EFFECTS OF HABITAT AND NONNATIVE FISHES ON THE PRESENCE AND RELATIVE ABUNDANCE OF RIO GRANDE CHUB AND RIO GRANDE SUCKER IN NEW MEXICO

Final Report

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ABSTRACT

Thirty-three study sites were sampled within nine streams across the extant range of Rio Grande Chub and Rio Grande Sucker in northern New Mexico. Rio Grande Chub (n=387) were collected at 13 sites and Rio Grande Sucker (n=447) were collected at 19 sites. Nonnative salmonids or White Sucker were collected in all nine study streams. Both Rio Grande Chub and Rio Grande Sucker existed across a broad elevational and geographical gradient and under a variety of habitat conditions. A multiple linear regression was performed to evaluate effects of habitat and nonnative fishes on relative abundance of Rio Grande Chub and Rio Grande Sucker, and a logistic regression was performed to evaluate how these factors influenced presence or absence of both species. Presence of nonnative predators or competitors negatively affected both relative abundance and presence of Rio Grande Chub and Rio Grande Sucker. Cover, including in-stream vegetation, overhanging vegetation, and undercut banks, was positively associated with presence of both species. Conversely, cover was negatively associated with relative abundance of Rio Grande Chub. Both species occupied sites with moderate depth (Chub [mean 26.3 cm]; Sucker [mean 28.0 cm]) and velocity (Chub [mean 0.31 m/s]; Sucker [mean 0.27 m/s]).

INTRODUCTION

Habitat degradation is one of the greatest threats to freshwater ecosystems worldwide, often resulting in decline or loss of species (Jelks et al. 2008). Degradation of habitat has contributed to declines of the Rio Grande Chub (*Gila pandora*) and Rio Grande Sucker (*Catostomus [Pantosteus] plebeius*) across their historical ranges, including populations in New Mexico (NMDGF 2022). Both species have been functionally extirpated from mainstem reaches and have greatly reduced distributions in their historical ranges, likely due to habitat loss, fragmentation in addition to, and the proliferation of nonnative fish species (Rees and Miller 2005; Rees et al. 2005). Habitat requirements and preferences are unknown for New Mexico populations of these species, and most habitat information was determined from ichthyofaunal surveys of distinct systems in Colorado. For example, much of the available habitat information for Rio Grande Sucker was obtained in Hot Creek, Colorado, which is a homothermal, spring-fed stream containing a genetically distinct population of suckers (Swift-Miller et al. 1999a), so caution should be used when applying these data to New Mexico populations. Likewise, habitat studies for Rio Grande Chub have primarily occurred in Colorado near the northern edge of the species' range (Bestgen et al. 2003; Rees et al. 2005). Habitat loss and degradation have been identified as threats to both species, but habitat requirements for New Mexico populations have yet to be identified. Recovery of the Rio Grande Chub and Rio Grande Sucker should begin with an understanding of habitat requirements that are specific to New Mexico populations. Many extant populations within New Mexico are present on USFS or BLM land and are thus subject to multiple use land management actions that could further impair habitat. Knowing optimal habitat requirements allows managers to mitigate impairment and improve habitat to benefit these species.

Rio Grande Chub was historically distributed throughout the Rio Grande Basin (Sublette et al. 1990), but populations have declined throughout their range due to a combination of habitat degradation and interactions with nonnative species (Rees et al. 2005) and are now functionally extirpated in mainstem reaches (Bestgen et al. 2003). Rio Grande Chub has been extirpated from the mainstem of the Rio Grande in New Mexico (NMDGF 2022) and Colorado (Bestgen et al. 2003) but are still present in its tributaries and in streams of the Pecos River and Red River Basins (NMDGF 2022). Rio Grande Chub exists in both riverine and lacustrine habitats that contain a variety of mesohabitats including riffles, runs, and pools (Bestgen et al. 2003; Rees et al. 2005). In riverine habitats, Rio Grande Chub is found in cooler, small- to moderate-sized streams flowing over gravel and rocky substrate in association with aquatic vegetation (Sublette et al. 1990; Platania 1991).

Rio Grande Chub spawns in riffles, primarily in spring and early summer, but may occasionally spawn in fall (Zuckerman and Langlois 1990, cited by Rees et al. 2005). Adult females are significantly larger than adult males (Rinne 1995). Adult males display more pronounced tubercles on their caudal peduncle, anal fins, and caudal fins (Rees et al. 2005) and have more pronounced coloration (Rinne

1995a). Hybridization with sympatric cyprinids (e.g., Longnose Dace ([*Rhinichthys cataractae*))]) is possible but generally not considered deleterious (Suttkus and Cashner 1981).

Habitats in the Rio Grande Basin have been degraded by reduced flows, land use practices, streambank degradation, and sedimentation (Bestgen et al. 2003; Rees et al. 2005), although the extent to which these changes impact Rio Grande Chub is unknown. Rio Grande Chub is a midwater, opportunistic carnivore that feeds on zooplankton, aquatic insects, juvenile fish, and occasionally detritus (Sublette et al. 1990). Rio Grande Chub is believed to be threatened by disease, nonnative species like Brown Trout (*Salmo trutta*); Ivie et al. 2022), and habitat degradation. This species is designated a sensitive species by the U.S. Bureau of Land Management (BLM) and U.S. Forest Service (USFS) and as a species of special concern by the state of Colorado (CPW 2015). The main threats to this species, as identified in the New Mexico State Wildlife Action Plan, are stream alterations and nonnative fishes (NMDGF 2016).

Rio Grande Sucker was historically distributed throughout the Rio Grande Basin but is now restricted to New Mexico and a small portion of Colorado and Mexico (Rees and Miller 2005). The subgenus *Pantosteus* is associated with cool mountain streams with moderate to rapid current and rocky substrate (Smith 1966) and favor low gradient (<3.5%) riverine systems (Smith 1966). Generally, Rio Grande Sucker is known to live in a variety of middle-elevation streams in riffles, glides, backwaters, and pools, usually over gravel and/or cobble (Sublette et al. 1990; Swift-Miller et al. 1999a). In Hot Creek, Colorado, Rio Grande Sucker occurs most frequently in riffles and glides and were less predominant in pools, possibly due to the amount of fine sediment (i.e., silt and sand) present in these pool habitats (Swift-Miller et al. 1999a). Rio Grande Sucker is algivorous, feeding on periphyton on medium to large substrate (i.e., cobble and gravel) and thus may be sensitive to land use changes that result in increased sediment production and reduced algal production (Swift-Miller et al. 1999b).

Rio Grande Sucker spawns in water temperatures of 11–16 °C. The spawning period ranges from early February in the southernmost part of their range through late summer and fall in the northern part of their range in New Mexico and Colorado (Rees and Miller 2005). Both adult females and males display tuberculation and coloration, with males having more pronounced features restricted to the head and gular region (Rinne 1995b). Rio Grande Sucker is sexually mature at age-2 or age-3 depending on temperature and food resources (Rees and Miller 2005).

Rio Grande Sucker has declined where they are sympatric with White Sucker (*Catostomus commersonii*); Calamusso and Rinne 1999), likely due to competition (Sublette et al. 1990). Although the Rio Grande Sucker is not federally protected under the U.S. Endangered Species Act, its listing as a sensitive species bythe BLM and the USFS, an endangered species by the state of Colorado (CPW 2015), and a Species of Greatest Conservation Need (SGCN) by the state of New Mexico (NMDGF 2016) warrant additional studies to increase understanding of its life history and ecology to improve conservation and management practices for this species.

Rio Grande Chub and Rio Grande Sucker have both been identified as a New Mexico SGCN and are further grouped as Immediate Priority Species (NMDGF 2016). Both species have been extirpated from much of their historical range and are threatened by habitat loss and degradation (Rees and Miller 2005; Rees et al. 2005, Jelks et al. 2008). Critically, climate predictions indicate that the Rio Grande drainage, which encompasses a large portion of the historic range for both species, will experience climate-induced flow declines, further reducing available habitats and degrading water quality (Dettinger et al. 2015). NMDGF 2016). Interactions with habitat conditions are known to affect fish population dynamics (Swift-Miller et al. 1999b; Bestgen et al. 2003), yet few studies have been performed to identify the influence of these factors on New Mexico populations of the Rio Grande Chub and Rio Grande Sucker or to determine these species' habitat preferences. This lack of knowledge impedes conservation efforts and limits the management actions that can be taken to protect or recover these species. This study seeks to identify habitat requirements of, and impacts of nonnative fishes on, Rio Grande Chub and Rio Grande Sucker in New Mexico to facilitate future conservation or repatriation efforts within New Mexico, protect existing populations, and provide resource managers with tools to better protect both species. Specifically, fish and habitat data were collected at multiple sites in different-sized streams across the extant range of Rio Grande Chub and Rio Grande Sucker and analyzed to characterize the complex relationships existing between fish populations, habitat requirements, and available riverine habitat.

STUDY AREA

The study area was in the northern extent of the New Mexico range of the Rio Grande Chub and Rio Grande Sucker. Study streams were selected by evaluating historical records, from the FishNet2 database, of Rio Grande Chub and Rio Grande Sucker (FishNet2 2013) on USFS and BLM property. Stream segments located on private property were excluded from the study due to restricted access. Rivers with sufficient densities of the target species present to perform habitat studies were identified within the Rio Grande Basin (J. Hatt pers. comm.) included: East Fork Jemez River, Rio Cebolla, Rio Guadalupe, Rio de las Vacas, Rio Grande del Rancho , Rio San Antonio, Rio Tusas, Rio Vallecitos, San Antonio Creek, and Santa Fe River. Rio Grande Chub and Rio Grande Sucker were expected to be sympatric in all but the Santa Fe River and Rio Grande del Rancho (J. Hatt pers. comm). The Santa Fe River and Rio Grande del Rancho were included in the original data analysis design to ensure that sites where target species are absent were represented to facilitate logistic regression analyses. However, due to the Calf Canyon/ Hermit's Peak fire, access to the Rio Grande del Rancho was restricted, thus this river was not sampled during the current study despite its inclusion in the original study design.

Study streams ranged in elevation from 1,734 m to 2,957 m (median 2,433 m) and included first-order (i.e., headwater streams) to fifth-order streams, with the headwaters of the Rio Tusas the smallest stream order and the Santa Fe River the largest. Stream order did not necessarily correspond to stream size, and many fourth-order streams had greater flows than the Santa Fe River. Terrestrial vegetation at lower elevation sites was characterized as juniper savannah and pinyon-juniper, whereas higher elevation sites were characterized as subalpine, mixed-conifer forest and ponderosa pine woodland. Study sites showed signs of a variety of land uses, including recreation and grazing.

METHODS

Study sites were selected using a Generalized Random Tessellation Stratified (GRTS) design to produce spatially-balanced samples (Stevens and Olsen 2004). Among streams (n=8), 35 study sites and 20 over-sample sites were selected. Over-sample sites were substituted for study sites if a study site could not be visited or could not be surveyed (e.g., access issues, site drying). Coordinates of GRTS sites represented the downstream extent of each study site. Fish and habitat were sampled starting July 2022 at baseflows to avoid potential confounding effects of seasonal flow variation. Sampling was initially intended to occur between May and early June 2022, but was postponed until late July due to the Hermit's Peak/ Calf Canyon and Cerro Pelado fires burning in the Carson and Santa Fe National Forests.

Study site dimensions were computed based on standardized sampling methodology for characterization of stream habitat such that stream segment length was at least twenty times greater than mean wetted stream width (Rahel and Hubert 1991; Fitzpatrick et al. 1998). Due to the narrow width of some study streams, the length of each study segment was computed as thirty times the mean stream width to appropriately represent the habitat variability present at each site. For example, for a site with mean width of 5 m, sampling segments extended upstream for 150 m. Mean stream width was calculated from three separate measurements of wetted stream width at the upstream, downstream, and center of each study area.

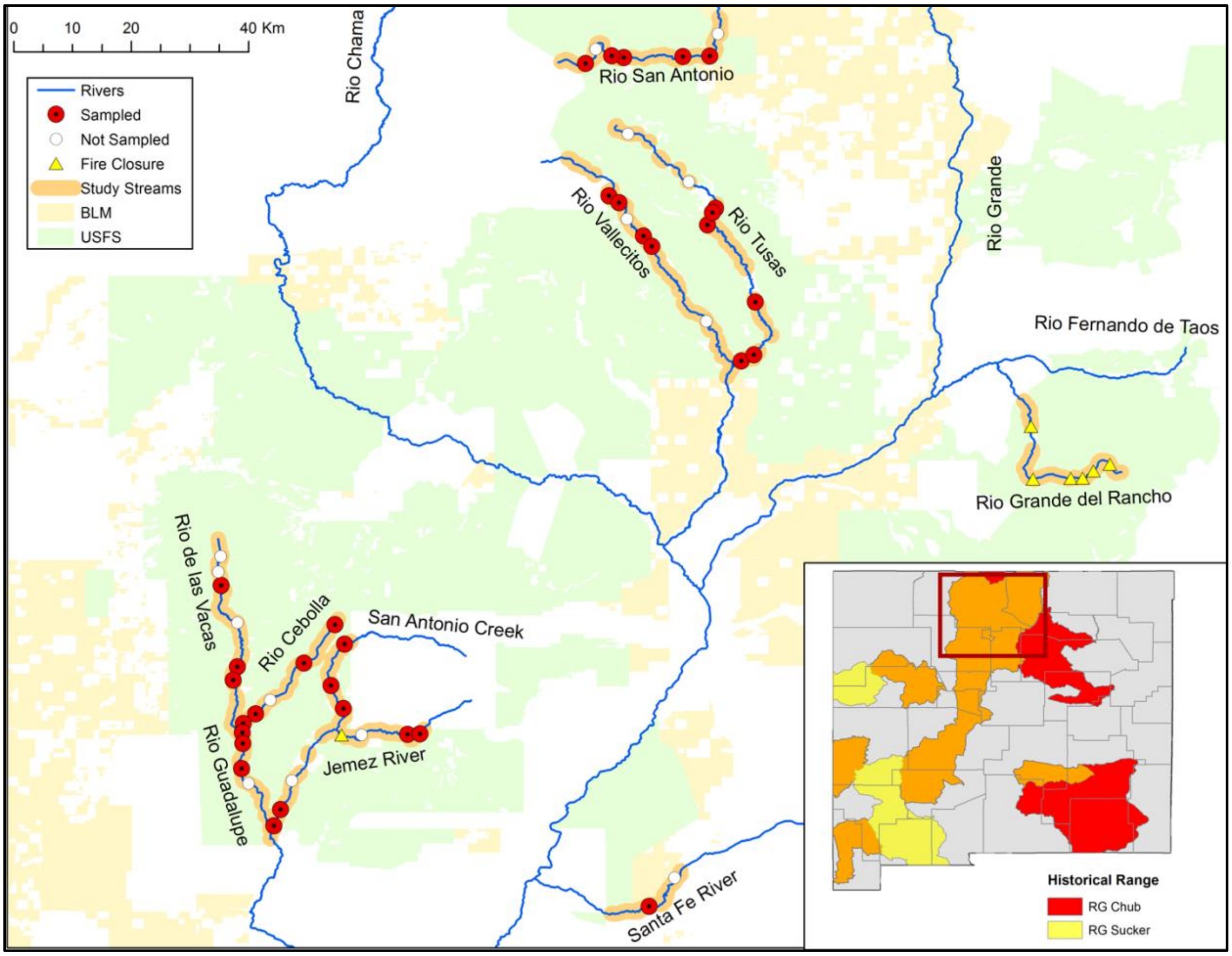

Figure 1 Study area for 2022 Rio Grande Chub and Rio Grande Sucker surveys. Study streams are indicated by light orange bands around the streams. Study sites (red points), oversample sites (white points), and sites that were inaccessible due to fire (yellow triangles) are indicated. Within the inset map, range overlap is denoted by orange color.

Multiple transects were designated at each study site based on site length and habitat complexity. Prior to sampling, each study site was divided into 15 m segments with habitat transects at each end. Transect-0 was placed at the downstream extent of the study site at the GRTS coordinates. Subsequent habitat transects were measured from transect-0 moving upstream until the entirety of the study site length had been delineated. Fish survey segments occurred between transects, e.g., fish survey segment-1 occurred between transect-0 and transect-1. Transects were evenly spaced in 15 m increments unless a distinct mesohabitat was encountered (e.g., riffle, run, pool), in which case length of fish survey segments (distance between transects) was adjusted to fully encompass each unique habitat feature between transects. Fish surveys were conducted within the 15 m segments and habitat parameters gathered at the end of each fish survey transect (see further details below)

Fishes were collected using a Smith-Root LR-24 backpack electrofisher. Sampling proceeded upstream from the GRTS waypoint with one person operating the electrofisher and two using dip nets to collect immobilized fishes. All fish were placed in live wells, and collections were matches with habitat parameters at the upstream habitat transect (e.g., fish collected between transect-0 and transect-1 were recorded and related to measured habitat parameters at transect-1). All fish were released live into the habitat from which they were removed. Fish were identified to species, enumerated, and Rio Grande Chub and Rio Grande Sucker were measured (mm total length [TL]). Fish counts and measurements were recorded at each transect so that abundance of target species along fish survey segments could be related to measured habitat parameters. Catch-per-unit-effort (CPUE) was used as an index of relative abundance for each target species and was calculated for each survey segment in a study site as the number of fish per m^2 (Quist et al. 2009). Although nonnative interactions were not a primary focus of the study, nonnative species interactions have been linked to lower abundances of both target species (Swift-Miller et al. 1999b; Bestgen et al. 2003) so the presence or absence of nonnative predators (e.g., Brook Trout [*Salvelinus fontinalis*], Brown Trout, Rainbow Trout [*Oncorhynchus mykiss*]) and competitors (White Sucker) was incorporated into analyses.

Following fish collections, each site was georeferenced at the downstream GRTS waypoint, elevation (m) was determined, and water quality parameters were measured (temperature, dissolved oxygen, conductivity, salinity, pH) using a Hanna HI98195 multimeter and Hanna HI98198 optical dissolved oxygen meter at a single point within each study site. Secchi depth (cm), an indicator of water clarity related to water turbidity, was measured in the deepest point in each sampling segment. At each habitat transect, stream width, depth, water velocity, dominant cover, and percentage of stream cover was measured. Dominant substrate was visually identified as silt, sand, gravel, cobble, and boulder based on the Wentworth scale (Wentworth 1922). Depth and velocity were recorded using a Marsh McBirney Flo-Mate 2000 at three equidistant points on river left, river right, and center along each transect greater than 2 m wide and at one point along each transect less than 2 m wide. Dominant cover was characterized at each transect as overhanging riparian vegetation, in-stream vegetation (including both inundated terrestrial vegetation and aquatic macrophytes), undercut banks, woody debris (including root wads), and boulders. Percent cover was measured at three points along each transect greater than 2m and at one point at each transect <2m using a spherical conical densiometer. The depth:width ratio at each transect was calculated as the mean depth divided by transect width and was included in analyses as an indicator of streambed morphology. Gradient was computed for the entirety of the study area as elevation gain (m) divided by length of the site (m).

All data were compiled and entered in an electronic spreadsheet, and statistics were performed using program R (R Core Team 2021). A multiple linear regression with simultaneous forward and backward AIC (Akaike's Information Criterion) model selection (Venables and Ripley 2002) was performed to evaluate the influence of habitat parameters, nonnative predators, and competitors on the relative abundance of each target species. Transects in which zero target species were collected were omitted from multiple linear regressions to better analyze the factors that influence abundance. Physical habitat parameters included percent cover, dominant cover, substrate, gradient, depth:width ratio, mean water velocity (m/s), and mean depth (m). Salinity (ppt) can be influenced by land use practices such as agriculture or road de-icing (Bolotin et al. 2023) and was included as an indicator of anthropogenic impacts on streams. Although turbidity can also serve as an indicator of anthropogenic impacts on streams, it was not included in the model because the secchi depth at many sites extended to the bottom of the streams and thus did not accurately represent turbidity in those sites. Finally, presence or absence of nonnative predators (Brook Trout, Brown Trout, Rainbow Trout) and competitors (White Sucker) were included as a binary response. Model parameters were evaluated for multicollinearity using the variance inflation factor (VIF; Fox and Weisberg 2019) and elevation gain (m) was removed from consideration in all models due to it having a VIF >5 (Daoud 2017).

A logistic (i.e., binomial logit-link) regression was performed to evaluate the influence of the measured -habitat parameters and nonnative species on the presence or absence of the Rio Grande Chub and Rio Grande Sucker. The glmutli package (Calcagano 2020) was used to exhaustively evaluate all possible logistic models and rank the best model using AIC_C (Burnham and Anderson 2002). Biotic and abiotic parameters with nonsignificant *P*-values, selected by model selection packages in R, were retained because they contributed to goodness of fit (R^2) of the models (Olusegun et al. 2015). The full dataset, including transects with no target species, was used in these analyses to evaluate factors that influence presence and absence of the Rio Grande Chub and Rio Grande Sucker.

RESULTS

A total of 233 transects were sampled across 33 GRTS sites in the Jemez River (n=4), Rio Cebolla (n=5), Rio de las Vacas (n=3), Rio Guadalupe (n=2), Rio San Antonio (n=5), Rio Tusas (n=6), Rio Vallecitos (n=4), San Antonio Creek (n=3), and Santa Fe River (n=1). Across all sites, 14,596 m^2 of habitat were sampled from chute (n=1), pool (n=21), rapid (n=3), riffle (n=48) and run (n=160) habitats. Dominant substrate included boulder (n=46), cobble (n=111), gravel (n=63), and sand (n=13). Sites ranged in elevation from 1,734 m to 2,957 m. The most common cover types across all transects were overhanging terrestrial vegetation (n=134) and instream vegetation (n=50). The remaining transects were characterized by boulder (n=20), debris (n=12), and undercut banks (n=4), or were devoid of cover (n=13).

A total of 1,892 fish representing 10 species were collected between 24 June and 30 August 2022 (Table 1). Rio Grande Cutthroat Trout and Rainbow Trout are congeneric (genus *Oncorhynchus*) and are indistinguishable in the field when below 20 mm in total length (TL), so small individuals (n=5) were classified to genus. Likewise, n=2 suckers were classified as *Catostomus sp.* because they were too small to be identified in the field. Nonnative salmonids and/or White Sucker were collected in every stream except the Santa Fe River (Figure 2).

Sites occurred across a broad longitudinal and elevational gradient, and water quality varied among sites: water temperature 11.8–28.3 °C (mean 19.4 °C), DO 4.48–9.25 mg/L (mean 6.7 mg/L), specific conductivity 35–677 µs/cm (mean 193.3 µs/cm), pH 8.03–9.33 (mean 8.57), and salinity 0.02–0.33 ppt (mean 0.09 ppt). At 15 sites, the secchi depth equaled the maximum stream depth (i.e., water was clear to the stream bottom). At the remaining 18 sites, secchi depth was 12–81 cm; higher values indicate greater water clarity.

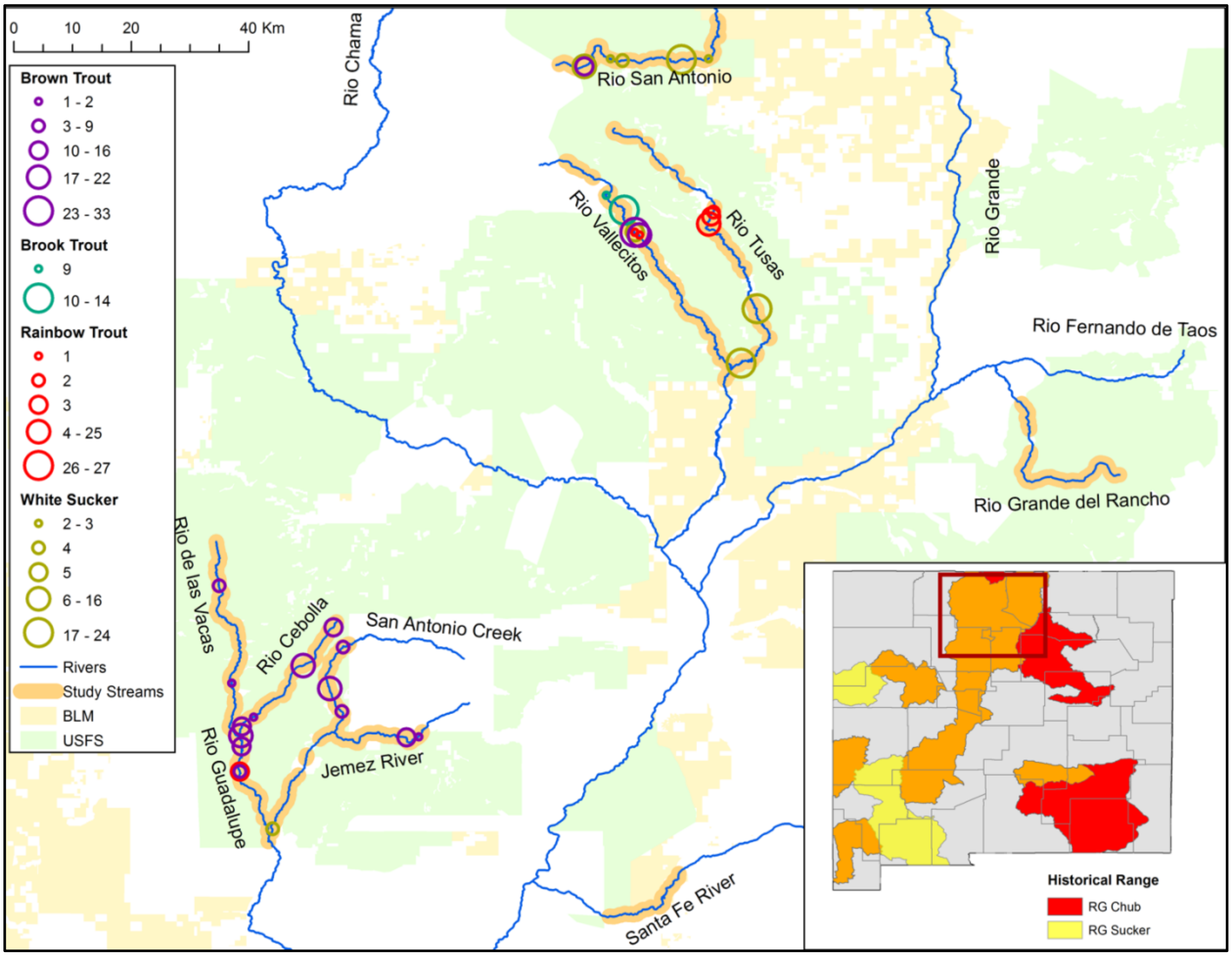

Figure 2 Distribution of nonnative salmonids and White Sucker within the study site. Count bins were calculated using natural breaks and are thus different between species. Each circle is proportional to the number of fish collected. Note: Rio Grande del Rancho was not sampled due to effects stemming from the Calf Canyon/ Hermit's Peak Fire.

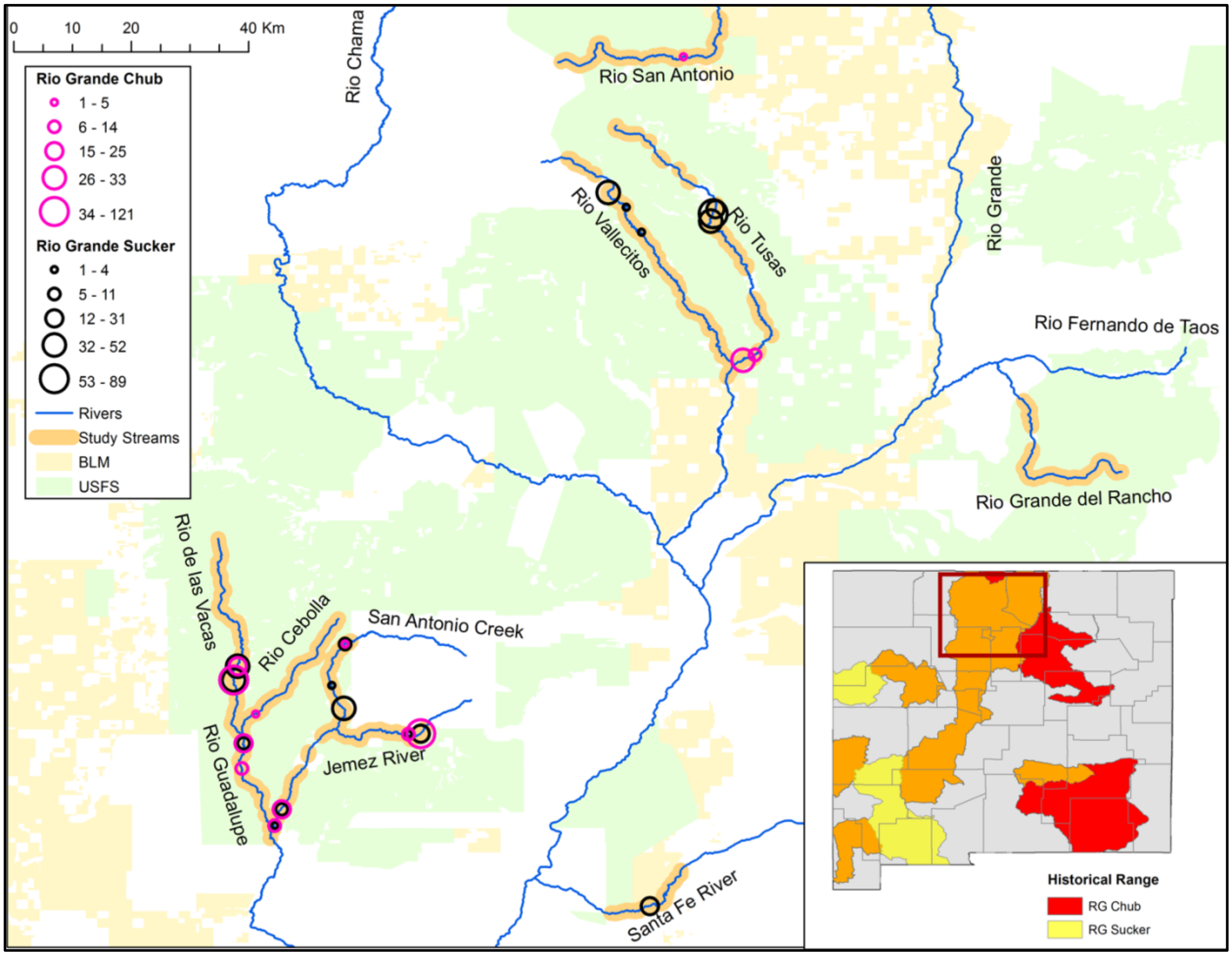

Figure 3 Distributions of Rio Grande Chub and Rio Grande Sucker within the study area. Count bins were calculated using natural breaks and are thus different between species. Each circle is proportional to the number of fish collected. Note: Rio Grande del Rancho was not sampled due to effects stemming from the Calf Canyon/ Hermit's Peak Fire.

Table 1 Fish species collected during sampling for Rio Grande Chub and Rio Grande Sucker in the northern extant portion of their range in New Mexico.

Common name	Species	n
Brook Trout	*Salvelinus fontinalis*	23
Brown Trout	*Salmo trutta*	213
Fathead Minnow	*Pimephales promelas*	175
Longnose Dace	*Rhinichthys cataractae*	460
Rainbow Trout	*Oncorhynchus mykiss*	63
Rio Grande Chub	*Gila pandora*	387
Rio Grande Chub x Longnose Dace	*Gila pandora* x *Rhinichthys cataractae*	1
Rio Grande Sucker	*Catostomus plebeius*	447
Rio Grande Cutthroat Trout	*Oncorhynchus clarkii*	6
Sucker sp.	*Catostomus sp.*	2
Trout sp.	*Oncorhynchus sp.*	5
White Sucker	*Catostomus commersonii*	110
Total		**1,892**

Rio Grande Chub

Rio Grande Chub (n=387) were collected at 13 sites across the study area (Figure 3). Rio Grande Chub were collected in all study streams except the Rio Vallecitos and the Santa Fe River. Rio Grande Chub size range was 15–211 mm TL (Figure 4). Rio Grande Chub were collected in water depths of 7–71 cm (mean 26.3 cm; Figure 5), water velocity of 0.03–0.99 m/s (mean 0.31 m/s; Figure 6), and across a wide range of elevations (1,734–2,672 m; mean 2,307 m; Figure 7). Rio Grande Chub were associated with cobble (n=169; 43.7%) and gravel (n=119; 30.7%) substrates, in-stream vegetation (n=191; 49.4%) and run habitat (n=296; 76.5%). The highest relative abundance of Rio Grande Chub were associated with gravel substrate (Figure 8) and boulder cover (Figure 9). A single suspected hybrid individual with intermediate characteristics of Rio Grande Chub x Longnose Dace was collected in the Jemez River (Figure 10]).

Linear regression

A multiple linear regression was performed to evaluate the influence of habitat parameters and nonnative species on the relative abundance of the Rio Grande Chub. Rio Grande Chub relative abundance (fish/m^2) was explained by Brown Trout presence, salinity, dominant cover, gradient, mean depth, and elevation (MLR: R^2=0.508, $F_{10,61}$=6.304, P<0.001). For parameters with significant P-values (<0.05), elevation was positively associated and depth (cm) was negatively associated with Rio Grande Chub relative abundance(Table 2).

Logistic regression

A logistic regression was used to evaluate the effects of habitat parameters and nonnative species on the presence or absence of the Rio Grande Chub. Rio Grande Chub presence/absence was explained by dominant cover type, substrate, elevation, gradient, and Rainbow Trout presence (GLM: Tjur's R^2=0.350; Wald's Test: χ^2=63.3, df=12, P<0.001). Among variables with significant P-values

(<0.05), in-stream vegetation and gradient were positively associated with Rio Grande Chub presence and elevation was negatively associated with Rio Grande Chub presence (Table *3*).

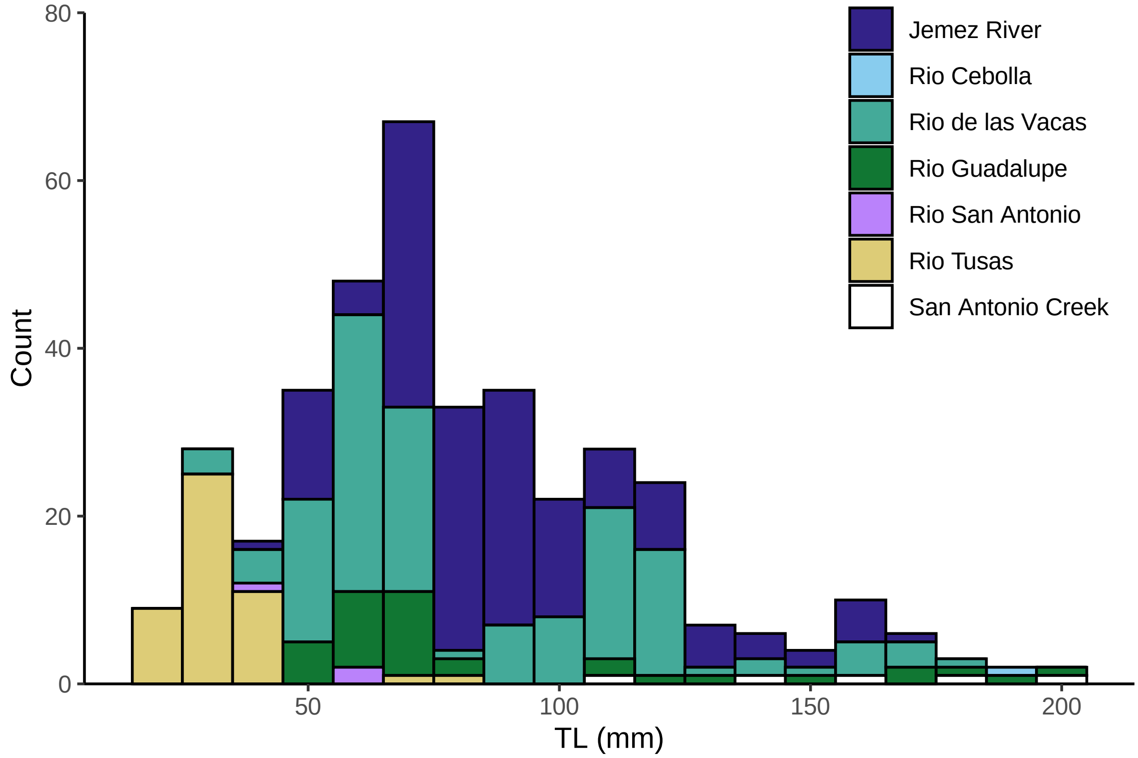

Figure 4 Length-frequency histogram of Rio Grande Chub collected during 2022.

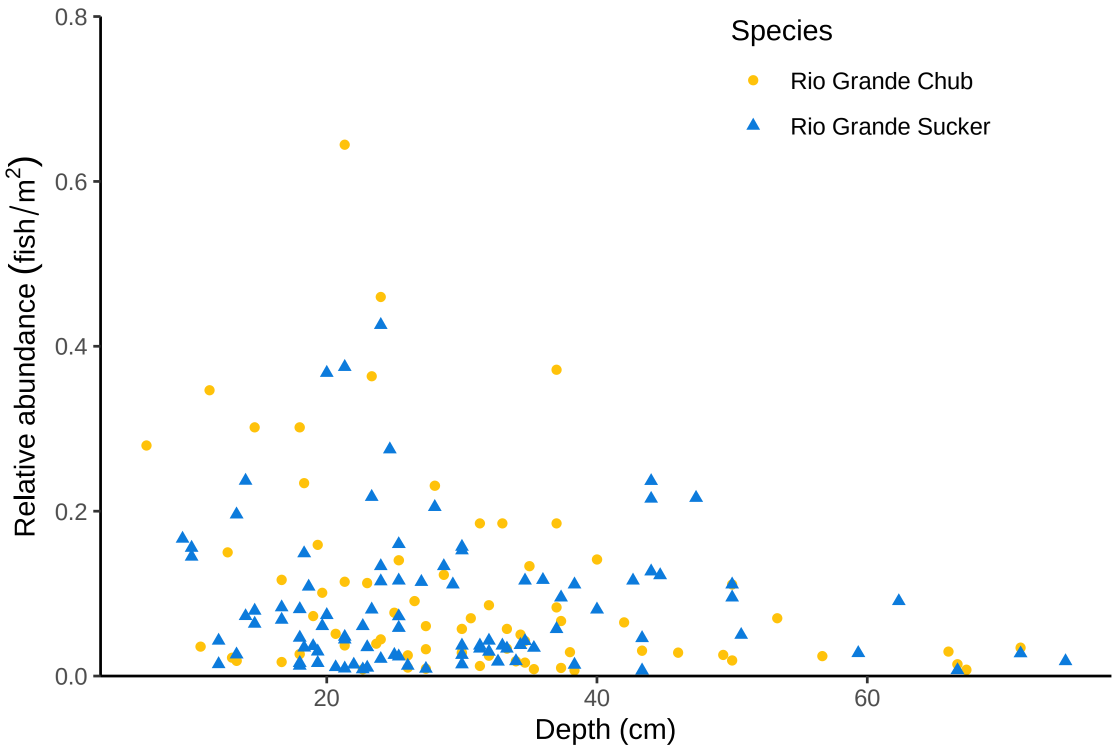

Figure 5 Relative abundance of Rio Grande Chub and Rio Grande Sucker vs. depth (cm). Each point represents one individual.

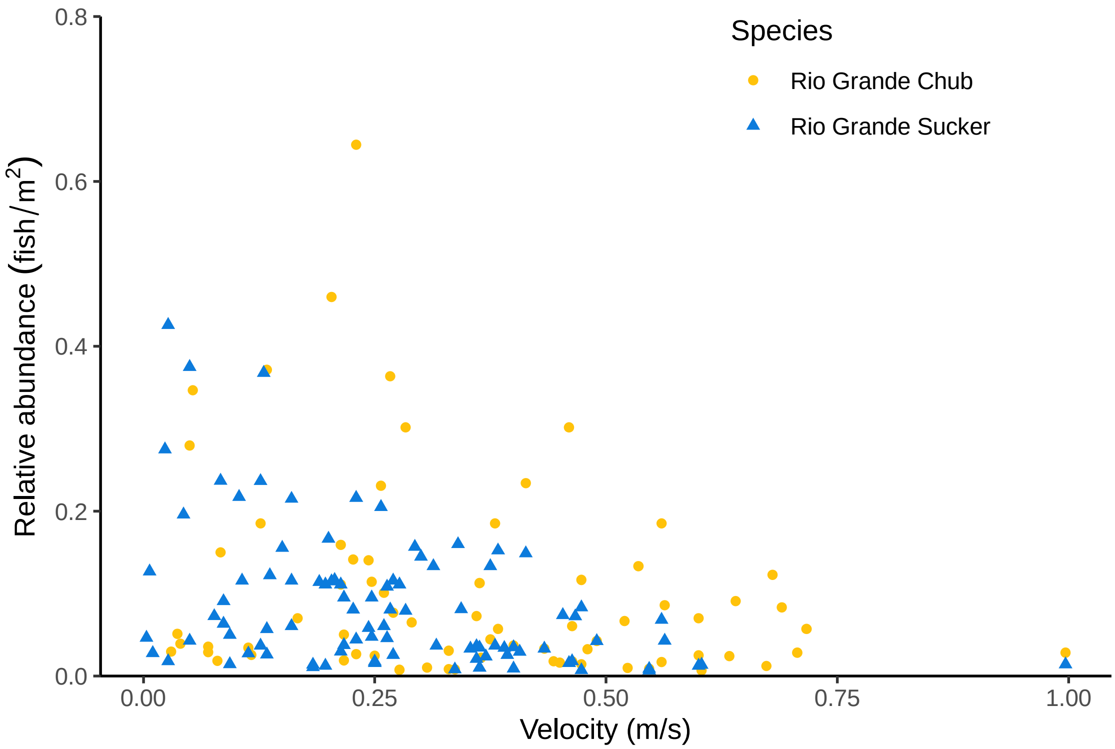

Figure 6 Relative abundance of Rio Grande Chub and Rio Grande Sucker vs. velocity (m/s). Each point represents one individual.

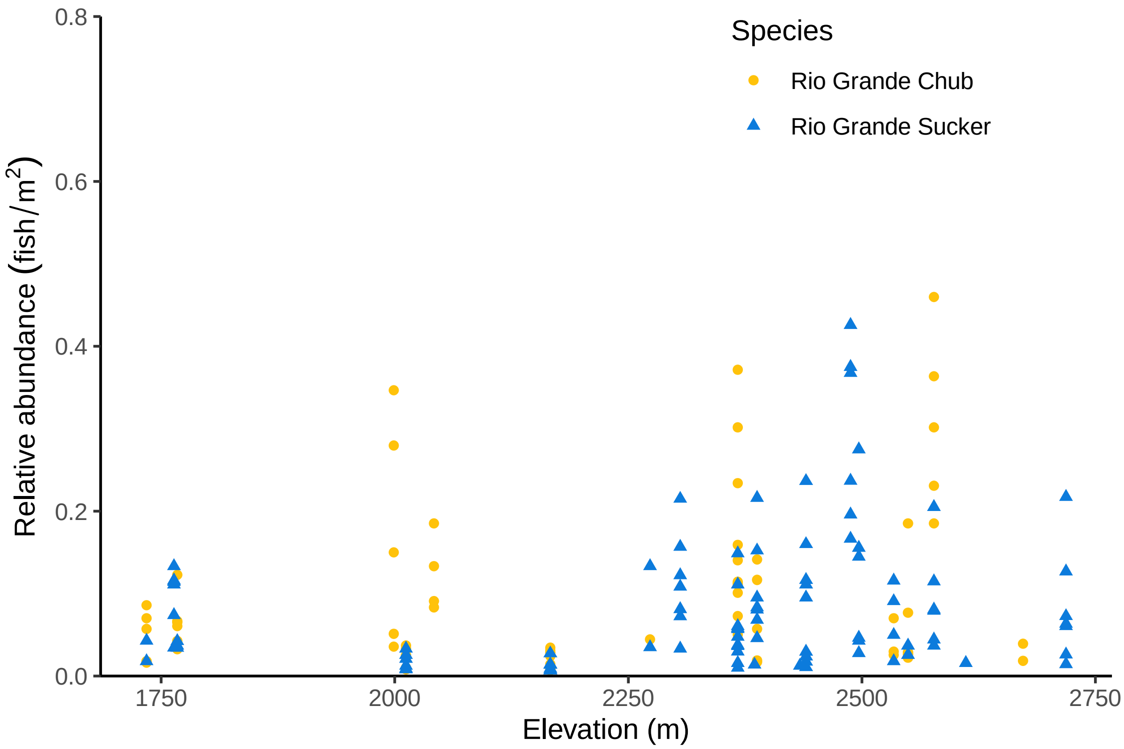

Figure 7 Relative abundance of Rio Grande Chub and Rio Grande Sucker vs. elevation (m). Each point represents one individual.

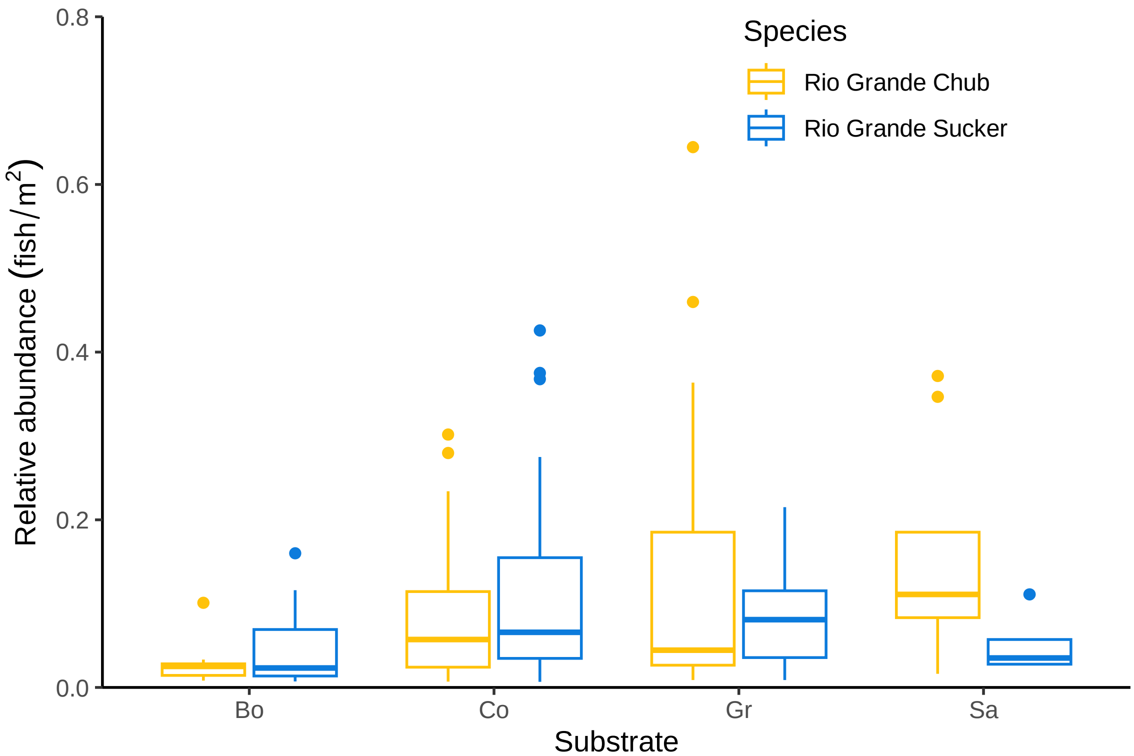

Figure 8 Box-and-whisker plots of Rio Grande Chub and Rio Grande Sucker relative abundance vs. substrate. Bo = boulder, Co = cobble, Gr = gravel, Sa = sand.

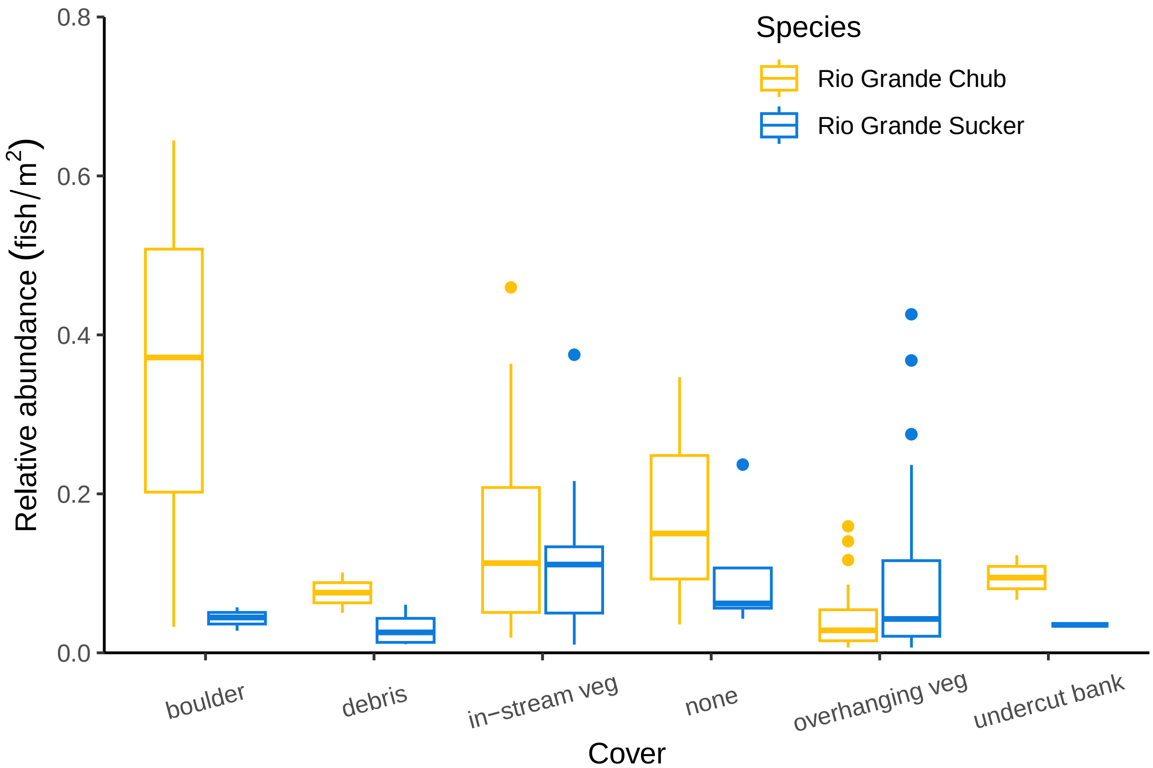

Figure 9 Box-and-whisker plots of Rio Grande Chub and Rio Grande Sucker relative abundance vs. dominant cover types.

Figure 10 Suspected hybrid Rio Grande Chub x Longnose Dace (center) photographed with examples of Longnose Dace (top) and Rio Grande Chub (bottom).

Table 2 Results from linear regression analysis of habitat parameter and nonnative species impacts on Rio Grande Chub relative abundance. Significant P-values (< 0.05) shown in bold.

Covariates	*ß*	*SE*	*P-value*
(Intercept)	-2.92×10^{-1}	2.33×10^{-1}	0.212
Brown Trout presence	-5.47×10^{-2}	2.80×10^{-2}	0.055
Salinity (ppt)	3.96×10^{-1}	2.64×10^{-1}	0.140
Dominant cover [boulder]	1.47×10^{-1}	7.86×10^{-2}	0.066
Dominant cover [debris]	-8.46×10^{-2}	8.67×10^{-2}	0.333
Dominant cover [in-stream vegetation]	-6.19×10^{-3}	6.25×10^{-2}	0.921
Dominant cover [overhanging vegetation]	-1.05×10^{-1}	5.87×10^{-2}	0.079
Dominant cover [undercut bank]	-3.00×10^{-2}	8.65×10^{-2}	0.729
Gradient	1.24×10^{-1}	6.44×10^{-2}	0.058
Average depth (cm)	-2.07×10^{-3}	9.28×10^{-4}	**0.029**
Elevation (m)	1.99×10^{-4}	8.67×10^{-5}	**0.025**

Table 3. Results from logistic regression evaluating effect of habitat parameters and nonnative species on presence/absence of Rio Grande Chub. Significant P-values (<0.05) shown in bold.

Covariates	*ß*	*SE*	*P-value*
Intercept	3.90	1.69	0.006
Dominant cover [boulder]	-0.94	1.07	0.379
Dominant cover [debris]	-1.13	1.17	0.335
Dominant cover [in-stream vegetation]	1.75	0.88	**0.047**
Dominant cover [overhanging vegetation]	-0.78	0.84	0.356
Dominant cover [undercut bank]	0.43	1.31	0.742
Substrate [cobble]	1.03	0.55	0.062
Substrate [gravel]	$1.90x10^{-1}$	$6.05x10^{-1}$	0.753
Substrate [sand]	1.69	0.95	0.075
Rainbow Trout presence	-1.95	1.09	0.073
Elevation (m)	$-3.01x10^{-3}$	$6.35x10^{-4}$	**<0.001**
Gradient	3.97	0.96	**<0.001**

Rio Grande Sucker

Rio Grande Sucker (n=447) were collected at 19 sites across the study area (Figure 3). Suckers were collected in all study streams except the Rio San Antonio. Rio Grande Sucker size range was 15–244 mm TL (Figure 11). Rio Grande Suckers were collected in depths of 9.3–74.7 cm (mean 28.0 cm; Figure 5), velocities of 0.003–0.997 m/s (mean 0.269 m/s; Figure 6), and at elevations of 1,734–2,718 m (mean 2,385 m; Figure 7). Most Rio Grande Sucker were collected in run habitat (n=294, 65.8%) and were associated with cobble substrate (n=260, 58.1%) and overhanging vegetation (n=270; 60.4%). The highest relative abundances of Rio Grande Sucker (fish/m^2) were associated with cobble substrate (Figure 8) and overhanging vegetation (Figure 9).

Linear regression

A multiple linear regression was performed to evaluate the influence of habitat parameters and nonnative species on the relative abundance of the Rio Grande Sucker. Rio Grande Sucker relative abundance (fish/m^2) was explained by substrate, depth:width ratio, mean depth, mean velocity, Rainbow Trout presence, and Brook Trout presence (MLR: R^2=0.367, $F_{8,85}$=6.16, *P*<0.001; Table *4*). Among parameters with significant P-values (<0.05), cobble substrate, depth:width ratio, and Rainbow Trout presence were positively associated, and Brook Trout presence, mean depth, and mean velocity were negatively associated, with Rio Grande Sucker abundance.

Logistic regression

A logistic regression was used to evaluate the effects of habitat parameters and nonnative species on the presence or absence of Rio Grande Sucker in each transect (GLM: Tjur's R^2=0.325; Wald's Test: χ^2=43.6, df=12, P<0.001;

Table 5). Rio Grande Sucker presence/absence was influenced by White Sucker presence, Brown Trout presence, dominant cover, salinity, elevation, depth:width ratio, and mean velocity. Among parameters with significant P-values (<0.05), White Sucker presence, Brown Trout presence, salinity, elevation, depth:width ratio, and mean velocity were negatively associated, and instream vegetation was positively associated, with Rio Grande Sucker presence.

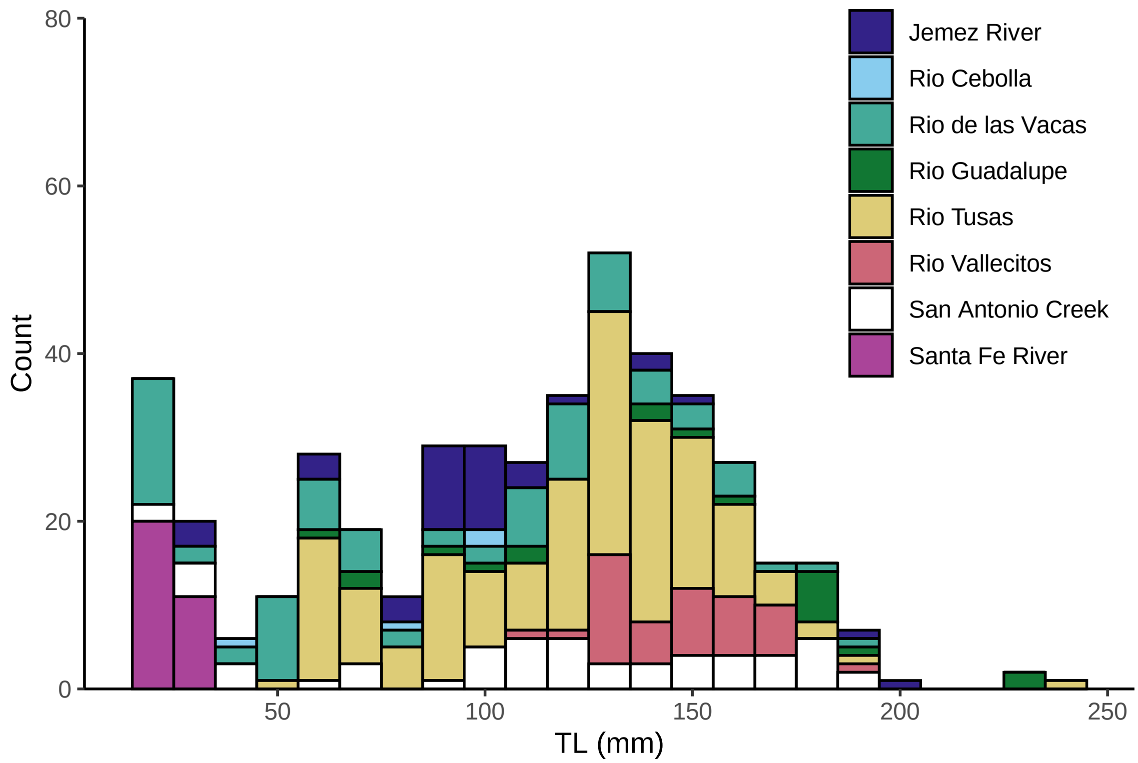

Figure 11 Length-frequency histogram of Rio Grande Sucker collected during 2022.

Table 4 Results from linear regression analysis of impacts of habitat parameters and nonnative species on Rio Grande Sucker relative abundance. Significant P-values (<0.05) shown in bold.

Covariates	*ß*	*SE*	*P-value*
(Intercept)	1.24×10^{-1}	3.26×10^{-2}	**<0.001**
Substrate [cobble]	5.30×10^{-2}	2.21×10^{-2}	**0.019**
Substrate [gravel]	1.94×10^{-3}	2.40×10^{-2}	0.936
Substrate [sand]	-9.07×10^{-3}	3.90×10^{-2}	0.817
Depth:Width ratio	6.05×10^{-3}	2.36×10^{-3}	**0.012**
Rainbow Trout presence	4.26×10^{-2}	2.14×10^{-2}	**0.049**
Brook Trout presence	-8.13×10^{-2}	3.06×10^{-2}	**0.009**
Average depth (cm)	-1.81×10^{-3}	8.11×10^{-4}	**0.028**
Average velocity (m/s)	-2.00×10^{-1}	4.83×10^{-2}	**<0.001**

Table 5 Results from logistic regression evaluating effect of habitat parameters and nonnative species on presence/absence of Rio Grande Sucker.

Covariates	*ß*	*SE*	*P-value*
Intercept	11.45	3.55	0.001
White Sucker presence	-4.52	1.11	**<0.001**
Dominant cover [boulder]	-0.83	0.99	0.402
Dominant cover [debris]	0.55	1.06	0.604
Dominant cover [in-stream vegetation]	1.89	0.89	**0.034**
Dominant cover [overhanging vegetation]	0.77	0.80	0.340
Dominant cover [undercut bank]	0.46	1.50	0.758
Brown Trout presence	-1.29	0.40	**0.001**
Salinity (ppt)	-8.31	3.58	**0.02**
Elevation (m)	-3.82×10^{-3}	1.20×10^{-3}	**0.002**
Depth:Width ratio	-8.88×10^{-2}	3.92×10^{-2}	**0.024**
Average Velocity (m/s)	-5.07	1.25	**<0.001**

DISCUSSION

Rio Grande Chub and Rio Grande Sucker were collected throughout the study area, however, relative abundance and presence varied widely among study streams. In the Rio Tusas, the two target species exhibited a partitioning of stream habitat along a relatively short longitudinal gradient. Rio Grande Sucker occupied the upstream extent, which was characterized by swift currents, canyon-bound habitat with primarily cobble/boulder substrate, and abundant overhanging vegetation. Rio Grande Chub occupied the downstream extent which was shallower, slower, lower elevation, and dominated by sand substrate. No Rio Grande Chub were collected in the Rio Vallecitos despite its confluence with the Rio Tusas downstream of the Rio Grande Chub population in the Rio Tusas. However, no GRTS sites occurred in the downstream extent of the Rio Vallecitos near the confluence with the Rio Tusas, so it is unknown if Rio Grande Chub occupy the downstream extent the Rio Vallecitos. Distribution of sampling sites in other streams within the study area was more spatially balanced, i.e., distributed across the study stream, and a geographical/elevational shift in site occurrence by target species was not observed. Rio Grande Chub and Rio Grande Sucker co-occurred in many of the study streams, though species-specific differences in habitat usage were observed.

Both species exhibited a range of body sizes, which was indicative of reproduction and recruitment in sampled populations. The length-frequency histogram for the Rio Grande Sucker was left-skewed and featured a high frequency of smaller individuals between 20–30 mm TL. These small individuals primarily occurred in the Santa Fe River, which was sampled one month earlier than National Forest sites that were temporarily closed because of forest fires. Differences in the amount of first-year growth that had occurred relative to the timing of sampling may account for the small size of these individuals (i.e., sampling occurred earlier in the Rio Grande Sucker reproductive cycle in the Santa Fe River as compared to sampling in the National Forest sites).

A variety of biotic and abiotic parameters influence the relative abundance and presence of Rio Grande Chub. Both presence and relative abundance of this species were positively associated with the stream gradients of study sites (this relationship was statistically significant only for presence). This positive relationship may reflect step-pool formation in high-gradient streams (O'Dowd and Chin 2016) that creates pool mesohabitat, which was observed to be a preferred habitat during this study and by Bestgen et al. (2003). Furthermore, pools in step-pool systems are characterized by cobble, gravel, and sand substrates (O'Dowd and Chin 2016), all of which were positively associated with Rio Grande Chub presence in this study.

Analysis of the relationship between Rio Grande Chub relative abundance or presence and stream cover was complicated by conflicting interactions between dominant cover and fish relative abundance and dominant cover and fish presence. Rio Grande Chub presence was positively associated with instream-vegetation cover, indicating that they were more likely to occur at a transect if there was available cover in the form of in-stream vegetation. However, abundance was negatively associated with all cover except for boulders. The Rio Grande Chub and Sucker Conservation Team (RGCSCT; 2021a) suggested that nonnative species may compete with Rio Grande Chubs for important habitat features like cover. Alternatively, if nonnative, piscivorous fishes utilize cover in the streams, Rio Grande Chubs may seek other habitats to avoid predation. In the current study, more Brown Trout were collected in association with debris (n=25), in-stream vegetation (n=50), and overhanging vegetation (n=129) than with boulders (n=7) suggesting that nonnative Brown Trout influenced Rio Grande Chub habitat usage. Further research is warranted to determine the mechanism that is influencing this relationship (i.e., predation or competition). Lastly, some patterns involving dominant cover could be partly due to collection bias arising from difficult sampling conditions. Debris, including woody debris like logs and root wads, was negatively associated with Rio Grande Chub presence in the current study, despite previous studies indicating a preference for this cover type by the species (RGCSCT 2021a). Stunned fishes occasionally got caught in dense woody debris and in-stream vegetation during sampling and were thus not sampled, so relative abundance for this species may be somewhat under-represented for these cover types.

Rio Grande Sucker relative abundance and presence were affected by multiple stream morphology parameters, cover, and substrate. This species' relative abundance was positively associated with larger substrates such as cobble and gravel. Rio Grande Sucker consume periphyton attached to large substrates, thus their substrate association likely reflects foraging habitats. Likewise, the negative association between relative abundance and sand substrate may reflect paucity of periphyton in these habitats. Greater relative abundance of Rio Grande Sucker occurred in transects with greater depth:width ratios. Conversely, mean depth was negatively associated with Rio Grande Sucker relative abundance. Though both terms utilize mean depth at the habitat transect at the end of a fish survey segment, the depth:width ratio also integrates the shape of the streambed into analyses, which may have implications for solar input that could relate to stream temperature (Tague et al. 2007). Relative abundance and presence of the Rio Grande Sucker in the current study were negatively impacted by velocity, which supports the relationship with velocity that was previously described for this species (Calamusso et al. 2002; Rees and Miller 2005).

There was a negative relationship between elevation and presence of both Rio Grande Chub and Rio Grande Sucker that reflected the upper limits of their collection during this study. Both species were collected at the lowest elevation site (Jemez River; 1,734 m). Maximum elevation for Rio Grande Chub collection was higher (2,672 m) than was previously documented by the RGCSCT (2,500 m; 2021a). Conversely, Rio Grande Sucker occurred at a lower maximum elevation (2,718 m) than was previously documented (3,000 m; RGCSCT 2021b; note that the highest elevation surveyed in the current study was <3,000 m).

Previous studies have documented a negative effect of the nonnative/piscivorous Brown Trout on Rio Grande Chub and Rio Grande Sucker (Bestgen et al. 2003; Ivie et al 2022). In the current study, Brown Trout presence was negatively related to relative abundance of Rio Grande Chub, whereas Brook Trout presence was negatively associated with Rio Grande Sucker relative abundance. These trout species are piscivorous (Sublette et al. 1990), may prey on Rio Grande Chub and Rio Grande Sucker

(Bestgen et al. 2003; George 2022), and likely compete with Rio Grande Chub for food resources. Brown Trout consume primarily invertebrates and fish, while Rio Grande Chub have been described as midwater carnivores that feed on invertebrates, fish, and detritus (Sublette et al. 1990); diet overlap specifically occurs between Rio Grande Chub and small Brown Trout (George 2022). Paradoxically, Rainbow Trout presence was positively associated with the relative abundance of Rio Grande Sucker. This association is likely due to overlapping habitat usage (Swift-Miller et al. 1999b) and is not causative in nature (i.e., presence of Rainbow Trout likely does not promote increased abundance of Rio Grande Sucker, but these species often co-occur).

Negative interactions between the native Rio Grande Sucker and the invasive White Sucker have been previously documented (Swift Miller et al. 1999b; Rio Grande Chub and Sucker Conservation Team 2021b). Diet composition of White Sucker and Rio Grande Sucker overlap (Swift Miller et al. 1999b), thus expansion of White Sucker into Rio Grande Sucker habitat may limit the native species' food resources. Due to their long life span, White Sucker have twice the reproductive output of Rio Grande Sucker, and this difference in fecundity likely contributes to the White Sucker's range expansion (McPhee 2007). In the current study, the presence of Rio Grande Sucker was negatively associated with presence of White Sucker. Rio Grande Sucker were absent from all five sites in the Rio San Antonio. The fish community of the Rio San Antonio, even at the highest upstream site, near the headwaters, was characterized by a high proportion of White Sucker; in contrast, Rio Grande Sucker were absent from all five sites in this river. The Rio San Antonio may serve as a cautionary example of the shift in fish communities that may occur if White Sucker continue to spread throughout the range of the Rio Grande Sucker.

All models were significant (P<0.001) and had coefficients of determination (R^2= 0.325–0.508) indicating that habitat parameters and presence of nonnative predators and competitors explained some, but not all, of the relative abundance and presence of target species. Other factors such as food availability, seasonal thermal/hydrologic variation (Rio Grande Chub and Sucker Conservation Team 2021a; 2021b), persistent drought (VerWey et al 2018), availability of refuge habitat during seasonal stream drying (Vander Vorste et al. 2020), or habitat intermittency (Kukula and Bylak 2022) could influence populations of Rio Grande Chub and Rio Grande Sucker. Because the current study over a short period, the aforementioned factors could not be evaluated but consistent and comprehensive monitoring of these populations in the future may further elucidate population response to, and the importance of, these factors. Further, biotic and abiotic parameters may synergistically interact to influence Rio Grande Chub and Rio Grande Sucker populations. Thus, future studies are warranted to elucidate long-term effects of these dynamic factors on the distribution and relative abundance of Rio Grande Chub and Rio Grande Sucker both within New Mexico and throughout their extant range.

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