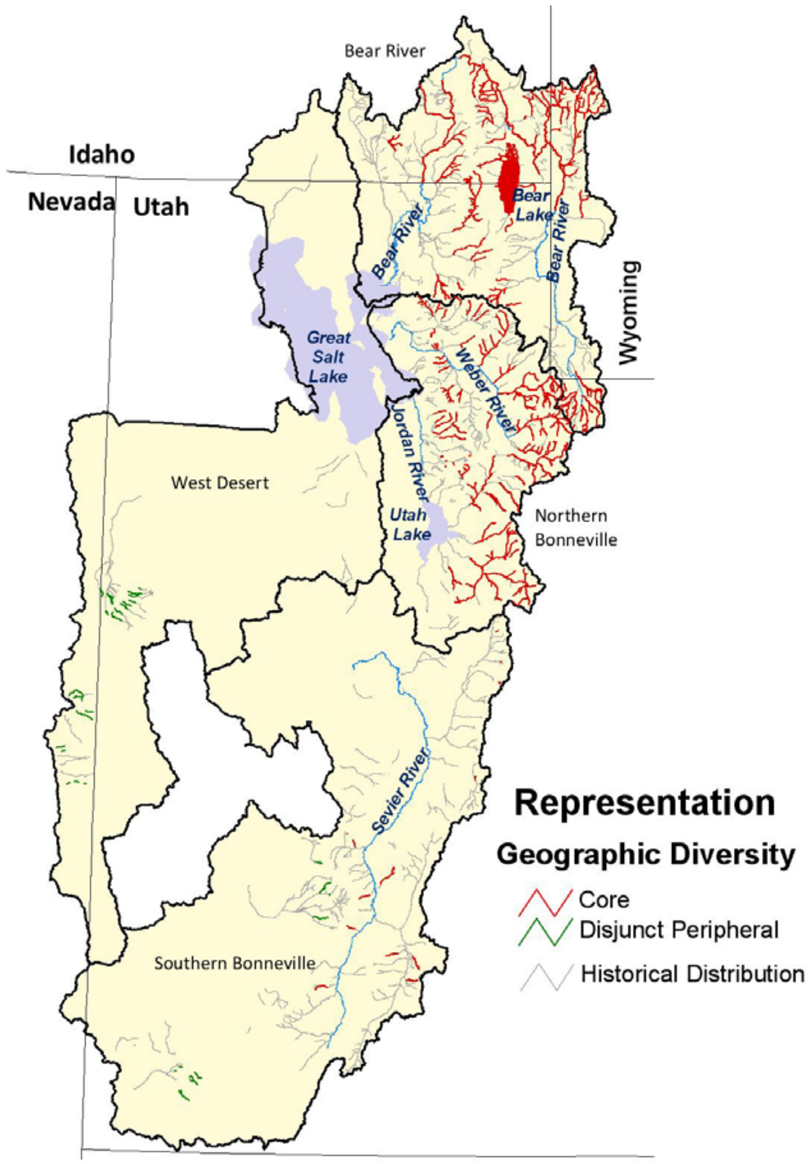

Figure 5. Representation: geographic diversity. Thirty-nine disjunct peripheral populations remain occupying 194 km of habitat in the West Desert and Southern Bonneville basins.

Resilience

In addition to restoring and protecting representative populations, a diverse portfolio should also include large interconnected populations, which are more likely to survive disturbances brought on by global warming. Populations with access to extensive and varied habitats are better able to survive and adapt to change than isolated populations with no options for relocation. A stream system temporarily degraded by a wildfire, flood or drought is more likely to be recolonized once conditions improve if it is part of a larger interconnected network.

Our assessment of resilience applies occupied habitat and patch size thresholds from Hilderbrand and Kershner (2000) and Rieman et al. (2007) to identify strongholds and metapopulations. Strongholds are defined as populations with an extent greater than 27.8 km of interconnected stream habitat and a habitat patch size of at least 10,000 ha while a metapopulation occupies at least 50 km of interconnected stream habitat, has a habitat patch size of 25,000 ha and supports a migratory life history.

Figure 6 shows the results of our assessment of resilience for Bonneville cutthroat trout. There are 26 conservation populations classified as resilient, occupying 2,290 km (68%) of the stream habitat (green or blue on map). Of these, 6 populations are classified as metapopulations with a migratory life history and occupy a total of 1,200 km of habitat (green on map). The Southern Bonneville and West Desert basins do not contain any resilient populations.

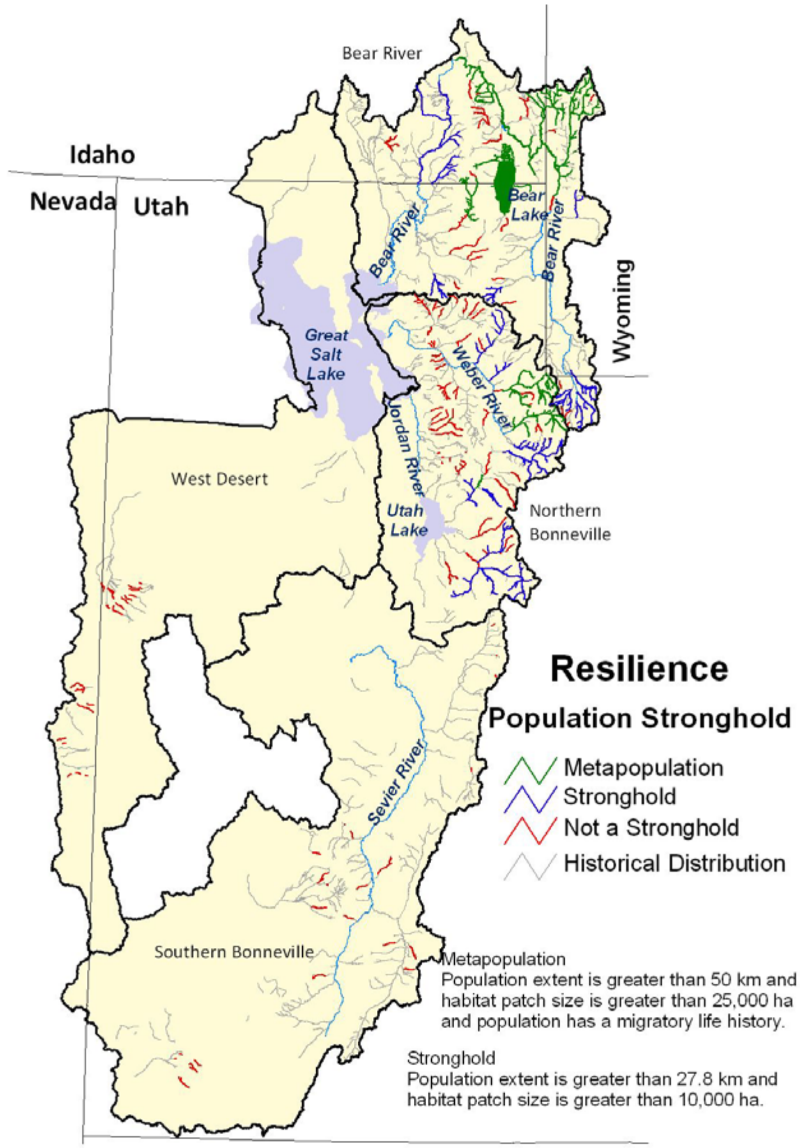

Figure 6. Resilience: 26 conservation populations are classified as resilient including 6 metapopulations (green on map.)

Redundancy

Redundancy provides the insurance that some populations can be lost without jeopardizing the subspecies. We rely on our assessment of population persistence and follow Rieman et al. (2007) to establish rangewide goals for redundancy. Since redundancy is intended to preserve genetic diversity across the subspecies' range, we have combined genetic integrity with our persistence analysis to identify those populations that contribute to the redundancy portion of the portfolio. Ideally we would only consider genetically pure populations.

However, many of the large well-connected populations contain hybridized individuals inter-mixed with unaltered fish. Therefore, referring back to Figure 3, all populations except for those classified as hybridized (dark red on Figure 3) contribute to redundancy if they satisfy the persistence criteria. At a minimum our goal is to secure five persistent populations or two stronghold populations that meet our genetics criteria within each sub-basin across the historical range. Recognizing that many of these populations are still limited compared to their historical extents, we have also set a goal of at least one metapopulation within each major river basin of the historical range. The West Desert and portions of the Southern Bonneville are characterized by extremely small habitats and disjunct peripheral populations. For these reasons, we adopt a modified redundancy goal of 10 replicate populations per sub-basin.

Figure 7 shows the results of our assessment of redundancy. Of the 164 conservation populations analyzed, 64 satisfy the minimum criteria for persistence. Of these, 47 populations also meet the genetics standards and therefore contribute to the redundancy portion of the portfolio (green on map). An additional seven populations (one in the Southern Bonneville and six in the West Desert) are classified as replicate populations and also contribute to redundancy, albeit with a reduced value.

Eight of the 20 currently occupied sub-basins meet our population goals for redundancy and six historically occupied sub-basins no longer contain any populations. Only the Bear River and Northern Bonneville basins satisfy our goal of supporting at least one large interconnected population with a migratory life history.

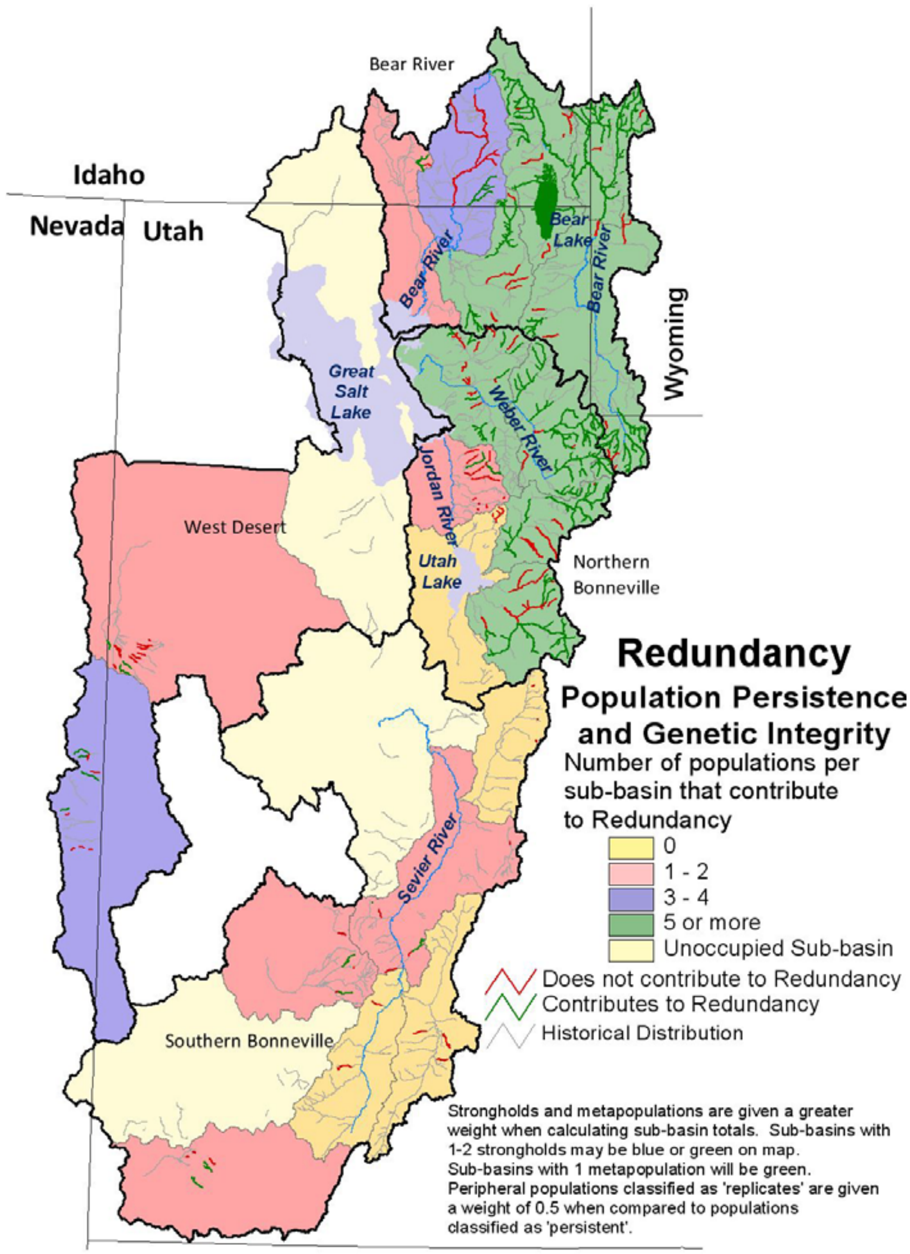

Figure 7. Redundancy: 47 persistent populations contribute to redundancy as well as seven replicate populations. Eight sub-basins satisfy the goal of five persistent and non-hybridized populations. The Northern Bonneville and Bear River basins also satisfy the goal of supporting at least one metapopulation.

Bear River Watershed Restoration

State and federal agencies along with Trout Unlimited and other partners are engaged in a multi-year effort to restore the historically important but now increasingly rare migratory life forms of Bonneville cutthroat trout in the Bear River watershed of SE Idaho, SW Wyoming and NE Utah. Our work in impacted areas of the watershed reconnects isolated tributary habitats and populations by restoring historic migration corridors. Within intact portions of the watershed we protect stronghold populations and their habitats by installing fish screens in irrigation canals to eliminate entrainment mortality, and advocating for the protection of critical roadless areas on public lands. The combination of migratory life histories, intact migration corridors, and accessible refuge habitats provides representation, redundancy, and resilience for the native BCT population in the Bear River watershed.

Representation—Migratory fish once provided a critical link between tributary habitats and main stem river and lake habitats. They moved large distances to take advantage of abundant food resources at lower elevations, but returned each spring to the pristine spawning and rearing habitats in headwater tributaries. Human settlements and associated habitat fragmentation and degradation were focused on main stem rivers and lakes, and impacted these migratory fish first. Now migratory life histories have been documented in fewer than 10% of existing BCT populations. TU's Bear River projects have restored migration corridors and increased numbers of migratory fish in the watershed in an effort to save this critical 'piece' of the native trout puzzle.

Resilience—Several areas within the Bear River watershed harbor large, connected habitat patches and BCT metapopulations. These strongholds build resilience and are prioritized for protection. Our fish screen projects in these areas have eliminated entrainment and mortality of native fish in irrigation systems. We have advocated for the protection of critical headwater roadless areas and against development projects that would erect new migration barriers and degrade additional main stem and tributary habitats.

Redundancy—Restoration projects also target historically important tributary habitats that became inaccessible to BCT populations when irrigation dams were constructed and streams were channelized or rerouted. We remove fish passage barriers and rebuild degraded stream channels to allow BCT and other native fish to recolonize historic tributary habitats. By reestablishing an intact network of loosely connected resident populations we build redundancy to buffer the population against environmental and demographic stochasticity—natural processes that are exacerbated by human activities and climate change.

Figure 8 provides the geographic reference for the sub-basin summaries of each of the portfolio elements presented in Tables 4-7. The sub-basins on the map provide the results of the redundancy assessment and the populations that contribute to redundancy are classified according to their resilience with the metapopulations (green on map) being the most resilient. The labels associated with each sub-basin (e.g. BR-01, NB-01) are referenced in Tables 4-7.

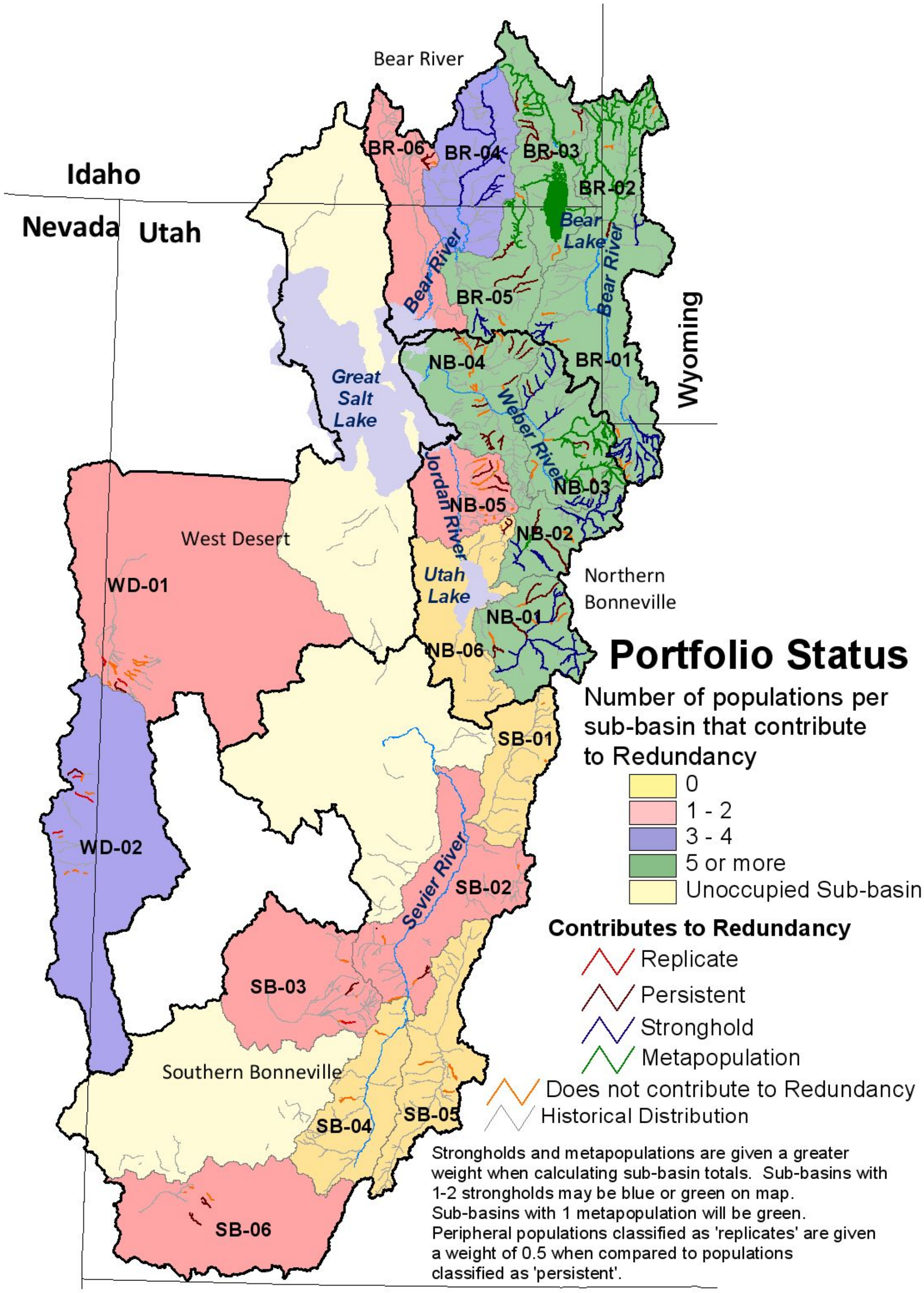

Figure 8. Conservation Portfolio: Sub-basin summaries of portfolio elements are described in Tables 4-7 according to the labels shown on the map (e.g. BR-01, WD-01)

Portfolio Status and Opportunities

Rangewide Summary (Table 3)

Results of the existing portfolio status for Bonneville cutthroat trout are summarized at the population level for each of the four occupied river basins within the historical range. The lack of resilience, redundancy, and life history diversity in the West Desert and Southern Bonneville basins underscores the vulnerability of these important peripheral populations to environmental change. Although the Northern Bonneville and Bear River basins contain all of the portfolio elements, further work is needed to secure them. The relatively low population counts for genetic integrity are indicative of the threat posed by hybridization while the low counts for redundancy indicate that many of the genetically pure populations do not meet the minimum criteria for persistence. Controlling nonnative species and restoring large interconnected populations throughout the historical range will increase the resilience of the entire portfolio.

			Representation			**Resiliency**		**Redundancy**
Basin	**Total Number of Pops.**	**Occupied Stream Habitat (Km)**	**Genetic Integrity (pops.)**	**Life Hist. Diversity (pops.)**	**Geographic Diversity (pops.)**	**Strong-hold (pops.)**	**Meta-pop. (pops.)**	**Persistent or Replicate & <= 10% Introgressed**
Bear River	37	1727	19	5 adfl. 8 fluv. 2 both	NA	10	4	15
Northern Bonneville	73	1344	43	3 adfl. 6 fluv.	NA	10	2	26
Southern Bonneville	25	150	24	0	10 disj.	0	0	5
West Desert	29	127	28	0	29 disj.	0	0	8
Total	164	3348	114	24	39	20	6	54

Table 3. Rangewide summary of portfolio for Bonneville cutthroat trout.

Building Resistance and Resilience to Climate Change

Our analysis of climate change risk to Bonneville cutthroat trout is based on the coarse filter assessment of four environmental factors described in Haak et al. (2010a): increased summer temperature, increased winter flooding, increased wildfire risk, and protracted drought. Figure 9 shows the composite risk from these four factors at the subwatershed scale across the historical range of Bonneville cutthroat trout. Subwatersheds found to be at high risk for three or four of these factors were classified as having a *very high* composite risk while those at high risk to any two of the factors were classified as *high* risk in Figure 9. Subwatersheds with no high risk and at least two low risk factors were classified as *low* risk and all other subwatersheds were considered to be at *moderate* risk.

Rangewide, nearly 60% of the conservation populations occupy habitat classified as high or very high risk based on the four factors analyzed. Of these, 65% do not meet the minimum criteria for persistence, underscoring the need to build resiliency in the portfolio. Only 20 populations are classified as low risk meaning that nearly all of the populations are at high risk for at least one of the four factors. Drought poses the greatest threat with 91 of the 164 conservation populations occupying habitat classified as high risk while summer temperature is the lowest risk, primarily affecting populations in the West Desert and at the southern extent of the distribution. Winter flooding and wildfire are a high risk for 62 and 78 of the populations, respectively, primarily affecting the mid elevations. Reducing non-climate stressors by restoring degraded habitats, controlling nonnative species and reconnecting isolated populations to larger river systems can mitigate some of these threats and provide Bonneville cutthroat with the opportunity to adapt to changing conditions. In situations such as the West Desert where migratory populations never existed, it is important to build redundancy so that the unique adaptations of these peripheral populations are not lost.

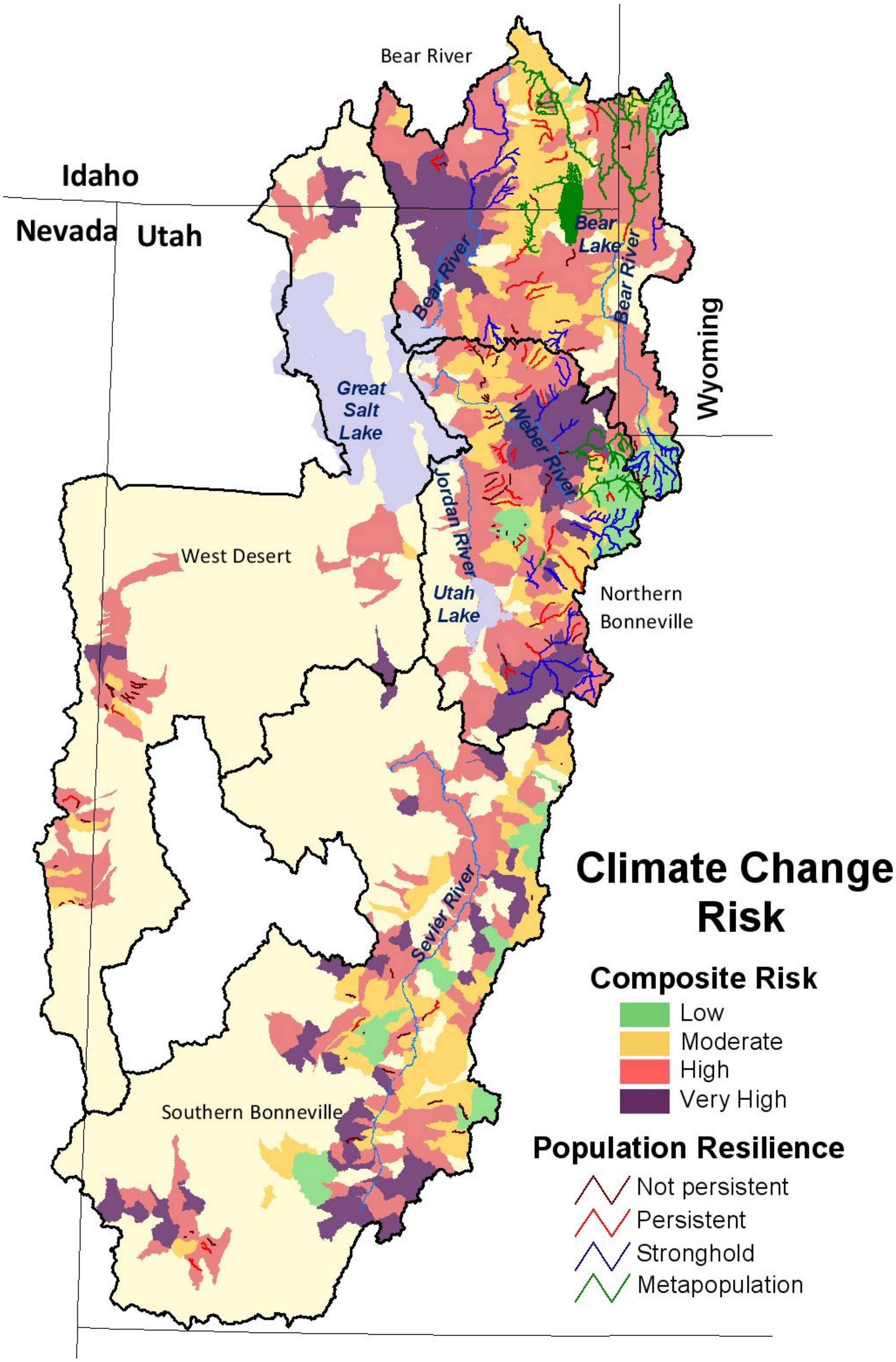

Figure 9. Composite climate risk and population resilience. Drought is the most pervasive threat with winter flooding and wildfire also at high risk in mid elevations and summer temperature a high risk for the low elevations.

Bear River (Table 4)

The Bear River basin is critical to the resiliency portion of the portfolio. It supports over one-half of the occupied stream habitat, the largest occupied lake system, and the majority of the migratory and resilient populations. Securing these important elements of diversity through multi-faceted watershed-scale projects such as the Bear River Watershed Restoration effort (BR-01, 02, 03, 04) is a high priority. Opportunities to create a metapopulation by reconnecting the four strongholds in the headwaters of the Bear River (BR-01) should also be explored. These populations all support a fluvial life history and collectively occupy nearly 200 km of stream habitat, the majority of which runs through U.S. Forest Service roadless areas. The Malad River watershed (BR-06) has experienced the most significant range contraction within the Bear River basin and currently contains only two populations occupying just 5% of the historical habitat in that sub-basin, one of which is greater than 10% introgressed. Although the remaining populations are located on forest service roadless areas, degraded habitat conditions through-out much of the watershed makes restoration challenging, particularly when considered in conjunction with high climate change risks.

			Representation			Resiliency		Redundancy
Sub-basin ID	**Total Number of Pops.**	**Occupied Stream Habitat (Km)**	**Genetic Integrity (pops.)**	**Life Hist. Diversity (pops.)**	**Geographic Diversity (pops.)**	**Strong-hold (pops.)**	**Meta-pop. (pops.)**	**Persistent & <=10% Introgressed**
BR-01	13	319	8	2 adfl. 5 fluv. 1 both	NA	6	0	5
BR-02	3	556	1	1 fluv. 1 adfl.	NA	0	1	1
BR-03	9	383	5	2 adfl. 1 both	NA	0	2	4
BR-04	3	223	0	0	NA	3	0	1
BR-05	7	218	4	2 fluv	NA	1	1	3
BR-06	2	28	1	0	NA	0	0	1
Total	37	1727	19	15	NA	10	4	15

Table 4. Results of the portfolio analysis for individual sub-basins within the Bear River system.

Northern Bonneville (Table 5)

The Northern Bonneville basin is also an important source of resiliency and life history diversity for the portfolio. The Weber River watershed (NB-03 and NB-04) contains the only two metapopulations within the basin and seven of the nine migratory populations. Much of the occupied habitat in the upper reaches of the Weber River is associated with forest service roadless areas and of high quality. A watershed scale restoration effort within the upper Weber that controls nonnative species and increases interconnectivity by extending these populations downstream into the mainstem of the Weber would help to secure these populations and the overall resiliency of the portfolio. Populations in the lower reaches of the Weber (NB-04) occur in lower quality habitat and are more fragmented with only nine of the 20 populations meeting our persistence criteria. In this sub-basin securing existing populations by controlling nonnative species and increasing persistence to build redundancy should be a priority.

The Jordan River watershed also presents opportunities for building resiliency in the tributaries upstream of Utah Lake (NB-01 and NB-02). Although these sub-basins support six stronghold populations only one-third of the populations are genetically pure, indicating a significant problem with hybridizing species. Although the potential exists to increase resiliency in these sub-basins and restore a fluvial life history, nonnative species will have to be controlled first. In the lower reaches of the Jordan River (NB-05 and NB-06) and smaller tributaries to Utah Lake, there are also significant issues of hybridization and only four of the 17 populations in these sub-basins satisfy persistence criteria. Given the high climate change risk associated with all of the populations in the Jordan River watershed, these small populations are particularly vulnerable to extinction.

			Representation			Resiliency		Redundancy
Sub-basin ID	**Total Number of Pops.**	**Occupied Stream Habitat (Km)**	**Genetic Integrity (pops.)**	**Life Hist. Diversity (pops.)**	**Geographic Diversity (pops.)**	**Strong-hold (pops.)**	**Meta-pop. (pops.)**	**Persistent & <=10% Introgressed**
NB-01	15	325	6	0	NA	3	0	4
NB-02	7	244	2	1 adfl.	NA	3	0	3
NB-03	14	492	9	1 adfl 6 fluv.	NA	4	2	9
NB-04	20	175	15	1 adfl.	NA	0	0	8
NB-05	15	90	11	0	NA	0	0	2
NB-06	2	18	0	0	NA	0	0	0
Total	73	1344	43	9	NA	10	2	26

Table 5. Results of the portfolio analysis for individual sub-basins within the Northern Bonneville system

Southern Bonneville (Table 6)

Extant populations in the Southern Bonneville basin are highly vulnerable to environmental change and stochastic events due to their lack of resiliency and life history diversity. There is also very limited redundancy in this basin placing the remnants of the historical Sevier River population at risk of extinction. These populations represent an important element of the portfolios geographic diversity and all but one are genetically pure making their continued protection from nonnative species particularly important. However, with an average habitat extent of less than 6 km and only four of the 25 populations satisfying our persistence criteria, conservation strategies should emphasize increasing persistence by extending habitats downstream and increasing density by improving habitat quality. In situations where increasing the population extent is not possible, replicating these populations into other suitable habitats within the basin is an important strategy.

			Representation			Resiliency		Redundancy
Sub-basin ID	**Total Number of Pops.**	**Occupied Stream Habitat (Km)**	**Genetic Integrity (pops.)**	**Life Hist. Diversity (pops.)**	**Geographic Diversity (pops.)**	**Strong-hold (pops.)**	**Meta-pop. (pops.)**	**Persistent or Replicate & <=10% Introgressed**
SB-01	3	4	3	0	NA	0	0	0
SB-02	5	34	5	0	NA	0	0	1
SB-03	5	30	4	0	5 disj.	0	0	2
SB-04	3	18	3	0	NA	0	0	0
SB-05	4	26	4	0	NA	0	0	0
SB-06	5	37	5	0	5 disj.	0	0	2
Total	25	150	24	0	10	0	0	5

Table 6. Results of the portfolio analysis for individual sub-basins within the Southern Bonneville system.

West Desert (Table 7)

All of the West Desert populations are disjunct peripheral populations and all but one are genetically pure making them an important element in the portfolios geographic and genetic diversity. Because of the small available and potential habitats, we adopt a modified redundancy goal of 10 populations per sub-basin that meet the effective population criterion regardless of habitat length. It is unlikely that these populations ever supported a migratory life history form and there are few if any opportunities to build larger resilient populations because of limited habitat throughout this region. Conservation strategies for these populations should focus on building redundancy by extending populations downstream where possible, improving habitat conditions to increase population size, and replicating existing populations into suitable habitat.

			Representation			Resiliency		Redundancy
Sub-basin ID	**Total Number of Pops.**	**Occupied Stream Habitat (Km)**	**Genetic Integrity (pops.)**	**Life Hist. Diversity (pops.)**	**Geographic Diversity (pops.)**	**Strong-hold (pops.)**	**Meta-pop. (pops.)**	**Persistent or Replicate & <=10% Introgressed**
WD-01	17	75	16	0	17 disj	0	0	3
WD-02	12	52	12	0	12 disj	0	0	5
Total	29	127	28	0	29	0	0	8

Table 7. Results of the portfolio analysis for individual sub-basins within the West Desert system

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Glossary of Terms

Adfluvial – a life history strategy in which fish born in tributaries migrate to lakes to feed and grow, then return to tributaries to spawn.

Basin – a major hydrologic division of river basins; 6-digit hydrologic unit code.

Conservation population – a population designated by resource managers as important to conservation due to its genetic purity, life history characteristics or adaptation to a unique environment.

Conservation Success Index – a broad-scale index developed by Trout Unlimited to make strategic conservation decisions.

Fluvial – a life history strategy in which fish born in tributaries migrate to larger habitats in mainstem rivers to feed and grow, then return to tributaries to spawn.

Life history diversity – the suite of alternative behaviors and strategies with in a population that help members to survive and reproduce successfully by allowing them to adapt to changing environmental conditions and exploit different habitats.

Genetic purity – the level of introgression or genetic contamination due to hybridization.

Hydrologic unit code – a commonly-used hierarchy of watershed-based planning units.

Metapopulation – a group of spatially separated populations that interact at some level.

Migratory – a population that moves between different habitats to support different stages in its life cycle. For trout, this includes travel between tributary streams and larger mainstem habitats (fluvial) or lakes (adfluvial).

Peripheral population – populations found at the geographic edge of a species' range, typically occupying marginal habitats at the limits of environmental suitability for a species. There are two types of peripheral populations, disjunct and continuous. Disjunct populations are those that are separated from the core such that genetic interactions are precluded while continuous populations occupy the outer edge of a species' range.

Persistence – the likelihood that a population is viable over the long term based on the extent of occupied habitat and population abundance. Populations that are not persistent are more vulnerable to extinction due to a lack of genetic diversity or demographic variability than populations with more individuals in a larger habitat.

Redundancy -- basic tenant of conservation, to save multiple copies of conservation elements so that some can be lost without jeopardizing the species.

Representation – basic tenant of conservation, to save some of everything such that the biological variation across the range of a single species or an entire ecosystem is protected.

Resident – a life history strategy in which fish born in tributaries spend their entire life cycle (growing, feeding and spawning) in a tributary stream.

Resilience – basic tenant of conservation, a population or habitat of sufficient quality to maintain itself in the face of natural or human-caused disturbances.

Subbasin – the first major hydrologic division of a river basin; 8-digit hydrologic unit code.

Subwatershed – a hydrologic subunit of a watershed; 12-digit hydrologic unit code.

Watershed -- a hydrologic subunit of a subbasin; 10-digit hydrologic unit code.

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