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Identification and Utility of Native Fish Conservation Areas in the Upper Snake River Basin, USA

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Abstract.—Native fish conservation areas (NFCAs) are watersheds where management emphasizes proactive conservation and restoration for long-term persistence of native fish assemblages while allowing for compatible uses. Native fish conservation areas are intended to complement traditional fisheries management approaches that are often reactive to population stressors and focused on single-species conservation efforts rather than complete assemblages. We identified potential NFCAs in the upper Snake River basin above Hells Canyon Dam using a process that ranked all subwatersheds (Hydrologic Unit Code 12) and used empirical data on distribution, abundance, and genetics for three native trout species (Bull Trout *Salvelinus confluentus*, Columbia River Redband Trout *Oncorhynchus mykiss gairdneri*, and Yellowstone Cutthroat Trout *O. clarkii bouvieri*, including the fine-spotted form) and both known occurrences and modeled potential distributions of native nongame fishes. Rankings also incorporated drainage network connectivity and land-protection status (e.g., national park, wilderness). Clusters of high-ranking subwatersheds were identified as potential NFCAs that were then classified according to the presence of nongame fishes identified as species of greatest conservation need in state wildlife action plans. The Pacific Creek

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and Goose Creek watersheds ranked high in the upper basin (above Shoshone Falls), and Little Jacks Creek and Squaw Creek ranked high in the lower basin. We then contrasted characteristics of a select few potential NFCAs, discuss the practical implementation and benefits of NFCAs for both fishes and other aquatic species in the upper Snake River basin, examined how the NFCA approach could enhance existing conservation partnerships, and discuss how designating select watersheds as NFCAs can create higher public awareness of the value of native fishes and other aquatic species and their habitats.

Introduction

Despite decades of allocating substantial resources to conserve freshwater ecosystems, North American freshwater fishes continue to decline at a much faster rate than their terrestrial counterparts (Master et al. 2000; Jelks et al. 2008). Williams (2019, this volume) discusses how current conservation approaches, such as the National Wildlife Refuge system, have been only moderately successful in protecting riverine ecosystems. Because rivers are linear in nature, approaches based on terrestrial features and land ownership often fail to consider watershed boundaries fundamental to aquatic conservation (Saunders el al. 2002; Roux et al. 2008).

Williams et al. (2011) proposed the concept of native fish conservation areas (NFCAs) to establish entire watersheds cooperatively managed for native fish communities. As a complement to existing conservation approaches (e.g., headwater isolation; Novinger and Rahel 2003), NFCAs emphasize intact and persistent native fish communities and healthy and resilient ecosystems while simultaneously striving to support compatible commercial and recreational uses. Dauwalter et al. (2011) explored the NFCA concept and its application in the upper Colorado River basin in Wyoming through a process that combined known and modeled species distributions, spatial prioritization analysis, and stakeholder discussions. Others have used the NFCA concept as an organizing framework for broad-scale native fish conservation initiatives and associated funding programs (Birdsong et al. 2015 and 2019, this volume).

In this paper, we further explore the utility of the NFCA concept by identifying potential NFCAs and their benefits in the upper Snake River basin upstream from Hells Canyon Dam. As described in detail below, we used known distributions and abundance of native trout species, known and modeled occurrences of nongame fishes, drainage network connectivity interrupted by large dams, and land-protection status (e.g., national parks, wilderness, wild and scenic river) to rank all subwatersheds based on their conservation value and identify potential NFCAs. We then summarize information by potential NFCAs, compare implementation of NFCAs in example watersheds, and discuss the utility of the NFCAs in the upper Snake River basin.

Upper Snake River Basin

The Snake River flows through a large basin draining portions of Wyoming, Idaho, Utah, Nevada, and Oregon. From its headwaters in Yellowstone National Park, Wyoming, the river flows southwest, then west, and then northwest before cascading north through Hells Canyon along the Idaho–Oregon border (Figure 1).

The upper Snake River basin lies above the Hells Canyon Complex of three dams (Brownlee, Oxbow, and Hells Canyon dams), that is, the present upstream limit to anadromous salmon and steelhead *Oncorhynchus mykiss* migrations into the Snake River in Idaho. The upper Snake River basin is naturally divided by Shoshone Falls, a 65-m waterfall near Twin Falls, Idaho that effectively separates the Snake

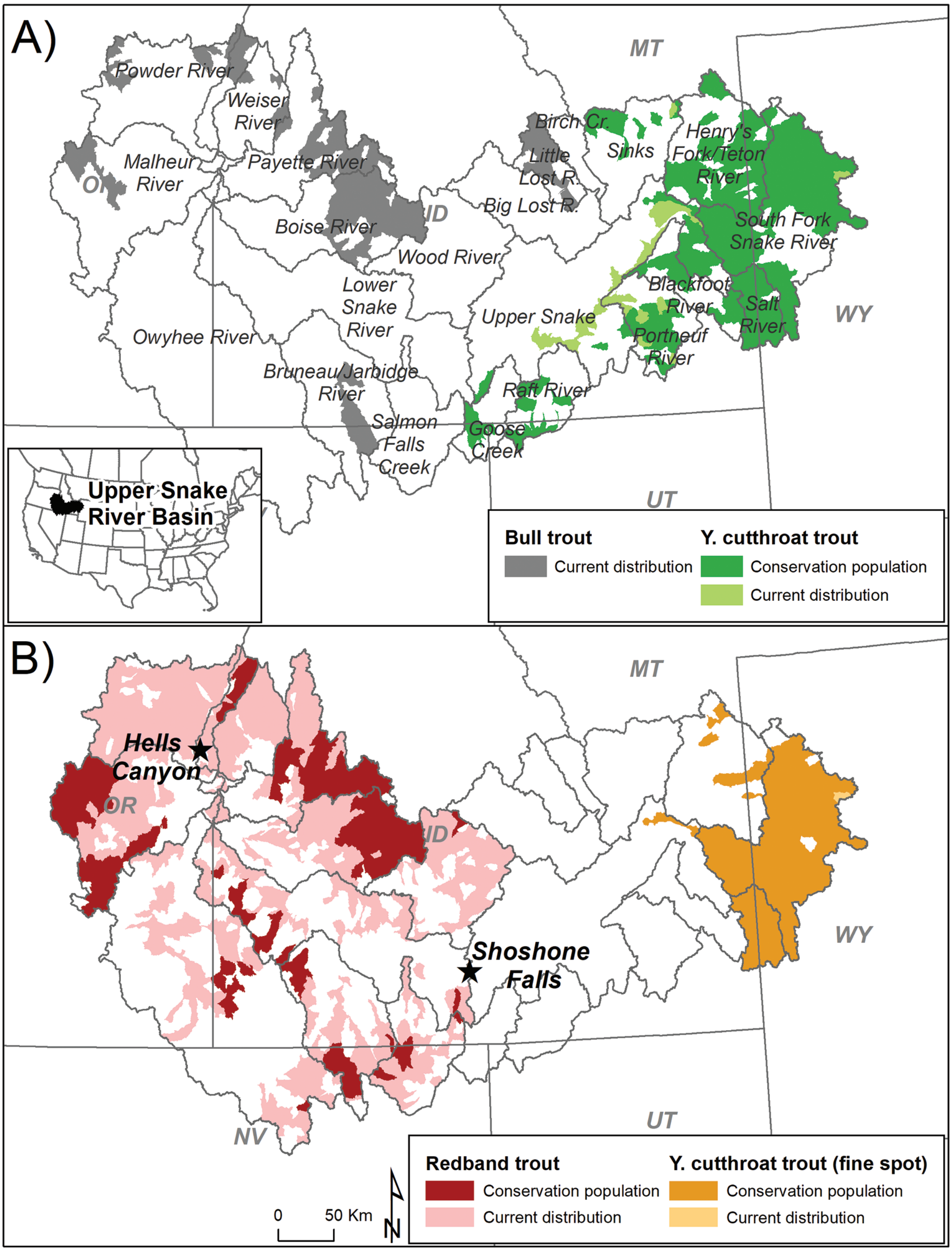

Figure 1. Conservation populations and current distributions of **(A)** Bull Trout *Salvelinus confluentus* and Yellowstone Cutthroat Trout *Oncorhynchus clarkii bouvieri* and **(B)** Columbia River Redband Trout *O. mykiss gairdneri* and the fine-spotted form of Yellowstone Cutthroat Trout in the upper Snake River basin.

River basin into upper and lower basins and is a complete barrier to fish migration (Figure 1; Benke and Cushing 2005). The falls, along with a unique geologic history and past connections with Pleistocene Lake Bonneville, have resulted in a unique history of species colonization that has strongly influenced the biogeography of fishes in the Snake River basin (Smith 1978; Campbell et al. 2011). The lower basin (Shoshone Falls to Hells Canyon Dam) supported 25 native fish species, of which 5 are extirpated (Table 1), compared to the upper basin (Yellowstone Park headwaters to Shoshone Falls), which supports 14 extant native species. Just seven extant species are native to both the upper and lower basins (Table 1; Wallace and Zaroban 2013; Sigler and Zaroban 2018).

Aquatic species management in the Snake River basin has focused primarily on native trout. Yellowstone Cutthroat Trout (including the fine-spotted form) are emphasized above Shoshone Falls, with Columbia River Redband Trout and Bull Trout emphasized below it (Figure 1). All are species of greatest conservation need (SGCN) as well as listed species of special concern in Idaho, Wyoming, Nevada, or Oregon. Bull Trout are also federally listed as a threatened species under the U.S. Endangered Species Act. Nevertheless, eight other SGCN species occur in the lower Snake River basin (such as Leopard Dace, Umatilla Dace, and the Shoshone Sculpin). Four nonsalmonid SGCN species occur in the upper Snake River basin, including Bluehead Sucker and Northern Leatherside Chub (Table 1), with only Mountain Whitefish abundantly occurring in both lower and upper basins. In addition to fishes, the upper Snake River basin provides critical habitat for a plethora of other SGCN species. In addition to the crayfish, fairy shrimp, pond snails, mud snails, mussels, frogs, and toads listed in Table 1, a wide diversity of SGCN birds, mammals, reptiles, and invertebrates persist in the upper Snake River basin (IDFG 2017).

Identification of NFCAs that support at-risk fishes, as well as other aquatic species of concern, has the potential to effectively integrate diverse conservation and management actions within large watersheds across extensive landscapes. This includes the upper Snake River basin, which has a diversity of ecosystems, land ownerships, and uses, as well as at-risk fishes and other aquatic species. For example, in the upper Snake River basin, NFCAs provide an opportunity to link the conservation of headwater Cutthroat Trout populations with downstream habitats supporting nongame fishes such as Bluehead Sucker, Northern Leatherside Chub, as well as conservation opportunities for other at-risk native aquatic species ranging from amphibians to birds to mammals. Consequently, the potential benefits of NFCAs are extremely diverse. For example, they may be managed to sustain the connectivity of critical habitats at watershed scales. Connectivity serves to enhance population persistence by facilitating natural metapopulation processes (Dunham and Rieman 1999; Hilderbrand and Kershner 2000; Compton et al. 2008). Simultaneously, NFCAs may provide discrete hydrologic units in which native fish and other aquatic communities can be isolated, if necessary, from nonnative invasions (Novinger and Rahel 2003; Fausch et al. 2009). To be most effective, proposed NFCAs should be large enough to support natural landscape processes that contribute to the long-term persistence of populations (Haak and Williams 2012). Yet NFCAs may also be small enough to encourage the integration of substantive management actions by diverse entities ranging from federal to tribal to state to private landholders. Consequently, the establishment of NFCAs may facilitate more efficient and effective cooperative actions to benefit a wider assemblage of native aquatic species.

Table 1. Fishes and other taxa native to the upper Snake River basin above Hells Canyon and their general distribution (upper or lower basin relative to Shoshone Falls), species of greatest conservation need (SCGN) status, number of occurrences (and total sites) in survey data, and species weight used to rank subwatersheds.

Taxonomic group	Common name (species abbreviation)	Scientific name	Distribution in basin	SCGN	Occurences (total sites)	Analysis weight
Fishes	Pacific Lamprey (PLY)	*Entosphenus tridentate*	Lower	ID, OR	Extirpated	
	White Sturgeon (WST)	*Acipenser transmontanus*	Lower	ID, OR		
	Chiselmouth (CSM)	*Acrocheilus alutaceus*	Lower		88 (1,452)	0.945
	Utah Chub (UTC)	*Gila atraria*	Upper		23 (1,280)	0.961
	Northern Leatherside Chub (NLC)	*Lepidomeda copei*	Upper	ID, WY	39 (1,210)	0.977
	Peamouth (PMT)	*Mylocheilus caurinus*	Lower		No data	–
	Northern Pikeminnow (PMT)	*Ptychocheilus oregonensis*	Lower		123 (1,448)	0.250
	Redside Shiner (RSS)	*Richardsonius balteatus*	Both		462 (3,045)	0.371
	Longnose Dace (LND)	*Rhinichthys cataractae*	Both		298 (3,002)	0.676
	Speckled Dace (SPD)	*Rhinichthys osculus*	Both		640 (3,047)	0.001
	Kendall Warm Springs Dace (KWD)	*Rhinichthys osculus thermalis*	Upper	WY	No data	–
	Leopard Dace (LPD)	*R. falcatus*	Lower	ID[a]	10 (660)	1.000
	Umatilla Dace (UMD)	*R. umatilla*	Lower	ID[a]	No data	–
	Utah Sucker (UTS)	*Catostomus ardens*	Both		55 (1,310)	0.938
	Bridgelip Sucker (BLS)	*C. columbianus*	Lower		290 (1,609)	0.250
	Wood River Bridgelip Sucker (WBLS)	*C. c. hubbsi*	Lower		No data	–
	Bluehead Sucker (BHS)	*C. discobolus*	Upper	ID[a], UT, WY	46 (1,296)	0.953
	Largescale Sucker (LSS)	*C.macrocheilus*	Lower		101 (1,609)	0.250
	Mountain Sucker (MTS)	*C. platyrhynchus*	Upper		118 (2,736)	0.820
	Snake River Sucker (SRS)	*Chasmistes muriei*	Upper		Extirpated	
	Yellowstone Cutthroat Trout (YCT)	*Oncorhynchus clarkii bouvieri*	Upper	ID, NV, WY		0.991
	fine-spotted form		Upper	ID, WY		0.736
	Columbia River redband trout (Rainbow Trout) (RBT)	*O. mykiss gairdneri*	Lower	ID, OR		0.923
	summer steelhead		Lower	ID, OR	Extirpated	

Table 1. Continued.

Taxonomic group	Common name (species abbreviation)	Scientific name	Distribution in basin	SCGN	Occurences (total sites)	Analysis weight
	Bull Trout (BLT)	*Salvelinus confluentus*	Lower	ID, NV, OR		1.025
	Chinook Salmon (CHS)	*Oncorhynchus tshawytscha*	Lower	ID, NV, OR	Extirpated	
	Sockeye Salmon (SES)	*O. nerka*	Lower	ID, OR	Extirpated	
	Coho Salmon (COS)	*O. kisutch*	Lower	ID, OR	Extirpated	
	Mountain Whitefish (MWF)	*Prosopium williamsoni*	Both	NV, WY	100 (1,354)	0.558
	Mottled Sculpin (MSC)	*Cottus bairdii*	Both		263 (2,628)	0.461
	Paiute Sculpin (PSC)	*C. beldingii*	Both		237 (2,456)	0.340
	Shorthead Sculpin (SSC)	*C. confusus*	Lower		239 (1,609)	0.719
	Shoshone Sculpin (ShSC)	*C. greenei*	Lower	ID	No data	–
	Wood River Sculpin (WSC)	*C. leiopomus*	Lower	ID	44 (154)	0.922
Crayfishes	Snake River pilose crayfish	*Pacifastacus connectens*	Both	ID, WY		
Shrimps	raptor fairy shrimp	*Branchinecta raptor*	Lower	ID		
Snails	Banbury Springs lanx	*Lanx* sp.	Lower	ID		
	pondsnail species group	*Stagnicola* sp.	Both	ID		
	Rocky Mountain dusky snail	*Colligyrus greggi*	Upper	ID		
	Bruneau Hot Spring snail	*Pyrgulopsis bruneauensis*	Lower	ID		
	Bliss Rapids snail	*Taylorconcha serpenticola*	Both	ID		
Mussels	California floater	*Anodonta californiensis*	Both	ID, NV, OR		
	western ridged mussel	*Gonidea angulata*	Both	ID, OR		
	western pearlshell	*Margaritifera falcata*	Both	ID		
Salamander	western tiger salamander	*Ambystoma mavortium*	Upper	WY		
Frogs	northern leopard frog	*Lithobates pipiens*	Both	ID, NV, WY		
	Columbia spotted frog	*Rana luteiventris*	Lower	ID, NV, OR		
Toads	Great Basin spadefoot	*Spea intermontana*	Both	NV, WY		
	western toad	*Anaxyrus boreas*	Both	ID, NV, OR, WY		
	Woodhouse's toad	*A. woodhouseii*	Lower	ID		

[a] Species listed as SGCN but status not assessed and available at time of analysis.

Methods

We identified potential NFCAs through a process that ranked all subwatersheds (Hydrological Unit Code [HUC] 12 watersheds) in the upper Snake River basin based on native trout abundance and distribution, modeled occurrence probabilities for native nongame fishes, differential weighting of species based on their prevalence, drainage network connectivity, and land-protection status. Rankings were intended to identify watershed-scale areas from the headwaters downstream where native trout overlap in distribution with, or occur near, native nongame fishes and where watershed scale conservation would benefit entire fish assemblages. Our analysis did not focus on identifying unique habitats with endemic fishes (e.g., spring habitats with Shoshone Sculpin) or genetically unique subpopulations or subspecies not currently recognized as distinct species (e.g., Wood River Bridgelip Sucker or Big Lost Mountain Whitefish), nor did we focus on large river fishes (e.g., White Sturgeon) or the main-stem Snake River because of the difficulty in managing large rivers to their headwaters per the NFCA concept. Clusters of high-ranking subwatersheds (i.e., the top 25%) were aggregated and characterized based on the native fish assemblage, land ownership and protected status, watershed size, habitat conditions, and future threats.

Fish data

Many different data sources were used to define the distribution and abundance of native trout and the occurrence of native nongame fishes. Distribution and abundance data for native trout were primarily derived from rangewide assessment databases. Yellowstone Cutthroat Trout data (including the fine-spotted form) were based on the 2010 rangewide assessment database (Gresswell 2011), and Columbia River Redband Trout data were based on the 2012 rangewide assessment database (Muhlfeld et al. 2015). For each database, only conservation populations were used to define distributions (Figure 1), and abundance was based on the midpoint of categorical population abundances in the database (e.g., 0–35, 35–100, 101–250, 251–625, 625–1,250, and >1,250 fish/km). Conservation populations were defined as those populations that had less than 10% genetic introgression or had unique genetic, ecological, or behavioral attributes (e.g., adfluvial behavior; UDWR 2000; Gresswell 2011; Muhlfeld et al. 2015). Bull Trout distribution data were obtained from Streamnet, and abundance data from agency databases (see Acknowledgments).

Native nongame fishes data were assembled from fish collections made across the upper Snake River basin, and those data were used to develop species probability of occurrence models. Nongame fishes were sampled primarily by electrofishing, but other methods were also used; for example, nongame species in Idaho were primarily sampled during Idaho Department of Fish and Game (IDFG) and Idaho Department of Environmental Quality electrofishing surveys (Meyer et al. 2013) while both electrofishing and minnow traps were used in other data sets (Blakney 2012). In all, more than 3,047 fish collection records were used to determine species occurrences (see Acknowledgments for sources). From these collections, presence–absence data were used to develop species-specific species distribution models (random forest; Breiman 2001) where probabilities of occurrence were modeled as a function of multiple environmental variables (% converted land, canal density, etc.) (see www.tu.org/USRB-multi-sp-assmt for details). The models for all species, except Leopard Dace, indicated good predictive ability with 10-fold cross-validated AUC values >0.75. The model for Leopard Dace, a species with only 10 occurrences, had the poorest predictive ability (AUC = 0.695). Species-specific models were then used to predict probability of occurrence in perennial stream segments in the National Hydrography Dataset Plus (NHDPlus; version 1; 1:100,000 scale), with drainage areas larger than 159,100 km^2. Predictions were only made in subbasins within the probable native ranges sampled by Meyer et al. (2013) and Gamett (2003).

Watershed rankings

To identify potential NFCAs, every subwatershed in the upper Snake River basin was ranked based on native trout distribution and abundance data, nongame fish probabilities of occurrence data, river network connectivity, and the percent of subwatersheds encumbered in Gap Analysis Program (GAP) Status 1 or 2 protected lands (e.g., wilderness, national parks; USGS 2011). The analysis was constructed to generally give higher ranks to clusters of interconnected subwatersheds with abundant trout populations and high native-fish richness (high biodiversity) within or near protected lands. More specifically, subwatershed rankings were obtained using the additive-benefit function in Zonation v3.0 conservation planning software to account for river system connectivity (Moilanen 2007; Moilanen et al. 2008, 2011). Zonation produces a hierarchical ranking of all subwatersheds (rescaled from 0 to 100) based on the minimum marginal loss across species-specific input values given species weights (minimum biodiversity loss) and offset by a cost function:

$$\delta_i = 1 / c_i w_j \sum_j \Delta V_j ,$$

where δ_i = the marginal loss across all j species for subwatershed i; c_i = 100 – % subwatershed protected, where % protected was based on protected lands identified as GAP status 1 or 2 lands; w_j = the weight for species j based on professional judgment for native trouts or nongame species prevalence, one measure of rarity, defined by Meyer et al. (2013)(see Table 1); and ΔV_j = is the marginal loss of species j values between all remaining subwatersheds minus the value within subwatershed i (see Moilanen et al. 2011). The value of V differed by species. For conservation populations of Yellowstone Cutthroat Trout and Columbia River Redband Trout (see above), V = the midpoint of fish/km ranges reported for those populations, V = subwatershed fish per km average (from fish survey data) for the current distribution of Bull Trout (a value of 1 was used if no abundance data were available), and V = the probability of occurrence (range from 0 to 1) for all nongame species. Rankings were determined by computing the minimum marginal loss across all species for each subwatershed and removing the subwatershed with the lowest marginal loss. This process effectively removed the subwatershed from the landscape that resulted in the minimum biodiversity loss, given species weights and amount of protected lands in the entire upper Snake River basin. The removal process was repeated iteratively until only one subwatershed remained during the last iteration, that is, the subwatershed with the highest marginal loss across all fish species and the most important subwatershed from a biodiversity standpoint. The sequence of removal resulted in the subwatershed rank. Trout data were represented by the spatial hydrography framework for each data source, and the probability of occurrence for nongame species was attributed on NHDPlus. All data were then converted to a 300-m grid for the analysis.

River networks are a nested hierarchy of drainage systems that pose challenges to conservation of fishes residing in riverine environments. Consequently, NFCAs are watersheds managed in their entirety for native aquatic communities. For this reason, river network connectivity was used to impart a penalty on the marginal loss across species based on whether a neighboring subwatershed has already been removed during the ranking process (i.e., has a lower rank). The penalty specifically translated into a reduction in subwatershed value (δ_i) based on the proportion of subwatersheds that had been removed upstream or downstream of the focal subwatershed (see Section 2.4.4 in Moilanen et al. 2011). The same penalties were used for all 21 species and were strong if upstream subwatersheds had already been removed and weak if downstream subwatersheds had been removed. Although connectivity was interrupted by large dams (i.e., those with reservoirs with ≥4 km^2 surface area), smaller dams or other barriers were not used to break connectivity because they are much more capable of being managed for fish passage. Figure 2 illustrates the analytical process.

Potential native fish conservation areas

Clusters of subwatersheds representing independent drainage networks within the top 25% of the landscape (rank > 75) were then aggregated into potential NFCAs. We summarized selected attributes of potential NFCAs: mean subwatershed rank, watershed size, documented native fish occurrences, presence of nongame fishes of greatest conservation need, percent of watershed protected, percent of perennial stream corridor protected, habitat integrity of subwatershed, and future security of subwatershed. The mean rank of subwatersheds in an NFCA was computed as an area-weighted mean from the subwatershed ranking analysis. Documented species occurrences were determined from rangewide assessment databases for native trout and documented presence of native nongame species in fisheries surveys. State wildlife action plans were used to identify species of greatest conservation need in each state (e.g., IDFG 2017). Land protection status was based on GAP Status 1 and 2 lands (USGS 2011). Sub-

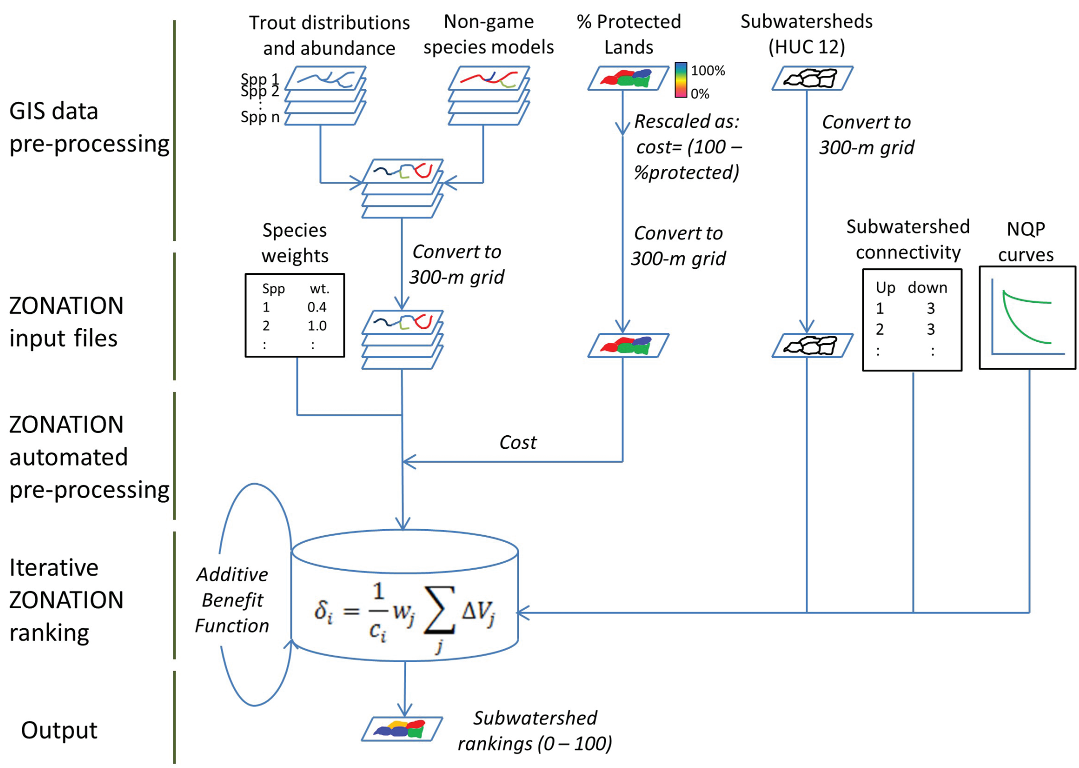

Figure 2. Conceptual model showing data integration for subwatershed ranking analysis.

watershed habitat integrity was based on the Trout Unlimited's conservation success index; a composite index ranging from 5 (low integrity) to 25 (high integrity) based on indicators of land protection, watershed connectivity, watershed condition, water quality, and flow regime, scored each from 1 (low integrity) to 5 (high integrity) (Williams et al. 2007). Future security of subwatersheds was also based on the Trout Unlimited's conservation success index, where future security is an index ranging from 5 (low security) to 25 (high security) based on individuals scores (1–5) for land conversion, resource extraction, energy development, climate change, and introduced species (Williams et al. 2007).

Results

Watershed rankings from the Zonation analysis identified entire subbasins where all subwatersheds ranked high, as well as individual or small clusters of a few high-ranking subwatersheds (Figure 3). Potential NFCA watersheds were primarily clustered in headwater areas, both within individual river systems (e.g., Boise, Payette, Little Jacks, Little Lost, and Goose drainages) and across the Snake River as a whole (e.g., South Fork Snake, Salt, and Blackfoot River subbasins). The Payette, Boise, South Fork Snake, Portneuf, and Blackfoot River subbasins represented large clusters of subwatersheds, with ranks exceeding 75 (of a range from 0 to 100), and representing the top

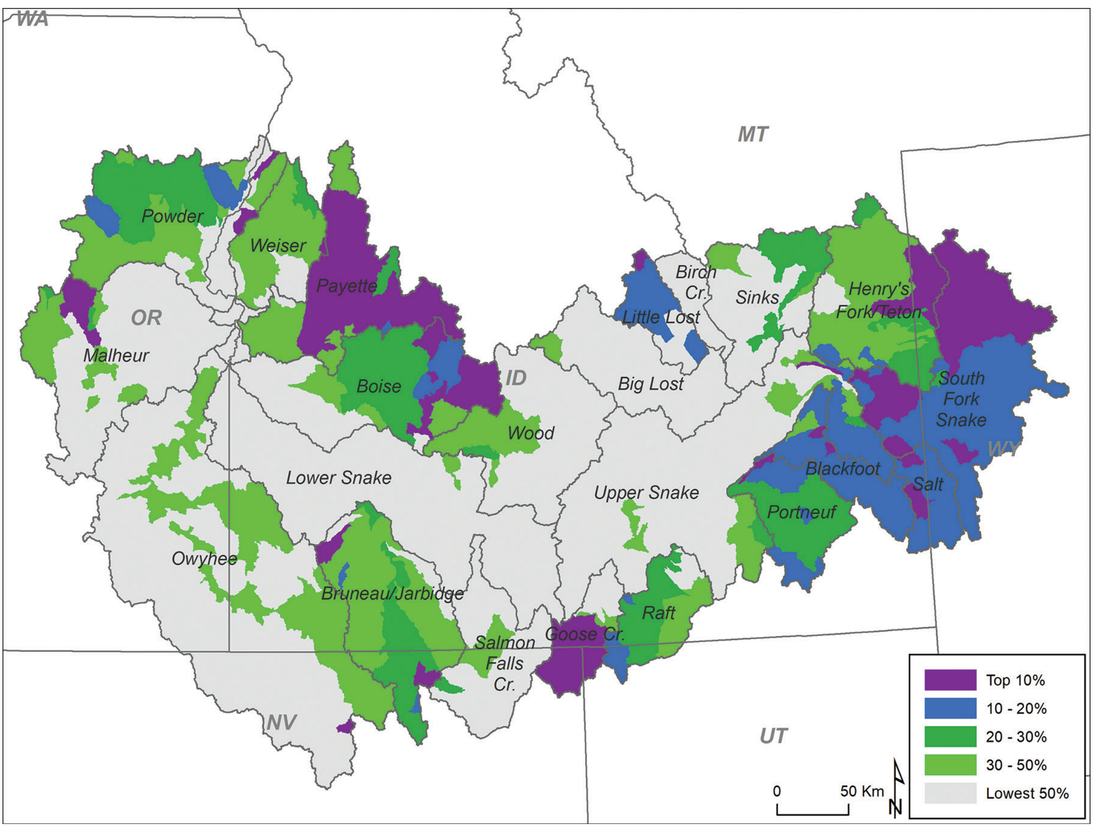

Figure 3. Subwatershed ranks in the upper Snake River basin based on native trout distributions and abundance, native nongame species occurrence probability, drainage network connectivity, and land-protection status.

25% of the entire upper Snake River basin. Smaller aggregations were present in the upper Malheur River, upper Jarbidge River, Goose Creek, Little Lost River, and Fall River/Conant Creek (Henrys Fork watershed). Examples of individual drainages with one or a few high-ranking subwatersheds were Little Jacks Creek, Jack Creek (Nevada), Indian Creek, Cassia Creek, upper Raft River, and Bitch Creek (Figure 4A).

After the clusters of high-ranking subwatersheds (top 25%) were aggregated, 44 watersheds (range from 56 to 4,344 km^2) were identified as potential NFCAs based on their high rank and native-species assemblages (Table 2). All potential NFCAs supported at least one native trout species, and all but three supported at least one native nongame species. Of those, 13 watersheds supported at least one nongame species of greatest state conservation need (Table 2; Figure 4A).

Land status (USGS 2004) within watersheds ranged from 72% private land (Portneuf River) to nearly the entire upper watershed protected in public land and national parks (upper Snake River, Cottonwood Creek, Fall River; Table 2; Figure 4A). Although stream corridors ranged widely in level of protection (Figure 4B), land status was not a reliable predictor of habitat integrity or future security.

Habitat integrity scores ranged from 12 to 25 (Table 2). Habitat integrity in the upper Snake River basin was low in areas with extensive agricultural or urban land use and high in upper elevation mountainous regions (Figure 5A). Watersheds comprised largely of public land (>90%) exhibited habitat integrity scores ranging from the highest possible (25) to 12. In potential NFCAs, habitat integrity was high for Pacific Creek in Grand Teton National Park (score 25 out of 25). In contrast, despite exhibiting species-rich fish assemblages (Table 2), habitat integrity was low for the Portneuf River and Conant Creek (scores of 12 out of 25) due to low scores (1 out of 5) in each of five individual indicators in at least one subwatershed. While increased levels of private land ownership within a watershed generally resulted in lower habitat-integrity scores, of the 11 watersheds with greater than 35% private land ownership, habitat integrity scores ranged from 12 in the Portneuf River and Conant Creek (Henry's Fork subbasin) to 18 in the upper Raft River, where 70% of the watershed is in private ownership.

Likewise, future security of habitats (and fishes) was variable across the basin (Figure 5B). It was typically high in protected areas and in areas with low human development. Within potential NFCAs, future security was high within several watersheds in national parks (scores 21 out of 25), whereas Indian Creek in Hells Canyon had low future security (scores 11 out of 25) because of threats from land conversion, resource extraction, and climate change (Table 2). Bear Creek in the South Fork Snake River subbasin had a future security score of 13, despite being 99% public lands and a habitat integrity score of 22, while Canyon Creek in the Henry's Fork Snake River subbasin, the lower South Fork Snake River, and several Payette River tributaries all had future security scores of 12 and 13 (Table 2).

Identification of potential NFCAs highlighted native-trout distributions and abundance coupled with presence of native nongame species, particularly rare and sensitive species (i.e., species of greatest conservation need; Figure 4). Potential NFCAs in the lower Snake River basin included assemblages of Columbia River Redband Trout and Bull Trout and from 1 to 11 nongame species (except for Indian Creek which contained native trout only). Nongame SGCN species (*n* = 4) are disproportionally represented in potential NFCAs in the upper basin.

To illustrate differences in the characteristics of potential NFCAs, we contrasted the characteristics of three watersheds: the Jarbidge River, Goose Creek, and the upper Blackfoot River (Figure 6). The Jarbidge

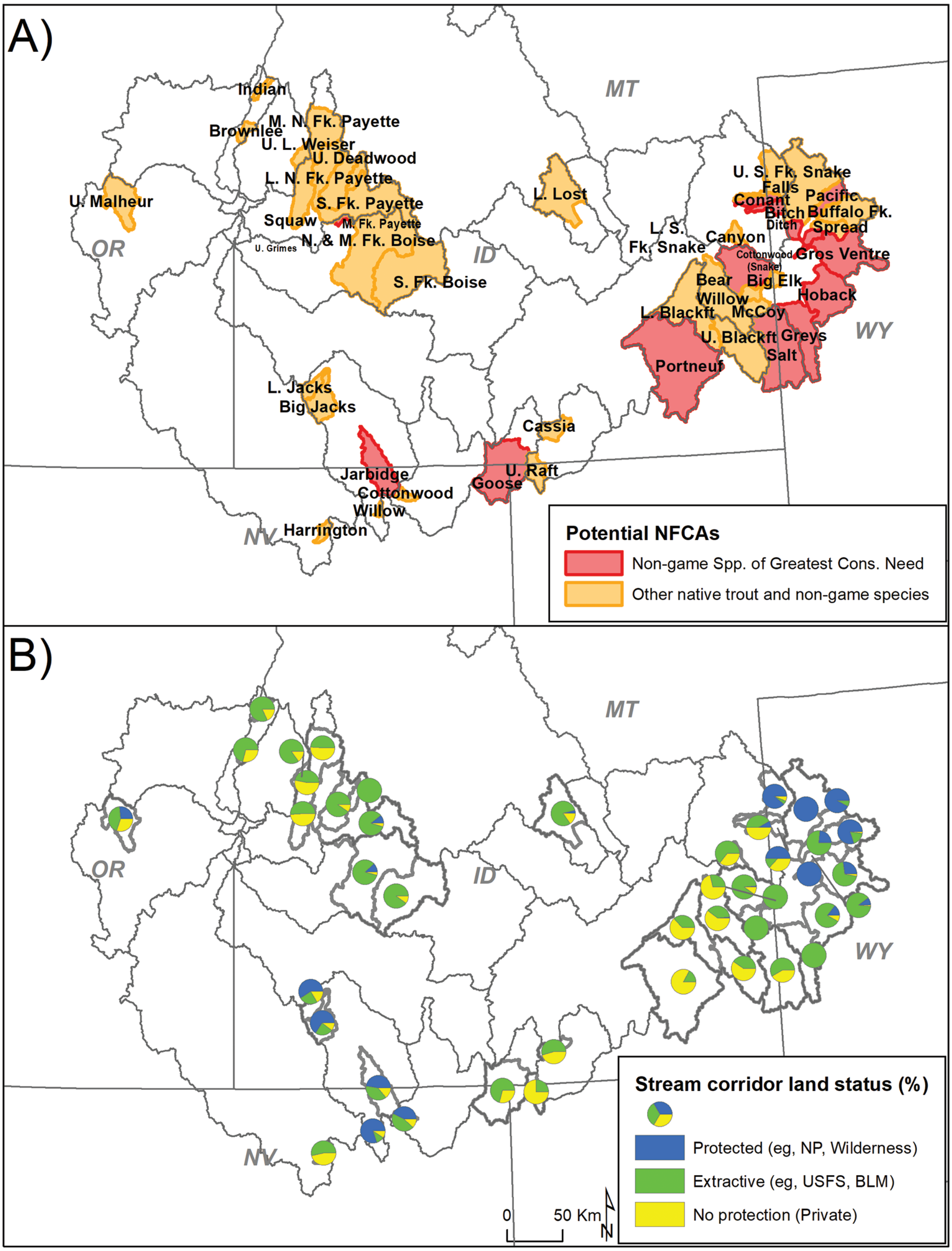

Figure 4. **(A)** Potential native fish conservation areas in the upper Snake River basin with the presence of nongame species of greatest conservation need and **(B)** pie charts illustrating the land status of perennial stream corridors. Details of each watershed are found in Table 2.

Table 2. Characteristics of potential native fish conservation areas in the upper Snake River basin. Species of greatest conservation need shown in bold. R. = River; Cr. = Creek; S. Fk. = South Fork; N. Fk. = North Fork. For Yellowstone Cutthroat Trout (YCT), fine = fine-spotted, lg. = large-spotted, and both = both fine and lg.

Watershed (subbasin)	Mean rank (0–100)	Watershed area (km²)	Native fishes[a]	Protected (%) (stream corridor)	Public land (%)	Habitat integrity[b] (5–25)	Future security[c] (5–25)
Above Shoshone Falls							
Pacific Cr. (S. Fk. Snake)	98.8	431	**YCT** (both), **NLC**	95.4 (92.3)	97.3	25	21
Upper S. Fk. Snake R.	98.7	2,086	YCT (both), UTS, LND, SPD, RSS, MSC, PSC, UTC	99.9 (99.8)	92.2	24	21
Fall R. (Henrys Fork)	97.6	894	**YCT** (both), MTS, LND, SPD, RSS, MSC, PSC	93.4 (88.8)	97.9	23	16
Buffalo Fork (S. Fk. Snake)	95.8	959	**YCT** (both)	75.4 (80.2)	97.6	23	20
Goose Creek	95.3	1,842	**YCT** (lg.), **BHS**, BLS, MTS, UTS, LND, SPD, RSS, **NLC**, MSC, PSC, SSC, UTC	0.2 (0.1)	85.6	17	16
Conant Cr. (Henrys Fork)	95.0	312	**YCT** (both), **BHS**, MTS, LND, SPD, RSS, MSC, PSC	20.5 (8.8)	51.9	12	14
Cottonwood Cr. (S. Fk. Snake)	94.3	189	**YCT** (both), **MWF**	100 (100)	89.6	23	20
Spread Cr. (S. Fk. Snake)	90.6	344	**YCT** (both), PSC	15.3 (23.7)	90.7	19	19
Lower S. Fk. Snake R.	90.6	1,396	**YCT** (both), **BHS**, LSS, MTS, UTS, LND, SPD, RSS, MSC, PSC, **MWF**	0.7 (1.7)	74.7	16	13
McCoy Cr.(S. Fk. Snake)	89.5	282	**YCT** (both), MTS, UTS, LND, SPD, RSS, MSC, PSC	0.0 (0.0)	99.2	21	14
Ditch Cr. (S. Fk. Snake)	89.2	160	**YCT** (both), **BHS**	41.6 (10.6)	74.4	17	16
Gros Ventre R. (S. Fk. Snake)	88.7	1,617	**YCT** (both), PSC, **MWF**	36.4 (26.8)	97.6	20	18
Hoback R. (S. Fk. Snake)	87.9	1,469	**YCT** (fine), MTS, LND, MSC, **MWF**	19.3 (14.4)	94.1	21	14
Salt R. (S. Fk. Snake)	87.6	2,309	**YCT** (both), **BHS**, MTS, UTS, LND, SPD, RSS, **NLC**, MSC, PSC, **MWF**	0.7 (0.0)	71.3	15	15

Table 2. Continued.

Watershed (subbasin)	Mean rank (0–100)	Watershed area (km²)	Native fishes[a]	Protected (%) (stream corridor)	Public land (%)	Habitat integrity[b] (5–25)	Future security[c] (5–25)
Above Shoshone Falls (continued)							
Upper Raft R.	87.3	411	**YCT** (lg.), MTS, LND, SPD, RSS, MSC, PSC	4.9 (0.0)	30.2	18	16
Bear Cr. (S. Fk. Snake)	87.0	219	**YCT** (both), SPD, RSS, MSC, PSC	0.0 (0.0)	98.8	22	13
Upper Blackfoot R.	86.0	1,458	**YCT** (lg.), MTS, UTS, LND, SPD, RSS, MSC, PSC, UTC	0.4 (0.1)	56.0	16	15
Greys R. (S. Fk. Snake)	85.2	1,178	**YCT** (both), MTS, LND, MSC, PSC, **MWF**	0.3 (0.1)	99.7	19	16
Little Lost R.	84.3	1,528	**BLT**, MSC, SSC	10.7 (4.0)	94.7	17	21
Lower Blackfoot R.	83.3	1,832	**YCT** (lg.), MTS, UTS, LND, SPD, RSS, MSC, PSC, UTC	0.1 (0.4)	21.6	13	15
Big Elk Cr. (S. Fk. Snake)	81.6	160	**YCT** (both), SPD, MSC, PSC	0.0 (0.0)	97.6	24	14
Portneuf R.	80.0	4,344	**YCT** (lg.), **BHS**, MTS, UTS, LND, SPD, RSS, MSC, PSC, UTC	2.5 (0.1)	27.8	12	17
Willow Cr.	79.6	1,676	**YCT** (lg.), MTS, UTS, LND, SPD, RSS, MSC, PSC	19.0 (1.7)	36.9	15	17
Bitch Cr. (Henrys Fork)	78.7	245	**YCT** (lg.), MSC, PSC, **MWF**	77.2 (50.0)	78.6	22	14
Canyon Cr. (Henrys Fork)	77.4	215	**YCT** (lg.), LND, SPD, PSC, sculpin species	0.0 (0.0)	57.1	13	13
Cassia Cr. (Raft)	74.8	367	**YCT** (lg.), UTS, LND, RSS, MSC, PSC, UTC	0.4 (0.0)	74.8	15	17
Below Shoshone Falls							
Indian Cr. (Hells Canyon)	99.9	104	RBT, BLT	0.1 (0.0)	90.1	14	11
Little Jacks Cr. (Bruneau)	98.3	267	**RBT**, SPD, MSC, SSC	43.5 (59.2)	98.4	18	15
Brownlee Cr. (Hells Canyon)	97.7	162	**RBT**, BLS, SSC, **MWF**	0.0 (0.0)	80.1	16	15
Squaw Cr. (Payette R.)	93.4	880	**RBT**, **BLT**, BLS, LSS, LND, SPD, RSS, NPM, MSC, SSC	0.0 (0.0)	52.8	16	15

Table 2. Continued.

Watershed (subbasin)	Mean rank (0–100)	Watershed area (km^2)	Native fishes[a]	Protected (%) (stream corridor)	Public land (%)	Habitat integrity[b] (5–25)	Future security[c] (5–25)
Below Shoshone Falls (continued)							
Lower N. Fk. Payette R.	93.1	810	**RBT,** LSS, SPD, RSS, NPM, MSC, SSC	0.0 (0.0)	50.3	15	12
Middle N. Fk. Payette R.	92.7	1,166	**RBT**, **BLT**, BLS, LSS, SPD, RSS, NPM, MSC	1.0 (0.4)	40.4	13	13
Middle Fork Payette R.	92.3	878	**RBT**, **BLT**, CSM, LND, SPD, RSS, MSC, SSC, **MWF**	0.2 (0.3)	93.4	18	15
S. Fk. Payette R.	90.0	1,918	**RBT**, **BLT**, LSS, CSM, LND, NPM, SSC	13.5 (10.7)	97.3	20	14
Upper Malheur R.	87.2	900	**RBT**, **BLT**, BLS, LSS, LND, SPD, RSS, NPM, MSC, **MWF**	18.8 (26.4)	76.3	15	18
S. Fk. Boise R.	86.2	2,527	**RBT**, **BLT**, BLS, LSS, CSM, MTS, LND, SPD, RSS, NPM, MSC, SSC, **MWF**	0.0 (0.0)	88.4	17	16
Willow Cr. (Bruneau)	82.8	56	RBT	79.8 (80.5)	95.2	17	15
North/Middle Fork Boise R.	79.7	3,156	**RBT**, **BLT**, BLS, LSS, LND, RSS, MSC, SSC, **MWF**	12.5 (12.3)	93.5	18	16
Jarbidge R. (Bruneau)	78.5	886	**RBT**, **BLT**, BLS, LSS, CSM, MTS, LND, SPD, RSS, NPM, MSC, SSC, **MWF**	47.7 (37.2)	89.6	18	16
Upper Little Weiser R.	78.4	205	**RBT**, **BLT**, LND, MSC, SSC	0.0 (0.0)	87.2	15	14
Upper Deadwood R. (Payette)	77.5	283	**RBT**, **BLT**, SSC, **MWF**	0.0 (0.0)	95.5	21	15
Harrington C. (Owyhee)	69.2	151	**RBT**, SPD, PSC	0.0 (0.0)	61.0	16	16
Big Jacks (Bruneau)	65.3	632	**RBT**, BLS, LND, SPD, RSS, NPM	33.0 (66.1)	97.3	18	15
Cottonwood Cr. (Salmon Falls)	61.2	133	**RBT**, BLS, SPD, RSS, PSC	46.7 (42.5)	96.7	16	18

[a] See Table 1 for species abbreviations. Native fish occurrence based on project database and not expert knowledge.
[b] Habitat integrity from Trout Unlimited's conservation success index. Subwatershed scores range from 5 (poor) to 25 (good). Habitat integrity based in indicators of riparian condition, watershed connectivity, watershed condition, water quality, and flow regime.
[c] Future Security from Trout Unlimited's conservation success index. Subwatershed scores range from 5 (not secure) to 25 (secure). Future security based in indicators of land conversion, resource extraction, energy development, climate change, and introduced species.

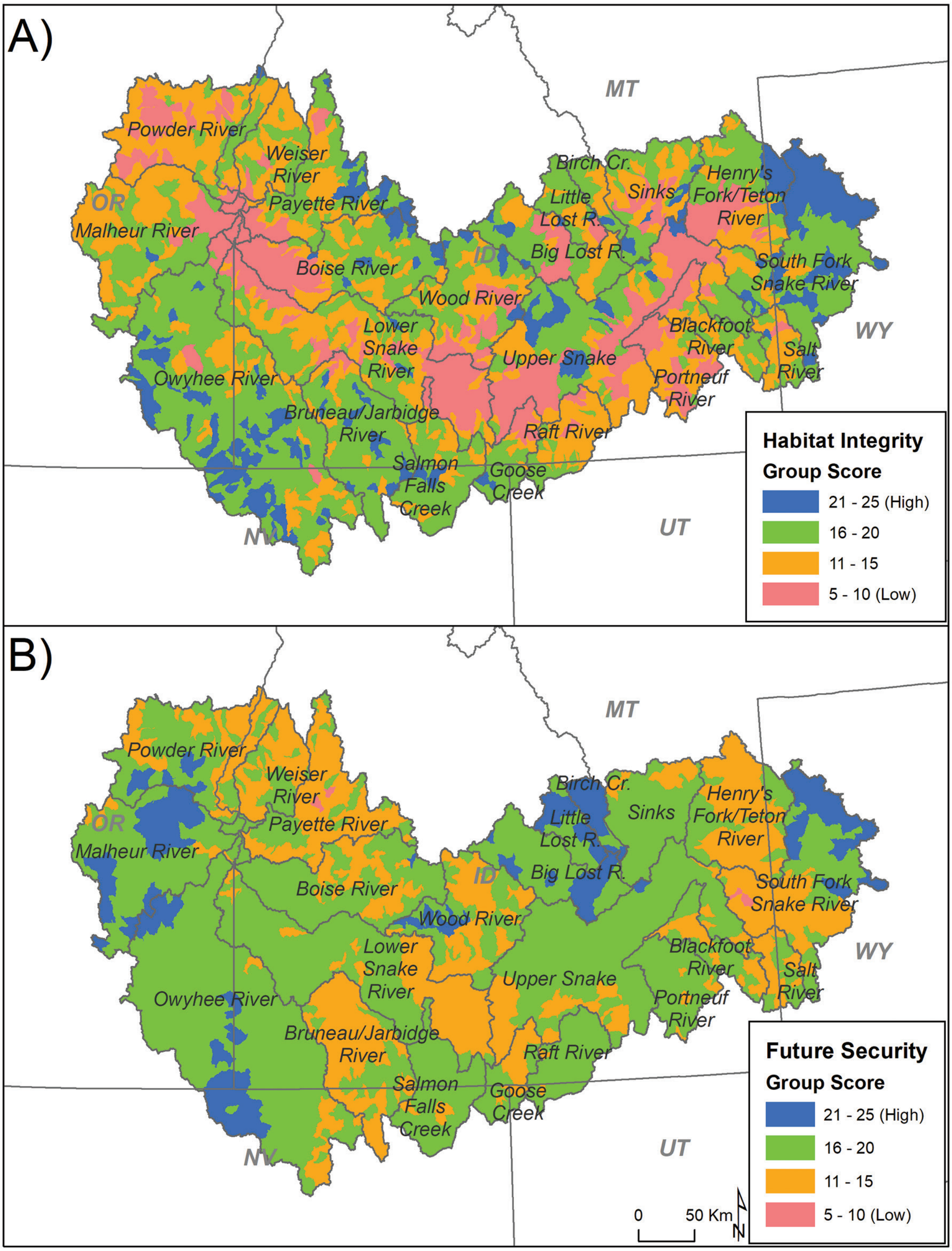

Figure 5. Spatial distribution of **(A)** habitat integrity and **(B)** future security scores for sub-watersheds (Hydrologic Unit Code 12: *n* = 2079) in the upper Snake River basin above Hells Canyon. Habitat integrity and future security indicators were based on Trout Unlimited's conservation success index (Williams et al. 2007).

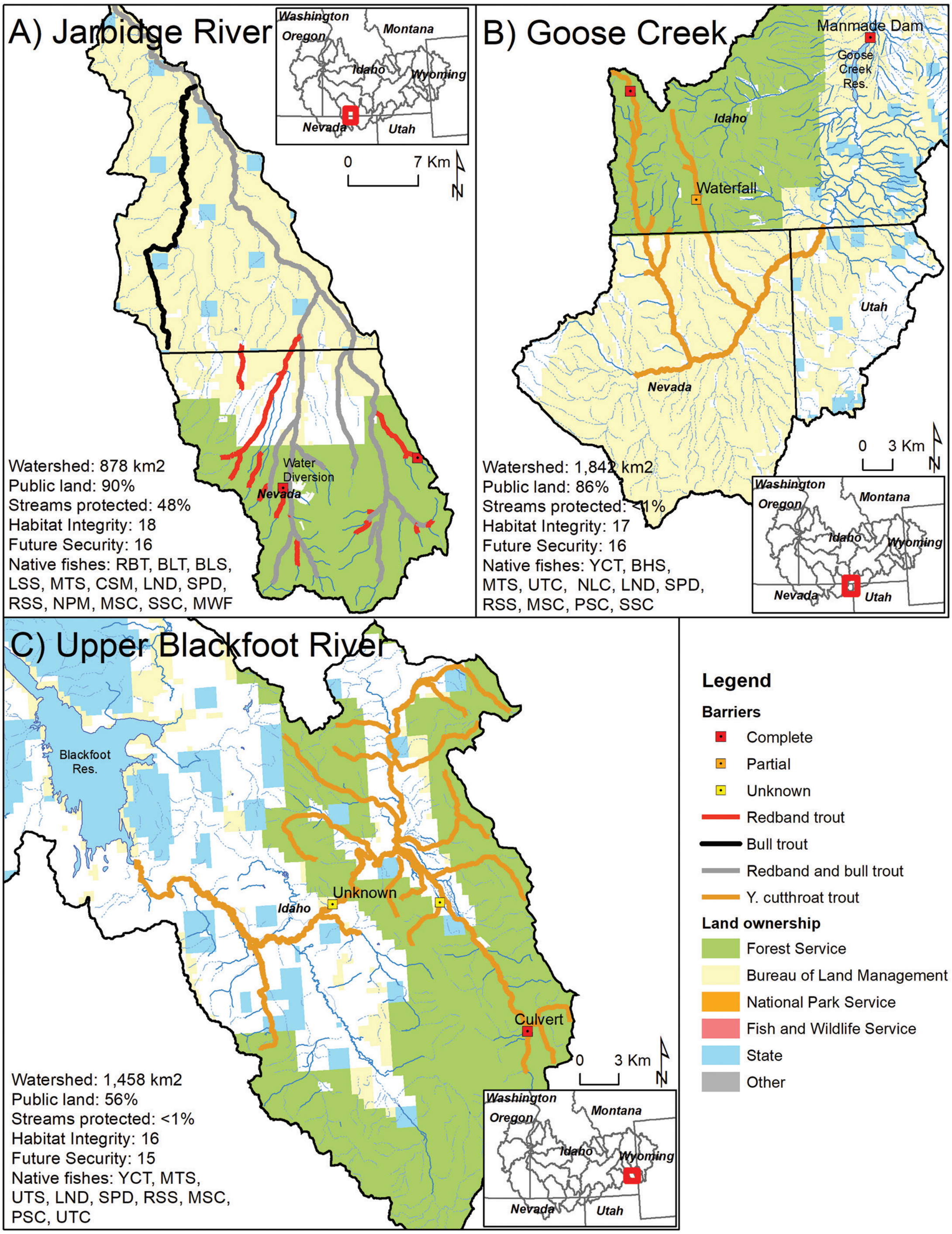

Figure 6. Land ownership and native trout distributions in the **(A)** Jarbidge River, **(B)** Goose Creek, and **(C)** upper Blackfoot River watersheds.

River supports two native trouts, Columbia River Redband Trout and Bull Trout, whereas the others have only Yellowstone Cutthroat Trout. The watersheds ranged in size from 878 to 1,842 km^2, but only two, Goose Creek and upper Blackfoot River, have natural downstream extents defined by dams impounding reservoirs. The Jarbidge River has no definitive downstream boundary and is connected to downstream rivers (a dam isolates the Bruneau River from the Snake River much further downstream). The amount of public land in the watersheds ranges from 56% to 90%, with U.S. Forest Service lands in the headwaters and a mix of Bureau of Land Management and state lands at lower elevations. Perennial stream corridors were 72–87% public land, except in the upper Blackfoot River where 41% of stream kilometers were on public land; however, the main stems of all streams and rivers were largely on private land. Little of the perennial streams had formal land protections, except in the Jarbidge River where 37% of perennial stream kilometers have formal protections in wilderness or wild and scenic river designation. Habitat integrity and future security for these three watersheds were moderate to high, in contrast for example to the future security of the South Fork Snake River and tributaries, which are lower and threatened by introduced species (e.g., Rainbow Trout *Oncorhynchus mykiss*), climate change (high drought risk), and energy development (potential hydropower development).

Discussion

Aquatic habitat in the western United States has been degraded by myriad factors, including overgrazing by domestic livestock (Beschta et al. 2013), water withdrawal (Deacon et al. 2007), oil and gas development (Dauwalter 2013), urbanization (Williams et al. 2007), hydroelectric development (Thurow et al. 2000), and forestry and mining practices (Lee et al. 1997), among other anthropogenic impacts. In turn, the distributions of inland trout have been substantially reduced; for example, all inland Cutthroat Trout subspecies occupy less than half of their historical habitat (Thurow et al. 1997; Haak and Williams 2013). Salmon have been extirpated from some rivers (Praggastis and Williams 2013), and nongame fishes have experienced declines in abundance and distribution in western North America (Brouder and Scheurer 2007). Habitat conditions are expected to continue to change in the future as runoff timing, stream discharge, and water temperatures are altered by climate warming (Wenger et al. 2011; Beschta et al. 2013; Meyer et al. 2014a; Isaak et al. 2015).

Benefits of native fish conservation areas for native fishes

Native fish conservation areas provide both a conceptual and formal framework for collaborative, watershed-scale conservation and restoration efforts targeting broader native fish communities that may include native trout in headwaters and native nongame species in both headwaters and downstream areas in western river systems (Williams et al. 2011). Watershed-scale conservation and restoration can improve instream habitat diversity closely linked to fish diversity in the upper Snake River basin (Walrath et al. 2016). North American Beaver *Castor canadensis* are increasingly important for restoring stream channels incised by livestock grazing and other impacts. Such efforts can be critical for SCGN species like Northern Leatherside Chub that have higher prevalence at sites with complex streamflows associated with beaver dams (Dauwalter and Walrath 2018). Stream habitat restoration and increased connectivity at the watershed scale are expected to improve current conditions for native aquatic assemblages and increase their resiliency to future threats like climate change (Thurow et al. 1997; Zoellick et al. 2005; Isaak et al. 2015).

We used a quantitative, data-driven approach to identify key locations in the upper

Snake River basin where watershed-scale restoration efforts will benefit native fish communities, such as in Goose Creek, the upper Blackfoot River, and Conant Creek (Figure 4A). Watershed-scale restoration might also be a management priority in watersheds that are juxtaposed to lands currently designated for protection as wild and scenic rivers, wilderness areas, or national parks because of the additional future security for the watersheds and aquatic communities. Examples of potential NFCA watersheds in designated status include the upper South Fork Snake, Pacific Creek, and Hoback Creek (Table 2; Figure 4A). Ultimately, adoption of these potential NFCAs as functional NFCAs will require a stakeholder-driven, collaborative process ensuring feasibility assessment and implementation (Dauwalter et al. 2011; Birdsong et al. 2015).

Decades ago, Lee et al. (1997) anticipated the need for NFCAs after examining historical and contemporary distributions of 15 native salmonid taxa in the interior Columbia River basin and portions of the Klamath River and Great Basin. The authors evaluated the native salmonids we examined in this study (Columbia River Redband Trout, two forms of Yellowstone Cutthroat Trout, Bull Trout, and Mountain Whitefish; Lee et al. 1997; Thurow et al. 1997). Their work identified habitat and biodiversity strongholds for native salmonids in the northern Cascades, the central Idaho mountains, and the Snake River headwaters and their connecting river corridors. Thurow et al. (1997) noted that maintaining the integrity of these declining native fishes and aquatic systems for the long term would require a network of well-connected, high-quality habitats (strongholds) that supported a diverse assemblage of native species, including a full expression of their life histories. Our finer-scaled analysis of the upper Snake River basin further illuminates areas of diverse, high-quality, interconnected habitat in the headwaters of the Boise, Payette, and upper Snake River drainages and the potential for NFCAs in several of these same watersheds (Figures 4 and 6).

For the NFCA approach to function and assist both the public interest and management agencies' long-term planning efforts, it is essential that NFCAs be identified at a scale that is practical and manageable. Aggregating smaller subwatersheds with common-species assemblages and management concerns into larger management units (as potential NFCAs) ensures that NFCA designation will be an effective management tool (Birdsong et al. 2019). Although our unit of analysis was a subwatershed (~12,000 ha), our analysis also explicitly accounted for connectivity of adjacent subwatersheds. This facilitated aggregation into larger watersheds where management considerations and actions were likely to be consistent. For example, IDFG manages Yellowstone Cutthroat Trout at the subbasin level (IDFG 2007), a scale representing a natural way to aggregate our results into larger units, as we illustrate (Figure 4).

Watershed scale NFCAs are also compatible with the proposed management strategies of many state and federal natural resource management plans because they rely on identifying management units based on habitat conditions, genetics, and population status. The Idaho Department of Fish and Game's management plan for conservation of Yellowstone Cutthroat Trout (IDFG 2007) defines 13 geographic management units addressing abundance, trends, genetics, and an evaluation of existing threats (Meyer et al. 2006). The status of Columbia River Redband Trout populations is summarized in a similar manner below Shoshone Falls (Meyer et al. 2014b).

The NFCA concept can also be used as an organizational framework for cross-partnership collaborations focusing on strategic restoration of fish habitat. Several multiagency partnerships, such as the Western Native Trout Initiative (WNTI;

www.westernnativetrout.org) and the Desert Fish Habitat Partnership (DFHP; www.desertfhp.org), are collaborative, multi agency and multistate partnerships focused on native trout conservation and restoration across the western United States and conservation and restoration of habitats used by nonsalmonid desert fishes, respectively. The WNTI and DFHP partnerships commonly collaborate on habitat restoration projects (Dauwalter et al. 2019, this volume). The NFCA concept provides an umbrella framework guiding expanded collaboration of watershed-scale restoration efforts that could benefit native trout in headwater streams, as well as native, nongame fishes in downstream, warmer main-stem habitats. For example, our upper Snake River analysis informs identification of focal watersheds for such cross-partnership collaboration, planning, and fundraising (e.g., Dauwalter et al. 2011, 2019; Haak and Williams 2013).

Native sport fishes such as Cutthroat Trout and black bass *Micropterus* spp. have been proposed as key species defining NFCAs because they range widely, are relatively well known compared to many other native stream fishes, and are of primary interest to both recreational anglers and state and federal management agencies, yet they are relatively sensitive to disturbance (Williams et al. 2011; Birdsong et al. 2019). Restoring and reconnecting stream networks has been proposed as a method to conserve native trout in the face of climate change by creating larger stronghold populations and facilitating development of migratory life histories that aid in long-term population persistence (Haak and Williams 2013). Haak and Williams (2013) describe such efforts for Rio Grande Cutthroat Trout *Oncorhynchus clarkii virginalis*, including restoration of 240 km of interconnected habitats in the Rio Costilla area of New Mexico that also creates a refuge for other native fishes of the Rio Grande basin.

The NFCA concept has also been applied to explore watershed level conservation and stakeholder partnerships in Colorado and across the southeastern United States. Dauwalter et al. (2011) compared the distribution of remaining Colorado River Cutthroat Trout *O. c. pleuriticus* with known distributions of three sensitive warmwater fishes (Roundtail Chub *Gila robusta*, Bluehead Sucker, and Flannelmouth Sucker *Catostomus latipinnis*) to identify potential NFCAs in the upper Colorado River drainages of Colorado, Utah, and Wyoming. Several watershed-scale opportunities were identified, including Muddy Creek in the Little Snake River, where multiple agencies and nonprofit groups are working to reconnect headwaters with downstream reaches in order to conserve the entire native fish community (Compton et al. 2008).

In the southeastern United States, the NFCA concept has been proposed as a preferred method to protect native stream fishes. Birdsong et al. (2015) recommended the use of the NFCA concept to protect native black bass, which are keystone species in southeastern stream systems. Their protection in large, functional watersheds would simultaneously help conserve numerous less well-known, native stream fishes in the region. Efforts are underway to identify NFCA watersheds for keystone black bass species, including Guadalupe Bass *Micropterus treculii* in the Llano River watershed in central Texas, Redeye Bass *M. coosae* in South Carolina's upper Savannah River watershed, and Shoal Bass *M. cataractae* in the Chipola River watershed in north-central Florida.

Benefits of native fish conservation areas for other aquatic species

Management focused on resilient watersheds will also likely benefit other imperiled aquatic species such spotted frogs *Rana luteiventris*, western ridged mussel *Gonidea angulata*, other diverse SCGN species (Table 1), as well as riparian obligate species such as the sage grouse *Centrocercus urophasianus* that require wet meadow habitat for early juvenile rearing. Such an approach would engage multiple partners and potentially leverage increased funding sources in a more efficient manner to serve a wide diversity of species (Birdsong et al. 2019).

An example of this multiorganization partnership approach was implemented in 2015 on North Carolina's Little Tennessee River (LTR), which became the nation's first designated NFCA (Harris and Williams 2016; Leslie et al. 2019, this volume). The LTR is an important global biological hotspot and is host to a unique assemblage of fish, amphibians, mollusks, crayfish, and aquatic insects. The North Carolina Wildlife Federation gathered interested organizations, agencies, and business to discuss long-term conservation of the LTR. As a result, the LTR Native Fish Conservation Partnership formed to assist management of the LTR watershed as an NFCA. The LTR Native Fish Conservation Partnership includes 25 collaborative partners comprising nongovernmental organizations, federal and state agencies, the Eastern Band of Cherokee Indians, and several private businesses.

Collaborative benefit of native fish conservation areas

Addressing specific local and regional aquatic conservation issues through the NFCA concept can facilitate important socioecological perspectives that are key to achieving both biological goals and the social and management goals of NFCA partnership members (e.g., the Little Tennessee River NFCA). Establishing the multistakeholder partnership, required to support an NFCA, fosters a collaborative, interdisciplinary approach necessitating active dialogue for sharing values and perspectives. Native fish conservation area collaboration provides the opportunity for effectively discussing and resolving conflict among user groups, managers, and fisheries biologists (Hand et al. 2018; Birdsong et al. 2019). Rieman et al. (2000) used a broadscale and spatially explicit classification of subbasins in the northwest to examine opportunities and conflicts related to terrestrial and aquatic ecosystem management. Birdsong et al. (2019) discuss a 6-year multipartner effort across watersheds in Texas that led to the development of the Texas Native Fish Conservation Areas Network. The Texas NFCA Network protects 91 freshwater fishes considered species of greatest conservation need and their associated watersheds through designation of 20 NFCAs identified to preserve the unique Texas freshwater fish diversity.

Because human disturbance is strongly associated with the condition of both aquatic and terrestrial ecosystems, the commonality in management goals and opportunities challenges managers of multiple disciplines to work together. Spatially explicit classifications such as NFCAs provides a mechanism for better integrating management. Rieman et al. (2000) suggested that such approaches assist integration through (1) communication among disciplines, (2) effective prioritization of limited conservation and restoration resources, and (3) establishing a framework for experimentation and demonstration of restoration techniques. Establishing a multidisciplinary and multiorganization partnership to support NFCAs is a critical element for creating the public and institutional support necessary for more effective, long-term conservation and restoration of aquatic systems, as demonstrated eloquently in the Little Tennessee River (Leslie et al. 2019) and across the Texas NFCA Network (Birdsong et al. 2019).

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