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Using native trout restoration to jumpstart freshwater conservation planning in the Interior West

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ABSTRACT: Freshwater biodiversity is in decline throughout North America at a higher rate than in terrestrial environments, yet systematic approaches to aquatic conservation planning remain relatively uncommon. In the western United States, existing problems for aquatic environments are compounded by increasing demands for fresh water, expanding energy development, and increasing uncertainty associated with climate change. Native trout are sensitive to disturbance, are well known to the general public compared to most aquatic species, and often are managed as important indicators of watershed integrity. Historically, native trout played a major ecological role in streams and lakes but many western taxa have declined in distribution and abundance and some now are listed as threatened or endangered. This paper describes a systematic approach to aquatic conservation planning that applies the financial concepts of portfolio management to trout conservation. The 3-R framework is used to describe the portfolio of native trout: **Representation** (genetic, life history, and geographic diversity), **Resilience** (large populations and large habitat patches), and **Redundancy** (multiple populations within geographic units). Viewed from this framework, most of the more vulnerable trout taxa have portfolios that inadequately address Representation by focusing primarily on genetic purity while underemphasizing life history diversity. Most of the portfolios of these more vulnerable trout also poorly address Resilience and Redundancy. As these portfolios are rebalanced, numerous other benefits to aquatic resource planning efforts can accrue, including restoration of the ecological values of native trout and the restoration of other native fishes within their ecosystems. We demonstrate the concepts with Rio Grande cutthroat trout, a subspecies that is a candidate for listing pursuant to the U.S. Endangered Species Act.

Keywords: freshwater biodiversity, conservation planning, climate change, representation, resilience, redundancy, fisheries

INTRODUCTION

The need for a systematic approach to freshwater conservation planning has never been greater. Nearly 40% of freshwater and diadromous fish species in North America are at risk of extinction (Jelks et al. 2008), as are nearly half of all freshwater crayfishes (Taylor et al. 2007) and two of every three species of freshwater mussels (Williams et al. 1993), despite expenditures for aquatic threatened and endangered species that exceed their terrestrial counterparts (Williams et al. 2011). Given these numbers, it is surprising that freshwater conservation planning lags behind conservation efforts for terrestrial and marine systems (Linke et al. 2011).

Some of the challenges to effective systematic planning for freshwater systems include the dendritic nature of river systems and nested nature of watersheds, which require that upstream and downstream influences, as well as local land use and surface and groundwater conditions, be considered when developing conservation strategies (Vannote et al. 1980; Fagan 2002; Fausch et al. 2002). Furthermore, the lack of comprehensive spatial data on many freshwater-dependent species makes landscape-scale planning based on the representation of aquatic diversity problematic (Williams et al. 2007). In order to compensate for a lack of biological data, some planning efforts have relied on abiotic factors (e.g. geomorphology, climate) and hierarchical classifications as surrogates for aquatic diversity (Higgins et al. 2005; Moilanen et al. 2011). However, Linke et al. (2011) argue for the use of actual biological data when defining surrogates in order to ensure that sites containing known biodiversity targets are selected during the prioritization process.

Because of their widespread distribution, relative abundance, and importance in recreation and local economies, native trout are considered to be management indicator species by many state fish and wildlife agencies. Many native trout depend on cold, clean water, which has made them important ecological indicators of watershed integrity (Lee et al. 1997; Williams et al. 2007). Declines in local populations often indicate larger ecological problems, and the presence of healthy, naturally reproducing populations indicate habitat integrity both locally and in contributing tributaries (Cross and Everest 1997).

Native trout are inherently resilient, relying on a variety of life history strategies and genetic diversity in order to prosper in a wide range of habitats and successfully adapt to changing climatic and environmental conditions (Rieman and Dunham 2000; Neville et al. 2006). For example, Dunham and Rieman (1999) describe resident, migratory, and metapopulation life history strategies in stream-dwelling bull trout (*Salvelinus confluentus)* with resulting genetic structuring among various stream and mainstem river populations.

In coldwater habitats, native trout are important components of lake and stream systems because of their large population sizes and their role as not only the top predator in the aquatic system but also as prey for a range of terrestrial species (Varley and Schullery 1998; Koel et al. 2005). The spawning runs of migratory populations play an important ecological role in moving nutrients upstream from lakes and rich valley bottom habitats to headwaters as adults move into shallow tributary streams to spawn (Tronstad 2008). As trout move into shallow water for spawning, they become more susceptible to predation by avian and mammalian species, and dead spawners become available to scavengers.

In recent decades, degraded habitat and nonnative fish introductions have led to the decline of native trout populations throughout the United States, resulting in many species and subspecies being listed as endangered or threatened pursuant to the U.S. Endangered Species Act (Young 1995; Williams et al. 2007). Many others are considered for listing or are classified as ‘sensitive’ by state and federal resource managers.

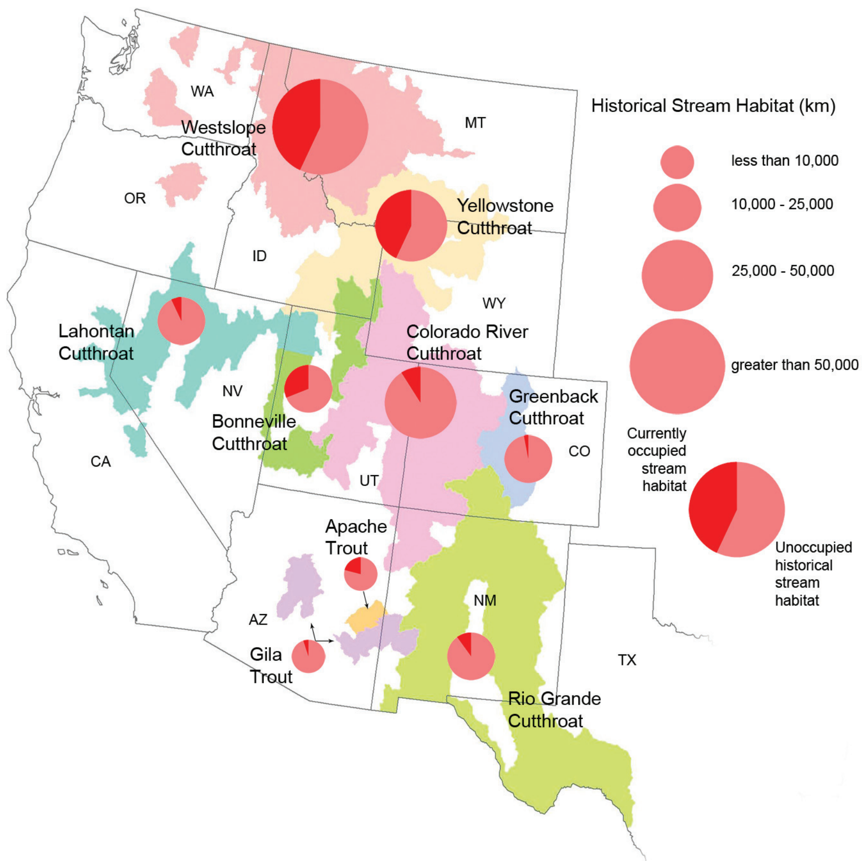
Recovery plans for listed western trout typically establish targets for a specific number of genetically pure populations, which results in management strategies that emphasize the isolation of populations in headwater streams above artificial barriers. The Apache Trout Recovery Plan, for example, has as its primary recovery objective the establishment of “30 self-sustaining discrete populations” (U.S. Fish and Wildlife Service 2009). Although this approach helps protect the Apache trout from hybridization with nonnative trout (e.g., rainbow trout (*Oncorhynchus mykiss*) and brook trout (*Salvelinus fontinalis*)), it often is done at the expense of the ability of the fish to migrate freely among an interconnected stream network, which historically has enabled them to prosper through evolution.

Inhibited migration also leaves the Apache trout more vulnerable to disturbance events such as wildfire, flood, or prolonged drought (Dunham et al. 2002; Fausch et al. 2009). In addition, these small isolated populations may lose much of their genetic diversity, further increasing the risk of extinction and significantly reducing the evolutionary potential to adapt to changing environmental conditions (Neville et al. 2006).

Reduced populations have left many native trout particularly vulnerable to changing environmental conditions driven by global warming that is predicted to raise stream temperatures and increase the frequency and intensity of disturbance events (Haak et al. 2010a; Kaushal et al. 2010; Wenger et al. 2011) and the spread of pathogens and nonnative fishes (Rahel and Olden 2008). Management practices that isolate populations in small headwater streams may inadvertently exacerbate these threats, as snowpack and streamflows already appear to be in decline across many western drainages (Kapnick and Hall 2009; Luce and Holden 2009; Clark 2010).

We herein describe a systematic approach to aquatic conservation planning that builds the resilience of native trout populations by restoring their genetic, life history, and geographic diversity. This is based on the concept that diversity builds stability and has been termed the “portfolio effect,” a concept analogous to the desire among financial managers to maintain a diverse economic portfolio as a hedge against uncertain futures (Figge 2004). Our presumption is that rebalancing the portfolio of native trout diversity across a suite of habitat types will not only increase their resilience to environmental change (Haak and Williams 2012) but will also benefit a myriad of other species dependent on the ecological integrity of coldwater habitats. After describing our approach, we quantify rangewide results for nine species and subspecies of native trout across the inland western United States (Figure 1). We use Rio Grande cutthroat trout (*O. clarkii virginalis*) as a case study to demonstrate the application of portfolio theory to the development of a freshwater conservation plan across a large landscape in New Mexico and Colorado.

Figure 1: Comparison of historical and current distributions for seven subspecies of cutthroat trout and Apache and Gila trout. The size of the pie chart associated with each fish is indicative of the amount of stream habitat historically occupied while the dark red ‘slice’ represents the percent of the historical stream habitat that is currently occupied. For example, Apache trout historically occupied less than 10,000 km of stream habitat and in 2011 only about 10% of that stream habitat was occupied. Data sources from the most recent rangewide assessments available from state and federal agencies and summarized at www.tu.org/science/conservation-success-index.



METHODS

One of the advantages of using native trout as the target for systematic conservation planning is the detailed status and trend data maintained by state and federal fisheries agencies. Because of native trout's conservation status and economic value, rangewide assessments are regularly compiled for most species and made available through recovery plans or annual management plans (e.g., Alves et al. 2007). These assessments provide a consistent, spatially explicit source for population-scale data on the geographic distribution, density, genetic purity, and life history of native trout and are the foundation of our approach.

The 3-R Framework

In order to provide a structure to describe the existing and potential future conservation status of native trout, we adopt the 3-R framework of **Representation** (genetic, life history, and geographic diversity), **Resilience** (large populations and large habitat patches), and **Redundancy** (multiple populations within geographic units) (Shaffer and Stein 2000). This framework may prove especially helpful in the conservation of sensitive and candidate species because it has been adopted for recovery planning by the U.S. Fish and Wildlife Service (USFWS) (Carroll et al. 2006). We expand on the conceptual approach used by USFWS and have developed a spatially explicit, quantitative framework for analyzing the conservation status of a species and establishing place-based objectives linked to the 3-R's. We used a GIS (Geographic Information Systems) environment to compile and analyze the population-scale assessment data for nine inland native trout. This included seven subspecies of cutthroat trout: westslope (*Oncorhynchus clarkii lewisi*), Yellowstone (*O.c. bouvieri*), Bonneville (*O. c. utah*), Lahontan (*O. c. henshawi*), Colorado River (*O. c. pleuriticus*), greenback (*O. c. stomias*), and Rio Grande (*O. c. virginalis*), as well as Gila trout (*O. gilae gilae*) and Apache trout (*O. g. apache*). Figure 1 shows the historical ranges for each of these fish. The cutthroat trout subspecies occupied a variety of riverine and lacustrine habitats extending from Canada to Mexico, whereas Gila and Apache trout were confined to much smaller drainages in Arizona and New Mexico. Our 3-R analysis for each of these fish uses the most recent and best available rangewide population data. For Gila trout, the population data are from 2010 and do not reflect the devastating effects of the 2012 Whitewater-Baldy Fire complex. The full effect of the wildfire on extant populations of Gila trout is not known at this time (Dave Propst, unpublished data).

Table 1 describes the criteria used for determining whether or not a population contributes to one of the 3-R's for that species. For example, populations that are genetically pure contribute to the genetic integrity portion of Representation, while a population occupying at least 27.8 km of stream habitat in a drainage area of at least 10,000 ha in size contributes to Resilience (Hilderbrand and Kershner 2000; Dunham et al. 2002). Populations that meet the minimum criteria for population persistence (i.e., effective population size of 500 interbreeding adults (Hilderbrand and Kershner 2000)) and are at least 90% genetically unaltered contribute to Redundancy. (See Haak and Williams 2012 for a more detailed discussion of the 3-R analysis.) We then summarized rangewide results for each fish according to the number of populations that contribute to each of the 3-R's. A single population may contribute to more than one element, depending on population-specific attributes (e.g., a migratory population in 50 km of stream habitat contributes to the life history diversity component of Representation as well as Resilience).

Table 1 also describes conservation objectives for each of the 3-R's that, if achieved, will contribute to a balanced portfolio. We do not use quantitative measures to determine the balance of a portfolio for each taxon but instead apply the concept along a continuum. At one end of the continuum is an 'unbalanced' portfolio characterized by a few small isolated populations in a limited portion of the historical range. At the other end is a 'balanced' portfolio, represented by the historical distribution and diversity. Our objectives reflect the historical population and habitat diversity that once characterized inland native trout. We recognize that it may not be feasible to fully restore these fish to historical conditions. However, we believe that, where possible, restoring the historical diversity that sustained these fish for millennia greatly improves the 'balance' of the portfolio and will increase the resilience of the species to environmental change. The 3-R framework provides a standardized approach for determining where each taxon falls on the continuum between a balanced and unbalanced portfolio.

Table 1: Criteria for classifying populations of native trout within the 3-R framework and rangewide objectives for achieving a balanced portfolio. Thresholds for necessary stream length and habitat patch size are derived from Hilderbrand and Kershner (2000) and Dunham et al. (2002).

3-R Element	Population Criteria	Portfolio Objectives
Representation 1. Genetic Integrity 2. Life history diversity 3. Geographic diversity	1. Genetically pure populations 2. Migratory populations 3. Peripheral populations	1. Genetically pure populations distributed across historical range. 2. Presence of all historical life history forms. 3. Historical peripheral habitat occupied.
Resilience	Occupied stream habitat exceeds 27.8 km and habitat patch size exceeds 10,000 ha.	Presence of large inter-connected populations within each major river basin of historical core habitat.
Redundancy	Effective population size of 500 adults and at least 90% genetically unaltered.	Multiple persistent populations present within each sub-basin historically occupied.

Developing a Conservation Plan

We use the results of the 3-R framework to develop a conservation plan for balancing the rangewide portfolio of Rio Grande cutthroat trout, a candidate for protection under the Endangered Species Act. In keeping with the conservation planning principles of complementarity and efficiency (Margules and Pressey 2000; Pressey et al. 2007; Linke et al. 2011), we identify conservation targets and establish quantitative population and habitat objectives for the explicit purpose of increasing these three measures: within-species diversity (Representation), the number of large populations (Resilience), and the number of populations in depleted areas (Redundancy). This process allows us to align place-based conservation actions with specific portfolio targets in an efficient manner, recognizing that local management decisions still need to be made based on available funds, ability to access desired project areas, and willing partner organizations. The geographic and life history elements of the portfolio help ensure that a variety of habitat types (i.e., stream, riverine, lacustrine) across diverse landscapes (e.g., forest, grassland, mountain) will be captured in the plan, thus accruing conservation benefits to an array of native aquatic species assemblages.

In developing our conservation objectives, we rely on current literature and our own experiences in stream restoration and the recovery of rare and endangered fishes. Numerous strategists have argued for conservation plans that focus priority efforts on protecting the best remaining habitats and populations (Moyle and Yoshiyama 1994;

Williams et al. 2011). Often such efforts are of the highest conservation priority because focusing on existing, intact habitats yields the highest conservation gain for minimal investment (Frissell 1997). After protecting and restoring the best remaining populations and habitats, secondary priorities typically focus on saving populations that are at high risk of loss. For native trout, this may include smaller peripheral populations that occur along the edges of the range and may be adapted to more specialized habitat conditions (Haak et al. 2010b).

Two additional factors greatly influence our conservation thinking for native trout. First, is the increasing vulnerability of small, isolated populations to flood, drought, and wildfire. In 2012, several populations of Gila trout in New Mexico and Lahontan cutthroat trout in Nevada were so severely impacted by wildfire that the few remaining fish had to be transported to refuge streams (David Propst, unpublished data; Carol Evans, unpublished data). This increased vulnerability argues for increasing Resilience in populations by increasing their population size and by reconnecting fragmented stream segments. Second, evidence is mounting that the spread of restoration efforts across large numbers of sites may result in insufficient progress to produce the desired increases in fish numbers as compared to restoration efforts that concentrate work into fewer high priority areas (Roni et al. 2010). Both of these factors argue for watershed-scale efforts to reestablish strongholds and metapopulations, including fish that can freely migrate among interconnected stream networks.

RESULTS

Applying the 3-R Framework to Western Trout

The results of our 3-R analysis for the nine species and subspecies of native trout are shown in Table 2. A north-south gradient of portfolio diversity is evident with the northern subspecies of cutthroat trout (i.e., westslope and Yellowstone cutthroat trout) supporting more balanced portfolios. For example, although just 13% of the westslope cutthroat trout populations are classified as resilient, they occupy 88% of the stream habitat, implying that the overwhelming majority of the current distribution is comprised of large migratory populations, similar to those that existed historically. In contrast, Rio Grande and Colorado River cutthroat trout have retained very little of their historical life history diversity or large, interconnected habitat. Similarly, Apache trout and Gila trout in the arid Southwest have lost much of their historical life history diversity and Resilience.

The presence of genetically pure populations is also an important indicator of the overall balance of each portfolio since these fish evolved in isolation from hybridizing species. Given the emphasis on genetic purity in recovery planning, it is not surprising that the portfolios for the three species protected under the Endangered Species Act, (i.e., Lahontan cutthroat, Gila, and Apache trout) are comprised of virtually all genetically pure populations. All of the remaining fish analyzed show some level of hybridization affecting approximately 25-40% of the current populations. Gila and Apache trout have virtually no Resilience (as defined by the presence of large connected populations), yet nearly one-half of the Apache trout populations satisfies both the persistence and genetics criteria for Redundancy, thus protecting the species from extinction due to a disturbance event, such as a wildfire, that may result in local population losses. Overall, the portfolios for Colorado River cutthroat and Rio Grande cutthroat trout are the most unbalanced. These subspecies have lost most of their historical life history forms and Resilience. Redundancy, intended to be a safety net when there is little Resilience, is also very low for these two subspecies. vulnerability argues for increasing resiliency in populations by increasing their population size and by reconnecting fragmented stream segments. Second, evidence is mounting that the spread of restoration efforts across large numbers of sites may result in insufficient progress to produce the desired increases in fish numbers as compared to restoration efforts that concentrate work into fewer high priority areas (Roni et al. 2010). Both of these factors argue for watershed-scale efforts to reestablish strongholds and metapopulations, including fish that can freely migrate among interconnected stream networks.

A Case Study of Rio Grande Cutthroat Trout

The most recent range-wide status assessment for Rio Grande cutthroat trout identifies 121 conservation populations occupying 1,124 km of stream habitat in New Mexico and Colorado (Alves et al. 2007). For purposes

Table 2: Conservation portfolio for species and subspecies of inland native trout. Percentage values represent percent of existing populations that support each element of diversity. INC. – incomplete data.

Species or Subspecies	Total Pops.	Representation (% of all pops)			Resilient		Redundant (% of all pops.)
		Genetic Integrity	Life History	Geog. Diversity	% of all pops	% of occ. habitat	
Westslope cutthroat	687	63%	13%	7%	13%	88%	36%
Yellowstone cutthroat	306	74%	22%	12%	20%	84%	32%
Bonneville cutthroat	164	70%	15%	24%	16%	68%	33%
Lahontan cutthroat	58	99%	19%	12%	12%	48%	22%
Colorado River cutthroat	314	62%	4%	11%	3%	20%	21%
Greenback cutthroat	34	INC.	20%	INC.	3%	17%	INC.
Rio Grande cutthroat	121	74%	3%	7%	<1%	7%	20%
Gila trout*	15	100%	0%	27%	0%	0%	33%
Apache trout	31	100%	0%	45%	6%	21%	42%

**Portfolio results for Gila trout are based on 2010 population data. The Baldy-Whitewater fire complex of 2012 has been devastating to Gila trout recovery efforts. With only 15 populations, no Resilience, and a limited geographic distribution, Gila trout have been highly vulnerable to environmental disturbance such as a wildfire. The full effect of the wildfire on extant populations of Gila trout is not known at this time (Dave Propst, unpublished data).*

Table 3: Conservation portfolio for Rio Grande cutthroat trout. Numbers are actual population counts for each element of the 3-R framework. Some populations may satisfy multiple objectives so counts should not be summed across rows.
NA: not applicable; these basins did not historically support peripheral populations and therefore do not contribute to geographic diversity.

Basin	Total # of Pops.	Occupied Stream Habitat (Km)	Representation (number of pops.)			Resilient (number of pops.)	Redundant (number of pops.)
			Genetic Integrity	Life Hist. Diversity	Geographic Diversity		
Rio Grande Headwaters	40	466	36	3	NA	1	10
Lower Rio Grande	58	489	37	1	8	0	12
Upper Canadian	12	109	9	0	NA	0	1
Pecos	11	60	7	0	0	0	1
Total	121	1124	89	4	8	1	24

Figure 2: Results of the Representation analysis for Rio Grande cutthroat trout shows the distribution of populations that are genetically pure, support a migratory life history, and/or are classified as peripheral.

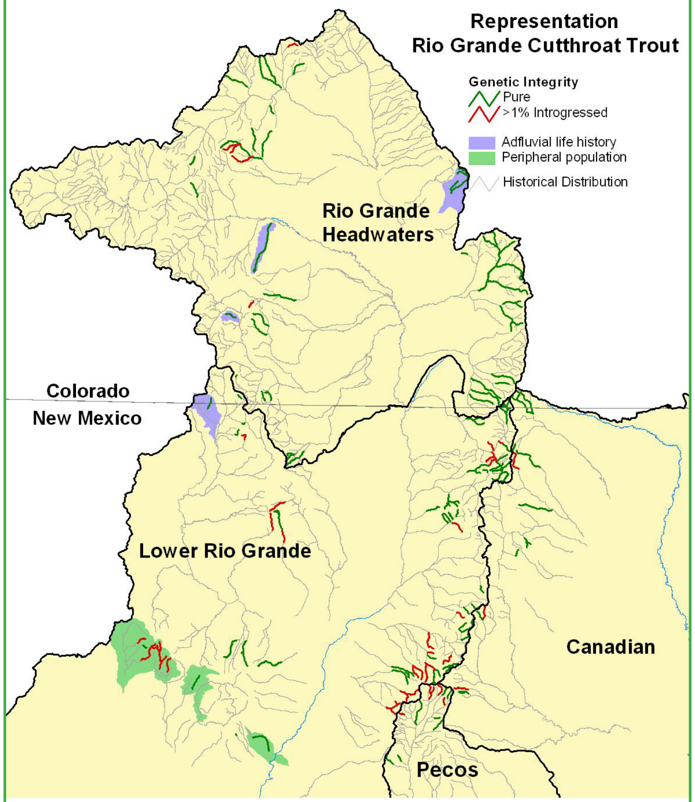
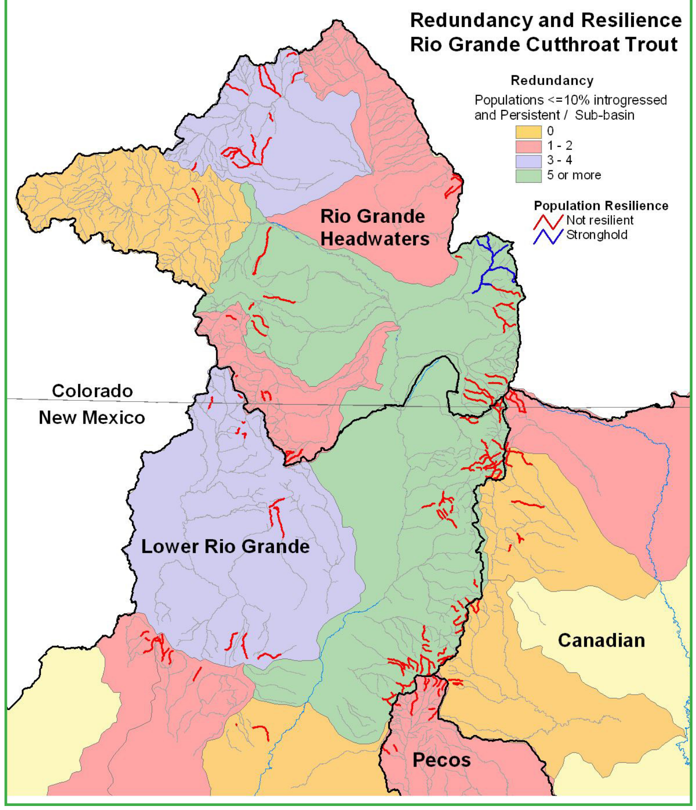


Figure 3: Results of the Resilience and Redundancy analyses for Rio Grande cutthroat trout shows only one population is classified as a stronghold and contributes to Resiliency in the portfolio. The number of populations that meet the genetics and persistence criteria for Redundancy is summarized by sub-basin.



of our analysis, their historical range is divided into four basins: Rio Grande Headwaters, Lower Rio Grande, Canadian, and Pecos. Their current distribution represents about 10% of their historically occupied stream habitat.

Table 3 provides the results of the 3-R analysis for Rio Grande cutthroat trout by each of the four major river basins still occupied. Figure 2 shows the spatial distribution of the three components analyzed as part of Representation (i.e., genetic integrity, life history diversity, and geographic diversity). All of the major river basins still support genetically pure populations although hybridized populations are also present in each of the basins. Four populations still support a migratory life history. However, as Figure 2 illustrates, these populations have very limited extents, migrating from small lakes (adfluvial life history) rather than from larger river systems (fluvial life history) that characterized their historical migratory behavior. Geographic diversity is also low with less than 10% of the historical peripheral habitat still occupied (Haak et al. 2010a). Of the eight remaining peripheral populations that contribute to geographic diversity, only three are genetically unaltered (Figure 2). The subspecies has been extirpated from much of the Pecos River basin and their historical range in west Texas (Garrett and Matlock 1991).

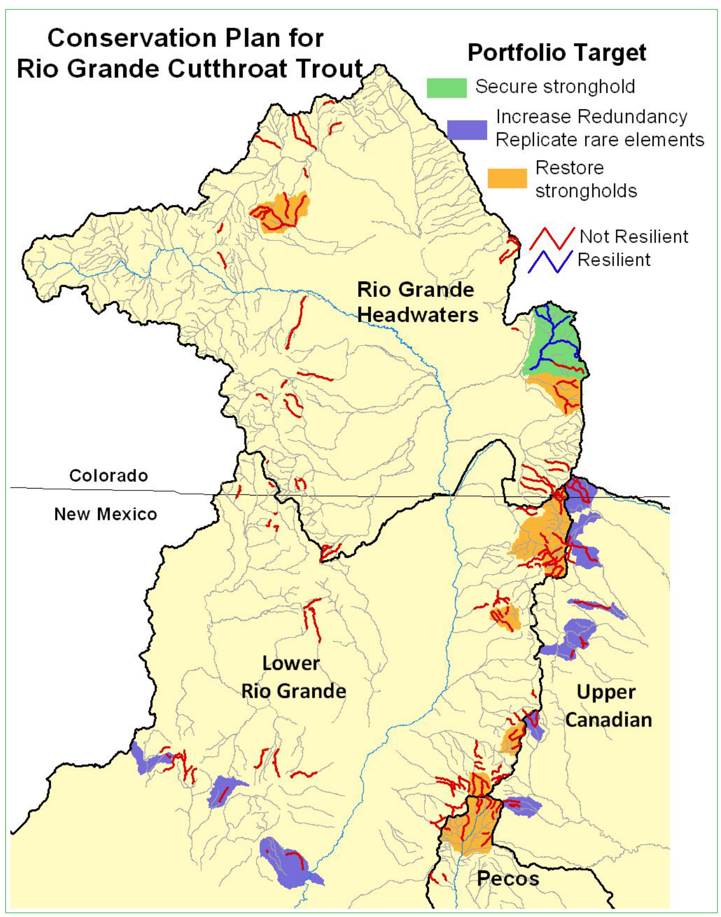
Only one population located in the Rio Grande Headwaters meets Resilience criteria within the entire range (Table 3 and Figure 3). Many remaining populations are in small streams with late season flows of less than 1 cfs compared to the larger riverine habitats that were occupied historically (Andrew Todd, unpublished data). This isolation in small habitats has resulted in the loss of rangewide Resilience and increased population vulnerability. The Upper Canadian and Pecos basins also lack Redundancy (Table 3 and Figure 3). Although they support nine and seven genetically unaltered populations respectively, most of these populations fail to meet our minimum criteria for persistence (i.e., effective population size of 500 adults) and therefore do not contribute to Redundancy (see Table 1 for criteria). As a result, much of the geographic and genetic diversity associated with populations of the Canadian and Pecos basins could be lost due to a wildfire or prolonged drought.

Based on the results of our 3-R assessment, we identified increasing Resilience by securing and/or restoring at least one large interconnected migratory population within each of the four major river basins as our highest conservation priority. This will move Rio Grande cutthroat trout towards having a more balanced portfolio by restoring some of their historical life history diversity and Resilience. We establish an additional rangewide goal of securing and/or restoring at least five persistent populations in the under-represented sub-basins along the margins of the current distribution; thereby increasing Redundancy as a safety net for geographic diversity, which is minimally represented in the current portfolio.

After determining our rangewide conservation objectives, we apply our professional judgement and basic conservation biology principles to an iterative selection process that identifies target areas based on the attributes of the individual populations we evaluated in the 3-R assessment. Whenever possible, multiple opportunities are identified for each portfolio target to allow for the consideration of local circumstances that may make any one site more or less desirable. This also allows for the consideration of other native species in the final project identification process. Since our highest priority for Rio Grande cutthroat is to increase Resilience, we first identify those habitats that support stronghold populations based on the theory that protecting the best remaining habitats and populations often yields the highest conservation gain for the least investment (Moyle and Yoshiyama 1994; Frissell 1997; Williams et al. 2011). As shown in Figure 4, only one stronghold population currently exists, so protection of this population from nonnative species and incompatible development activities is a high priority. Additional opportunities for increasing Resilience by

Figure 4: A conservation plan for Rio Grande cutthroat trout showing conservation objectives linked to specific quantitative goals for improving the balance of the rangewide portfolio.

Some objectives have multiple potential targets allowing for the consideration of local conditions in project selection.



restoring stronghold populations through the reconnection and expansion of isolates have also been identified (Figure 4). These areas were selected based on the juxtaposition of existing populations. Those watersheds with multiple populations in close proximity are assumed to present the best opportunities for reconnecting fragmented habitats and expanding populations downstream into larger river systems. Multiple opportunities in the Rio Grande headwaters and lower Rio Grande were identified, recognizing that not all will be feasible. Only one such opportunity exists in the Pecos River basin.

DISCUSSION

Historically, trout ranged widely in the interior West of the United States from small headwater streams to large mainstem rivers and terminal lakes. As habitats became degraded over time, waters warmed and nonnative species invaded the former range of many native trout, forcing them into smaller headwater areas. This increasing isolation of native trout has been facilitated by fishery managers who have sought to protect native trout from hybridization with nonnative trout by introducing them in headwater streams above artificial barriers (Fausch et al. 2009). Although this isolation has helped to maintain the genetic purity of many trout populations by isolating them from invading species, transplant efforts may have inadvertently reduced the integrity of the larger aquatic system by fragmenting stream habitats and introducing trout into smaller habitats, including some that were historically fishless. Nonetheless, current recovery plans for listed species such as the Apache trout describe recovery goals in terms of the number of genetically pure populations that are to be established and protected (U.S. Fish and Wildlife Service 2009).

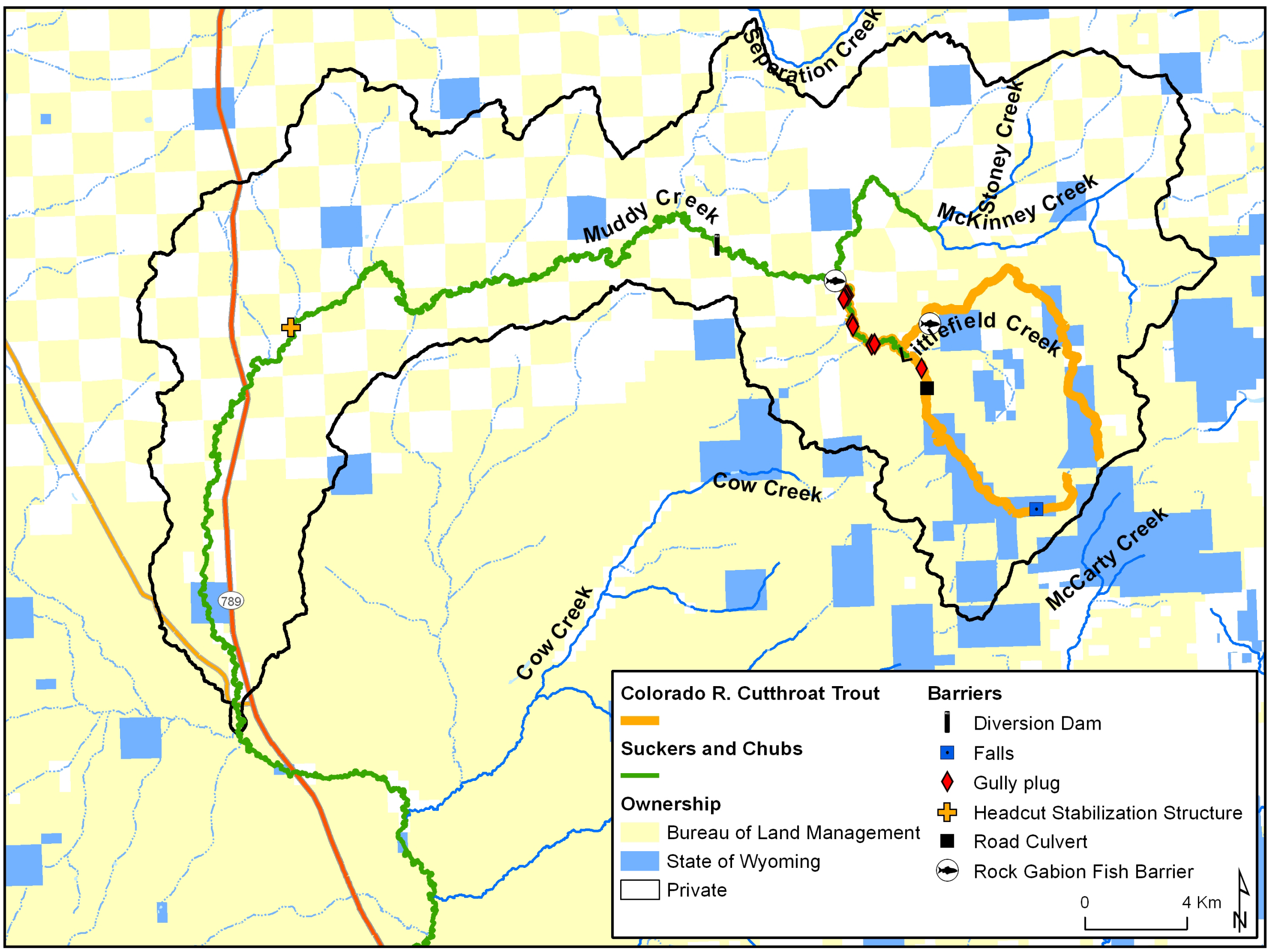
Establishing large, interconnected stronghold populations that exhibit life history diversity may be the key to conserving trout biodiversity in a future characterized by global warming and increasing disturbances such as wildfire, floods and drought (Heller and Zavaleta 2009; Lawler 2009). For aquatic systems, where habitat fragmentation by dams and water diversions have been particularly prominent, strategies that reconnect aquatic systems can be particularly valuable if problems associated with nonnative species can be adequately addressed (Fausch et al. 2009; Haak and Williams 2012).

Recent efforts to restore and reconnect fragmented Colorado River cutthroat trout populations in the upper Colorado River drainage of Wyoming, Colorado, and Utah provide examples of how rebalanced portfolios can have broader benefits to aquatic conservation. The current portfolio of Colorado River cutthroat trout shows that existing populations have retained little life history diversity or large, intact habitat patches that characterized historical conditions. A new program to restore native fish communities reconnects fragmented Colorado River cutthroat trout populations with sensitive warmwater fishes, such as bluehead sucker (*Catostomus discobolus*) and roundtail chub (*Gila robusta*), to create watershed-scale conservation areas in the upper basin (Dauwalter et al. 2011) (Figure 5). Re-establishing larger trout populations not only increases Resilience in the portfolio but also allows the trout to re-establish a migratory life history, which often is a minimized component in Representation.

The conservation portfolio and 3-R framework described herein provide one example of a systematic approach to trout restoration that can be applied to aquatic conservation planning for the protection and restoration of biodiversity. To be most useful in such broader conservation efforts, trout restoration must seek to reconnect fragmented populations and restore migratory life histories to create multiple, large, resilient stronghold populations. Such an approach would compliment the more common practice of introducing trout upstream of instream barriers in an effort to isolate them from nonnative species (Fausch et al. 2009). We make clear that the portfolio approach does not suggest abandoning the practice of isolating populations for the purpose of protecting their genetic integrity, rather it suggests the need to balance this approach with others that also would provide for life history diversity and Resilience – factors that are underrepresented in the current conservation portfolios of many trout.

Restoring larger stronghold trout populations requires interconnected stream habitat and large watersheds, which provide more habitat diversity for the support of a broader native fish community. In the Rio Costilla watershed of northern New Mexico, restoration of a Rio Grande cutthroat trout metapopulation provides habitat for longnose dace (*Rhinichthys cataractae*), Rio Grande sucker (*Catostomus plebius*), Rio Grande chub (*Gila pandora*), and other native

Figure 5: Using Colorado River cutthroat trout populations to anchor native fish conservation areas in the Muddy Creek drainage. Wyoming Game & Fish Department, Trout Unlimited, Bureau of Land Management and others reconnect formerly fragmented cutthroat trout populations in headwater streams and expand their distribution downstream into historical habitats now occupied by a suite of rare native warmwater fishes, creating a watershed-scale native fish conservation area as noted by black watershed boundary (from Dauwalter et al. 2011).



species. The Rio Costilla Restoration Project has been a 10-year collaborative effort among the Truchas Chapter of Trout Unlimited, the New Mexico Game & Fish Department, Carson National Forest, private landowners, and nonprofit organizations. Upon completion of the project, migratory Rio Grande cutthroat trout will be restored to their historical habitat in 240 km of interconnected streams and 25 lakes, making a significant contribution to a more balanced portfolio. For many native trout, restoration of larger, migratory populations that are more resilient to disturbance is a priority.

Although the broad range of native trout and their sensitivity to environmental change facilitates their usefulness in the conservation of larger aquatic communities, we suggest caution in using native trout as surrogates for the conservation needs of other species. Native trout are occasionally considered to be umbrella species because their conservation can protect many lesser-known aquatic species. However, such proclamations must always be viewed with care, as life history and habitat needs of multiple species seldom precisely overlap (Hitt and Frissell 2004).

As described previously, there is an increasing imperative to address stream fish conservation, especially for those streams containing coldwater fishes. Warming winters and record-breaking hot summers are occurring in recent years at a much higher frequency than in the mid-20th century due to global warming (Hansen et al. 2012). The adverse effects of these rising temperatures are exacerbated by land conversion and other forms of habitat degradation, causing widely observed increases in stream and river temperatures across the United States (Kaushal et al. 2010). Furthermore, it appears that disturbance events associated with increased warming pose a new type of threat not adequately considered when many current conservation strategies were developed. For example, Brown et al. (2001) documented losses of Gila trout populations from a combination of wildfire and subsequent debris flows. More recently, in 2012 New Mexico recorded its largest wildfire in known history, which burned across the range of several of the small, isolated populations of Gila trout. Disturbance can be lethal to small, isolated populations compared to more interconnected stream systems where fish may find refuge and be able to recolonize habitat once it recovers (Dunham et al. 2002).

Native trout are iconic species in many western landscapes and play important ecological roles. The rate of environmental change is likely to increase and confound problems associated with nonnative species (Rahel and Olden 2008). Whether we will be able to maintain the historical, functional roles of native trout remains to be seen. Yet it is clear that management strategies that maximize multiple levels of diversity, increase the Resilience of systems to disturbance and uncertainty, and aim to build in Redundancy are within our reach. Incorporating these concepts into recovery plans for listed trout is likely to help them persist in a future that is characterized by rapid environmental change and increased uncertainty.

Fortunately, native trout are well studied, with population-scale data available across the ranges of most species. This information, in conjunction with our understanding of their evolutionary history and behavioral strategies, allows for the development of a biologically sound planning framework that will help to restore the ecological role of native trout in freshwater ecosystems, thus benefitting a broad array of other aquatic species. Such an approach can provide for a more balanced management strategy that includes restoration of multiple, large metapopulations and restoration of life history diversity, in addition to the protection of genetic integrity that is provided by isolation of fish above instream barriers.

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