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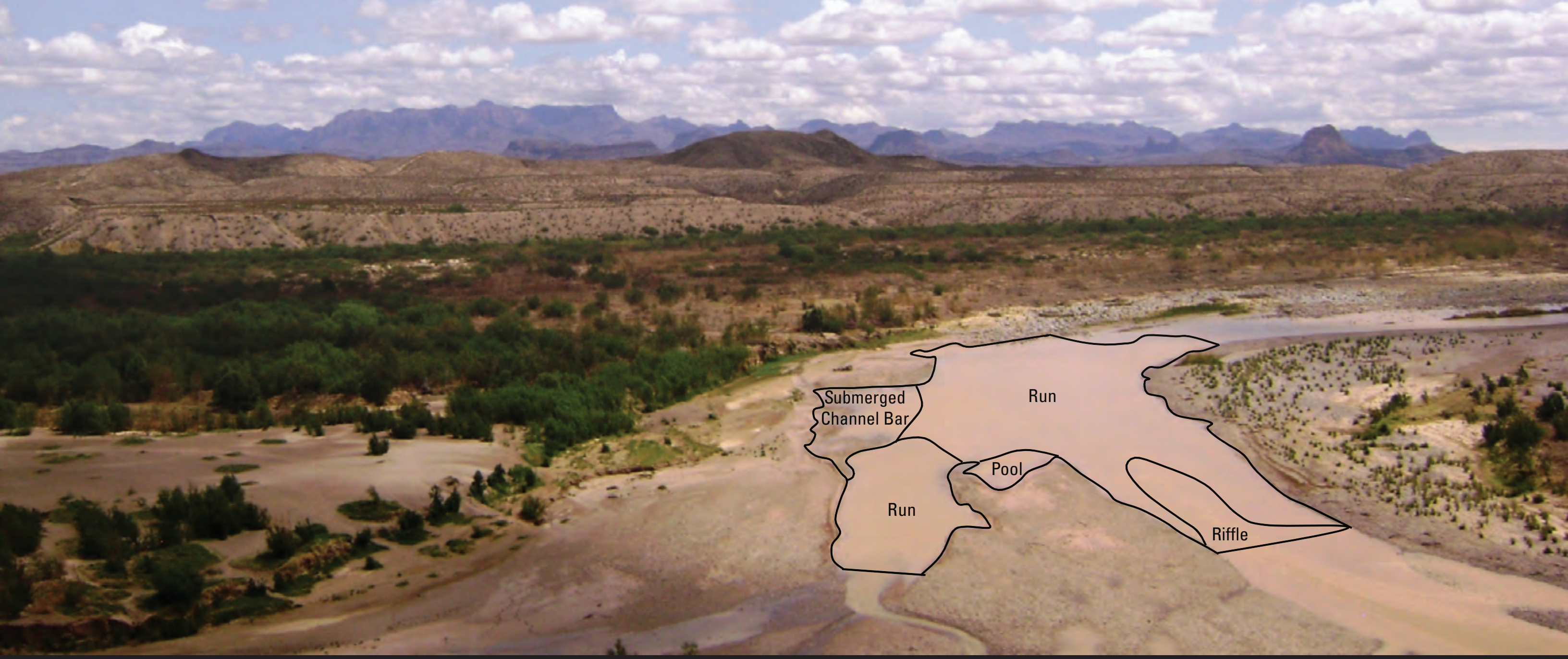

Scientific Investigations Report 2013–5210

U.S. Department of the Interior
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Cover:

Left, U.S. Geological Survey employee measuring stream velocity with a hand-held acoustic Doppler velocimeter attached to a wading rod at high flow on the Rio Grande at the Santa Elena site, Big Bend National Park, Texas, August 31, 2010 (photograph by James B. Moring, U.S. Geological Survey).

Center, View of the Rio Grande oriented downstream from the upstream boundary of the Stillwell Crossing site near the State of Texas Black Gap Wildlife Management Area, September 3, 2010 (photograph by Daniel K. Pearson, U.S. Geological Survey).

Right, Mapping crew delineating edge of water at high flow on the Rio Grande at the Santa Elena site, Big Bend National Park, Texas, August 31, 2010 (photograph by Alec MacDonald, U.S. Geological Survey).

Background, View of the Rio Grande oriented northwest from the Santa Elena Canyon Trail at the upper portion of the Santa Elena site, Big Bend National Park, Texas, with the Chisos Mountains in the distance, April 15, 2010 (photograph by Daniel K. Pearson, U.S. Geological Survey); hypothetical mesohabitat boundaries derived from visual cues are overlaid on the photograph.

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SALLY JEWELL, Secretary

U.S. Geological Survey
Suzette M. Kimball, Acting Director

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Conversion Factors, Datums, Water-Quality Units, and Nomenclature

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
square foot (ft^2)	0.0929	square meter (m^2)
	Mass	
pound (lb)	453.6	gram (g)
	Volume	
gallon (gal)	3.785	liter (L)
gallon (gal)	3785	cubic centimeter (cm^3)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
	Velocity	
foot per second (ft/s)	0.3048	meter per second (m/s)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

SI to Inch/Pound

Multiply	By	To obtain
	Length	
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Area	
hectare (ha)	2.471	acre
square kilometer (km^2)	0.3861	square mile (mi^2)
square meter (m^2)	10.76	square foot (ft^2)
	Mass	
gram (g)	0.03527	ounce, avoirdupois (oz)
milligram (mg)	0.00003527	ounce, avoirdupois (oz)
	Volume	
cubic centimeter (cm^3)	0.0002642	gallon (gal)
cubic meter (m^3)	0.0008107	acre-foot (acre-ft)
	Velocity	
meters per second (m/s)	3.281	foot per second (ft/s)
	Flow rate	
cubic meters per second (m^3/s)	35.31	cubic foot per second (ft^3/s)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

°F=(1.8×°C)+32

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

°C=(°F-32)/1.8

Datums

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Water-Quality Units

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 °C).

Mesohabitats, Fish Assemblage Composition, and Mesohabitat Use of the Rio Grande Silvery Minnow Over a Range of Seasonal Flow Regimes in the Rio Grande/Rio Bravo del Norte In and Near Big Bend National Park, Texas, 2010–11

By James B. Moring, Christopher L. Braun, and Daniel K. Pearson

Abstract

In 2010–11, the U.S. Geological Survey (USGS), in cooperation with the U.S. Fish and Wildlife Service, evaluated the physical characteristics and fish assemblage composition of mapped river mesohabitats at four sites on the Rio Grande/Rio Bravo del Norte (hereinafter Rio Grande) in and near Big Bend National Park, Texas. The four sites used for the river habitat study were colocated with sites where the U.S. Fish and Wildlife Service has implemented an experimental reintroduction of the Rio Grande silvery minnow (*Hybognathus amarus*), a federally listed endangered species, into part of the historical range of this species. The four sites from upstream to downstream are USGS station 08374340 Rio Grande at Contrabando Canyon near Lajitas, Tex. (hereinafter the Contrabando site), USGS station 290956103363600 Rio Grande at Santa Elena Canyon, Big Bend National Park, Tex. (hereinafter the Santa Elena site), USGS station 291046102573900 Rio Grande near Ranger Station at Rio Grande Village, Tex. (hereinafter the Rio Grande Village site), and USGS station 292354102491100 Rio Grande above Stillwell Crossing near Big Bend National Park, Tex. (hereinafter the Stillwell Crossing site).

In-channel river habitat was mapped at the mesohabitat scale over a range of seasonal streamflows. A late summer (August–September 2010) high-flow regime, an early spring (April–May 2010) intermediate flow regime, and a late spring (May 2011) low-flow regime were the seasonal flows used in the study. River habitat was mapped in the field by using a geographic information system and a Global Positioning System unit to characterize the sites at the mesohabitat scale. Physical characteristics of a subset of mesohabitats in a reach of the Rio Grande at each site were measured during each flow regime and included depth, velocity, type and size of the substrate, and percent embeddedness. Selected water-quality properties (dissolved oxygen, pH, specific conductance, and temperature) of a subset of mesohabitats were also measured. The fish assemblage composition at the four sites was determined during the three flow regimes, and fish were collected by seining in each mesohabitat where physical characteristic data were measured, except during some periods of high flow when electrofishing was done to supplement seining.

The total number and number of types of mesohabitats were larger during low flows compared to intermediate flows, and larger during intermediate flows compared to high flows. Decreases in streamflow typically led to increases in channel complexity in terms of the number of different types and total number of mesohabitats present. The total wetted area increased and the number of mesohabitat types generally decreased as streamflow increased. At all four sites, the smallest depths and velocities were generally measured during low flow and the largest depths and velocities at high flow. Specific conductance was relatively consistent between the Contrabando and Santa Elena sites, the two most upstream sites. Specific conductance decreased appreciably between the Santa Elena site and the Rio Grande Village, and decreased slightly between the Rio Grande Village site and the Stillwell Crossing site. Specific-conductance values within and among mesohabitat types at a given site were relatively consistent. The pH values measured within and among mesohabitat types also were relatively consistent at all four sites. Median dissolved oxygen concentrations were relatively consistent between the Contrabando and Santa Elena sites (8.34 and 8.54 milligrams per liter [mg/L], respectively) but decreased along the stretch of river between the Santa Elena and Rio Grande Village sites to 7.31 mg/L, possibly because of small dissolved oxygen concentrations associated with contributions from springs between the Santa Elena and Rio Grande Village sites. Dissolved oxygen concentrations increased substantially

between the Rio Grande Village and Stillwell Crossing sites to 10.06 mg/L. Mesohabitat water temperatures were generally highest in mesohabitats commonly associated with shallow water depths and low velocities (forewaters, backwaters, and embayments).

Of the 21 species of fish collected during the three flow regimes, red shiner (*Cyprinella lutrensis*) was the most abundant species overall, accounting for about 35 percent of all fish collected. Another minnow, the endemic Tamaulipas shiner (*Notropis braytoni*), was second in overall abundance. A nonnative species, the common carp (*Cyprinus carpio*), was the third most abundant species overall. No statistically significant differences in fish-species richness were found among the different mesohabitat types. Median fish-species richness and maximum fish-species richness values were larger, and fish-species richness was more variable in runs, pools, forewaters, and backwaters during low flow compared to the fish-species richness values calculated for intermediate and high flows. Fish density in backwater mesohabitats was significantly different from fish densities in run mesohabitats, but fish densities were not significantly different among the other mesohabitat types.

Of the 39 Rio Grande silvery minnow individuals collected at the four study sites, 21 (more than half) were collected at the Santa Elena site, 12 at the Contrabando site, and 3 each at the Rio Grande Village and Stillwell Crossing sites. Rio Grande silvery minnow fish-species densities followed the same order as abundance of this species at the sites; fish-species densities ranged from 0.95 fish per 100 square meters (m^2) at the Santa Elena site to 0.11–0.47 fish per 100 m^2 at the other three sites. The Rio Grande silvery minnow was most common in pools and runs during low- and intermediate-flow regimes. This species was less commonly collected in backwaters, embayments, and rapids, and none were collected in forewaters or submerged channel bars. The Tamaulipas shiner has similar life-history characteristics compared to the Rio Grande silvery minnow, including similar feeding habits and habitat use. Tamaulipas shiner was most common in backwater, run, and riffle mesohabitats (in decreasing order) during low and intermediate flow and was less common in submerged channel bar, pool, forewater, rapid, and embayment mesohabitats (in decreasing order) during the same flows. The overall relative percent density (composite of all three flow regimes) of Rio Grande silvery minnow was largest in rapid and pool mesohabitats and for Tamaulipas shiner was largest in backwater mesohabitats.

There were no statistically significant differences between the stream velocities associated with seine hauls of the Rio Grande silvery minnow and Tamaulipas shiner. Stream velocities associated with the seine hauls that included Rio Grande silvery minnow indicate that this species is predominantly found in low-velocity mesohabitats. Velocities associated with seine hauls that included the Tamaulipas shiner represented a much broader overall range of velocities than those associated with Rio Grande silvery minnow collections. No statistically significant differences were found between the depths for seine hauls that included Rio Grande silvery minnow or Tamaulipas shiner. The Rio Grande silvery minnow was more commonly collected in seine hauls from mesohabitats dominated by cobble substrates and less frequently collected in mesohabitats with substrates dominated by fine-sized silt and clay particles, gravels, and sands, in that order. In contrast, the Tamaulipas shiner was broadly distributed among mesohabitats characterized as having gravel, cobble, and silt and clay.

Introduction

The Rio Grande silvery minnow (*Hybognathus amarus*) is a federally listed endangered species that the U.S. Fish and Wildlife Service (USFWS) is reintroducing into part of its historical range in accordance with species recovery provisions described in section 10(j) of the Endangered Species Act (U.S. Fish and Wildlife Service, 2008). The Rio Grande silvery minnow was historically one of the most widespread fishes in the Rio Grande Basin, occurring from northern New Mexico to the Gulf of Mexico (Bestgen and Platania, 1991), and was also found in the Pecos River from its headwaters to the confluence of the Pecos River with the Rio Grande/Rio Bravo del Norte (hereinafter Rio Grande) near Del Rio, Texas (Bestgen and Propst, 1996). When the USFWS began the experimental reintroduction program in 2008, the range of this species was limited to a 280-kilometer (km) section of the Rio Grande between Cochiti Lake and Elephant Butte Reservoir and to a small part of the lower Jemez River, all in New Mexico—about 7 percent of its historical range (U.S. Fish and Wildlife Service, 2010).

The USFWS began the experimental reintroduction of the Rio Grande silvery minnow into part of its historical range in the “Big Bend reach” of the Rio Grande in and near Big Bend National Park (fig. 1) in December 2008 (U.S. Fish and Wildlife Service, 2008) by releasing approximately 430,000 Rio Grande silvery minnows at four sites in this reach. To date, approximately 1,825,000 silvery minnows have been released in this reach, and releases are projected to continue annually until a self-sustaining population of Rio Grande silvery minnow is established in this reach or until the reestablishment of this species in potentially suitable habitat becomes highly likely (Mike Montagne, U.S. Fish and Wildlife Service, written commun., 2013). Reestablishment in the Big Bend reach is one of the primary goals described in the Rio Grande Silvery Minnow Recovery Plan (U.S. Fish and Wildlife Service, 2010). The “Big Bend reach” refers to a reach of the Rio Grande that begins at Mulato Dam about 25 km downstream from Presidio, Tex.; flows through Big Bend Ranch State Park, Big Bend National Park, and Black Gap Wildlife Management Area; and ends at the downstream boundary of the Rio Grande Wild and Scenic River at the border between Terrell and Val Verde Counties, Tex. (fig. 1).

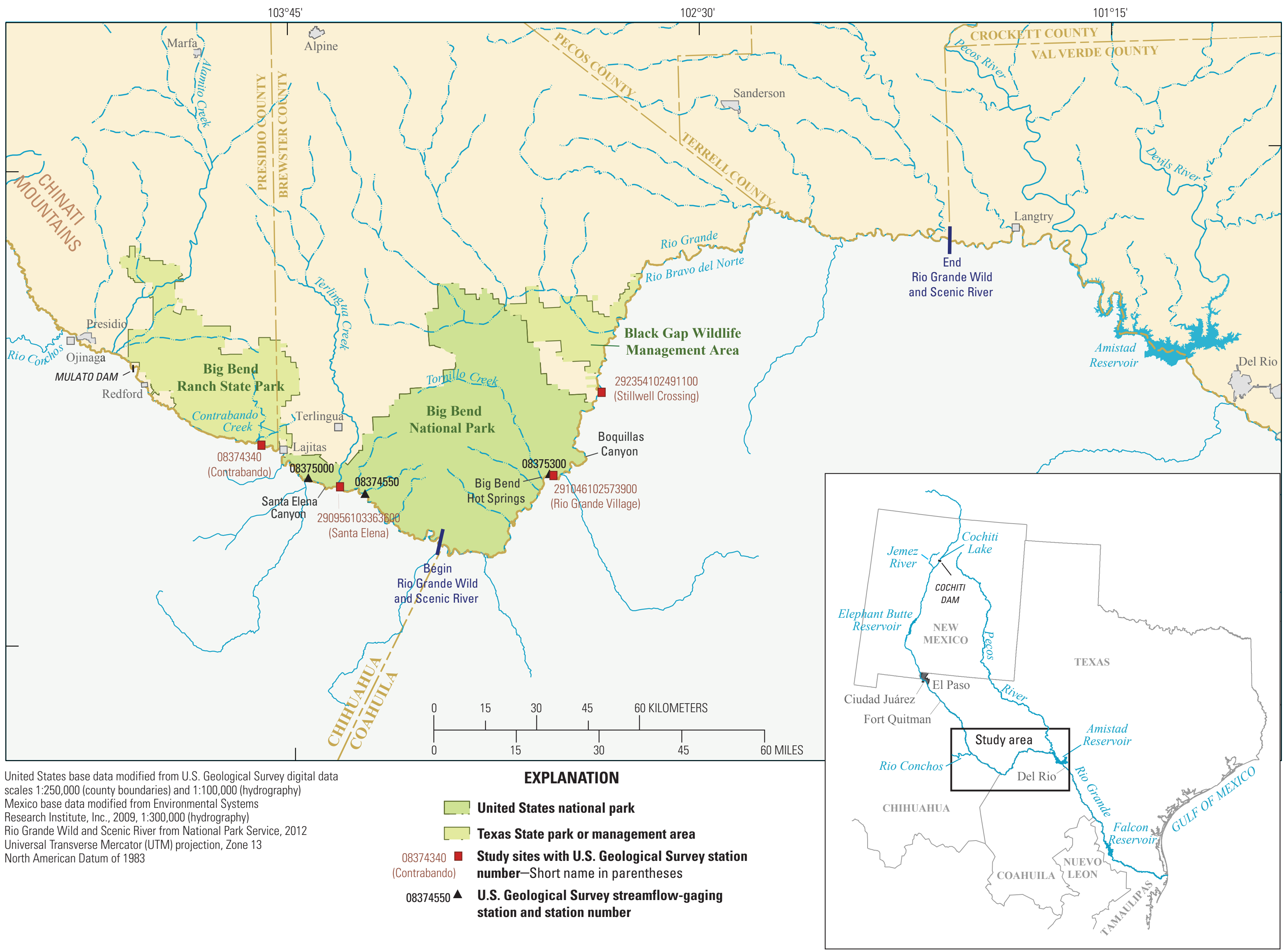


Figure 1. Location of study area.

The Rio Grande silvery minnow is 1 of 7 species in the genus *Hybognathus*. Adults of this species reach a maximum length of 89 millimeters (mm); coloration on the dorsal side is brown to olive and on the ventral side is white (Thomas and others, 2007). Members of the *Hybognathus* genus are pelagic (broadcast) spawners producing thousands of semibuoyant eggs that require streamflows supportive of extensive drifts of eggs and larvae to sustain a population (Bestgen and Platania, 1991). Various life stages of the Rio Grande silvery minnow require low-velocity habitats with fine-sized silt and clay particles (sediment particles less or equal to 0.0625 mm in size) or sand (sediment particles greater than 0.0625 and less than or equal to 2 mm in size) composing the substrate (Wentworth, 1922; Guy, 1969); preferred habitats of this species include side channels and backwaters (Bestgen and Platania, 1991).

Throughout its historical range, decline of the Rio Grande silvery minnow has been attributed to a number of factors, including altered natural flow regimes, channel drying, reservoir construction, stream channelization, declining water quality, and interactions with nonnative fish (Cook and others, 1992; Edwards, 2005). The Rio Grande silvery minnow is extirpated (locally extinct) from the Big Bend reach of the Rio Grande, and natural repopulation is not possible without human assistance (U.S. Fish and Wildlife Service, 2010). The Rio Grande silvery minnow was once the predominant minnow species in the Rio Grande in Texas (Treviño-Robinson, 1955, 1959). The last documented occurrence of the Rio Grande silvery minnow in the Big Bend reach was in 1960 (Bestgen and Platania, 1991). The specific reasons for the extirpation of this species in the Rio Grande in Texas are unknown but are believed to be related to drought, decreased streamflows, alterations to in-stream and overbank riparian habitat, increased diversions, and declining water quality (Edwards and others, 2002, 2004; Edwards, 2005). An important aspect of the declining water quality is the increasing salinity concentrations measured in the Rio Grande in Texas (Miyamoto and others, 1995). Despite the many possible factors leading to the decline of the Rio Grande silvery minnow, the presence of similar species including the Tamaulipas shiner (*Notropis braytoni*), speckled chub (*Macrhybopsis aestivalis*), Rio Grande shiner (*Notropis jemezanus*), and longnose dace (*Rhinichthys cataractae*) provides some evidence that the Big Bend reach could support the reestablishment of a reproducing population of the Rio Grande silvery minnow. The Tamaulipas and Rio Grande shiner belong to the same pelagic spawning guild as the Rio Grande silvery minnow (Thomas and others, 2007).

The amount and quality of habitat in a stream vary depending on the amount of streamflow. For example, in other river systems it has been documented that habitat drying and streamflow reductions can affect growth, recruitment, and survival of small fish like the Rio Grande silvery minnow (Falke and others, 2010). The relation between the amount of streamflow and habitat for the Rio Grande silvery minnow and similar species of fish in the Big Bend reach is not well understood, and gaining a better understanding of the relation between streamflow and habitat in this reach is important to the success of the USFWS Rio Grande silvery minnow recovery plan. Because habitat needs vary throughout a species' life cycle, and because the size and distribution of habitats can change over time in response to streamflow, it was important to assess fish habitat at the mesohabitat scale. Mesohabitats are visually distinct units of habitat within a stream (Pardo and Armitage, 1997) with unique depths, velocities, slopes, substrates, and cover. Although the size and distribution of mesohabitats change over time, the collective group or assemblage of different mesohabitats in a stream is stable (Armitage, 1995). Because the assemblage of mesohabitat types is stable, aquatic organisms have adapted to the physical characteristics and temporal dynamics of the mesohabitats with which they are associated (Southwood, 1988), meaning that the mesohabitat scale is often the ideal scale for evaluating fish habitat. The specific types and amounts of mesohabitats present at any given time change in response to changes in streamflow and channel geomorphology. Because of this dynamic relation between mesohabitats and streamflow, assessments of streamflow in relation to available habitat are considered by many ecologists and geomorphologists as critical for the development of practical river management tools (Harper and Everard, 1998; Newson and Newson, 2000).

To gain a better understanding of available river habitat for the Rio Grande silvery minnow and other fish species native to the Big Bend reach of the Rio Grande, during 2010–11, the U.S. Geological Survey (USGS), in cooperation with the USFWS, mapped mesohabitats during three flow regimes (high, intermediate, and low) and then collected physical characteristic data and completed fish assemblage assessments in a subset of mapped mesohabitats. In this study, "fish assemblage" refers to the species of fish that coexist in a habitat. Data collected during three flow regimes were analyzed: a period of high flow (1,500–2,480 cubic feet per second [ft^3/s]) in August–September 2010, a period of intermediate flow (141–473 ft^3/s) in April–May 2010, and a period of low flow (29.6–71.3 ft^3/s) in May 2011 (table 1). Data were also collected from remote imagery to document overbank land cover features, and the imagery was captured during a fall 2008 flood of more than 10,000 ft^3/s that exceeded the high-flow regime used in this study, but these data were not analyzed in this report. All of the mesohabitat physical and fish assemblage data were collected from four sampling sites in the Big Bend reach the Rio Grande that were colocated with the minnow release sites used for the USFWS Rio Grande silvery minnow recovery plan. Results from this study are intended to help the USFWS refine the Rio Grande silvery minnow reintroduction strategies based on available habitat and to provide detailed habitat information for the species over a range of different streamflows.

Table 1. Description of the four study sites in the Rio Grande/Rio Bravo del Norte (Rio Grande) and stream regimes (high, intermediate, and low flow) during which data were collected, Texas, 2010–11.

[USGS, U.S. Geological Survey; ft^3/s, cubic feet per second; °, degrees; ′, minutes; ″, seconds]

Study site					Flow regime					
					High flow		Intermediate flow		Low flow	
USGS station number	USGS station name	Short name	Latitude[a]	Longitude[a]	Date	Discharge (ft^3/s)[b]	Date	Discharge (ft^3/s)[c]	Date	Discharge (ft^3/s)[d]
08374340	Rio Grande at Contrabando Canyon near Lajitas, Tex.	Contrabando	29°16′45″	103°50′36.7″	8/30/2010	1,500[e]	4/13/2010	473	5/16/2011	35.1
290956103363600	Rio Grande at Santa Elena Canyon, Big Bend National Park, Tex.	Santa Elena	29°9′55.9″	103°36′36.5″	8/31/2010	1,640	4/14/2010	141	5/17/2011	29.6
291046102573900	Rio Grande near Ranger Station at Rio Grande Village, Tex.	Rio Grande Village	29°16′45″	102°57′39″	9/1/2010	2,480	5/20/2010	169	5/18/2011	47.9
292354102491100	Rio Grande above Stillwell Crossing near Big Bend National Park, Tex.	Stillwell Crossing	29°23′54.5″	102°49′11.6″	9/2/2010	1,740	5/18/2010	172	5/19/2011	71.3

[a]Latitude and longitude of USGS station correspond to the upstream boundary of the sampling reach at each study site.

[b]Instantaneous discharge from single section acoustic Doppler current profiler measurement on sampling date for each site.

[c]Instantaneous discharge at 12 p.m. from USGS streamflow-gaging station 08374550 for Contrabando and Santa Elena study sites and from USGS streamflow-gaging station 8375300 for Rio Grande Village and Stillwell Crossing study sites on the sampling dates for the sites.

[d]Average of two discharge measurements made on the sampling date for each site.

[e]Estimated discharge based on acoustic Doppler current profiler measurement from a single pass using the profiler.

Purpose and Scope

Mesohabitats were mapped at four study sites on the Rio Grande in and near Big Bend National Park in Texas during 2010–11 to determine mesohabitat physical characteristics and fish habitat use and availability in the Big Bend reach of the Rio Grande. The physical characteristics and fish assemblages associated with the mapped mesohabitats are described. Comparisons of physical characteristic and fish assemblage data are made at the mesohabitat scale among the sampling sites for three different streamflow regimes (high, intermediate, and low flow). Mesohabitat physical characteristics including wetted area, stream velocity, depth, and substrate type are compared among the three flow regimes. Fish assemblage composition is evaluated at the mesohabitat scale. Comparisons of fish assemblage data within and among the sampling sites are made by analyzing total abundance data, species richness information, relative abundance, total fish density, fish-species density, and other metrics. Statistical analysis of fish data includes use of a nonparametric statistical analysis, Kruskal-Wallis one-way analysis of variance, a Tukey-type nonparametric multiple comparison, and a multivariate statistical analysis, canonical correspondence analysis (CCA). Water-quality properties (dissolved oxygen, pH, specific conductance, and temperature) that were measured in May 2011 during the low-flow regime are compared among sites because these properties are considered most crucial for sustaining aquatic biota. All of the data that were collected and used in analysis are in the geospatial database included with this report.

Description of Study Area

The study area is the Big Bend reach of the Rio Grande, which includes 37 km of the river bordering Big Bend Ranch State Park, 190 km of the river that forms the southern boundary of Big Bend National Park, and 15 km of the river bordering the State of Texas Black Gap Wildlife Management Area (fig. 1). The fish species of the reach of the Rio Grande from Big Bend National Park to where the river is affected by backwater from Amistad Reservoir at the confluence of the Rio Grande and Pecos River was investigated by Garrett (2002); the Big Bend reach is part of this larger reach of the Rio Grande. Of the 46 species of fish known to occur historically in the Rio Grande and its tributaries from Big Bend National Park to the former confluence of the Rio Grande and Pecos River, 39 are native and 7 are nonnative. Of the 39 native species, 3 are extinct, and 5 have been extirpated (locally extinct) from the Rio Grande and its tributaries in the study area (Garrett, 2002). Of the remaining native species, the blue sucker (*Cycleptus elongatus*), Chihuahua shiner (*Notropis chihuahua*), and Mexican stoneroller (*Campostoma ornatum*) are listed by the State of Texas as threatened (Texas Parks and Wildlife Department, 2012). The Rio Grande shiner and headwater catfish (*Ictalurus lupus*) are considered species of concern, and the Big Bend gambusia (*Gambusia gaigei*) and Rio Grande silvery minnow are listed by the USFWS as federally endangered species (U.S. Fish and Wildlife Service, 2013a).

The Big Bend reach of the Rio Grande is a fluvial system dominated by long-term channel incision punctuated by episodes of channel aggradation likely driven by fluctuations in climate since the river formed in the late Pliocene to early Pleistocene (Dethier, 2001; Connell and others, 2005). In the early 20th century, the river through much of the Big Bend reach was a wide and meandering channel prone to avulsion (cyclic rapid formation and abandonment of river channels) (Mueller, 1975; Dean and Schmidt, 2011). During the past 100 years, the large-scale development of water resources of the Rio Grande in the United States, and of the Rio Conchos in Mexico, has created a much narrower and aggraded river channel through the Big Bend reach of the Rio Grande compared to the predevelopment geomorphology of the river (Dean and Schmidt, 2011). These geomorphic changes in the Rio Grande have been exacerbated by increases in nonnative riparian vegetation including salt cedar (*Tamarix* spp.) and giant river cane (*Arundo donax*) that acts as a positive feedback mechanism for channel narrowing and vertical accretion of sediment (Dean and Schmidt, 2011).

Inflows from the Rio Conchos in Mexico accounted for 66 percent of streamflow in the Big Bend reach in the early 20th century (Schmidt and others, 2003). Inflows from the upper parts of the Rio Grande Basin resulting from snowmelt runoff in the Rio Grande would historically dominate the flows in the Big Bend reach during late spring and early summer and cause seasonal flooding. Dams and diversions in the upper Rio Grande Basin in New Mexico completed in the 20th century have eliminated the seasonal flooding caused by snowmelt runoff that was an annual part of the natural flow regime. Since the impoundments were completed, little or no streamflow passes Fort Quitman, Tex., upstream from the confluence of the Rio Conchos and Rio Grande near Presidio, Tex. (Schmidt and others, 2003). Today, peak streamflows in the Rio Grande near Presidio are about one-half of what they were prior to 1915. For example, the maximum daily mean streamflow with a 2-year recurrence interval was 7,663 ft^3/s prior to 1915, but it was 4,450 ft^3/s (International Boundary and Water Commission, 2013) after the completion of Elephant Butte Reservoir (fig. 1) in 1916 in New Mexico (U.S. Bureau of Reclamation, 2013). The frequency of overbank streamflows of 10,000 ft^3/s or more that would routinely flood riparian parts of the channel in the Big Bend reach has decreased with the completion of major impoundments in the 1940s and appear to have further decreased since about 1990 (fig. 2). Compared to overbank flooding flow, the frequency of smaller flooding flows and within-bank high pulses (less than 5,000 ft^3/s) has decreased even more during the last 20 years.

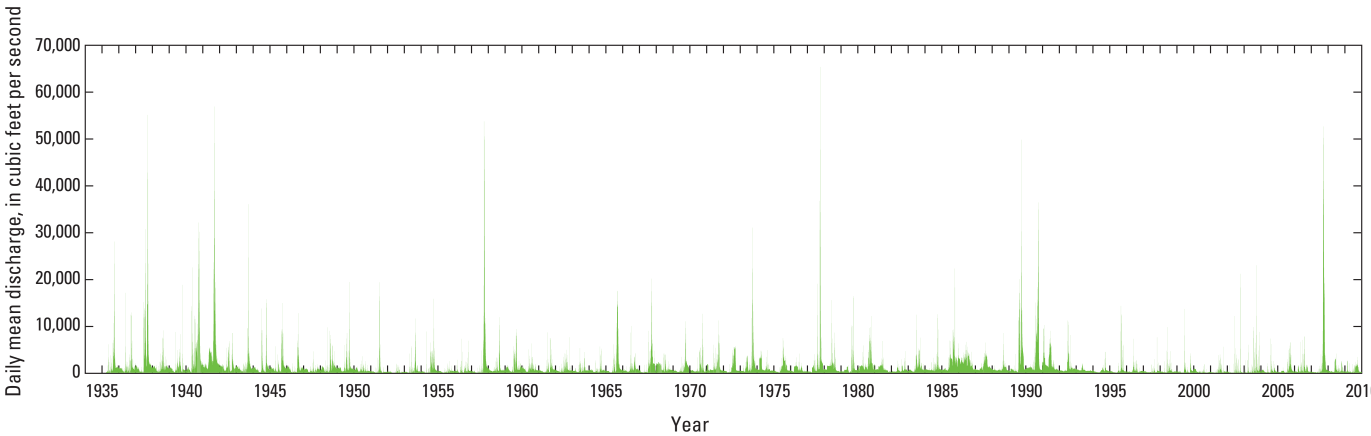


Figure 2. Measured daily mean streamflow at International Boundary and Water Commission (IBWC) streamflow-gaging station 08375000 Rio Grande at Johnson Ranch near Castolon, Texas, and Santa Elena, Chihuahua, Mexico, April 1, 1936–December 31, 2010 (data obtained from International Boundary and Water Commission, 2013).

Methods of Investigation

All of the data were collected from four study sites on the Rio Grande colocated with the sites where the USFWS has released Rio Grande silvery minnow under the recovery plan for this species. The farthest upstream site (USGS station 08374340 Rio Grande at Contrabando Canyon near Lajitas, Tex. [hereinafter the Contrabando site]), is approximately 9 river km west of Lajitas, Tex., in Big Bend Ranch State Park (fig. 1). This site is immediately downstream from the confluence of the Rio Grande with Contrabando Creek (fig. 3). The second site (USGS station 290956103363600 Rio Grande at Santa Elena Canyon, Big Bend National Park, Tex. [hereinafter the Santa Elena site]), is approximately 40 river km downstream from the Contrabando site (fig. 1). The Santa Elena site is just downstream from the mouth of Santa Elena Canyon and the confluence of the Rio Grande with Terlingua Creek (fig. 4). The third study site (USGS station 291046102573900 Rio Grande near Ranger Station at Rio Grande Village, Tex. [hereinafter the Rio Grande Village site]) is approximately 120 river km downstream from the Santa Elena site (fig. 1). The Rio Grande Village site is in Big Bend National Park adjacent to a campground by the same name (fig. 5). The farthest downstream study site (USGS station 292354102491100 Rio Grande above Stillwell Crossing near Big Bend National Park, Tex. [hereinafter the Stillwell Crossing site]) is approximately 70 river km downstream from the Rio Grande Village site (figs. 1 and 6).

Mesohabitat Assessment

A hand-held laser rangefinder that reported distances in metric units was used for locating the downstream extent of sampling reaches established at each of the four study sites, for measuring mesohabitat widths in excess of 5 meters (m), and for locating habitat measurement locations within large (greater than 25 m long) mesohabitats. Metric measuring tapes were used to determine the extents of mesohabitats less than 25 m long. Distances between study sites were determined from maps. Stream depths were measured in feet by using a hand-held wading rod or an acoustic Doppler current profiler (ADCP). All measurements are reported in the units in which they were measured.

The wetted area, physical characteristics, and fish assemblage of mesohabitats were assessed within reaches approximately 1 km in length at each of the four study sites (table 1). The upstream extent of the reach at each site approximated the location of each USFWS Rio Grande silvery minnow release sites. Each of the four study sites was assessed over a range of streamflows (table 1; fig. 7). Mesohabitat assessments were completed at each site by using a subset of mapped mesohabitats over a range of within-bank streamflows in spring and summer 2010–11 to evaluate the seasonal variability in mesohabitat wetted area, habitat use, and distribution of fishes.

Mesohabitats were mapped and characterized during high, intermediate, and low flows as defined for this study (table 1).) Figures 3–6 provide visual examples of conditions at each site during the different streamflow regimes during which data were collected. The mesohabitat types that were mapped included rapid, riffle, run, pool (including channel, eddy, and isolated pools), forewater, backwater, embayment, and submerged channel bar (fig. 8). Point bars and channel bars that were not submerged (exposed) (fig. 8*A*) were also mapped to provide a more complete map of the active channel at each study site, although the physical characteristics of these channel features were not used in data analysis. The mapping of exposed point bars and channel bars also were useful channel features for the identification of the mesohabitats. Data from the three types of pools—channel, eddy, and isolated—were combined into a “pools” category for analysis to have an adequate sample size of “pools” and because combining the three pool types into a single “pool” category was thought to be more appropriate for the analysis of fish data. Stream velocities and depths in pools ranged from -0.68 to 1.95 feet per second (ft/s) and 0.03 to 14.5 feet (ft), respectively. Backwaters, forewaters, and embayments were slow-moving mesohabitats mapped during this study. Stream velocities in backwater, forewater, and embayment mesohabitats ranged from -0.60 to 0.54 ft/s, whereas depths ranged from 0.05 to 2.90 ft. The mesohabitat types used in this study are further described in table 2.

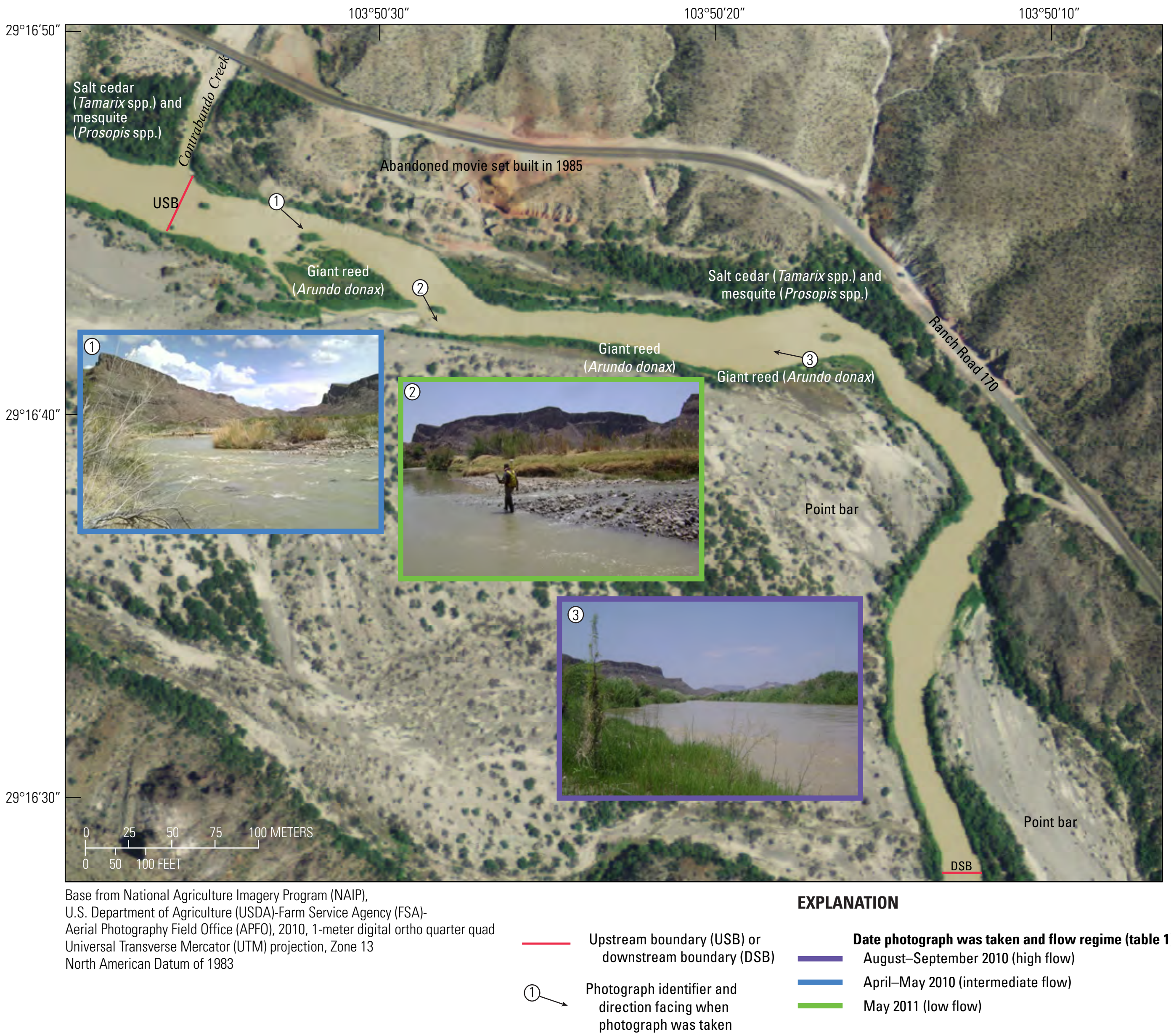


Figure 3. Reach of the Rio Grande/Rio Bravo del Norte (Rio Grande) at U.S. Geological Survey station 08374340 Rio Grande at Contrabando Canyon near Lajitas, Texas (Contrabando site).

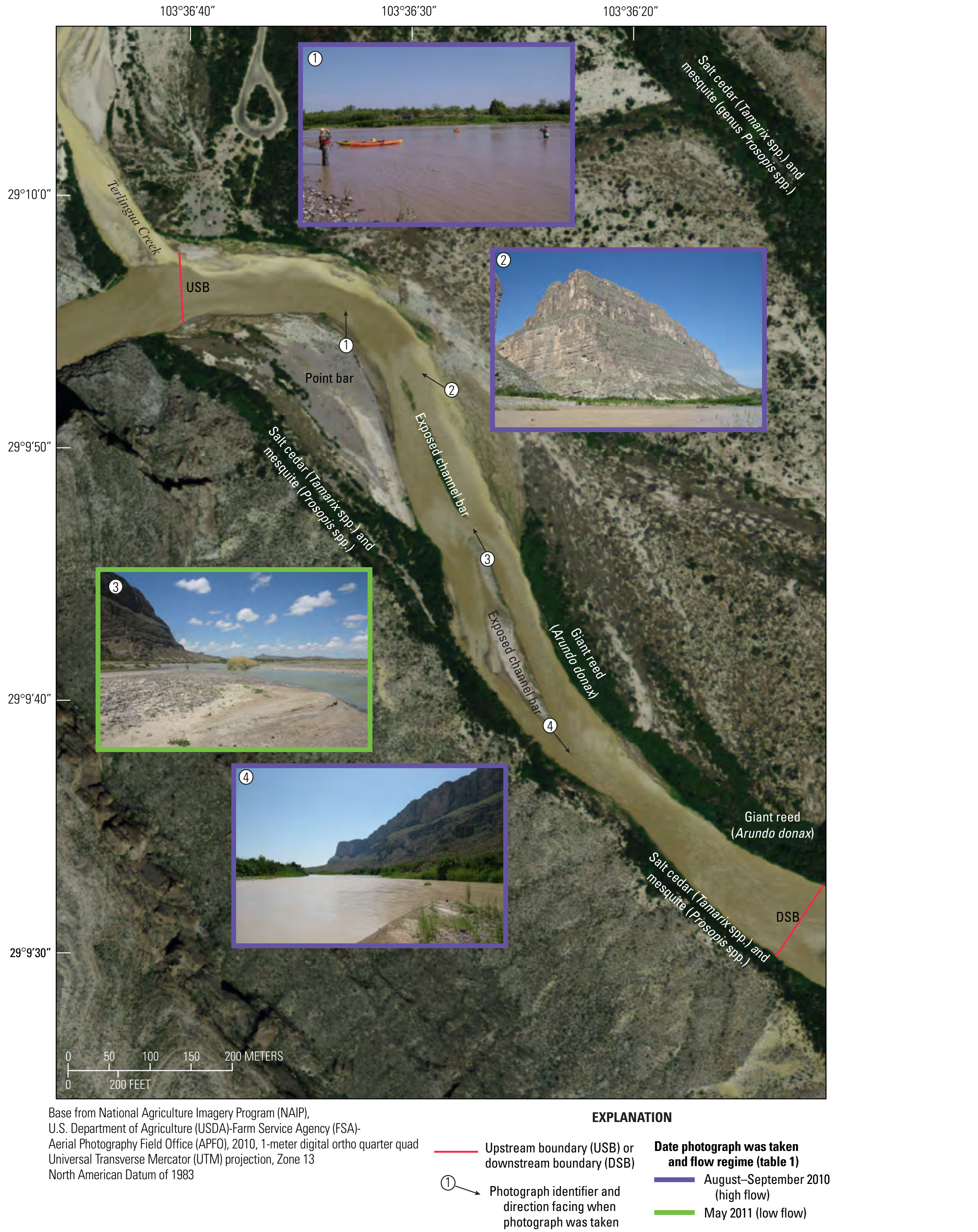


Figure 4. Reach of the Rio Grande/Rio Bravo del Norte (Rio Grande) at U.S. Geological Survey station 290956103363600 Rio Grande at Santa Elena Canyon, Big Bend National Park, Texas (Santa Elena site).

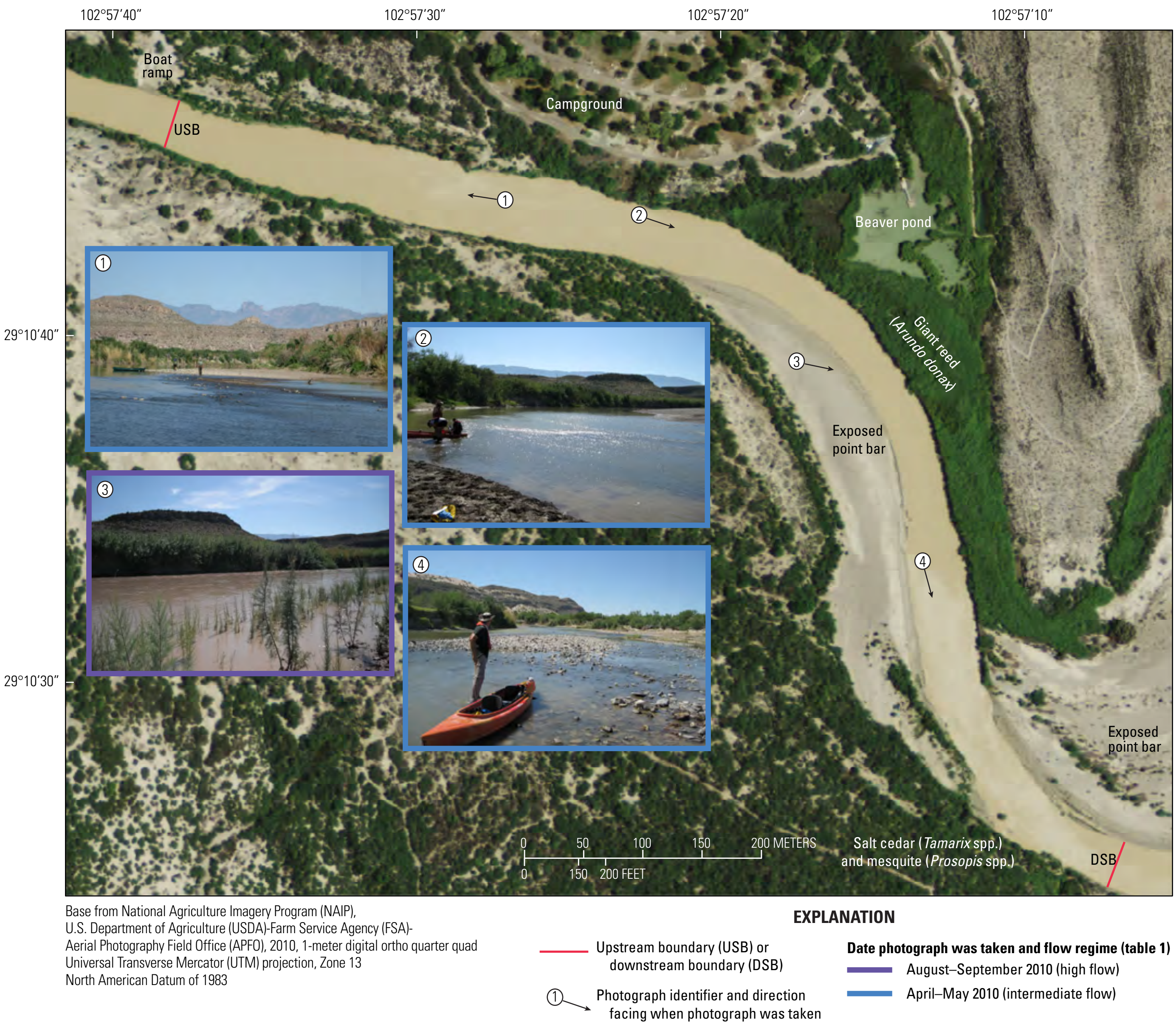


Figure 5. Reach of the Rio Grande/Rio Bravo del Norte (Rio Grande) at U.S. Geological Survey station 291046102573900 Rio Grande near Ranger Station at Rio Grande Village, Texas (Rio Grande Village site).

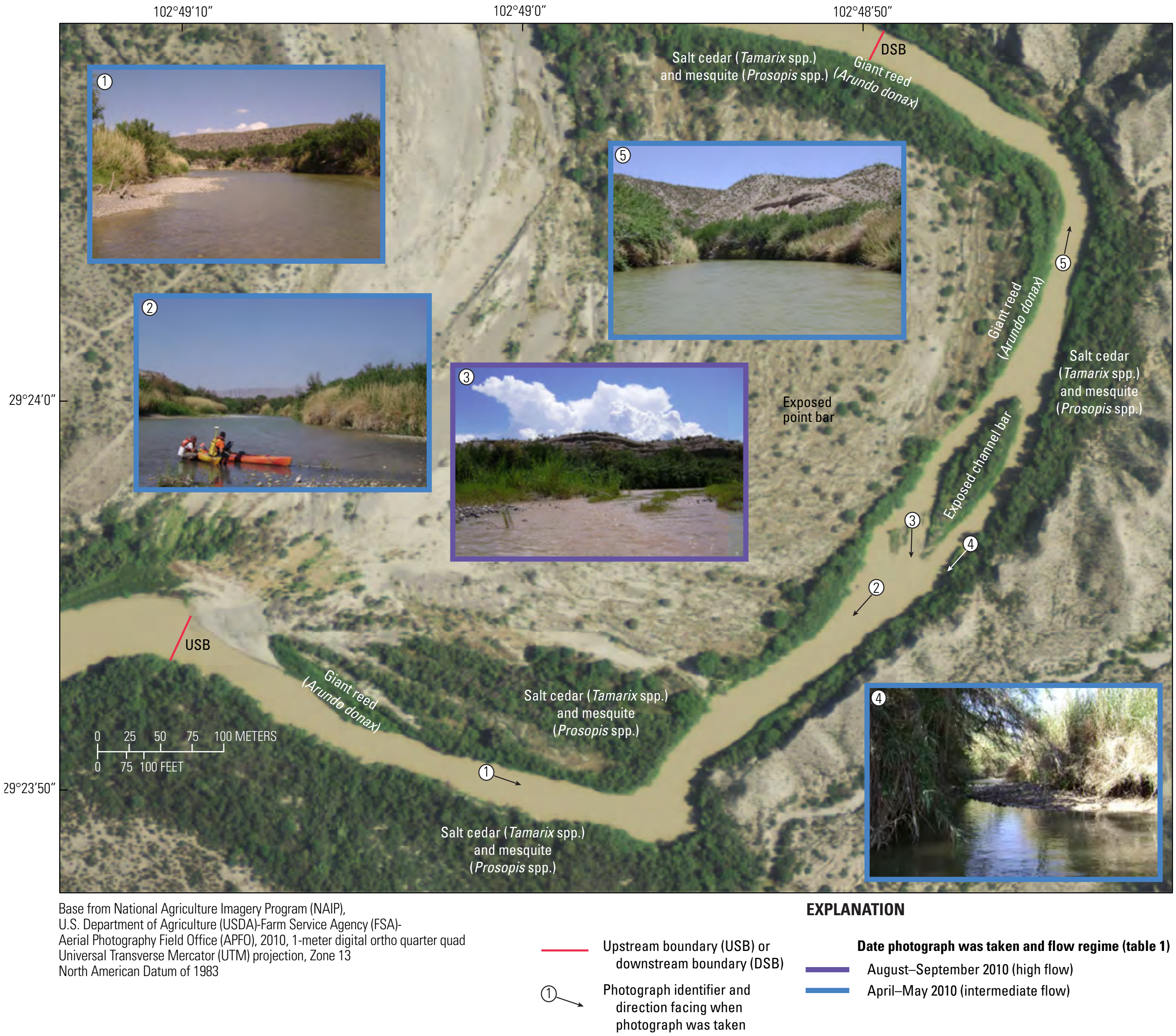


Figure 6. Reach of the Rio Grande/Rio Bravo del Norte (Rio Grande) at U.S. Geological Survey station 292354102491100 Rio Grande above Stillwell Crossing near Big Bend National Park, Texas (Stillwell Crossing site).

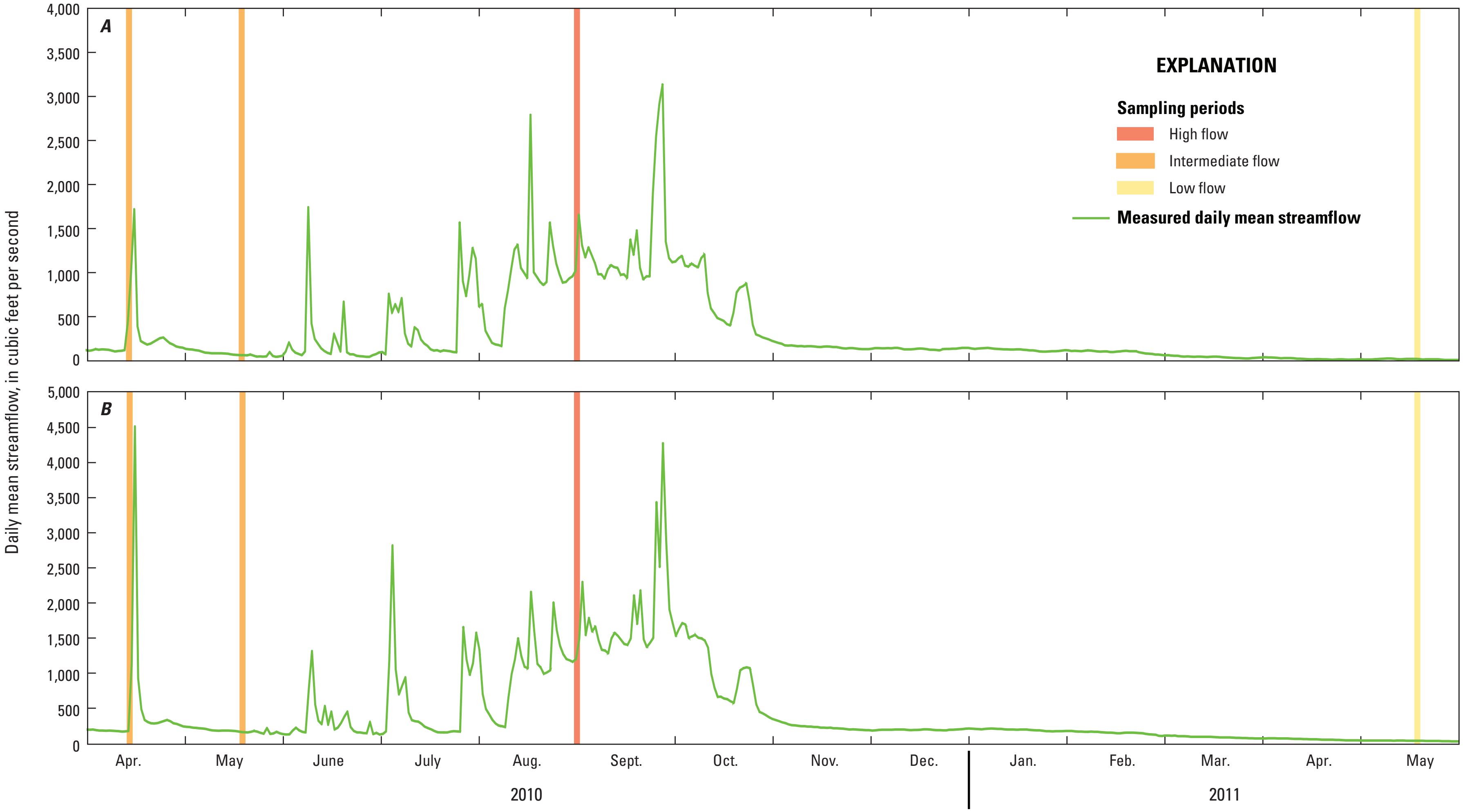


Figure 7. Measured daily mean streamflow at U.S. Geological Survey (USGS) streamflow-gaging stations, April 1, 2010–May 31, 2011. *A*, 08374550 Rio Grande near Castolon, Tex. *B*, 08375300 Rio Grande at Rio Grande Village, Big Bend National Park, Tex.

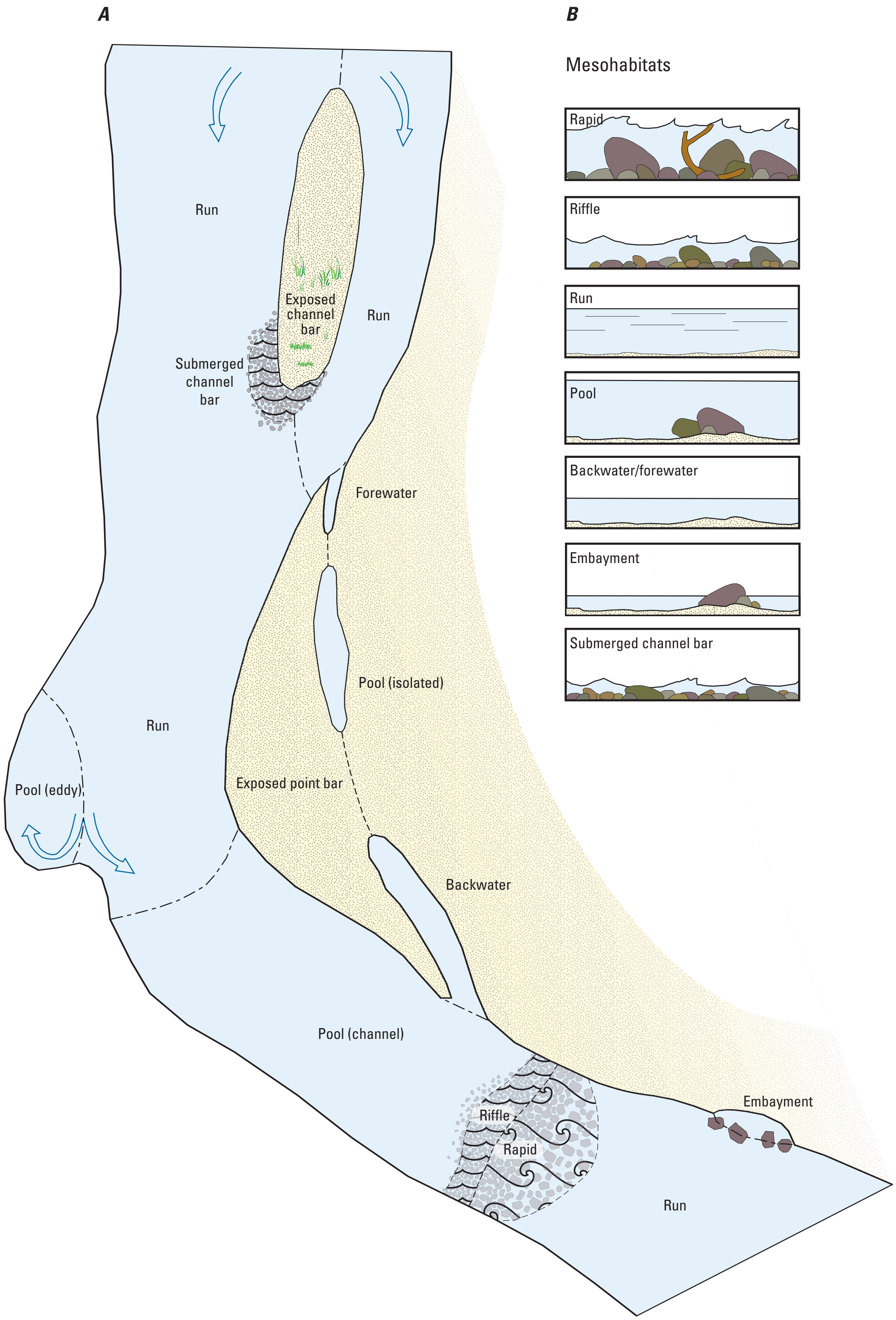


Figure 8. Mesohabitat types and channel features identified in the Rio Grande/Rio Bravo del Norte (Rio Grande) in Big Bend National Park (modified from Platania, 1993). *A*, Overview of example study reach. *B*, Planar view of mesohabitat types.

Table 2. Descriptions of mesohabitat types (modified from Platania, 1993) and channel features that were mapped on the Rio Grande/Rio Bravo del Norte (Rio Grande), Texas, 2010–11.

[ft/s, feet per second; ft, feet; NA, not applicable]

Mesohabitat type	Description	Velocity minimum to maximum (ft/s)	Depth minimum to maximum (ft)
Rapid	Relatively deep and high velocity feature characterized by very turbulent water.	-0.15–5.62	0.35–3.90
Riffle	Relatively shallow and low to moderate velocity feature characterized by moderately turbulent water.	0.01–6.42	0.01–4.20
Run	Relatively high velocity feature with laminar flow and a nonturbulent surface.	-0.30–4.22	0.10–11.5
Pool	Relatively low velocity feature that may be deep in places.	-0.68–1.95	0.03–14.5
a.) Channel pool	Type of pool that extends across the entire width of the main channel.		
b.) Eddy pool	Type of pool where current moves in the opposite direction relative to flow in the main channel.		
c.) Isolated pool	Type of pool that is separate from the main channel; frequently a portion of a former backwater or forewater that has become disconnected from the secondary channel.		
Forewater	Relatively shallow, low velocity feature connected to the main channel, oriented into the principal direction of flow.	-0.09–0.27	0.18–1.10
Backwater	Relatively shallow, low velocity feature connected to the main channel, oriented in an opposing direction to the principal flow direction.	-0.39–0.54	0.05–2.90
Embayment	Relatively shallow, low velocity feature located adjacent to the channel and oriented perpendicular to flow.	-0.60–0.50	0.50–1.60
Submerged channel bar	Very shallow feature typically located on the periphery of an existing exposed point or channel bar; caused by a slight rise in stage.	NA	NA
Channel feature	**Description**		
Exposed point bar	Crescent-shaped depositional feature located on the inside of a stream bend; typically either devoid of or containing annual vegetation.	NA	NA
Exposed channel bar	Transitory parcel of land surrounded by water; typically either devoid of or containing annual vegetation.	NA	NA

Mapping of Mesohabitats

Digital mapping techniques were used for all spatial measurements collected during this project. A combination of different hardware, software, and field methods were employed to accomplish the project mapping goals and overcome the challenges of working in a remote riverine environment. To characterize the sites, mapping included the use of a geographic information system (GIS) and a Global Positioning System (GPS) unit. GPS data were obtained by using a Trimble DSM 232 modular receiving unit. A corrected signal from Omnistar (subscription service) was received through the Trimble GPS unit to gain the acceptable level of accuracy (less than or equal to 1 ft, real time) necessary for mapping. At the site, the field GPS data were input directly into the Environmental Systems Research Institute, Inc. (Esri), ArcGIS 9.3 software package loaded on a laptop computer. Geospatial measurements were used to document the different mesohabitat types. A hierarchical classification system was used for describing habitat characteristics at the mesohabitat scale (Bovee and others, 1998). Mesohabitat features were identified by similarities in channel slope, shape, and structure.

Field mapping was accomplished by a using a variety of approaches based on streamflow, river depth, and riverbank accessibility. Each site was visited three times corresponding to the three flow regimes (table 1). For the majority of the field mapping, project personnel began by wading near the water's edge throughout the entire site to collect GPS data along the entire extent of the reach at each site (fig. 9). This process required tethering two project personnel together by using cables connecting the GPS receiver held by one person and a laptop computer held by the other. Near the end of the project, wireless Bluetooth technology was implemented, making it possible to use a wireless connection between the GPS and laptop equipment. Once the water's edge was identified, the reach was subdivided into smaller polygons, each representing an individual mesohabitat. Large continuous runs, that were often half or more of the 1 km reach in length, were subdivided and mapped as separate runs by using the upstream and downstream boundaries of channel features like point bars and channel bars to set the mapped upstream and downstream boundaries of these mesohabitats. Polygons created through this process were stored and attributed in an ArcGIS 9.3 personal geospatial database (Microsoft Access compatible) in conjunction with high-resolution remotely sensed imagery, creating a detailed map of the reach at each site for each of the three targeted flow regimes. All of the data that were collected were entered into the geospatial database, including data for overbank land cover features observed during a flood event in 2008 that exceeded the upper limit of the high-flow regime; data from the 2008 flood event were not discussed or analyzed for this report.

Streamflow remained within the banks during the period of high flow in August–September 2010, but the ability of project personnel to access the water's edge by wading was greatly diminished, so mapping was done from boats instead. Kayaks and inflatable rafts were used during the high-flow regime to access the upstream and downstream extents of mesohabitats within the channel and to collect data along the water's edge. The accuracy and precision of mesohabitat mapping during the high-flow regime were likely less compared to the accuracy and precision of mesohabitat mapping during the intermediate and low-flow regimes because of inherent difficulties with access and safety concerns during the high flow compounded by the challenges of mapping from a moving boat compared to mapping while traversing the water's edge on foot.

Physical Characteristics and Water-Quality Properties of Mesohabitats

Physical characteristic data (width, depth, velocity, substrate type and size, and percent embeddedness) were collected at each of the four study sites at specified locations along transects in each mesohabitat sampled. The physical characteristics measured are environmental variables that will vary among the mesohabitat types in relation to streamflow, and these hydrologic patterns vary over short distances and can influence the fish assemblage structure over the same distance (Biggs and others, 1990; Poff and Allan, 1993). Physical characteristics were not measured in all of the mapped mesohabitat units because of time constraints, so a subset of the mapped mesohabitats in proportion to the relative abundance of each mesohabitat type was randomly selected for the collection of physical characteristic data. Whenever possible, at least three of the different types of mesohabitat were selected for collection of physical characteristic data at each site. If fewer than three of a particular type of mesohabitat were present within the study site, then all available mesohabitats of that type were typically selected for habitat analysis.

Mesohabitats selected for collection of physical characteristic data were distributed throughout the entire reach at each sampling site where possible. Once a particular mesohabitat had been selected, representative points for physical characteristic measurements were selected by establishing 5 evenly spaced transects oriented perpendicularly to the direction of streamflow across each mesohabitat (or 3 evenly spaced transects for mesohabitats less than 10 m long parallel to flow direction) and randomly selecting a starting measurement location (left center, center, or right center) at the first transect (fig. 10*A*). Physical characteristics were measured at 1 of 3 different locations (left center, center, or right center) along each transect. The measurement location along the first transect measured within a mesohabitat was randomly selected; subsequent measurements were made at each transect following a progression from left to right. For example, if the first transect measurement was randomly selected at (1) the center location, then the measurements at subsequent transects were collected at (2) right center, (3) left center, (4) center, and (5) right center.

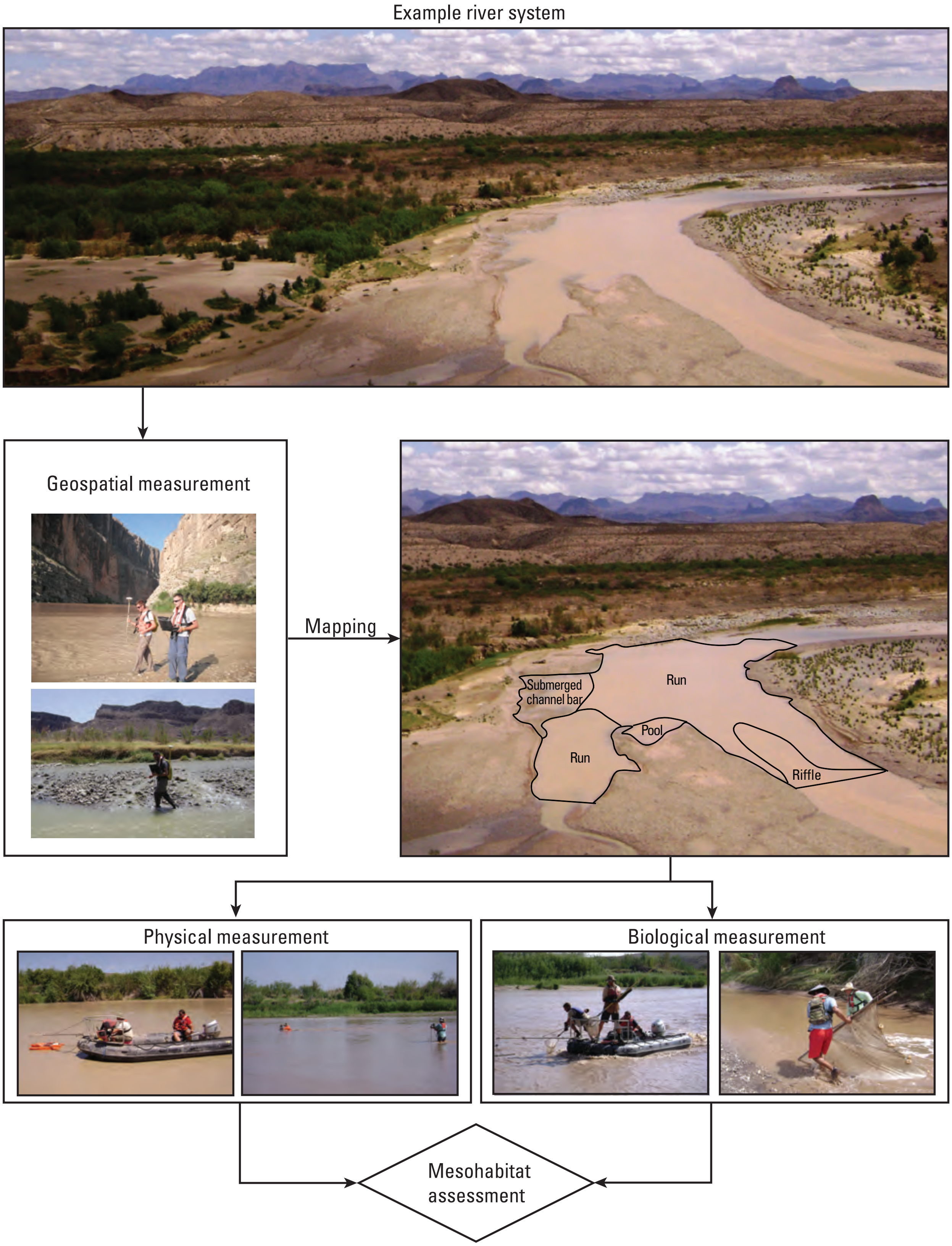


Figure 9. Overview of the approach used to assess mesohabitats (modified from Parasiewicz and Dunbar, 2001).

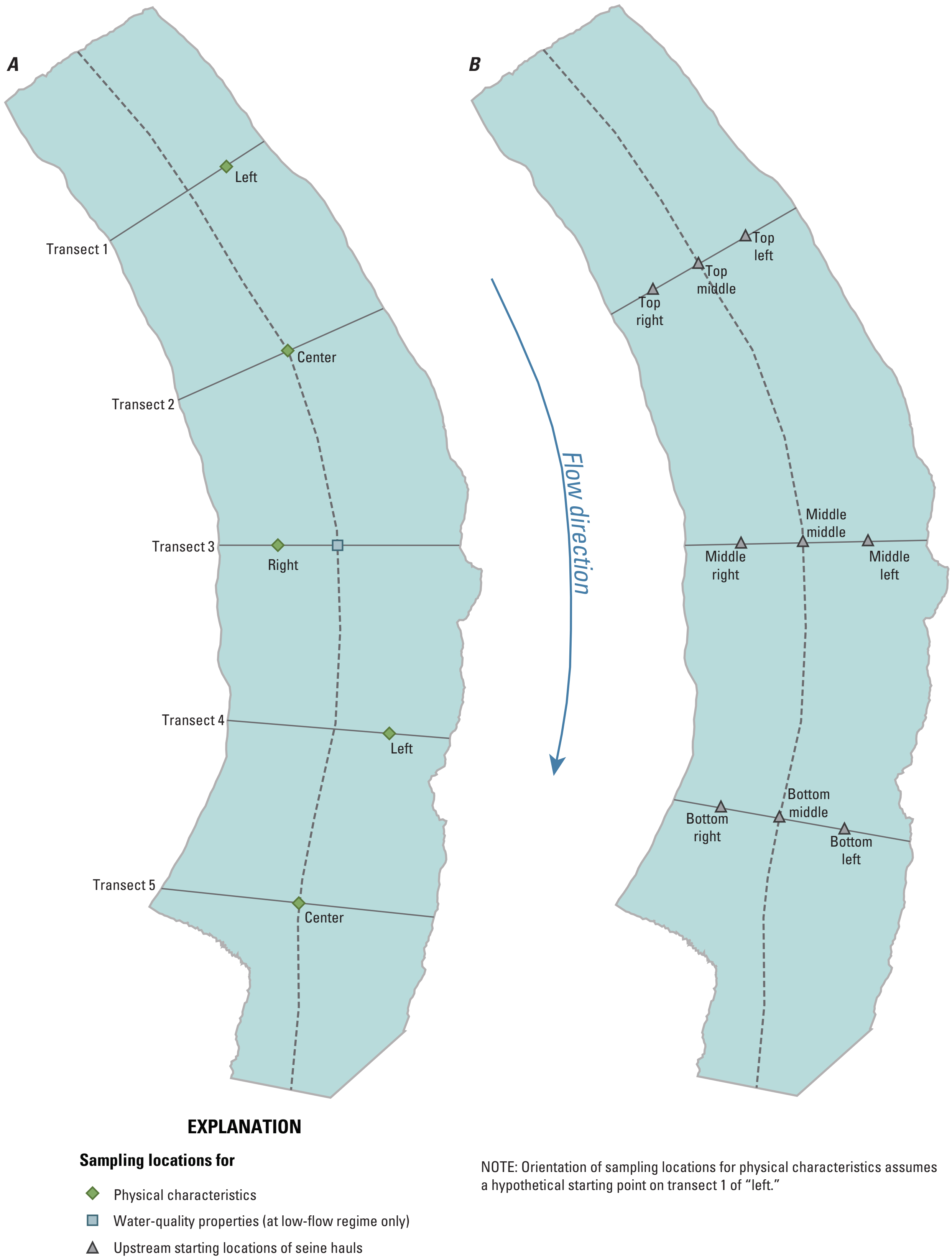


Figure 10. Sampling patterns in mesohabitats. *A*, Sampling pattern for collection of physical characteristics and water-quality properties. *B*, Sampling patterns for seine hauls.

Velocity and depth measurements were made by wading the stream with a Flowtracker hand-held acoustic Doppler velocimeter attached to a wading rod (SonTek, 2013) (hereinafter referred to as a “Flowtracker”) or by using an ADCP operated from a boat (Mueller and Wagner, 2009). Standard USGS protocols for measuring velocity were followed (Rantz and others, 1982; Turnipseed and Sauer, 2010). During most periods of low or intermediate flow, depths and velocities could be readily measured with the Flowtracker by wading the stream. In some instances during intermediate and high flows, depths and velocities could not be measured by safely wading at the predetermined measurement location because either the water was too deep or the velocity was too great, and measurements were instead made at a wadeable stream transect within 10 ft of the predetermined location. During high flow at the Rio Grande Village and Stillwell Crossing sites, an ADCP mounted on a boat was used to collect depth and velocity data, as well as streamflow data, along a series of transects. The Flowtracker was used exclusively to measure velocity and depth at the Contrabando and Santa Elena sites because the reaches at these sites were accessible by wading during all flow regimes. All of the velocity and depth data were processed by using WinRiver II software (Teledyne RD Instruments, 2007) and were output as data points with a two-dimensional XY planar position and a mean velocity magnitude and direction.

For most high-flow measurements, two passes were made along each transect line selected for the measurement of velocity data, with the second pass used to ensure the quality of the first pass and to account for any directional bias associated with the movement of the ADCP across the channel during data collection. A velocity profile was generated for each of the two passes. Directional bias was assumed to be negligible on the basis of a review of the velocity profile pair data. Velocity data were extracted from one of the two profiles rather than determining the mean from the velocity data from both passes. By using velocities extracted from one profile, the introduction of any errors associated with extracting location-specific data from each profile was avoided. Velocity measurements were extracted from whichever profile had fewer data gaps and less noise. If the two profiles collected along a single transect looked comparable with regards to data gaps and noise, then velocity measurements were extracted from the first profile collected. In a few cases, only one profile was collected along a transect line; in these cases, velocity measurements were extracted from that profile.

Velocity and depth data were obtained from five equally spaced locations along each of the profiles analyzed. Standard quality assurance procedures for collecting velocity profile data by using ADCPs were followed, including instrument calibration procedures (Oberg and others, 2005). In some cases, there were gaps in the velocity data that precluded the extraction of velocity data at all five locations. If only one complete set of velocity measurements existed within a column of velocity data at any of the locations selected for velocity data extraction, the velocity from that set of measurements was assigned to that location in the study reach. If, however, there were two or more complete sets of velocity measurements within an ensemble column of velocity data, a mean of the velocities measured in the uppermost and lowermost set of measurements was assigned to that location in the reach.

Physical characteristics measured in the river margins were measured at only the center transect of each mesohabitat that was selected for data collection. In this study, the river margin was defined as the relatively shallow area adjacent to the water’s edge characterized by relatively lower velocities compared to the more central parts of the channel. These shallow, relatively low velocity river-margin areas are often associated with large algal productivity (Bixby and Burdett, 2009), and Rio Grande silvery minnow and similar species are often associated with these productive areas of a stream (Dudley and Platania, 1997). River-margin measurements were made on both sides of the channel but were not made at locations where the edge of the mesohabitat at the measuring point was not adjacent to the bank. For example, river-margin data were not collected if the edge of the mesohabitat bordered another mesohabitat or a channel bar. River-margin width was defined by the first noticeable change in bed slope starting from the bank toward the center of the stream or when a depth of 1 ft was reached, whichever was first. If the bank was vertical, then a default margin width of 1 ft was assigned. Few river-margin data were collected during high flow because velocities or depths were generally too large to allow access to river-margin habitats. The following river-margin specific data were collected from the margins at each site: margin width, margin depth (collected at midpoint of margin), velocity (collected at midpoint of margin), substrate type and size, percent embeddedness, percent periphyton cover (collected within a 0.25 square meter [m^2] quadrat with the margin midpoint as the center of the quadrat), canopy cover (based on densitometer readings), and bank angle (adjacent to margin). Percent periphyton (algae or aquatic plants attached to a submerged surface) cover was measured in the river margins because Rio Grande silvery minnow are algal feeders (U.S. Fish and Wildlife Service, 2008). River-margin data are included in the geospatial database because of interest in the data on the part of USFWS and others, but these data were not analyzed for this report.

Selected water-quality properties were measured by using a YSI 600XL multiparameter sonde (Xylem Analytics, 2013). The sonde was calibrated in the field each day prior to the collection of field measurements. The following water-quality properties were measured: dissolved oxygen, in milligrams per liter; pH; specific conductance, in microsiemens per centimeter at 25 degrees Celsius; and temperature, in degrees Celsius. Dissolved oxygen, pH, specific conductance, and water temperature were measured at the center of each mesohabitat where habitat data were collected during the low-flow regime in May 2011. The sonde was placed approximately 1 ft below the water surface or mid-depth at the center of a mesohabitat, depth permitting.

Water-quality properties were measured during only low flow because it was hypothesized that any extreme values in water-quality properties that could be limiting to fishes were most likely to occur during this flow regime and because of expressed interest in these field data from scientists with the USFWS Southwestern Native Aquatic Resources and Recovery Center in New Mexico, where Rio Grande silvery minnow are held under controlled water-quality conditions and propagated for reintroduction efforts like the one ongoing in the Big Bend reach (U.S. Fish and Wildlife Service, 2013b).

Fish Assemblages in Mesohabitats

Surveys of fish assemblages in mesohabitats were done at each of the four sites during all three flow regimes. Mesohabitats (minimum of 20 per site) were sampled for fish in proportion to their relative abundance in each reach, and if three or fewer of a given mesohabitat type occurred in the study reach, all mesohabitats of that type were sampled. Sampling the mesohabitats for fish was primarily done by using seines. A seine is a net suspended vertically in the water by floats at the top and weights at the bottom. Catching fish with seines is referred to as “seining,” and a single sampling effort or “drag” of a seine in this study is referred to as a seine haul. One or more seine hauls were completed in each mesohabitat. A flat-panel seine 3.0 m in length and 1.5 m in height with a mesh size of 0.006 m was used for each seine haul. The sampling approach used was deliberately biased towards collecting fish from the large number of shallow, low-velocity mesohabitats sampled, which are preferred by the Rio Grande silvery minnow and similar fish, and 0.006-m mesh seines were used to increase the likelihood of collecting Rio Grande silvery minnow and other minnow species. Each seine-haul location was randomly selected from nine available sampling points in each mesohabitat corresponding to a middle, left of middle, and right of middle point along each of three transects (fig. 10*B*). Left bank and right bank were designated facing downstream. Transects in each mesohabitat were distributed at intervals equal to one-quarter, one-half, and three-quarters the length of each mesohabitat to ensure that all seine-haul locations were within the mesohabitat being sampled. Seining was done in a downstream direction in each mesohabitat with the exception of riffles, where a kick-seining technique was used. Kick-seining involved holding the seine in a fixed position at the downstream end of the seine-haul location while 1 or 2 field-crew members disturbed the substrate with their feet while moving downstream towards the seine, and the seine was lifted from the water when the field-crew members reached the seine. Data obtained from kick-seine samples were not distinguished from seine hauls for the purpose of data analysis. At least 1 seine haul was made in each mesohabitat, and 2–4 seine hauls were made in larger (more than 50 m in length) mesohabitats.

Fish were collected exclusively with seines by wading during low-flow and intermediate streamflow regimes. Seining was supplemented by boat electrofishing during the high flow when some mesohabitats were either too deep or not accessible for wading with seines. Boat electrofishing was used to sample pools and runs that were inaccessible by wading during the high-flow regime by making 1 or 2 passes through these mesohabitats, and the number of seconds that electrical current was applied to the water was recorded to keep track of sampling effort. An inflatable raft equipped with a generator powered pulsator (GPP) electrofishing system (Smith-Root, Inc., 2012) was used for electrofishing in deep pools and runs. One person (referred to as the “netter”) was positioned in the bow or front of the raft, while another in the stern or back of the raft operated the boat’s engine and the control box of the electrofishing system. The netter collected fish that moved towards the positive (anode) array that was suspended from the bow of the boat and placed the netted fish in an onboard aerated holding tank. The length and width of each seine haul were recorded for the calculation of density of fish per seine haul and density per mesohabitat type; recording this information facilitated reporting the number of fish per unit area regardless of the number of seine hauls completed in each reach. Density was calculated by multiplying the length of each haul by the seine width to obtain a total area seined and dividing the total number of fish caught in the seine haul by the total area seined to obtain a fish density per unit area seined. Mean water column velocity, maximum depth, and substrate were recorded at the centroid of each seine haul. Substrate was determined by recording the substrate, based on particle size (Fitzpatrick and others, 1998), directly under the base of the Flowtracker wading rod at the center of the seine haul where velocity and depth measurements were taken. During sampling of low flow, water-quality data were collected from the center of each seine-haul location by using a YSI multiparameter sonde (Xylem Analytics, 2013). Dissolved oxygen (in milligrams per liter), pH, specific conductance (in microsiemens per centimeter at 25 degrees Celsius), and water temperature (in degrees Celsius) were recorded for each seine haul during low-flow sampling.

Staff with the USFWS New Mexico Fish and Wildlife Conservation Office in Albuquerque, N. Mex., did all fish assemblage surveys because they held the required Federal permit to collect and handle Rio Grande silvery minnow, and they were responsible for onsite fish identifications and counts. All fish collected in each haul were identified, counted, and released. There was little concern for collecting the same individual fish from a previous seine haul because of the distance (generally more than 10 m) between each seine haul. All fish-related data were recorded in the field on waterproof data sheets, reviewed by staff at the USGS Texas Water Science Center for completeness and accuracy, and entered into an electronic spreadsheet.

Summary statistics and statistical analyses of the fish and associated physical characteristic data collected from the mesohabitats at each site were done by using statistical software (StatSoft, 2008; XLSTAT, 2012). Statistical analyses used included a Kruskal-Wallis nonparametric analysis of variance, a Tukey-type nonparametric multiple comparison, and a canonical correspondence analysis (CCA). The Kruskal-Wallis test is a nonparametric test that can be used to determine the general equivalence of groups of data (Helsel and Hirsch, 2002) and can be used with data collected by using a randomized sampling design (Zar, 1984). A Tukey-type multiple comparison test is a nonparametric test to determine the difference between groups when the Kruskal-Wallis test is applied and the null hypothesis is rejected (Zar, 1984). For this analysis, a 99 percent confidence level was used, so Kruskal-Wallis and Tukey-type test results indicated significant differences among groups when the probability value (p-value) was less than 0.01 ($p<0.01$) (Helsel and Hirsch, 2002). The Kruskal-Wallis test was used to test for any differences in fish-species richness and fish density among the mesohabitat types, and if the test results indicated a statistically significant difference among mesohabitats for these variables (rejection of the null hypothesis), then a Tukey-type multiple comparison test was used to determine which mesohabitats were significantly different. CCA is a multivariate analysis technique developed to relate species composition to “known variations” in the environment (ter Braak, 1986). In this analysis, CCA was used to evaluate how fish-species composition was related to mesohabitat types and environmental variables (channel depth, velocity, and substrate particle size). The relations between fish-species abundance and these environmental variables are generally nonlinear, and species abundance is generally a unimodal function of one or more environmental variables (ter Braak and Verdonschot, 1995). That is, CCA was used to determine how correlated fish-species composition was to each of the mesohabitat types and to channel depth, velocity, and substrate particle size. The input for CCA analysis was a table containing the total abundance of each fish species and the means of depth, velocity, and substrate particle size by mesohabitat type combined for all three flow regimes. CCA is used by ecologists to relate the abundance of multiple species to one or more environmental variables thought to influence their abundance (ter Braak, 1986). The CCA diagram consists of four quadrants, and the x (CCA Axis 1) and y (CCA Axis 2) axes (referred to as ordination axes) are dimensionless linear combinations of the explanatory or environmental variables (Guisan and Zimmermann, 2000). CCA extracts synthetic environmental gradients from datasets, and the gradients are the basis for describing and visualizing different habitat preferences (preferences for depth, velocity, and substrate) of species in an ordination diagram (ter Braak and Verdonschot, 1995) that maximizes the niche separation among the species along the ordination axes. As an eigenvalue-ordination procedure, the first eigenvalue calculated by CCA is equal to the maximum dispersion of species scores along the first CCA axis (ter Braak, 1987), and therefore, the first CCA axis explains the majority of the variation in species and environmental variables. The eigenvalue associated with the second CCA axis is equal to the next largest dispersion of species scores, and this axis explains the next largest variation in species and environmental variables. Theoretically, there can be as many ordination axes in CCA as there are environmental variables, and each axis explains less variation and is uncorrelated to the axis or axes extracted previously (ter Braak and Verdonschot, 1995).

Geospatial Database and Mapping Application

Project data were processed and entered into a geospatial database designed to facilitate end-user data queries. For example, geographic and tabular data can be exported by using a GIS to create maps and perform spatial analyses.

A geospatial database is a spatially enabled database that contains spatial and tabular data and allows users to associate tabular data with physical and spatial components (Zeiler, 1999; Shah and Houston, 2007). A geospatial database is capable of handling data efficiently through the use of a relational database management system. By using a GIS, the spatial data can be viewed in combination with other relevant geospatial data layers, including aerial imagery, to analyze distribution patterns, data gaps, and spatial relations, and to create cartographic representations of the geospatial database contents. A geospatial database contains several database objects: feature classes, relationship classes, and attribute tables. Feature classes store geospatial data objects of similar geometry type (point, line, or polygon). A collection of feature classes is stored and managed in a feature dataset, which uses a single, defined geographic or projected coordinate system for all data stored within the database object. Relationship classes link geospatial data stored in the feature classes with related tabular information stored in attribute tables. Relationship classes allow the end-user to query data by establishing connections between geospatial data stored in the feature classes and related tabular information stored within the geospatial database attribute tables (Zeiler, 1999). The geospatial database design was based on an Esri ArcGIS 10.0 personal geospatial database platform. ArcGIS personal geospatial databases store database information as Microsoft Access (1997–2003) files.

The geospatial database contains a collection of all of the geographic and tabular data collected in the field (fig. 11). The geographic data presented in the geospatial database include the mapped mesohabitat polygons for each of the three target flows. The polygon feature classes (mesohab_highflow, mesohab_intermediateflow, mesohab_lowflow) contain information related to the areal extent of each unit, as well as descriptions of each mesohabitat class and the length of the mapped feature. The related tabular information, derived from the collection of physical characteristic data and fish sampling in the field, was parsed out into seven different related tables per flow regime (high, intermediate, and low flow). Each data table is related to a corresponding geographic feature through the use of a primary key. The primary key is a unique identifier (unique_id) utilized by the relationship class to link the geographic and tabular data (Zeiler, 1999). The unique

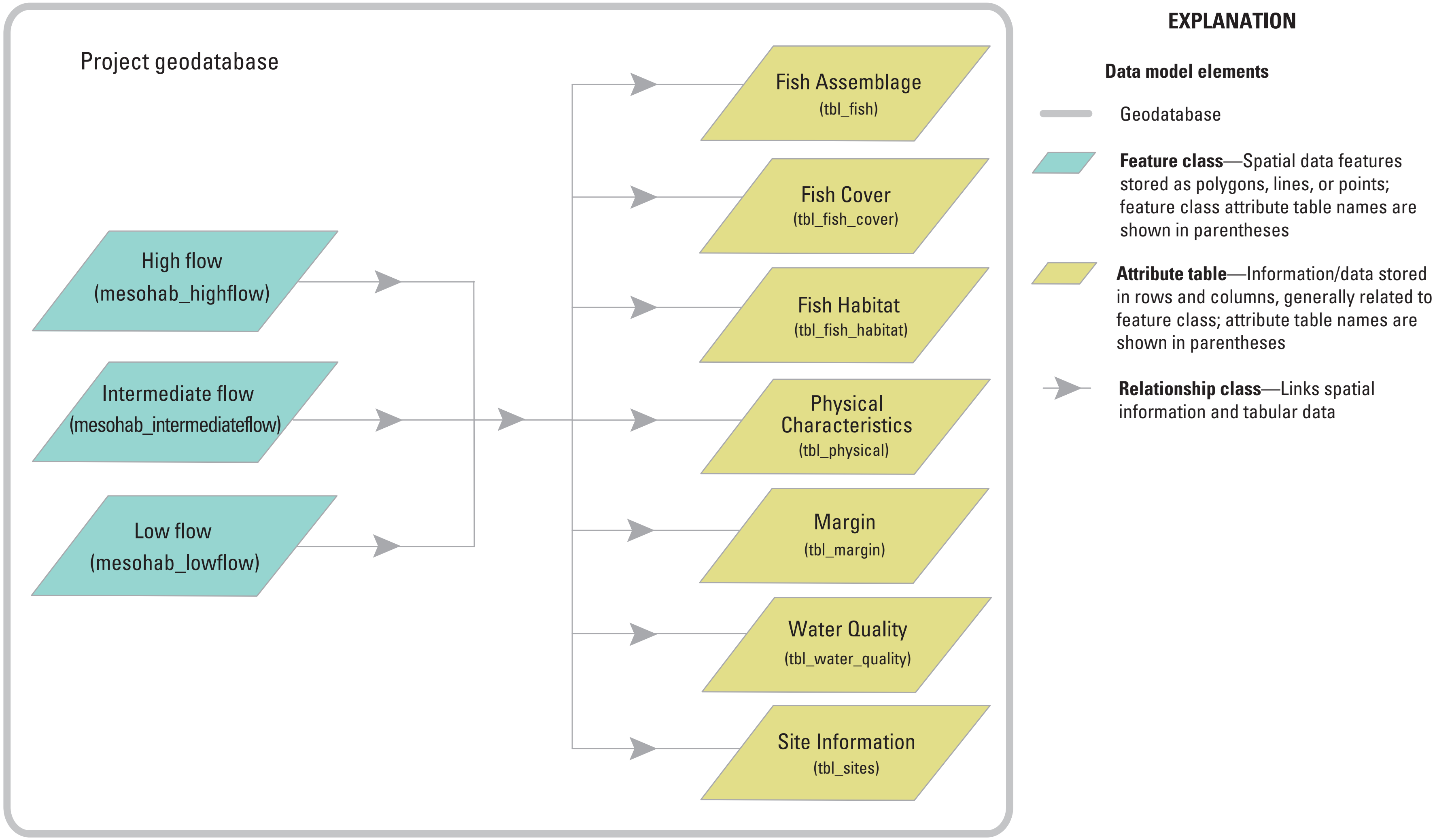


Figure 11. Simplified geospatial database data model for the spatial and tabular mesohabitat data collected from sites on the Rio Grande/Rio Bravo del Norte (Rio Grande) in Big Bend National Park, Texas, 2010–11.

identifier is generated by concatenating the site abbreviation with the sample identifier and the mesohabitat identifier, where the sample identifier refers to the flow regime and the mesohabitat identifier is a unique number that corresponds to a specific mapped mesohabitat (see app. 1 for more details).

Figure 11 provides an overview of the geospatial database model. Figure elements are shaded to highlight the distinction between data elements in the geospatial database used to store spatial information and those used to store related tabular information. Collecting GPS data, converting GPS data into polygon features, ensuring data quality, and documenting the associated metadata were the primary steps in creating the geospatial database. In addition, a geospatial database data dictionary is included in appendix 1 to explain in greater detail information relating to each field in the database such as field name, field definition, and explanation of coded values stored in the geospatial database.

Metadata

Federal Geographic Data Committee (FGDC) compliant metadata were created for each spatial data layer in the geospatial database (app. 2). Metadata are information that captures the basic characteristics of a data or information resource (Federal Geographic Data Committee, 2013). FGDC metadata include data categories such as title, abstract, publication date, and sourcing information. In addition, the metadata record describes the geographic setting for each spatial data layer, including the geographic or projected coordinate system and vertical/horizontal datum. Further, the metadata record describes the attribute label definitions and domain values for fields in the attribute table of the spatial data layer.

Mesohabitats

The total number and number of types of mesohabitats were larger during low flows compared to intermediate flows and larger during intermediate flows compared to high flows. Decreases in streamflow typically led to increases in channel complexity in terms of the number of different types and total number of mesohabitats present (fig. 12). One exception was the Rio Grande Village site, where the number of different mesohabitats was slightly larger during the May 2010 intermediate flow compared to the May 2011 low flow; at this site, 6 types of mesohabitats were mapped in May 2010 compared to 5 types mapped in May 2011. The relative contributions to wetted areal extent by different mesohabitats during three flow regimes are depicted in figure 13.

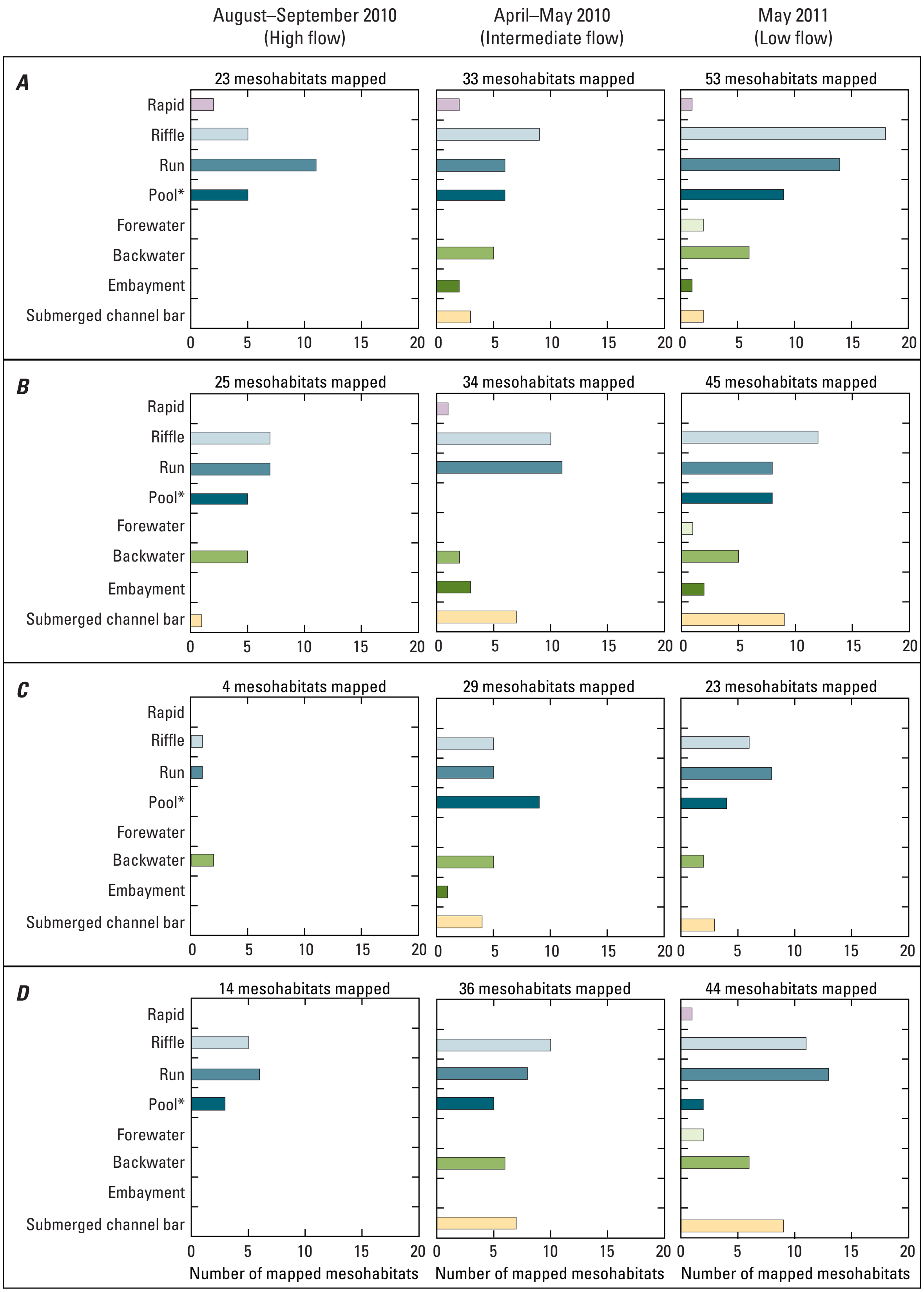
The total wetted area and number of mesohabitat types varied during the high, intermediate, and low-flow regimes described in table 1. Upstream to downstream sequences of riffle-run-pool combinations interspersed with submerged channel bars and mesohabitats with slow-moving water (pools, forewaters, backwaters, and embayments) were common at all four sites. At the Rio Grande Village site, 29 mesohabitats were mapped in May 2010 compared to 23 in May 2011 (fig. 12). The total wetted area increased and the number of mesohabitat types generally decreased as streamflow increased. This pattern of increasing wetted area and decreasing number of mesohabitat types with increasing streamflow was consistent between high, intermediate, and low flow. At two sites (Rio Grande Village and Stillwell Crossing sites), however, the wetted area of mesohabitats was larger during low flow than it was during intermediate flow (fig. 13).

The Contrabando site, which overall was the most complex of the four sites in terms of the number of different types of mesohabitats present, was dominated by runs, riffles, and rapids at high flow (fig. 14). All three of these mesohabitat types exhibited a decrease in relative contribution to the total wetted area at intermediate and low flows (fig. 13; figs. 15–16). Mesohabitats typically characterized by slow-moving water such as pools, forewaters, backwaters, and embayments were most prominent during low or intermediate flow at this site (fig. 13; figs. 15–16).

Runs and riffles were the most common mesohabitats at the Santa Elena during high flow (fig. 12). The number of mesohabitats does not correspond to the wetted area represented by the different mesohabitats; runs accounted for 58 percent and riffles accounted for 40 percent of the total wetted area (fig. 13; fig. 17). Most of the area occupied by runs at high flow (46,129 m^2) was also occupied by runs at the intermediate flow (38,754 m^2); however, because of the difference in total wetted area between the two flow regimes, the relative contribution of runs to wetted area was 78 percent at the intermediate flow (figs. 13, 17, and 18) as compared to 58 percent at high flow. Most of the area occupied by riffles at high flow either was absent at the intermediate flow or had been replaced by submerged channel bars. The transition from intermediate flow to low flow (figs. 18–19) led to a transition from a run-dominated environment to a pool-dominated environment (68 percent of wetted area; fig. 13).

The Rio Grande Village site tended to be the least complex of the four sites in terms of both the number of different types of mesohabitats present and the total number of mesohabitats mapped (figs. 20–22). Variations in flow at the Rio Grande Village site did not to have an effect on the number of mesohabitats compared to the other three sites or on the relative contribution of different mesohabitat types to wetted area. The Rio Grande Village site was dominated by runs at high flow (90 percent of wetted area), intermediate flow (76 percent of wetted area), and low flow (82 percent); riffles provided a lesser relative contribution during each flow regime (fig. 13). A much larger percentage of the wetted area was made up pools, backwaters, and submerged channel bars, at the intermediate and low flow at this site compared to the combined wetted area of these mesohabitats during high flow.

The amount of wetted area attributable to different mesohabitat types during high flow and low flow at the Stillwell Crossing site was similar (fig. 13; figs. 23–25).



* Includes channel pool, eddy pool, and isolated pool.

Figure 12. Number of mesohabitats of different types mapped during three flow regimes (high, intermediate, and low flow) at study sites on the Rio Grande/Rio Bravo del Norte (Rio Grande) during 2010–11. *A*, Contrabando. *B*, Santa Elena. *C*, Rio Grande Village. *D*, Stillwell Crossing.

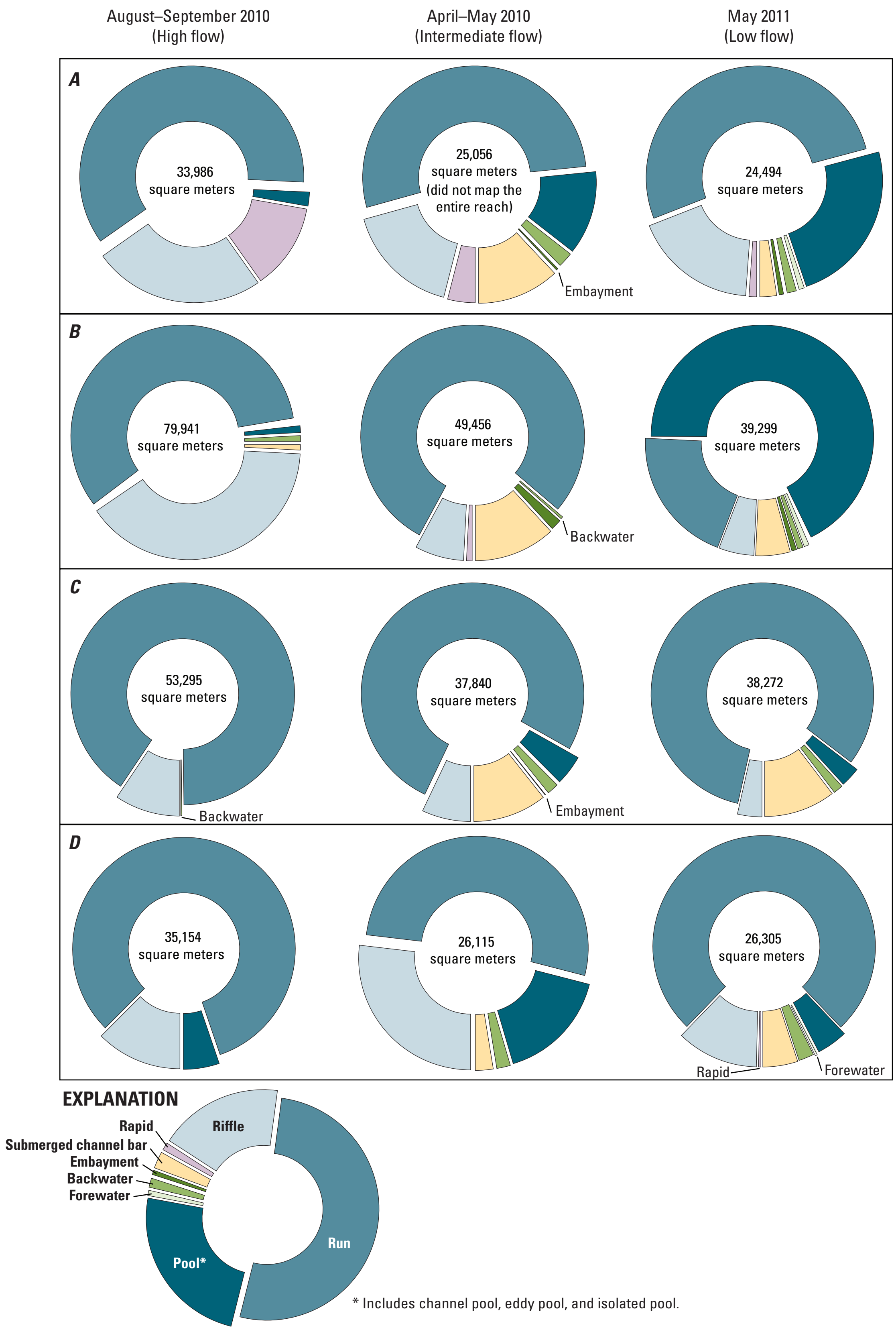


Figure 13. Relative contributions to wetted areal extent by different mesohabitats during three flow regimes (high, intermediate, and low flow) at sites on the Rio Grande/Rio Bravo del Norte (Rio Grande) during 2010–11. *A*, Contrabando. *B*, Santa Elena. *C*, Rio Grande Village. *D*, Stillwell Crossing.

Figure 14. Mapped mesohabitats and channel features associated with high flow in the Rio Grande/Rio Bravo Del Norte (Rio Grande) at the Contrabando site near Lajitas, Texas, August 2010.

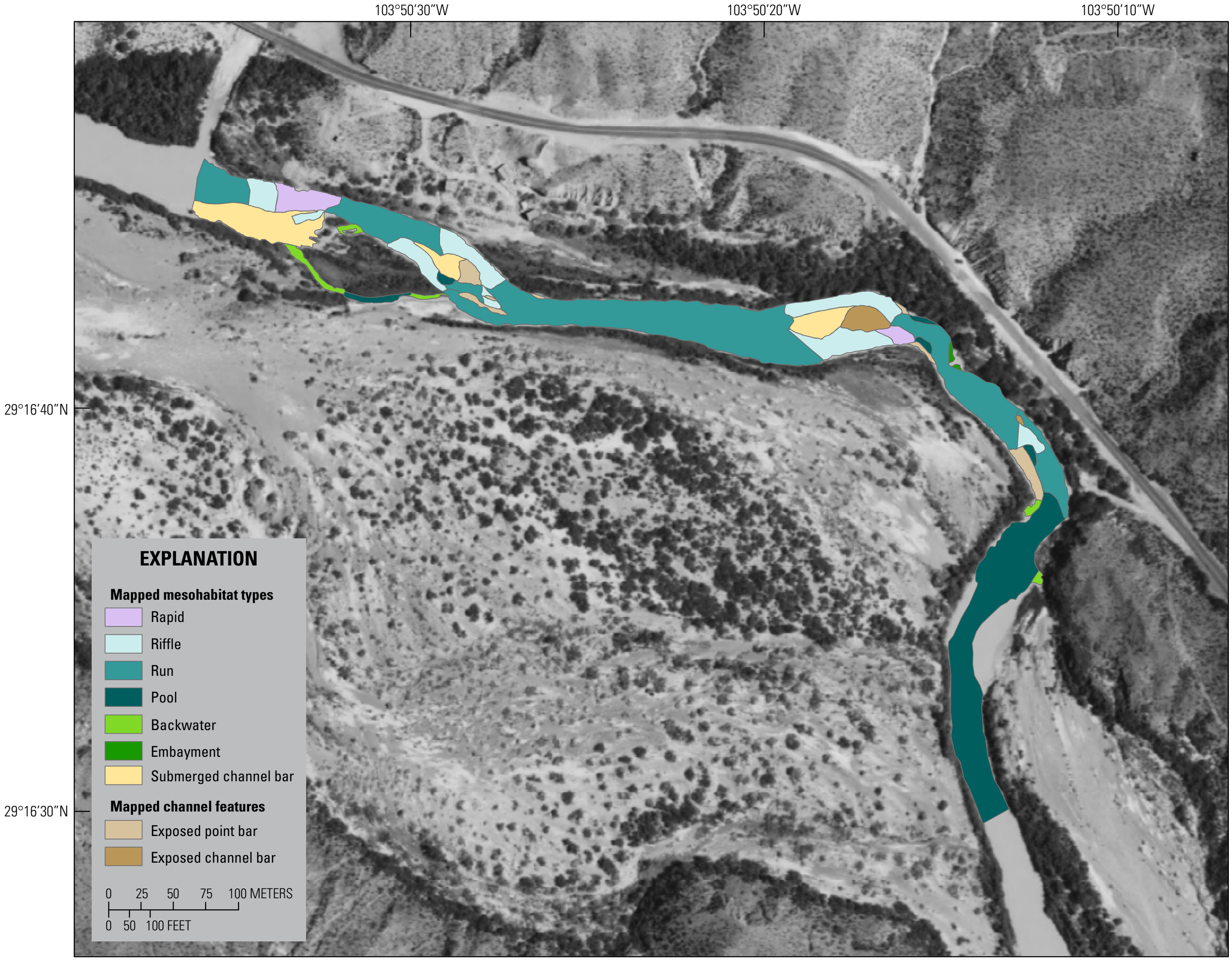
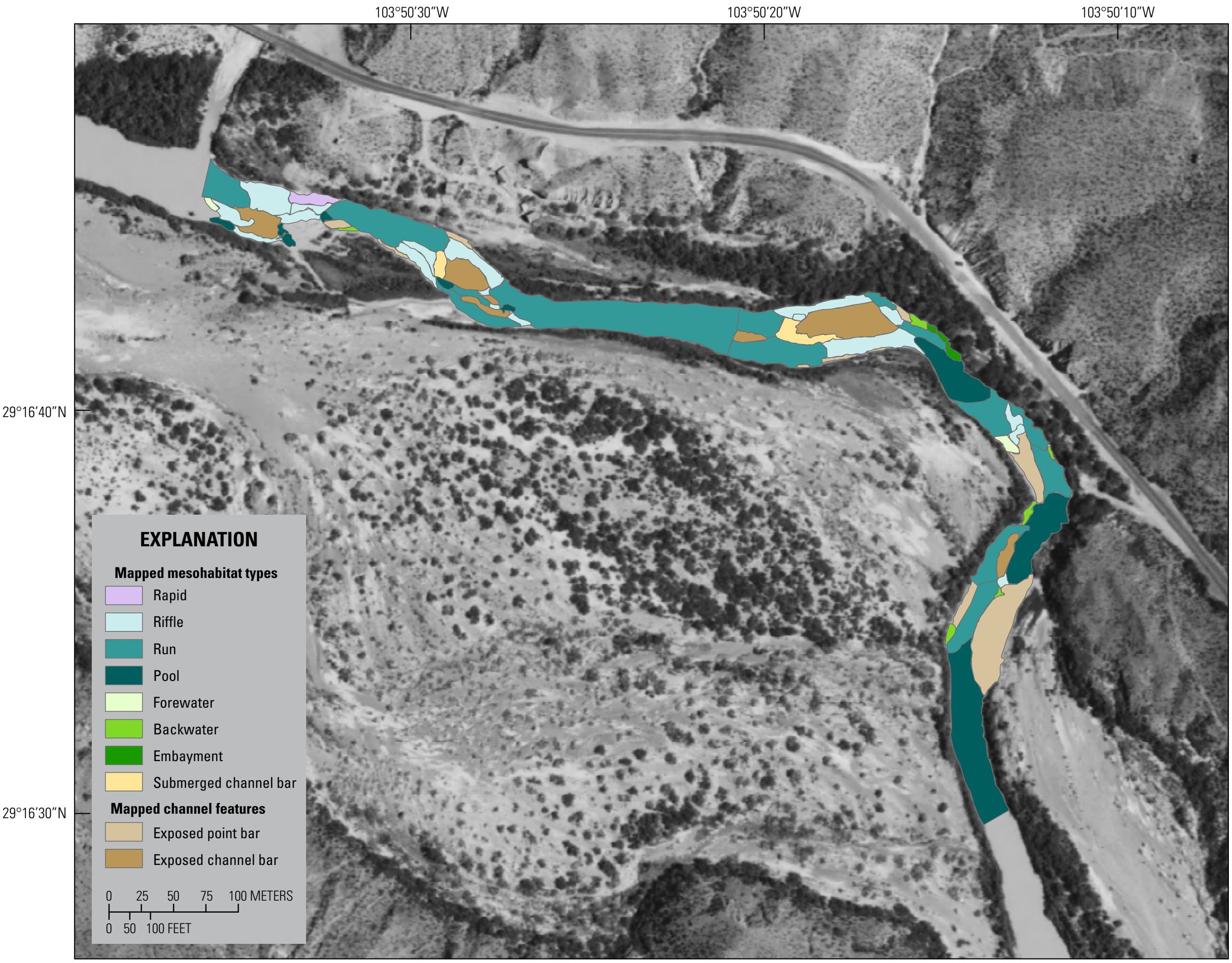
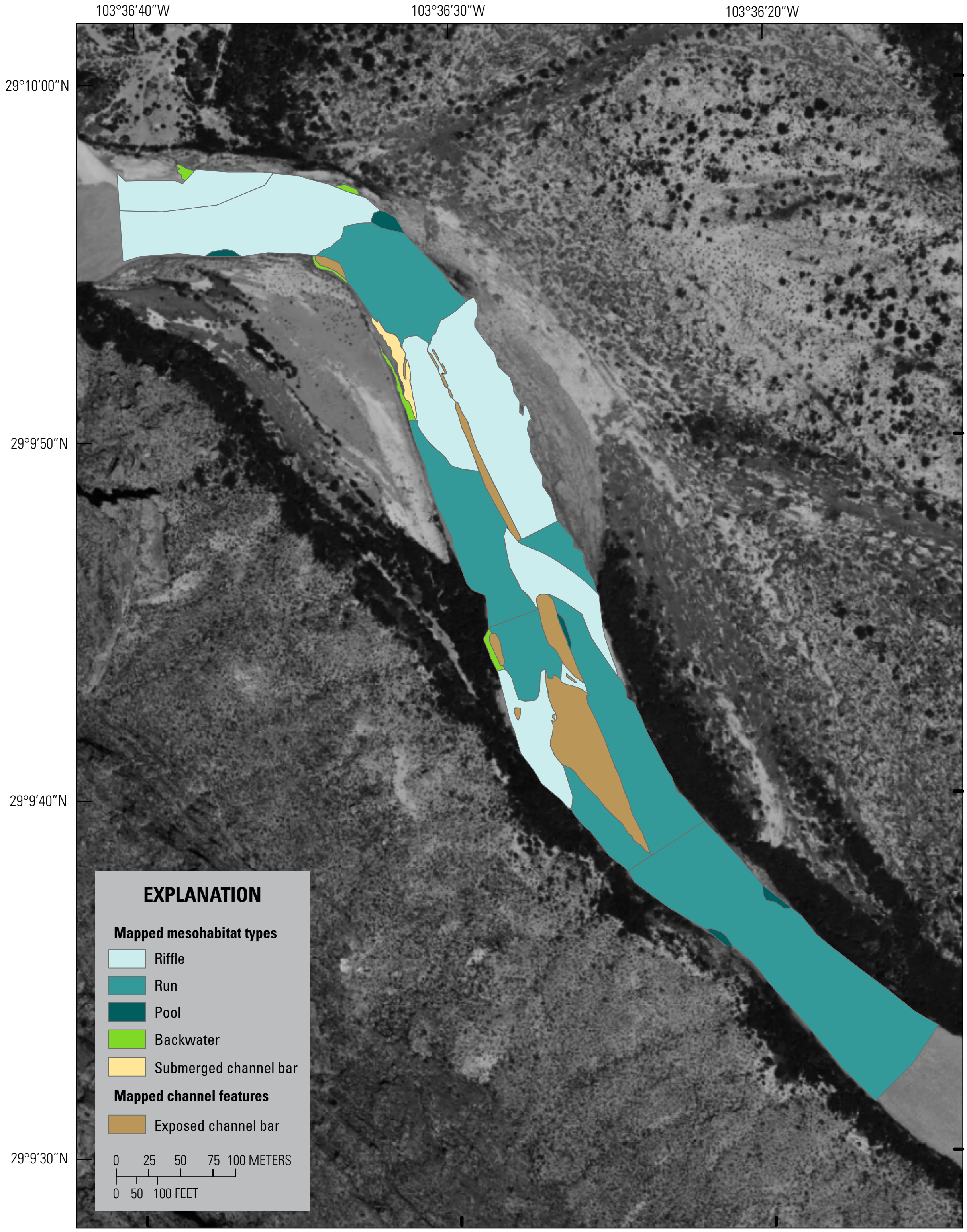


Figure 15. Mapped mesohabitats and channel features associated with intermediate flow in the Rio Grande/Rio Bravo del Norte (Rio Grande) at the Contrabando site near Lajitas, Texas, April 2010.



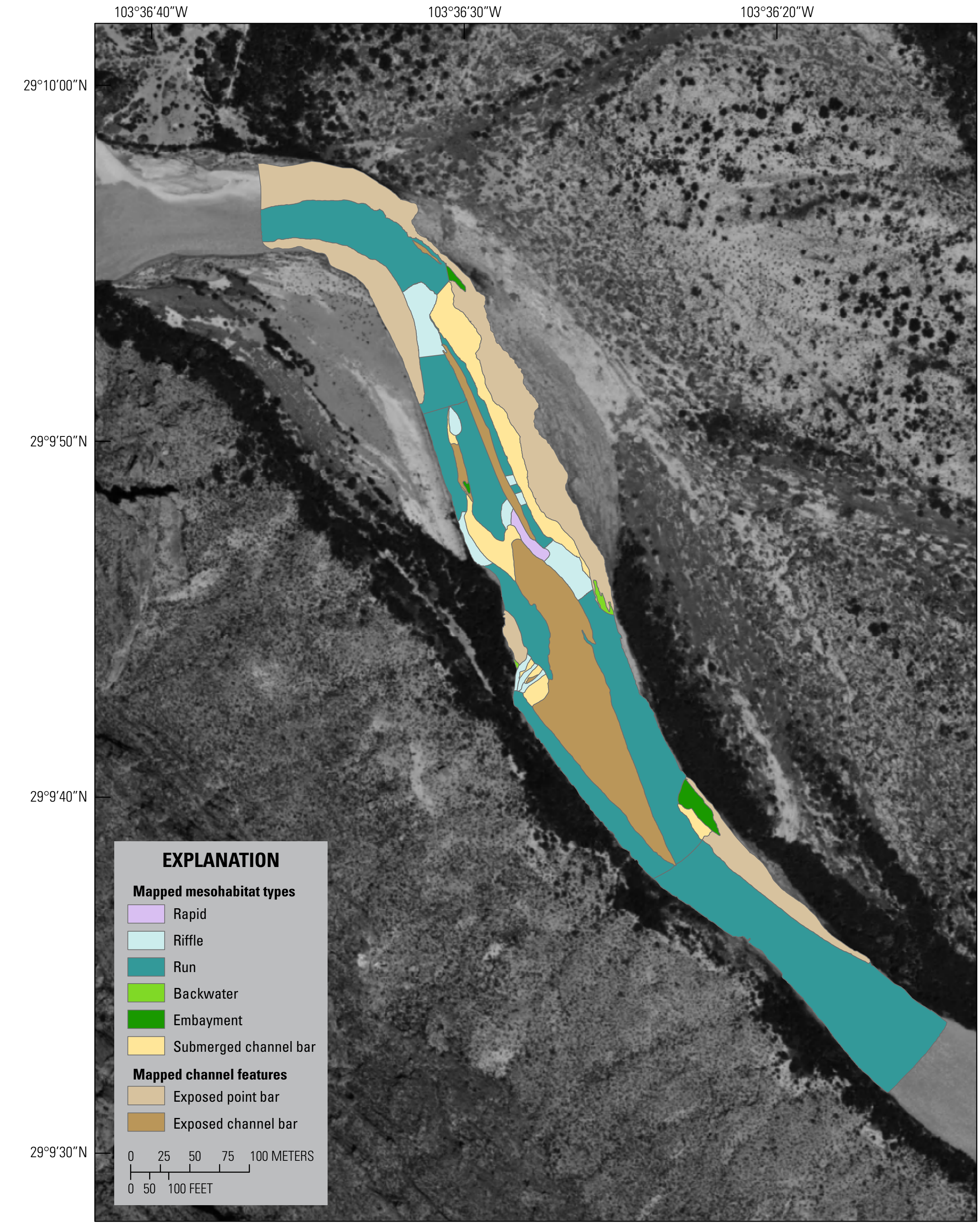
Base from National Agriculture Imagery Program (NAIP),
U.S. Department of Agriculture (USDA)-Farm Service Agency (FSA)-
Aerial Photography Field Office (APFO), 2010, 1-meter digital ortho quarter quad
Universal Transverse Mercator (UTM) projection, Zone 13
North American Datum of 1983

Figure 16. Mapped mesohabitats and channel features associated with low flow in the Rio Grande/Rio Bravo del Norte (Rio Grande) at the Contrabando site near Lajitas, Texas, May 2011.



Base from National Agriculture Imagery Program (NAIP),
U.S. Department of Agriculture (USDA)-Farm Service Agency (FSA)-
Aerial Photography Field Office (APFO), 2010, 1-meter digital ortho quarter quad
Universal Transverse Mercator (UTM) projection, Zone 13
North American Datum of 1983

Figure 17. Mapped mesohabitats and channel features associated with high flow in the Rio Grande/Rio Bravo del Norte (Rio Grande) at the Santa Elena site in Big Bend National Park, Texas, August 2010.



Base from National Agriculture Imagery Program (NAIP),
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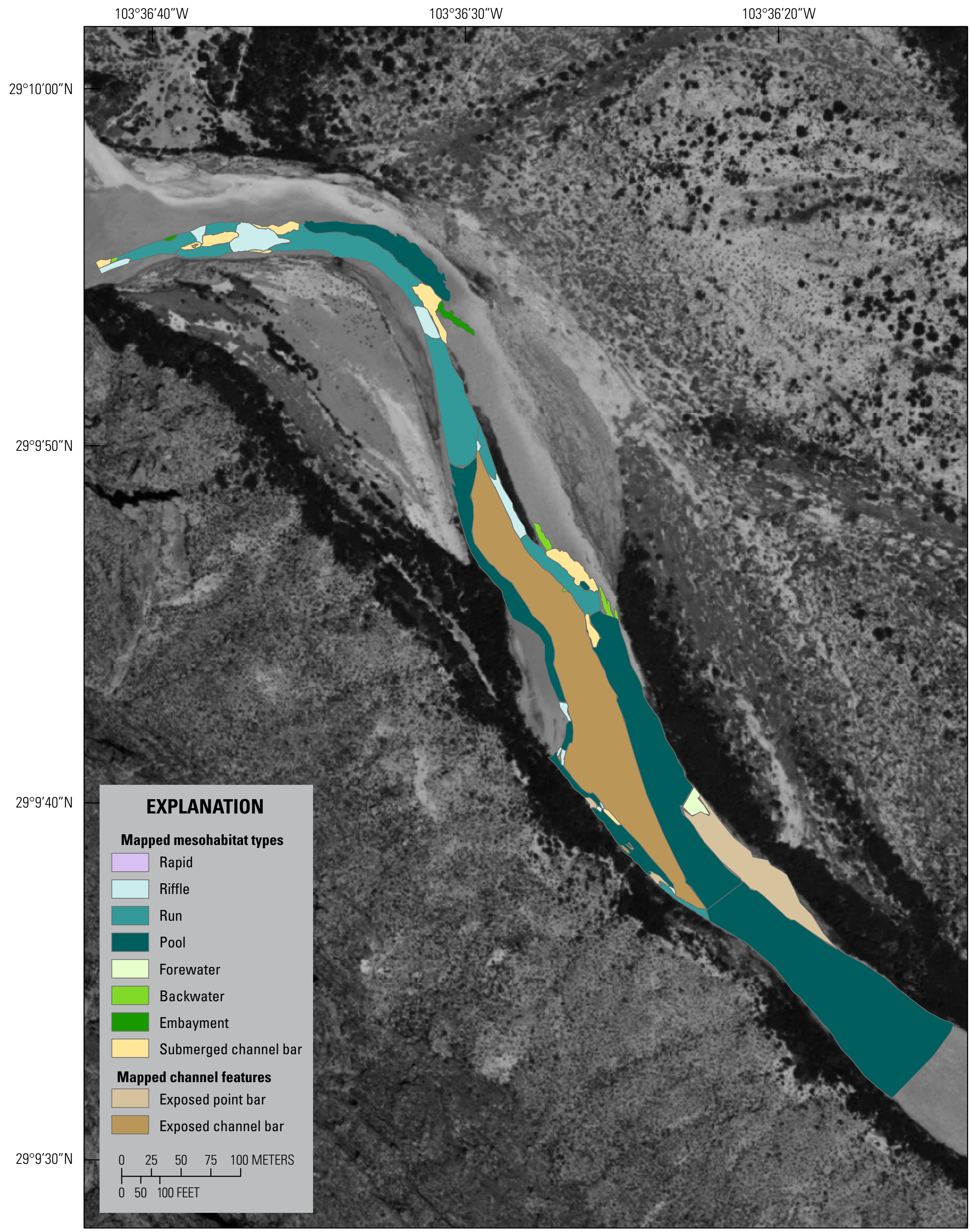
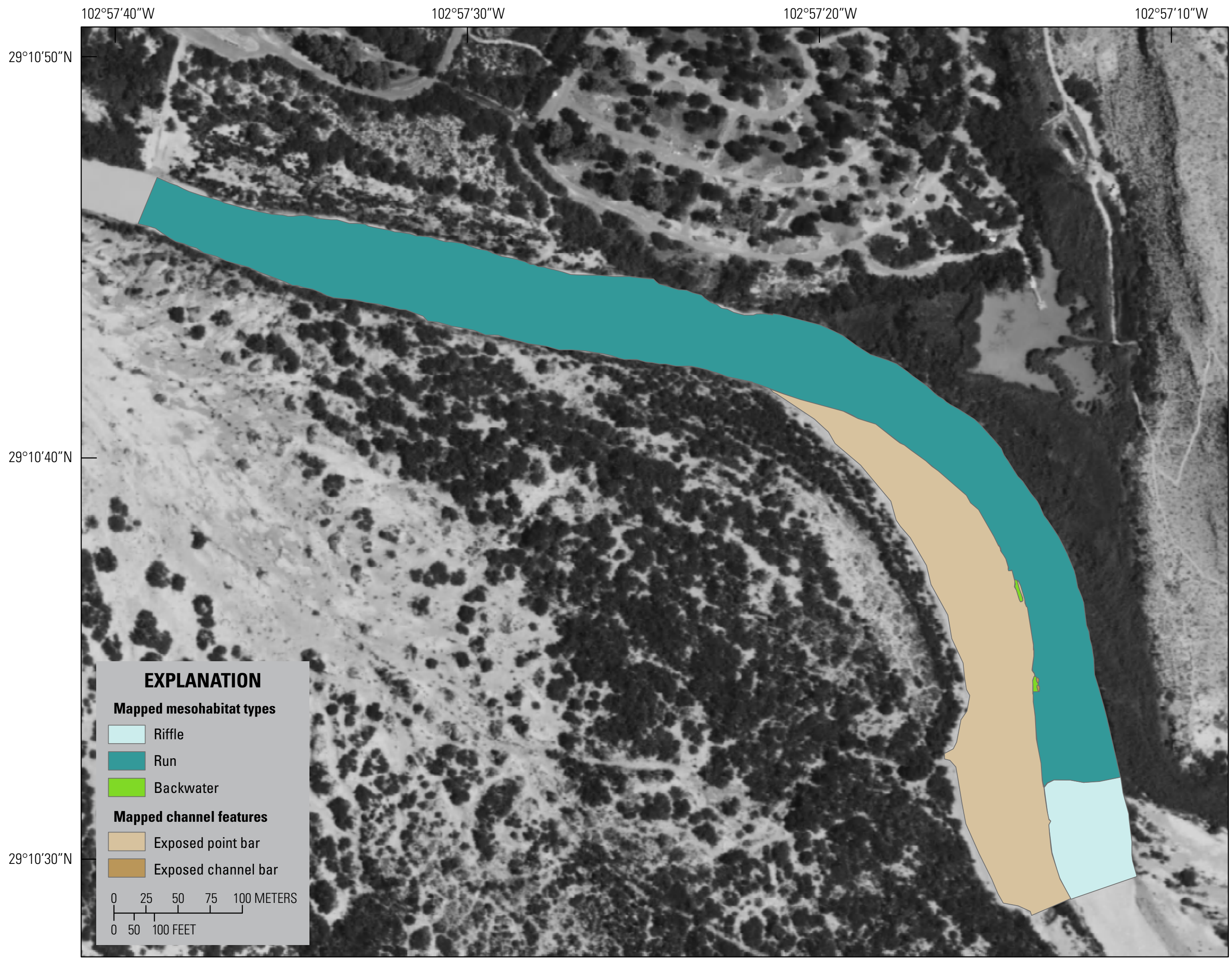
Aerial Photography Field Office (APFO), 2010, 1-meter digital ortho quarter quad
Universal Transverse Mercator (UTM) projection, Zone 13
North American Datum of 1983

Figure 18. Mapped mesohabitats and channel features associated with intermediate flow in the Rio Grande/Rio Bravo del Norte (Rio Grande) at the Santa Elena site in Big Bend National Park, Texas, April 2010.



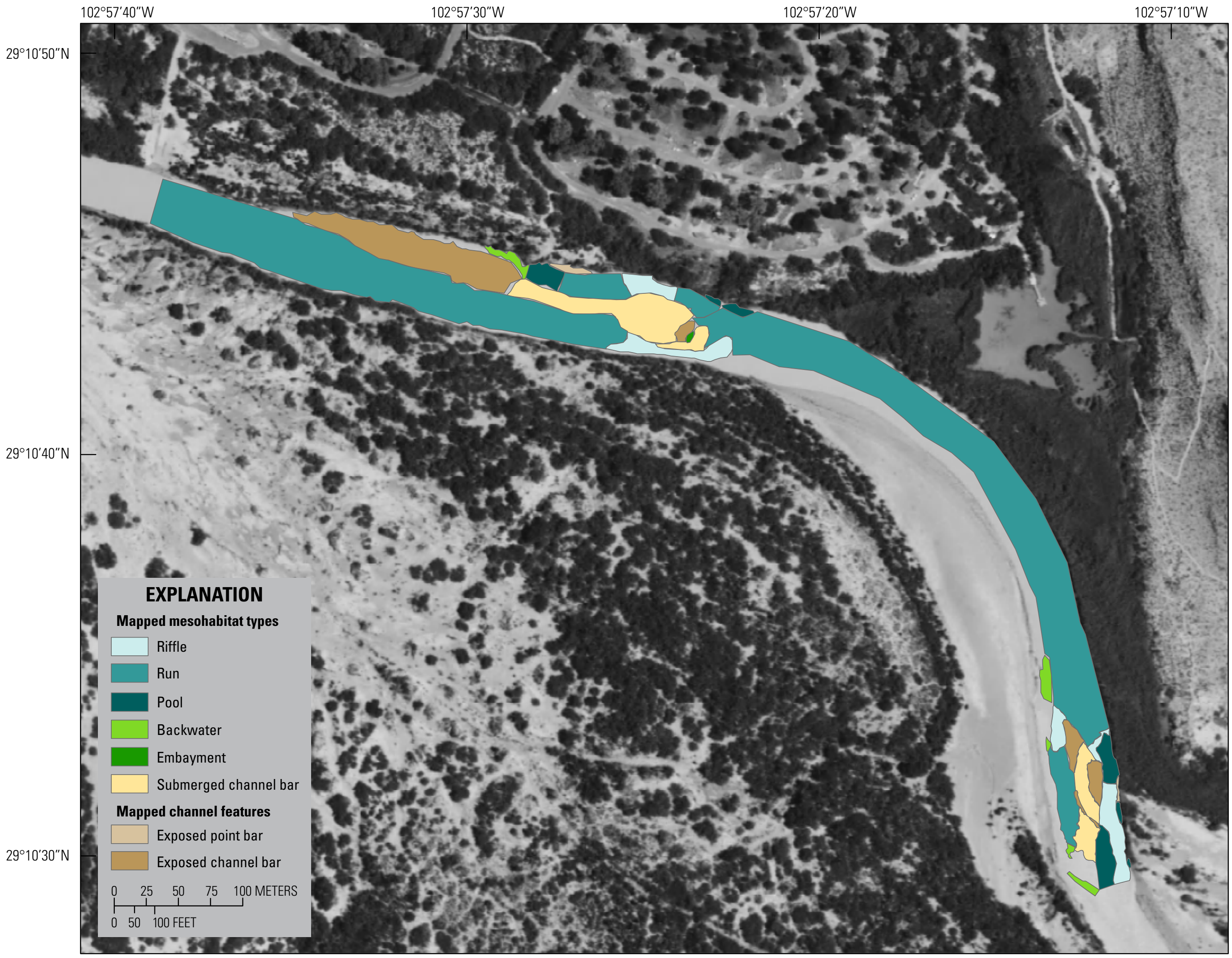
Base from National Agriculture Imagery Program (NAIP),
U.S. Department of Agriculture (USDA)-Farm Service Agency (FSA)-
Aerial Photography Field Office (APFO), 2010, 1-meter digital ortho quarter quad
Universal Transverse Mercator (UTM) projection, Zone 13
North American Datum of 1983

Figure 19. Mapped mesohabitats and channel features associated with low flow in the Rio Grande/Rio Bravo del Norte (Rio Grande) at the Santa Elena site in Big Bend National Park, Texas, May 2011.



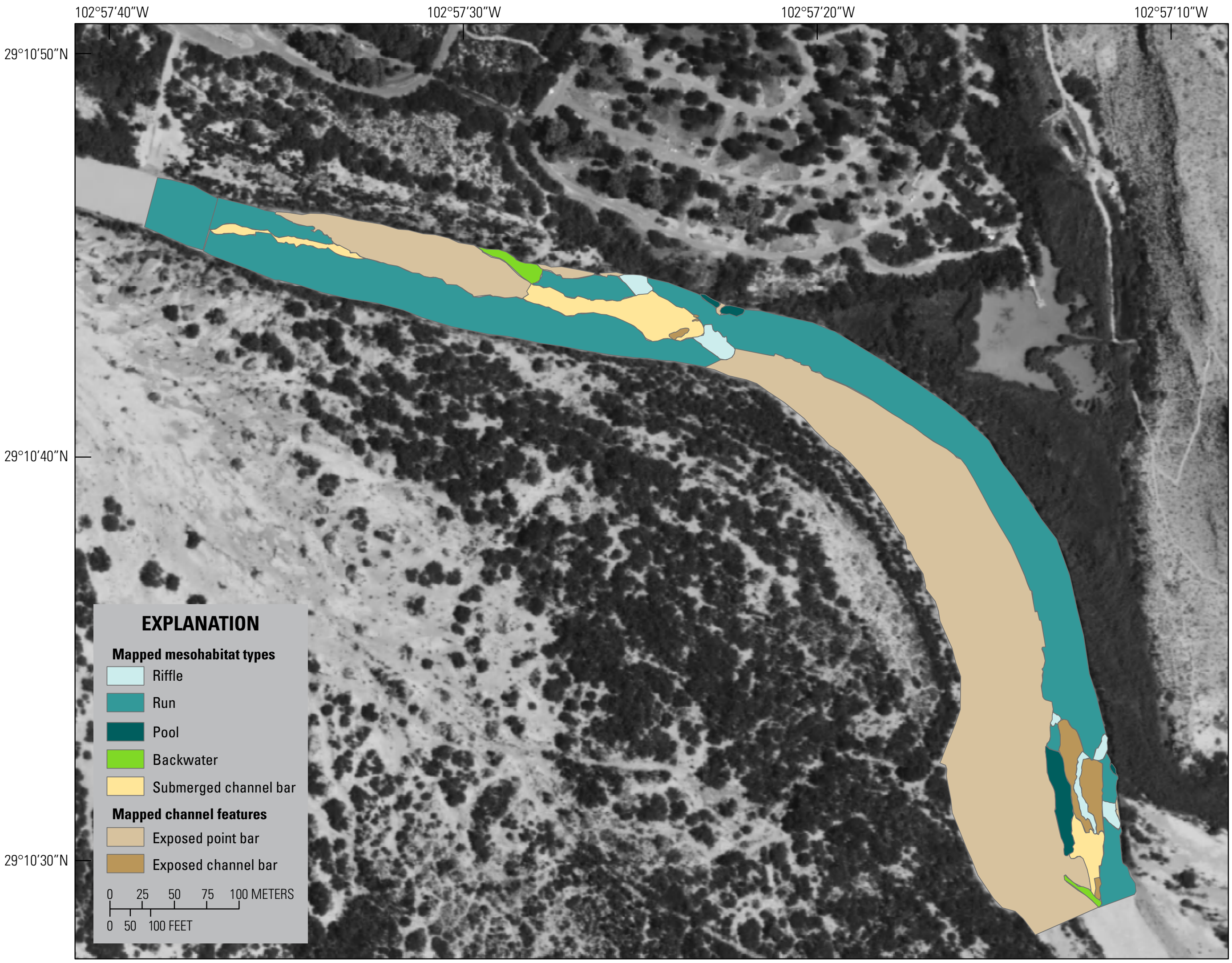
Base from National Agriculture Imagery Program (NAIP),
U.S. Department of Agriculture (USDA)-Farm Service Agency (FSA)-
Aerial Photography Field Office (APFO), 2010, 1-meter digital ortho quarter quad
Universal Transverse Mercator (UTM) projection, Zone 13
North American Datum of 1983

Figure 20. Mapped mesohabitats and channel features associated with high flow in the Rio Grande/Rio Bravo del Norte (Rio Grande) at the Rio Grande Village site in Big Bend National Park, Texas, September 2010.



Base from National Agriculture Imagery Program (NAIP),
U.S. Department of Agriculture (USDA)-Farm Service Agency (FSA)-
Aerial Photography Field Office (APFO), 2010, 1-meter digital ortho quarter quad
Universal Transverse Mercator (UTM) projection, Zone 13
North American Datum of 1983

Figure 21. Mapped mesohabitats and channel features associated with intermediate flow in the Rio Grande/Rio Bravo del Norte (Rio Grande) at the Rio Grande Village site in Big Bend National Park, Texas, May 2010.



Base from National Agriculture Imagery Program (NAIP),
U.S. Department of Agriculture (USDA)-Farm Service Agency (FSA)-
Aerial Photography Field Office (APFO), 2010, 1-meter digital ortho quarter quad
Universal Transverse Mercator (UTM) projection, Zone 13
North American Datum of 1983

Figure 22. Mapped mesohabitats and channel features associated with low flow in the Rio Grande/Rio Bravo del Norte (Rio Grande) at the Rio Grande Village site in Big Bend National Park, Texas, May 2011.

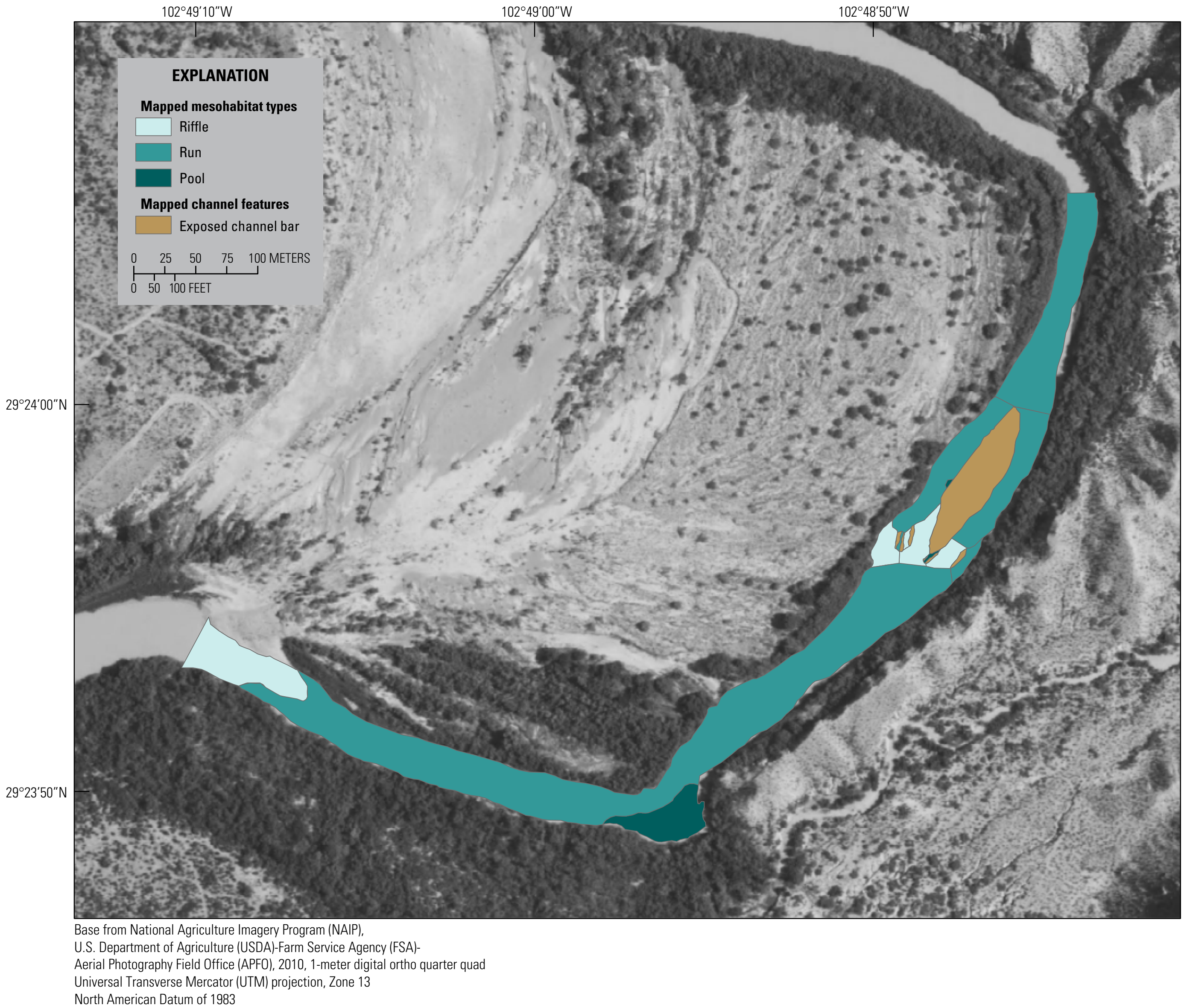
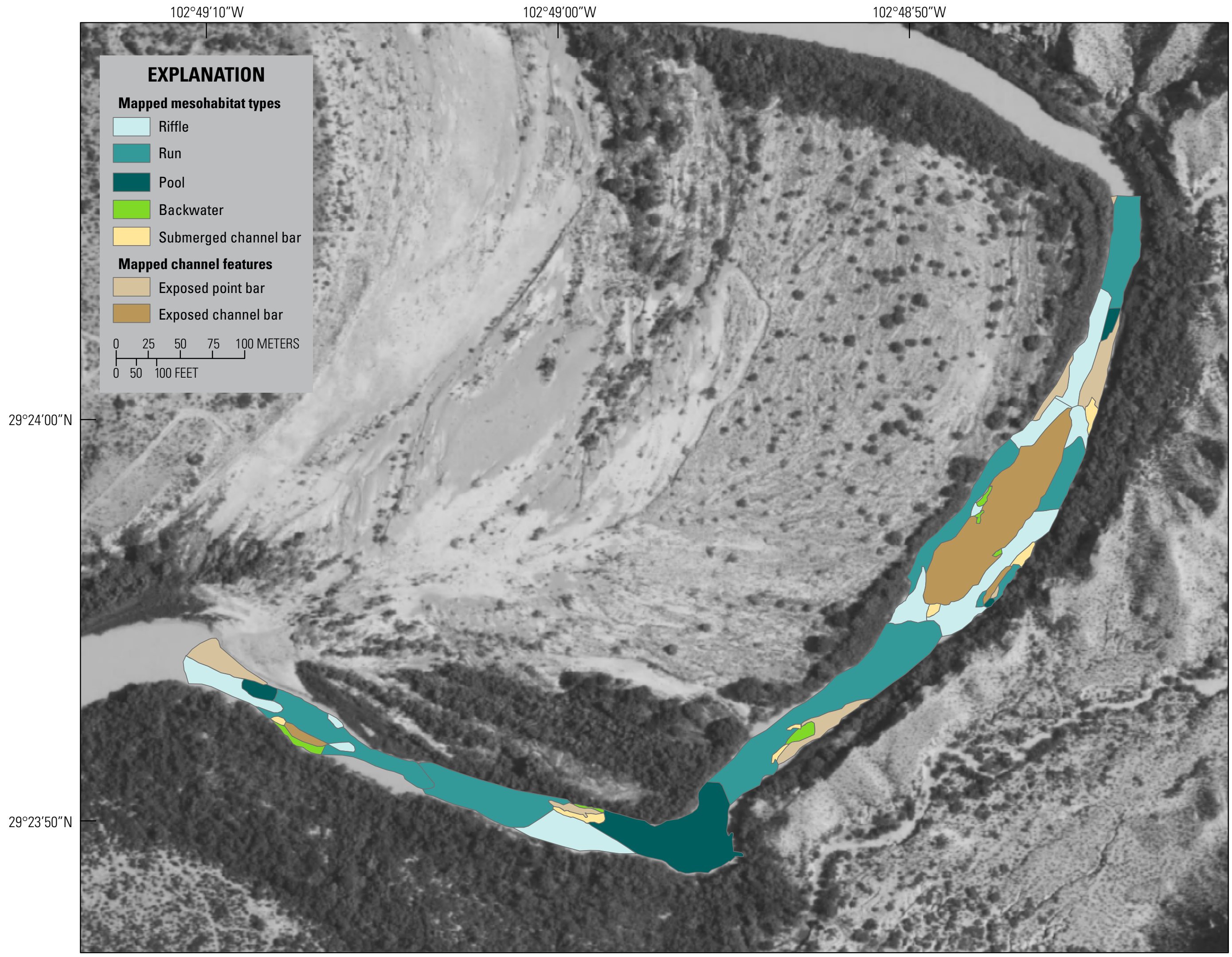


Figure 23. Mapped mesohabitats and channel features associated with high flow in the Rio Grande/Rio Bravo del Norte (Rio Grande) at the Stillwell Crossing site near Big Bend National Park, Texas, September 2010.



Base from National Agriculture Imagery Program (NAIP),
U.S. Department of Agriculture (USDA)-Farm Service Agency (FSA)-
Aerial Photography Field Office (APFO), 2010, 1-meter digital ortho quarter quad
Universal Transverse Mercator (UTM) projection, Zone 13
North American Datum of 1983

Figure 24. Mapped mesohabitats and channel features associated with intermediate flow in Rio Grande/Rio Bravo del Norte (Rio Grande) at the Stillwell Crossing site near Big Bend National Park, Texas, May 2010.

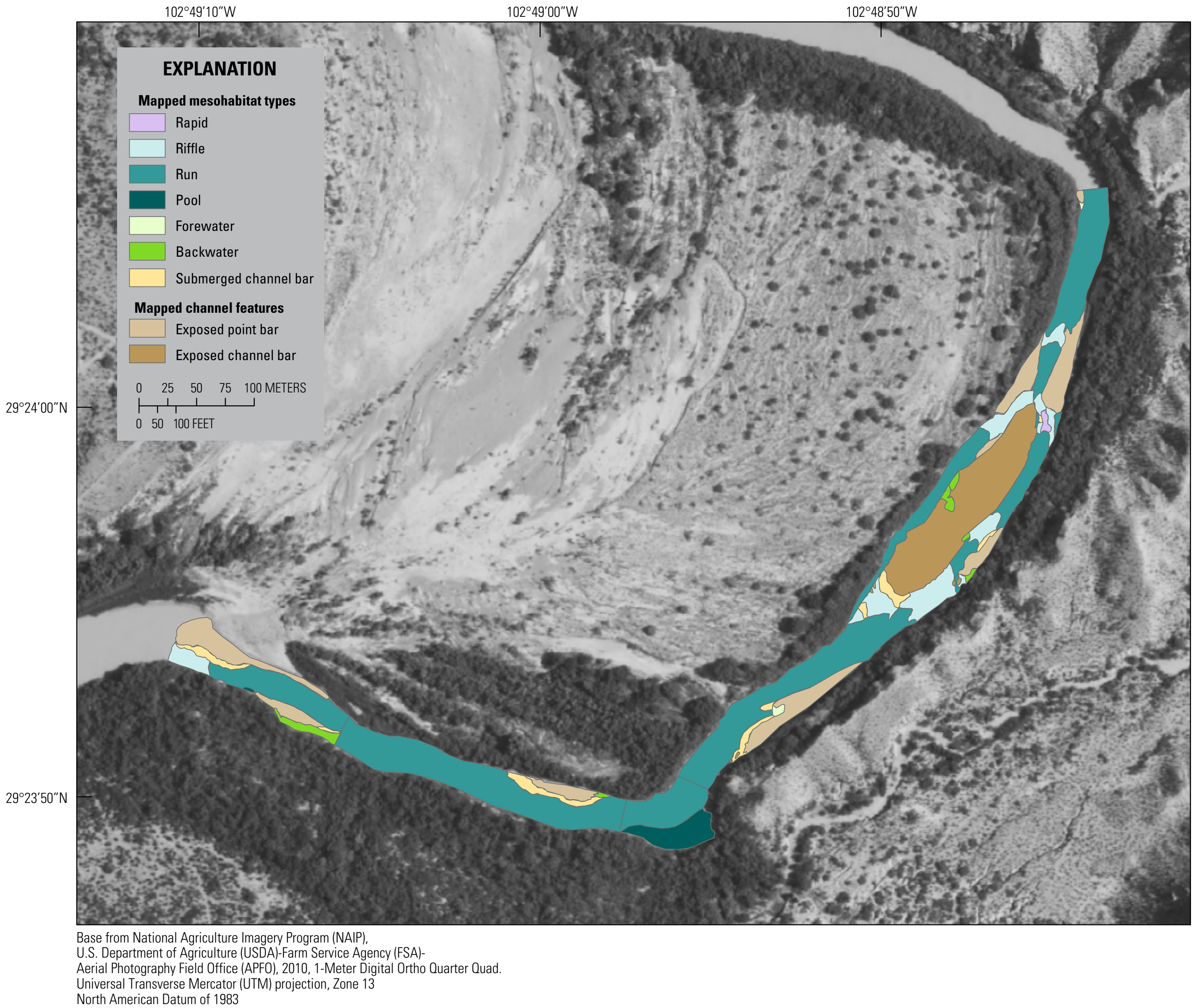


Figure 25. Mapped mesohabitats and channel features associated with low flow in the Rio Grande/Rio Bravo del Norte (Rio Grande) at the Stillwell Crossing site near Big Bend National Park, Texas, May 2011.

Runs were the largest contributor to wetted area at both high (82 percent) and low flow (76 percent). Riffles and pools were present at almost the same percentages at high flow (12 percent riffles and 5 percent pools) and low flow (12 percent riffles and 4 percent pools). Additional mesohabitat types were mapped at low flow compared to high flow, and these additional mesohabitats account for differences in the contributions of runs to wetted area during these two flow regimes. Compared to high flow, the additional mesohabitats mapped during low flows (and the number of each mesohabitat type mapped) were rapids (1), forewaters (2), backwaters (6), and submerged channel bars (9). At intermediate flow, runs were still the largest contributor to wetted area at 52 percent, but riffles and pools provided much larger relative contributions to the wetted area (27 and 16 percent, respectively) compared to all other mesohabitat types (fig. 13).

The depths and velocities measured at all four sampling sites are available in the geospatial database attribute table “Physical Characteristics” (fig. 11). On an overall basis, the smallest depths and velocities were measured at all four sites during low flow, and the largest depths and velocities were measured during high flow (table 3; figs. 26–29). Exceptions to the relations between depth and flow regime and velocity and flow regime occurred at the Rio Grande Village site, where a slightly smaller mean depth at intermediate flow (1.17 ft) was measured relative to that at low flow (1.28 ft), and at the Stillwell Crossing site, where a slightly smaller mean velocity at intermediate flow (0.81 ft/s) was measured relative to the mean velocity at low flow (0.88 ft/s). At the Rio Grande Village site, a slightly smaller maximum velocity was measured at intermediate flow (3.25 ft/s) compared to low flow (3.44 ft/s). At the Stillwell Crossing site, a much larger maximum depth was measured at intermediate flow (14.5 ft) compared to high flow (7.7 ft). These discrepancies were likely caused, at least in part, by the fact that physical characteristics were not measured in the same mesohabitats during the low and intermediated flows at this site. It was not possible to map the same mesohabitats during each of the three flow regimes because the extent and type of each mesohabitat changed from one flow regime to the next.

Of the four sites, the largest mean velocity for all three flow regimes (table 3; 1.76 ft/s) was measured at the Stillwell Crossing site, which was largely caused by a mean velocity of 5.08 ft/s during high flow. Among the four sites, the second largest mean velocity for all three flow regimes was measured at the Santa Elena site (1.51 ft/s), where the largest mean velocities during the intermediate and low-flow regimes were also measured (1.81 and 0.90 ft/s, respectively). The smallest mean velocity (1.30 ft/s) among all three flow regimes was measured at the Contrabando site. The largest mean velocity among the sites was measured at the Rio Grande Village site (5.11 ft/s).

The deepest overall study reach (based on a mean depth for all three flow regimes of 1.96 ft) was measured at the Stillwell Crossing site, where the largest mean depths during intermediate and low flow were also measured. The second deepest overall study reach (based on the mean depth for all three flow regimes of 1.85 ft) was measured at the Contrabando site, followed by the Rio Grande Village (1.64 ft) and Santa Elena sites (1.37 ft). The largest mean depth was measured at the Rio Grande Village site during high flow (4.30 ft); the largest range in mean depth among the three flow regimes (3.13 ft) was also measured at this site. Mean depths were more consistent over the course of the three flow regimes at the Santa Elena site, where depths ranged from 1.00 ft at low flow to 1.81 ft at high flow. Among the four sites, the mean wetted channel widths over all three flow regimes ranged from 29 to 36 m at the Contrabando site, 48 to 81 m at the Santa Elena site, 37 to 50 m at the Rio Grande Village site, and 32 to 39 m at the Stillwell Crossing site (table 3).

A larger range of riffle-mesohabitat depths was measured at the Santa Elena (fig. 27) and Stillwell Crossing (fig. 29) sites compared to the range of riffle-mesohabitat depths at the other two sites. At all sites, velocities were more variable in shallow riffles less than 2 ft deep (figs. 26–29). The larger variability in velocity in shallow riffles might have been an artifact of sampling size; at all of the sites the sample size was larger for shallow riffles than it was for deeper riffles. Velocities in riffles were more variable at shallow depths at the Rio Grande Village and Stillwell Crossing sites compared to the velocities in riffles at the other two sites (figs. 28 and 29). Deeper run mesohabitats with larger velocities were characteristic of the Stillwell Crossing site (fig. 29), whereas shallower run mesohabitats with smaller velocities were characteristic of the Santa Elena site (fig. 27). Among all four sites, pools were more variable in velocity and shallow in depth at the Rio Grande Village site (fig. 28) and were deeper with smaller velocities at the Contrabando site (fig. 26). Some of the larger and more variable velocities were measured at the Santa Elena site for shallow mesohabitats (forewaters, backwaters, and embayments) (fig. 27), and velocities in these mesohabitats were most variable in very shallow depths (<0.1 ft) at the Contrabando site (fig. 26).

Dissolved oxygen, pH, specific conductance, and water temperature data for all four sites are available in the geospatial database attribute table “Water Quality” (fig. 11). Median dissolved oxygen concentrations (fig. 30; table 4) were relatively consistent between the Contrabando and Santa Elena sites (8.34 and 8.54 mg/L, respectively). Median dissolved oxygen concentrations decreased along the stretch of river between the Santa Elena and Rio Grande Village sites to 7.31 mg/L, possibly because of small dissolved oxygen concentrations associated with contributions from springs between the Santa Elena and Rio Grande Village sites. Dissolved oxygen concentrations increased substantially between the Rio Grande Village and Stillwell Crossing sites to 10.06 mg/L. Dissolved oxygen percent saturation values equal to or more than 100 percent were measured at 17 of the 20 mesohabitats at the Stillwell Crossing site where dissolved oxygen was measured, and percent saturation values of more than 120 percent were measured at13 out of these 17 sites.

Table 3. Summary statistics of physical characteristic data collected at the mesohabitat scale at four study sites in the Rio Grande/Rio Bravo del Norte (Rio Grande), Texas, 2010–11.

[m, meters; ft/s, feet per second; ft, feet; NA, not applicable]

Date	Flow regime	Reach length (m)	Mean values					Median values					Maximum values	
			Wetted channel width (m)	Meso-habitat length (m)	Meso-habitat width (m)	Velocity (ft/s)	Depth (ft)	Wetted channel width (m)	Meso-habitat length (m)	Meso-habitat width (m)	Velocity (ft/s)	Depth (ft)	Velocity (ft/s)	Depth (ft)
Contrabando site (table 1)														
8/30/2010	High	995	36	90.3	16.7	2.70	3.74	33	47.0	15.0	2.49	2.70	6.42	11.5
4/13/2010	Intermediate	1,010	33	63.0	13.7	1.20	1.84	29	53.0	12.0	0.80	1.50	5.62	8.0
5/16/2011	Low	1,000	29	40.3	10.1	0.69	0.89	23	33.5	8.0	0.34	0.69	3.96	2.4
All dates/all flows[a]		NA	33	60.3	13.0	1.30	1.85	28	45.5	10.0	0.80	1.22	6.42	11.5
Santa Elena site (table 1)														
8/31/2010	High	1,082	81	108.8	33.0	2.17	1.81	81	89.5	35.0	2.63	1.40	5.27	4.0
4/14/2010	Intermediate	983	62	95.6	17.5	1.81	1.51	58	47.0	14.0	1.50	1.50	4.35	3.8
5/17/2011	Low	1,115	48	83.5	16.3	0.90	1.00	48	48.0	11.0	0.79	0.80	3.79	3.7
All dates/all flows[a]		NA	64	94.2	21.9	1.51	1.37	62	52.5	15.0	1.15	1.10	5.27	4.0
Rio Grande Village site (table 1)														
9/1/2010	High	1,017	50	116.0	55.0	5.11	4.30	52	116.0	56.0	4.71	4.25	7.78	6.0
5/20/2010	Intermediate	1,024	37	92.5	12.3	0.75	1.17	35	39.0	9.0	0.44	1.00	3.25	5.0
5/18/2011	Low	1,035	42	89.7	14.0	0.50	1.28	38	43.0	13.0	0.22	0.90	3.44	4.0
All dates/all flows[a]		NA	43	91.9	14.5	1.39	1.64	42	40.0	12.0	0.49	1.10	7.78	6.0
Stillwell Crossing site (table 1)														
9/2/2010	High	1,010	39	53.8	18.7	5.08	3.00	35	32.0	18.0	4.33	3.18	14.96	7.7
5/18/2010	Intermediate	1,043	33	83.1	13.6	0.81	2.10	30	82.0	10.5	0.35	1.60	3.79	14.5
5/19/2011	Low	1,039	32	69.3	13.3	0.88	1.34	28	45.5	12.0	0.53	1.05	5.05	4.4
All dates/all flows[a]		NA	35	73.7	14.0	1.76	1.96	31	56.0	12.0	0.81	1.57	14.96	14.5

[a]Means and medians for “all dates/all flows” incorporate all individual mesohabitat measurements at a given site in the calculations.

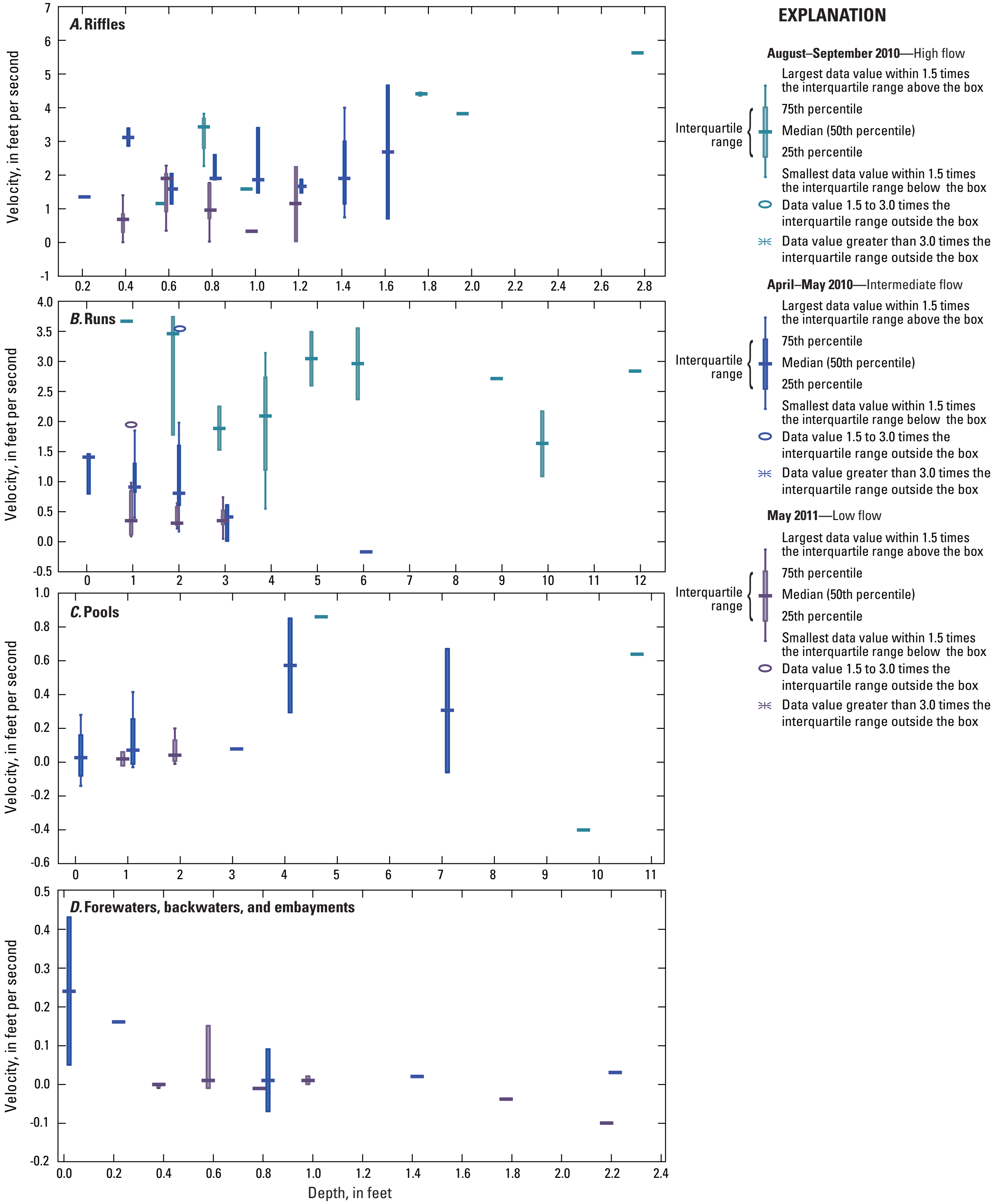


Figure 26. Relation between velocity and depth in the Rio Grande/Rio Bravo del Norte (Rio Grande) at the Contrabando site during high (August–September 2010), intermediate (April–May 2010), and low (May 2011) flows in mesohabitat types. *A*, Riffles. *B*, Runs. *C*, Pools. *D*, Forewaters, backwaters, and embayments.

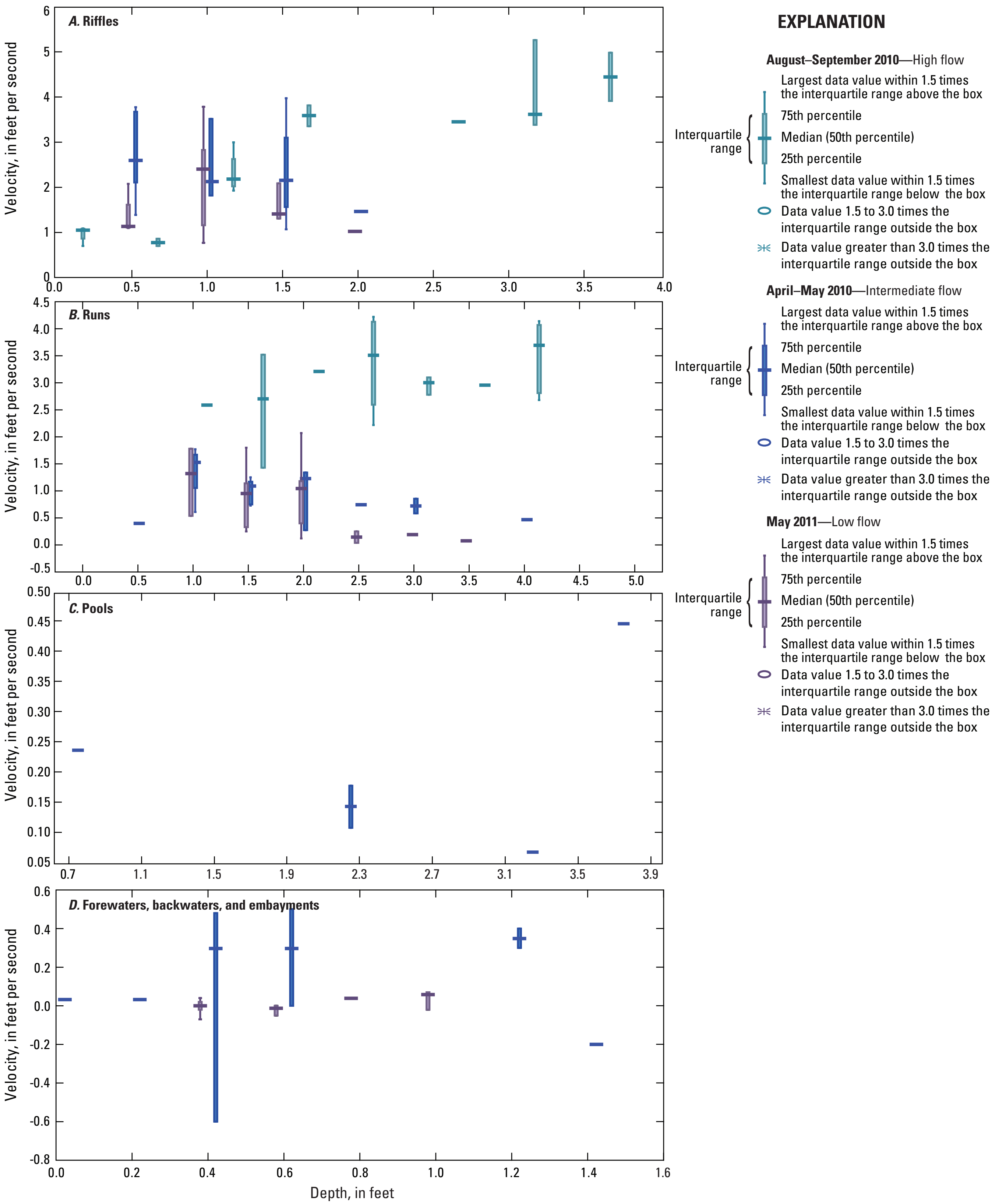


Figure 27. Relation between velocity and depth in the Rio Grande/Rio Bravo del Norte (Rio Grande) at the Santa Elena site during high (August–September 2010), intermediate (April–May 2010), and low (May 2011) flows in mesohabitat types. *A*, Riffles. *B*, Runs. *C*, Pools. *D*, Forewaters, backwaters, and embayments.

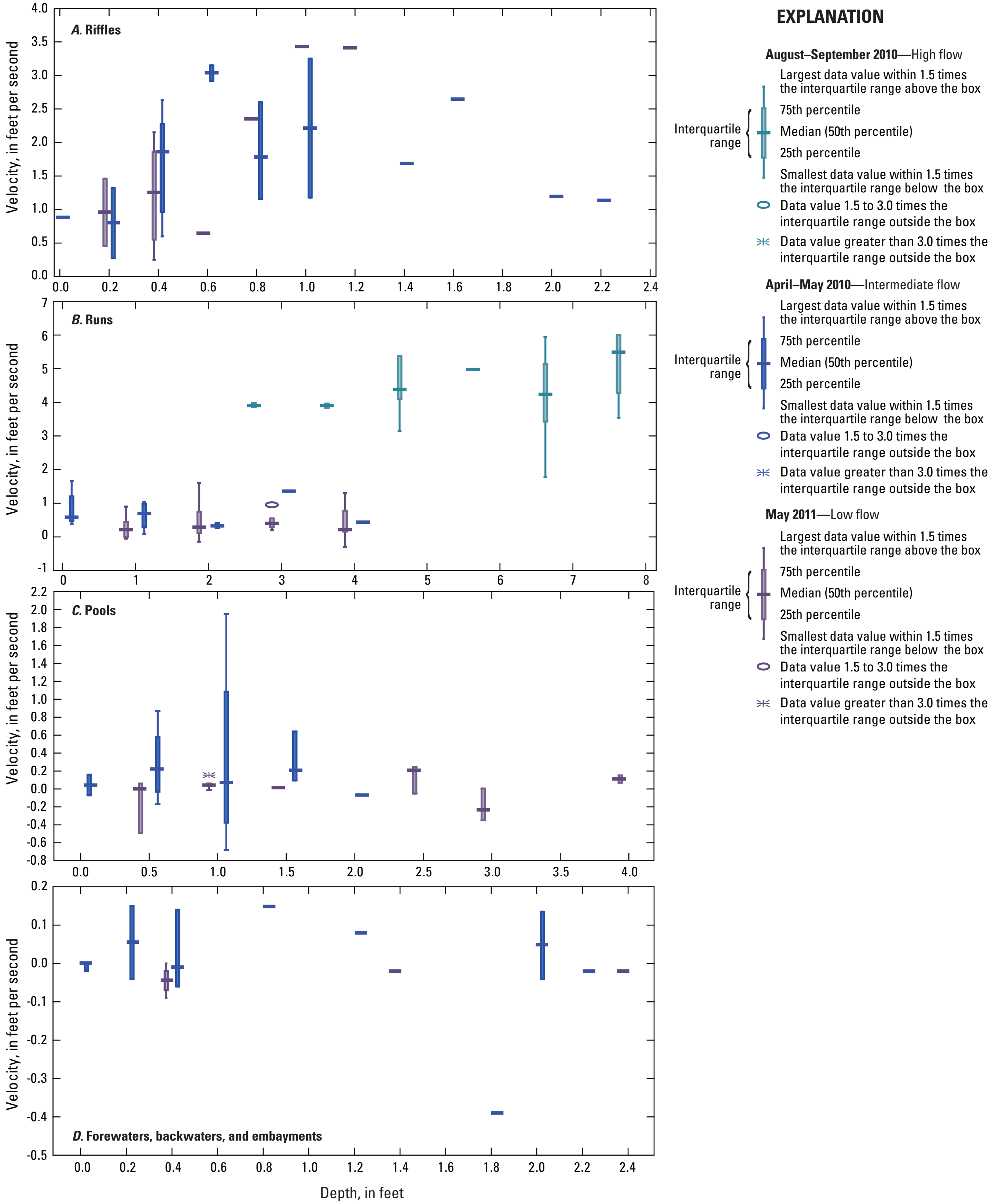


Figure 28. Relation between velocity and depth in the Rio Grande/Rio Bravo del Norte (Rio Grande) at the Rio Grande Village site during high (August–September 2010), intermediate (April–May 2010), and low (May 2011) flows in mesohabitat types. *A*, Riffles. *B*, Runs. *C*, Pools. *D*, Forewaters, backwaters, and embayments.

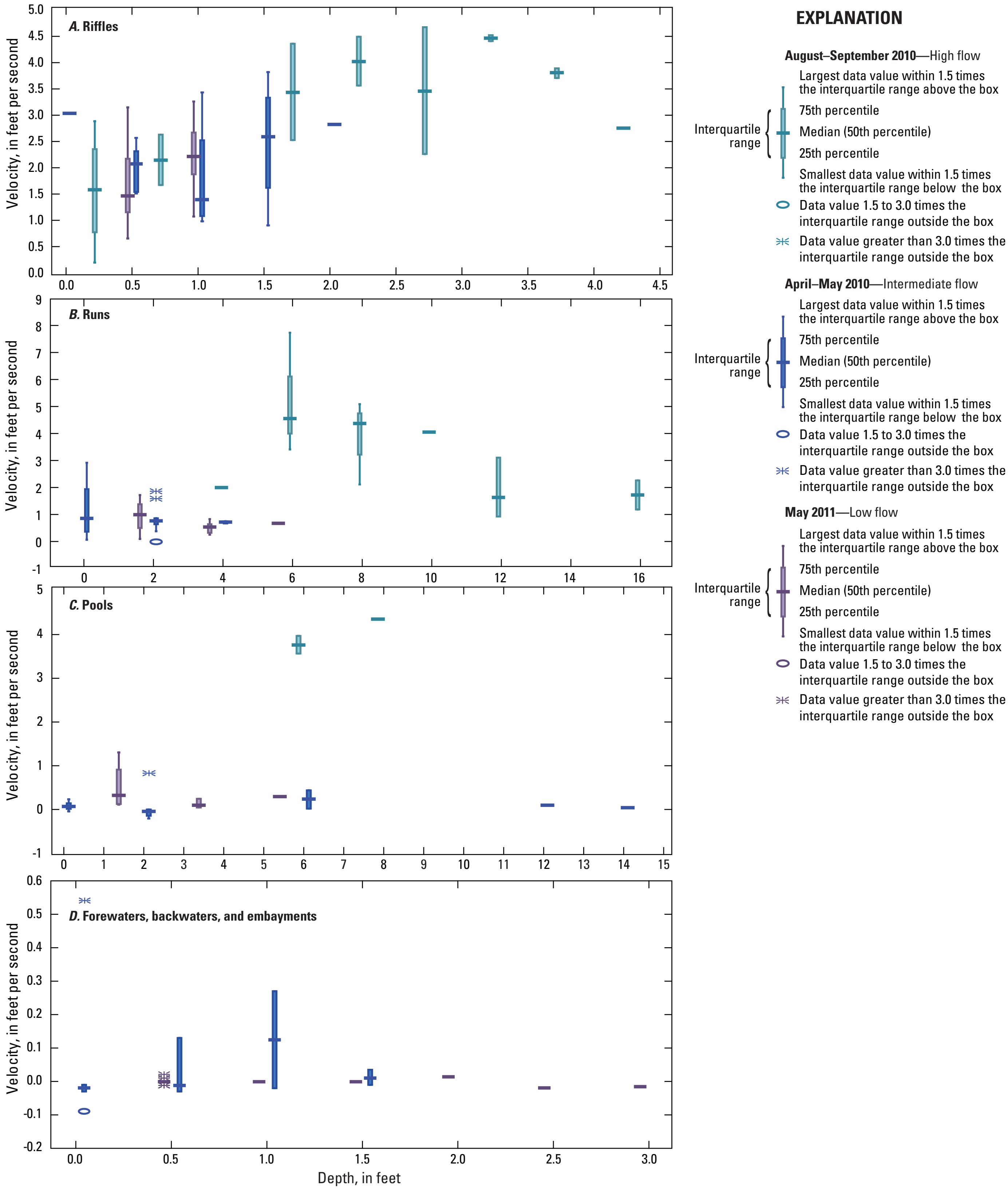


Figure 29. Relation between velocity and depth in the Rio Grande/Rio Bravo del Norte (Rio Grande) at the Stillwell Crossing site during high (August–September 2010), intermediate (April–May 2010), and low (May 2011) flows in mesohabitat types. *A*, Riffles. *B*, Runs. *C*, Pools. *D*, Forewaters, backwaters, and embayments.

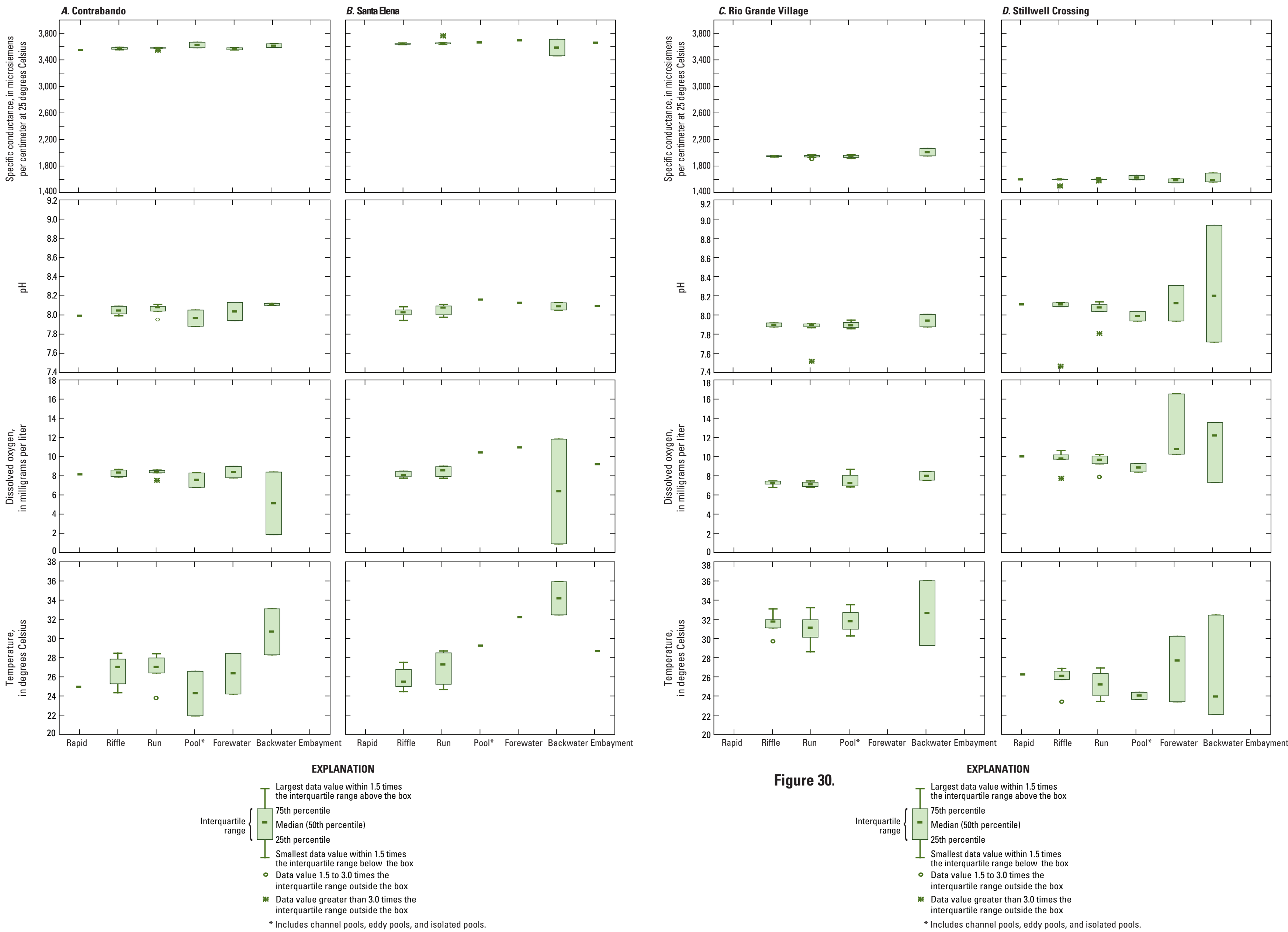


Figure 30.

Figure 30. Water-quality properties measured during low flow at sites in the Rio Grande/Rio Bravo del Norte (Rio Grande), May 2011. *A*, Contrabando. *B*, Santa Elena. *C*, Rio Grande Village. *D*, Stillwell Crossing.

Table 4. Water-quality properties measured during low flow at the centroid of selected mapped mesohabitats at four study sites in the Rio Grande/Rio Bravo del Norte (Rio Grande), Texas, May 2011.

[µs/cm at 25 °C, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; °C, degrees Celsius]

Mesohabitat identifier (see app. 1)	Mesohabitat type	pH	Specific conductance (µs/cm at 25 °C)	Dissolved oxygen (mg/L)	Temperature (°C)
Contrabando site 5/16/2011 (table 1)					
1	Forewater	7.94	3,550	7.82	24.19
2	Run	7.95	3,545	7.57	23.74
3	Riffle	7.99	3,552	7.96	24.32
4	Riffle	8.01	3,560	8.23	25.24
5	Rapid	7.99	3,550	8.16	24.90
6	Pool	7.88	3,666	6.82	21.94
9	Pool	8.05	3,583	8.33	26.52
10	Run	8.04	3,576	8.35	26.36
11	Backwater	8.12	3,643	1.83	32.96
13	Riffle	8.06	3,576	8.49	26.55
19	Run	8.08	3,580	8.38	26.93
20	Riffle	8.09	3,584	8.70	27.34
21	Riffle	8.03	3,588	7.91	28.39
25	Run	8.09	3,583	8.63	27.90
27	Riffle	8.09	3,584	8.64	27.78
28	Run	8.11	3,585	8.60	28.34
31	Backwater	8.10	3,586	8.42	28.23
36	Forewater	8.13	3,582	9.02	28.37
	Mean	8.04	3,582	7.88	26.67
	Median	8.06	3,583	8.34	26.74
Santa Elena site 5/17/2011 (table 1)					
1	Riffle	7.95	3,645	7.77	24.48
2	Riffle	8.08	3,667	8.48	26.77
4	Run	7.99	3,649	7.76	24.69
8	Run	8.02	3,657	7.95	25.24
9	Riffle	8.02	3,652	7.91	25.00
13	Riffle	8.05	3,658	8.07	25.48
16	Run	8.06	3,777	8.75	26.51
18	Embayment	8.13	3,675	9.22	28.66
19	Run	8.13	3,661	8.56	27.46
21	Run	8.11	3,667	8.54	27.29
22	Riffle	8.12	3,670	8.48	27.51
23	Run	8.12	3,669	8.95	28.50
24	Backwater	8.17	3,725	11.81	35.88
27	Backwater	8.08	3,479	0.96	32.45
30	Run	8.15	3,672	9.01	28.70
31	Forewater	8.17	3,710	10.93	32.18
33	Pool	8.21	3,678	10.42	29.23
	Mean	8.09	3,665	8.45	28.00
	Median	8.11	3,667	8.54	27.46

Table 4. Water-quality properties measured during low flow at the centroid of selected mapped mesohabitats at four study sites in the Rio Grande/Rio Bravo del Norte (Rio Grande), Texas, May 2011.—Continued

[µs/cm at 25 °C, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; °C, degrees Celsius]

Mesohabitat identifier (see app. 1)	Mesohabitat type	pH	Specific conductance (µs/cm at 25 °C)	Dissolved oxygen (mg/L)	Temperature (°C)
			Rio Grande Village site 5/18/2011 (table 1)		
2	Run	7.88	1,969	7.00	30.65
4	Run	7.53	1,929	6.83	28.68
5	Riffle	7.89	1,941	7.18	31.18
7	Backwater	7.89	1,950	7.60	29.35
8	Run	7.91	1,941	7.01	30.21
9	Riffle	7.89	1,933	6.84	29.77
10a	Run	7.91	1,938	6.83	30.20
10b	Run	7.92	1,953	7.43	31.78
11	Pool	7.90	1,942	6.88	30.33
12	Pool	7.91	1,952	7.09	31.75
13	Riffle	7.93	1,946	7.51	31.81
14	Run	7.90	1,949	7.31	31.71
16	Riffle	7.91	1,952	7.31	32.03
17	Run	7.92	1,953	7.34	32.27
19	Riffle	7.93	1,951	7.50	33.16
20	Run	7.92	1,902	7.51	33.29
21	Pool	7.96	1,965	8.74	33.60
23	Backwater	8.02	2,061	8.49	36.09
99	Pool	7.87	1,911	7.49	31.96
	Mean	7.89	1,949	7.36	31.57
	Median	7.91	1,949	7.31	31.75

Table 4. Water-quality properties measured during low flow at the centroid of selected mapped mesohabitats at four study sites in the Rio Grande/Rio Bravo del Norte (Rio Grande), Texas, May 2011.—Continued

[µs/cm at 25 °C, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; °C, degrees Celsius]

Mesohabitat identifier (see app. 1)	Mesohabitat type	pH	Specific conductance (µs/cm at 25 °C)	Dissolved oxygen (mg/L)	Temperature (°C)
Stillwell Crossing site 5/19/2011 (table 1)					
1	Riffle	7.48	1,620	7.74	23.41
3	Run	7.82	1,620	7.89	23.45
4	Pool	7.95	1,617	8.43	23.67
5	Backwater	7.73	1,609	7.35	23.94
7	Run	8.05	1,617	9.28	24.04
9	Backwater	8.21	1,583	12.21	22.11
11	Pool	8.05	1,680	9.30	24.40
12	Run	8.05	1,620	9.29	24.58
14	Forewater	8.13	1,608	10.80	27.68
18	Riffle	8.10	1,521	9.76	25.75
20	Run	8.12	1,620	10.09	25.81
22	Backwater	8.95	1,716	13.59	32.46
24	Riffle	8.12	1,620	9.83	26.09
25	Riffle	8.14	1,621	10.67	26.62
28	Forewater	7.95	1,628	10.29	23.42
33	Run	8.12	1,620	10.25	26.37
35	Rapid	8.12	1,620	10.03	26.25
42	Riffle	8.14	1,622	10.21	26.90
43	Run	8.15	1,621	10.09	26.95
44	Forewater	8.32	1,570	16.57	30.25
	Mean	8.09	1,618	10.18	25.71
	Median	8.12	1,620	10.06	25.78

The large dissolved oxygen percent saturation values at the Stillwell Crossing site indicate that there was likely more photosynthetic activity taking place in the reach at this site relative to the reaches at the other sites. Dissolved oxygen concentrations greater than 13.5 mg/L and 185 percent saturation were measured in two mesohabitats (a backwater and a forewater) at the Stillwell Crossing site. Temperatures of more than 4 degrees Celsius (°C) greater than the median temperatures for the reach at the site were measured in the backwater and forewater mesohabitats with dissolved oxygen concentrations greater than 13.5 mg/L, indicating that there was likely little mixing with the main channel, and the degree of photosynthetic activity was relatively large. The Contrabando and Santa Elena sites each contained a single backwater mesohabitat where dissolved oxygen concentrations were approaching anoxic conditions (1.83 and 0.96 mg/L at the Contrabando and Santa Elena sites, respectively) (U.S. Geological Survey, 2010). Because the temperatures in these two mesohabitats were elevated (more than 4 °C greater than the median temperatures for the overall reach at each of these sites), it is likely that there was little mixing between the backwater mesohabitat and the main channel and minimal photosynthetic activity in the backwater mesohabitat at these sites as indicated by the low (less than about 2 mg/L) dissolved oxygen concentrations measured during the day in these mesohabitats. The reach at the Santa Elena site contained two mesohabitats (an additional backwater and a forewater) with elevated dissolved oxygen concentrations compared to other slack water mesohabitats (greater than 10.9 mg/L and 150 percent saturation); each of these mesohabitats also had elevated temperatures (more than 4 °C greater than the median temperatures for the overall reach at each of these sites), indicating that there was likely little mixing among the backwater, forewater, and main channel mesohabitats; however, the large dissolved oxygen concentration indicated the potential for large photosynthetic activity in these mesohabitats at the Santa Elena site. In the larval stage, Rio Grande silvery minnow use shallow areas of the stream with little or no velocity. Rio Grande silvery minnow larvae feed on algae in shallow, low-velocity mesohabitats such as backwaters, forewaters, and embayments (Dudley and Platania, 1997), and these mesohabitats at the Santa Elena and Contrabando sites provide an important nursery habitat for this species.

The pH was relatively consistent at each of the four sites, with the median pH ranging from 7.91 at the Rio Grande Village site to 8.12 at the Stillwell Crossing site (table 4). Compared to the pH measured at the other three sites, the slightly smaller pH measured at the Rio Grande Village site might be caused by an influx of groundwater from natural hot springs observed discharging to the stream channel near this site, although this could not be determined by this study. A smaller pH (7.9) at the Rio Grande Village site compared to sites upstream and downstream of this location is consistent with results from river samples collected as part of a streamflow gains and losses and associated water-quality study completed in 2006 (Raines and others, 2012). At some sites, pH varied appreciably by mesohabitat type (table 4). For example, compared to the median pH of 8.12 at the Stillwell Crossing site, somewhat smaller pH values were measured in runs (7.82) and riffles (7.48), and the range in pH at this site was relatively large in both backwaters (7.73–8.95) and forewaters (7.95–8.32) (table 4; fig. 30). These relatively large pH ranges in backwaters and forewaters are likely related to somewhat supersaturated or undersaturated conditions with respect to dissolved oxygen concentrations, with larger dissolved oxygen concentrations occurring when the pH was near the upper end of its range in the backwaters and forewaters (Pankow, 1991).

Specific conductance was relatively consistent between the Contrabando site (median of 3,583 microsiemens per centimeter at 25 degrees Celsius [µs/cm at 25 °C]) and the Santa Elena site, the next site downstream (median of 3,667 µs/cm at 25 °C). Large differences in specific conductance were evident between the Santa Elena site and Rio Grande Village site (median of 1,949 µs/cm at 25 °C), which is downstream from the Santa Elena site. An influx of groundwater from a series of springs approximately 5 km upstream from the Rio Grande Village site may be partially responsible for the decrease in specific conductance at the Rio Grande Village site compared to the more upstream Santa Elena and Contrabando sites. A relatively small decrease in specific conductance was measured between the Rio Grande Village site and the Stillwell Crossing site (median of 1,620 µs/cm at 25 °C). Among the different mesohabitat types, specific conductance was generally consistent at each of the four sites (fig. 30).

Median water temperatures (table 4; fig. 30) during the low-flow regime were consistent in three of the four study reaches when considered as a whole (Contrabando site [26.74 °C], Santa Elena site [27.46 °C], and Stillwell Crossing site [25.78 °C]). The Rio Grande Village site had elevated temperature readings (median of 31.75 °C) compared to the other sites at least in part because of contributions from hot springs in and near this site. Among mesohabitat types, water temperatures generally were higher in mesohabitats typically associated with shallow, slow moving water, such as backwaters, forewaters, and embayments, at all of the study sites. At each of the four sites, the highest water temperatures were measured in backwater mesohabitats (32.96 °C at Contrabando, 35.88 °C at the Santa Elena site, 36.09 °C at the Rio Grande Village site, and 32.46 °C at the Stillwell Crossing site). Compared to other mesohabitat types, temperatures were generally lower at each of the sites in main-channel mesohabitats, such as pools (21.94 °C at the Contrabando site), riffles (24.48 °C at the Santa Elena site), and runs (28.68 °C at the Rio Grande Village site). An exception is the Stillwell Crossing site, where the lowest temperature was measured at 22.11 °C in a backwater that was likely shaded when the temperature was measured.

Fish Assemblage Composition and Habitat Associations

All data used in this section of the report are available in two tables in the geospatial database (fig. 11). All fish data are available in the “Fish Assemblage” attribute table in the geospatial database, and environmental data (depth, velocity, and substrate type) associated with seine hauls are available in the “Fish Habitat” attribute table, which is also in the geospatial database.

Twenty-one species of fish (table 5) were collected during the three flow regimes sampled. Fish-species richness, calculated herein as the total number of fish species collected during each sampling event, is a commonly used metric for comparing fish assemblages among sites and flow regimes (Ludwig and Reynolds, 1988). Fish-species richness ranged from 15 at the Contrabando site to 19 at the Santa Elena site. The largest number of fish (3,086 individuals) and highest fish-species richness (19) were collected at the Santa Elena site. These results are consistent with a baseline survey of fishes done in 1999 (Moring, 2002) that found larger numbers of fish and higher fish-species richness at a site that was also downstream from the confluence of Terlingua Creek and about 500 m downstream from the downstream end of the Santa Elena site used in this study. The higher fish-species richness and abundance values calculated for the Santa Elena site compared to upstream sampling sites were also consistent with the results of a study by Heard and others (2012) in which more fish species (18 species) were collected at a site downstream from the confluence of Terlingua Creek compared to upstream sampling sites. The smallest number of fish (1,909 individuals) collected during our study was at the Stillwell Crossing site followed by the Contrabando site (1,990 individuals) and the Rio Grande Village site (2,109 individuals).

Table 5. Fish species, number of individuals collected, and density of fish from four study sites colocated with experimental Rio Grande silvery minnow (*Hybognathus amarus*) release sites on the Rio Grande/Rio Bravo del Norte (Rio Grande) in and near Big Bend National Park, Texas, 2010–11.

[Family, a category comprising one or more species of common evolutionary origin; Species, a group of organisms recognized as evolutionarily distinct from other organisms; no., number; indivs., individuals; m^2, square meters; NA, not applicable]

			Contrabando site (table 1)		
Family	Species	Species common name	Total no. of indivs.	Total no. of indivs. from seine hauls[a]	Fish-species density from seine hauls (no. of fish per 100 m^2)[b]
Lepisosteidae	*Lepisosteus osseus*	Longnose gar	9	9	0.35
Clupeidae	*Dorosoma cepedianum*	Gizzard shad	105	105	4.13
Cyprinidae	*Cyprinella lutrensis*	Red shiner	822	813	31.98
	Cyprinus carpio	Common carp	455	455	17.90
	Hybognathus amarus	Rio Grande silvery minnow	12	12	0.47
	Macrhybopsis aestivalis	Speckled chub	43	42	1.65
	Notropis braytoni	Tamaulipas shiner	146	137	5.39
	Rhinichthys cataractae	Longnose dace	2	2	0.08
Atherinopsidae	*Menidia beryllina*	Inland silverside	0	0	0.00
Fundulidae	*Fundulus zebrinus*	Plains killifish	0	0	0.00
Catostomidae	*Carpiodes carpio*	River carpsucker	124	124	4.88
	Cycleptus elongatus	Blue sucker	72	71	2.79
	Ictiobus bubalus	Smallmouth buffalo	0	0	0.00
Characidae	*Astyanax mexicanus*	Mexican tetra	0	0	0.00
Ictaluridae	*Ictalurus furcatus*	Blue catfish	17	17	0.67
	Ictalurus punctatus	Channel catfish	41	36	1.42
	Pylodictis olivaris	Flathead catfish	4	3	0.12
Poeciliidae	*Gambusia affinis*	Western mosquitofish	135	135	5.31
Centrarchidae	*Lepomis macrochirus*	Bluegill	0	0	0.00
	Lepomis megalotis	Longear sunfish	3	3	0.12
Sciaenidae	*Aplodinotus grunniens*	Freshwater drum	0	0	0.00
Total no. of fish			1,990	1,964	NA
Total density (no. of fish per 100 m^2)			NA	NA	77.24
Total no. of species (fish-species richness)			15	15	NA

[a]The total number of individuals is the sum of fish collected by electrofishing and seine hauls.

[b]Density is determined by dividing the number of fish collected by seining by the total area seined in meters multiplied by 100 to report the density as number of fish in 100 m^2.

Santa Elena site (table 1)			Rio Grande Village site (table 1)			Stillwell Crossing site (table 1)				
Total no. of indivs.	Total no. of indivs. from seine hauls[a]	Fish-species density from seine hauls (no. of fish per 100 m^2)[b]	Total no. of indivs.	Total no. of indivs. from seine hauls[a]	Fish-species density from seine hauls (no. of fish per 100 m^2)[b]	Total no. of indivs.	Total no. of indivs. from seine hauls[a]	Fish-species density from seine hauls (no. of fish per 100 m^2)[b]	Total no. of indivs.	Relative abundance (percent)
17	11	0.50	18	18	0.67	25	25	0.95	69	0.76
11	8	0.36	1	1	0.04	2	2	0.08	119	1.31
1,367	1,325	60.08	456	439	16.43	534	534	20.34	3,179	34.96
583	583	26.44	17	17	0.64	64	64	2.44	1,119	12.30
21	21	0.95	3	3	0.11	3	3	0.11	39	0.43
55	55	2.49	8	8	0.30	20	19	0.72	126	1.39
415	410	18.59	1,103	1,032	38.61	555	553	21.07	2,219	24.40
11	10	0.45	47	47	1.76	8	8	0.30	68	0.75
1	0	0.00	0	0	0.00	0	0	0.00	1	0.01
0	0	0.00	3	3	0.11	2	2	0.08	5	0.05
383	381	17.28	232	232	8.68	161	161	6.13	900	9.90
182	180	8.16	2	2	0.07	8	8	0.30	264	2.90
0	0	0.00	0	0	0.00	1	1	0.04	1	0.01
1	1	0.05	14	14	0.52	39	39	1.49	54	0.59
7	4	0.18	11	4	0.15	23	21	0.80	58	0.64
11	6	0.27	24	21	0.79	3	3	0.11	79	0.87
6	5	0.23	4	4	0.15	3	3	0.11	17	0.19
11	11	0.50	142	142	5.31	389	389	14.82	677	7.44
1	0	0.00	0	0	0.00	0	0	0.00	1	0.01
2	2	0.09	24	24	0.90	69	69	2.63	98	1.08
1	0	0.00	0	0	0.00	0	0	0.00	1	0.01
3,086	3,013	NA	2,109	2,011	NA	1,909	1,904	NA	9,094	100.00
NA	NA	136.62	NA	NA	75.24	NA	NA	72.54	NA	NA
19	16	NA	17	17	NA	18	18	NA	21	NA

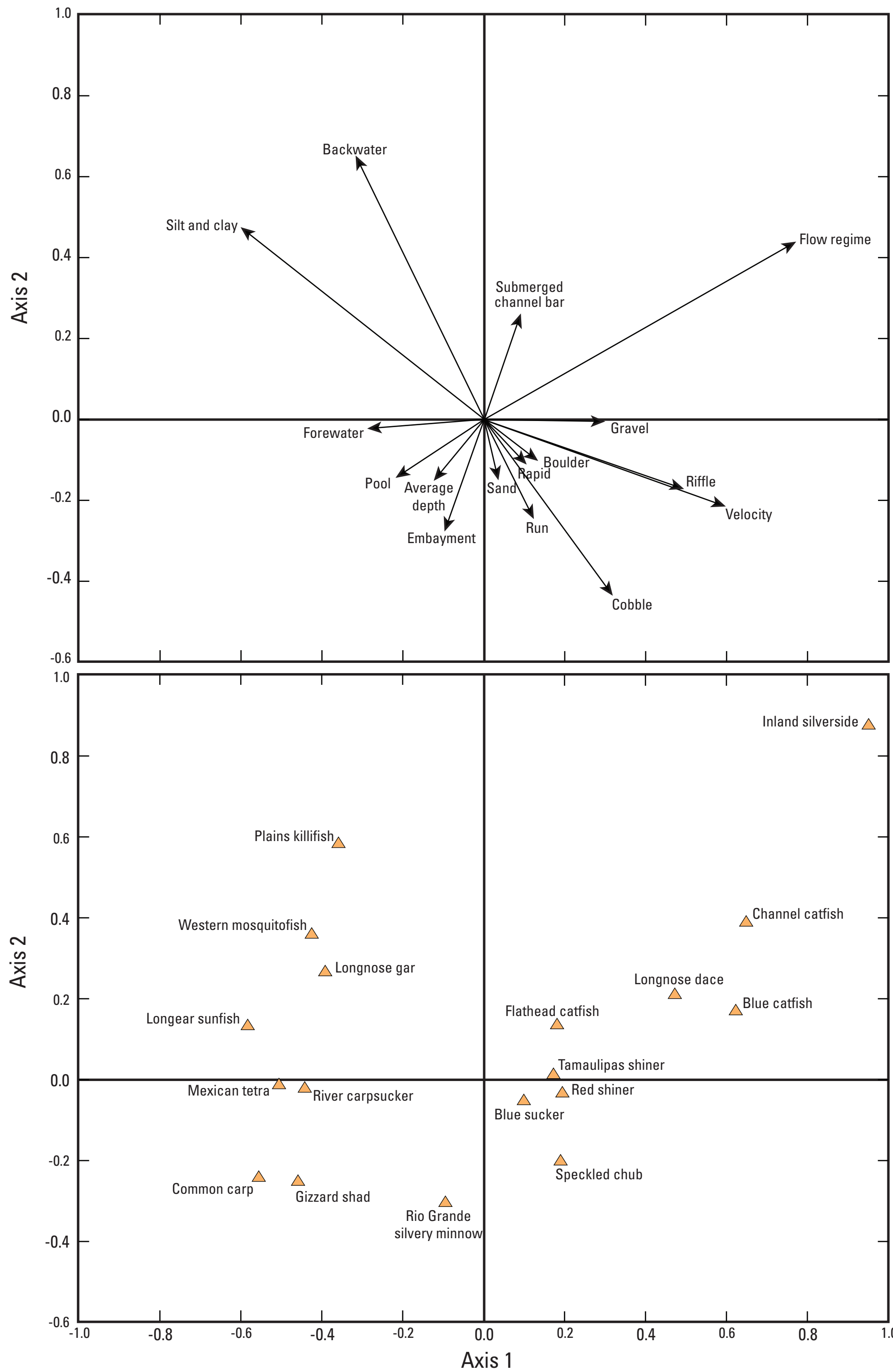
Red shiner (*Cyprinella lutrensis*) was the most abundant species overall, accounting for about 35 percent of all fish collected, and was the most abundant species at the Contrabando and Santa Elena sites (table 5). Another minnow, the endemic Tamaulipas shiner (*Notropis braytoni*), was second in overall relative abundance (about 24 percent) and was more abundant than the red shiner and all other species at the Rio Grande Village and Stillwell Crossing sites. Heard and others (2012) collected fish from seven Rio Grande sites in and near Big Bend National Park and similarly reported that red shiner was the most abundant (46 percent relative abundance) and that Tamaulipas shiner was second most abundant (35 percent relative abundance). Additionally, the red shiner was identified in a previous USGS study as the most abundant species at all sites surveyed on the Rio Grande in Big Bend National Park (Moring, 2002). The common carp (*Cyprinus carpio*), a nonnative species, was the third most abundant species overall but was much more abundant at the Contrabando and Santa Elena sites than at the Rio Grande Village and Stillwell Crossing sites. The majority of common carp and river carpsucker (*Carpiodes carpio*) collected in seine hauls were juveniles (Jason Remshardt, U.S. Fish and Wildlife Service, oral commun., 2013). The abundance of juvenile common carp, along with juvenile river carpsucker, western mosquitofish (*Gambusia affinis*), and several species of cyprinids (table 5), reflects a study design that included sampling fish in a large number of shallow, relatively low velocity near-shore habitats with small-mesh seines to increase the likelihood of collecting the Rio Grande silvery minnow. The Rio Grande silvery minnow was an uncommon species at all sites accounting for less than 1 percent of the combined total of individuals collected from all sites, as did freshwater drum (*Aplodinotus grunniens*), plains killifish (*Fundulus zebrinus*), smallmouth buffalo (*Ictiobus bubalus*), flathead catfish (*Pylodictis olivaris*), bluegill (*Lepomis macrochirus*), and inland silverside (*Menidia beryllina*) (table 5).

Relations between fish-species abundance and selected environmental variables (physical characteristic data collected at the mesohabitat scale [depth, velocity, and substrate particle size], flow regime, and mesohabitat types) were explored by using canonical correspondence analysis (CCA) (fig. 31). Each orange triangle in the CCA analysis represents a species' central tendency related to environmental variables graphically displayed on ordination gradients (axes 1 and 2 in fig. 31). Species that plot close together tended to be sampled in similar mesohabitat types with similar environmental variables (ter Braak and Verdonschot, 1995). To minimize effects of highly skewed distributions of species' abundances in the CCA model, data were logarithmically transformed (base 10), thereby increasing the number of values (n) by 1. Fish species that were collected infrequently were downweighted to prevent them from plotting as misleading outliers in the CCA model (Gauch, 1982). The chi-square distances for individual species in the CCA model are weighted by the inverse of the number of individuals of each species that was collected. As a result, species that were collected infrequently tend to be over-emphasized in the CCA model, and downweighting is used to correct this (Lepš and Šmilauer, 2003. To test significance ($p<0.05$) of variation, a Monte Carlo randomization test with 5,000 permutations was performed on the CCA model (ter Braak and Šmilauer, 2002).

Environmental variables explained 18.4 percent ($p<0.01$) of the variability in Rio Grande fish assemblage (fig. 31). Environmental variables strongly associated with CCA axis 1 were flow regime (0.77), velocity (0.58), riffles (0.48), and occurrence of backwaters (-0.32) with silt and clay (-0.60). Environmental variables strongly associated with CCA axis 2 were backwaters (0.65) with silt and clay (0.47), flow regime (0.43), and cobble (-0.43). Among fishes associated with CCA axes 1 and 2, inland silverside (*Menidia beryllina*), channel catfish (*Ictalurus punctatus*), blue catfish (*Ictalurus furcatus*), and longnose dace (*Rhinichthys cataractae*) were collected most frequently when flows were high. Heard and others (2012) observed similar increases in inland silverside, channel catfish, and blue catfish below reservoirs and attributed their relatively high numbers to water releases. Fishes associated with low-velocity mesohabitats, such as plains killifish (*Fundulus zebrinus*), western mosquitofish (*Gambusia affinis*), and longnose gar (*Lepisosteus osseus*), were most common during low flow in backwaters with silt and clay (fig. 31). Rio Grande silvery minnows were generally and positively associated with pools, embayments, and depth. Abundant fishes, such as red shiner and Tamaulipas shiner, were ubiquitously distributed among most habitat types but with a central tendency for moderately swift currents and shallow depths in runs and riffles with gravel, cobble, and sand substrates.

Fish collected by seining and by boat electrofishing were included in fish-species richness calculations. Fish-species richness varied among sites and flow regimes but was typically highest at all sites during low flow (fig. 32). Among the sites, a minimum of 9 species was identified during the high flow regime and a maximum of 16 species during the low flow regime at the Rio Grande Village site. Compared to the Rio Grande Village site, fish-species richness was much less variable among flow regimes at the Contrabando and Stillwell Crossing sites, ranging from 11 to 12 species at these sites during the different flow regimes. The tendency to observe larger fish-species richness values during low flow compared to intermediate and high flow can in part be explained by differences in sampling efficiency (better access to the river channel and to most mesohabitats during the low-flow regime compared to the other flow regimes).

Kruskal-Wallis test results ($p=0.134$) indicated that fish-species richness values were similar among mesohabitat types (fig. 33). Statistical analyses of fish-species richness by mesohabitat at different flow regimes were not done because sample sizes were small; however, some general observations were made regarding fish-species richness in mesohabitats during different flow regimes. Median fish-species richness and maximum fish-species richness values were larger and fish-species richness was more variable in runs, pools, forewaters, and backwaters during low flow compared to the fish-species richness values calculated for intermediate and high flows (fig. 34). Fish-species richness among mesohabitat types was lower overall and less variable during intermediate and high flows compared to low flow.



EXPLANATION

- △ **Fish species**
- ↙ **Environmental variables**

Sediment categories (size in millimeters)—
Modified from Wentworth, 1922; Guy, 1969
Boulder (greater than 256)
Cobble (greater than 64 and less than or equal to 256)
Gravel (greater than 2 and less than or equal to 64)
Sand (greater than 0.0625 and less than or equal to 2)
Silt and clay (less than or equal to 0.0625)

NOTE: The overall similarity of fish species to mesohabitat type and selected environmental variables (depth, velocity, and substrate size) is graphically depicted by using species and mesohabitat type scores arrayed along synthetic ordination axes derived by the canonical correspondence analysis (CCA). Each species point corresponds to the weighted average score of the axis scores of the mesohabitats where the species occurred. Scores for mesohabitats correspond to the coordinates of the mesohabitats on the best or, in this case, first two axes derived by the CCA. The environmental variables are displayed as arrows from the origin of the diagram, the coordinates of which are the correlations of the variable with the axes (ter Braak and Verdonschot, 1995).

NOTE: Scientific names corresponding to the common names shown here are provided in table 5.

Figure 31. Canonical correspondence analysis ordination biplot showing correlation between fish species and mesohabitats and between fish species and three environmental variables at four study sites colocated with experimental Rio Grande silvery minnow (*Hybognathus amarus*) release sites on the Rio Grande/Rio Bravo del Norte in and near Big Bend National Park, Texas, 2010–11.

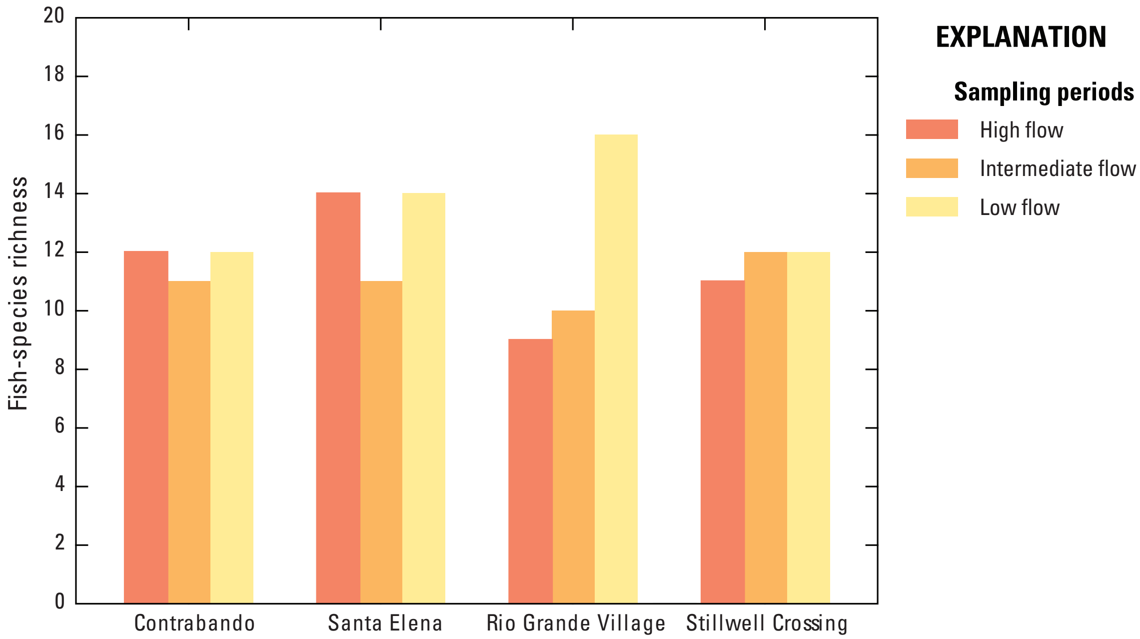


Figure 32. Fish-species richness during three flow regimes at four study sites colocated with experimental Rio Grande silvery minnow (*Hybognathus amarus*) release sites on the Rio Grande/Rio Bravo del Norte in and near Big Bend National Park, Texas, 2010–11.

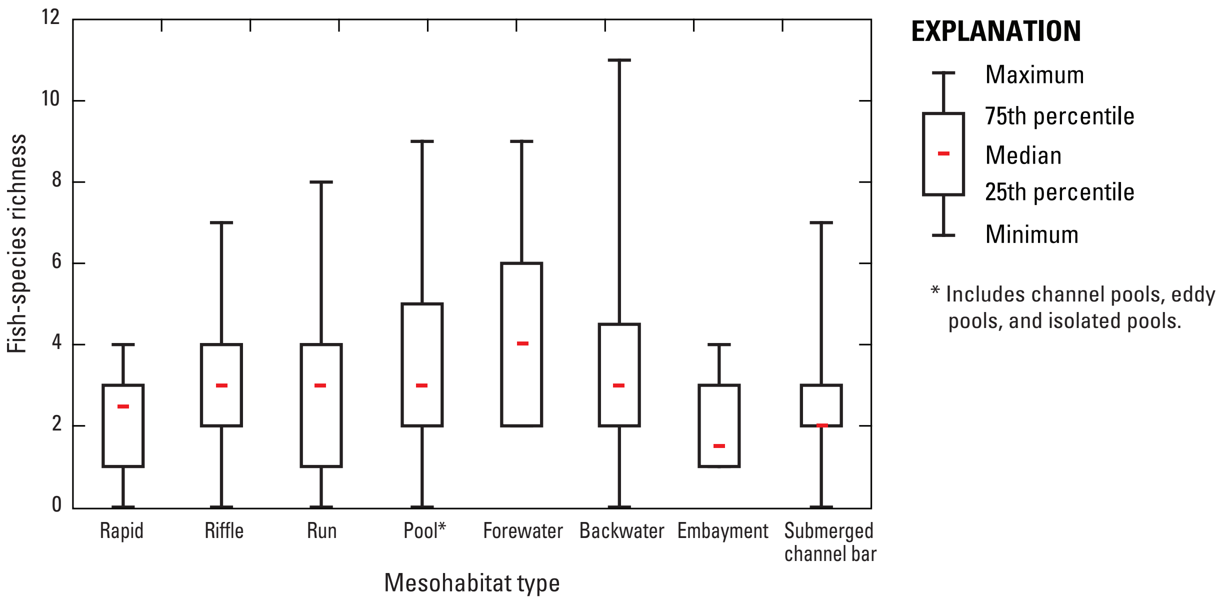


Figure 33. Fish-species richness by mesohabitat type from four study sites colocated with experimental Rio Grande silvery minnow (*Hybognathus amarus*) release sites on the Rio Grande/Rio Bravo del Norte in and near Big Bend National Park, Texas, 2010–11.

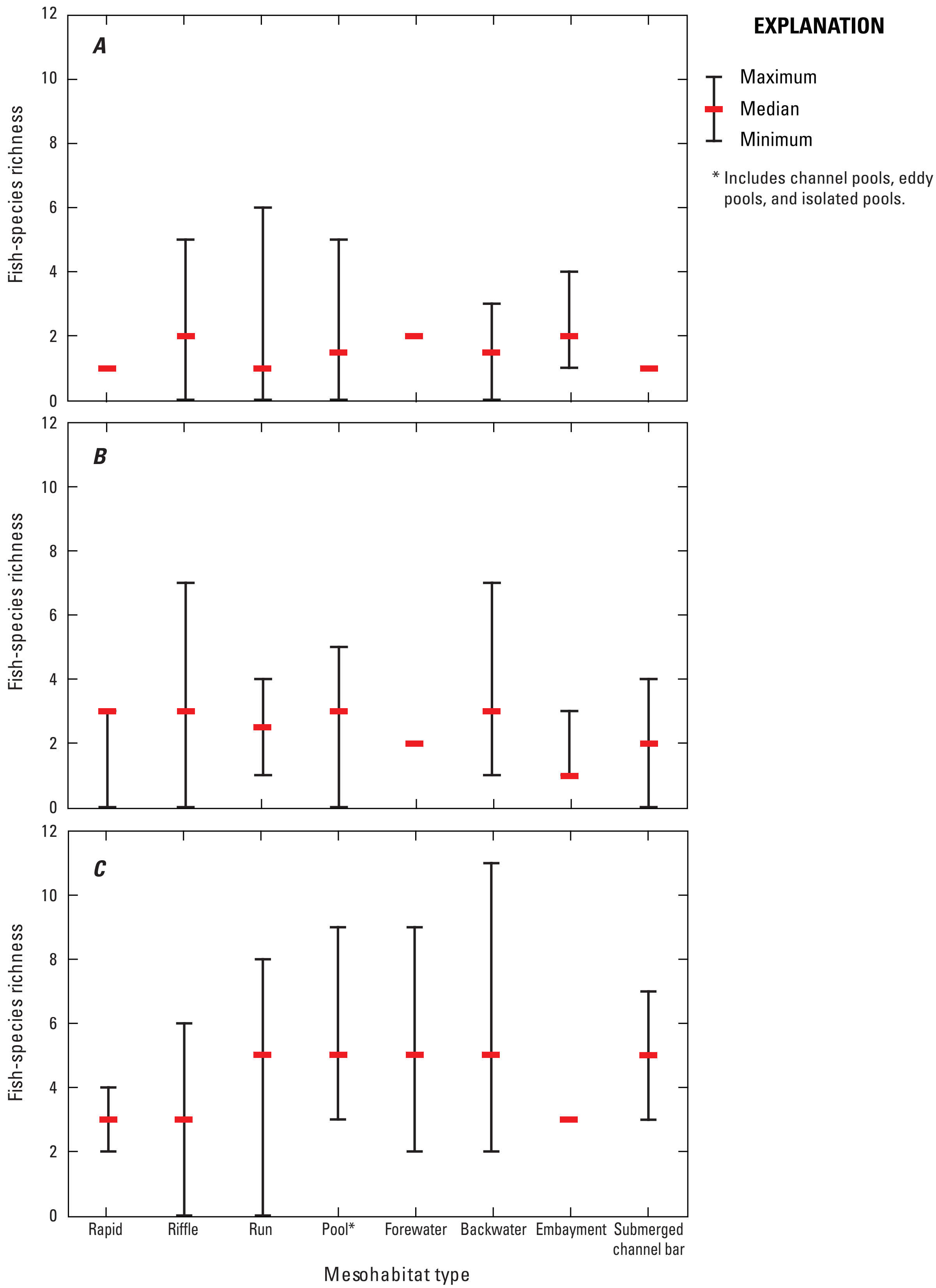


Figure 34. Fish-species richness by mesohabitat type and flow regime from four study sites colocated with experimental Rio Grande silvery minnow (*Hybognathus amarus*) release sites on the Rio Grande/Rio Bravo del Norte in and near Big Bend National Park, Texas, 2010–11. *A*, High flow. *B*, Intermediate flow. *C*, Low flow.

Total fish densities were calculated with seine haul data and do not include boat electrofishing data. Compared to low and high flows, total fish density was largest during intermediate flow at all sites except the Rio Grande Village site (fig. 35). Total fish densities ranged from a minimum of about 16 fish per 100 m^2 at the Stillwell Crossing site during high flow to a maximum of about 180 fish per 100 m^2 at the Santa Elena site during intermediate flow. Total fish densities were smallest for collections made during high flow and were generally about 3–10 times larger during intermediate and low flows. The smaller total fish densities measured during high flow might have been caused by differences in sampling efficiency, as discussed previously in reference to fish-species richness.

Kruskal-Wallis test results indicated that total fish density was significantly different among only two of the mesohabitat types ($p<0.01$). Tukey-type multiple comparison test results indicated that total fish density in backwater mesohabitats was significantly different ($p<0.01$) compared to total fish densities in run mesohabitats (fig. 36), and total fish density was not significantly different between other mesohabitat types.

Statistical analyses of total fish density by mesohabitat at different flow regimes were not done because the sample size was too small. Although sample size was small, some observations regarding total fish density in mesohabitats during the different flow regimes can be made. Total fish densities were larger and more variable during low and intermediate flows compared to total fish densities measured during high flow (fig. 37). The largest total fish density was measured in backwater mesohabitats during intermediate flow (2,190 fish per 100 m^2), and the smallest total fish densities (0 fish per 100 m^2) were measured for several mesohabitats during all flow regimes. Total fish densities were generally smaller in all mesohabitats during high flow, which can be attributed to the smaller number of shallow, low-velocity mesohabitats such as backwaters and forewaters present during this flow regime (fig. 12). The majority of backwaters and forewaters were inundated during high flow (figs. 14, 17, 20, and 23), and fewer of these mesohabitats were mapped during high flow.

Mesohabitat Use by Rio Grande Silvery Minnow

Among the 39 Rio Grande silvery minnow collected during the study, 21 (more than half) were collected at the Santa Elena site, 12 were collected at the Contrabando site, and 3 each at the Rio Grande Village and Stillwell Crossing sites (table 5). Fish-species density of the Rio Grande silvery minnow was largest at the Santa Elena site (0.95 fish per 100 m^2). At the other three sites, fish-species density of the Rio Grande silvery minnow ranged from 0.11 to 0.47 fish per 100 m^2. The small number of Rio Grande silvery minnow collected during this study (and correspondingly small fish-species densities) was not unexpected because the USFWS was in only the third year of the experimental reintroduction of this species into the Big Bend study reach of the Rio Grande when the first of the fish surveys described in this report was completed in 2010.

Rio Grande silvery minnows were most common in pools and runs (table 6) during low and intermediate flows. This species was less commonly collected in backwaters, embayments, and rapids, and none were collected from forewaters or submerged channel bars. No Rio Grande silvery minnow individuals were collected in any mesohabitats during the high-flow regime.

The Tamaulipas shiner has similar life-history characteristics compared to the Rio Grande silvery minnow, including similar feeding habits and habitat use (Gilbert, 1980; Thomas and others, 2007). Tamaulipas shiner was most common in backwater, run, and riffle mesohabitats (in decreasing order) during low and intermediate flow (table 6) and was less common in submerged channel bar, pool, forewater, rapid, and embayment mesohabitats (in decreasing order) during the same flows. Of the 200 Tamaulipas shiner individuals collected during high flow, the majority (156) were collected in run mesohabitats.

Total number of individuals and density of Rio Grande silvery minnow (*Hybognathus amarus*) and Tamaulipas shiner (*Notropis braytoni*), area seined, and total wetted area by mesohabitat type and flow regime from four sites (Contrabando, Santa Elena, Rio Grande Village, and Stillwell Crossing) colocated with Rio Grande silvery minnow release sites in the Rio Grande/Rio Bravo del Norte (Rio Grande) in and near Big Bend National Park, Texas, 2010–11.

The rank order of Rio Grande silvery minnow density by mesohabitat type and flow regime was the same as or similar to the rank order of abundance, with the exception of the comparatively low density of 0.30 Rio Grande silvery minnow per 100 m^2 in runs and the comparatively large density of 0.82 Rio Grande silvery minnow per 100 m^2 in rapids (table 6). There were 14 Rio Grande silvery minnows collected in runs, but because of the relatively large area seined in runs (about 4,627 m^2) compared to the seined area of all other mesohabitats combined (about 5,363 m^2), the density of Rio Grande silvery minnow was relatively small in this mesohabitat. Only one Rio Grande silvery minnow was collected in rapids, and the relatively high density of Rio Grande silvery minnow in this mesohabitat is explained by the small total area (121 m^2) seined in rapids among the sites during the three different flow regimes (table 6) compared to the seined area of other mesohabitats.

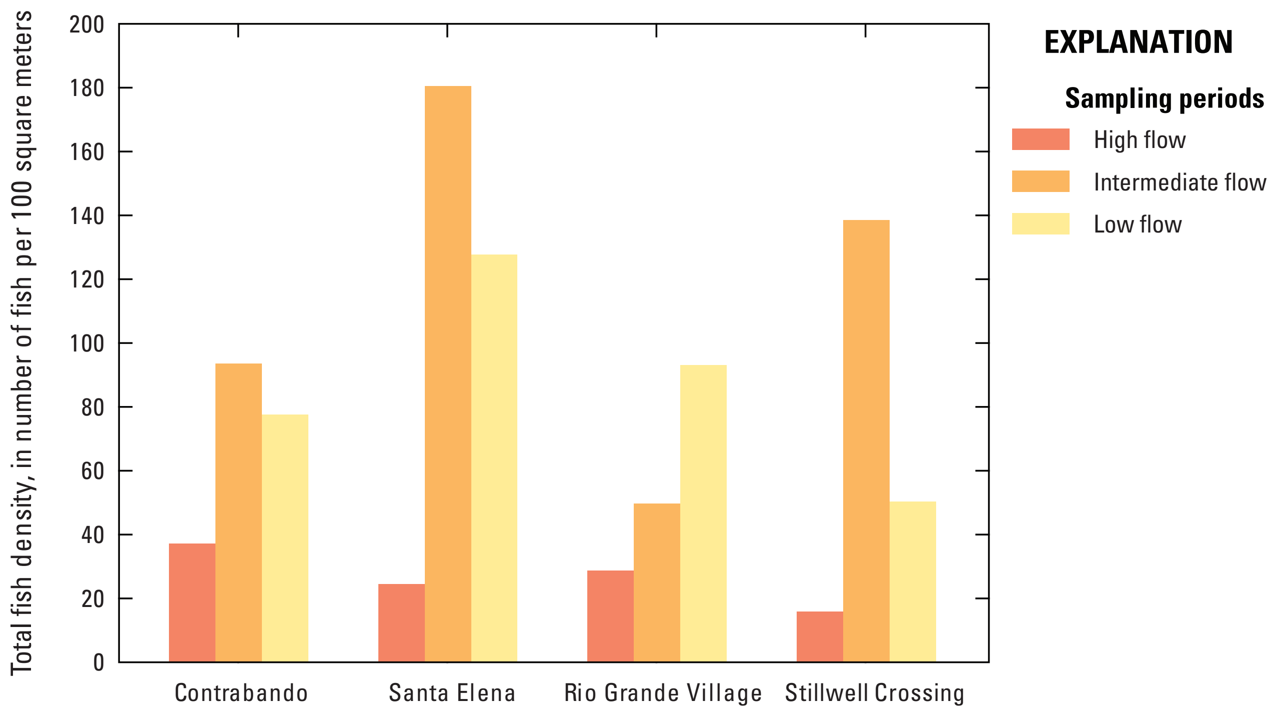


Figure 35. Total fish density during three flow regimes from four study sites colocated with experimental Rio Grande silvery minnow (*Hybognathus amarus*) release sites on the Rio Grande/Rio Bravo del Norte in and near Big Bend National Park, Texas, 2010–11.

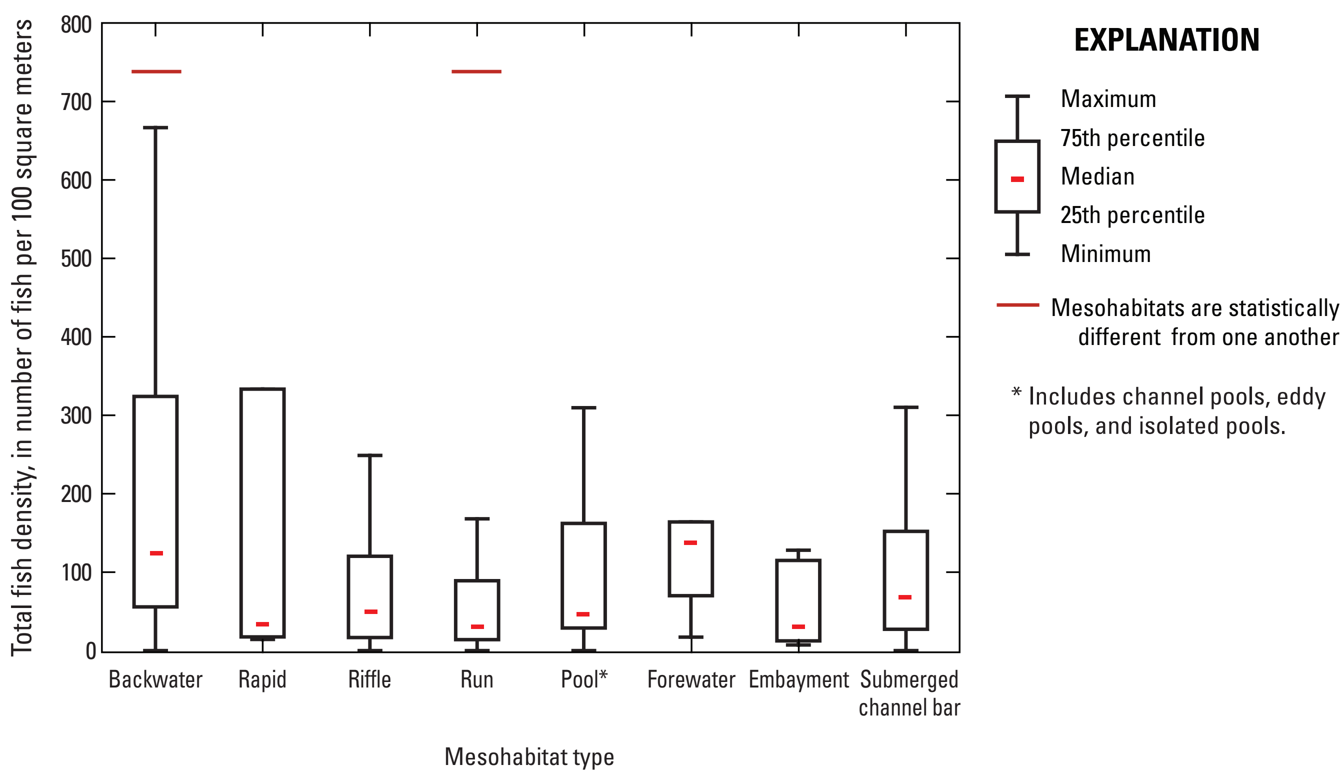


Figure 36. Total fish density by mesohabitat type at four study sites colocated with experimental Rio Grande silvery minnow (*Hybognathus amarus*) release sites on the Rio Grande/Rio Bravo del Norte in and near Big Bend National Park, Texas, 2010–11.

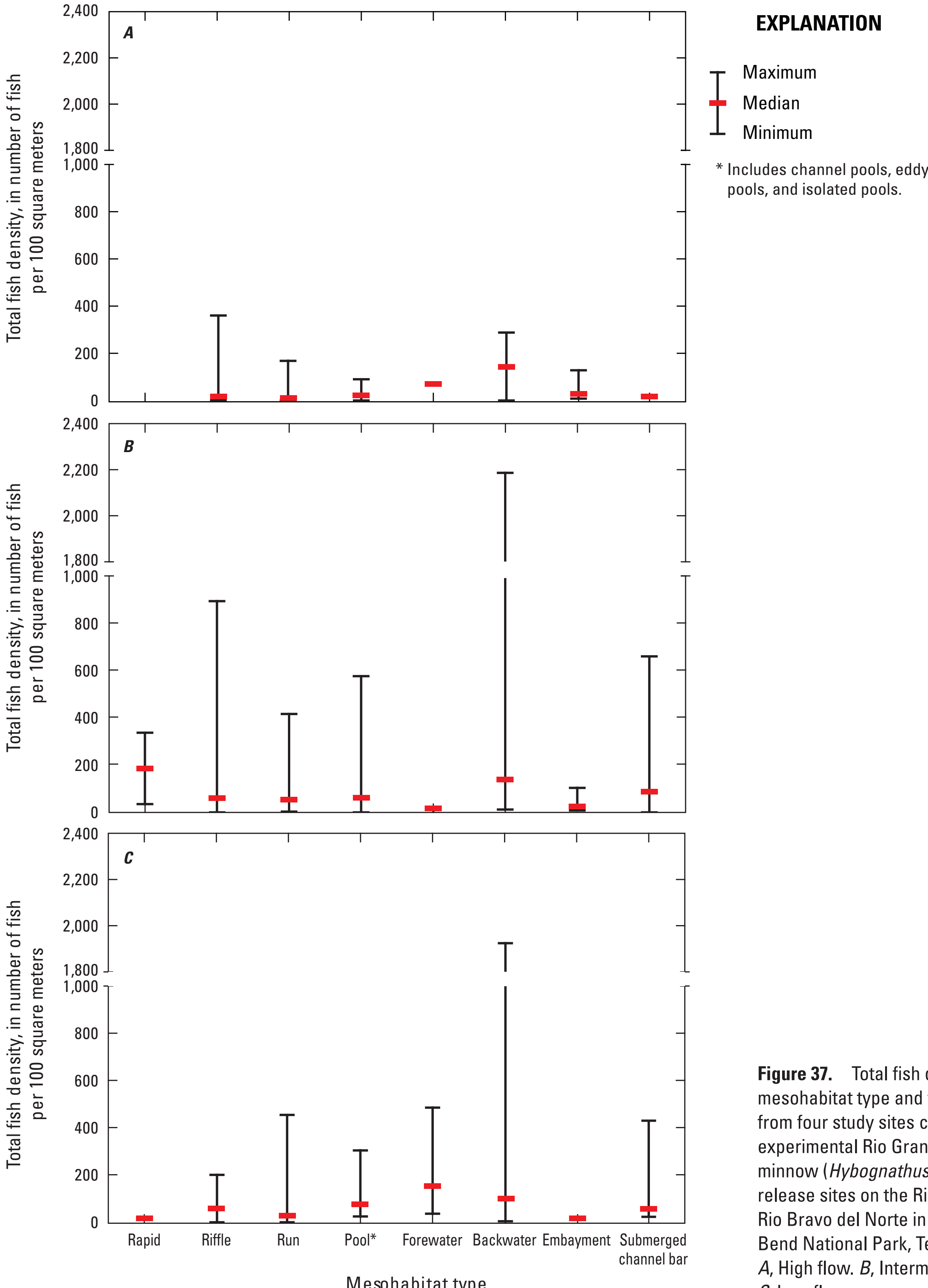


Figure 37. Total fish density by mesohabitat type and flow regime from four study sites colocated with experimental Rio Grande silvery minnow (*Hybognathus amarus*) release sites on the Rio Grande/Rio Bravo del Norte in and near Big Bend National Park, Texas, 2010–11. *A*, High flow. *B*, Intermediate flow. *C*, Low flow.

In addition to evaluating abundance and density, mesohabitat use by Rio Grande silvery minnow and Tamaulipas shiner was compared by using relative percent density, calculated as follows:

$$\text{Relative percent density} = (d_s/D_t)\times 100,$$

where

d_s = fish-species density (number of fish of a given species/100 m^2) in the mesohabitat, and

D_t = total fish density (total number of fish from all species/100 m^2) in the mesohabitat.

Overall relative percent density (composite of all three flow regimes) was largest in rapid and pool mesohabitats for the Rio Grande silvery minnow and in backwater mesohabitats for Tamaulipas shiner (fig. 38). The overall relative percent density of Rio Grande silvery minnow in pools (1.20) was about 11 percent of the overall relative percent density of Tamaulipas shiner in pools (11.22), and the overall relative percent density of Rio Grande silvery minnow in embayments (0.91) was about 7 percent of the overall relative percent density of Tamaulipas shiner in embayments (12.73). In all other mesohabitats, the overall relative percent densities of Rio Grande silvery minnow were less than 3 percent of the overall relative percent densities of Tamaulipas shiner. Overall relative percent densities of Rio Grande silvery minnow were small in shallow, low-velocity mesohabitats including backwaters, forewaters, and submerged channel bars.

No Rio Grande silvery minnows and only a small number of Tamaulipas shiners were collected during high flow compared to the other flow regimes, resulting in less meaningful relative percent density data for this regime (fig. 39*A*). Smaller and shallower mesohabitats including backwaters, embayments, riffles, and many smaller pools were largely absent (figs. 14, 17, 20, and 23) during high flow because the river was deeper and swifter during this flow regime. Relative percent density of Rio Grande silvery minnow was largest in rapid and pool mesohabitats during intermediate flow (fig. 39*B*) and was largest in pools and embayments during low flow (fig. 39*C*). Relative percent density of Tamaulipas shiner was largest in rapid and riffle mesohabitats during intermediate flow (fig. 39*B*) and was largest in riffle and backwater mesohabitats during low flow (fig. 39*C*).

Stream velocities associated with seine hauls of Rio Grande silvery minnow and Tamaulipas shiner were not significantly different (Kruskal-Wallis analysis; p=0.151). Stream velocities (fig. 40*A*) associated with the collection of the Rio Grande silvery minnow indicate that this species is predominantly found in low-velocity mesohabitats. The 25th–75th percentile range of stream velocities where Rio Grande silvery minnows were collected was 0.10–1.18 ft/s, and most stream velocities were less than 1 ft/s in seine hauls that included individuals of this species. One Rio Grande silvery minnow was collected in a rapid (velocity of 2.39 ft/s) at the Contrabando site in one seine haul, but all other collections of Rio Grande silvery minnows were from seine hauls where velocities were between -0.01 and 1.93 ft/s—a range of velocities more characteristic of riffle, run, and pool mesohabitats than of rapid mesohabitats Negative velocities were recorded in some in-channel pools because of the circulation of water in these mesohabitats. Stream velocities associated with seine hauls of Tamaulipas shiner represented a much broader overall range (minimum of 0 ft/s and maximum of 4.51 ft/s) than those associated with Rio Grande silvery minnow collections (fig. 40*A*). The broader distribution of stream velocities associated with collections of Tamaulipas shiner likely reflects the relatively large abundance of this species during the low- and intermediate-flow regimes compared to the abundance of this species during the high-flow regime and the observation that Tamaulipas shiner inhabits a broader range of mesohabitats with larger stream velocities than Rio Grande silvery minnow typically inhabits (Heard and others, 2012). Similar to the Rio Grande silvery minnow, the Tamaulipas shiner was most frequently collected in low-velocity mesohabitats. The largest number of seine hauls that included Tamaulipas shiner occurred where velocity ranged from 0.16 to 1.54 ft/s (the 25th–75th percentile for velocity measurements where this species was collected) (fig. 40*A*).

Depths associated with seine hauls (fig. 40*B*) of Rio Grande silvery minnow and Tamaulipas shiner were not significantly different (Kruskal-Wallis analysis; p=0.819). Depths for Rio Grande silvery minnow ranged from a maximum 3.00 ft to a minimum of 0.40 ft, with the largest number of observations (seven) occurring in the depth interval 0.0–0.50 ft. Not only were the majority of Rio Grande silvery minnow individuals collected in low-velocity pool and run mesohabitats, but these fish were also collected from relatively shallow pool and run mesohabitats. Depths associated with the collection of Tamaulipas shiner ranged from 0.1 to 4.9 ft, and the majority of depths associated with the collection of Tamaulipas shiner were also shallow: 121 of 162 seine hauls that included Tamaulipas shiner were less than 1.5 ft in depth.

Of the seine hauls that included collections of Rio Grande silvery minnow, 53 percent were from mesohabitats dominated by cobble substrates consisting of particles greater than 64 mm and less than or equal to 256 mm in size (Wentworth, 1922; Guy, 1969); 32 percent of the seine hauls were from mesohabitats dominated by fine-sized silt and clay particles; 10 percent of the seine hauls were from mesohabitats dominated by gravel; and 5 percent were collected from mesohabitats dominated by sand (fig. 41). In contrast with these findings, Remshardt (2008) reported for sampling sites on the Rio Grande in New Mexico that the Rio Grande silvery minnows were typically associated with sand and silt substrates and were less frequently collected

Table 6. Total number of individuals and density of Rio Grande silvery minnow (*Hybognathus amarus*) and Tamaulipas shiner (*Notropis braytoni*), area seined, and total wetted area by mesohabitat type and flow regime from four sites (Contrabando, Santa Elena, Rio Grande Village, and Stillwell Crossing) colocated with Rio Grande silvery minnow release sites in the Rio Grande/Rio Bravo del Norte (Rio Grande) in and near Big Bend National Park, Texas, 2010–11.

[no., number; m^2, square meters; BW, backwater; EM, embayment; FW, forewater; PL, pool; RL, riffle; RN, run; RP, rapid; SB, submerged channel bar]

Mesohabitat	Flow event	Total no. of Rio Grande silvery minnow	Total no. of Tamaulipas shiner	Total no. of fish
RP	Low	0	2	13
RP	Intermediate	1	32	96
RP	High	0	0	0
Total		1	34	109
RL	Low	0	202	391
RL	Intermediate	6	217	773
RL	High	0	11	60
Total		6	430	1,224
RN	Low	12	208	1,385
RN	Intermediate	2	163	838
RN	High	0	156	154
Total		14	527	2,377
PL	Low	8	40	812
PL	Intermediate	8	105	477
PL	High	0	4	39
Total		16	149	1,328
FW	Low	0	39	632
FW	Intermediate	0	1	8
FW	High	0	23	28
Total		0	63	668
BW	Low	0	636	1,150
BW	Intermediate	1	166	693
BW	High	0	3	36
Total		1	805	1,879
EM	Low	1	0	31
EM	Intermediate	0	11	40
EM	High	0	3	39
Total		1	14	110
SB	Low	0	78	191
SB	Intermediate	0	91	707
SB	High	0	0	1
Total		0	169	899
Overall total		39	2,191	8,594

[a]Density was determined by dividing the total number of fish collected by the total area (in square meters) seined multiplied by 100.

[b]Less than values were not used in totals.

Rio Grande silvery minnow density (no. of fish per 100 m²)[a]	Tamaulipas shiner density (no. of fish per 100 m²)[a]	Total fish density (no. of fish per 100 m²)[a]	Seined area (m²)	Total wetted area of mesohabitat (m²)
0.00	2.61	16.96	76.64	357.80
2.23	71.43	214.29	44.80	1,398.10
0.00	0.00	0.00	0.00	4,241.20
0.82	28.00	89.76	121.44	5,997.10
0.00	33.50	64.85	602.90	10,859.40
0.90	32.45	115.58	668.80	17,371.50
0.00	2.73	14.91	402.50	49,554.60
0.36	25.68	73.11	1,674.20	77,785.50
0.37	6.44	42.90	3,228.40	71,793.60
0.19	15.81	81.28	1,031.00	94,392.00
0.00	42.45	41.90	367.50	143,839.60
0.30	11.39	51.37	4,626.90	310,025.20
1.03	5.13	104.17	779.50	34,796.80
1.85	24.29	110.34	432.30	8,988.20
0.00	2.13	20.80	187.50	3,331.80
1.14	10.65	94.90	1,399.30	47,116.80
0.00	11.92	193.21	327.10	549.40
0.00	2.15	17.20	46.50	<10[b]
0.00	57.50	70.00	40.00	<10[b]
0.00	15.23	161.51	413.60	549.40
0.00	129.03	233.31	492.90	1,752.80
0.34	56.95	237.74	291.50	1,881.60
0.00	8.00	96.00	37.50	766.40
0.12	97.94	228.62	821.90	4,400.80
0.58	0.00	17.88	173.40	421.00
0.00	11.42	41.54	96.30	873.00
0.00	5.22	67.83	57.50	<10[b]
0.31	4.28	33.62	327.20	1,294.00
0.00	38.63	94.60	201.90	7,839.30
0.00	22.99	178.63	395.80	13,563.30
0.00	0.00	13.33	7.50	643.10
0.00	27.92	148.55	605.2	22,045.70
0.40	21.75	84.07	9,989.74	469,214.5

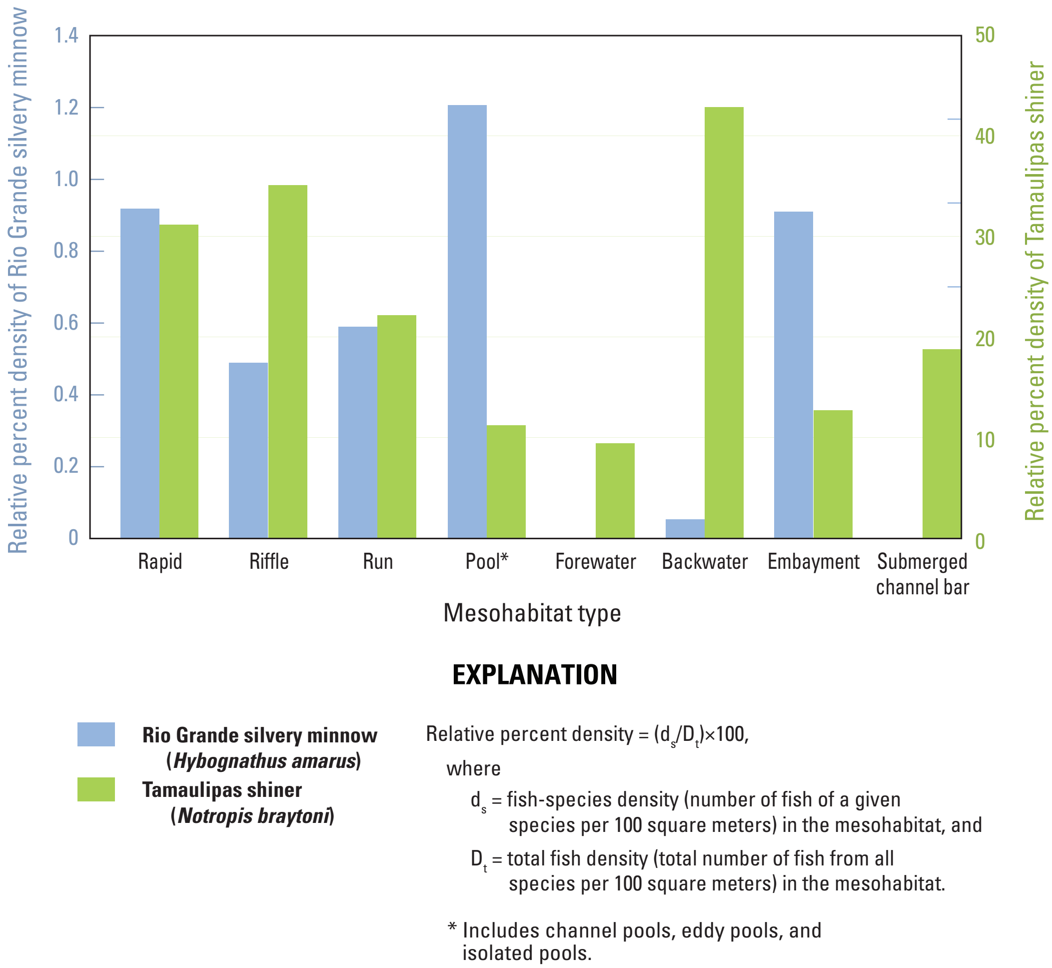
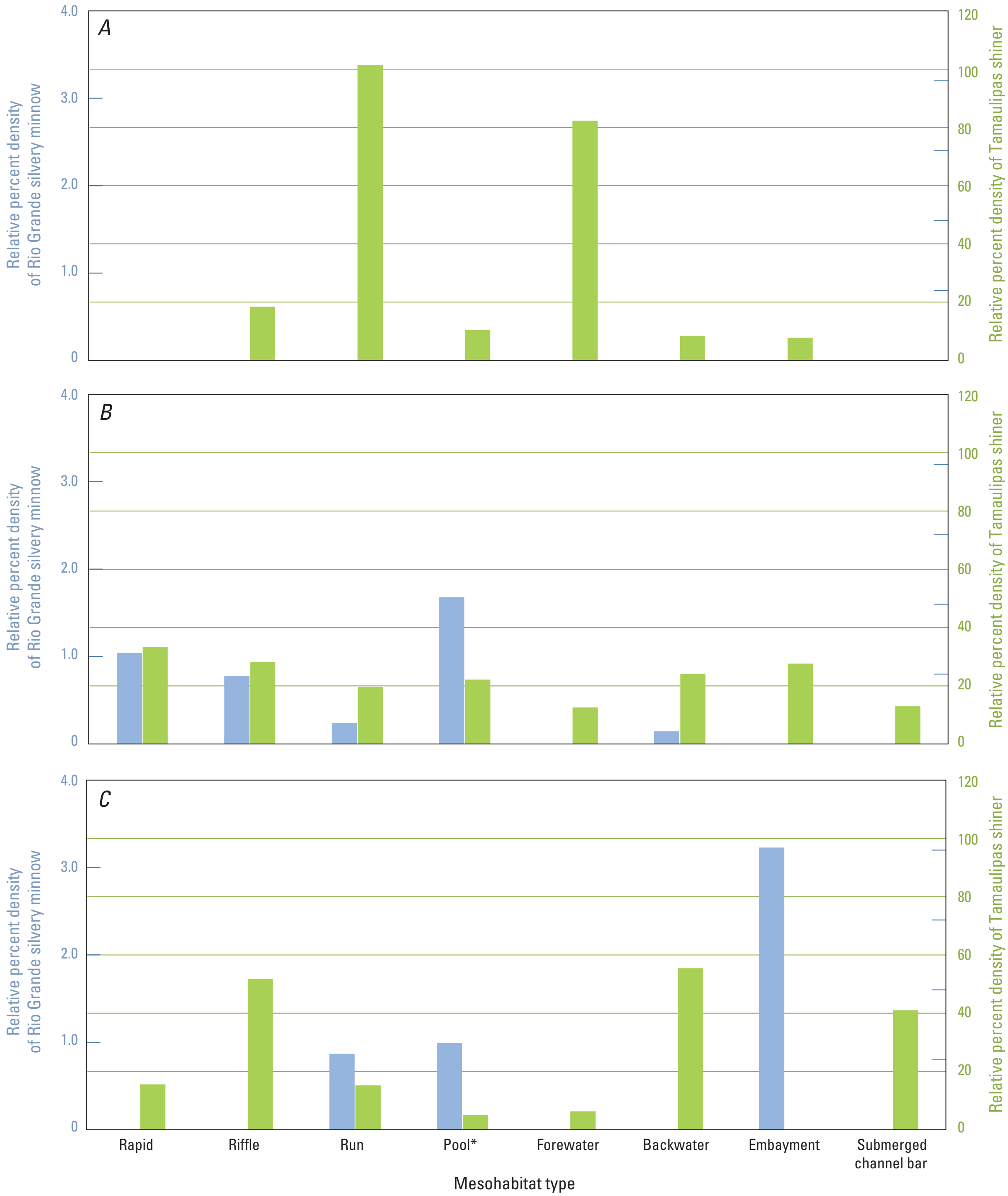


Figure 38. Relative percent density of Rio Grande silvery minnow (*Hybognathus amarus*) and Tamaulipas shiner (*Notropis braytoni*) by mesohabitat type at four study sites colocated with experimental Rio Grande silvery minnow release sites on the Rio Grande/Rio Bravo del Norte in and near Big Bend National Park, Texas, 2010–11.



EXPLANATION

Rio Grande silvery minnow (*Hybognathus amarus*)	Blue bar
Tamaulipas shiner (*Notropis braytoni*)	Green bar

Relative percent density = $(d_s/D_t) \times 100$,

where

d_s = fish-species density (number of fish of a given species per 100 square meters) in the mesohabitat, and

D_t = total fish density (total number of fish from all species per 100 square meters) in the mesohabitat.

* Includes channel pools, eddy pools, and isolated pools.

Figure 39. Relative percent density of Rio Grande silvery minnow (*Hybognathus amarus*) and Tamaulipas shiner (*Notropis braytoni*) by mesohabitat type and flow regime at four study sites colocated with experimental Rio Grande silvery minnow release sites on the Rio Grande/Rio Bravo del Norte in and near Big Bend National Park, Texas, 2010–11. *A*, High flow. *B*, Intermediate flow. *C*, Low flow.

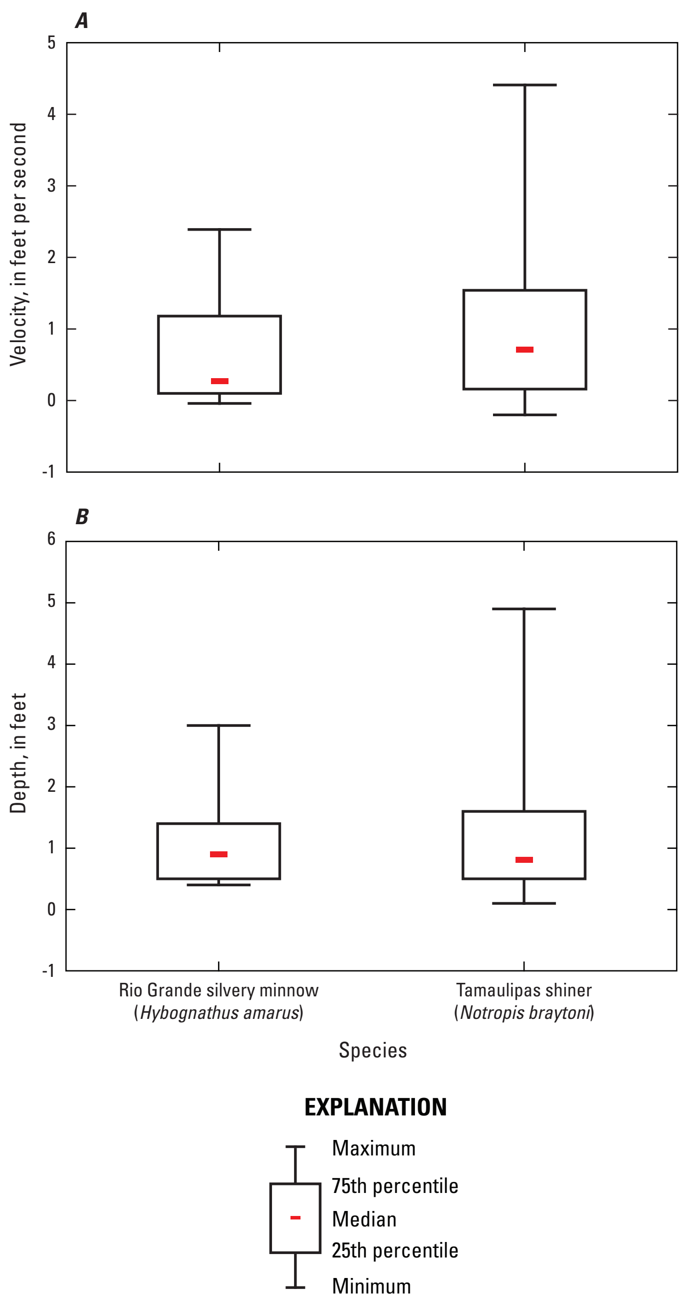


Figure 40. Velocities and depths associated with the collection of Rio Grande silvery minnow (*Hybognathus amarus*) and Tamaulipas shiner (*Notropis braytoni*) from four study sites colocated with experimental Rio Grande silvery minnow release sites on the Rio Grande/Rio Bravo del Norte in and near Big Bend National Park, Texas, 2010–11. *A*, Stream velocities. *B*, Water depths.

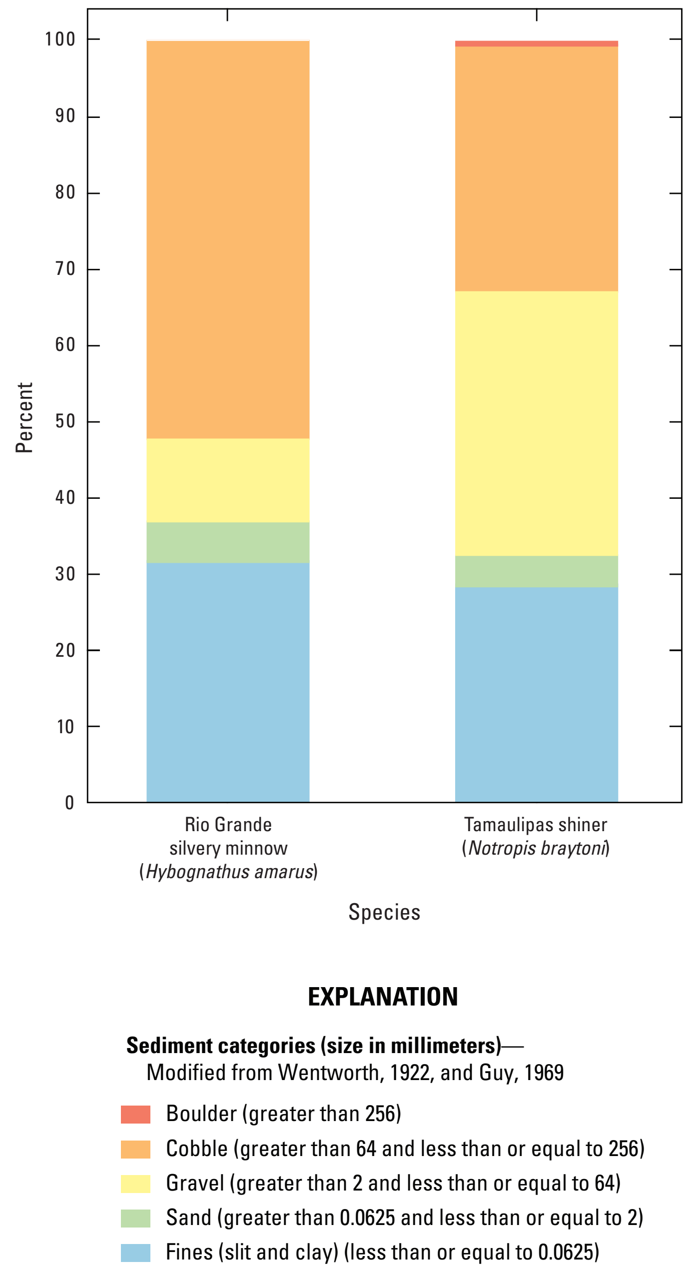


Figure 41. Percent by sediment particle type associated with collections of Rio Grande silvery minnow (*Hybognathus amarus*) and Tamaulipas shiner (*Notropis braytoni*) from four study sites colocated with experimental Rio Grande silvery minnow release sites on the Rio Grande/Rio Bravo del Norte in and near Big Bend National Park, Texas, 2010–11.

in mesohabitats dominated by gravel or cobble. In addition, Dudley and Platania (1997) observed free-swimming larval stages of the Rio Grande silvery minnow associated with shallow, low-velocity mesohabitats dominated by silt substrates composed of fine-sized silt and clay particles or substrates composed of a mixture of fine- and sand-sized particles. The combination of a small sample size (n=39) of Rio Grande silvery minnow in the Big Bend reach and the differences in geomorphic characteristics and associated bed materials between the study sites in New Mexico and Texas may account for the association of Rio Grande silvery minnow with larger substrates (for example, gravel and cobble) in the Big Bend reach compared to the finer bed materials (sand and silt) associated with Rio Grande silvery minnow in the Rio Grande in New Mexico. In contrast to the Rio Grande silvery minnow collections, Tamaulipas shiner collections were relatively evenly distributed among substrates consisting of gravel (34 percent), cobble (33 percent), and silt and clay (28 percent). Four percent of Tamaulipas shiner individuals were associated with a mesohabitat dominated by sand substrates, and 1 percent was associated with mesohabitats dominated by boulder substrates. Tamaulipas shiner and other rheophiles (species that prefer to live is fast-moving water) including speckled chub (*Macrhybopsis aestivalis*) and longnose dace were more commonly associated with gravel substrates in run and riffle geomorphic units in the Rio Grande in and near Big Bend National Park (Heard and others, 2012).

Summary

In 2010–11, the U.S. Geological Survey (USGS), in cooperation with the U.S. Fish and Wildlife Service, evaluated the physical characteristics and fish assemblage composition of mapped river mesohabitats at four sites on the Rio Grande/Rio Bravo Del Norte (hereinafter Rio Grande) in and near Big Bend National Park, Texas. The four sites used for the river habitat study were colocated with sites where the U.S. Fish and Wildlife Service has implemented an experimental reintroduction of the Rio Grande silvery minnow (*Hybognathus amarus*), a federally listed endangered species, into part of the historical range of this species. The farthest upstream site (USGS station 08374340 Rio Grande at Contrabando Canyon near Lajitas, Tex. [hereinafter the Contrabando site]) is approximately 9 river kilometers (km) west of Lajitas, Tex., in Big Bend Ranch State Park. This site is immediately downstream from the confluence of the Rio Grande with Contrabando Creek. The second site (USGS station 290956103363600 Rio Grande at Santa Elena Canyon, Big Bend National Park, Tex. [hereinafter the Santa Elena site]) is approximately 40 river km downstream from the Contrabando site. The Santa Elena site is just downstream from the mouth of Santa Elena Canyon and the confluence of the Rio Grande with Terlingua Creek. The third site (USGS station 291046102573900 Rio Grande near Ranger Station at Rio Grande Village, Tex. [hereinafter the Rio Grande Village site]) is approximately 120 river km downstream from the Santa Elena site. The farthest downstream study site (USGS station 292354102491100 Rio Grande above Stillwell Crossing near Big Bend National Park, Tex. [hereinafter the Stillwell Crossing site]) is approximately 70 river km downstream from the Rio Grande Village site.

In-channel river habitat was mapped at the mesohabitat scale over a range of seasonal streamflows. A late summer (August–September 2010) high-flow regime, an early spring (April–May 2010) intermediate flow regime, and a late spring (May 2011) low-flow regime were the seasonal flows used in the study. River habitats were mapped in the field by using a geographic information system and a Global Positioning System unit to characterize the sites at the mesohabitat scale.

Physical characteristics of a subset of mesohabitats in a reach of the Rio Grande at each site were measured during each flow regime and included depth, velocity, type and size of the substrate, and percent embeddedness. Selected water-quality properties (dissolved oxygen, pH, specific conductance, and temperature) of a subset of mesohabitats were also measured. The fish assemblage composition at the four sites was determined during the three flow regimes, and fish were collected by seining in each mesohabitat where physical characteristic data were measured, except during some periods of high flow when electrofishing was done to supplement seining.

The total number and number of types of mesohabitats were generally larger during low flows compared to intermediate flows, and larger during intermediate flows compared to high flows. Decreases in streamflow typically led to increases in channel complexity in terms of the number of different types and total number of mesohabitats present. One exception was the Rio Grande Village site, where the number of different mesohabitats was slightly larger during the May 2010 intermediate flow compared to the May 2011 low flow. As streamflow increased, the total wetted area of mesohabitats generally increased while the number of mesohabitat types generally decreased. This pattern of generally increasing wetted area and decreasing number of mesohabitat types with increasing streamflow was found for high, intermediate, and low flows. At two sites (Rio Grande Village and Stillwell Crossing sites), however, the wetted area of mesohabitats was larger during low flow than it was during intermediate flow. The Contrabando site, which tended to be the most complex of the four sites in terms of the number of different types of mesohabitats present, was dominated by runs, riffles, and rapids at high flow, and as expected, mesohabitats typically characterized by slow-moving water such as pools, forewaters, backwaters, and embayments were most prominent during low or intermediate flow at this site. Mesohabitats at the Santa Elena site consisted almost exclusively of runs and riffles at high flow. The Rio Grande Village site tended to be the least complex of the four sites in terms of both the number of different types of mesohabitats present, as well as the total number of mesohabitats mapped. Variations in flow at the Rio Grande Village site did not to have an effect on the number of mesohabitats compared to the other three sites or on the relative contribution of different mesohabitat types to wetted area. The amount of wetted area attributable to different mesohabitat types during high flow and low flow at the Stillwell Crossing site was similar. On an overall basis, the smallest depths and velocities were measured at all four sites during low flow, and the largest depths and velocities were measured during high flow. The maximum measured depths and velocities at each of the four sites also tended to be largest at high flow and smallest at intermediate flow.

Specific conductance was relatively consistent between the Contrabando and Santa Elena sites, the two most upstream sites. Specific conductance decreased appreciably between the Santa Elena site and the Rio Grande Village, and decreased slightly between the Rio Grande Village site and the Stillwell Crossing site. Specific-conductance values within and among mesohabitat types at a given site were relatively consistent. The pH values measured within and among mesohabitat types also were relatively consistent at all four sites. Median dissolved oxygen concentrations were relatively consistent between the Contrabando and Santa Elena sites (8.34 and 8.54 milligrams per liter [mg/L], respectively) but decreased along the stretch of river between the Santa Elena and Rio Grande Village sites to 7.31 mg/L, possibly because of small dissolved oxygen concentrations associated with contributions from springs between the Santa Elena and Rio Grande Village sites. Dissolved oxygen concentrations increased substantially between the Rio Grande Village and Stillwell Crossing sites to 10.06 mg/L. Mesohabitat water temperatures were generally highest in mesohabitats commonly associated with shallow water depths and low velocities (forewaters, backwaters, and embayments).

A total of 21 species of fish were collected among the four sites during the three flow regimes that were sampled. The number of fish species collected ranged from 15 at the Contrabando site to 19 at Santa Elena site. The largest number of fish (3,086 individuals) and largest number of species were collected at the Santa Elena site. The smallest number of fish (1,909 individuals) was collected at the Stillwell Crossing site. Red shiner (*Cyprinella lutrensis*) was the most abundant species overall and was the most abundant species at the Contrabando and Santa Elena sites. The endemic Tamaulipas shiner (*Notropis braytoni*) was second in overall relative abundance (about 24 percent) and was more abundant than the red shiner and all other species at the Rio Grande Village and Stillwell Crossing sites. The common carp (*Cyprinus carpio*), a nonnative species, was the third most abundant species overall.

Among the sites, a minimum of 9 species was identified during high flow and a maximum of 16 species during low flow at the Rio Grande Village site. Compared to the Rio Grande Village site, fish-species richness was much less variable at the Contrabando and Stillwell Crossing sites, ranging from 11 to 12 species at these sites during the different flow regimes. Fish-species richness varied among sites and flow regimes but was typically greatest at all sites during low flow. Median fish-species richness and maximum fish-species richness values were larger, and fish-species richness was more variable in runs, pools, forewaters, and backwaters during low flow compared to fish-species richness values calculated during intermediate and high flows.

Total fish density in backwater mesohabitats was significantly different ($p<0.01$) from densities in run mesohabitats, but total fish densities were not significantly different among the other mesohabitat types. Compared to total fish density at low and high flows, total fish density was larger during intermediate flow with the exception of total fish density at the Rio Grande Village site. Total fish densities ranged from a minimum of about 16 fish per 100 square meters (m^2) at the Stillwell Crossing site during high flow to a maximum of about 180 fish per 100 m^2 at the Santa Elena site during intermediate flow. Total fish densities were smallest for collections made during high flow and were generally about 3–10 times larger during intermediate and low flows.

Of the 39 Rio Grande silvery minnow collected during the study, 21 were collected at the Santa Elena site, 12 were collected at the Contrabando site, and 3 each at the Rio Grande Village and Stillwell Crossing sites. The small number of Rio Grande silvery minnow collected during this study was not unexpected because the USFWS was in only the third year of the experimental reintroduction of this species into the Big Bend study reach of the Rio Grande when the first of the fish surveys described in this report was completed in 2010.

Rio Grande silvery minnows were most common in pools and runs during low and intermediate flows. This species was less commonly collected in backwaters, embayments, and rapids, and none were collected from forewaters or submerged channel bars. No Rio Grande silvery minnow individuals were collected in any mesohabitats during the high-flow regime. Tamaulipas shiner was most common in backwater, run, and riffle mesohabitats (in decreasing order) during low and intermediate flow and was less common in submerged channel bar, pool, forewater, rapid, and embayment mesohabitats (in decreasing order) during the same flows.

In addition to evaluating abundance and density, mesohabitat use by Rio Grande silvery minnow and Tamaulipas shiner was compared by using relative percent density of each species expressed as the fish-species density in a given mesohabitat type in relation to the total fish density in that same mesohabitat type. The overall relative percent density (composite of all three flow regimes) of Rio Grande silvery minnow was largest in rapid and pool mesohabitats and for Tamaulipas shiner was largest in backwater mesohabitats. The overall relative percent density of Rio Grande silvery minnow in pools (1.20) was about 11 percent of the relative percent density of Tamaulipas shiner in pools (11.22), and the overall relative percent density of Rio Grande silvery minnow in embayments (0.91) was about 7 percent of the overall relative percent density of Tamaulipas shiner in embayments (12.73). In all other mesohabitats, the overall relative percent densities of Rio Grande silvery minnow were less than 3 percent of the overall relative percent densities of Tamaulipas shiner. Overall relative percent densities of Rio Grande silvery minnow were small in shallow, low-velocity mesohabitats including backwaters, forewaters, and submerged channel bars.

Stream velocities associated with seine hauls of Rio Grande silvery minnow and Tamaulipas shiner were not significantly different (p=0.151). Stream velocities associated with the collection of the Rio Grande silvery minnow indicate that this species is predominantly found in low-velocity mesohabitats. Stream velocities associated with seine hauls of Tamaulipas shiner represented a much broader overall range than those associated with Rio Grande silvery minnow seine hauls. The broader distribution of stream velocities associated with collections of Tamaulipas shiner likely reflects the relatively large abundance of this species during the low- and intermediate-flow regimes compared to the abundance of this species during the high-flow regime and the observation that Tamaulipas shiner inhabits a broader range of mesohabitats with larger stream velocities than Rio Grande silvery minnow typically inhabits. The depths associated with seine hauls of Rio Grande silvery minnow and Tamaulipas shiner were not significantly different (Kruskal-Wallis analysis; p=0.819).

Of the seine hauls that included collections of Rio Grande silvery minnow, 53 percent were from mesohabitats dominated by cobble substrates; 32 percent were from mesohabitats dominated by fine-sized silt and clay particles; 10 percent were from mesohabitats dominated by gravel; and 5 percent were from mesohabitats dominated by sand. In contrast to the Rio Grande silvery minnow collections, Tamaulipas shiner collections were relatively evenly distributed among substrates consisting of gravel (34 percent), cobble (33 percent), and silt and clay (28 percent), with the remaining percent split among sand (4 percent) and boulder (1 percent) substrates.

References

Armitage, P.D., 1995, Faunal community change in response to flow manipulation, *in* Harper, D.M., and Ferguson, A.J.D., eds., The ecological basis for river management: Chichester, United Kingdom, John Wiley, p. 59–78.

Bestgen, K.R., and Platania, S.P., 1991, Status and conservation of the Rio Grande silvery minnow, *Hybognathus amarus*: Southwestern Naturalist, v. 36, p. 225–232.

Bestgen, K.R., and Propst, D.L., 1996, Redescription, geographic variation, and taxonomic status of the Rio Grande silvery minnow, *Hybognathus amarus* (Girard 1856): Copeia, v. 1, p. 41–55.

Biggs, B.J.F., Duncan, M.J., Jowett, I.G., Quinn, J.M., Hickey, C.W., Davies-Colley, R.J., and Close, M.E., 1990, Ecological characterization, classification, and modeling of New Zealand rivers—An introduction and synthesis: New Zealand Journal of Marine and Freshwater Research, v. 24, p. 277–304.

Bixby, R.J., and Burdett A.S., 2009, Nutrient and water quality influences on periphyton biomass and community composition in an arid land river: Abstract, 94th Ecological Society of America Meeting, Albuquerque, N. Mex.

Bovee, K.D., Lamb, B.L., Bartholow, J.M., Stalnaker, C.B., Taylor, Jonathan, and Henriksen, J., 1998, Stream habitat analysis using instream flow incremental methodology: U.S. Geological Survey Biological Resources Division Information Technology Report USGS/BRD 1998–0004, 131 p. (Also available at http://www.fort.usgs.gov/Products/Publications/3910/3910.pdf.)

Connell, S.D., Hawley, J.W., and Love, D.W., 2005, Late Cenozoic drainage development in the southwestern Basin and Range of New Mexico, southeasternmost Arizona, and western Texas, *in* Lucas, S.G., Morgan, G.S., and Zeigler, K.E., eds., New Mexico's ice ages: Albuquerque, New Mexico Museum of Natural History and Science Bulletin 28, p. 125–150.

Cook, J.A., Bestgen, K.R., Propst, D.L., and Yates, T.L., 1992, Allozymic divergence and systematics of the Rio Grande silvery minnow, *Hybognathus amarus* (Teleostei: Cyprinidae): Copeia, v. 1992, no. 1, p. 36–44.

Dean, D.J., and Schmidt, J.C., 2011, The role of feedback mechanisms in historic channel changes of the lower Rio Grande in the Big Bend region: Geomorphology, v. 126, p. 333–349.

Dethier, D.P., 2001, Pleistocene incision rates in the Western United States calibrated using Lava Creek B tephra: Geology, v. 29, no. 9, p. 783–786.

Dudley, R.K., and Platania, S.P., 1997, Habitat use of Rio Grande silvery minnow: Report submitted to the New Mexico Department of Game and Fish and Bureau of Reclamation, 96 p.

Edwards, R.J., 2005, Feasibility of reintroducing Rio Grande silvery minnows (*Hybognathus amarus*) to the Rio Grande, Big Bend region, Texas: Final report to the U.S. Fish and Wildlife Service, 54 p.

Edwards, R.J., Garrett, G.P., and Allan, N.L., 2004, Aquifer-dependent fishes of the Edwards Plateau region, chap. 13 *in* Mace, R.E., Angle, E.S., and Mullican, W.F., eds., Aquifers of the Edwards Plateau: Texas Water Development Board Report 360, 366 p.

Edwards, R.J., Garrett, G.P., and Marsh-Matthews, E., 2002, Conservation and status of the fish communities inhabiting the Río Conchos Basin and Middle Rio Grande, México and U.S.A.: Reviews in Fisheries and Fish Biology, v. 12, p. 119–132.

Environmental Systems Research Institute, Inc., 2009, ArcGIS Desktop 9.2—Data and maps, Mexico base 1:300,000 (hydrography): Redlands, Calif., Environmental Systems Research Institute, Inc., accessed August 24, 2010, at http://www.esri.com/.

Falke, J.A., Bestgen, K.R., and Fausch, K.D., 2010, Streamflow reductions and habitat drying affect growth, survival, and recruitment of brassy minnow across a Great Plains riverscape: Transactions of the American Fisheries Society, v. 139, p. 1566–1583.

Federal Geographic Data Committee, 2013, Geospatial metadata: Accessed August 2, 2013, at http://www.fgdc.gov/metadata.

Fitzpatrick, F.A., Waite, I.R., D'Arconte, P.J., Meador, M.R., Maupin, M.A., and Gurtz, M.E., 1998, Revised methods for characterizing stream habitat in the National Water-Quality Assessment Program: U.S. Geological Survey Water-Resources Investigations Report 98–4052, 77 p.

Garrett, G.P., 2002, Historic and current ichthyofauna of the Rio Grande and associated tributaries within Big Bend National Park and the Lower Canyons: Alpine, Tex., Sul Ross State University, master's thesis, 62 p.

Gauch, H.G., Jr., 1982, Multivariate analysis in assemblage ecology: Cambridge, Cambridge University Press, 298 p.

Gilbert, C.R., 1980, *Notropis jemezanus* (Copeia), Rio Grande shiner, *in* Lee, D.S., Gilbert, C.R., Hocutt, C.H., Jenkins, R.E., McAllister, D.E., and Stauffer, J.R., Jr., eds., Atlas of North American freshwater fishes: Raleigh, North Carolina State Museum of Natural History, p. 279.

Guisan, Antoine, and Zimmermann, N.E., 2000, Predictive habitat distribution models in ecology: Ecological Modelling, v. 135, p. 147–186. (Also available at http://www.uprm.edu/biology/profs/chinea/ecolplt/lectesc/guisan_e2000.pdf).

Guy, H.P., 1969, Laboratory theory and methods for sediment analysis: U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. C1, 58 p.

Harper, D., and Everard, M., 1998, Why should the habitat-level approach underpin holistic river survey and management: Regulated Rivers, v. 8, p. 395–413.

Heard, T., 2008, Spatial and temporal patterns in a Chihuahuan Desert fish assemblage: San Marcos, Texas State University, master's thesis, 50 p.

Heard, T.C., Perkin, J.S., and Bonner, T.H., 2012, Intra-annual variation in fish communities and habitat associations in a Chihuahua Desert study reach of the Rio Grande/Rio Bravo del Norte: Western North American Naturalist, v. 72, p. 1–15.

Helsel, D.R., and Hirsch, R.M., 2002, Statistical methods in water resources: U.S. Geological Survey Techniques of Water-Resources Investigations, book 4, chap. A3, 510 p. (Also available at http://pubs.usgs.gov/twri/twri4a3/.)

International Boundary and Water Commission, 2013, Rio Grande water flows: Accessed March 20, 2013, at http://ibwc.state.gov/wad/DDQJOHNS.htm.

Lepš, Jan, and Šmilauer, Petr, 2003, Multivariate analysis of ecological data using CANOCO: Cambridge, Cambridge University Press, 269 p.

Ludwig, J.A., and Reynolds, J.F., 1988, Statistical ecology: New York, John Wiley, 337 p.

Miyamoto, S., Fenn, L.B., and Swietlik, D., 1995, Flow, salts, and trace elements in the Rio Grande—A review: Texas Water Resources Institute Technical Report TR–169. (Also available at http://twri.tamu.edu/reports/1995/169/tr169.pdf.)

Moring, J.B., 2002, Baseline assessment of instream and riparian-zone biological resources on the Rio Grande in and near Big Bend National Park, Texas: U.S. Geological Survey Water-Resources Investigations Report 02–4106, 33 p.

Mueller, D.S., and Wagner, C.R., 2009, Measuring discharge with acoustic Doppler current profilers from a moving boat: U.S. Geological Survey Techniques and Methods 3A–22, 72 p. (Also available at http://pubs.water.usgs.gov/tm3a22.)

Mueller, J.E., 1975, Restless river: Texas Western Press, The University of Texas at El Paso, 155 p.

National Park Service, 2012, Big Bend National Park, Texas—Park map: Accessed April 24, 2012, at http://www.nps.gov/bibe/index.htm.

Newson, M.D., and Newson, C.L., 2000, Geomorphology, ecology and river channel habitat—

Mesoscale approaches to basin-scale challenges: Progress in Physical Geography, v. 24, p. 195–217.

Oberg, K.A., Morlock, S.E., and Caldwell, W.S., 2005, Quality-assurance plan for discharge measurements using acoustic Doppler current profilers: U.S. Geological Survey Scientific Investigations Report 2005–5183, 35 p.

Pankow, J.F., 1991, Aquatic chemistry concepts: Chelsea, Mich., Lewis Publishers, 673 p.

Parasiewicz, P., and Dunbar, M.J., 2001, Physical habitat modeling for fish—A developing approach: Archives for Hydrobiologia Supplement, v. 135, nos. 2-4, 1–30 p.

Pardo, Isabel, and Armitage, P.D., 1997, Species assemblages as descriptors of mesohabitats: Hydrobiologia, v. 344, p. 111–128, accessed May 6, 2013, at http://link.springer.com/content/pdf/10.1023%2FA%3A1002958412237.pdf

Platania, S.P., 1993, The fishes of the Rio Grande between Velarde and Elephant Butte Reservoir and their habitat associations: Report to the New Mexico Department of Game and Fish, Santa Fe, N. Mex., and Bureau of Reclamation (Albuquerque Project Office), Albuquerque, N. Mex., 188 p.

Poff, N.L., and Allan, J.D., 1993, Streamflow variability, fish community structure, and implications for climatic change: U.S. Environmental Protection Agency Report REL–D 2765.

Raines, T.H., Turco, M.J., Connor, P.J., and Bennett, J.B., 2012, Streamflow gains and losses and selected water-quality observations in five subreaches of the Rio Grande/Rio Bravo del Norte from near Presidio to Langtry, Texas, Big Bend area, United States and Mexico, 2006: U.S. Geological Survey Scientific Investigations Report 2012–5125, 30 p.

Rantz, S.E., and others, 1982, Measurement and computation of streamflow—Volumes 1 and 2: U.S. Geological Survey Water-Supply Paper 2175, 631 p.

Remshardt, W.J., 2008, Rio Grande silvery minnow augmentation in the Middle Rio Grande, New Mexico: Annual Report 2006 submitted to Bureau of Reclamation, Albuquerque, N. Mex., 69 p.

Schmidt, J.C., Everitt, B.L., and Richard, G.A., 2003, Hydrology and geomorphology of the Rio Grande and implications for river rehabilitation, *in* Garrett, G.P., and Allan, A.L., eds., Aquatic fauna of the northern Chihuahuan Desert—Contributed papers from a special session within the Thirty-Third Annual Symposium of the Desert Fishes Council: Lubbock, Tex., Museum of Texas Tech University, Special Publications No. 46, p. 22–45.

Shah, S.D., and Houston, N.A., 2007, Geologic and hydrogeologic information for a geospatial database for the Brazos River alluvium aquifer, Bosque County to Fort Bend County, Texas (version 3): U.S. Geological Survey Open-File Report 2007–1031, 10 p.

Smith-Root, Inc., 2012, Electrofishers: Accessed April 26, 2013, at http://www.smith-root.com/electrofishers/gpp/.

SonTek, 2013, FlowTracker handheld acoustic Doppler velocimeter: Accessed February 6, 2013, at http://www.sontek.com/flowtracker.php.

Southwood, T.R.E., 1988, Tactics, strategies and templates: Oikos, v. 52, p. 3–18.

StatSoft, 2008, Statistica Version 8.0: Accessed June 22, 2013, at http://www.statsoft.com/support/download/statistica-software-updates/.

Teledyne RD Instruments, 2007, WinRiver II user’s guide: San Diego, Calif., Teledyne RD Instruments, P/N 957–6231–00, 166 p.

ter Braak, C.J.F., 1986, Canonical correspondence analysis—A new eigenvector technique for multivariate direct gradient analysis: Ecology, v. 67, p. 1167–1179.

ter Braak, C.J.F., 1987, The analysis of vegetation—Environmental relationships by canonical correspondence analysis: Vegetation, v. 69, p. 69–77.

ter Braak, C.J.F., and Šmilauer, Petr, 2002, CANOCO reference manual and CanoDraw for Windows user’s guide—Software for canonical community ordination (version 4.5): Wageningen, The Netherlands, Biometris, International, 500 p.

ter Braak, C.J.F., and Verdonschot, P.F.M., 1995, Canonical correspondence analysis and related multivariate methods in aquatic ecology: Aquatic Sciences, v. 57, p. 1015–1621.

Texas Parks and Wildlife Department, 2012, Nongame and rare species program—Federal and State listed fish species: Accessed June 21, 2013, at http://www.tpwd.state.tx.us/huntwild/wild/wildlife_diversity/texas_rare_species/listed_species/fish.phtml.

Thomas, C., Bonner, T.H., and Whiteside, B.G., 2007, Freshwater fishes of Texas—A field guide: Accessed August 27, 2013, at http://txstate.fishesoftexas.org/.

Treviño-Robinson, D., 1955, The ichthyofauna of the lower Rio Grande river, from the mouth of the Pecos to the Gulf of Mexico: Austin, University of Texas, master’s thesis, 107 p.

Treviño-Robinson, D., 1959, The ichthyofauna of the lower Rio Grande, Texas and Mexico: Copeia, p. 255–256.

Turnipseed, D.P., and Sauer, V.B., 2010, Discharge measurements at gaging stations: U.S. Geological Survey Techniques and Methods, book 3, chap. A8, 87 p. (Also available at http://pubs.usgs.gov/tm/tm3-a8/.)

U.S. Bureau of Reclamation, 2013, Elephant Butte Powerplant: Accessed November 19, 2013, at *h*ttp://www.usbr.gov/projects/Powerplant.jsp?fac_Name=Elephant+Butte+Powerplant.

U.S. Department of Agriculture (USDA)-Farm Service Agency (FSA)-Aerial Photography Field Office (APFO), 2010, National Agriculture Imagery Program (NAIP): Accessed May 18, 2010, at http://www.fsa.usda.gov/FSA/apfoapp?area=home&subject=prog&topic=nai.

U.S. Fish and Wildlife Service, 2008, Establishment of a nonessential experimental population of Rio Grande silvery minnow in the Big Bend study reach of the Rio Grande in Texas, Final Rule: 50 CFR Part 17, 32 p.

U.S. Fish and Wildlife Service, 2010, Rio Grande Silvery Minnow (*Hybognathus amarus*) Recovery Plan, First Revision: Albuquerque, N. Mex., 210 p., accessed May 18, 2013, at http://ecos.fws.gov/docs/recovery_plan/022210_v2.pdf.

U.S. Fish and Wildlife Service, 2013a, Species report—Listings and occurrences for Texas: Accessed May 18, 2013, at http://www.fws.gov/ecos/ajax/tess_public/pub/stateListingAndOccurrenceIndividual.jsp?state=TX .

U.S. Fish and Wildlife Service, 2013b, SW Native Aquatic Resources & Recovery Center: Accessed November 19, 2013, at http://www.fws.gov/southwest/fisheries/dexter/contact.html.

U.S. Geological Survey, 2010, Volatile organic compounds in the Nation's ground water and drinking- water supply wells—Supporting information. Glossary: Accessed May 8, 2013, at http://water.usgs.gov/nawqa/vocs/national_assessment/report/glossary.html.

Wentworth, C.K., 1922, A scale of grade and class terms for clastic sediments: The Journal of Geology, v. 30, p. 377–392.

XLSTAT, 2012, Products and solutions: Accessed June 21, 2012, at http://www.xlstat.com/en/.

Xylem Analytics, 2013, YSI—Monitor, analyze, and protect the world's natural resources: Accessed May 18, 2013, at http://www.ysi.com/index.php.

Zar, J.H., 1984, Biostatistical analysis (2d ed.): Englewood Cliffs, N. J., Prentice-Hall, 718 p.

Zeiler, Michael, 1999, Modeling our world—The ESRI guide to geospatial database design: Redlands, Calif., Environmental Systems Research Institute Press, 216 p.

Appendix 1. Data Tables and Definitions of Data Elements Associated with the Geospatial Database

tbl_fish – Fish assemblage data

Field code	Field name	Definition	Codes (if applicable)
collection_no	Collection number	Unique number associated with each fish sampling event.	W, in water field sample; JR, initials of biologist responsible for fish samples and data management; 10, year of sample with preceding “20” missing; 949, unique numerical ID for each event.
site_abv	Site abbreviation	Site abbreviation associated with each study site.	CNT – Contrabando STL – Stillwell Crossing RGV – Rio Grande Village TER – Terlingua Creek
sample_id	Sample identifier	Sampling event identifier	1 – intermediate flow 2 – high flow 3 – low flow
mesohab_id	Mesohabitat identifier	Mesohabitat identifier	
unique_id	Unique identifier	Unique identifier composed of site_abv +sample_id + mesohab_id	
mesohab_cl	Mesohabitat class	Mesohabitat class as defined by the mapping crew in situ	1 – pool 3 – riffle 4 – rapid 7 – backwater 10 – run 14 – embayment 15 – forewater
sample_cd	Sample code	Sampling method used for fish collection	S – seine haul EF – electrofishing
location_id	Location identifier	Mesohabitat fish sampling location identifier	TL – top left TM – top middle TR – top right ML – middle left MM – middle middle MR – middle right BL – bottom left BM – bottom middle BR – bottom right
LEPOSS	*Lepisosteus osseus*	Fish count for species	
DORCEP	*Dorosoma cepedianum*	Fish count for species	
ASTMEX	*Astyanax mexicanus*	Fish count for species	
CYPCAR	*Cyprinus carpio*	Fish count for species	
CYPLUT	*Cyprinella lutrensis*	Fish count for species	

HYBAMA	*Hybognathus amarus*	Fish count for species	
MACAES	*Macrohybopsis aes-tivalis*	Fish count for species	
NOTBRA	*Notropis braytoni*	Fish count for species	
RHICAT	*Rhinichthys cataractae*	Fish count for species	
CARCAR	*Carpiodes carpio*	Fish count for species	
CYCELO	*Cycleptus elongatus*	Fish count for species	
ICTBUB	*Ictiobus bubalus*	Fish count for species	
ICTFUR	*Ictalurus furcatus*	Fish count for species	
ICTPUN	*Ictalurus punctatus*	Fish count for species	
PYLOLI	*Pylodictis olivaris*	Fish count for species	

tbl_fish_cover – Fish cover data

Field code	Field name	Definition	Codes (if applicable)
unique_id	Unique identifier	Unique identifier composed of site_abv +sample_id + mesohab_id	
mesohab_cl	Mesohabitat class	Mesohabitat class as defined by the mapping crew in situ	1 – pool 3 – riffle 4 – rapid 7 – backwater 10 – run 14 – embayment 15 – forewater
transect_id_fc	Transect identifier (fish cover)	Transect identifier for each mesohabitat sampled (1-5 transects per unit)	
fil_algae	Filamentous algae	Presence of filamentous algae along transect	0 – Absent (0 percent) 1 – Sparse (1–10 percent) 2 – Moderate (11–40 percent) 3 – Heavy (41–75 percent) 4 – Very Heavy (>75 percent)
macrophytes	Macrophytes	Presence of macrophytes along transect	0 – Absent (0 percent) 1 – Sparse (1–10 percent) 2 – Moderate (11–40 percent) 3 – Heavy (41–75 percent) 4 – Very Heavy (>75 percent)
woody_deb	Woody debris	Presence of woody debris (<0.3 m in diameter) along transect	0 – Absent (0 percent) 1 – Sparse (1–10 percent) 2 – Moderate (11–40 percent) 3 – Heavy (41–75 percent) 4 – Very Heavy (>75 percent)
lg_woody_deb	Large woody debris	Presence of large woody debris (>0.3 m in diameter) along transect	0 – Absent (0 percent) 1 – Sparse (1–10 percent) 2 – Moderate (11–40 percent) 3 – Heavy (41–75 percent) 4 – Very Heavy (>75 percent)
lv_tree_roots	Live tree roots	Presence of live tree roots along transect	0 – Absent (0 percent) 1 – Sparse (1–10 percent) 2 – Moderate (11–40 percent) 3 – Heavy (41–75 percent) 4 – Very Heavy (>75 percent)
overhang_veg	Overhanging vegetation	Presence of overhanging vegetation along transect	0 – Absent (0 percent) 1 – Sparse (1–10 percent) 2 – Moderate (11–40 percent) 3 – Heavy (41–75 percent) 4 – Very Heavy (>75 percent)
undercut_bnk	Undercut bank	Presence of undercut bank along transect	0 – Absent (0 percent) 1 – Sparse (1–10 percent) 2 – Moderate (11–40 percent) 3 – Heavy (41–75 percent) 4 – Very Heavy (>75 percent)

boulders	Boulders	Presence of boulders along transect	0 – Absent (0 percent) 1 – Sparse (1–10 percent) 2 – Moderate (11–40 percent) 3 – Heavy (41–75 percent) 4 – Very Heavy (>75 percent)
cobble	Cobble	Presence of cobble along transect	0 – Absent (0 percent) 1 – Sparse (1–10 percent) 2 – Moderate (11–40 percent) 3 – Heavy (41–75 percent) 4 – Very Heavy (>75 percent)
art_struct	Artificial structures	Presence of artificial structures along transect	0 – Absent (0 percent) 1 – Sparse (1–10 percent) 2 – Moderate (11–40 percent) 3 – Heavy (41–75 percent) 4 – Very Heavy (>75 percent)

tbl_fish_habitat – Fish habitat data

Field code	Field name	Definition	Codes (if applicable)
unique_id	Unique identifier	Unique identifier composed of site_abv +sample_id + mesohab_id	
mesohab_cl	Mesohabitat class	Mesohabitat class as defined by the mapping crew in situ	1 – pool 3 – riffle 4 – rapid 7 – backwater 10 – run 14 – embayment 15 – forewater
sample_cd	Sample code	Sampling method used for fish collection	S – seine haul EF – electrofishing
location_id	Location cdentifier	Mesohabitat fish sampling location identifier	TL – top left TM – top middle TR – top right ML – middle left MM – middle middle MR – middle right BL – bottom left BM – bottom middle BR – bottom right
habitat_ds	Habitat description	Description of mesohabitat type in situ by field crew, not used by mapping crew	
substrate_cd	Substrate code	Description of substrate type	BD – boulders CB – cobble FN – fines GR – gravel SA – sand
sample_w_m	Sample width	Sample width, in meters	
sample_ln_m	Sample length	Sample length, in meters	
sample_ar_m2	Sample area	Sample area, in square meters	

depth1_ft	Depth 1	Water depth, in feet	
depth2_ft	Depth 2	Water depth, in feet	
depth3_ft	Depth 3	Water depth, in feet	
avg_depth_ft	Average depth	Average water depth, in feet	
vel1_fts	Velocity 1	Water velocity, in feet per second	
vel2_fts	Velocity 2	Water velocity, in feet per second	
vel3_fts	Velocity 3	Water velocity, in feet per second	
avg_vel_fts	Average velocity	Average water velocity, in feet per second	

tbl_margin – Margin habitat data

Field code	Field name	Definition	Codes (if applicable)
unique_id	Unique identifier	Unique identifier composed of site_abv +sample_id + mesohab_id	
mesohab_cl	Mesohabitat class	Mesohabitat class as defined by the mapping crew in situ	1 – pool 3 – riffle 4 – rapid 7 – backwater 10 – run 14 – embayment 15 – forewater
transect_id	Transect identifier (margin)	Transect identifier for each margin mesohabitat sampled (1-5 transects per unit)	
lmargin_w_ft	Left margin width	Left margin width, in feet	
lmargin_d_ft	Left margin depth	Left margin depth, in feet	
lmargin_v_fts	Left margin velocity	Left margin velocity, in feet per second	
lmargin_subs	Left margin substrate type	Left margin dominant substrate type	BD – boulders BR – bedrock CB – cobble CL – clay FN – fines GC – gravel coarse GF – gravel fine GR – gravel SA – sand
lmargin_subs_sz	Left margin substrate size	Left margin substrate size, in millimeters	
lmargin_subdom	Left margin subdominant substrate type	Left margin subdominant substrate type	BD – boulders BR – bedrock CB – cobble CL – clay FN – fines GC – gravel coarse GF – gravel fine GR – gravel SA – sand
lmargin_subdom_sz	Left margin subdominant substrate size	Left margin subdominant substrate size, in millimeters	
lembed_pct	Left sargin embeddedness	Left margin substrate embeddedness, in percent	
lmargin_peri_pct	Left margin periphyton	Left margin periphyton cover, in percent	
lmargin_densi	Left margin densiometer	Left margin densiometer measurement (0–17)	

rmargin_w_ft	Right Margin Width	Right margin width, in feet	
rmargin_d_ft	Right margin depth	Right margin depth, in feet	
rmargin_v_ft	Right margin Velocity	Right margin velocity, in feet per second	
rmargin_subs	Right margin substrate type	Right margin dominant substrate type	BD – boulders BR – bedrock CB – cobble CL – clay FN – fines GC – gravel coarse GF – gravel fine GR – gravel SA – sand
rmargin_subs_sz	Right margin substrate size	Right margin substrate size, in millimeters	
rmargin_subdom	Right margin subdominant substrate type	Right margin subdominant substrate type	BD – boulders BR – bedrock CB – cobble CL – clay FN – fines GC – gravel coarse GF – gravel fine GR – gravel SA – sand
rmargin_subdom_sz	Right margin subdominant substrate type	Right margin subdominant substrate size, in millimeters	
rembed_pct	Right margin embeddedness	Right margin substrate embeddedness, in percent	
rmargin_peri_pct	Right margin periphyton	Right margin periphyton cover, in percent	
rmargin_densi	Right margin densiometer reading	Right margin densiometer measurement (0–17)	
rbank_angle	Left margin bank angle	Right margin bank angle, in degrees	

tbl_physical – Physical data

Field code	Field name	Definition	Codes (if applicable)
unique_id	Unique identifier	Unique identifier composed of site_abv +sample_id + mesohab_id	
mesohab_cl	Mesohabitat class	Mesohabitat class as defined by the mapping crew in situ	1 – pool 3 – riffle 4 – rapid 7 – backwater 10 – run 14 – embayment 15 – forewater
transect_id	Transect identifier (mesohabitat)	Transect identifier for each mesohabitat sampled (1–5 transects per unit)	
transect_w_m	Transect width	Transect width, in meters	
depth_ft	Depth	Depth, in feet	
velocity_ft/s	Velocity	Velocity, in feet per second	
subs_cd	Substrate type	Substrate type	BD – boulders BR – bedrock CB – cobble CL – clay FN – fines GC – gravel coarse GF – gravel fine GR – gravel SA – sand
subs_sz	Substrate size	Substrate size, in millimeters	
subs_sz_rk	Substrate size remark	Substrate size remark code noted as < or >	< – less than > – greater than
embed_pct	Embeddedness	Substrate embeddedness, in percent	
comment_tx	Comment	Comments related to transect measurements	

tbl_sites_sample – Site data

Field code	Field name	Definition	Codes (if applicable)
site_nm	Site name	Long site name for sampling location	CONTRABANDO TERLINGUA RGVILLAGE STILLWELL
site_abv	Site abbreviation	Site abbreviation for sampling location	CNT – Contrabando TER – Terlingua RGV – Rio Grande Village STL – Stillwell Crossing
sample_id	Sample identifier	Sampling event identifier	1 – intermediate flow 2 – high flow 3 – low flow
mesohab_id	Mesohabitat identifier	Mesohabitat identifier	
unique_id	Unique identifier	Unique identifier composed of site_abv +sample_id + mesohab_id	
mesohab_cl	Mesohabitat class	Mesohabitat class as defined by the mapping crew in situ	1 – pool 3 – riffle 4 – rapid 7 – backwater 10 – run 14 – embayment 15 – forewater
site_dt	Site Sample date	Sample date	
mesohab_cl	Mesohabitat class	Mesohabitat class as defined by the mapping crew in situ	1 – pool 3 – riffle 4 – rapid 7 – backwater 10 – run 14 – embayment 15 – forewater
length_m	Mesohabitat length	Main channel length of mesohabitat, in meters	
position_cd	Position sampling	Starting position for transect measurements	

tbl_water_quality – Water quality data

Field code	Field name	Definition	Codes (if applicable)
unique_id	Unique identifier	Unique identifier composed of site_abv + sample_id + mesohab_id	
mesohab_cl	Mesohabitat class	Mesohabitat class as defined by the mapping crew in situ	1 – pool 3 – riffle 4 – rapid 7 – backwater 10 – run 14 – embayment 15 – forewater
ph_va	pH measurement	pH value measured by using the pH scale	
spc_va	Specific conductance measurement	Specific conductance, in microsiemens per centimeter	
do_pct_va	Dissolved oxygen measurement 1	Dissolved oxygen, in percent saturation	
do_mgl_va	Dissolved oxygen measurement 2	Dissolved oxygen, in micrograms per liter	
temp_c_va	Temperature	Temperature, in degrees Celsius	

Appendix 2. Federal Geographic Data Committee Compliant Metadata Record

Identification_Information

Citation: Low-flow mesohabitats

Citation_Information:

Originator: U.S. Geological Survey

Publication_Date: 20131227

Title: Mesohabitats, Fish Assemblage Composition, and Comparison of Mesohabitat Use Between the Rio Grande Silvery Minnow and Tamaulipas Shiner Over a Range of Seasonal Flow Regimes in the Rio Grande/Rio Bravo del Norte, In and Near Big Bend National Park, Texas, 2010–11

Geospatial_Data_Presentation_Form: vector digital data

Description:

Abstract:

In 2010–11, the U.S. Geological Survey (USGS), in cooperation with the U.S. Fish and Wildlife Service, evaluated the physical characteristics and fish assemblage composition of mapped river mesohabitats at four sites on the Rio Grande/Rio Bravo del Norte (hereinafter Rio Grande) in and near Big Bend National Park, Texas. The four sites used for the river habitat study were colocated with sites where the U.S. Fish and Wildlife Service has implemented an experimental reintroduction of the Rio Grande silvery minnow (*Hybognathus amarus*), a federally listed endangered species, into part of the historical range of this species. The four sites from upstream to downstream are USGS station 08374340 Rio Grande at Contrabando Canyon near Lajitas, Tex. (hereinafter the Contrabando site), USGS station 290956103363600 Rio Grande at Santa Elena Canyon, Big Bend National Park, Tex. (hereinafter the Santa Elena site), USGS station 291046102573900 Rio Grande near Ranger Station at Rio Grande Village, Tex. (hereinafter the Rio Grande Village site), and USGS station 292354102491100 Rio Grande above Stillwell Crossing near Big Bend National Park, Tex. (hereinafter the Stillwell Crossing site).

In-channel river habitat was mapped at the mesohabitat scale over a range of seasonal streamflows. A late summer (August–September 2010) high-flow regime, an early spring (April–May 2010) intermediate flow regime, and a late spring (May 2011) low-flow regime were the seasonal flows used in the study. River habitat was mapped in the field by using a geographic information system and a Global Positioning System unit to characterize the sites at the mesohabitat scale. Physical characteristics of a subset of mesohabitats in a reach of the Rio Grande at each site were measured during each flow regime and included depth, velocity, type and size of the substrate, and percent embeddedness. Selected water-quality properties (dissolved oxygen, pH, specific conductance, and temperature) of a subset of mesohabitats were also measured. The fish assemblage composition at the four sites was determined during the three flow regimes, and fish were collected by seining in each mesohabitat where physical characteristic data were measured, except during some periods of high flow when electrofishing was done to supplement seining.

The total number and number of types of mesohabitats were larger during low flows compared to intermediate flows, and larger during intermediate flows compared to high flows. Decreases in streamflow typically led to increases in channel complexity in terms of the number of different types and total number of mesohabitats present. The total wetted area increased and the number of mesohabitat types generally decreased as streamflow increased. At all four sites, the smallest depths and velocities were generally measured during low flow and the largest depths and velocities at high flow. Specific conductance was relatively consistent between the Contrabando and Santa Elena sites, the two most upstream sites. Specific conductance decreased appreciably between the Santa Elena site and the Rio Grande Village, and decreased slightly between the Rio Grande Village site and the Stillwell Crossing site. Specific-conductance values within and among mesohabitat types at a given site were relatively consistent. The pH values measured within and among mesohabitat types also were relatively consistent at all four sites. Median dissolved oxygen concentrations were relatively consistent between the Contrabando and Santa Elena sites (8.34 and 8.54 milligrams per liter [mg/L], respectively) but decreased along the stretch of river between the Santa Elena and Rio Grande Village sites to 7.31 mg/L, possibly because of small dissolved oxygen concentrations associated with contributions from springs between the Santa Elena and Rio Grande Village sites. Dissolved oxygen concentrations increased substantially between the Rio Grande Village and Stillwell Crossing sites to 10.06 mg/L. Mesohabitat water temperatures were generally highest in mesohabitats commonly associated with shallow water depths and low velocities (forewaters, backwaters, and embayments).

Of the 21 species of fish collected during the three flow regimes, red shiner (*Cyprinella lutrensis*) was the most abundant species overall, accounting for about 35 percent of all fish collected. Another minnow, the endemic Tamaulipas shiner (*Notropis braytoni*), was second in overall abundance. A nonnative species, the common carp (*Cyprinus carpio*), was the third most abundant species overall. No statistically significant differences in fish-species richness were found among the different mesohabitat types. Median fish-species richness and maximum fish-species richness values were larger, and fish-species richness was more variable in runs, pools, forewaters, and backwaters during low flow compared to the fish-species richness values calculated for intermediate and high flows. Fish density in backwater mesohabitats was significantly different from fish densities in run mesohabitats, but fish densities were not significantly different among the other mesohabitat types.

Of the 39 Rio Grande silvery minnow individuals collected at the four study sites, 21 (more than half) were collected at the Santa Elena site, 12 at the Contrabando site, and 3 each at the Rio Grande Village and Stillwell Crossing sites. Rio Grande silvery minnow fish-species densities followed the same order as abundance of this species at the sites; fish-species densities ranged from 0.95 fish per 100 square meters (m^2) at the Santa Elena site to 0.11–0.47 fish per 100 m^2 at the other three sites. The Rio Grande silvery minnow was most common in pools and runs during low- and intermediate-flow regimes. This species was less commonly collected in backwaters, embayments, and rapids, and none were collected in forewaters or submerged channel bars. The Tamaulipas shiner has similar life-history characteristics compared to the Rio Grande silvery minnow, including similar feeding habits and habitat use. Tamaulipas shiner was most common in backwater, run, and riffle mesohabitats (in decreasing order) during low and intermediate flow and was less common in submerged channel bar, pool, forewater, rapid, and embayment mesohabitats (in decreasing order) during the same flows. The overall relative percent density (composite of all three flow regimes) of Rio Grande silvery minnow was largest in rapid and pool mesohabitats and for Tamaulipas shiner was largest in backwater mesohabitats.

There were no statistically significant differences between the stream velocities associated with seine hauls of the Rio Grande silvery minnow and Tamaulipas shiner. Stream velocities associated with the seine hauls that included Rio Grande silvery minnow indicate that this species is predominantly found in low-velocity mesohabitats. Velocities associated with seine hauls that included the Tamaulipas shiner represented a much broader overall range of velocities than those associated with Rio Grande silvery minnow collections. No statistically significant differences were found between the depths for seine hauls that included Rio Grande silvery minnow or Tamaulipas shiner. The Rio Grande silvery minnow was more commonly collected in seine hauls from mesohabitats dominated by cobble substrates and less frequently collected in mesohabitats with substrates dominated by fine-sized silt and clay particles, gravels, and sands, in that order. In contrast, the Tamaulipas shiner was broadly distributed among mesohabitats characterized as having gravel, cobble, and silt and clay.

Time_Period_of_Content:

Time_Period_Information:

Single_Date/Time:

Calendar_Date: 2012

Currentness_Reference: 2010–2011

Status:

Progress: On-going

Maintenance_and_Update_Frequency: None Planned

Spatial_Domain:

Bounding_Coordinate:

West_Bounding_Coordinate: -103.903888

East_Bounding_Coordinate: -101.816520

North_Bounding_Coordinate: 31.420552

South_Bounding_Coordinate: 30.356220

Keywords:

Theme:

Theme_Keyword: Rio Grande silvery minnow

Theme_Keyword: biology

Theme_Keyword: surface water

Theme_Keyword: water quality

Theme_Keyword: mesohabitats

Place:

Place_Keyword: Big Bend National Park

Place_Keyword: Trans-Pecos

Place_Keyword: Brewster County

Place_Keyword: Presidio County

Place_Keyword: Terrell County

Use_Constraints: These data are for informational purposes only. The data are released on the condition that the U.S. Geological Survey, its cooperators, or the U.S. Government may not be held liable for any damages resulting from its authorized or unauthorized use. Although these data have been processed successfully on a computer system at the U.S. Geological Survey, no warranty expressed or implied is made regarding the accuracy or utility of the data on any other system or for general or scientific purposes, nor shall the act of distribution constitute any such warranty.

Native_Data_Set_Environment: Microsoft Microsoft Windows XP Version 5.1 (Build 2600) Service Pack 3; ESRI ArcGIS 10.0.0.2414

Data_Quality_Information:

Lineage:

Process_Step:

Process_Description: Geographic data were collected by using Trimble DSM 232 GPS receiver. GPS data were translated and captured in ArcGIS. The data were postprocessed and stored in a geodatabase as polygon features representing the each of the mapped mesohabitat units. Additional data collected (fish assemblage, physical characteristics and water-quality information) were stored in attribute tables within the geodatabase and link to the geographic information via relationship class.

Process_Date: 20120801

Spatial_Data_Organization_Information:

Direct_Spatial_Reference_Method: Vector

Point_and_Vector_Object_Information:

SDTS_Terms_Description:

SDTS_Point_and_Vector_Object_Type: Entity polygon

Point_and_Vector_Object_Count: 8242

Spatial_Reference_Information:

Horizontal_Coordinate_System_Definition:

Geographic:

Latitude_Resolution: 0.000000

Longitude_Resolution: 0.000000

Geographic_Coordinate_Units: Decimal degrees

Geodetic_Model:

Horizontal_Datum_Name: North American Datum of 1983

Ellipsoid_Name: Geodetic Reference System 80

Semi-major_Axis: 6378137.000000

Denominator_of_Flattening_Ratio: 298.257222

Entity_and_Attribute_Information:

Detailed_Description:

Entity_Type:

Entity_Type_Label: mesohab_lowpulse

Attribute:

Attribute_Label: OBJECTID

Attribute_Definition: Internal feature number.

Attribute_Definition_Source: ESRI

Attribute_Domain_Values:

Unrepresentable_Domain: Sequential unique whole numbers that are automatically generated.

Attribute:

Attribute_Label: SHAPE

Attribute_Definition: Feature geometry.

Attribute_Definition_Source: ESRI

Attribute_Domain_Values:

Unrepresentable_Domain: Coordinates defining the features.

Attribute:

Attribute_Label: site_abv

Attribute_Definition: Site abbreviation.

Attribute:

Attribute_Label: sample_id

Attribute_Definition: Sample event ID.

Attribute:

Attribute_Label: unique_id

Attribute_Definition: Unique mesohabitat identifier. Combination of site_abv, sample_id and mesohab_id

Attribute:

Attribute_Label: mesohab_id

Attribute_Definition: Mesohabitat identifier.

Attribute:

Attribute_Label: mesohab_ds

Attribute_Definition: Mesohabitat description used to identify primary and secondary channel.

Attribute:

Attribute_Label: mesohab_cl

Attribute_Definition: Mesohabitat class type.

Attribute:

Attribute_Label: X

Attribute_Definition: Longitude in decimal degrees.

Attribute:

Attribute_Label: Y

Attribute_Definition: Latitude in decimal degrees.

Distribution_Information:

Resource_Description: Downloadable Data

Metadata_Reference_Information:

Metadata_Date: 20120801

Metadata_Contact:

Contact_Information:

Contact_Organization_Primary:

Contact_Organization: U.S. Geological Survey

Contact_Person: Public Information Officer

Contact_Address:

Address_Type: mailing and physical address

Address: 1505 Ferguson Lane

City: Austin

State_or_Province: Texas

Postal_Code: 78754

Country: USA

Contact_Voice_Telephone: 512–927–3500

Contact_Facsimile_Telephone: 512–927–3590

Contact_Electronic_Mail_Address: gs-w-txpublic-info@usgs.gov

Metadata_Standard_Name: FGDC Content Standards for Digital Geospatial Metadata

Metadata_Standard_Version: FGDC–STD–001–1998

Metadata_Time_Convention: local time

Metadata_Extensions:

Online_Linkage: http://www.esri.com/metadata/esriprof80.html

Profile_Name: ESRI Metadata Profile

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