May 12, 2011

Developing a Diverse Conservation Portfolio for Yellowstone 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 Stern 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.

Conservation Portfolio for Yellowstone Cutthroat Trout

Conservation populations of Yellowstone cutthroat trout occupy 54% of the historically occupied subwatersheds. Land protection has secured many of the core populations while populations along the margins of the subspecies' range have been fragmented to the extent that many no longer meet the minimum criteria for long-term persistence. Climate change, nonnative species, and land development are the greatest threats to remaining populations.

Representation:

- Genetic integrity – 75% of stream and lake conservation populations are genetically pure. However, many are isolated in small headwater streams, occupying 57% of the currently occupied stream habitat.
- Life history diversity – Yellowstone Lake and the headwaters of Yellowstone River support the largest remaining population that still exhibits fluvial and adfluvial migratory behaviors. Although large migratory populations are found in each of the major river basins, over 50% of the populations no longer harbor migratory components.
- Geographic diversity – six disjunct and 32 continuous peripheral populations remain in the downstream extents of the Lower Snake and Bighorn basins. About 85% of peripheral populations have been extirpated, a much greater rate of loss than for the subspecies as a whole.

Resiliency: 62 populations (20%) are classified as resilient, 37 of which function as metapopulations with a migratory life history. The presence of lake trout in Yellowstone and Jackson lakes threaten the resilience of some of the largest migratory metapopulations remaining. Of the genetically pure populations, just over 10% are considered resilient.

Redundancy: 30% of the conservation populations satisfy the persistence and genetics criteria for contributing to the redundancy portion of the portfolio. Nineteen of the 36 sub-basins currently occupied meet our portfolio objectives. All of the major river basins, with the exception of the Tongue, meet our goal of supporting one metapopulation.

Conservation Priorities

Although the rangewide portfolio for this subspecies contains many important elements, further work is needed to secure them. Protection of small, isolated populations should be balanced with other strategies that protect and restore genetically pure migratory and resilient populations. Nonnative trout introductions have greatly reduced the ability of large natural lakes to support stronghold populations and metapopulations of YCT that are resilient to large-scale habitat disturbances. Reconnecting habitat and controlling nonnative species will improve the diversity of the portfolio. Populations around the margins, particularly in the Lower Snake River and Bighorn basins, are important to the preservation of geographic representation and should be a priority for restoration and protection.

May 12, 2011

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. 5 persistent populations within each sub-basin, or 1b. 2 or more strongholds within each sub-basin, or 1c. 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 et al. 2007) 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.

Although the following analyses use the most recent rangewide population data available (May et al. 2007 and Montana Fish Wildlife and Parks 2010), 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 Yellowstone 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 Yellowstone 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.

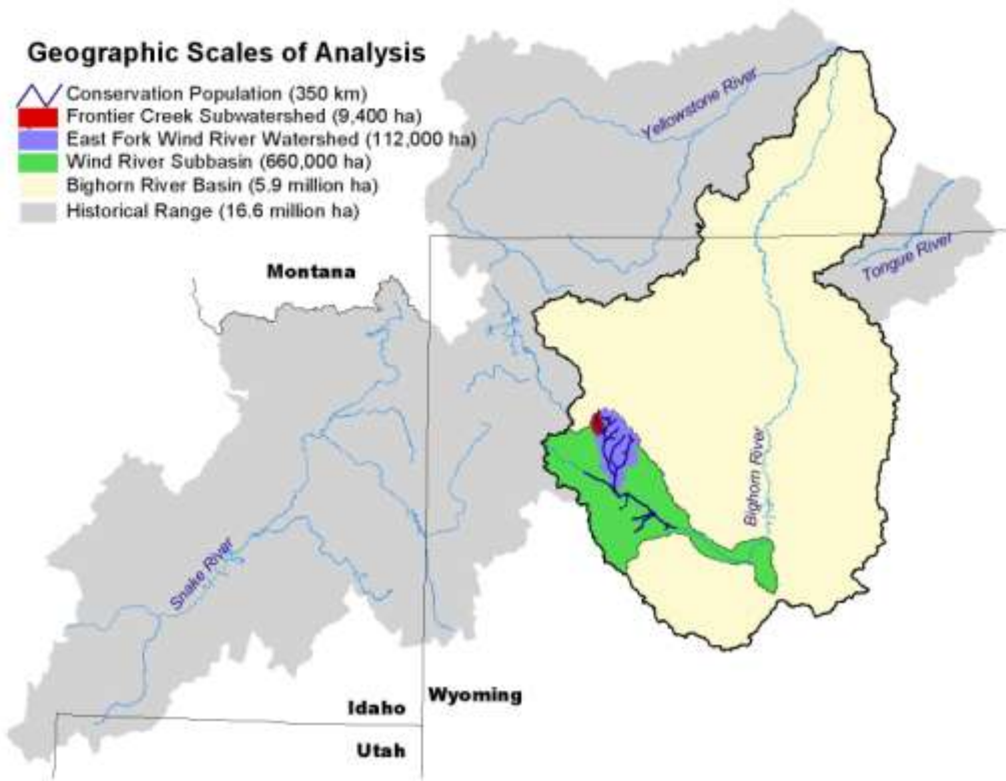

Figure 1. Geographic scales used in development of the Yellowstone cutthroat trout conservation portfolio.

Figure 2 shows the current and historical distributions of Yellowstone cutthroat trout at the subwatershed scale. May et al. (2007) and MFWP et al. (2010) identified over 12,800 km of occupied stream habitat, including 306 conservation populations in 11,700 km of that habitat based on important genetic and/or life history traits. Forty-two of these populations are also associated with 65,000 ha of lake habitat. An additional 78 populations identified are found only in lakes covering 2,000 hectares of habitat. Together, these 384 conservation populations are the focus of this report. We follow May et al. (2007) in combining Yellowstone cutthroat trout with Snake River fine-spotted cutthroat trout for the purposes of this assessment.

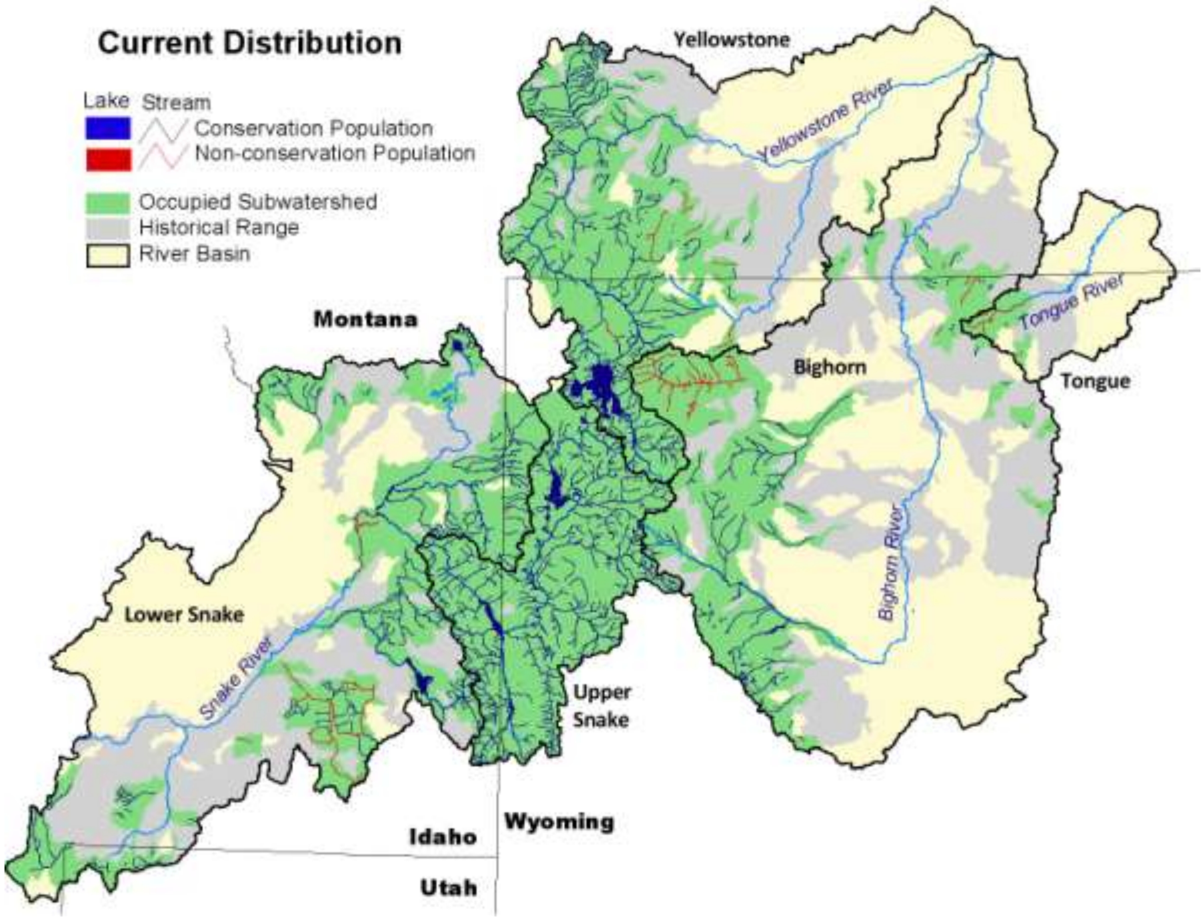

Figure 2. Distribution of Yellowstone cutthroat trout: 1800's and 2008. Historical range is shown in gray while currently occupied subwatersheds are in green. Conservation populations (blue lines) occur in 550 of the 623 occupied subwatersheds.

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 et al. (2007) and MFWP et al. (2010) 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 Yellowstone 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). The populations of Yellowstone cutthroat trout above Yellowstone Lake and in the Upper Snake basin comprise the core of genetically unaltered populations. Populations in the lower reaches of the Yellowstone River and tributaries to the Lower Snake are generally a mixture of unaltered and hybridized. This distribution is illustrative of the increasing pressure being placed on the core populations as rainbow trout move further into the core habitats. Additional pockets of unaltered populations are scattered throughout the range, particularly in the Bighorn basin where small populations have been established in high elevations above waterfalls and in alpine lakes. The Greybull River in the Bighorn Basin provides the most extensive habitat for genetically pure populations outside of the core area.

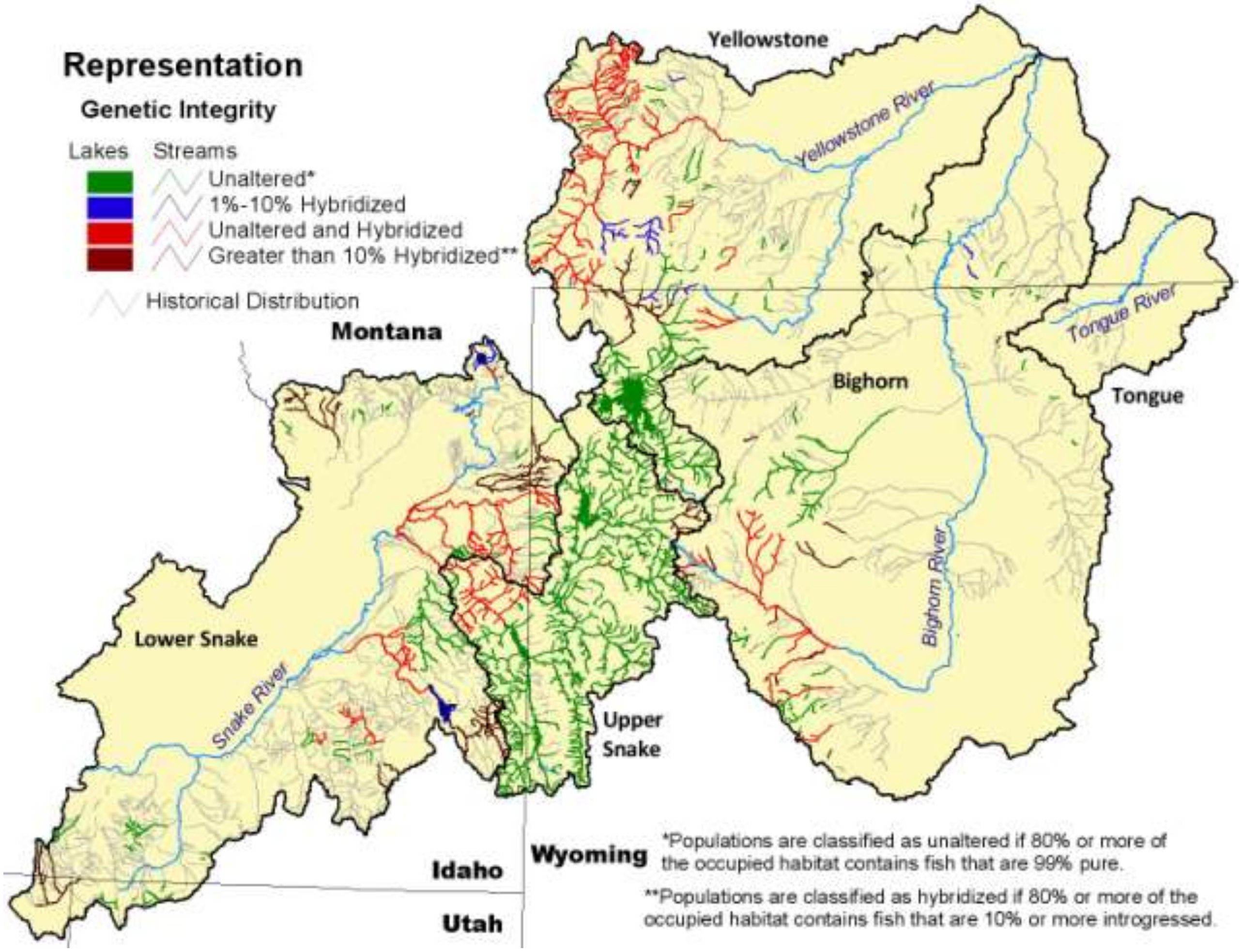

Figure 3. Representation: genetic integrity. Of the 306 stream or stream and lake-based conservation populations, 227 are genetically unaltered (6,700 km and 55,300 ha) and 65 of the 78 lake populations (644 ha) are also genetically pure.

Life History Diversity

Historically, Yellowstone cutthroat trout used 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 degradation and man-made structures such as diversions, dams and culverts has separated formerly migratory populations from their historical 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 wildfires and are unable to recolonize disturbed habitats once they have recovered.

Figure 4 shows the results of our analysis of life history diversity. The headwaters of the Yellowstone River, including Yellowstone Lake, and the headwaters of the Snake River including Jackson Lake support the largest remaining populations that still exhibit all three life history forms (green on map). The headwaters of the Bighorn River also support a high degree of life history diversity as well as the South Fork of the Snake River. The Yellowstone River below the Lake has retained a fluvial life history form (blue on map) as have other populations in the Lower Snake and Bighorn basins. However, many populations that once exhibited a migratory strategy are now isolated in smaller stream systems that only support the resident form.

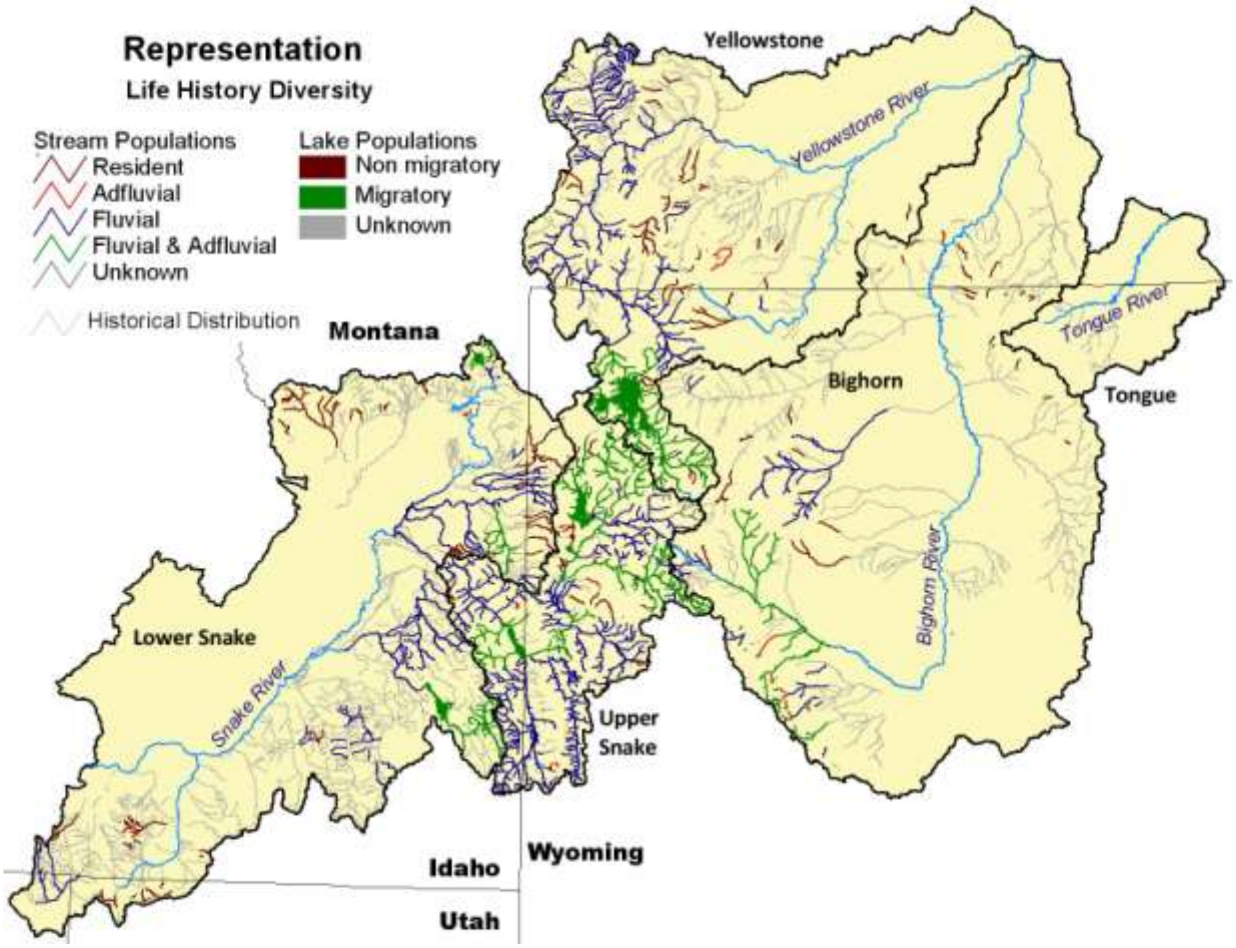

Figure 4. Representation: life history diversity. Of the 306 populations that spawn in streams, 146 are migratory and occupy 9,900 km and 64,800 ha of stream and lake habitat, respectively.

Geographic Diversity

Yellowstone cutthroat trout have evolved in a variety of habitats spanning the Continental Divide as they range from northeastern Nevada to southern Montana. Cegelski et al. (2006) found high levels of genetic differentiation between populations in different drainages, underscoring the importance of preserving geographic diversity in order to retain genetic diversity. 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 Yellowstone cutthroat trout occupied over 1,300 km of habitat in the Tongue River basin of Wyoming and the Beaver Creek and Medicine Lodge drainages in Idaho while continuous populations were found in 3,300 km of habitat at the downstream extents of the Snake and Bighorn rivers. Figure 5 shows remaining peripheral populations which represent just 15% of the historically occupied peripheral habitat. Of the conservation populations analyzed in this assessment, just six populations in 216 km of habitat (green on map) and 32 populations in 452 km of habitat (blue on map) were classified as disjunct and continuous peripheral populations, respectively.

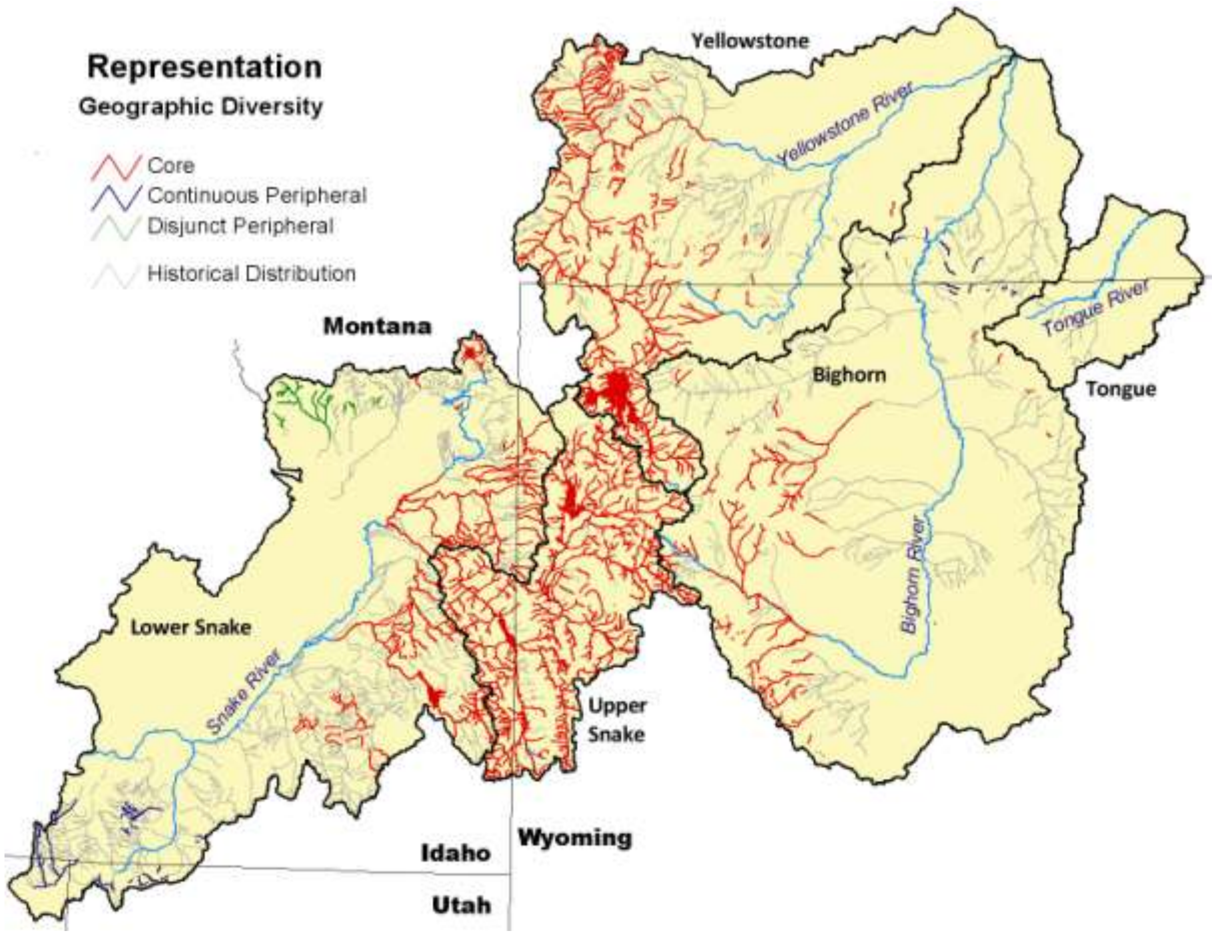

Figure 5. Representation: geographic diversity. Six disjunct (occupying 216 km) and 32 continuous (occupying 452 km) peripheral populations remain

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 Yellowstone cutthroat trout. There are 62 stream populations, including 14 lakes (occupying 9,800 km and 64,000 ha) classified as resilient, occupying 84% of the stream habitat (green or blue on map). Of these, 37 populations are classified as metapopulations with a migratory life history and occupy a total of 8,600 km of habitat (green on map). Resilient populations occur in each of the major river basins within the historical range, with the exception of the Tongue.

Historically, large natural lakes, such as Jackson and Yellowstone lakes, supported stronghold populations and metapopulations of Yellowstone cutthroat trout but many of these have been reduced or eliminated by nonnative trout introductions. Yellowstone Lake provides habitat for numerous discrete spawning populations of Yellowstone cutthroat trout that migrate from the lake into tributaries but these populations have been greatly reduced by a large population of introduced lake trout (Gresswell et al. 1994; Koel et al. 2010). If nonnative trout could be eliminated or controlled, these large historical lake habitats could provide substantial resilience to climate change.

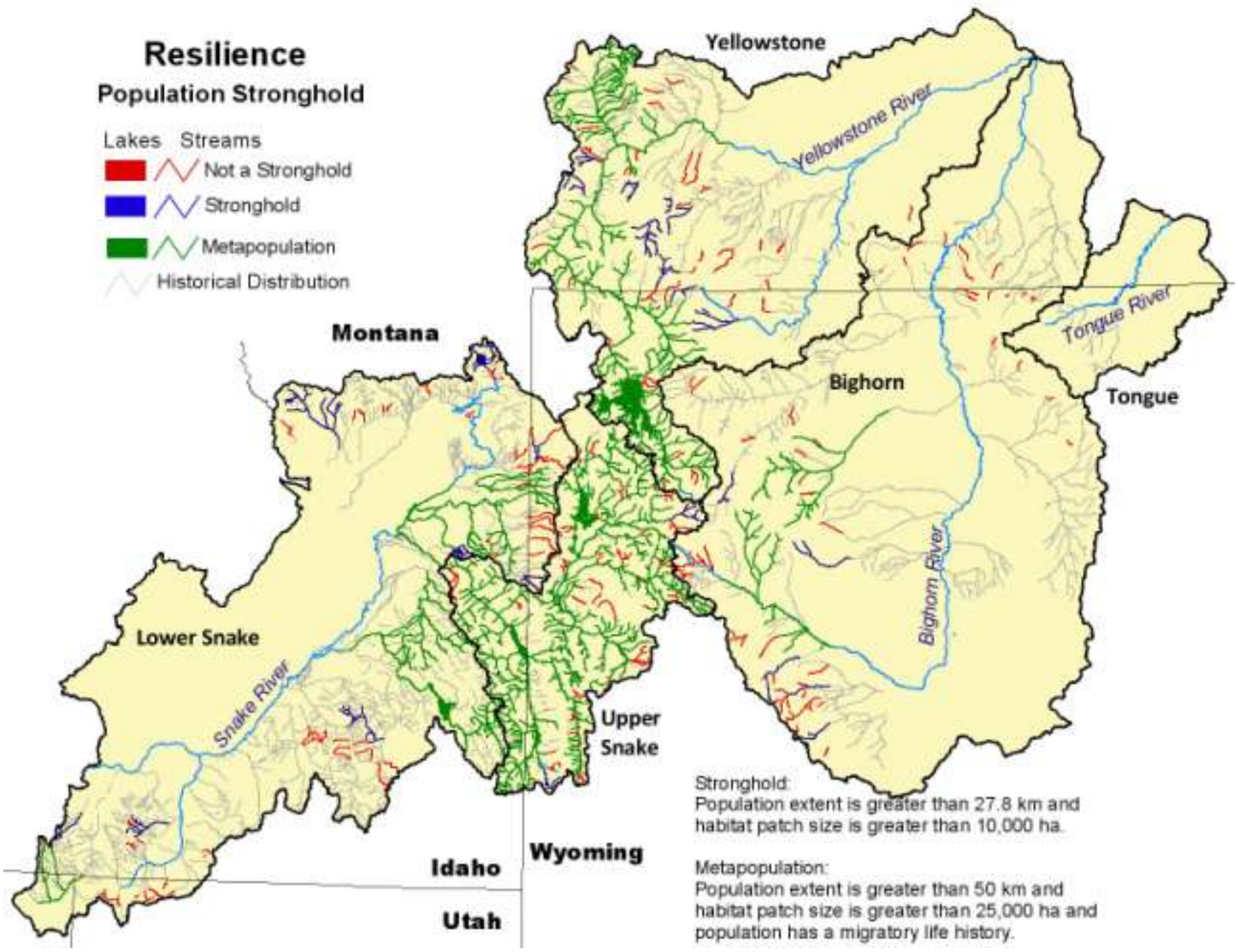

Figure 6. Resilience: Sixty-two stream populations, including 14 lakes (occupying 9.800 km and 64,000 ha) are classified as resilient including 37 metapopulations (green on map.)

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.

Figure 7 shows the results of our assessment of redundancy. Of the 306 conservation populations analyzed, 112 satisfy the minimum criteria for persistence. Of these, 96 populations also meet the genetics standards and therefore contribute to the redundancy portion of the portfolio (green on map). There are 19 sub-basins that meet our population goals for redundancy (green) and all of the basins except for the Tongue meet our basin-wide goal of at least one metapopulation.

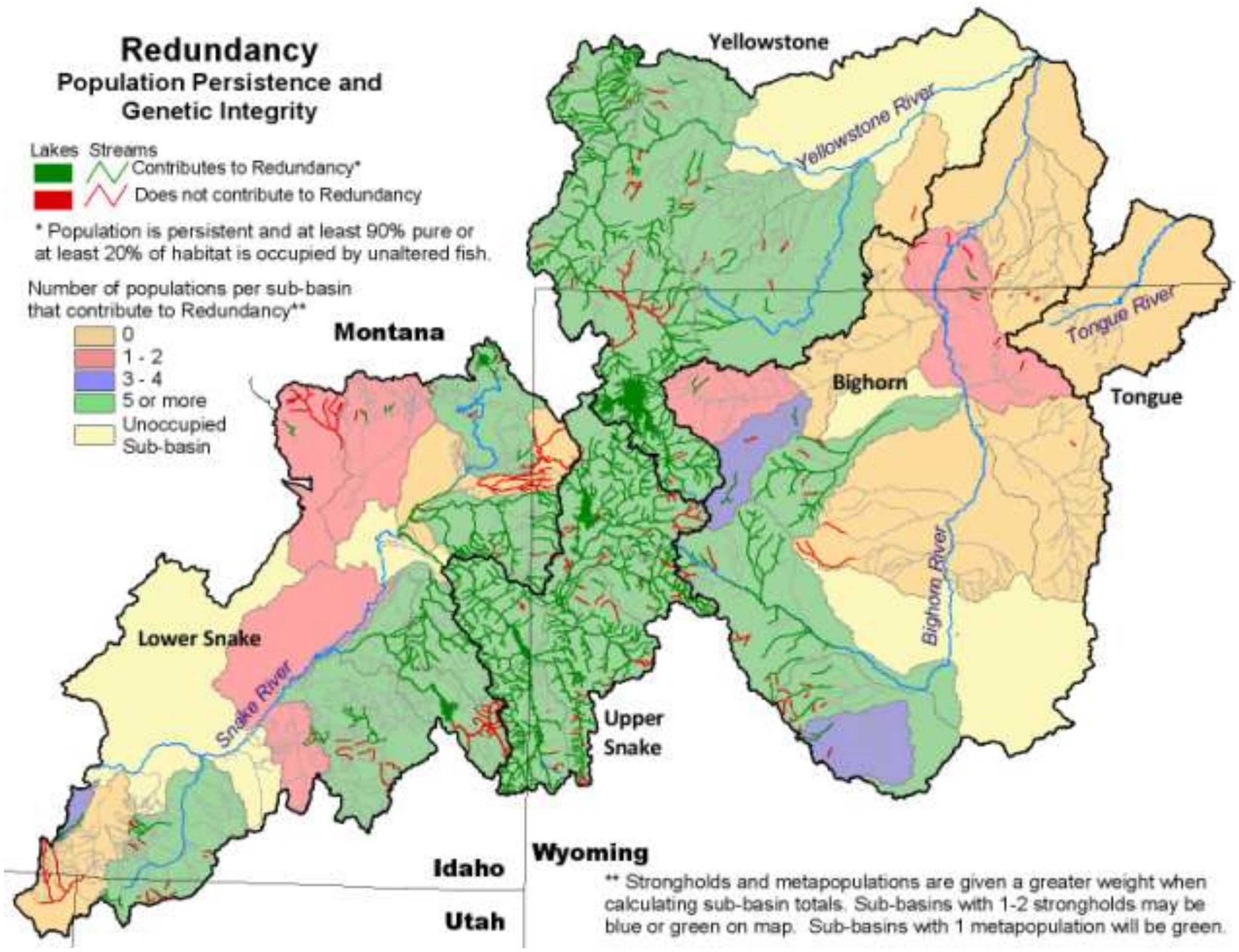

Figure 7. Redundancy: 96 populations contribute to redundancy in the portfolio and 19 sub-basins satisfy the goal of five persistent and non-hybridized populations. All of the basins with the exception of the Tongue meet the goal of supporting at least one metapopulation.

South Fork Snake River Watershed Restoration

The South Fork Snake River Watershed Project was initiated in 2001 in response to growing concerns from scientists, resource managers and anglers that the future vitality of these cutthroat populations was at risk from introduced rainbows, floodplain development, habitat degradation, barriers, and flow alteration from management of Palisades Dam and irrigation diversions. Major partners in this multi-faceted restoration effort include Idaho Department of Fish and Game, U.S. Forest Service, U.S. Bureau of Reclamation, Natural Resources Conservation Service, Trout Unlimited and other state and federal agencies, non-governmental organizations, and private land owners.

Representation – The South Fork Snake watershed supports five conservation populations of Yellowstone cutthroat trout, both large and fine-spotted, in over 400 km of habitat. The largest of these populations is found in over 300 km of habitat. This is one of the largest remaining populations of native Yellowstone cutthroat in Idaho containing fluvial and adfluvial life history forms. Introduced rainbow trout threaten the genetic integrity of this important stronghold so restoration efforts include angler education to encourage the harvest of nonnative rainbows rather than releasing them back into the river. Changes in the flow management regime at Palisades Dam are trying to mimic a more natural hydrograph that will benefit cutthroat trout and reduce main-stem spawning habitat available to rainbow trout in the spring.

Resilience – Securing the South Fork Snake River metapopulation requires restoration of the valley bottoms and ecosystem processes. When water supplies allow, spring flooding flows are released from Palisades Dam to rejuvenate riparian habitats, including cottonwood forests, which are important for shading and stream cooling in the hot summer months. Local ranchers are contributing to the effort by changing livestock grazing and irrigation practices to improve habitat quality along spawning tributaries.

Redundancy – Restoration work includes a number of reconnection projects that will provide Yellowstone cutthroat with increased access to historic spawning grounds. This includes repairing or removing old culverts and providing passage around irrigation diversions. By increasing the quantity and quality of spawning and rearing habitat available to native cutthroat in the watershed, the populations become less vulnerable to environmental disturbances such as fires and floods that are exacerbated by human activities and climate change.

Developing a Diverse Conservation Portfolio for Yellowstone Cutthroat Trout

Figure 8 provides the geographic reference for the sub-basin summaries of each of the portfolio elements presented in Tables 3-6. 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. YS-01, US-01) are referenced in Tables 3-6.

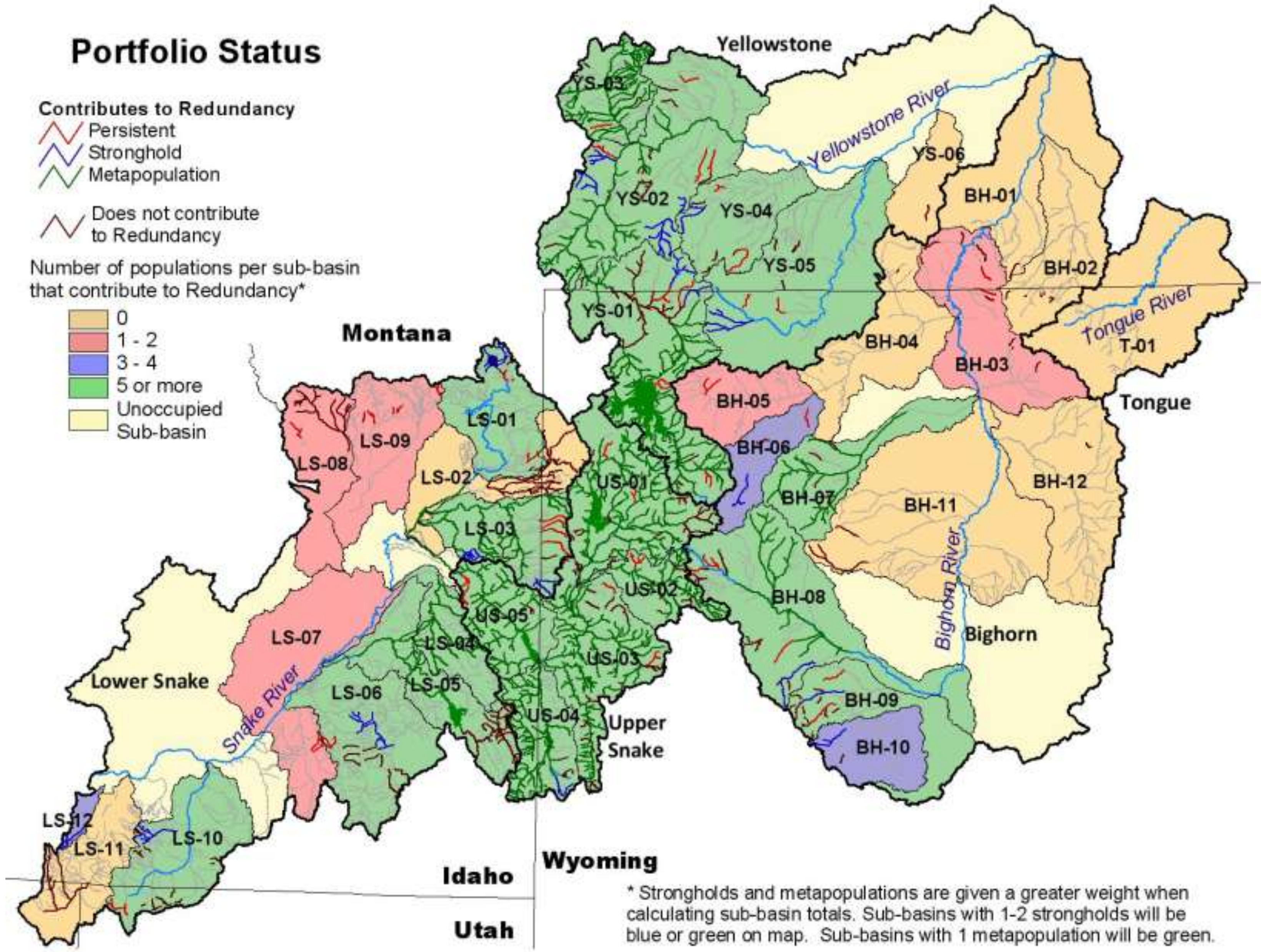

Figure 8. Conservation Portfolio: Sub-basin summaries of portfolio elements are described in Tables 3-6 according to the labels shown on the map (e.g. LS-01, US-01).

Portfolio Status and Opportunities

Rangewide Summary (Table 3)

Although the rangewide portfolio for Yellowstone cutthroat trout contains numerous important elements, further work is needed to secure them. Increasing reliance on small, isolated populations increases the vulnerability of the entire portfolio. Nonnative trout introductions have greatly reduced the ability of large natural lakes to support stronghold populations and metapopulations of Yellowstone cutthroat trout that historically were resilient to large-scale habitat disturbances. Controlling these nonnative species and restoring large populations that support a migratory life history will increase the resilience of the portfolio. Populations around the margins, particularly in the Lower Snake River and Bighorn basins, are important to the preservation of geographic and genetic diversity and should be a priority for restoration and protection.

				Representation			Resiliency		Redundancy
Basin	**Number of Pops. (pops.)**	**Occupied Habitat (km)**	**(ha)**	**Genetic Integrity (pops.)**	**Life Hist. Diversity (pops.)**	**Geographic Diversity (pops.)**	**Strong-hold (pops.)**	**Meta-pop. (pops.)**	**Persistent and <=10% introgressed (Sub-basin Total)**
Upper Snake	102	4217	20465	93	56	NA	2	20	28
Yellowstone	53	3387	34373	35	25	NA	9	6	26
Lower Snake	84	2740	9310	51	29	23	9	7	25
Bighorn	66	1358	912	47	36	14	5	4	17
Tongue	1	1	0	1	0	1	0	0	0
Total	306	11703	65060	227	146	38	25	37	96

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

Building Resistance and Resilience to Climate Change

Our analysis of climate change impacts on Yellowstone 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 Yellowstone 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.

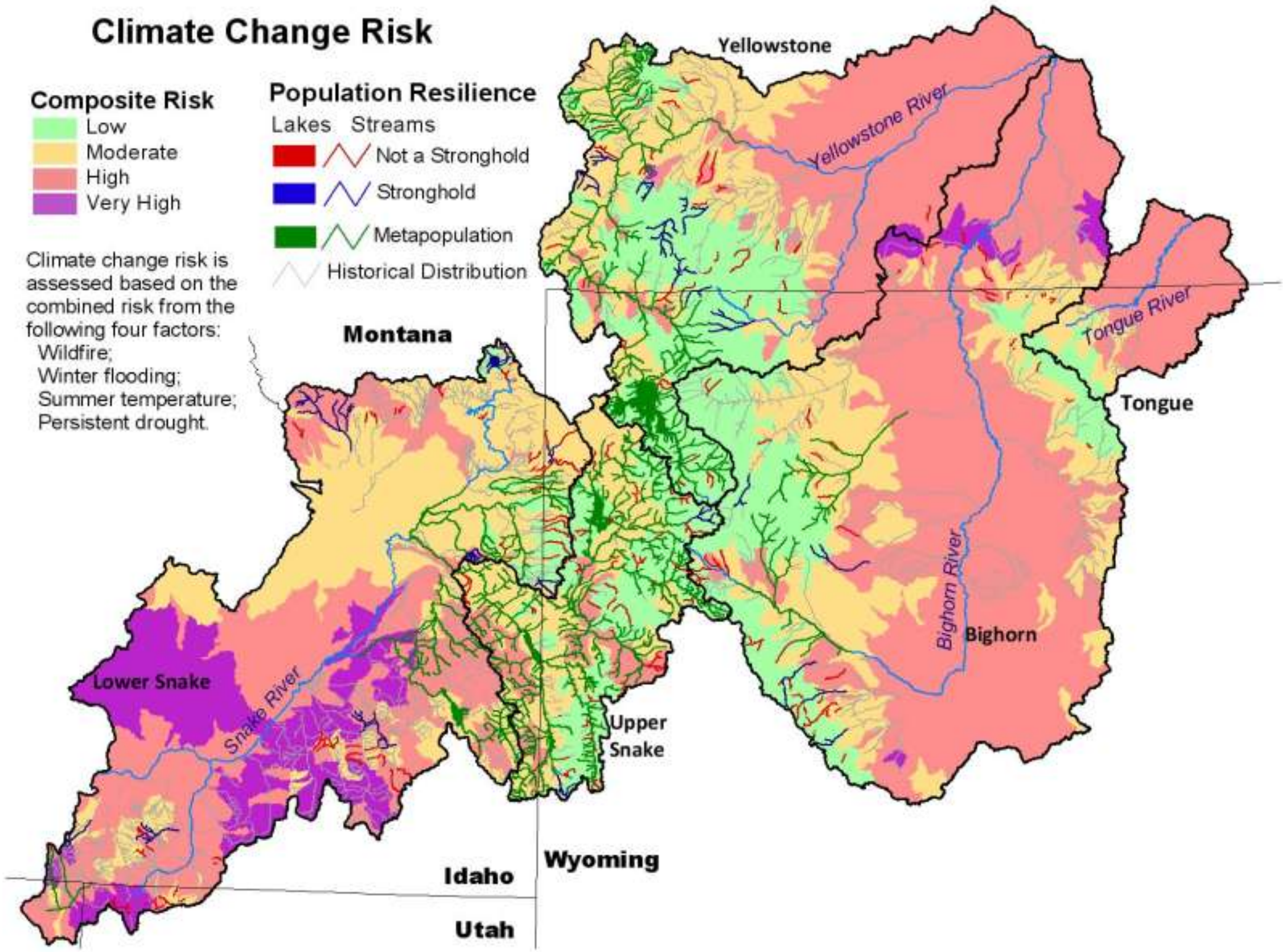

Figure 9. Composite climate risk and population resilience. The lower elevations are generally at highest risk for temperature and drought while the mid-elevations are at higher risk for winter flooding and wildfire. Much of the high elevation core habitat has a relatively low risk.

Table 4 provides a rangewide summary of each portfolio element by climate change risk factor. Each population is assigned a low, moderate, or high risk factor according to its extent relative to the climate risk categories shown in Figure 9. In situations where a single population overlaps two or more climate risk categories, the population is assigned to the risk class associated with the largest percent of the total population extent. For example, if a population with an extent of 25 km has 12 km in the high risk category, 8 km in moderate risk, and 5 km in low risk, the entire population would be classified as high risk for the purposes of this analysis. The one exception to this is in the reporting of occupied habitat which reflects actual total kilometers in each risk category.

							Representation									Resiliency						Redundancy		
Basin	**Number of Pops. (pops.)**			**Occupied Habitat (km)**			**Genetic Integrity (pops.)**			**Life Hist. Diversity (pops.)**			**Geographic Diversity (pops.)**			**Stronghold (pops.)**			**Metapop. (pops.)**			**Persistent & <=10% introgressed (Sub-basin Total)**		
Climate Change Risk	**H**	**M**	**L**	**H**	**M**	**L**	**H**	**M**	**L**	**H**	**M**	**L**	**H**	**M**	**L**	**H**	**M**	**L**	**H**	**M**	**L**	**H**	**M**	**L**
Upper Snake	13	23	66	820	1815	1529	12	22	59	6	14	36	NA			0	0	2	4	11	5	5	15	8
Yellowstone	6	20	27	242	1208	1861	5	11	19	0	13	12	NA			0	2	7	0	3	3	3	7	16
Lower Snake	30	49	5	1151	1272	300	22	25	4	13	15	1	16	7	0	5	3	1	3	4	0	12	9	4
Bighorn	14	19	33	264	451	641	9	17	21	2	13	21	9	5	0	1	0	4	0	1	3	4	3	10
Tongue	0	0	1	0	0	1	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Total	**63**	**111**	**132**	**2477**	**4746**	**4332**	**48**	**75**	**104**	**21**	**55**	**70**	**25**	**12**	**1**	**6**	**5**	**14**	**7**	**19**	**11**	**24**	**34**	**38**

Table 4. Rangewide summary showing climate change risk category for each portfolio element. **H** = high or very high risk; **M** = moderate risk; and **L** = low risk.

Rangewide, 20% of the populations and just over 20% of the occupied stream habitat is classified as high or very high risk. However, when reviewing individual portfolio elements, the risk is variable with geographic diversity being the most vulnerable. Over 65% of these peripheral populations are classified as high risk and only the single isolate in the Tongue basin is at low risk. Given how much geographic diversity has already been lost, opportunities to build the resistance and resilience of these populations through habitat restoration and expansion and control of nonnative species should be pursued. In contrast, just 14% and 21% of populations important for life history diversity and resilience (both strongholds and metapopulations), respectively, are classified as high risk. These large interconnected populations have access to a variety of habitats and thus are able to spread the risk across their extent and minimize their vulnerability to population-scale extirpation.

Upper Snake (Table 5)

Land protection in the Upper Snake basin has helped to maintain this area as an important part of the core with 4,100 km and 20,000 ha of occupied habitat. However, outside of the protected areas, habitat fragmentation and nonnative species threaten these populations. Ninety-three of the 102 conservation populations in the basin are classified as genetically pure and 53 of these unaltered populations have retained a migratory life history, 18 of which are classified as metapopulations and one is a stronghold. However, many of the larger populations are threatened by hybridization and have hybridized individuals within the occupied habitat. Protecting these populations by controlling nonnative species without compromising the important life history diversity and resilience still retained by these populations should be a priority. Basin-wide, 22 populations are classified as resilient and occupy 90% of the stream habitat. All of the sub-basins contain resilient populations that also satisfy the genetic criteria to meet our objectives for redundancy and the basin exceeds our basin-wide goal of at least one metapopulation.

In general, the Upper Snake provides important refugia from climate change impacts. Just 12% of the populations and 20% of the occupied stream habitat is classified as high risk. Of the climate change factors analyzed, drought and wildfire are the two greatest threats to populations in the Upper Snake (Haak et al. 2010a). Protecting and restoring healthy watersheds and hydrologic function can help mitigate these effects while reconnecting isolated populations to main stem habitats so that they have access to other drainages will minimize the risk of losing an entire population.

Yellowstone (Table 6)

The headwaters of the Yellowstone River basin around Yellowstone Lake (YS-01) benefits from protected national park land that has minimized habitat fragmentation. Over 90% of the occupied habitat supports a population with a migratory life history form. However, land protection has not eliminated the threat of nonnative species and just 10 of the 16 populations in this sub-basin are genetically unaltered. A hybridized population occupying over 200 km of stream habitat is found in the main stem and tributaries of the Yellowstone River immediately downstream of the large Yellowstone Lake population. In addition to hybridization with nonnative salmonids, nonnative lake trout in Yellowstone Lake also threaten by competition and predation the resiliency of numerous populations of Yellowstone cutthroat that migrate to the lake. Elimination or control of nonnatives in the lake as well as streams will not only secure the genetic integrity of native cutthroat populations but also increase their resilience and ability to adapt to changing environmental conditions.

Lower elevation populations are increasingly fragmented (YS-02 and YS-03). Although the main stem of the Yellowstone River supports a 600 km metapopulation consisting of unaltered and hybridized individuals, only 12 of the 23 other populations found in the tributary streams support a migratory life history and just four are classified as resilient. Another four populations are also classified as strongholds but they lack a migratory life history. Many of the larger interconnected populations are compromised genetically. The mean population extent for genetically unaltered populations in these two sub-basins is less than 12 km compared to a mean extent of 71 km for all populations in these two sub-basins. Further downstream many of the populations that historically occupied habitat in the Stillwater River and Clarks Fork sub-basins (YS-04 and YS-05) have been extirpated and the populations that remain lack resilience. Just four of the 13 populations remaining in these sub-basins support a migratory life history, two of which are comprised of small stream and lake habitats. Although these sub-basins meet our objectives for redundancy, these populations are highly vulnerable to disturbance events. Extending them into historically occupied habitat to build resilience and restore a fluvial life history is important for their long-term persistence and to prevent complete extirpation within these sub-basins.

Lower Snake (Table 7)

The Lower Snake basin contains much of the geographic diversity in the portfolio as it extends downstream away from the core populations in the headwaters. Twenty-three continuous and disjunct peripheral populations remain in the northwest and southwest sub-basins (LS-08 through LS-12). Although 20 of the peripheral populations have retained their genetic integrity, the two largest populations, in Medicine Lodge and Goose Creek watersheds (LS-08 and LS-11 respectively) have been hybridized. Of the genetically unaltered peripheral populations, none have retained a migratory life history and only two are strongholds while another four are classified as persistent. The remaining 14 peripheral populations have an average extent of less than 6 km and do not meet the minimum criteria for persistence. Many of these peripheral populations are also at high to very high risk from environmental disturbances due to climate change. In order to minimize the threat of local extirpations, habitats should be extended and opportunities to provide access to multiple drainages should be pursued while maintaining the genetic integrity of these populations through the control of nonnative species.

Basin-wide the effects of habitat fragmentation and nonnative species are evident with over 40% of the populations having some level of hybridization and less than 20% being classified as resilient. Loss of life history diversity is also evident, particularly in the lower sub-basins where fragmentation is the most pronounced. These populations are also particularly vulnerable to climate change impacts such as drought and temperature so reconnecting populations and restoring a migratory life history is important for building resistance and resilience to a rapidly changing environment. The redundancy component of the portfolio is also lacking in this basin with ½ of the sub-basins not meeting our goal although the basin does satisfy our criteria for supporting at least one metapopulation.

Bighorn (Table 8)

The Wind, Greybull, and Shoshone rivers (BH-08-10, BH-07, and BH-04-06, respectively) drain the headwaters of the Bighorn basin and historically supported large interconnected core populations. However, today many of these populations have been cut-off from their historical habitat and no longer support a migratory life history. The Wind River supports the largest population in the basin with a 360 km metapopulation consisting of both hybridized and unaltered fish. However, many of the tributary populations have been cut-off from the main-stem habitat and do not support a migratory life history. This is particularly the case in the lower Wind River (BH-09 and BH-10) where populations have been introduced into small habitats above waterfalls that were not historically occupied. Reconnecting populations throughout the Wind River system to build resilience and restore fluvial life history should be a priority.

The Greybull sub-basin (BH-07) supports seven populations, all genetically pure, occupying 372 km of habitat. The three largest populations support fluvial life histories and are classified as metapopulations. The remaining four populations have extents of less than 10 km and do not meet persistence criteria. Watershed-scale restoration that reconnects these populations would provide a significant component to the portfolio in a basin that has been severely compromised. Nearly all of the currently occupied stream habitat in this sub-basin is classified as low to moderate risk for climate change and could provide important refugia.

The Shoshone River (BH-04, BH-05 and BH-06) supports just six populations, only one of which is classified as a stronghold. Five of the populations are genetically pure and should be expanded in order to build their resilience. The lower end of the basin (BH-01, BH-02 and BH-03) supports 14 continuous peripheral populations, 12 of which are genetically pure. Nine of these populations are classified as high risk for climate change yet none are resilient and only two satisfy our minimum criteria for population persistence. Expanding these populations to build their resistance and resilience to environmental change should be a priority. None of these sub-basins satisfy portfolio objectives for redundancy so replicating populations into suitable historical habitat should also be a part of conservation strategies in these sub-basins. Overall, the Bighorn basin meets our basin-wide goal of supporting at least one metapopulation. However, only two of the 12 sub-basins meet our sub-basin goals for redundancy underscoring the need to restore connectivity throughout this basin.

Tongue (Table 8)

The Tongue River basin historically supported over 300 km of disjunct peripheral populations. Today just one population in one kilometer of habitat remains. Although it is in habitat classified as low risk for climate change, its limited extent makes it highly vulnerable to extirpation. This population is genetically pure so replicating this lineage and reintroducing it into appropriate historic stream habitat that is devoid of hybridizing species should be a priority in order to preserve this element of geographic diversity.

				Representation			Resiliency		Redundancy
Sub-basin ID	Number of Pops. (pops.)	Occupied Habitat (km)	(ha)	Genetic Integrity (pops.)	Life Hist. Diversity (pops.)	Geographic Diversity (pops.)	Strong-hold (pops.)	Meta-pop. (pops.)	Persistent and <=10% introgressed (Sub-basin Total)
US-01	32	1172	13510	26	8 fluv; 1 adfl., 4 both	NA	1	7	9
US-02	14	494	282	13	1 adfl., 4 fluv, 1 both	NA	0	1	2
US-03	42	1193	233	42	24 fluv, 2 adfl., 1 both	NA	0	7	9
US-04	7	782	11	7	1 adfl, 3 fluv	NA	1	2	3
US-05	7	576	6429	5	1 adfl., 4 fluv	NA	0	3	5
Total	102	4217	20005	93	43 fluv, 6 adfl, 7 both	NA	2	20	28

Table 5. Upper Snake

				Representation			Resiliency		Redundancy
Sub-basin ID	Number of Pops. (pops.)	Occupied Habitat (km)	(ha)	Genetic Integrity (pops.)	Life Hist. Diversity (pops.)	Geographic Diversity (pops.)	Strong-hold (pops.)	Meta-pop. (pops.)	Persistent and <=10% introgressed (Sub-basin Total)
YS-01*	16	1493	34282	10	8 fluv. 1 both	NA	2	4	9
YS-02*	19	925	0	10	8 fluv.	NA	5	2	10
YS-03*	6	712	0	4	6 fluv	NA	0	2	3
YS-04	7	101	91	5	1 fluv, 2 adfl	NA	1	0	3
YS-05	6	145	0	5	1 fluv	NA	1	0	3
YS-06	1	11	0	1	0	NA	0	0	0
Total	53	3387	34373	35	22 fluv, 2 adfl 1 both	NA	9	6	26

Table 6. Yellowstone (*One population spans three sub-basins so Total population counts do not equal sum of columns.)

				Representation			Resiliency		Redundancy
Sub-basin ID	Number of Pops. (pops.)	Occupied Habitat (km)	(ha)	Genetic Integrity (pops.)	Life Hist. Diversity (pops.)	Geographic Diversity (pops.)	Strong-hold (pops.)	Meta-pop. (pops.)	Persistent and <=10% introgressed (Sub-basin Total)
LS-01	7	106	2493	2	2 fluv, 1 adfl, 1 both	NA	1	0	3
LS-02*	26	400	0	10	7 fluv	NA	1	2	1
LS-03*	12	657	2	9	2 fluv, 1 both	NA	2	2	8
LS-04	1	327	0	1	1 fluv	NA	0	1	1
LS-05	2	441	6815	0	1 fluv, 1 both	NA	0	2	1
LS-06	11	198	0	6	10 fluv	NA	2	0	3
LS-07	2	27	0	2	2 fluv	NA	0	0	2
LS-08	2	186	0	1	0	2 disjunct	1	0	1
LS-09	4	41	0	4	0	3 disjunct	0	0	3
LS-10	15	165	0	14	0	15 continuous	1	0	2
LS-11	2	157	0	1	1 fluv	2 continuous	0	1	0
LS-12	1	34	0	1	0	1 continuous	1	0	1
Total	84	2739	9308	51	25 fluv, 1 adfl, 3 both	5 disj 18 cont.	9	7	25

Table 7. Lower Snake

*One population spans both sub-basins so Total population counts reflect actual number of populations and does not equal sum of columns.

				Representation			Resiliency		Redundancy
Sub-basin ID	Number of Pops. (pops.)	Occupied Habitat (km)	(ha)	Genetic Integrity (pops.)	Life Hist. Diversity (pops.)	Geographic Diversity (pops.)	Strong-hold (pops.)	Meta-pop. (pops.)	Persistent and <=10% introgressed (Sub-basin Total)
BH-01	1	11	0	1	0	1 cont	0	0	0
BH-02	5	19	0	5	0	5 cont	0	0	0
BH-03	11	80	0	8	0	8 cont	0	0	2
BH-04	1	3	0	1	0	NA	0	0	0
BH-05	2	23	4	2	1, fluv, 1 adfl	NA	0	0	1
BH-06	3	53	0	2	0	NA	1	0	2
BH-07	7	372	0	7	5 fluv	NA	0	3	3
BH-08	14	554	407	5	7 fluv,3 adfl 2 both	NA	1	1	5
BH-09	15	125	493	13	6 fluv, 9 adfl	NA	1	0	3
BH-10	2	38	9	0	1 fluv, 1 both	NA	1	0	1
BH-11	2	71	0	0	0	NA	1	0	0
BH-12	3	10	0	3	0	NA	0	0	0
T-01	1	1	0	1	0	1 disjunct	0	0	0
Total	67	1359	913	48	20 fluv 13 adfl 3 both	14 cont 1 disj	5	4	17

Table 8. Bighorn and Tongue

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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 main stem 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 through dispersal so that populations that become extirpated can be re-colonized by individuals from other local populations.

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.

Sub-basin – 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 sub-basin; 10-digit hydrologic unit code.

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