Conservation Assessment for Native Fish in the Upper Colorado River Basin

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Summary

Fishes of the Upper Colorado River Basin have one of the highest levels of endemism in the United States. The range and abundance of these fish has declined over the last century and continues to decline as a result of legacy impacts from past management practices, current water management, interactions with non-natives, and other impacts. Seven of these fish are considered imperiled by the American Fisheries Society and four are listed as endangered by the U.S. Fish and Wildlife Service.

We applied a complementarity-based approach to develop priority ranks (0 – 1; low to high) for catchments in the Upper Colorado River Basin. We used methods and a framework that we had previously developed for the Lower Colorado River Basin so both basins could be integrated into a cohesive unit. Our approach incorporated an anthropogenic threat index, fish species distribution models, and other metrics (i.e., habitat fragmentation, non-native species richness) potentially impacting conservation value of the riverscape. We developed the anthropogenic threat index based on the presence/absence of stressors known to influence the persistence of fish species. For the species distribution models, we incorporated metrics describing the topography, hydrology, land use, climate, and biogeography of the basin to model predicted probability of occurrence for native and non-native species.

Contiguous regions with high conservation value (> 0.8) are located in the headwaters of the upper Green, Yampa, and San Juan rivers, Green-Colorado and San Juan-Colorado rivers confluences, and designated wilderness areas of the Rocky Mountains. This information could be used by land managers to evaluate where they might have the largest return on conservation actions. These datasets could be used to identify areas of high conservation value or to compare the relative conservation values for catchments/stream segments where restoration projects are proposed to benefit native fish species or communities.

The intent was to provide an ecologically-based conservation assessment using the distribution of native fish species and the threats to persistence that could be used by land managers in the decision-making process to strategically place conservation efforts. Potential uses are: a) identify focal conservation areas, b) identify conservation strategies (e.g., non-native removal, habitat restoration, native species reintroduction, land protection), and c) compare/contrast factors influencing the conservation value. Because the Desert Fish Habitat Partnership and the Western Native Trout Initiative share overlapping geographic regions of interest, this could be used to identify regions of mutual conservation interest.

Objectives

Objectives for this project were to develop a) a geo-referenced anthropogenic threat index for the Upper Colorado River Basin using techniques based on our published research (Paukert *et al.* 2011; Strecker *et al.* 2011; Whittier *et al.* 2013) and b) conservation priority rankings for fish at the scale of the NHD plus V1 catchment boundaries (http://www.horizon-systems.com/nhdplus/nhdplusv1_home.php). The purpose for developing a conservation priority data layer was to provide agencies and multi-agency partnerships with an additional tool to assist in the decision–making process for aquatic habitat conservation. This tool is based on spatial patterns in the predicted distribution of native species and threats to persistence (i.e., non-native species, land use, and habitat fragmentation).

Background

The Upper Colorado River Basin (UCRB) covers an area of about 290,000 km^2 in the states of Wyoming, Colorado, Utah, New Mexico, and Arizona. Major tributaries include the Upper Colorado River (above Glen Canyon Dam), the Green River, and the San Juan River (Fig. 1). The waters of the UCRB originate in mountain meadows on the western slope of the Rocky Mountains, and flow through a semi-arid desert plateau characterized by sandstone canyons (Valdez and Muth 2005). The stream flows are driven primarily by mountain snowmelt, and thus water temperature and flow varies dramatically throughout the year, with peak flows occurring from late April to early June (Van Steeter and Pitlick 1998).

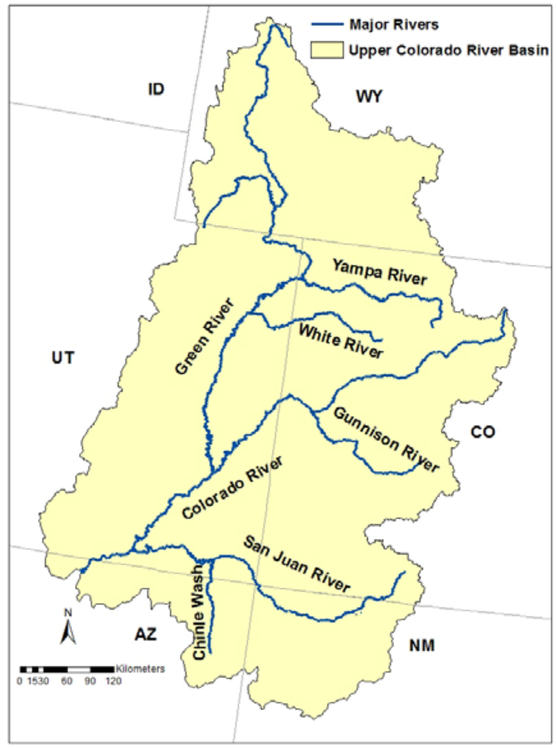


Figure 1. Map of the Upper Colorado River Basin.

The UCRB has one of the most threatened fish faunas in the United States (Tyus and Saunders 2000). There are only 14 native fish species or subspecies in the UCRB, of which 8 are endemic (Tyus *et al.* 1982). Most have declined in their range and abundance in the last 100 years (Carlson and Muth 1989; Valdez and Muth 2005). Seven of these native fish species are considered imperiled by the American Fisheries Society (Jelks et al. 2008) and four are listed as endangered under the U.S. Endangered Species Act (Dauwalter *et al.* 2011). The Colorado Pikeminnow (*Ptychocheilus lucius*), once a popular sportfish (Quartarone 1995) is now present only in about 25% of its former range in the UCRB, the Humpback Chub is present in about 68% of its former range (Valdez and Muth 2005), and the Bonytail Chub (*Gila elegans*) and Razorback Sucker (*Xyrauchen texanus*) are down to 0 and 2 wild populations, respectively (UCRRP 2013). Multi-state conservation agreements have been developed for four species with the intent to proactively manage the populations: Colorado River Cutthroat Trout (*Oncorhynchus clarki pleuriticus*), Roundtail Chub (*Gila robusta*), Bluehead Sucker (*Catostomus discobolus*), and Flannnelmouth Sucker (*Catostomus latipinnis*).

Native fishes in the Colorado River Basin have been adversely impacted by modifications to natural flow regimes, physical habitat, stream temperatures and other human-induced agents of environmental change. Dams and diversions have significantly altered the aquatic habitat in the UCRB by presenting navigational barriers, flattening the peaks and troughs of seasonal water flow, trapping sediment in reservoirs, and creating permanently clear and cold water stream reaches in the tailwaters of the dams (Van Steeter and Pitlick 1998). Water quality in the UCRB has been affected by agricultural runoff and pollution from mining and oil and gas development (Valdez and Muth 2005).

In addition, non-native introductions have substantially impacted the native fish fauna in the UCRB. Over 50 non-native species were introduced into the UCRB over the last 100 years, with many of these having become established and are now widespread (Valdez and Muth 2005). The now-endangered native species in the UCRB were seen as “trash fish” by locals in the mid-20th century, and prior to dam construction on the Green River, rotenone was applied to the river in 1962 to kill off the native minnow and sucker species and make way for trout fisheries. Prior introduction of the Channel Catfish (*Ictalurus* *punctatus*) to the UCRB has also harmed native fish populations (Quartarone 1995). Other aggressive non-native fish such as the Red Shiner (*Cyprinella lutrensis*) and Fathead Minnow (*Pimephales promelas*) were accidentally introduced alongside trout (Tyus and Saunders 2000). Non-native fish negatively impact native fish through predation (Northern Pikeminnow *Ptychocheilus oregonensis*; Tyus and Beard 1990, Channel Catfish; Ruppert et al. 1993), competition (Red Shiner and others; Karp and Tyus 1990), and hybridization (White Sucker *Catostomus commersonii*; MacDonald et al. 2008).

The UCRB has several multi-agency partnerships and multi-state conservation agreements. The Western Native Trout Initiative (WNTI), Desert Fish Habitat Partnership (DFHP), and Reservoirs Fish Habitat Partnership are formally recognized regional, multi-agency partnerships under the National Fish Habitat Plan, which is a national effort to protect, restore, and enhance fish habitat across the United States. Two additional and prominent conservation organizations for native fish of the UCRB are the Upper Colorado River Endangered Fish Recovery Program (UCRRP), established in 1988, and the San Juan River Basin Recovery Implementation Program (SJRIP), established in 1992. The UCRRP is a partnership of state and federal agencies, water and power companies, and environmental groups working to recover the four endangered UCRB fish species that occur throughout the UCRB by managing stream flows, restoring habitat, rearing native fish in hatcheries for restocking, and managing non-native fish species (UCRRP 2013). THE SJRIP is a similar coalition of public agencies and Native American tribal organizations as well as water interests focused mainly on the Colorado Pikeminnow and Razorback Sucker in the San Juan basin (SJRIP 2013). More recently, multi-state conservation agreements have been reached between states and federal agencies to restore the Colorado River Cutthroat Trout (*Onchorhynchus clarkii pleuriticus*), and the federally unprotected Roundtail Chub (*Gila robusta*), Flannelmouth Sucker (*Catostomus latipinnis*), and Bluehead Sucker (*Catostomus discobolus*) (Valdez and Muth 2005).

Stakeholder Engagement

We presented the results of this project at the Nov. 12 – 14, 2014 meeting of the DFHP to gain feedback and suggestions for modifying our final products (WNTI was also represented at this meeting). This meeting was attended by 22 individuals representing 14 federal, state, and non-profit agencies and organizations. Based on feedback, we modified the results of the species distribution models to better reflect where perennial waters are found in the basin and excluded predictions for native species from Lake Powell Reservoir (see the section on Species Distribution Models for details). The DFHP Science and Data Committee also reviewed our products.

Methods

Overview

The methods and framework used to develop the threat index and identify conservation priority rankings for catchments (~1-km2) in the UCRB followed those used for the Lower Colorado River Gap Analysis Project (LCRGAP; Strecker *et. al.* 2011, Whittier *et al.* 2013) to allow compatibility and use of rankings across both basins. Using this framework we took into account anthropogenic threats, fish distributions (native and non-native), and other factors (i.e., habitat fragmentation) that influence the value of habitat for aquatic species in the Colorado River Basin. The species distribution models incorporated metrics that have been linked to the occurrence of native species. For species with too few documented occurrences to develop a distribution model, we were able to incorporate the known occurrences for those species. Additionally we used a suite of anthropogenic threats, river disconnectivity, introduced fish species richness, and estimated home range requirements. Because our objective for the conservation priority rankings was to determine areas of high conservation value for the entire suite of native fish species, the product did not just rank areas of high biodiversity as important but also areas with few or single native species that did not have many introduced species, had adequate connectivity, and low threats.

Data Sources

Anthropogenic Data

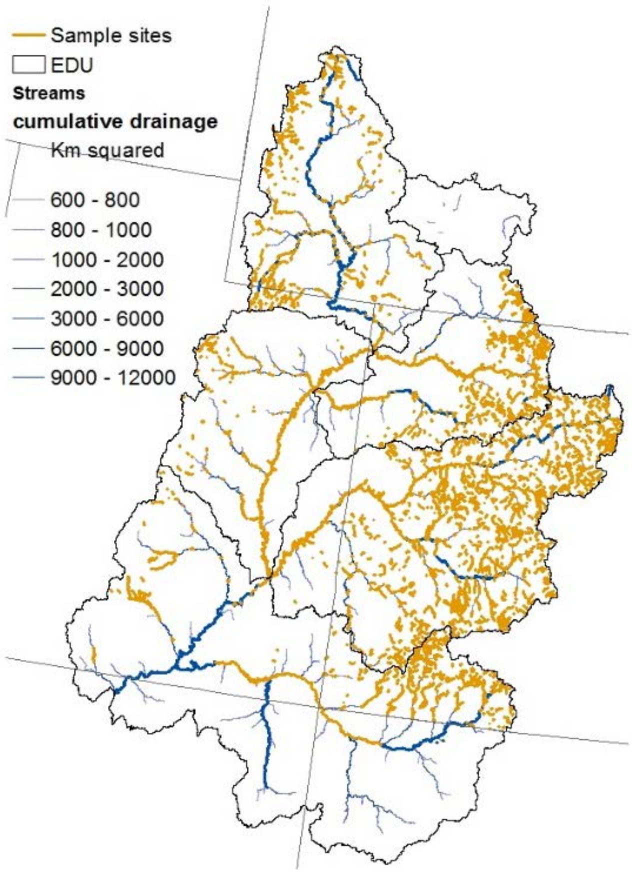
Datasets for anthropogenic stressors incorporated into the threat index (see *Anthropogenic Threat Index* section below) were obtained from several sources (Table 1). Stressors were selected based on documented influence on freshwater species assemblages and availability of spatial data, such as presence of barriers, alterations to streams, and land use practices (Mandrak 1995; Wang *et al.* 1997; Matthews 1998; Marchetti and Moyle 2001; Lamouroux *et al.* 2002; Zorn *et al*. 2002).

Table 1. Anthropogenic stressors, metric, and source of spatial data used to derive the threat index for the Upper Colorado River Basin. Source year for the dataset is provided in parentheses.

Stressor Type	Metrics	Data Source
Canals	Density (m/km^2)	USGS, National Hydrography Dataset (2006)
Dams	Density (#/km^2), reservoir storage density (m^3/km^2)	US Army Corp of Engineers, National Inventory of Dams (2010)
US EPA 303d-listed impaired streams	Density (m/km^2)	Impaired stream classification developed by Environmental Protection Agency, Water Quality Standards Database (2002)
Agriculture and urban landuse	Proportion of agriculture and urban	National Landcover Database (2006)
Mines	Density (#/km^2)	USGS, National Minerals Information Center (2010)
Pollution discharge sites	Density (#/km^2)	Environmental Protection Agency, Permit Compliance System (2006)
Railroads	Density (m/km^2)	US Census Bureau, Tiger files (2006)
Roads	Density (m/km^2)	US Census Bureau, Tiger files (2006)
Stream crossings	Density (#/km^2)	US Census Bureau, Tiger files (2006), US Geological Survey, National Hydrography Dataset (2005)
Waste facilities	Density (#/km^2)	Environmental Protection Agency, Superfund (2006), Toxic Release Inventory (TRI; 2006) and – Resource Conservation and Recovery Act, hazardous waste sites (RCRA; 2006) databases

Fish Species Data

We compiled ~100,000 geo-referenced fish samples (Fig. 2) provided by state and federal agencies within the UCRB (e.g., Colorado Parks and Wildlife, U.S. Forest Service, Wyoming Game and Fish, U.S. Fish and Wildlife Service, Utah Division of Wildlife Resources). These records are primarily for the upper Yampa River (n = 896), the Colorado River downstream of the Green River confluence (n = 174), and the lower Duchesne River (n = 63; Fig. 2). In total, we received > 2.6 million individual fish observations for the UCRB for 13 native (Table 2) and 60 introduced fish species (Table 3). The only native species of the UCRB that we lacked data for was the Kendall Warm Springs dace (*Rhinichthys osculus thermalis)*, whose distribution is limited to Kendall Warm Springs Creek, Wyoming (Valdez and Muth 2005). The fish collection data were attributed to the NHDplus V1 stream network using ArcGIS (ESRI 2011). Approximately 2,500 stream segments were sampled from 1980 – 2010 which is the time period we used to develop the species distribution models.



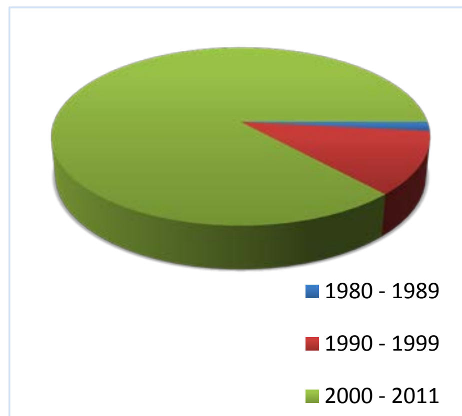


Figure 2. The map depicts the distribution of geo-referenced fish sample locations in the Upper Colorado River Basin. Black boundaries indicate Ecological Drainage Unit (EDU) Boundaries. The pie chart indicates the proportional distribution of samples per time period.

Table 2. Number of stream segments with native fish records in the Upper Colorado River Basin. **Bold** typeface indicates Federally Endangered species. An asterisk (*) indicates a parent species of a native subspecies.

Family	Common name	Scientific name	Stream segments
Catostomidae	Bluehead Sucker	*Catostomus discobolus*	928
	Flannelmouth Sucker	*Catostomus latipinnis*	958
	Mountain Sucker	*Catostomus platyrhynchus*	329
	Razorback Sucker	*Xyrauchen texanus*	659
Cottidae	Mottled Sculpin	*Cottus bairdii*	857
	Paiute Sculpin	*Cottus beldingii*	**20**

Cyprinidae	**Humpback Chub**	*Gila cypha*	147
	Bonytail Chub	*Gila elegans*	211
	Roundtail Chub	*Gila robusta*	556
	Colorado Pikeminnow	*Ptychocheilus lucius*	1028
	Speckled Dace	*Rhinichthys osculus*	1267
Salmonidae	Colorado River Cutthroat Trout	*Oncorhynchus clarkii pleuriticus*	904
	Mountain Whitefish	*Prosopium williamsoni*	261

Table 3. Number of stream segments were non-native fish species were recorded in the Upper Colorado River Basin.

Family	Common name	Scientific name	Stream segments
Catostomidae	Utah Sucker	*Catostomus ardens*	5
	Longnose Sucker	*Catostomus catostomus*	136
	White Sucker	*Catostomus commersonii*	689
	Rio Grande Sucker	*Catostomus plebeius*	1
Centrarchidae	Green Sunfish	*Lepomis cyanellus*	490
	Pumpkinseed	*Lepomis gibbosus*	2
	Bluegill	*Lepomis macrochirus*	221
	Smallmouth Bass	*Micropterus dolomieu*	583
	Largemouth Bass	*Micropterus salmoides*	296
	White Bass	*Morone chrysops*	1
	White Crappie	*Pomoxis annularis*	6
	Black Crappie	*Pomoxis nigromaculatus*	258
Clupeidae	Gizzard Shad	*Dorosoma cepedianum*	99
Cyprinidae	Goldfish	*Carassius auratus*	2
	Lake Chub	*Couesius plumbeus*	21
	Grass Carp	*Ctenopharyngodon idella*	10
	Red Shiner	*Cyprinella lutrensis*	614
	Common Carp	*Cyprinus carpio*	542
	Utah Chub	*Gila atraria*	31
	Rio Grande Chub	*Gila pandora*	2
	Brassy Minnow	*Hybognathus hankinsoni*	2
	Bigmouth Shiner	*Hybopsis dorsalis*	1
	Bigeye Chub	*Hybopsis gracilis*	1
	Northern Leatherside Chub	*Lepidomeda copei*	13
	Golden Shiner	*Notemigonus crysoleucas*	3
	River Shiner	*Notropis blennius*	3
	Spottailed Shiner	*Notropis hudsonius*	2
	Sand Shiner	*Notropis stramineus*	424
	Southern Redbelly Dace	*Phoxinus erythrogaster*	4
	Bluntnose Minnow	*Pimephales notatus*	2
	Fathead Minnow	*Pimephales promelas*	840

	Longnose Dace	*Rhinichthys cataractae*	87
	Redside Shiner	*Richardsonius balteatus*	203
	Creek Chub	*Semotilus atromaculatus*	148
Esocidae	Northern Pike	*Esox lucius*	173
Fundulidae	Plains Topminnow	*Fundulus sciadicus*	1
	Plains Killifish	*Fundulus zebrinus*	164
Gadidae	Burbot	*Lota lota*	3
Gasterosteidae	Brook Stickleback	*Culaea inconstans*	47
Ictaluridae	Black Bullhead	*Ameiurus melas*	296
	Yellow Bullhead	*Ameiurus natalis*	22
	Channel Catfish	*Ictalurus punctatus*	450
Moronidae	Striped Bass	*Morone saxatilis*	58
Percidae	Iowa Darter	*Etheostoma exile*	20
	Johnny Darter	*Etheostoma nigrum*	2
	Yellow Perch	*Perca flavescens*	21
	Walleye	*Sander vitreus*	80
Poeciliidae	Western Mosquitofish	*Gambusia affinis*	245
Salmonidae	Yellowstone Cutthroat Trout	*Oncorhynchus clarkii bouvieri*	12
	Snake River Cutthroat Trout	*Oncorhynchus clarkii ssp.*	40
	Greenback Cutthroat Trout	*Oncorhynchus clarkii stomias*	5
	Bonneville Cutthroat Trout	*Oncorhynchus clarkii utah*	16
	Rio Grande Cutthroat Trout	*Oncorhynchus clarkii virginalis*	2
	Rainbow Trout	*Oncorhynchus mykiss*	1041
	Sockeye Salmon	*Oncorhynchus nerka*	60
	Brown Trout	*Salmo trutta*	1020
	Brook Trout	*Salvelinus fontinalis*	1157
	Lake Trout	*Salvelinus namaycush*	24
	Arctic Grayling	*Thymallus arcticus*	1

Anthropogenic Threat Index

The stressor metrics were attributed to the NHDplus V1 catchments (http://www.horizon-systems.com/nhdplus/nhdplusv1_home.php) and summarized by the upstream watershed in a geographical information system (GIS). Catchments are the land area draining individual confluence-to-confluence (~1-km) stream segments. Upstream watershed included all land draining into and including the focal catchment (Fig. 3). We used the same metrics for the Upper Colorado that we previously used for the Lower Colorado threat index (Paukert *et al*. 2011) with the exception of diversions. We found that inconsistencies in definition between state agencies made creating a uniform dataset impossible. For both the Upper and Lower Colorado basins, we calculated the threat

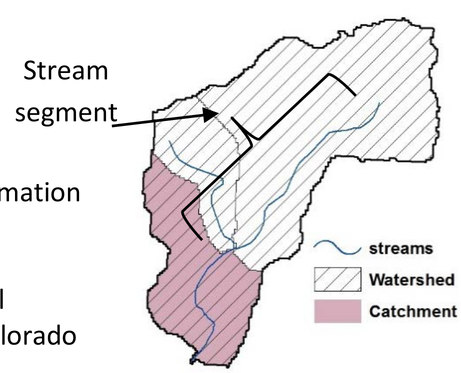


Figure 3. Depiction showing how stream segment, focal catchment and upstream watershed were defined.

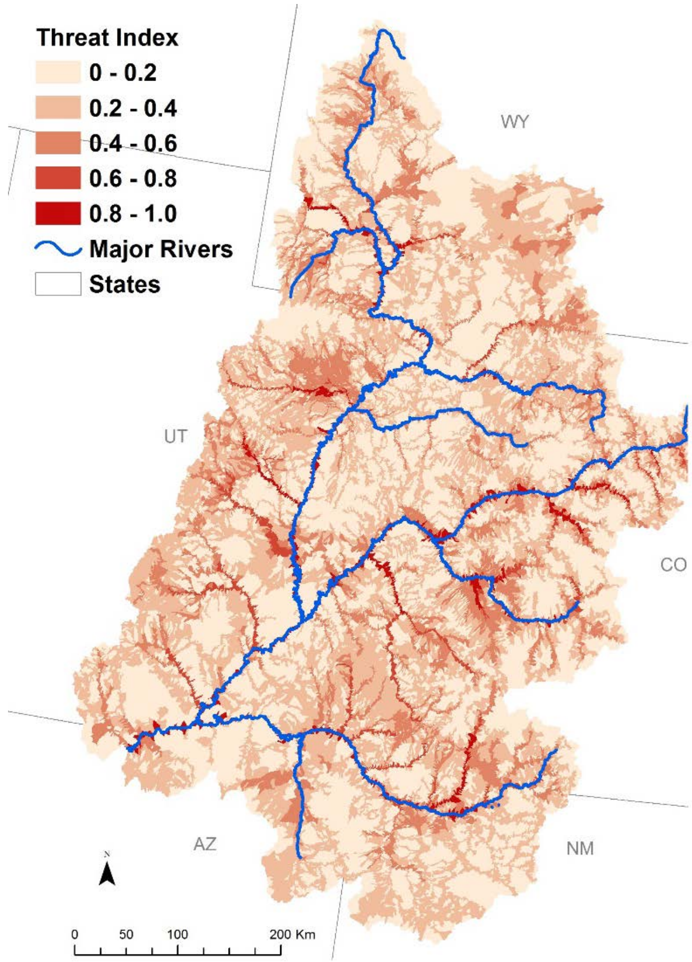


Figure 4. Map of the Threat Index for the Upper Colorado River Basin. The Threat Index is based on a count of presence of threat categories

index based on presence of stressor types (Table 1) in the upstream watershed. For each focal catchment we summed the number of stressor types in the upstream watershed and then scaled the results to range from 0 (no stressors) to 1 (highest number of stressors) without weighting any of the stressor types (presence/absence with equal severity; Paukert *et al*. 2011; Fig. 4).

Conservation Priority Rankings

The conservation priority ranking for catchments was intended to provide resource managers and other decision makers with a scientifically based prioritization using the distribution of native fish species and the threats to their persistence (including distribution of non-native fish). This is a coarse-filter tool and should be used in conjunction with additional information such as local knowledge of a region. We used a complementarity analysis approach which took into account areas with high native species richness and also those areas with low diversity but high importance for individual species due to their restructured ranges (ie., poor representation across the UCRB) Moilanen et al. 2005). Conservation planning typically requires spatially–extensive information on species distributions (Elith and Leathwick 2009). This poses a challenge for areas where species occurrences are incomplete. The cost and time investment to determine and maintain databases on current species distributions across vast geographic extents generally is not feasible. For this reason, we used species distribution models

(SDMs) to supplement recent sampling data to gage the likelihood of a species occurring in each catchment in the basin, including those where fish collection have never been attempted.

Species Distribution Models

To develop the SDMs we used native and non-native fish occurrences using data from 1980 – 2010 and evaluated the primary factors driving the distribution of fishes at three spatial scales: stream segment, focal catchment, and upstream watershed (Fig. 3). Predictive models were developed to determine predicted probability of occurrence for each species in all catchments across the UCRB. As with the LCRB, multivariate adaptive regression splines (MARS) was the method selected to develop the species distribution models using the option to model communities (multi-response models) which may contribute to more robust models for data poor species (Friedman 1991; Elith *et al.* 2006). To meet the assumptions for the multi-response method (Elith *et al.* 2006), we only used sampling records where at least two species had been recorded, assuming that these represented community sampling efforts that would have recorded the occurrence of all species collected. We realize that by making this assumption we may have included records that were not community sampling efforts; however, given the low diversity of this system, it is expected that community sampling efforts would frequently result in only a few species being collected and recorded. We also restricted the distribution modeling to only those species that had been recorded in at least 30 stream segments (Tables 2 and 3). Given the similar species composition within the Lower and Upper Colorado River basins, we utilized the same metrics that we found to be important predictors of species distribution in the LCRB (i.e., elevation, land use, presence of dams; Poole *et al.* 2010, Strecker *et al.* 2011).

We assessed predictive performance of the SDMs we used the area under the Receiver Operating Curve (AUC; Fielding and Bell 1997) and considered AUC values > 0.75 as indicating useful models (Pearce and Ferrier 2000). Additional details can be found in Strecker *et al.* (2011) and Whittier *et al.* (2013). After input from members of the Desert Fish Habitat Partnership, we modified the likelihood of occurrence within SDMs to zero for stream segments where stream order was < 4 and the stream type was intermittent to better capture area without perennial water (from the NHDplus V1 data). We also eliminated predicted probability of occurrence within Lake Powell for native species (*note: we were not able to develop robust distribution models for Razorback Suckers which do occur in Lake Powell*).

Zonation

As with the species distribution models, we computed the conservation priority rankings of catchments in the UCRB using the methods and framework developed for the Lower Colorado River Gap Analysis Project (LCRGAP; Strecker *et al*. 2011, Whittier *et al*. 2013) with a few exceptions. As with the Lower Colorado, we took into account 1) representation of native fish species, 2) nonnative fish species richness, 3) species-specific responses to habitat fragmentation based on upstream and downstream connectivity following Moilanen *et al*. (2009), 4) presence of threats using the threat index, and 5) species-specific connectivity requirements based on estimates of home range size. Conservation value was assessed using basic core-area Zonation as our cell removal rule with the Zonation conservation planning software package (v4.0.0; Moilanen *et al*. 2009).

Native species were incorporated into the conservation assessment based on the probability of occurrence or for species that we were not able to model, as present based on known occurrences from fish collection records. Non-native species richness was based on the count of species with a probability of occurrence > 0.5 or the known occurrence records for species which were not modeled. The total number of non-native species was calculated for every catchment in the basin, and incorporated into the conservation priority rankings using the species interaction feature of Zonation, which reduced the conservation priority rankings for catchments with higher non-native species richness.

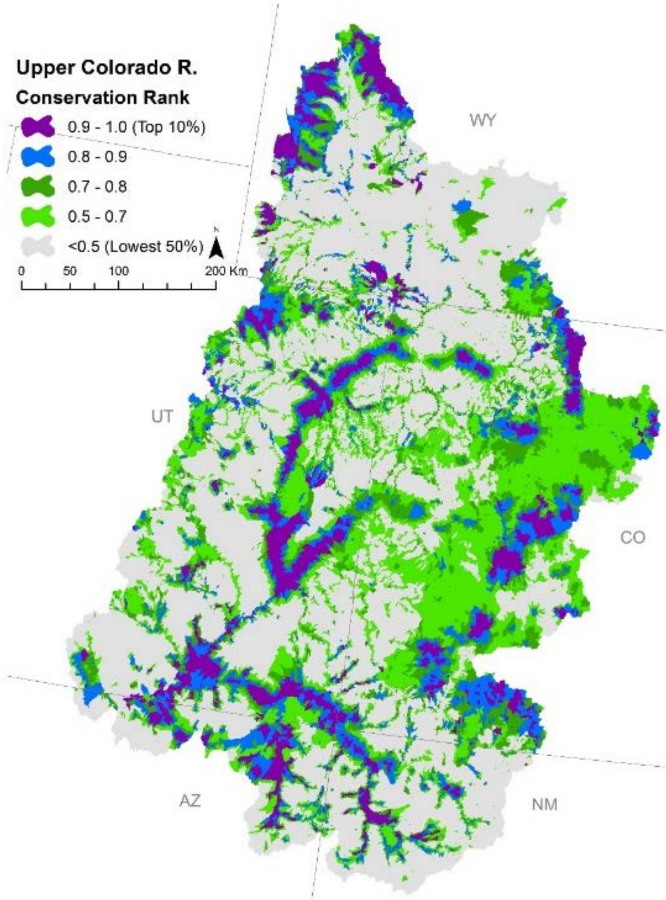


Figure 5. Map depicting the distribution of conservation priority ranks for catchments of the Upper Colorado River Basin. High values indicate greater potential conservation value.

Species-specific responses to habitat fragmentation were based on the scale-area slope calculations from Fagan *et al.* (2005). For many native species this scale-area slope was known, however when it was unknown we used the average value for other species in the same genus. When this relationship was unknown for any species in the same genus, we used the average value for all native species in the Upper Colorado Basin. Habitat fragmentation was determined by splitting the stream network at the locations of large dams (USAOE, National Inventory of Dams 2010), which allowed upstream and downstream connectivity to be calculated using the program RivEx v10.15 (Hornby 2014). Landscape threat data was incorporated into the conservation prioritization process through the use of the distribution discounting feature of Zonation, which reduced the priority of catchments with high threat impacts, based on decreased certainty in the ability of species to persist in a catchment at high threat levels. Catchments were prioritized from least to most valuable (rankings scaled from 0 – 1.0) based on the factors and methodology described above. With this information we were able to develop a map of the conservation rankings for catchments (at a 900 km^2 scale) in the Upper Colorado Basin. Contiguous regions with high conservation value (> 0.8) are located in the headwaters of the upper Green, Yampa, and San Juan rivers, Green-Colorado and San Juan-Colorado rivers confluences, and designated wilderness areas of the Rocky Mountains (Fig. 5).

Conservation Assessment

The conservation priority rankings provide an ecologically based tool that can aid in the process to strategically identify and implement conservation actions. The NHDplus catchments have been ranked (valued) based on the representation of native fish species given the threats to their persistence (i.e., non-native fish species, land use, and habitat fragmentation). The ranking process placed importance on areas with several native species as well as areas important to individual species with restricted distributions and so is not simply a species "hot spot" assessment.

Examples of potential uses are: a) identify focal conservation areas (e.g., identify high value areas of overlap for WNTI and DFHP collaboration), b) identify conservation strategies (e.g., non-native removal, habitat restoration, native species reintroduction, land protection), and c) determine the conservation values of two or more catchments where habitat restoration projects are proposed for the benefit of native fishes, that is, give proposed projects some context as to where they fit within the broader landscape. By ranking catchments, decision makers (i.e., resource managers, conservation planners) have the opportunity to compare and contrast the catchment values based on the anthropogenic threat index, non-native species richness, and predicted community composition. For example, land managers could use the assessment to select regions of high conservation value with low protection to focus landowner cooperative agreements or other land protection measures. The conservation priority ranks could be used during the selection process for annual project proposals. Projects that occur in areas with high conservation value might be ranked above projects being proposed in areas with low conservation value. Conversely sites with low conservation value and high non-native species richness might be selected for non-native removal projects to improve those sites for native species. This assessment could be utilized by land stewards in numerous ways. Below is a general schematic for a site selection process (Fig. 6).

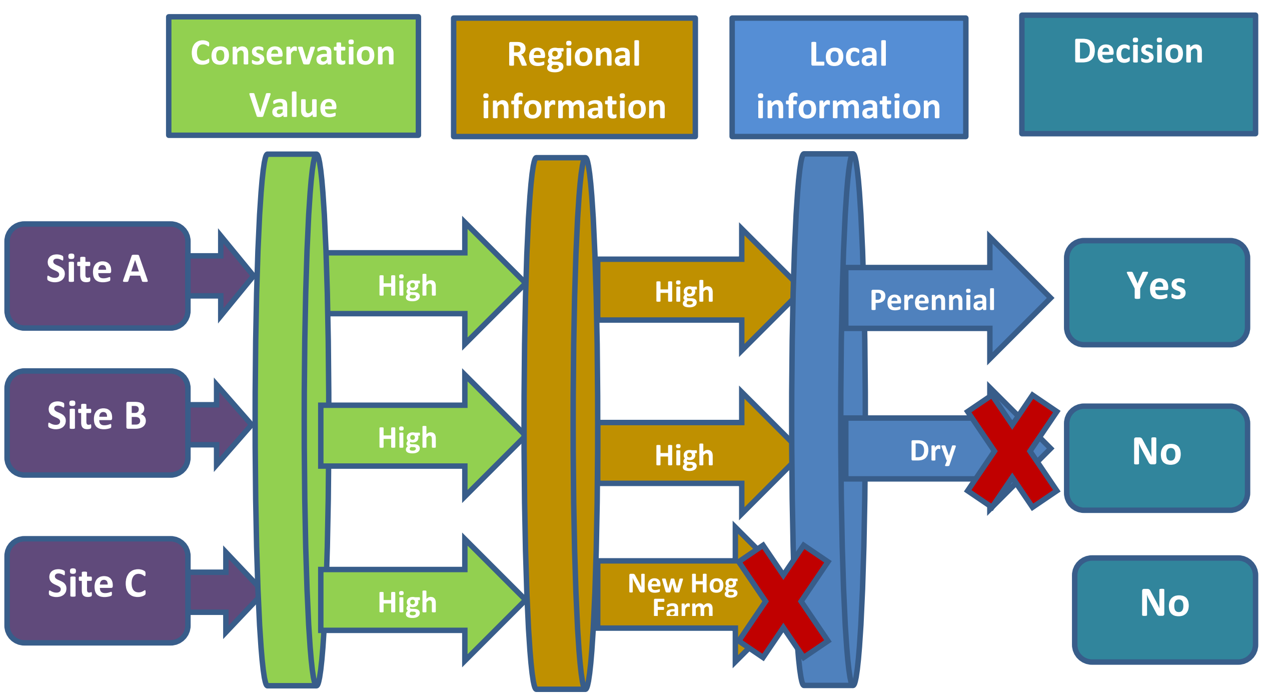


Figure 6. General schematic depicting how the conservation assessment data might be used as a decision support tool to select a site for a conservation effort.

Metadata

Metadata is provided for all products using the Federal Geographic Data Committee (FGDC) standards. The intent of the metadata is to document who, what, when, where, why, and how each dataset was developed.

Literature Cited

Abell, R. A., P. T. Hurley, D. M. Olson, and E. Dinerstein. 2000. Freshwater ecoregions of North America: a conservation assessment. World Wildlife Fund – US, Island Press, Washington, D.C.

Bailey, R. G. 1976. Ecoregions of the United States. Map scale 1:7,500,000. Ogden, UT: USDA Forest Service Intermountain Region.

Baker, E. A., K. E. Wehrly, P. W. Seelbach, L. Wang, M. J. Wiley, and T. Simon. 2005. A multimetric assessment of stream condition in the northern lakes and forests ecoregion using spatially explicit statistical modeling and regional normalization. Transactions of the American Fisheries Society 134:697–710.

Beven, K. J., and M. J. Kirkby. 1979. A physically based, variable contributing area model of basin hydrology. Hydrological Sciences Bulletin 24:43–69.

Carlson, C. A., and R. T. Muth. 1989. The Colorado River: lifeline of the American Southwest. Canadian Special Publication of Fisheries and Aquatic Sciences 106:220–239.

Darlington, P. J. 1957. Zoogeography: The Geographical Distribution of Animals. John Wiley & Sons, New York, New York.

Dauwalter, D. C., S. J. Wenger, K. R. Gelwicks and K. A. Fesenmyer. 2011. Land use associations with distributions of declining native fishes in the Upper Colorado River Basin. Transactions of the American Fisheries Society, 140:646–658.

Dinerstein, E., D. M. Olson, D. J. Graham, A. L. Webster, S. A. Primm, M. P. Bookbinder, and G. Ledec. 1995. A conservation assessment of the terrestrial ecoregions of Latin America and the Caribbean. Washington, DC: The World Bank.

Elith, J., *et al*. 2006. Novel methods improve prediction of species' distributions from occurrence data. Ecography 29:129–151.

Elith, J., and J. R. Leathwick. 2009. Species Distribution models: Ecological explanation and prediction across space and time. Annual Review of Ecology, Evolution, and Systematics 40:677–697.

Fagan, W. F., C. M. Kennedy, and P. J. Unmack. 2005. Quantifying rarity, losses, and risks for native fishes of the lower Colorado River Basin: Implications for conservation listing. Conservation Biology 19:1872–1882.

Friedman, J. H. 1991. Multivariate adaptive regression splines. Annals of Statistics 19:1–67.

Gido, K. B., J. A. Falke, R. M. Oakes, and K. J. Hase. 2006. Fish-habitat relations across spatial scales in prairie streams. Pages 265-286 *in* R. M. Hughes, L. Wang, and P. W. Seelbach, editors. Landscape influences on stream habitats and biological assemblages. American Fisheries Society, Symposium 48, Bethesda, Maryland.

Higgins, J. V., M. T. Bryer, M. L. Khoury, and T. W. Fitzhugh. 2005. A freshwater classification approach for biodiversity conservation planning. Conservation Biology 19:432–445.

Hoeinghaus, D. J., K. O. Winemiller, and J. S. Birnbaum. 2007. Local and regional determinants of stream fish assemblage structure: inferences based on taxonomic vs. functional groups. Journal of Biogeography 34:324–338.

Hornby, D. D. 2014. RivEX (Version 10.15) [Software]. Available from http://www.rivex.co.uk.

Infante, D. M., and J. D. Allan. 2010. Responses of stream fish assemblages to local-scale habitat as influenced by landscape: a mechanistic investigation of stream fish assemblages. Pages 371-400 *in* K.

B. Gido and D. A. Jackson, editors. Community ecology of stream fishes: concepts, approaches, and techniques. American Fisheries Society Symposium 73, Bethesda, Maryland.

Infante, D. M., M. J. Wiley, and P. W. Seelbach. 2006. Relationships among channel slope, catchment characteristics, and fish in lower Michigan streams. Pages 339-358 *in* R. M. Hughes, L. Wang, and P. W. Seelbach, editors. Landscape influences on stream habitats and biological assemblages. American Fisheries Society, Symposium 48, Bethesda, Maryland.

Jelks, H. L., S. J.Walsh, S. Contreras-Balderas, E. D´ıaz-Pardo, N. M. Burkhead, D. A. Hendrickson, J. Lyons, N. E. Mandrak, F. McCormick, J. S. Nelson, S. P. Platania, B. A. Porter, C. B. Renaud, J. J. Schmitter-Soto, E. B. Taylor, and M. L. Warren. 2008. Conservation status of imperiled North American freshwater and diadromous fishes. Fisheries 33:372–407.

Jenness, J. 2006. Topographic Position Index (tpi_jen.avx) extension for ArcView 3.x, v. 1.3a. Jenness Enterprises. Available at: http://www.jennessent.com/arcview/tpi.htm.

Karp, C. A., and H. M. Tyus. 1990. Behavioral interactions between young Colorado squawfish and six fish species. Copeia 1990:25–34.

Lamouroux, N., N. L. Poff, and P. L Angermeier. 2002. Intercontinental convergence of stream fish community traits along geomorphic and hydraulic gradients. Ecology 53:1792–1897.

Mandrak, N. E. 1995. Biogeographic patterns of fish species richness in Ontario lakes in relation to historical and environmental factors. Canadian Journal of Fisheries and Aquatic Sciences 52:1462–1474.

Marchetti, M. P. and P. B. Moyle. 2001. Effects of flow regime on fish assemblages in a regulated California stream. Ecological Applications 11:530-539.

Matthews, W. J. 1998. Patterns in Freshwater Fish Ecology. Chapman and Hall, New York, New York. 756 pages.

Maxwell, J. R., C. J. Edwards, M. E. Jensen, S. J. Paustian, H. Parrott, and D. M. Hill. 1995. A hierarchical framework of aquatic ecological units in North America (Nearctic Zone). US Forest Service, North Central Forest Experiment Station, St. Paul, Minnesota. General Technical Report NC-176.

McKenna, J. E., Jr. 2005. Application of neural networks to prediction of fish diversity and salmonid production in the Lake Ontario Basin. Transactions of the American Fisheries Society 134:28-43.

McKenna Jr., J. E., R. P. McDonald, C. Castiglione, S. S. Morrison, K. P Kowalski, and D. R. Passino-Reader. 2006. A broad-scale fish-habitat model development process: Genesee Basin, New York. Pages 533–554 *in* R. M. Hughes, L. Wang, and P. W. Seelbach, editors. Landscape influences on stream habitats and biological assemblages. American Fisheries Society, Symposium 48, Bethesda, Maryland.

Moilanen, A., H. Kujala, and J. Leathwick. 2009. The Zonation framework and software for conservation prioritization. Pages 196-210 in A. Moilanen, K. A. Wilson, and H. P. Possingham, editors. Spatial conservation prioritization: quantitative methods and computational tools. Oxford University Press, Oxford, UK.

Moyle, P. B., and P. J. Randall. 1998. Evaluating the biotic integrity of watersheds in the Sierra Nevada, California. Conservation Biology 12:1318-1326.

Pearce, J., and S. Ferrier. 2000. Evaluating the predictive performance of habitat models developed using logistic regression. Ecological Modelling 133:225–245.

Oakes, R. M., K. B. Gido, J. A. Falke, J. D. Olden, and B. L. Brock. 2005. Predictive modeling of stream fish assemblages in the Great Plains, U.S.A. Ecology of Freshwater Fish 14:361-374.

Olden, J. D., and N. L. Poff. 2005. Long-term trends in native and non-native fish faunas of the American Southwest. Animal Biodiversity and Conservation 28:75-89.

Olden, J. D., N. L. Poff, and K. B. Bestgen. 2006. Life-history strategies predict fish invasions and extirpations in the Colorado River basin. Ecological Monographs 73:25-40.

Olden, J. D., N. L. Poff, and K. R. Bestgen. 2008. Trait synergisms and the rarity, extirpation, and extinction risk of desert fishes. Ecology 89:847-856.

Omernik, J. M. 1987. Ecoregions of the conterminous United States. Annals of the Association of American Geographers 77:118–125.

Paukert, C. P., K. L. Pitts, J. B. Whittier, and J. D. Olden. 2011. Development and assessment of a landscape-level ecological threat index of the Lower Colorado River Basin. Ecological Indicators 11:304-310.

Peterson, A. T. 2003. Predicting the geography of species' invasions using ecological niche modeling. The Quarterly Review in Biology 78: 419-533.

Pool, T. K., J. D. Olden, J. B. Whittier, and C. P. Paukert. 2010. Environmental drivers of fish functional diversity and composition in the lower Colorado River basin. Canadian Journal of Fisheries and Aquatic Sciences 67:1791-1807.

Quartarone, F. 1995. Historical accounts of upper Colorado River basin endangered fish. Information and Education Committee, Upper Colorado River Endangered Fish Recovery Program, Denver.

Ruppert, J. B., R. T. Muth, and T. P. Nesler. 1993. Predation on fish larvae by adult red shiner, Yampa and Green Rivers, Colorado. Southwestern Naturalist 38:397-399.

San Juan River Basin Recovery Implementation Program. 2013. San Juan River Basin Recovery Implementation Program. <http://www.fws.gov/southwest/sjrip/ > Accessed 5 July 2013.

Sowa, S., D. D. Diamond, R. Abbitt, G. M. Annis, T. Gordon, M. E. Morey, G. R. Sorensen, and D. True. 2005. A GAP analysis for riverine ecosystems of Missouri. Final Report.

Sowa, S. P., G. Annis, M. E. Morey and D. D. Diamond. 2007. A GAP analysis and comprehensive conservation strategy for riverine ecosystems of Missouri. Ecological Monographs 77:301-334.

Strecker, A. L., J. D. Olden, J. B. Whittier, and C. P. Paukert. 2011. Defining conservation priorities for freshwater fishes according to taxonomic, functional, and phylogenetic diversity. Ecological Applications 21:3002-3013.

Theobald, D. M. 2007. LCaP v1.0: Landscape Connectivity and Pattern tools for ArcGIS. Colorado State University, Fort Collins, CO.

Tyus, H. M, and J. F. Saunders. 2000. Non-native fish control and endangered fish recovery: lesson from the Colorado River. Fisheries 25:17-24.

Upper Colorado River Endangered Fish Recovery Program. 2013. Upper Colorado River Endangered Fish Recovery Program. <http://www.coloradoriverrecovery.org/general-information/index.html> Accessed 5 July 2013.

Valdez, R. A., and R. M. Muth. 2005. Ecology and conservation of native fishes in the Upper Colorado River Basin. Pages 157-205 *in* J. Rinne, R. M. Hughes, and B. Calamusso (editors). Historical changes on large river fish assemblages of the Americas. American Fisheries Society Symposium 45, Bethesda, Maryland.

Van Steeter, M. M., and J. Pitlick. 1998. Geomorphology and endangered fish habitats of the upper Colorado River 1. Historic changes in streamflow, sediment load, and channel morphology. Water Resources Research 34:287–302.

Wall, S. S., and C. R. Berry Jr. 2004. Threatened fishes of the world: *Notropis topeka* Gilbert, 1884 (Cyprinidae). Environmental Biology of Fishes 70:246.

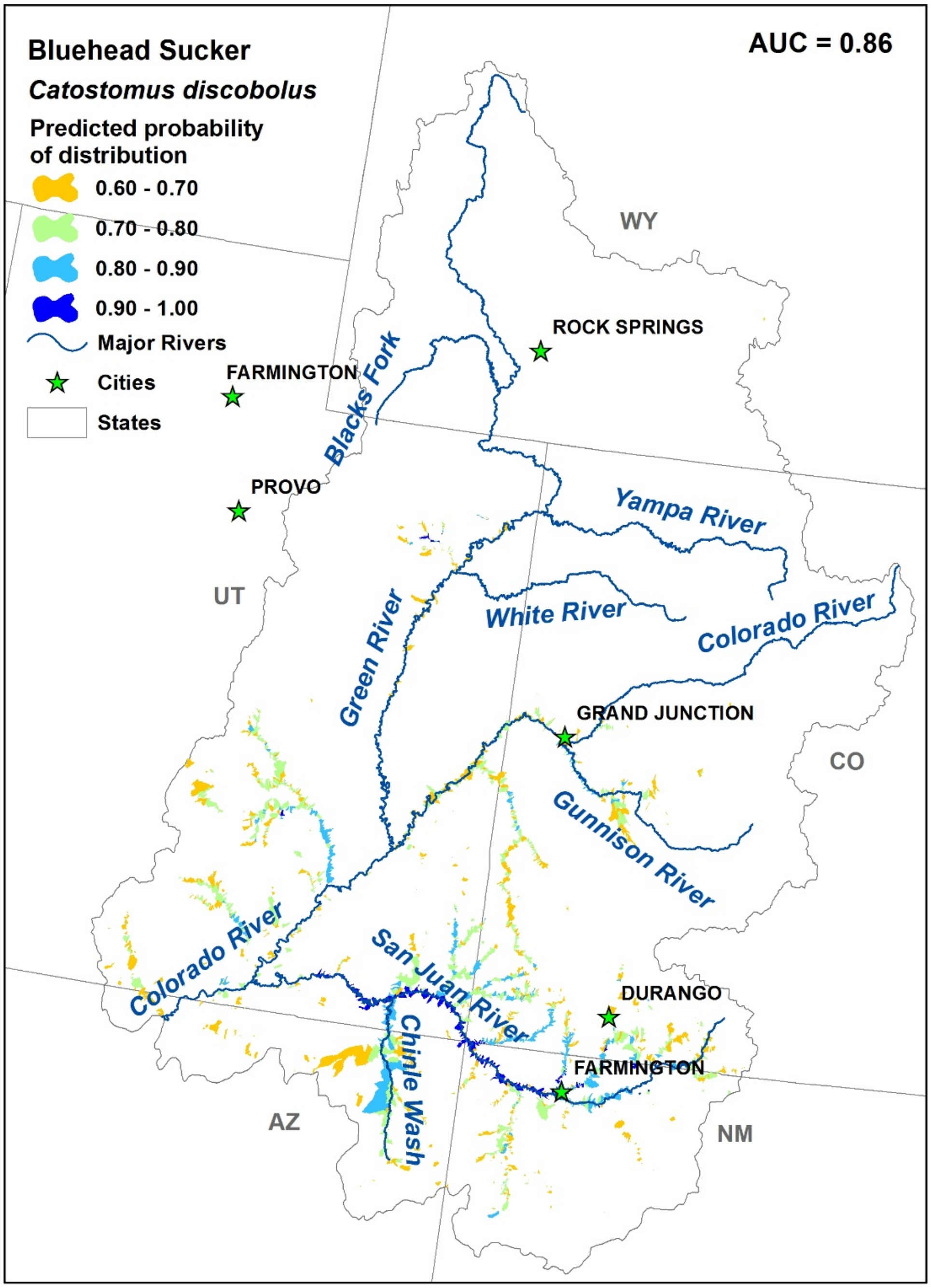
Wang, L., J. Lyons, P. Kanehl, and R. Gatti. 1997. Influences of watershed land use on habitat quality and biotic integrity in Wisconsin streams. Fisheries 22:6-12.

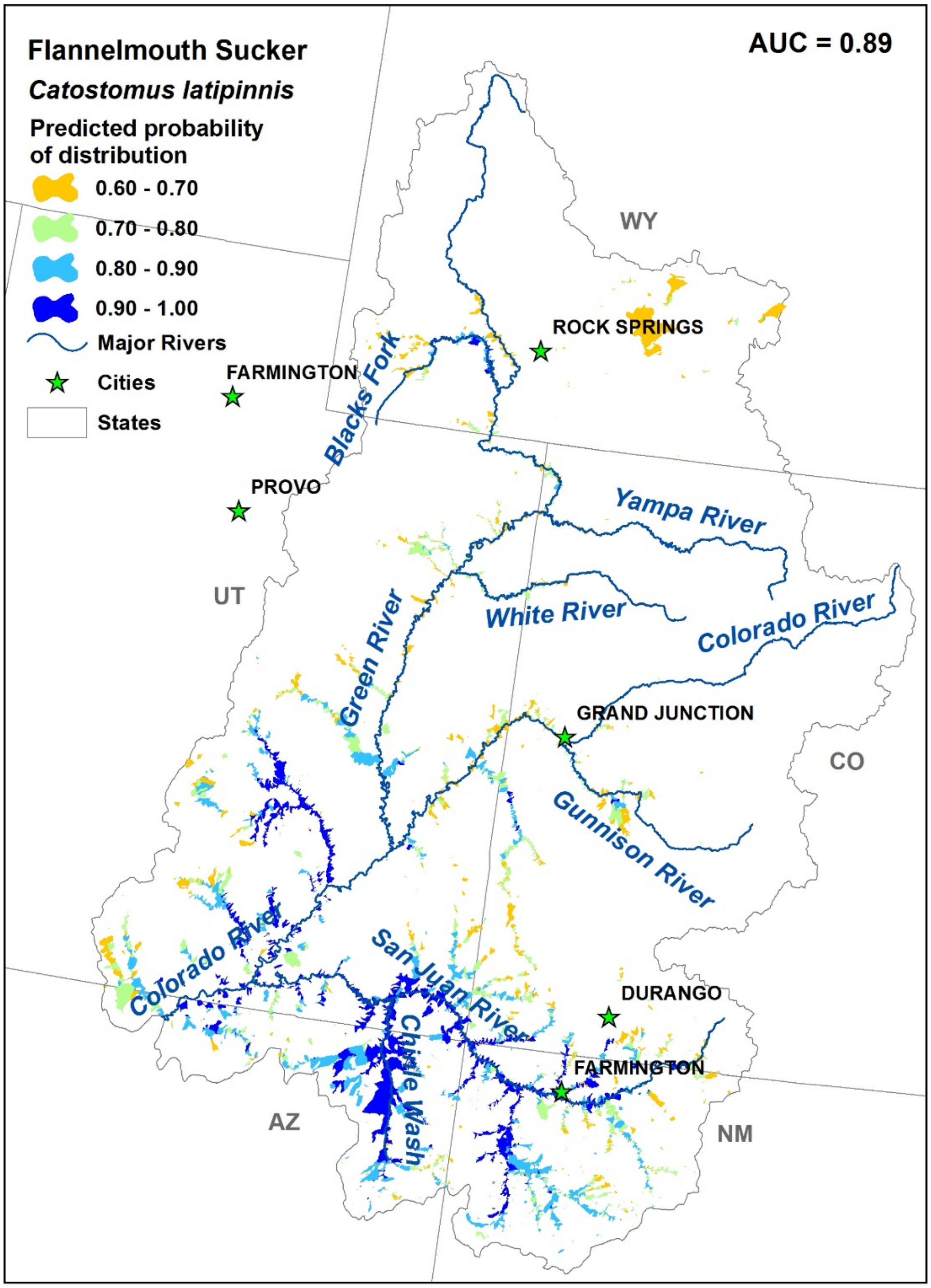
Wang, L., P. W. Seelbach, and J. Lyons. 2006. Effects of levels of human disturbance on the influence of catchment, riparian, and reach-scale factors on fish assemblages. Pages 199-220 *in* R. M. Hughes, L. Wang, and P. W. Seelbach, editors. Landscape influences on stream habitats and biological assemblages. American Fisheries Society, Symposium 48, Bethesda, Maryland.

Weigel, B. M., J. Lyons, P. W. Rasmussen, and L. Wang. 2006. Relative influence of environmental variables at multiple spatial scales on fishes in Wisconsin's warmwater nonwadeable rivers. Pages 493-512 *in* R. M. Hughes, L. Wang, and P. W. Seelbach, editors. Landscape influences on stream

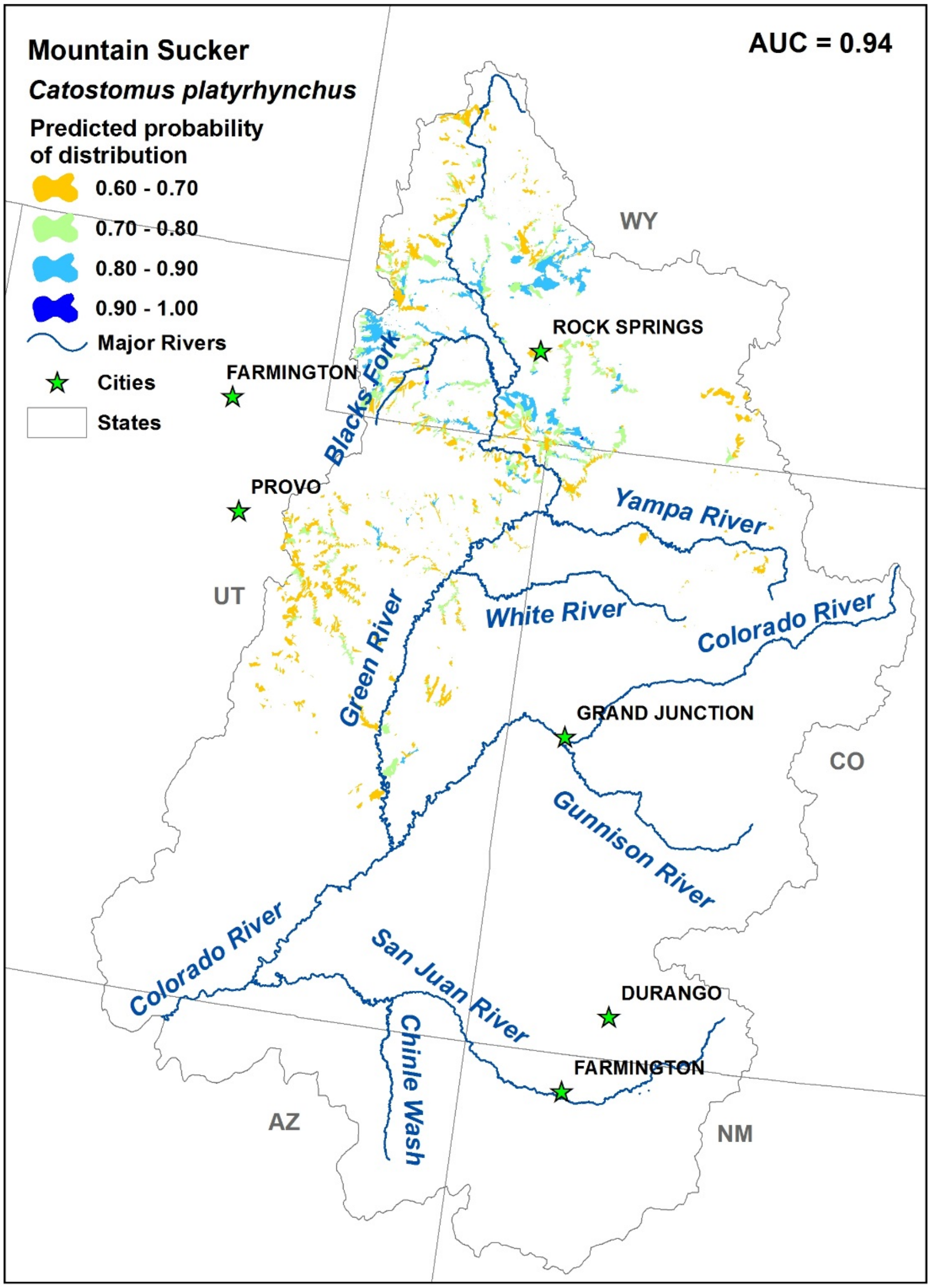
habitats and biological assemblages. American Fisheries Society, Symposium 48, Bethesda, Maryland.
Weiss, A. 2001. Topographic position and landforms analysis. Poster presentation, ESRI User Conference, San Diego, California.
Wikle, C. K. 2003. Hierarchical Bayesian models for predicting the spread of ecological processes. Ecology 84:1382-1394.
Zorn, T. G., P. W. Seelbach, and M. J. Wiley. 2002. Distributions of stream fishes and their relationship to stream size and hydrology in Michigan's lower peninsula. Transactions of the American Fisheries Society 131:70-85.

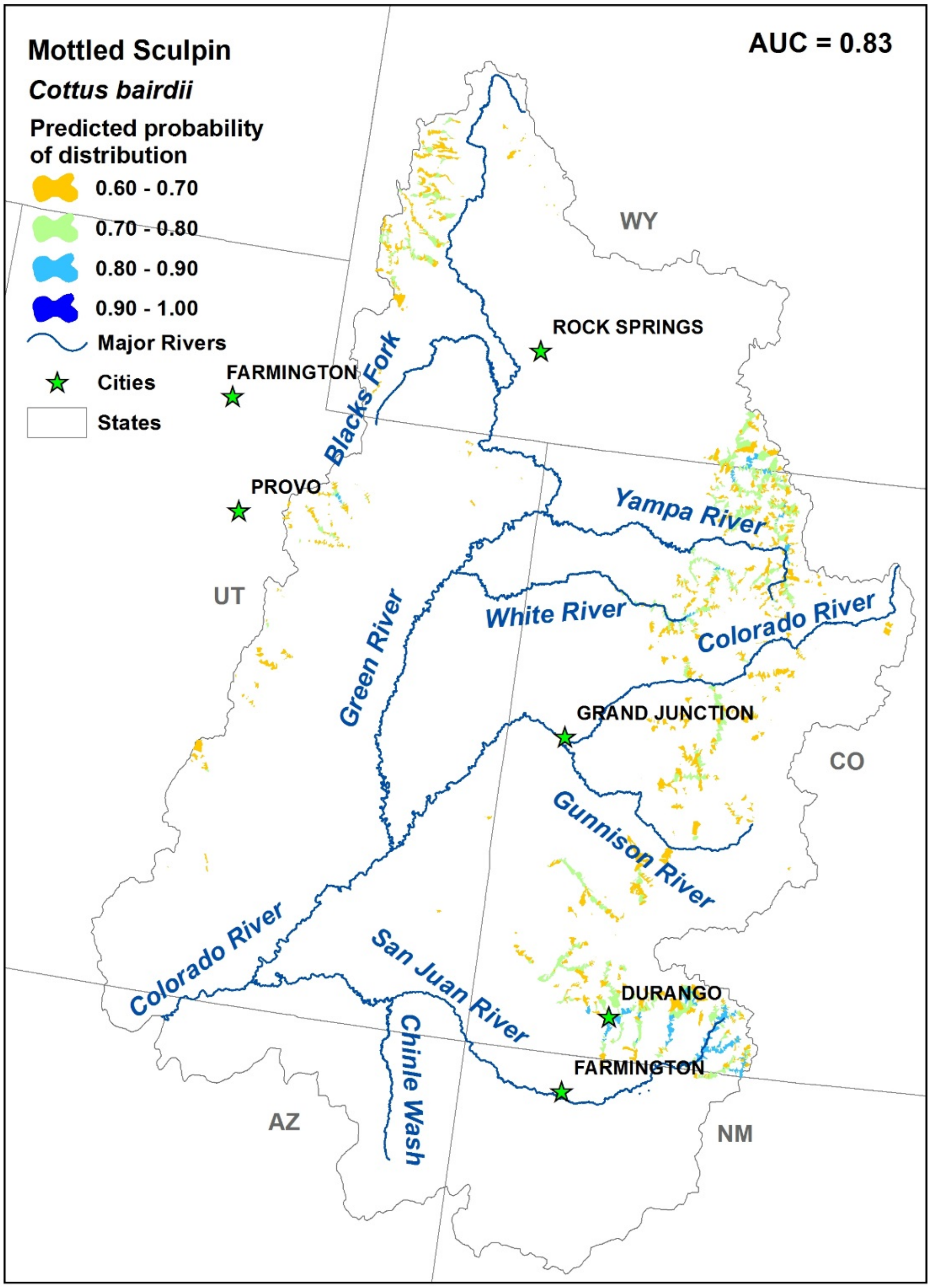
Appendix A. Predicted distribution maps for native fish of the Upper Colorado River Basin. AUC = area under the curve and is a measure of fit for the specified species distribution model.

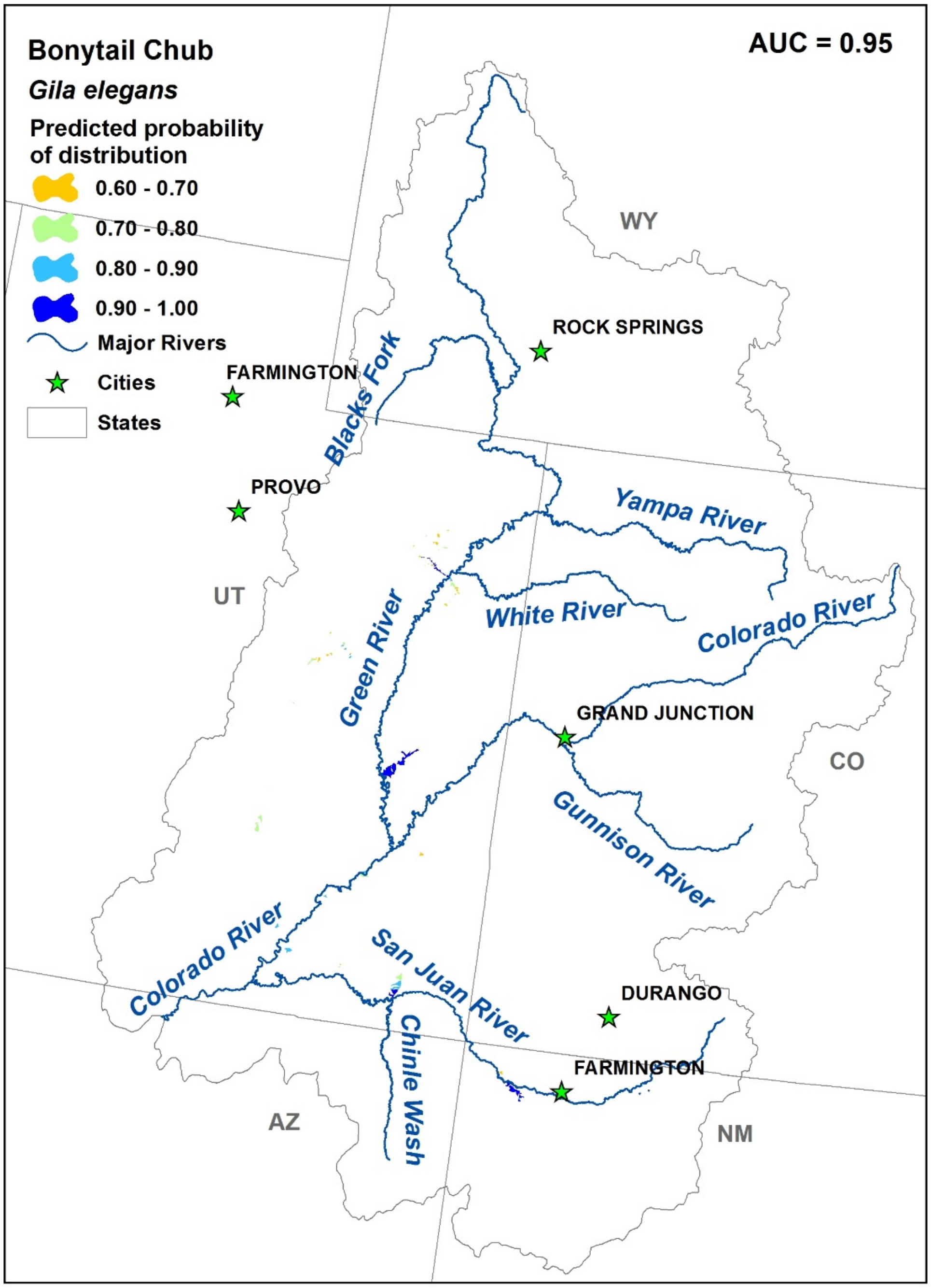




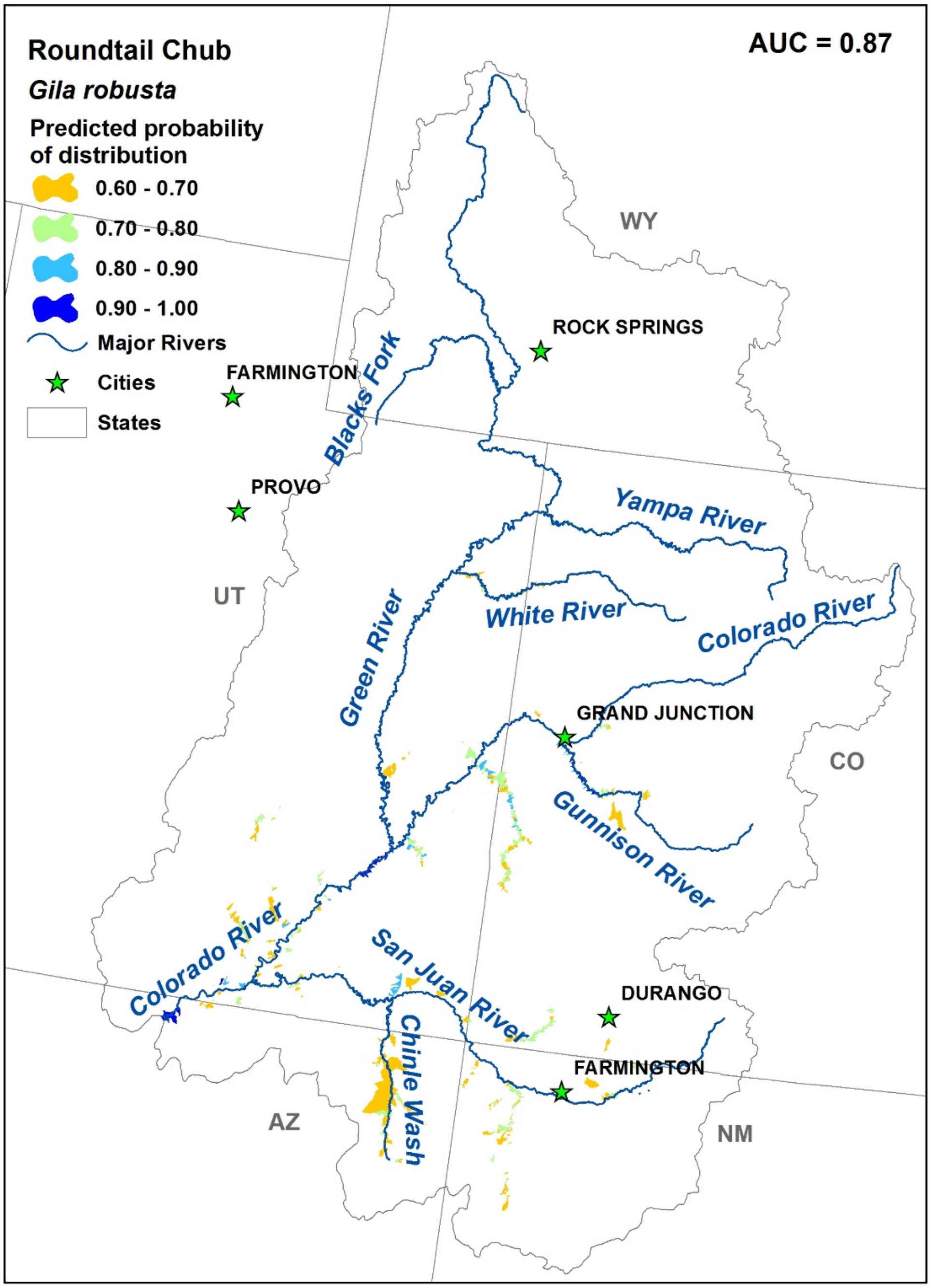
Flannelmouth Sucker
Catostomus latipinnis
Predicted probability of distribution
0.60 - 0.70
0.70 - 0.80
0.80 - 0.90
0.90 - 1.00
Major Rivers
Cities
States
AUC = 0.89
WY
ROCK SPRINGS
FARMINGTON
Blacks Fork
PROVO
Yampa River
UT
Green River
White River
Colorado River
GRAND JUNCTION
CO
Gunnison River
Colorado River
San Juan River
DURANGO
FARMINGTON
Chinle Wash
AZ
NM

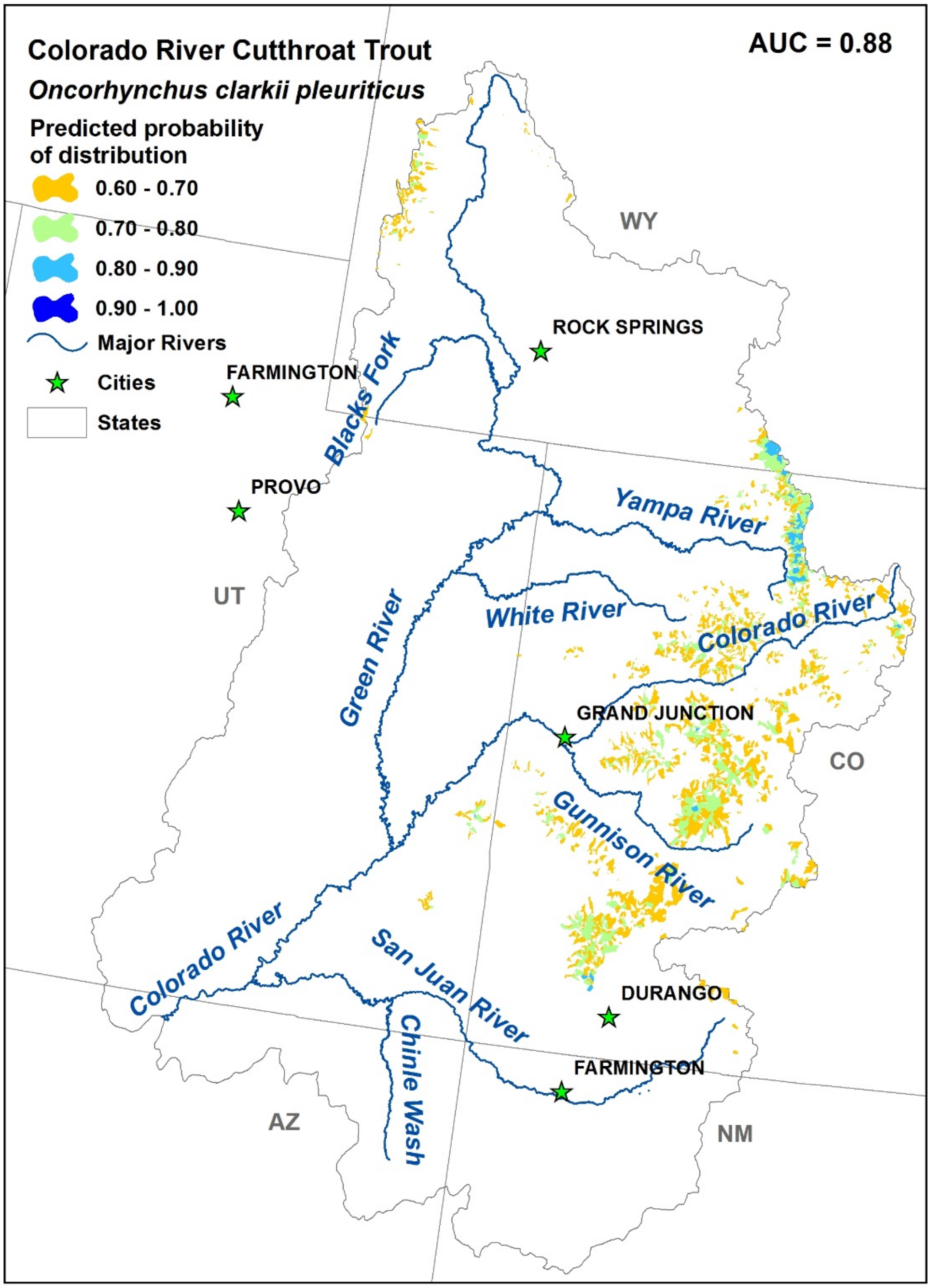

Mountain Sucker
Catostomus platyrhynchus
AUC = 0.94
Predicted probability of distribution
0.60 - 0.70
0.70 - 0.80
0.80 - 0.90
0.90 - 1.00
Major Rivers
Cities
States
WY
ROCK SPRINGS
FARMINGTON
Blacks Fork
PROVO
Yampa River
UT
White River
Colorado River
Green River
GRAND JUNCTION
CO
Gunnison River
Colorado River
San Juan River
DURANGO
FARMINGTON
Chinle Wash
AZ
NM

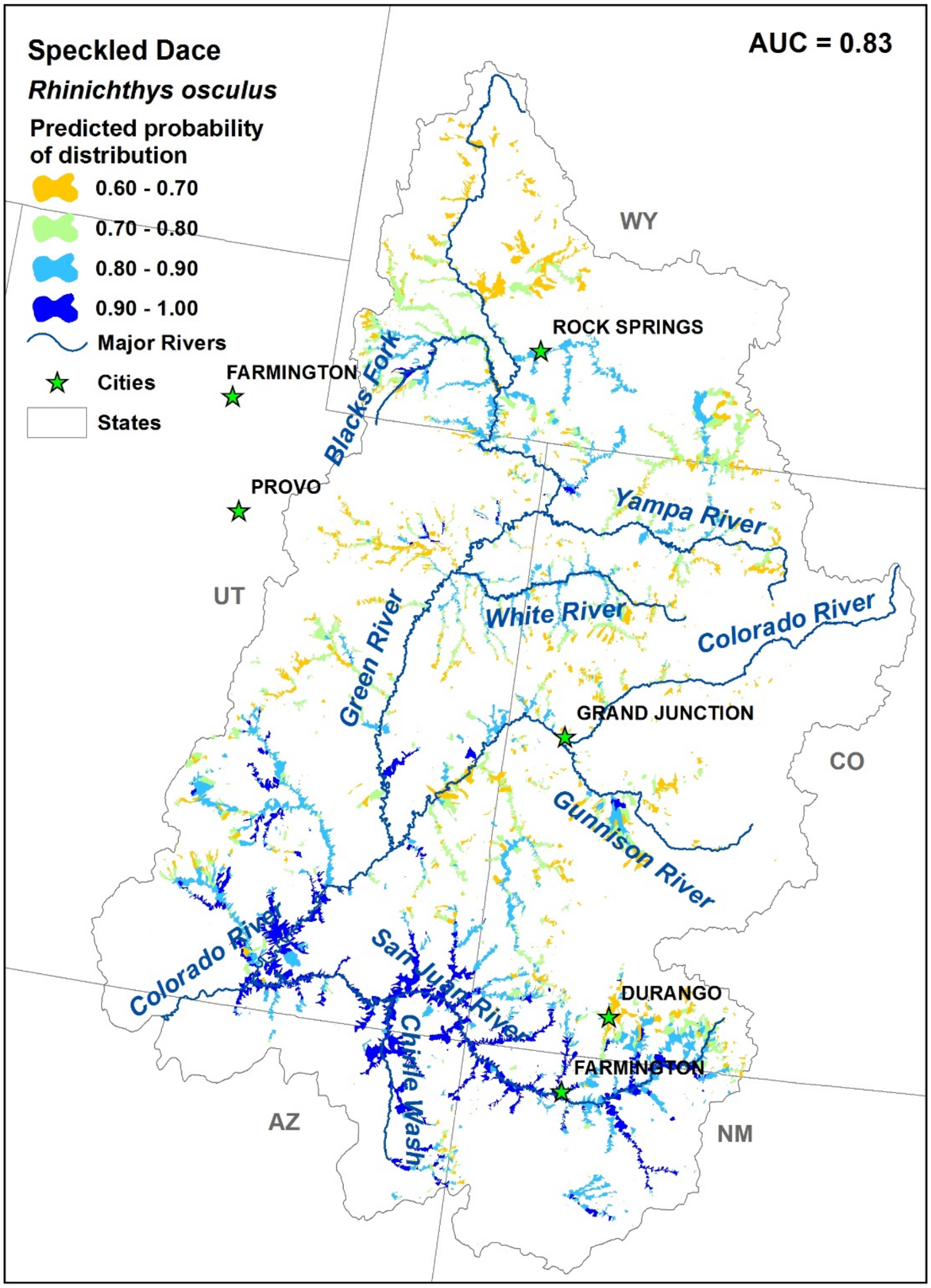

Mottled Sculpin
Cottus bairdii
Predicted probability of distribution
0.60 - 0.70
0.70 - 0.80
0.80 - 0.90
0.90 - 1.00
Major Rivers
Cities
States
AUC = 0.83
WY
ROCK SPRINGS
FARMINGTON
Blacks Fork
PROVO
Yampa River
UT
White River
Colorado River
Green River
GRAND JUNCTION
CO
Gunnison River
Colorado River
San Juan River
DURANGO
Chinle Wash
FARMINGTON
AZ
NM

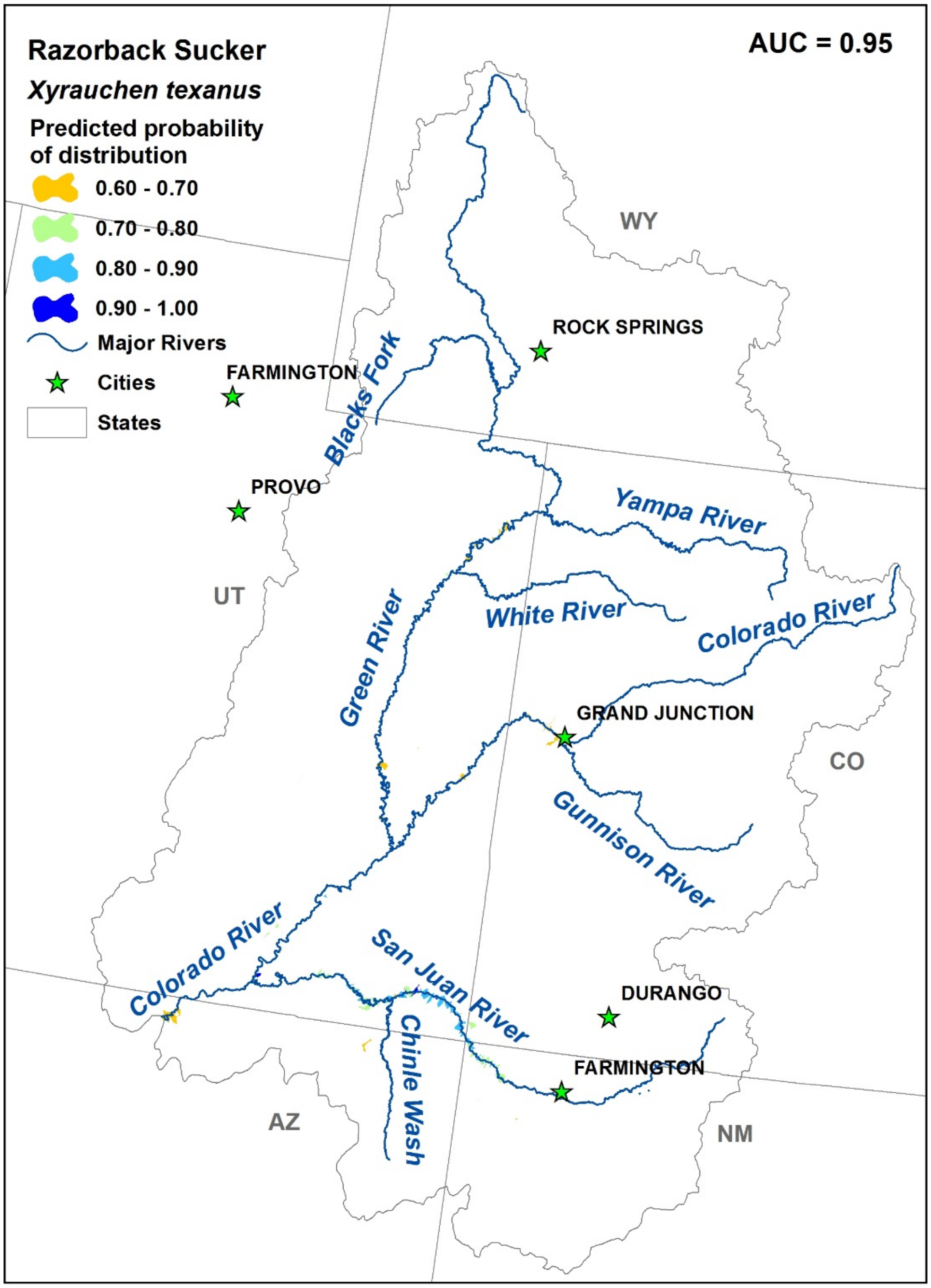


Bonytail Chub
Gila elegans
AUC = 0.95
Predicted probability of distribution
0.60 - 0.70
0.70 - 0.80
0.80 - 0.90
0.90 - 1.00
Major Rivers
Cities
States
WY
UT
CO
AZ
NM
ROCK SPRINGS
FARMINGTON
PROVO
GRAND JUNCTION
DURANGO
FARMINGTON
Blacks Fork
Yampa River
White River
Green River
Colorado River
Gunnison River
Colorado River
San Juan River
Chinle Wash


Roundtail Chub
Gila robusta
Predicted probability of distribution
0.60 - 0.70
0.70 - 0.80
0.80 - 0.90
0.90 - 1.00
Major Rivers
Cities
States
AUC = 0.87
WY
ROCK SPRINGS
FARMINGTON
Blacks Fork
PROVO
UT
Yampa River
White River
Colorado River
Green River
GRAND JUNCTION
CO
Gunnison River
Colorado River
San Juan River
DURANGO
Chinle Wash
FARMINGTON
AZ
NM


Colorado River Cutthroat Trout
Oncorhynchus clarkii pleuriticus
AUC = 0.88
Predicted probability of distribution
0.60 - 0.70
0.70 - 0.80
0.80 - 0.90
0.90 - 1.00
Major Rivers
Cities
States
WY
UT
CO
AZ
NM
ROCK SPRINGS
FARMINGTON
PROVO
GRAND JUNCTION
DURANGO
FARMINGTON
Blacks Fork
Yampa River
White River
Colorado River
Green River
Gunnison River
Colorado River
San Juan River
Chinle Wash


Speckled Dace
Rhinichthys osculus
AUC = 0.83
Predicted probability of distribution
0.60 - 0.70
0.70 - 0.80
0.80 - 0.90
0.90 - 1.00
Major Rivers
Cities
States
WY
UT
CO
AZ
NM
ROCK SPRINGS
FARMINGTON
PROVO
GRAND JUNCTION
DURANGO
FARMINGTON
Blacks Fork
Yampa River
White River
Colorado River
Green River
Gunnison River
Colorado River
San Juan River
Chinle Wash


Razorback Sucker
Xyrauchen texanus
AUC = 0.95
Predicted probability
of distribution
0.60 - 0.70
0.70 - 0.80
0.80 - 0.90
0.90 - 1.00
Major Rivers
Cities
States
WY
ROCK SPRINGS
FARMINGTON
Blacks Fork
PROVO
UT
Yampa River
White River
Colorado River
Green River
GRAND JUNCTION
CO
Gunnison River
Colorado River
San Juan River
DURANGO
Chinle Wash
FARMINGTON
AZ
NM