Prepared in cooperation with the U.S. Army Corps of Engineers, Albuquerque District, and the U.S. Fish and Wildlife Service

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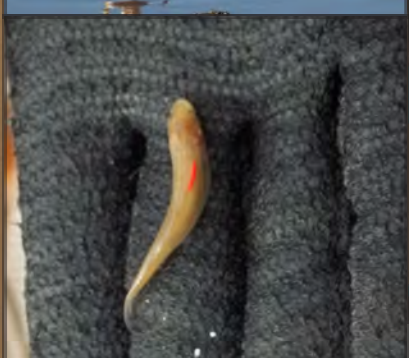

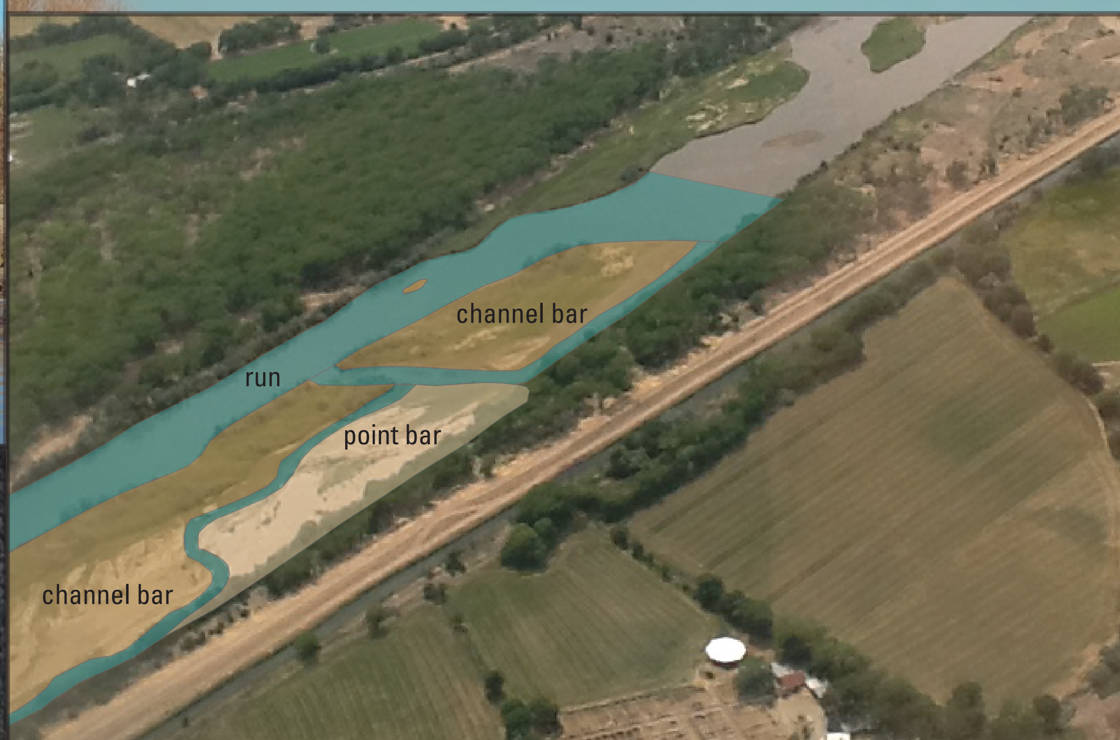

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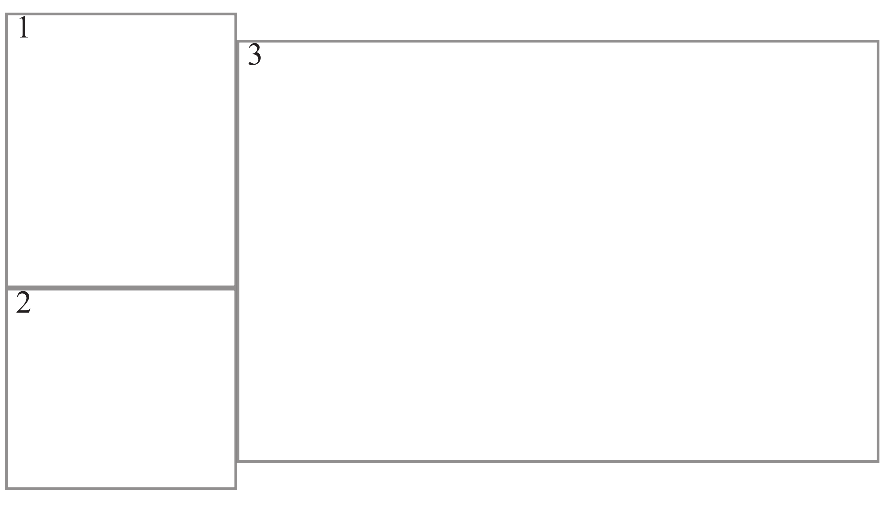

Cover.

1. Photograph of Christopher Braun delineating the right bank of the Rio Grande (Daniel Pearson, U.S. Geological Survey)
2. Photograph of Rio Grande silvery minnow with tagged dorsal fin (Daniel Pearson, U.S. Geological Survey)
3. Delineated, shaded, and labeled large-scale mesohabitats (Daniel Pearson, U.S. Geological Survey)

Background Image

Photograph of the Rio Grande at the Bosque del Apache I site (Daniel Pearson, U.S. Geological Survey)

Physical Characteristics and Fish Assemblage Composition at Site and Mesohabitat Scales over a Range of Streamflows in the Middle Rio Grande, New Mexico, Winter 2011–12, Summer 2012

By Christopher L. Braun, Daniel K. Pearson, Michael D. Porter, and J. Bruce Moring

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Conversion Factors

Inch/Pound to International System of Units

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	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)

International System of Units to Inch/Pound

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Area	
square meter (m^2)	10.76	square foot (ft^2)
	Flow rate	
centimeter per second	0.3937	inch per year

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as °F=(1.8×°C)+32

Datum

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

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

Supplemental Information

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

Concentrations of chemical constituents in water are given in milligrams per liter (mg/L).

Abbreviations

CCA	Canonical correspondence analysis
CPUE	Catch per unit effort
GIS	Geographic information system
GPS	Global Positioning System
MRGBI	Middle Rio Grande Bosque Initiative
USGS	U.S. Geological Survey

Physical Characteristics and Fish Assemblage Composition at Site and Mesohabitat Scales over a Range of Streamflows in the Middle Rio Grande, New Mexico, Winter 2011–12, Summer 2012

By Christopher L. Braun,[1] Daniel K. Pearson,[1] Michael D. Porter,[2] and James B. Moring[1]

Abstract

In winter 2011–12 and summer 2012, the U.S. Geological Survey (USGS), in cooperation with the U.S. Army Corps of Engineers, Albuquerque District and the U.S. Fish and Wildlife Service New Mexico Fish and Wildlife Conservation Office in Albuquerque, New Mexico, evaluated the physical characteristics and fish assemblage composition of available mesohabitats over a range of streamflows at 15 sites on the Middle Rio Grande in New Mexico. The fish assemblage of the Middle Rio Grande includes several minnow species adapted to hydrologically variable but seasonably predictable rivers, including the *Hybognathus amarus* (Rio Grande silvery minnow), a federally listed endangered species. Gaining a better understanding of habitat usage by the Rio Grande silvery minnow was the impetus for studying physical characteristics and fish assemblages in the Middle Rio Grande during different streamflow conditions. Data were collected at all 15 sites during winter 2011–12 (moderate streamflow), and a subset was collected at the 13 most downstream sites in summer 2012 (low streamflow). Sites were grouped into four river reaches separated by diversion dams listed in downstream order (names of the diversion dams are followed by short names of the sites nearest each dam in parentheses, listed in downstream order): (1) Cochiti (Peña Blanca), (2) Angostura (Bernalillo, La Orilla, Barelas, Los Padillas), (3) Isleta (Los Lunas I, Los Lunas II, Abeytas, La Joya, Rio Salado), and (4) San Acacia (Lemitar, Arroyo del Tajo, San Pedro, Bosque del Apache I, and Bosque del Apache II). Stream habitat was mapped in the field by using a geographic information system in conjunction with a Global Positioning System. Fish assemblage composition was determined during both streamflow regimes, and fish were collected by seining in each mesohabitat where physical characteristic data (depth, velocity, dominant substrate type and size, and percent embeddedness) and water-quality properties (temperature, dissolved oxygen, specific conductance, and pH; during summer 2012 only) were measured.

Nineteen species of fish were collected among the 15 sites and four reaches over both sampling periods; 10 of these 19 species are introduced. Fish-species richness (total number of fish species collected at each site during each sampling event) among sites that were sampled during both sampling periods ranged from 6 at Rio Salado to 12 at La Orilla. Fish were most abundant at the Lemitar site (1,786 individuals) and least abundant at the San Pedro site (275 individuals). The native *Cyprinella lutrensis* (red shiner) was the most abundant species collected among all of the sites, accounting for about 42 percent of fish collected. Fish-species richness and catch per unit effort (CPUE) were higher (or equivalent) at all sites during summer 2012 compared to winter 2011–12.

The relations between fish assemblage composition (that is, total abundance, which refers to the number of individuals of each species that were collected) and selected environmental variables (physical characteristic data collected at the mesohabitat scale [depth, velocity, and substrate particle size], and mesohabitat types) were explored by using canonical correspondence analysis. Environmental variables explained 8 percent ($p=0.48$) of the variability in the Middle Rio Grande fish assemblage during winter 2011–12, and Rio Grande silvery minnow were weakly associated with sand substrates, relatively moderate velocities (qualitative descriptors are derived from synthetic gradients extracted from CCAs), and relatively shallow depths. Environmental variables explained 14 percent ($p < 0.01$) of the variability in the Middle Rio Grande fish assemblage during summer 2012, when Rio Grande silvery minnow were associated with run mesohabitats, relatively high velocities, sand substrates, and relatively moderate depths.

[1]U.S. Geological Survey.

[2]U.S. Army Corps of Engineers.

The mean fish-species richness was greater in summer 2012 than in winter 2011–12 for each mesohabitat type, and the overall fish-species richness across all mesohabitat types was 0.62 during winter 2011–12, compared to 1.49 during summer 2012. The highest mean CPUE during winter 2011–12 was in isolated pools (54.3 fish per 100 square meters [m^2]), whereas the lowest was in flats (18.9 fish per 100 m^2). Ranges in CPUE were higher in summer 2012 relative to winter 2011–12 in each mesohabitat type sampled. As in winter 2011–12, the highest mean CPUE during summer 2012 was in isolated pools (233 fish per 100 m^2), whereas the lowest was in flats (29.6 fish per 100 m^2). Overall mean CPUE per mesohabitat across all mesohabitat types was 29.1 fish per 100 m^2 during winter 2011–12 compared to 85.3 fish per 100 m^2 during summer 2012.

Four species of minnows (red shiner, Rio Grande silvery minnow, *Pimephales promelas* [fathead minnow], and *Platygobio gracilis* [flathead chub]) were selected to compare preferred mesohabitat characteristics because all are small-bodied minnows and because more than 200 individuals of each of these species were collected. Red shiner were collected across the largest range of depths in both winter 2011–12 (0.02–4.31 feet [ft]) and summer 2012 (0.05–3.4 ft), as well as the largest range of velocities (0.0–4.31 feet per second [ft/s]) during winter 2011–12 among the four minnow species of interest. Rio Grande silvery minnow occurred in the narrowest range of depths (0.30–2.1 ft) during summer 2012, as well as the narrowest range of velocities in both winter 2011–12 (0.0–3.18 ft/s) and summer 2012 (0.02–1.51 ft/s).

Water-quality properties were only collected during summer 2012, when low-streamflow conditions existed and water-quality properties were thought to be potentially most limiting to aquatic life. Area-weighted mean water temperatures tended to be higher at the sites that were sampled in August 2012 (25.57 degrees Celsius [°C]) compared to June 2012 (24.61 °C). The highest area-weighted mean water temperature at a given site (29.03 °C) was measured at the Lemitar site on August 7, 2012, coincident with the lowest measured discharge (4.13 cubic feet per second [ft^3/s]). Area-weighted mean dissolved oxygen concentrations tended to be lower in August (7.46 milligrams per liter [mg/L]) compared to June (8.33 mg/L). The highest area-weighted mean dissolved oxygen concentration (9.13 mg/L) was measured at the Lemitar site on August 7, 2012, and the lowest area-weighted mean dissolved oxygen concentration (6.23 mg/L) was measured at the Los Padillas site on August 10, 2012. Area-weighted specific conductance in the sites upstream from La Joya did not exceed 400 microsiemens per centimeter (µS/cm) at 25 °C, whereas the area-weighted mean specific conductance at La Joya (837 µs/cm at 25 °C), Rio Salado (857 µs/cm at 25 °C), and Lemitar (1,300 µs/cm at 25 °C) were all well above the average of the area-weighted means for the 10 remaining sites (433 µs/cm at 25 °C). Lower area-weighted mean pH values were measured at the 3 sites in and near Albuquerque (La Orilla, Barelas, and Los Padillas—7.98, 8.08, and 7.81, respectively) compared to any of the 10 remaining sites, which had an overall mean pH of 8.44.

Introduction

The Rio Grande begins in Colorado (fig. 1), flows through New Mexico, and becomes the border between Texas and Mexico before emptying into the Gulf of Mexico. It is the second longest river in North America (Schmidt and others, 2003). Much of the Rio Grande Basin is arid to semiarid, and native aquatic organisms including *Hybognathus amarus* (Rio Grande silvery minnow) are adapted to a natural streamflow regime that includes seasonal floods. Schmidt and others (2003) explain that from the headwaters in Colorado to Presidio, Tex., the natural streamflow regime of the Rio Grande is snowmelt driven, with seasonal floods between April and July in response to snowmelt in the headwaters. Historically, streamflow in the Rio Grande Basin fluctuated between peak streamflow (typically from snowmelt runoff in the northern part of the basin and rainfall runoff in the southern part of the basin) (U.S. Army Corps of Engineers and others, 2007) and periods of low streamflow characterized by fragmentation, when some segments of the Rio Grande would go dry (Tetra Tech, Inc., 2014). Beginning in the early 1900s, the construction of impoundments for flood control and irrigation, diversion channels, and canals (collectively referred to as “river training actions”) altered the natural streamflow regime and geomorphic characteristics of the river (Makar and AuBuchon, 2012). River training structures (man-made structures designed and built within a river reach to alter the streamflow and sediment response of a river (U.S. Army Corps of Engineers, 2014) followed in the 1940s, including Kelner Jetties (jetty jacks) and levees and freeboard dikes (U.S. Bureau of Reclamation, 2012; The Texas Tribune, 2014).

The Middle Rio Grande, defined for the purpose of this report as the 280-kilometer (km) reach of the Rio Grande from Cochiti Dam downstream to Elephant Butte Reservoir, is in an arid part of the Rio Grande Basin dependent on inflows from upstream (fig. 1). Prior to the construction of Cochiti dam in 1975 (U.S. Bureau of Reclamation, 2012), large seasonal floods from snowmelt runoff in Colorado and New Mexico would occur most years on the Middle Rio Grande (Schmidt and others, 2003). Since the construction of Cochiti Dam, seasonal peaks in streamflow in the Middle Rio Grande from snowmelt runoff upstream have been much smaller. Makar and Aubuchon (2012, p. 55–56) explain how the natural streamflow regime has changed:

> The current hydrologic regime has limited flood magnitude and modified flood frequency. The frequencies have changed in two ways: large peaks are less frequent because of flood management, while smaller flood peaks and low flows are more frequent because water storage and release for irrigation and water is pumped from the Low Flow Conveyance Channel (LFCC) to provide minimum flows for habitat. Consequently, the river system does not experience the tremendous peaks or very low flows of the past.

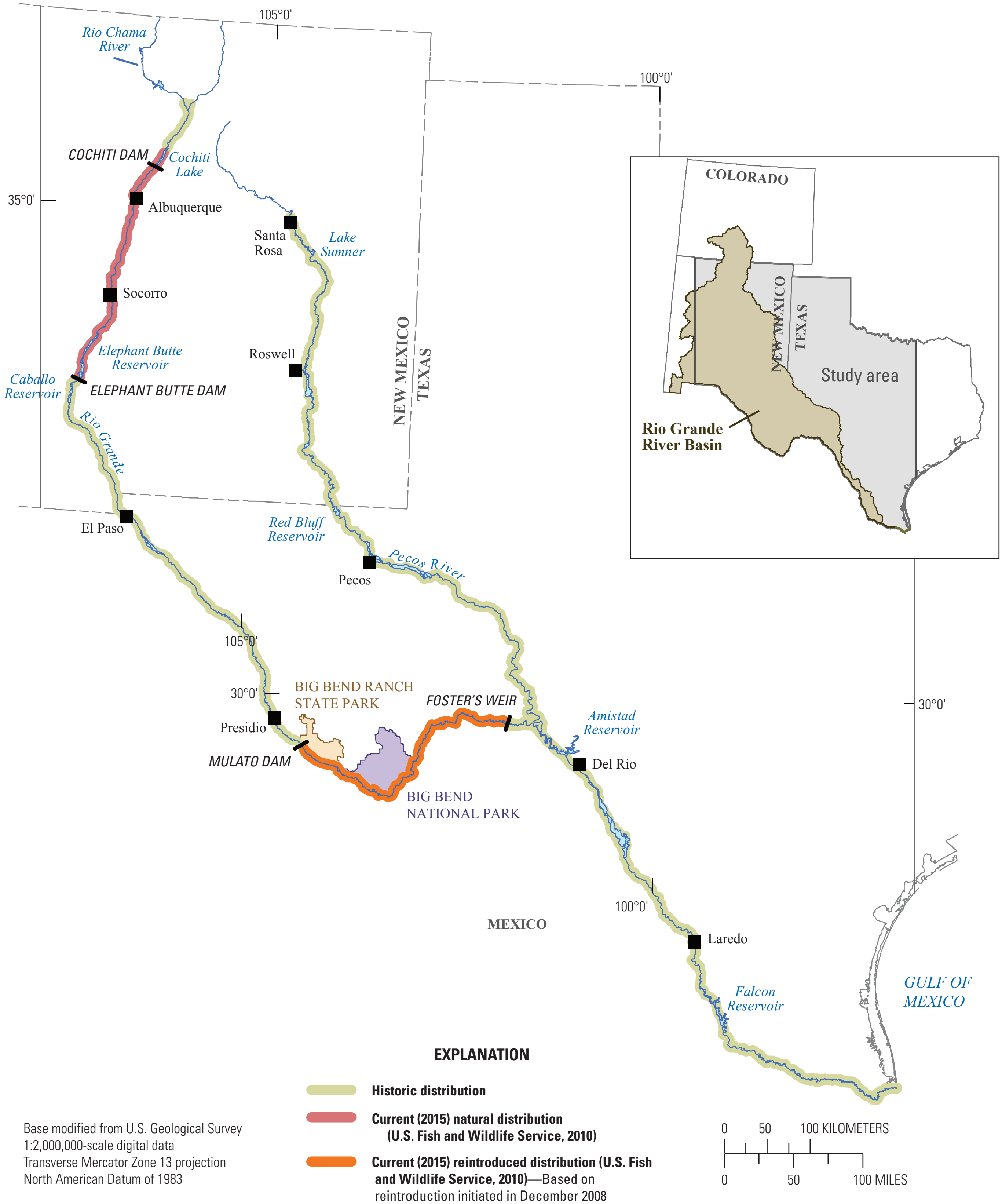

Figure 1. Historic and current geographic extent of *Hybognathus amarus* (Rio Grande silvery minnow) in New Mexico and Texas.

Makar and Aubuchon (2012, p. 161) further explain that the “lower [part] of the Middle Rio Grande [upstream from Elephant Butte Reservoir] contains several drainages, which can contribute significant flows during local thunderstorms.” Localized flooding can result from large thunderstorms. During floods, streamflow might briefly overtop the banks, but more typically streamflow remains within the stream channel, filling parts of the channel that are typically dry for extended periods, providing additional habitat to a wide range of species including native fish (Tetra Tech, Inc., 2014).

The fish assemblage of the Middle Rio Grande contains several minnow species adapted to hydrologically variable but seasonably predictable rivers, including the Rio Grande silvery minnow (Medley and Shirey, 2013). Gaining a better understanding of habitat usage by the Rio Grande silvery minnow, a federally listed endangered species, was the impetus for studying physical characteristics and fish assemblages in the Middle Rio Grande during different streamflow conditions.

The historical range of the Rio Grande silvery minnow was 4,000 km in the Rio Grande and the Pecos River Basins (fig. 1) (U.S. Fish and Wildlife Service, 2010). Natural populations of the Rio Grande silvery minnow currently (2015) are only found in the 280-km Middle Rio Grande reach of the Rio Grande. The once common Rio Grande silvery minnow was federally listed as an endangered species in 1994 (U.S. Fish and Wildlife Service, 1994). In addition to the natural population in the Middle Rio Grande, an experimental, reintroduced population of the Rio Grande silvery minnow is found in the Big Bend (300 km) reach of the Rio Grande that begins at Mulato Dam in Texas, flows through Big Bend National Park, and continues downstream to Foster’s Weir (fig. 1). In 2008, the U.S. Fish and Wildlife Service began efforts to restore the Rio Grande silvery minnow to this part of its former historical range (U.S. Fish and Wildlife Service, 2010; Moring and others, 2014). Throughout its historical range, Rio Grande silvery minnow decline has been attributed to modifications of the natural streamflow regime, channel drying, reservoir construction, stream channelization, declining water quality, and interactions with nonnative fish (Cook and others, 1992; Edwards, 2005; U.S. Fish and Wildlife Service, 2010).

Understanding habitat availability and use by Rio Grande silvery minnow is an essential element for the Recovery Implementation Program to be successful (Galat and others, 2001; Middle Rio Grande Endangered Species Collaborative Program, 2013). 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 with apparent uniformity and similar depth, velocity, slope, substrate, and cover (Pardo and Armitage, 1997; Parasiewicz, 2001; Parasiewicz and Dunbar, 2001). A “mesohabitat-scale” assessment of available habitat in relation to streamflows is considered by many ecologists and fluvial geomorphologists to be critical for the development of practical tools in river management (Harper and Everard, 1998; Newson and Newson, 2000).

Moring and others (2014, p. 4) explain the importance of assessing habitat for different streamflow conditions and the usefulness of assessing fish assemblage composition (the different species of fish coexisting in a habitat) in streams supporting or believed capable of supporting the sustainable populations of Rio Grande silvery minnow:

> 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. *** 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 relation between the amount of streamflow and habitat for Rio Grande silvery minnow and similar species of fish in the Middle Rio Grande is not well understood. To better understand the spatial extent of available mesohabitats over a range of streamflows, the U.S. Geological Survey (USGS), in cooperation with the U.S. Army Corps of Engineers, Albuquerque District and the U.S. Fish and Wildlife Service New Mexico Fish and Wildlife Conservation Office in Albuquerque, N. Mex., evaluated the physical characteristics and fish assemblages during 2011–12 at 15 sites on the Middle Rio Grande in New Mexico, in the reach downstream from Cochiti Dam to Elephant Butte Reservoir.

Background and Previous Studies

Rio Grande silvery minnow are small-bodied minnows (Sublette and others, 1990) with silver coloration (preserved specimens are brown to olive [dorsal] and white [ventral]). Rio Grande silvery minnow adults use low-velocity habitats (Dudley and Platania, 1997; Bovee and others, 2008) with a silty (fine-sized silt and clay particles less than 0.062 millimeters [mm] in size) or sandy (sand-sized particles greater than 0.062 to 2 mm in size) (Wentworth, 1922; Guy, 1969) substrate. Rio Grande silvery minnow are broadcast spawners that produce thousands of semibuoyant eggs (Cowley and others, 2005; Medley and Shirey, 2013). During the spring, extensive drift of eggs has been documented during low volume pulses of streamflow (Dudley and Platania, 2007), whereas recruitment is associated with the availability of low water velocity (backwater) habitats used by larval and juvenile Rio Grande silvery minnows (Pease and others, 2006).

Previous habitat studies (apps. 1 and 2) have used a hydraulic approach to: represent the range of hydrologic and geomorphologic variation within the Middle Rio Grande and Rio Chama (U.S. Army Corps of Engineers and others, 2007); assess Rio Chama and Rio Grande fish habitat quality (upstream from Cochiti Lake; Buntjer and Remshardt, 2005); incorporate geomorphic patterns with diversion dams and irrigation returns (Remshardt and Tashjian, 2003); and focus on specific sites (Torres and others, 2008). In addition, Bovee and others (2008) applied the Instream Flow Incremental Methodology (Bovee and others, 1998) toward understanding streamflow relationships for fish habitat management in a short reach. Fish sampling, often done in concert with habitat suitability assessments, has been done by using mesohabitat classification (Dudley and Platania, 1997) as a criterion for fish population monitoring and assessment (Dudley and others, 2012, 2013).

Mesohabitat-scale mapping provides information on habitat area as a function of alterations in streamflow, channel planform, and other activities (Parasiewicz, 2001). Development of an integrated habitat restoration strategy that achieves a population-level response requires understanding mesohabitat use by Rio Grande silvery minnows and quantifying the area of available habitat for all life stages (Middle Rio Grande Endangered Species Collaborative Program, 2013).

Mesohabitat use by Rio Grande silvery minnows along with stream depth, velocity, and substrate (Dudley and Platania, 1997) have been the basis for numerous studies (Dudley and others, 2012, 2013; Moring and others, 2014); however, information on the spatial extent of available mesohabitats over a range of streamflows throughout the Middle Rio Grande is sparse (Remshardt and Tashjian, 2003). This report is intended to build on previous investigations that were done to understand habitat use by Rio Grande silvery minnow. The availability of functional habitat is essential for maintaining viable fish populations (Lapointe and others, 2013). The spatial extent, physical characteristics, and use of mesohabitat types for different streamflows were obtained for all fish species present at selected sites on the Middle Rio Grande during 2011–12. This information was collected in support of ongoing efforts by the Middle Rio Grande Endangered Species Collaborative Program to promote sustainable populations of Rio Grande silvery minnow.

Purpose and Scope

The purpose of this report is to describe mesohabitats and their use by fish during different seasonal streamflow regimes (winter 2011–12 and summer 2012) at 15 sites on the Middle Rio Grande in New Mexico (fig. 2); winter in this report refers to November 2011 through February 2012, and summer refers to June through August 2012. Data were collected at all 15 sites during winter 2011–12 (moderate streamflow), and a subset was collected at the 13 most downstream sites in summer 2012 (low streamflow). Physical characteristic and fish assemblage data were collected and assessed at the mesohabitat scale during the winter and summer sampling periods. Comparisons of fish assemblage data within and among the 15 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 multivariate statistical analysis, the canonical correspondence analysis (CCA). Water-quality properties (dissolved oxygen, pH, specific conductance, and temperature) measured in summer 2012 (a period characterized by relatively low streamflow) are compared among sites because these properties are considered most crucial for sustaining aquatic biota. All of the data that were collected and used for analysis are in the geospatial database included with this report.

Description of Study Area

Currently (2015), the Middle Rio Grande is a highly regulated system influenced by multiple storage and flood control reservoirs, several diversion dams, and almost 1,500 km of irrigation canals and drainages between Cochiti Dam and Elephant Butte Reservoir. Dams, diversions, and canals have not altered the preregulation seasonal streamflow pattern (fig. 3) but have dampened the magnitude and duration of extreme streamflow events (U.S. Army Corps of Engineers and others, 2007) and have led to increased stream fragmentation, including extended periods with no streamflow downstream from Albuquerque between river mile 168 (near the Los Lunas I site) and river mile 73 (about 2 miles downstream from the Bosque del Apache II site) during summer to early fall irrigation (Tetra Tech, Inc., 2014) (sites are referred to throughout this report by their short names, as shown in table 1).

By summarizing the work of others, Padilla and Baird (2010) explain that the Middle Rio Grande is estimated to have been aggrading during the past 11,000 to 22,000 years (Leopold and others, 1964; Hawley and others, 1976) because inflows contributed more sediment than the river could transport (Crawford and others, 1993). The historically large sediment load of the Middle Rio Grande resulted in aggradation of the channel and flood plain (Happ, 1948; Leopold and others, 1964; Scurlock, 1998; Makar and AuBuchon, 2012). Historically, the Middle Rio Grande alternated between narrow channels in canyon-bound reaches and wider, braided, sandy channels between the canyon reaches (Lagasse, 1980; Scurlock, 1998; Makar and Massong, 2009; Makar and AuBuchon, 2012). As a result of river training actions during the past 100 years, the channel planform of the Middle Rio Grande changed from a relatively wide, braided, and aggrading sand-bed channel to a relatively narrow, single-threaded, and mostly degrading channel that is dominated by a gravel bed through much of its length (Makar and AuBuchon, 2012). In addition to reductions in sediment supply, narrowing in the width of the Rio Grande has been attributed to changes in peak spring flows caused by upstream flood control, channelization activities, and other river training actions used to manage flows for irrigation purposes

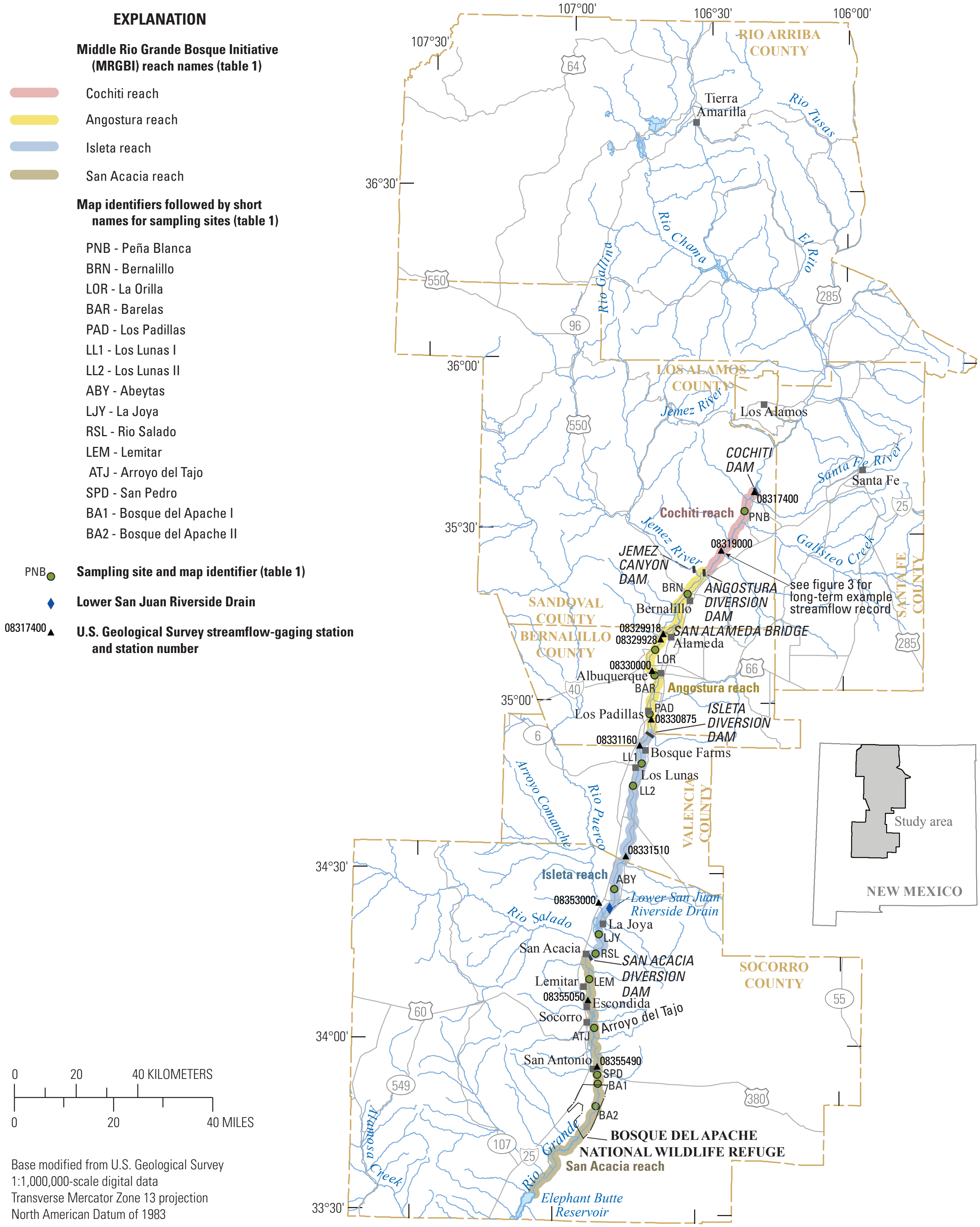

Figure 2. Sites where mesohabitats were assessed and Middle Rio Grande Bosque Initiative reaches on the Middle Rio Grande, New Mexico, 2011–12.

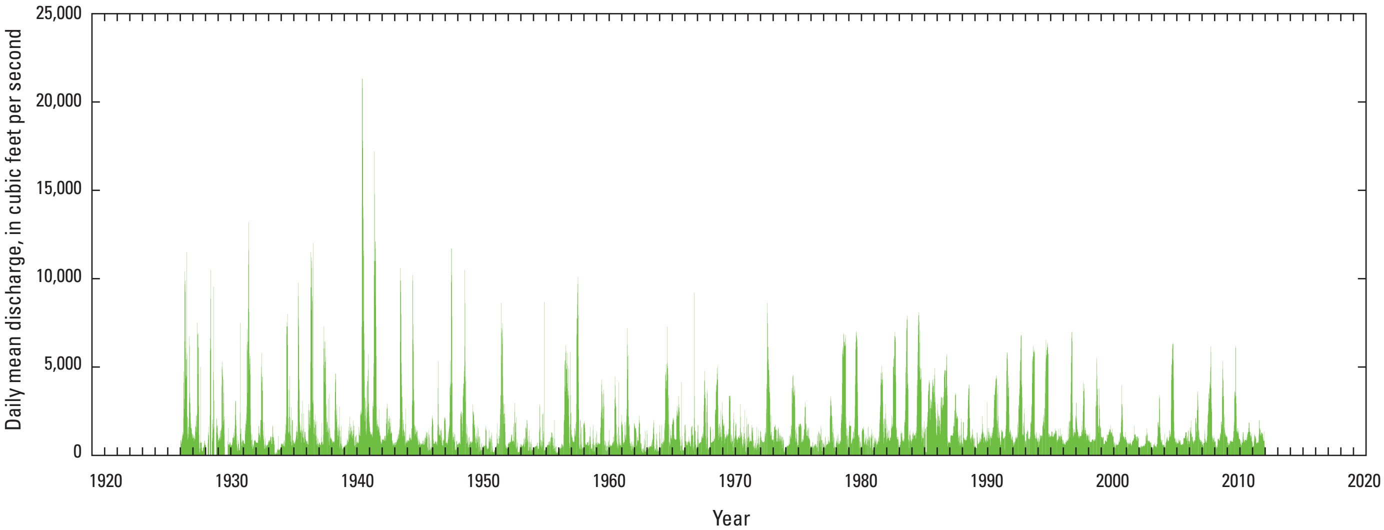

Figure 3. Measured daily mean discharge at U.S. Geological Survey streamflow-gaging station 08319000 Rio Grande at San Felipe, New Mexico, January 1, 1927–August 31, 2012.

(Makar and AuBuchon, 2012). Padilla and Baird (2010, p. 1) describe an exception in which the Middle Rio Grande is still aggrading, not because of natural flow conditions, but rather as a result of Elephant Butte Reservoir filling to capacity and slowing stream velocities, noting "Elephant Butte Reservoir filled to capacity in 1985. This led to delta sediments being deposited (aggradation) in the channel for a distance of about 40 miles upstream [from] the full reservoir pool location."

Prior to becoming a highly regulated system, the Rio Grande conveyed the sixth largest mean sediment load of any river in North America (Schmidt and others, 2003). Sediment supply in the Rio Grande is affected by land-use practices and natural cycles of erosion and deposition (Vogt, 2003) and water management (Makar and AuBuchon, 2012), but Cochiti Dam has the largest effect on sediment supply in the Middle Rio Grande. In addition to controlling the water discharge, Cochiti Dam traps virtually the entire sediment load that would naturally enter the Middle Rio Grande reach (Richard, 2001). Differences in sediment supply and sediment transport capacity result in changes to the channel planform (Makar and AuBuchon, 2012). In degrading channels, the loss of bed sediment (streambed downcutting) and transition from sand to gravel beds are common because the sediment load is smaller than the transport capacity; channel bed and bank erosion allows the stream to regain at least part of its sediment load (Kondolf, 1997). Between 1935 and 1989, the channel area of Middle Rio Grande decreased by about 50 percent (Crawford and others, 1993). Over this period, the typical flood-plain width was reduced from more than 9,000 meters (m) to as small as 2,000 m. Conveyance capacity of the Rio Grande was reduced to less than 7,000 cubic feet per second (ft^3/s) in the more narrow reaches, compared to approximately 42,000 ft^3/s in broader reaches (Crawford and others, 1993).

Vegetated bars split the channel at high streamflows, creating an anastomosing channel form, a river pattern "consisting of multiple channels separated by islands which are usually excised from the continuous flood plain and which are large relative to the size of the channels" (Knighton and Nanson, 2000, p. 101).

Methods of Investigation

The wetted area, physical characteristics, and fish assemblage of river mesohabitats were characterized within a 1-km length of stream channel at each site. Fifteen sites distributed along the Middle Rio Grande were selected starting about 3 km downstream from Cochiti Dam and ending about 40 km upstream from Elephant Butte Reservoir (table 1, fig. 2). Sites were grouped into four river reaches separated by diversion dams. In downstream order, the names of the diversion dams followed by short names of the sites (in parentheses) were Cochiti (Peña Blanca), Angostura (Bernalillo, La Orilla, Barelas, Los Padillas), Isleta (Los Lunas I, Los Lunas II, Abeytas, La Joya, Rio Salado), and San Acacia (Lemitar, Arroyo del Tajo, San Pedro, Bosque del Apache I, and Bosque del Apache II). The Cochiti, Angostura, and Isleta reaches are bound by upstream and downstream diversion dams (fig. 2), whereas there is a diversion dam at the upstream boundary of the San Acacia reach, but the downstream boundary of the reach is the upstream extent of Elephant Butte Reservoir. Stream habitat was mapped in the field by using a geographic information system (GIS) in conjunction with a Global Positioning System (GPS). The four reaches delineated in this report are also being assessed as part of the Middle

Table 1. Physical characteristics and fish assemblage sampling sites and sampling dates, Middle Rio Grande, New Mexico, 2011–12.

[MRGBI, Middle Rio Grande Bosque Initiative; ft^3/s, cubic feet per second; --, no data were collected during indicated time period]

MRGBI reach names	Site name	U.S. Geological Survey station number	Short name	Map identifier (fig. 2)	River mile	Flow regime								
						Moderate streamflow						Low streamflow		
						Date		Discharge[2] (ft^3/s)	Date		Discharge[2] (ft^3/s)	Date		Discharge[2] (ft^3/s)
						Mapping	Fish and aquatic habitat[1]		Mapping	Fish and aquatic habitat[1]		Mapping	Fish and aquatic habitat[1]	
Cochiti	Rio Grande near Peña Blanca, N. Mex.	353330106213500	Peña Blanca	PNB	227.5	Nov. 10	Nov. 11	552	--	--	--	--	--	--
Angostura	Rio Grande downstream from Highway 550 at Bernalillo, N. Mex.	351848106333400	Bernalillo	BRN	203.6	Nov. 11	Nov. 12	570	--	--	--	--	--	--
Angostura	Rio Grande upstream from Montano Road northwest at Albuquerque, N. Mex.	350859106402600	La Orilla	LOR	189.0	Nov. 16	Nov. 17	746	--	--	--	Aug. 11	Aug. 13	430
Angostura	Rio Grande upstream from Highway 314 at Albuquerque, N. Mex.	350432106400500	Barelas	BAR	183.0	Nov. 9	Nov. 10	[3]850	--	--	--	Aug. 10	Aug. 11	[4]351
Angostura	Rio Grande upstream from Interstate Highway 25 near Los Padillas, N. Mex.	345732106410800	Los Padillas	PAD	173.0	Nov. 15	Nov. 16	851	--	--	--	Aug. 9	Aug. 10	334
Isleta	Rio Grande upstream from Highway 6 at Los Lunas, N. Mex.	344852106424200	Los Lunas I	LL1	162.5	Nov. 12	Nov. 14	749	--	--	--	June 5	June 6	258
Isleta	Rio Grande near Los Chavez, N. Mex.	344457106443300	Los Lunas II	LL2	157.0	Nov. 14	Nov. 15	[3]1,050	--	--	--	June 6	June 7	243
Isleta	Rio Grande upstream from Highway 60 near Contreras, N. Mex.	342644106481300	Abeytas	ABY	133.0	Nov. 28	Nov. 29	940	--	--	--	June 7	June 8	179
Isleta	Rio Grande near La Joya, N. Mex.	341842106511100	La Joya	LJY	122.0	Nov. 29	Nov. 30	991	--	--	--	Aug. 8	Aug. 9	49.5
Isleta	Rio Grande downstream from Arroyo Rosa de Castillo, San Acacia, N. Mex.	341542106520700	Rio Salado	RSL	117.5	Nov. 30	Dec. 1	970	--	--	--	Aug. 7	Aug. 8	37.9
San Acacia	Rio Grande near Lemitar, N. Mex.	341044106530300	Lemitar	LEM	109.0	Dec. 1	Dec. 2	921	--	--	--	Aug. 6	Aug. 7	4.13
San Acacia	Rio Grande downstream from Arroyo del Tajo near Socorro, N. Mex.	340215106515500	Arroyo del Tajo	ATJ	97.0	Dec. 1	Dec. 3	870	--	--	--	June 8	June 9	140
San Acacia	Rio Grande downstream from Hwy 380 near San Antonio, N. Mex.	335403106505800	San Pedro	SPD	86.5	Dec. 3	[4]Dec. 6	857	Feb. 6	Feb. 7	--	June 9	June 11	69.3
San Acacia	Rio Grande north of Bosque del Apache, San Antonio, N. Mex.	335229106505800	Bosque del Apache I	BA1	84.5	--	--	--	Feb. 7	Feb. 8	633	June 11	June 12	48
San Acacia	Rio Grande at Bosque del Apache near San Antonio, N. Mex.	334833106512200	Bosque del Apache II	BA2	78.0	Dec. 6	--	--	Feb. 8	Feb. 9	588	June 12	June 13	45.7

[1]Includes instantaneous discharge measurements, in most cases, and water-quality property measurements at low streamflow.

[2]Instantaneous discharge measured between 9:00 a.m. and 1:00 p.m. during fish and aquatic habitat data collection.

[3]Mean daily discharge from nearest streamflow-gaging station upstream from the site.

[4]Fish were not collected on this date.

Rio Grande Bosque Initiative (MRGBI). The MRGBI “is an ongoing, congressionally supported, interagency ecosystem management effort to coordinate activities related to the ecological restoration and management of the Middle Rio Grande” (U.S. Fish and Wildlife Service, 2014a, p. 1).

Selection of Sites and Streamflow Regimes

To help build on previous studies, 13 of the 15 sites where data were collected for this study were at the same locations where data were collected in previous Rio Grande aquatic habitat studies (table 1, app. 1). The Upper Rio Grande Water Operations Study characterized geomorphologic variation in the Middle Rio Grande and the Rio Chama (U.S. Army Corps of Engineers and others, 2007). The U.S. Fish and Wildlife Service study by Remshardt and Tashjian (2003) was based on a tiered approach established by the U.S. Bureau of Reclamation and Bosque Hydrology Group (U.S. Fish and Wildlife Service, 2014b). The three tiers for selecting sites were fluvial geomorphology (first), hydrological reaches delineated by diversion dams (second), and local influence of arroyos and irrigation outfalls (third) (Remshardt and Tashjian, 2003). The U.S. Fish and Wildlife Service also revisited the Peña Blanca site by using similar methods (Torres and others, 2008). The USGS selected three sites to estimate habitat upstream from San Acacia Diversion Dam as a function of streamflow from the Lower San Juan Riverside Drain (Bovee and others, 2008). One habitat restoration site was included in the study (Los Lunas II; Kissock, 2011), along with an additional site proposed by Bosque del Apache National Wildlife Refuge (Bosque del Apache II).

During this study, 13 of the 15 sites were assessed under two different seasonal streamflow regimes during winter 2011–12 and summer 2012 (table 1, fig. 4); the two remaining sites (Peña Blanca and Bernalillo) were only assessed in winter 2011–12. Mesohabitat assessments were completed at differing seasonal streamflow regimes to evaluate variability in mesohabitat wetted area and associated differences in the occurrence and distribution of fish among sites and mesohabitat types. The original intent of the study was to complete the assessments during moderate streamflow conditions in winter 2011–12 and during a period of higher streamflow conditions from snowmelt runoff in the late spring to early summer of 2012; however, the lack of appreciable runoff during late spring to early summer of 2012 (fig. 4 compared to prior years on fig. 3) resulted in lower summer streamflows compared to what was anticipated. Therefore, mesohabitats were assessed during a period of moderate winter streamflow ranging from 552 to 1,050 ft^3/s (table 1, fig. 4) between November 2011 and February 2012 and during a period of low summer streamflow ranging from 4.13 to 430 ft^3/s between June and August 2012 (table 1; fig. 4). The low streamflow in the summer of 2012 resulted in an opportunity to assess fish habitat and assemblages during a period of relative extremes in certain environmental variables. Water quality tends to be lower, and mesohabitats are less available during periods of low streamflow compared to periods with higher streamflow.

The Middle Rio Grande was flowing in all reaches where the sites were located during the winter 2011–12 sampling period (figs. 5*A* and 5*B*); however, because of the potential for periods of stream fragmentation at some sites in the summer of 2012, the sampling order in summer 2012 was changed relative to the sampling order in winter 2011–12. In winter 2011–12, sites were sampled generally from upstream to downstream, whereas in summer 2012, sites were sampled in an order that would ensure that all sites were flowing at the time of sampling. The reordered sampling facilitated the assessment of as many mesohabitats as possible, as well as the measurement of physical characteristics and sampling of fish during lower streamflow conditions. Those sites that were at the greatest risk of drying were visited in early June 2012, and those sites that were expected to have streamflow throughout the summer were visited in August 2012 (table 1, fig. 5*B*).

Mesohabitat Assessment

The approach used to assess mesohabitats in the Middle Rio Grande, N. Mex., was modified from Parasiewicz and Dunbar (2001). Mesohabitat assessment generally consists of three steps that together lead to conclusions regarding the effects of various management options (fig. 6). To assess mesohabitats, geospatial measurements (data associated with a particular location) are made as a first step to generate maps, which provide quantitative descriptions of the ecohydraulic habitat conditions in the river over a range of streamflows (that is, how the various mesohabitat types change under different streamflow conditions) (Bovee and others, 1998, 2008). The second and third steps include the collection of physical measurements and biological measurements, respectively, both of which are used to determine habitat use by selected fish species. Changes in habitat conditions with changing streamflow magnitude can then be determined by using mechanistic hydraulic models or statistical approaches.

Because the size and distribution of habitats can change in response to changes in streamflow, it is important to evaluate the physical characteristics and fish assemblage at the appropriate scale. Mesohabitats are an appropriate scale for mapping; although their size and distribution may change, the assemblage of mesohabitats is generally constant (Armitage, 1995), and aquatic organisms have adapted to the physical characteristics and temporal dynamics of the mesohabitat with which they are associated (Southwood, 1988).

In this study, mesohabitats were mapped at the mesohabitat scale at each site. The following mesohabitats were mapped: riffles, runs, pools (channel and eddy), isolated pools, forewaters, backwaters, embayments, and flats (table 2; fig. 7). Point bars and channel bars (table 2; fig. 7) were also mapped to provide a more complete assessment of the active channel at each site. Data from two types of pools—channel

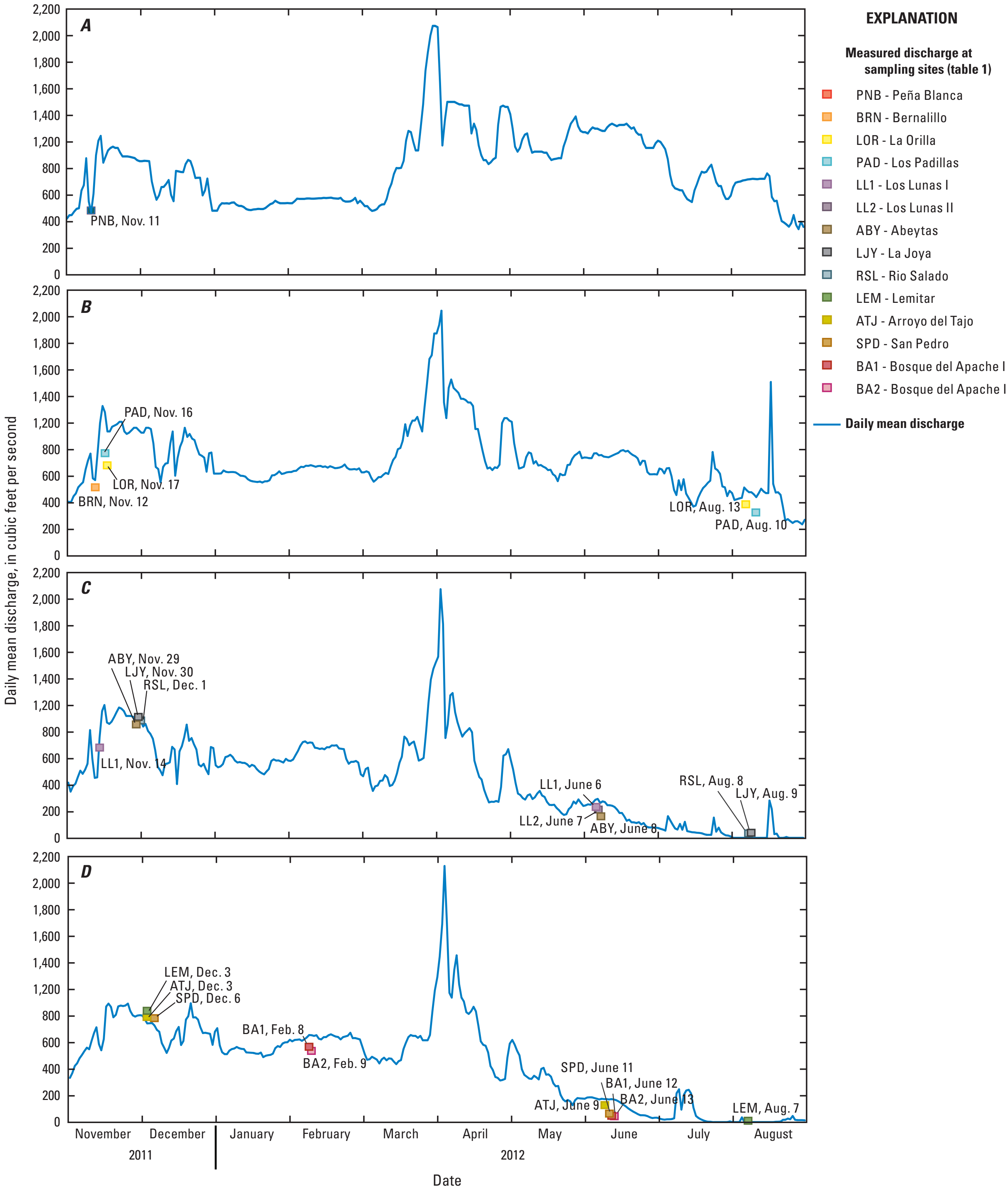

Figure 4. Measured daily mean discharge at U.S. Geological Survey streamflow-gaging stations *A*, 08317400 Rio Grande below Cochiti Dam, New Mexico; *B*, 08329918 Rio Grande at Alameda Bridge at Alameda, N. Mex.; *C*, 08331160 Rio Grande near Bosque Farms, N. Mex.; and *D*, 08355050 Rio Grande at bridge near Escondida, N. Mex.; November 1, 2011–August 31, 2012.

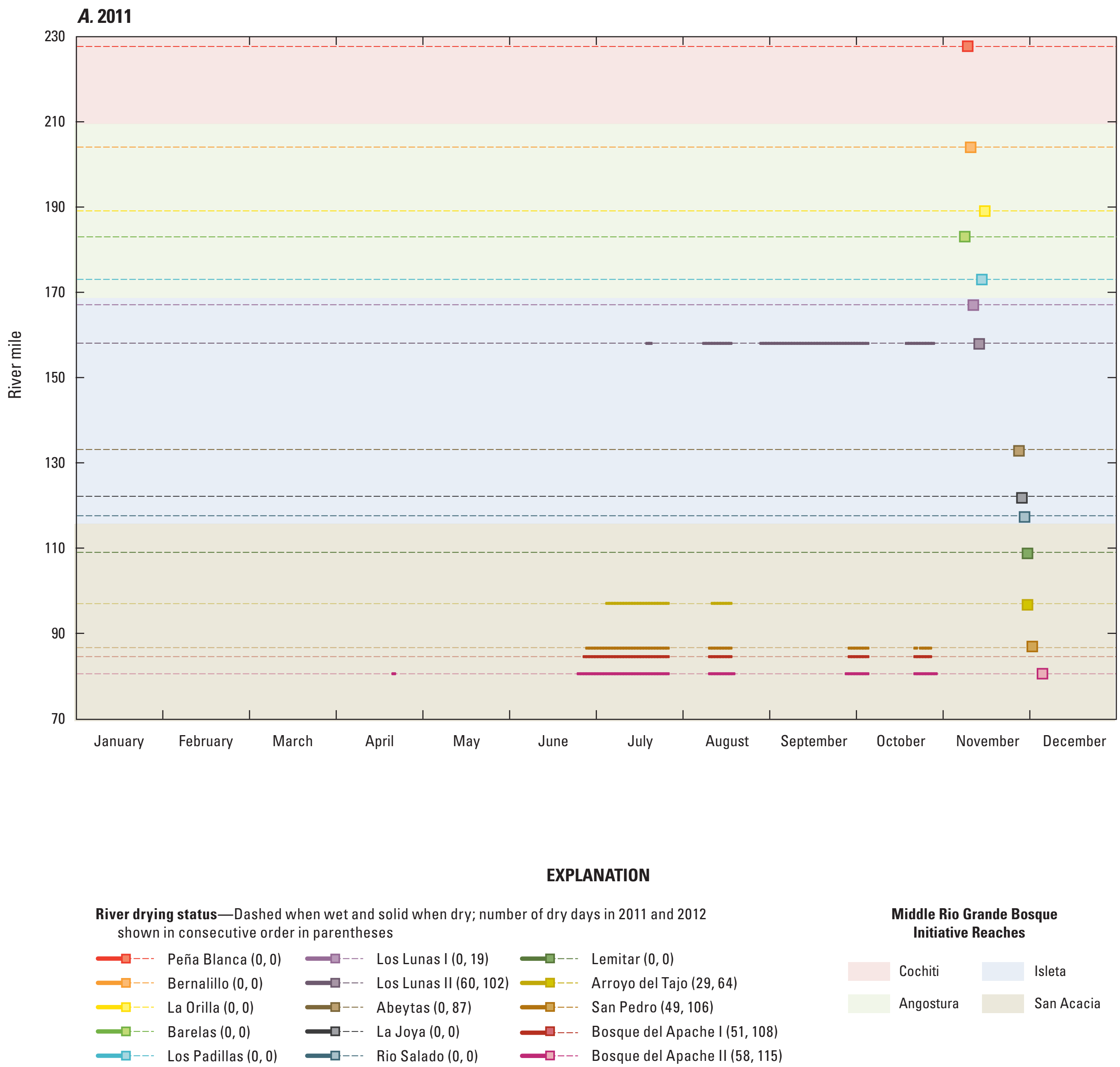

Figure 5. Periods of streamflow and river fragmentation in the Middle Rio Grande, New Mexico, January 1, 2011–December 31, 2012.

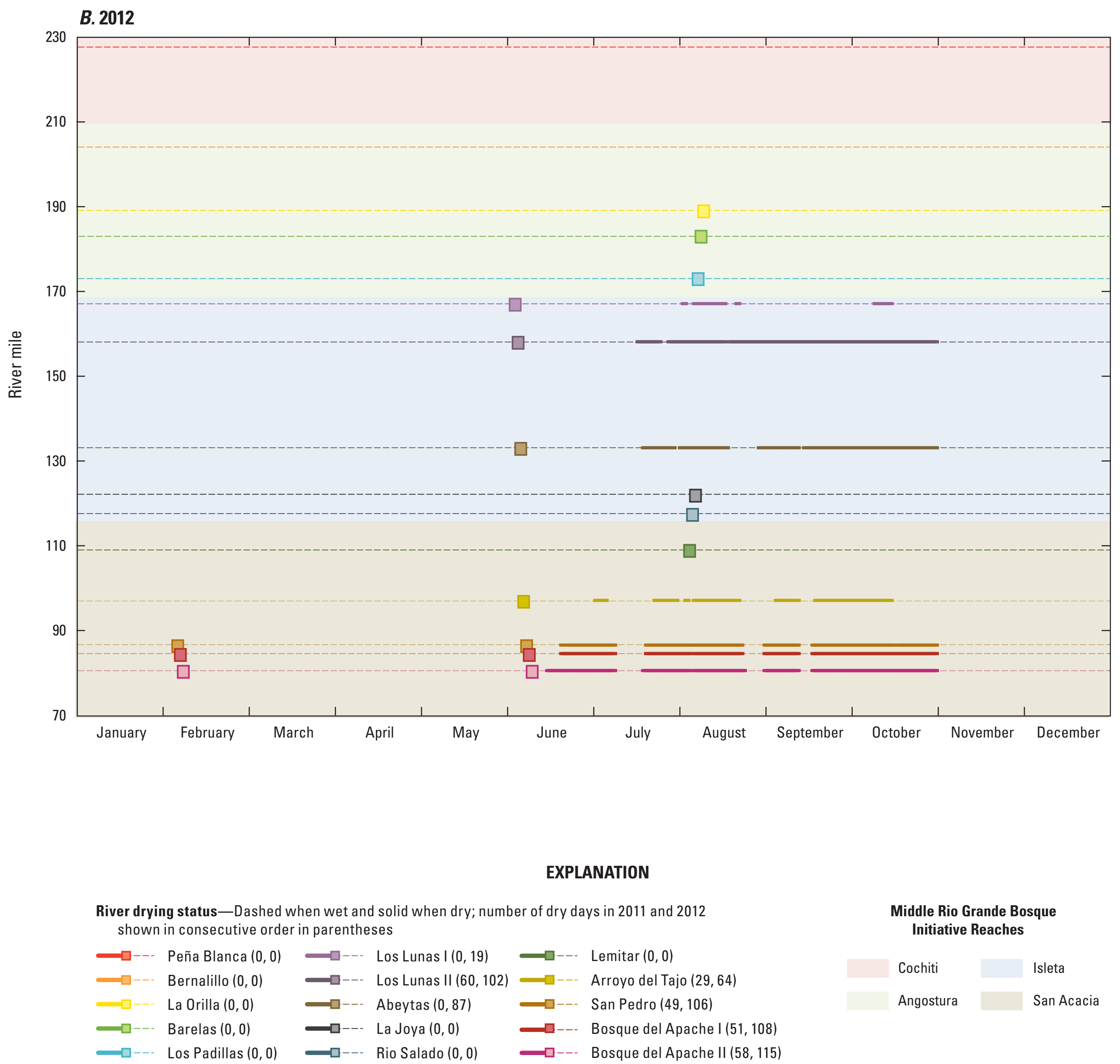

Figure 5. Periods of streamflow and river fragmentation in the Middle Rio Grande, New Mexico, January 1, 2011–December 31, 2012.—Continued

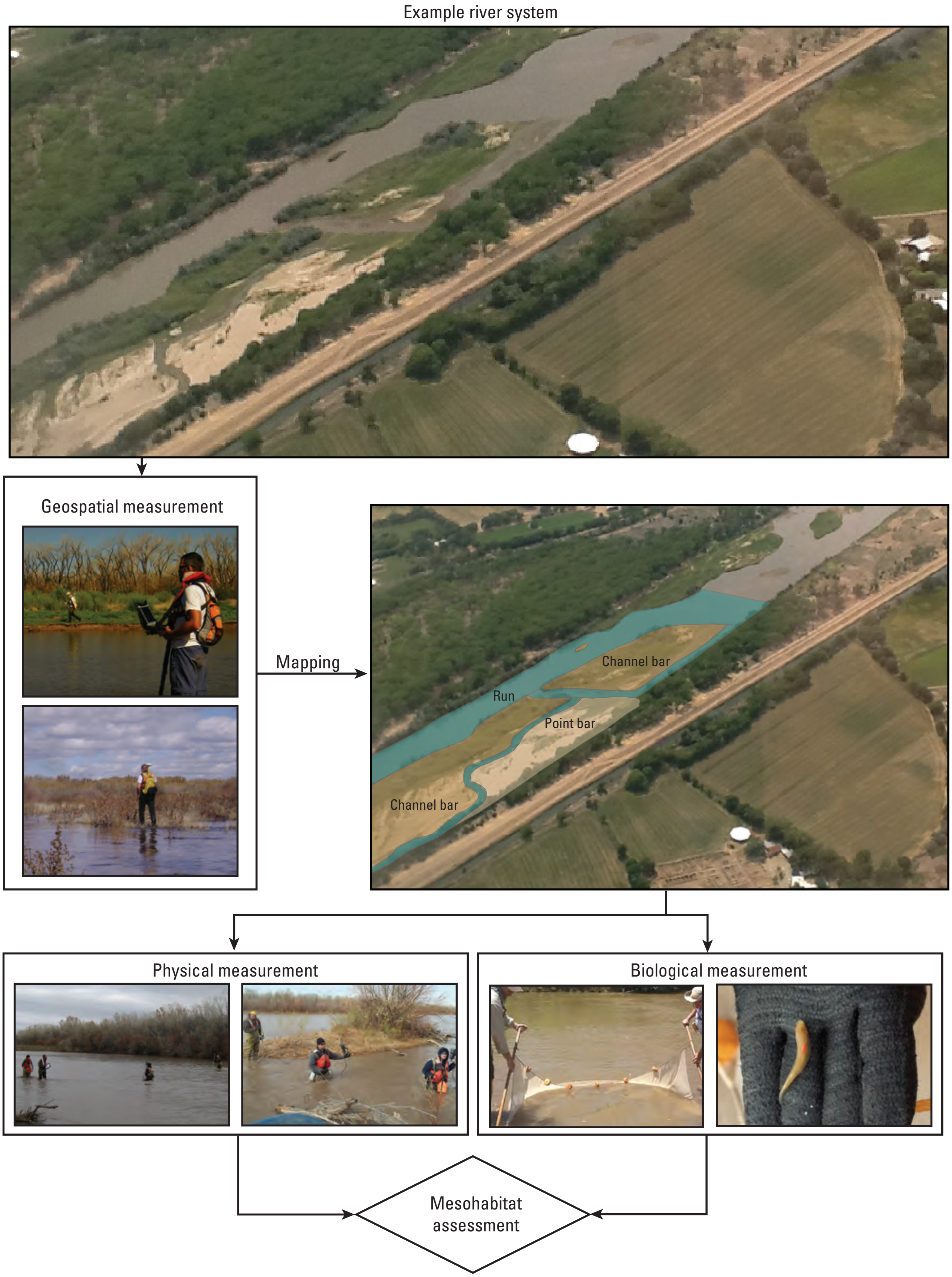

Figure 6. Overview of approach used to assess mesohabitats in the Middle Rio Grande, New Mexico (modified from Parasiewicz and Dunbar, 2001).

and eddy—were combined into a “pools” category for analysis because combining the two pool types into a single “pool” category resulted in an adequate sample size of “pools” and was thought to be more appropriate for the analysis of fish data. In this report, forewaters, backwaters, and embayments were collectively referred to as “margin pool” mesohabitats because the physical characteristics (depth, velocity, and bed substrate) of the three mesohabitats were so similar. The mesohabitat types used in this report are further described in table 2.

Various software, hardware, and field mapping methods were employed to accomplish the project mapping goals. Digital mapping techniques were used for all spatial measurements collected during this study. Mapping included the use of a GIS (Esri, 2013) and a GPS in concert to capture the mapping image in the field. The GPS data were captured by using a Trimble DSM 232 modular receiving unit (Trimble, 2015a). For purposes of this study, a corrected signal from OmniSTAR (subscription service) (Trimble, 2015b) was received through the Trimble receiving unit to gain the accuracy (subfoot, real time) needed for mapping. The GPS data were input directly into a laptop computer and visualized onsite by using GIS.

Field mapping was done by using a variety of approaches based on streamflow conditions, river depth, and riverbank accessibility. All 15 sites were visited at least once (table 1), and 13 sites were visited twice during each of the two streamflow regimes identified for this study. For the majority of the field mapping, project personnel began by walking the water’s edge along the 1-km reach at each site in order to collect GPS data along the study area extent. This process required two individuals, one of which would delineate the edge of discrete mesohabitats by using the GPS receiver, while the second individual would attribute the incoming GPS data in real time. Large, continuous runs, which were often 500 m or more of the 1-km reach length at a given site, 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 the GIS in association with high-resolution remotely sensed imagery, creating a detailed map of each study reach at each targeted streamflow.

Table 2. Description of mesohabitat types (modified from Platania, 1993) and channel features that were mapped on the Middle Rio Grande, New Mexico, 2011–12.

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

Mesohabitat type	Description	Velocity minimum to maximum (ft/s)	Depth minimum to maximum (ft)
Riffle	Relatively shallow and low to moderate velocity feature characterized by moderately turbulent water	-0.05–4.80	0.01–2.58
Run	Relatively high-velocity feature with laminar flow and a nonturbulent surface	-1.05–5.39	0.02–4.31
Pool	Feature with little or no velocity that may be deep in places	-2.14–1.70	0.04–4.40
(a) Channel	Type of pool where current moves in the same flow direction as the channel		
(b) Eddy	Type of pool where current moves in the opposite direction relative to flow		
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 a secondary channel	-0.06–0.21	0.01–2.40
Forewater	Slackwater feature oriented into the principal direction of flow	-0.10–0.08	0.01–1.00
Backwater	Slackwater feature oriented in an opposing direction to the principal flow direction	-0.23–2.25	0.01–2.87
Embayment	Slackwater feature located adjacent to the channel and oriented perpendicular to flow	-0.27–1.02	0.03–1.26
Flat	Very shallow, low-velocity feature typically located on the periphery of an existing point or channel bar; caused by a slight rise in stage	-0.62–3.13	0.01–2.4
Channel feature	**Description**		
Point bar	Crescent-shaped depositional feature located on the inside of a stream bend; typically either devoid of or containing annual vegetation	NA	NA
Channel bar	Transitory parcel of land surrounded by water; typically either devoid of or containing annual vegetation	NA	NA

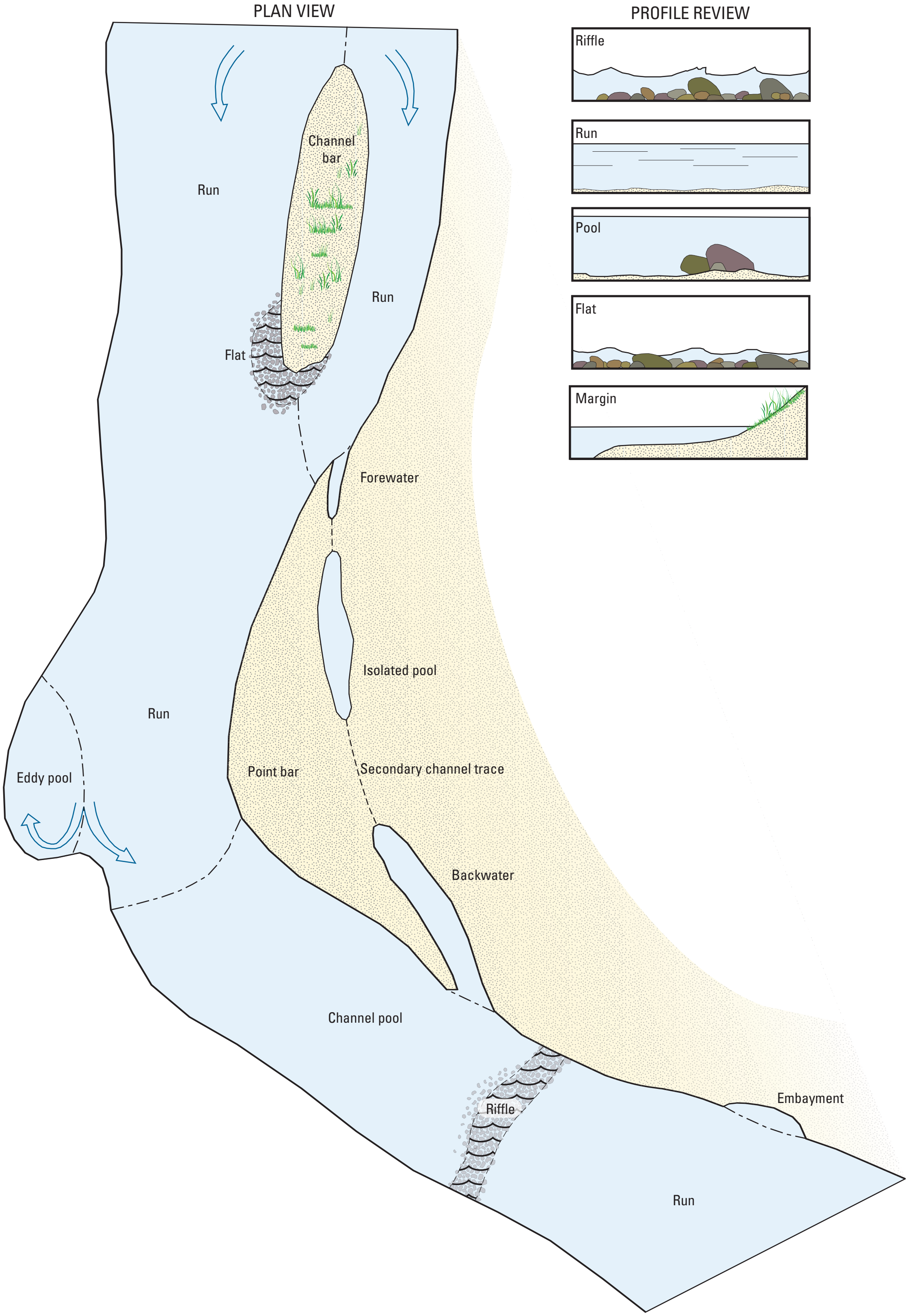

Figure 7. Mesohabitat types identified in the Middle Rio Grande, New Mexico (modified from Platania, 1993).

Physical Characteristics and Water-Quality Properties of Mesohabitats

Physical characteristics were not measured in all of the mapped mesohabitats because of time constraints; the number of each mesohabitat type sampled was in proportion to the abundance of that mesohabitat type. A subset of 20 mesohabitats at each site was evaluated in winter 2011–12; this was increased to 30 mesohabitats during the summer of 2012 because of the opportunity for increased sampling effort afforded by lower river streamflows and extended daylight hours. If three or fewer of a given mesohabitat type were present in the study reach, then all mesohabitats of that type were typically sampled. Mesohabitats selected for collection of physical characteristics were distributed throughout the entire study reach where possible.

Once a particular mesohabitat had been selected, representative locations for physical characteristic measurements were established by delineating five evenly spaced transects oriented perpendicularly to the direction of streamflow across each mesohabitat (or three 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. 8*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, and subsequent measurements were made at each transect by following a progression from left to right; for example, if the first transect measurement was randomly selected at the left center location, the subsequent transect measurements were consecutively made at center, right center, left center, and center.

The following physical characteristic measurements were made at the specified location along each transect: depth, velocity, dominant substrate type and size, and percent embeddedness. 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). Standard USGS protocols for measuring velocity were followed (Rantz and others, 1982; Turnipseed and Sauer, 2010). Velocities were measured by orienting the acoustic velocimeter upstream, and in the case of several eddy pools, which have currents that move in the opposing direction to the main current, negative velocity measurements were common. Small negative velocities can also be caused by wind blowing upstream over stagnant water, particularly in relatively shallow mesohabitats such as isolated pools, forewaters, backwaters, and embayments (table 2). In order to convey the directional aspect associated with measured velocities and thereby describe the magnitude of streamflow within eddy pools, the negative sign was retained. In some cases, depths and velocities could not be measured at the predetermined measurement location because the water was either more than 4 feet (ft) deep and thus too deep for a conventional wading rod measurement, or the velocity was too great for the technician to safely wade the stream. In these circumstances, the technician would make the measurement as close as possible to the predetermined measurement location (typically within a few meters). Dominant substrate was determined by the technician while he or she was positioned at a given location in the stream transect for the purpose of making velocity and depth measurements. Particles were classified by referring to the Wentworth scale, which classifies sediment particles as cobbles if they are greater than 64 mm and less than or equal to 256 mm in length, as gravel if they are greater than 2 mm and less than or equal to 64 mm in length, as sand if they are greater than 0.0625 mm and less than or equal to 2 mm in length, and fines (silt and clay) if they are less than or equal to 0.0625 mm in length (Wentworth, 1922). Embeddedness was determined by measuring (particles greater than or equal to 2 mm) or estimating (particles less than 2 mm) the percentage (to the nearest 10 percent) of the surface area of the particle that was covered in sand or finer bed material (Fitzpatrick and others, 1998).

Physical characteristic measurements along the stream margins were only measured at the center transect of each mesohabitat selected for physical assessment. In this study, a margin was defined as the relatively shallow area (fig. 7) adjacent to the edge of the water, which is characterized by low velocities compared to more central sections of the stream channel. Stream-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. Shallow, low-velocity, nearshore areas are often associated with large algal productivity (Bixby and Burdett, 2009), and Rio Grande silvery minnow is often associated with these productive areas of a stream (Dudley and Platania, 1997). Measurements of margin physical characteristics were made on both the left and right bank (facing downstream) but were not made if the edge of the mesohabitat at the measuring point was embedded in the stream channel and not adjacent to a bank, island, channel bar, or point bar. The following margin-specific data were collected at each margin within a 0.25-square meter (m^2) quadrat centered at the midpoint of margin width: width, depth (collected at midpoint of margin), two-dimensional velocity (collected at midpoint of margin), dominant substrate type and size, subdominant substrate type and size, percent embeddedness, percent periphyton cover, bank angle, and canopy cover (based on densiometer readings). Periphyton cover was estimated as the percent (to the nearest 10 percent) of the area within the 0.25-m^2 quadrat that was covered by algae or vascular plants. Bank angle was defined in this study as the angle of the above-water shoreline associated with the channel feature (island, channel bar, point bar) that bounded the mesohabitat, and as many as three angle measurements (to the nearest degree) were collected (by using a clinometer) from the edge of water to the first break in slope on the shoreline and used to calculate a mean bank angle. If the bank was a cut

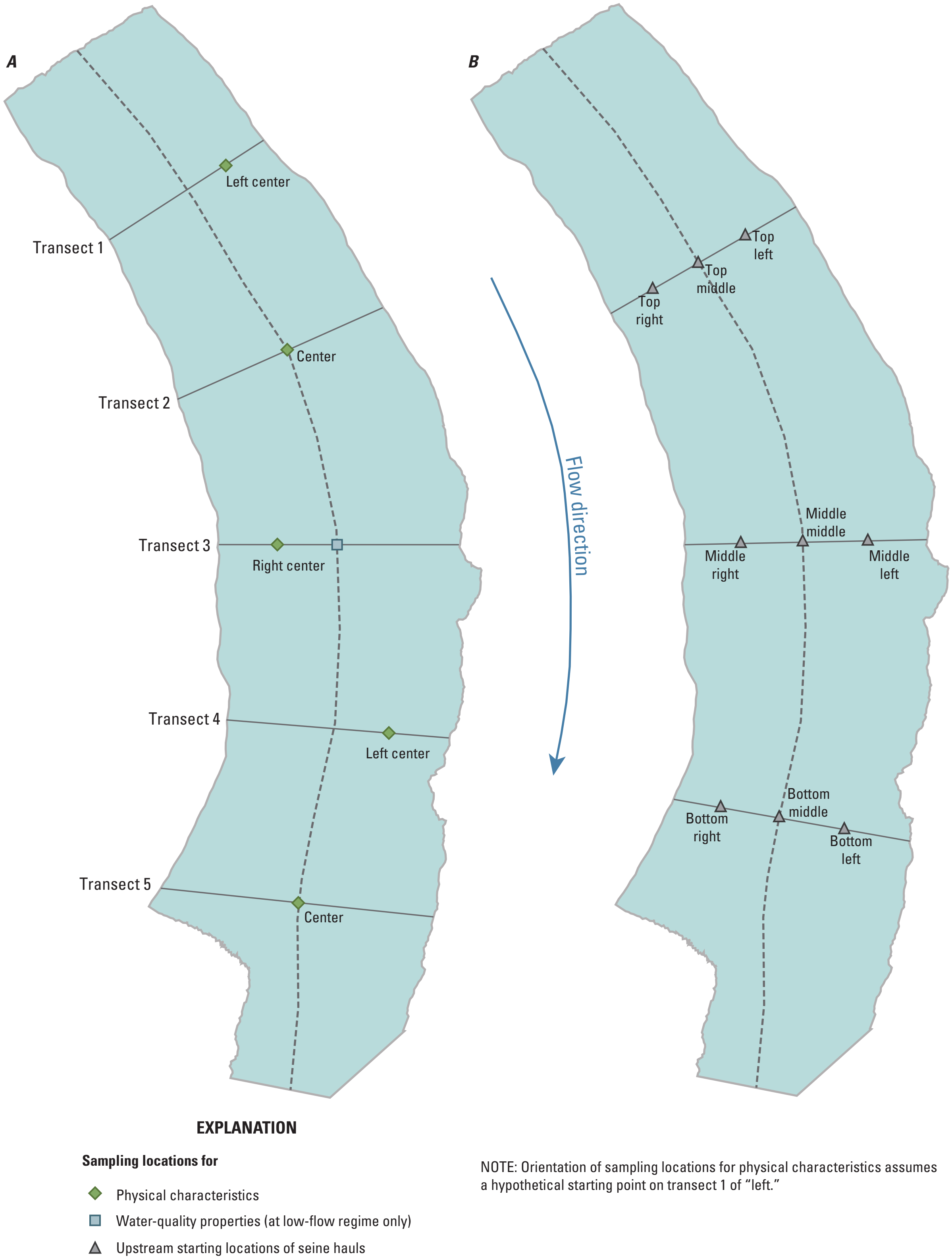

Figure 8. Sampling patterns in mesohabitats. *A*, Sampling pattern for collection of physical characteristics and water-quality properties. *B*, Sampling patterns for seine hauls.

bank (bank angle greater than 70 degrees at the edge of water), then a margin width of 0.25 m was assigned because the cut bank was in effect the first break in slope off of the bank. The margin-specific data are included in the project geospatial database but were not analyzed as part of this investigation.

Selected water-quality properties were measured by using a YSI 600XL multiparameter sonde (Xylem, Inc., 2013) by following procedures outlined in the USGS National Field Methods Manual (U.S. Geological Survey, variously dated). Each probe (other than temperature, which is not calibrated but rather is checked semiannually) was calibrated in the field daily prior to the collection of field measurements. The following data were recorded: temperature (in degrees Celsius [°C]), specific conductance (in microsiemens per centimeter [µs/cm] at 25 °C), dissolved oxygen (in milligrams per liter [mg/L]), and pH (in standard units).

Water-quality data were collected at one location (at the midpoint of the middle transect) within a given mesohabitat by the crew of technicians collecting mesohabitat data and at a second location within a given mesohabitat by the crew of technicians collecting fish. The sonde was placed approximately 1 ft below the water surface at these locations during data collection, depth permitting; otherwise, the sonde was placed at the midpoint of the water column. Water-quality data were collected only during the morning to early afternoon and did not capture the thermal maxima (late afternoon) and dissolved oxygen minima (early morning). Water-quality properties were only collected during summer 2012, when low-streamflow conditions existed and water-quality properties were thought to be potentially most limiting to aquatic life. Water temperatures in the Middle Rio Grande are typically higher, and dissolved oxygen concentrations are typically lower during relatively low-streamflow conditions compared to relatively high-streamflow conditions. Water temperature inversely controls the solubility of oxygen in water; as temperature increases, oxygen is less soluble. Dissolved oxygen concentrations in streams are therefore typically lower during the warmer summer months compared to the rest of the year. Measurement of water temperature and dissolved oxygen was not done to verify thresholds for dissolved oxygen (less than 3.3 mg/L; Matthews and Maness, 1979) and temperature (more than 30 °C; U.S. Fish and Wildlife Service, 2003) that have been established for Rio Grande silvery minnow but rather as additional field data to augment the primary mesohabitat data that are the focus of this report.

Fish Assemblage Surveys of Mesohabitats

Fish assemblage surveys were done to assess species composition at all 15 sites during winter 2011–12 and at 13 of the 15 sites during summer 2012 (table 1). The two most upstream sites, Peña Blanca and Bernalillo, were not sampled during summer 2012 because streamflows were much higher at these sites when they were scheduled for sampling compared to streamflows at the more downstream sites (fig. 4). In addition, streamflows at Peña Blanca and Bernalillo during summer 2012 were not representative of a summer low-streamflow regime that was targeted for sampling. Staff with the U.S. Fish and Wildlife Service New Mexico Fish and Wildlife Conservation Office in Albuquerque, N. Mex., conducted all fish assemblage surveys, maintained required Federal permits to collect and handle Rio Grande silvery minnow, and were responsible for onsite fish identifications and counts.

Twenty mesohabitats were subsampled at each site during winter 2011–12, and 30 mesohabitats were subsampled during summer 2012. Twenty was initially selected as the number of mesohabitats to sample because that was thought to be the number of mesohabitats that could be sampled in the 1 day per site that was available for sampling. Catch per unit effort (CPUE), which was lower than expected during winter 2011–12, was expected to improve in summer 2012. Compared to winter, summer is when fish are generally more active because of warmer water temperatures, and thus more likely to be caught. Fish also are more abundant in summer compared to winter as a result of spring and summer recruitment, and more mesohabitats at each site are accessible during the summer compared to winter. Despite the expected improvement in CPUE in summer 2012 relative to winter 2011–12, the number of mesohabitats sampled in summer 2012 was increased to 30 mesohabitats to increase sampling effort. The number of each mesohabitat type sampled was in approximate proportion to the abundance of that mesohabitat type. If three or fewer of a given mesohabitat type were present in a given study reach, all mesohabitats of that type were typically sampled.

Fish were collected by using a seine while wading during both winter and summer sampling. 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.” A flat-panel seine, 3.0 m in length and 1.5 m in height, with a mesh size of 3.0 mm was used. The sampling approach was the same as the sampling approach described in Moring and others (2014) and was deliberately biased toward collecting fish from shallow, low-velocity, nearshore habitats preferred by Rio Grande silvery minnow and similar fish; for example, 3.0-mm mesh seines were used, as opposed to a larger mesh size, to increase the likelihood of collecting Rio Grande silvery minnow and other minnow species. During each seine haul, two biologists dragged the seine through the water in an upstream to downstream direction for a distance of at least 1 m and as much as approximately 25 m depending on the size of the mesohabitat being sampled; the distance that the seine was dragged is referred to as the “seine-haul length.” 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 the seine being held in a fixed position at the downstream end of the seine-haul location, while 1 or 2 people disturbed the substrate with their feet as they moved downstream toward the seine; the seine was lifted from the water when the 1 or 2 people reached the seine.

At least two seine-haul locations were selected in each mesohabitat sampled except in small mesohabitats (less than 5 m long), which were only seined once. Each seine-haul location was randomly selected from nine available sampling points in each mesohabitat corresponding to a near left bank (left), near center channel (middle), and near right bank (right) points along each of three transects. Sampling 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 embedded within the sampled mesohabitat (fig. 8*B*). All fish collected in each haul were identified, counted, and released. There was little concern for recollecting the same fish from a previous seine haul because of the distance between each seine haul (typically at least 10–20 m) and because all seine hauls were made from upstream to downstream. Fish data were recorded in the field by using waterproof data sheets during winter 2011–12 and tablet computers in summer 2012; all of the data were reviewed by staff at the USGS Texas Water Science Center for completeness and accuracy. The reviewed data were entered into an electronic spreadsheet and incorporated into a geospatial database.

Comparisons of fish assemblage data within and among the sites that were assessed during the study were made by analyzing total abundance data, fish-species richness, relative abundance, total fish density, and CPUE. Total abundance refers to the number of individuals of each species that were collected. Fish-species richness refers to the total number of fish species collected and is a commonly used metric for comparing fish assemblages among sites and streamflow regimes (Ludwig and Reynolds, 1988). For this report, relative abundance refers to the proportion of individuals of a given species that were collected relative to the total number of individuals of all species that were collected; relative abundance is reported as a percentage. The dimensions of each seine haul were recorded to enable the calculation of CPUE per seine haul, which reports the number of fish per unit area, thereby allowing for comparisons between sites regardless of the number of seine hauls completed at each site. The CPUE was calculated by dividing the total number of fish caught by either the total area seined or by the area kicked from a kick-seine haul; the resulting quotient was then multiplied by 100 m^2 to obtain the CPUE. The use of CPUE to standardize fish data allows for direct comparisons between stream reaches or mesohabitats of different sizes; the use of CPUE is a common practice among aquatic biologists (Nielsen and Johnson, 1983).

Canonical correspondence analysis was used to evaluate the relation of fish-species composition to selected environmental variables (physical characteristic data collected at the mesohabitat scale [depth, velocity, and substrate particle size] and mesohabitat types); 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. Canonical correspondence analysis is a multivariate analysis technique developed to relate species composition to “known variation” in the environment (ter Braak, 1986; p. 1167). The input for CCA was a table containing the total abundance of each fish species, the means of depth and velocity, and predominant substrate particle size in each mesohabitat sampled during both sampling periods. Depth, velocity, and substrate particle size were measured from 3 to 5 times (depending on the length of the mesohabitat) within each randomly selected mesohabitat. Ecologists use CCA 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). The CCA extracts synthetic environmental gradients from datasets, and the gradients are the basis for describing and visualizing different habitat preferences (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[1]

Data collected during the study were processed in two ways. First, a geospatial database was developed for the management of field-collected data. This format allows end-users to query, manipulate, and export the geographic and tabular data by using a GIS to create maps and perform spatial analyses by using the geographic features and their related tabular information. Second, the data presented in the geospatial database were organized for inclusion with this report.

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 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

[1]This section was modified from Moring and others (2014).

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 (Esri, 2013). ArcGIS personal geospatial databases store database information as Microsoft Access (1997–2003) files.

The project geospatial database contains a collection of all the geographic and tabular data collected in the field in addition to the associated metadata (fig. 9). The geographic data presented in the geodatabase include the mapped mesohabitat polygons for each of the winter 2011–12 data collection efforts, as well as the summer 2012 data collection efforts. The polygon feature classes (mesohab_11092011, mesohab_02052012, and mesohab_06052012) 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. Each record in the data tables is related to a corresponding geographic feature through the use of a primary key. The primary key is a unique identifier (unique_id) that is utilized by the relationship classes to link the geographic and tabular data (Zeiler, 1999) (fig. 9). Data tables and definitions of data elements associated with the project geospatial database are described in appendix 3, and the Federal Geographic Data Committee compliant metadata record for the project database is shown in appendix 4.

Physical Characteristics and Water-Quality Properties of Mesohabitats over a Range of Streamflows

The physical characteristics of measured depth and velocity (fig. 10) varied greatly by mesohabitat type, site, and sampling period (winter 2011–12 or summer 2012). Measured depths ranged from 0.01 ft in six mesohabitats at five different locations to 4.4 ft in a pool at the Bosque del Apache II site on June 13, 2012. In some cases, the stage (water-surface elevation of the stream above an arbitrary datum) (Langbein and Isseri, 1960; Rantz and others, 1982) may have changed slightly between the time that a site was mapped and the time that physical characteristics were measured (typically a day later; table 1). The lowest velocity (-2.14 feet per second [ft/s]) was measured in a pool at the Peña Blanca site on November 11, 2011; whereas, the highest velocity (5.39 ft/s) was measured in a run at the Lemitar site on December 2, 2011 (fig. 10). Physical characteristics of measured depth and velocity for the San Pedro site are not shown on figure 10 for December 6, 2011, because no associated fish data were collected on that date; therefore, physical characteristic data from February 7, 2012, are shown.

To represent the relative contributions to mean water-quality properties of the different mesohabitats, area weighting was applied to the mesohabitat areas delineated at each site. Area-weighted values by site were made by summing the products of the areal extent of each mesohabitat where water-quality properties were measured by the value for the water-quality property associated with that same mesohabitat for all mesohabitats where water-quality properties were measured; the resulting sum was then divided by the sum of the areal extents for all mesohabitats where water-quality properties were measured. Areal extents for all mesohabitats can be found in the geospatial database in the following tables: mesohab_11092011 (sites mapped during November and December 2011), mesohab_02052012 (sites mapped during February 2012), and mesohab_06052012 (sites mapped during June and August 2012). Area weighting ensured that mean values reported for each site would be proportional to the areal extent of the mesohabitats. All references to mean depths, velocities, and water-quality properties in this report refer to area-weighted mean values calculated for each site; substrate composition was also area weighted.

After applying area weighting to the depth and velocity, the sites that were sampled in winter 2011–12 and summer 2012 tended to have smaller mean depths and mean velocities during summer 2012, when streamflows tended to be lower compared to winter 2011–12 (fig. 11). There were three instances in which mean depths or mean velocities were higher in summer 2012 at a site than they were in winter 2011–12: the Barelas site had a slightly lower mean depth in winter 2011–12 (1.33 ft) relative to summer 2012 (1.45 ft), and the Abeytas site had both a lower mean depth (1.03 ft) and mean velocity (0.95 ft/s) in winter 2011–12 relative to summer 2012 (1.22 ft and 1.22 ft/s, respectively). Larger mean depths or velocities at these three sites during summer 2012 were likely caused, at least in part, by the fact that physical characteristics were not measured in the same mesohabitats during both sampling periods. It was not possible to map the same mesohabitats with each sampling period at any of the sites because the extent and type of each mesohabitat changed from winter 2011–12 to summer 2012. Most of the

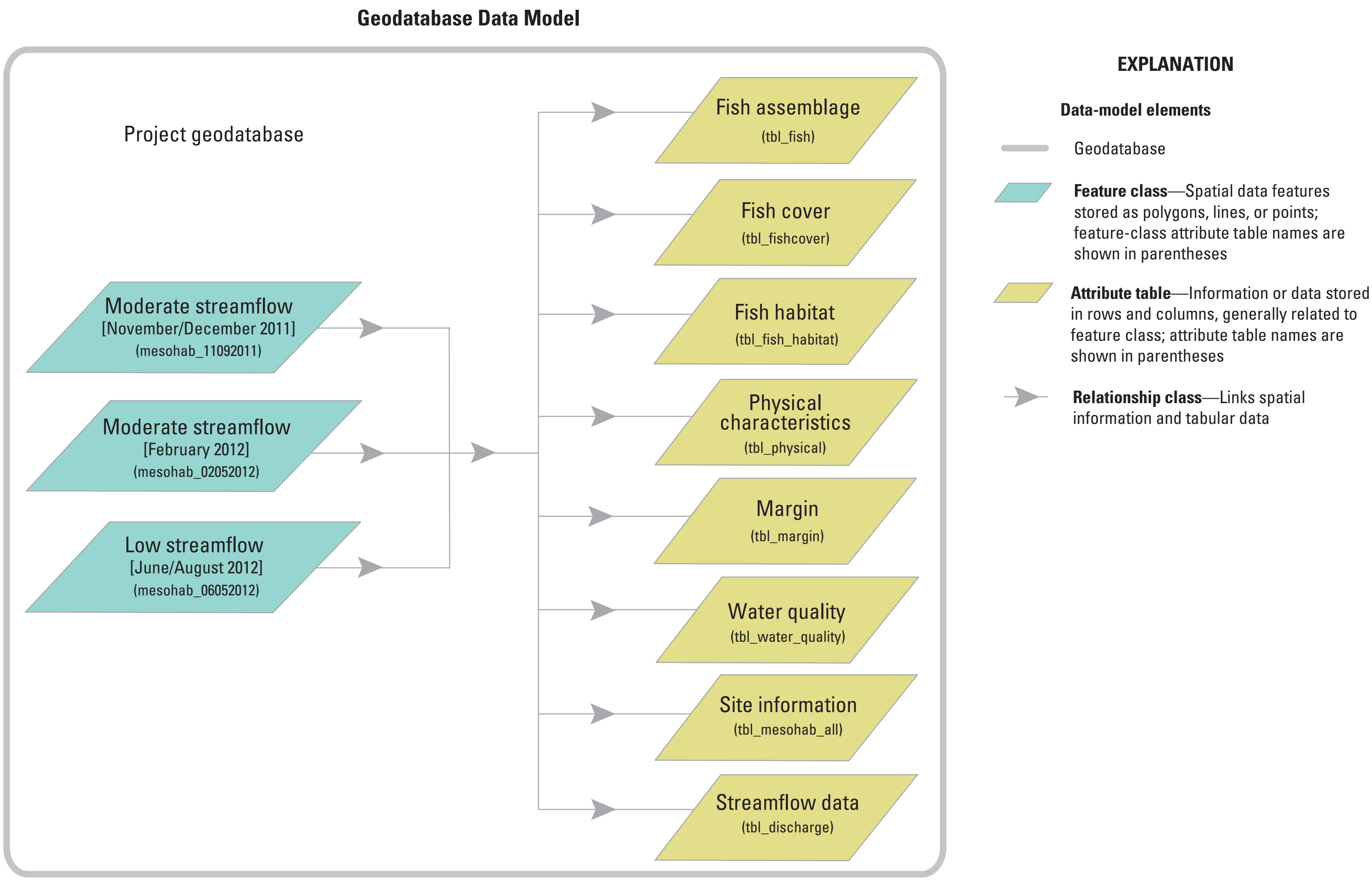

Figure 9. Simplified geospatial database data model for the spatial and tabular mesohabitat data collected from 15 U.S. Geological Survey sites on the Middle Rio Grande, New Mexico, winter 2011–12 and summer 2012.

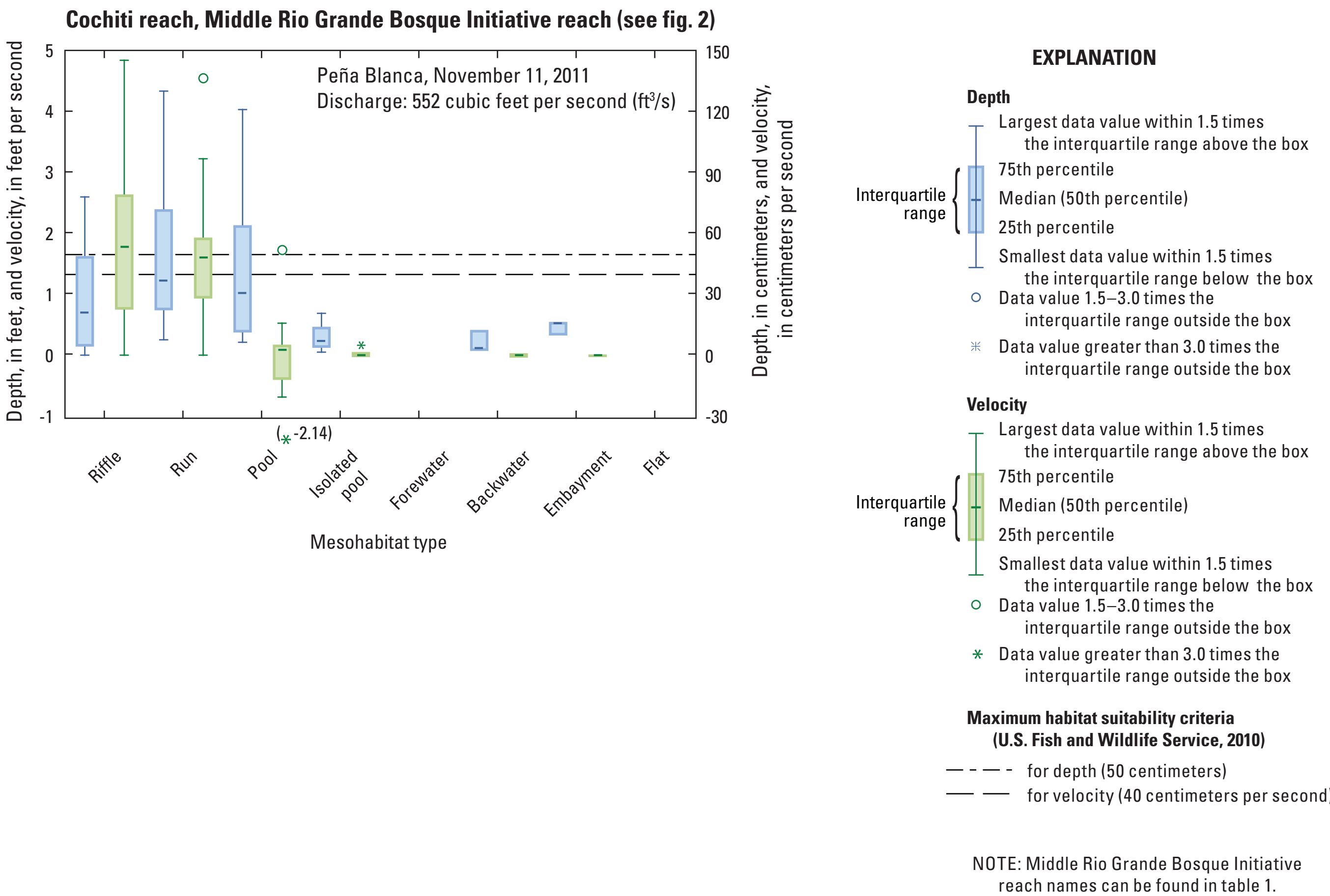

Figure 10. Depth and velocity in different mesohabitat types at 15 sites on the Middle Rio Grande, New Mexico, winter 2011–12 and summer 2012.

sites included one or more deep, wide, high-velocity runs that greatly contributed to mean depths and velocities. These deep, wide, high-velocity runs were typically adjacent to one another and behaved as a single continuous run. The ratio of the areal extent of deep, wide, high-velocity runs where physical habitat features were measured (on the basis of the random selection process described previously) relative to the total areal extent that these runs occupied varied a great deal from site to site, which likely had a large effect on the mean depths and velocities that were calculated for each site. Because instantaneous discharge was not measured at the San Pedro site on February 7, 2012, physical characteristics measured at the San Pedro site on December 6, 2011, were used in figure 11.

The streamflows at each site were determined one of two ways. Instantaneous discharge measurements were made at most sites in accordance with standard USGS discharge measurement methods (Rantz and others, 1982; Turnipseed and Sauer, 2010). At the following sites (Barelas on November 10, 2011, and August 11, 2012; Los Lunas II on November 15, 2011), the mean daily discharge was obtained from the USGS National Water Information System (NWIS) for the nearest upstream USGS streamflow-gaging station (table 1). Instantaneous discharge measurements were stored in NWIS (U.S. Geological Survey, 2014). Although the amount of discharge measured was at times highly variable between sites during winter 2011–12, discharge tended to increase in the downstream direction at the 6 most upstream sites, whereas discharge tended to decrease in the downstream direction at the 9 remaining sites (fig. 11*E*). This overall pattern might be an artifact of water-management decisions as the six upstream sites had likely not yet reached equilibrium during the nonirrigation season; that is, residual irrigation return flows were likely still contributing to streamflow at the six most upstream sites. During winter 2011–12, discharge measurements at sites ranged from 552 ft^3/s at the Peña Blanca site on November 11, 2011, to 991 ft^3/s at the La Joya site on November 30, 2011 (a November 15, 2011 discharge of 1,050 ft^3/s is listed in table 1 for the Los Lunas II site, but this higher value is from USGS streamflow-gaging station 08331160 (fig. 2) approximately 10 miles upstream from the Los Lunas II site). During summer 2012, discharge ranged from 4.13 ft^3/s at the Lemitar site on August 7, 2012, to 430 ft^3/s at the La Orilla site on August 13, 2012 (table 1).

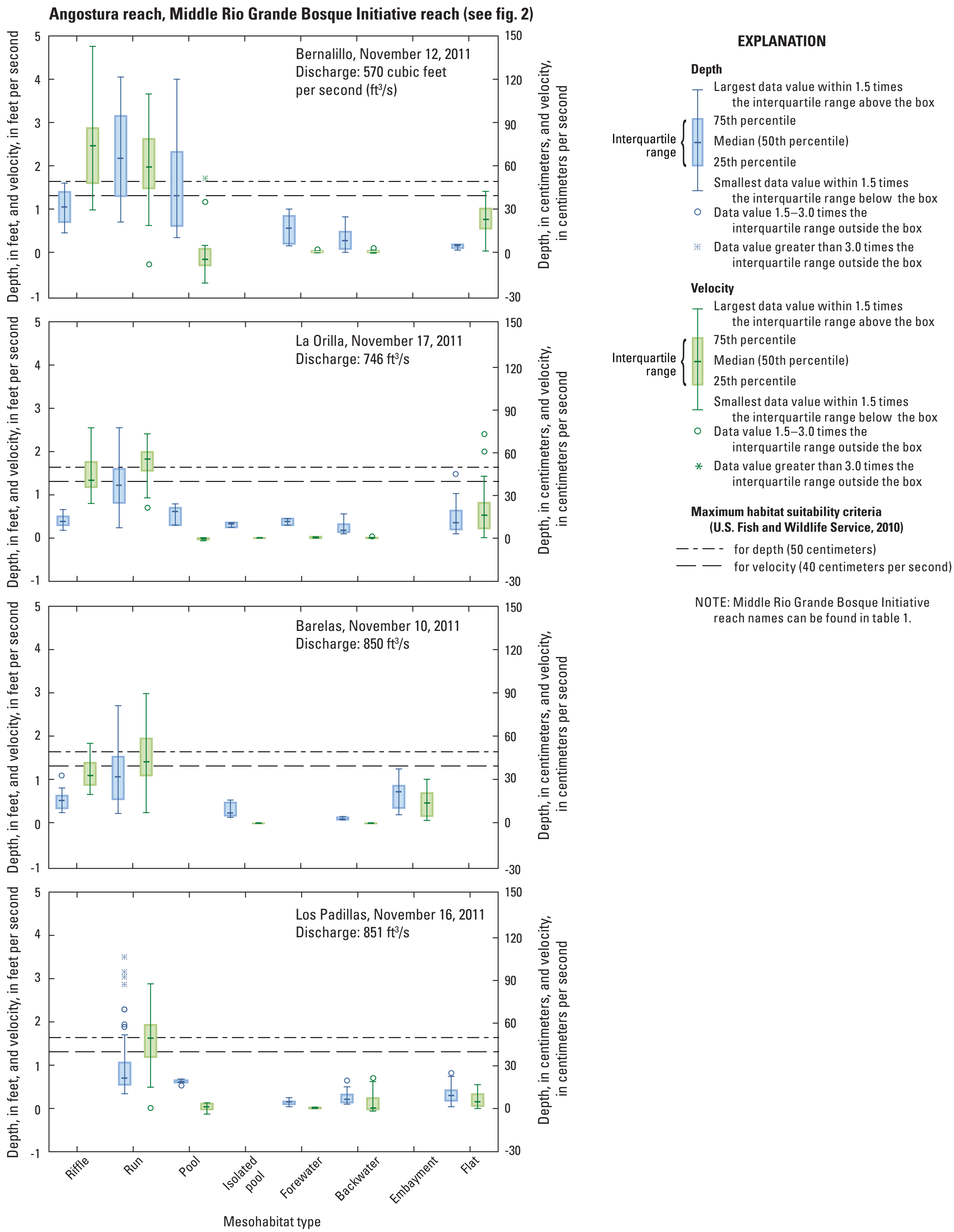

Figure 10. Depth and velocity in different mesohabitat types at 15 sites on the Middle Rio Grande, New Mexico, winter 2011–12 and summer 2012.—Continued

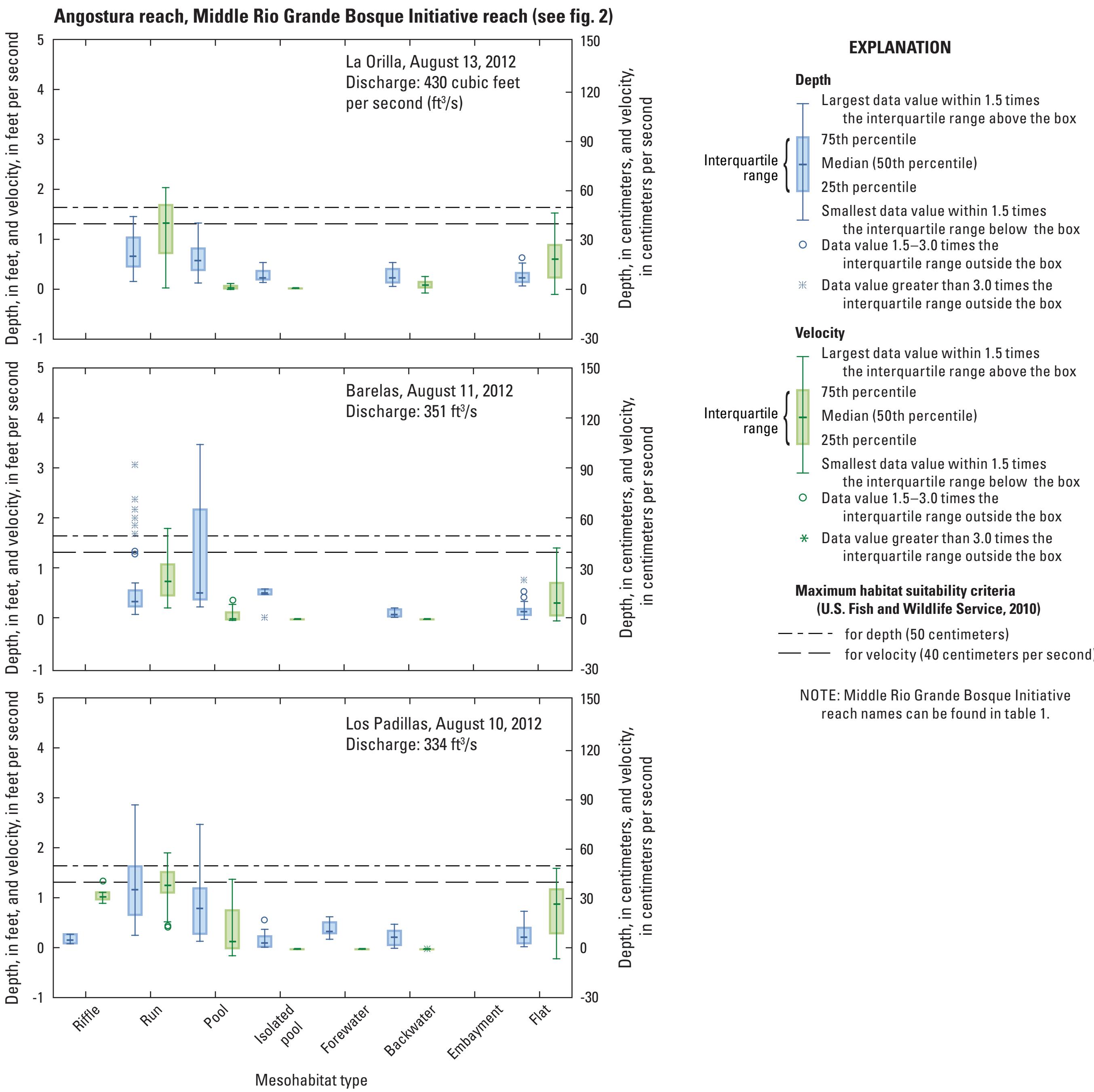

Figure 10. Depth and velocity in different mesohabitat types at 15 sites on the Middle Rio Grande, New Mexico, winter 2011–12 and summer 2012.—Continued

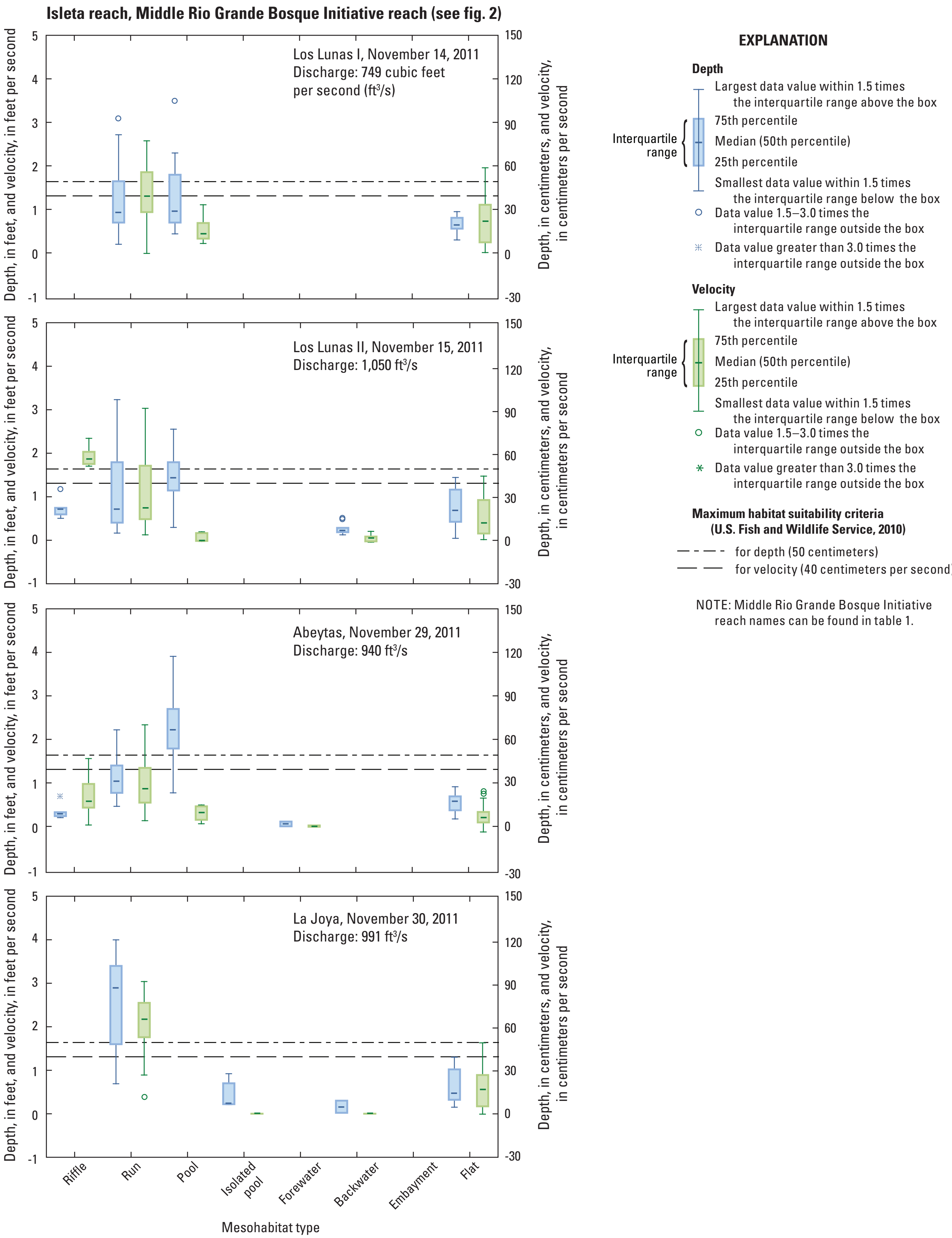

Figure 10. Depth and velocity in different mesohabitat types at 15 sites on the Middle Rio Grande, New Mexico, winter 2011–12 and summer 2012.—Continued

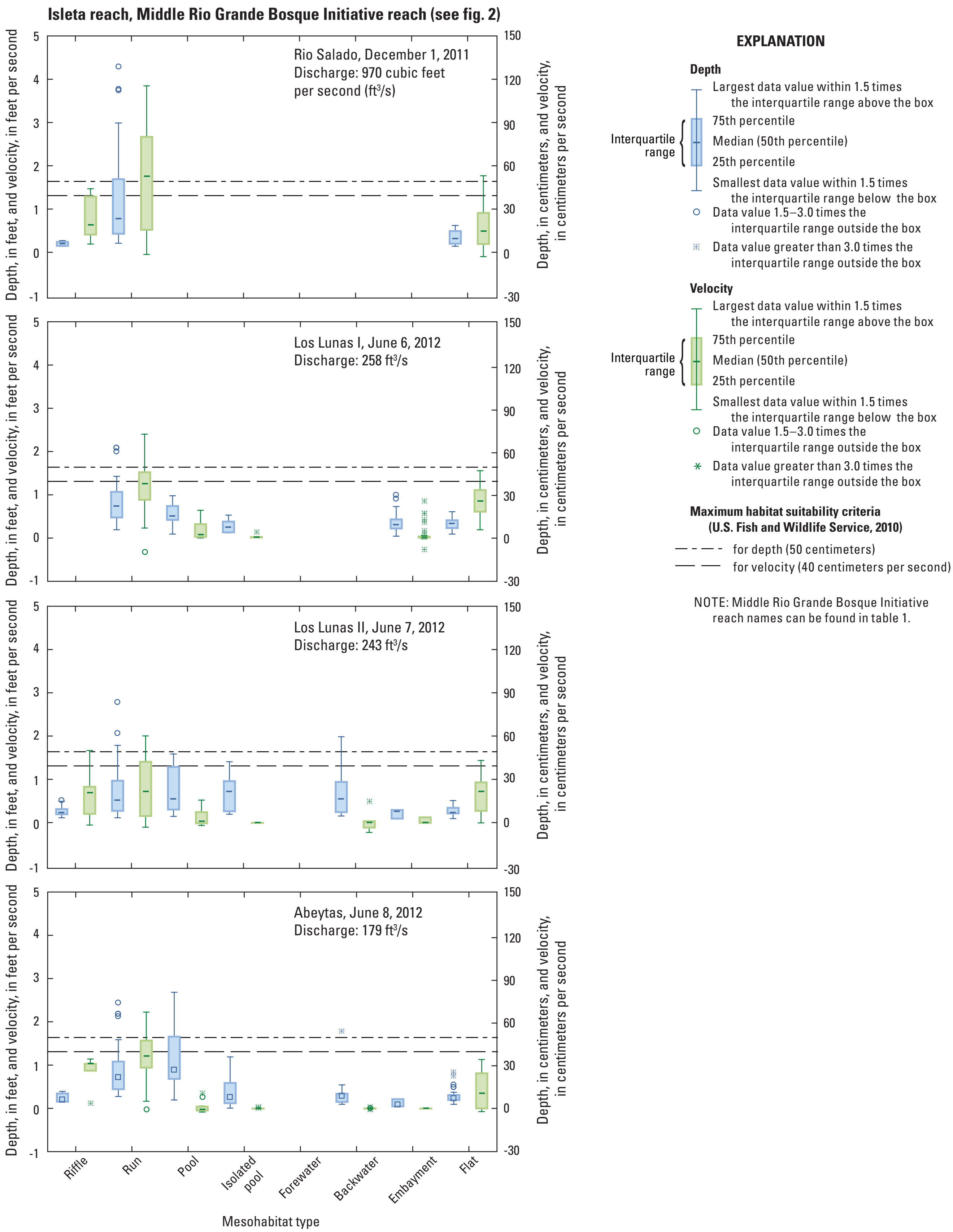

Figure 10. Depth and velocity in different mesohabitat types at 15 sites on the Middle Rio Grande, New Mexico, winter 2011–12 and summer 2012.—Continued

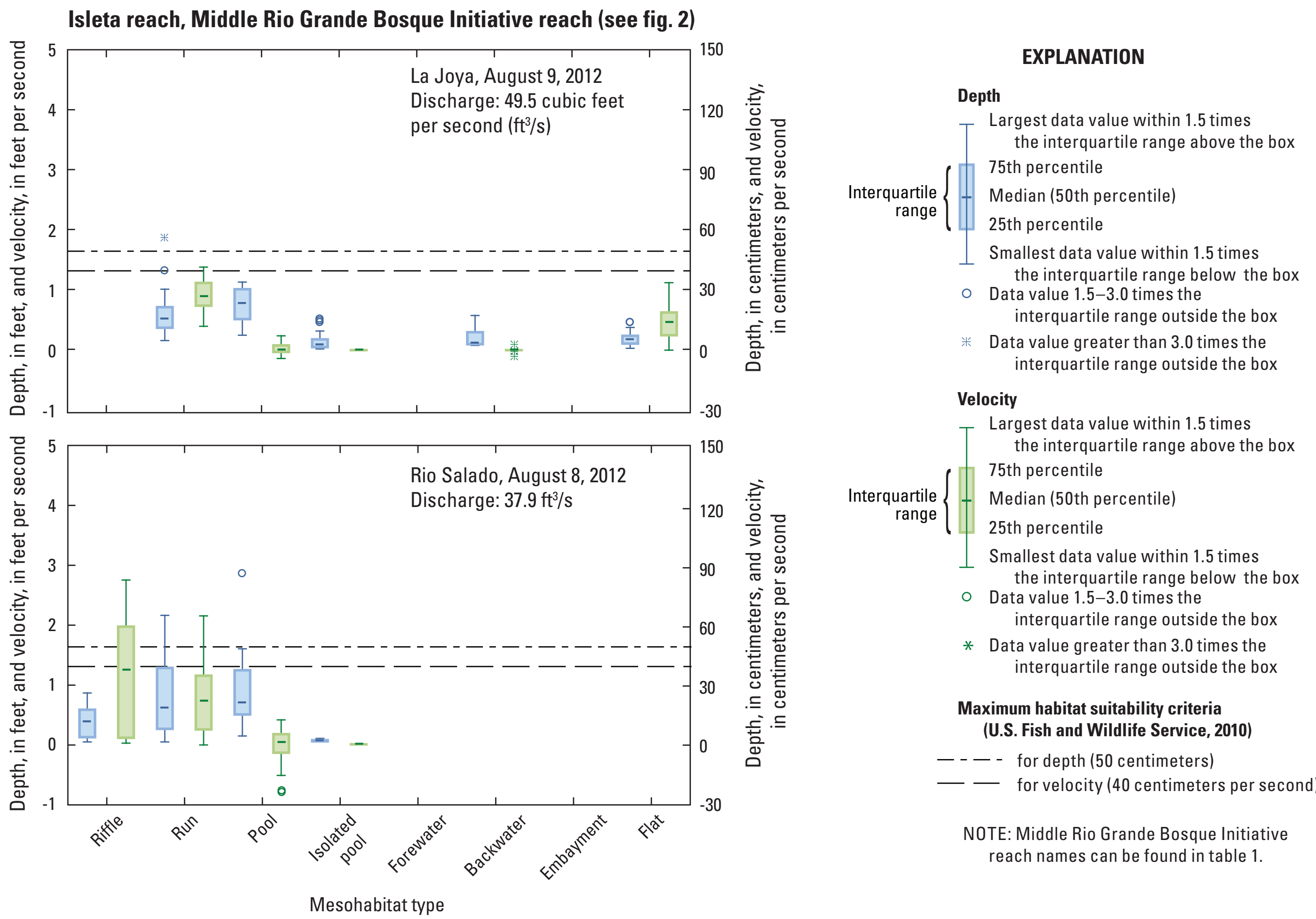

Figure 10. Depth and velocity in different mesohabitat types at 15 sites on the Middle Rio Grande, New Mexico, winter 2011–12 and summer 2012.—Continued

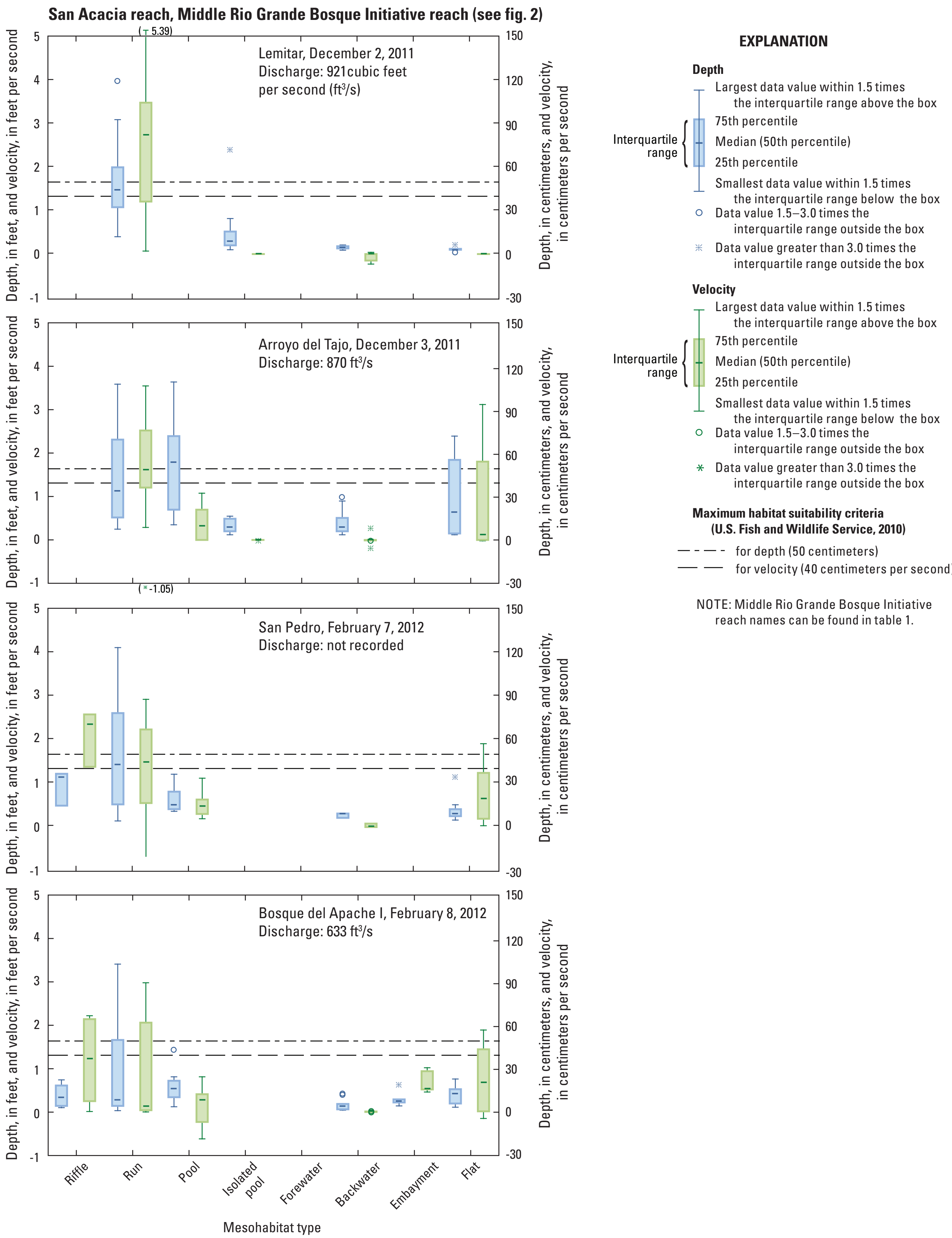

Figure 10. Depth and velocity in different mesohabitat types at 15 sites on the Middle Rio Grande, New Mexico, winter 2011–12 and summer 2012.—Continued

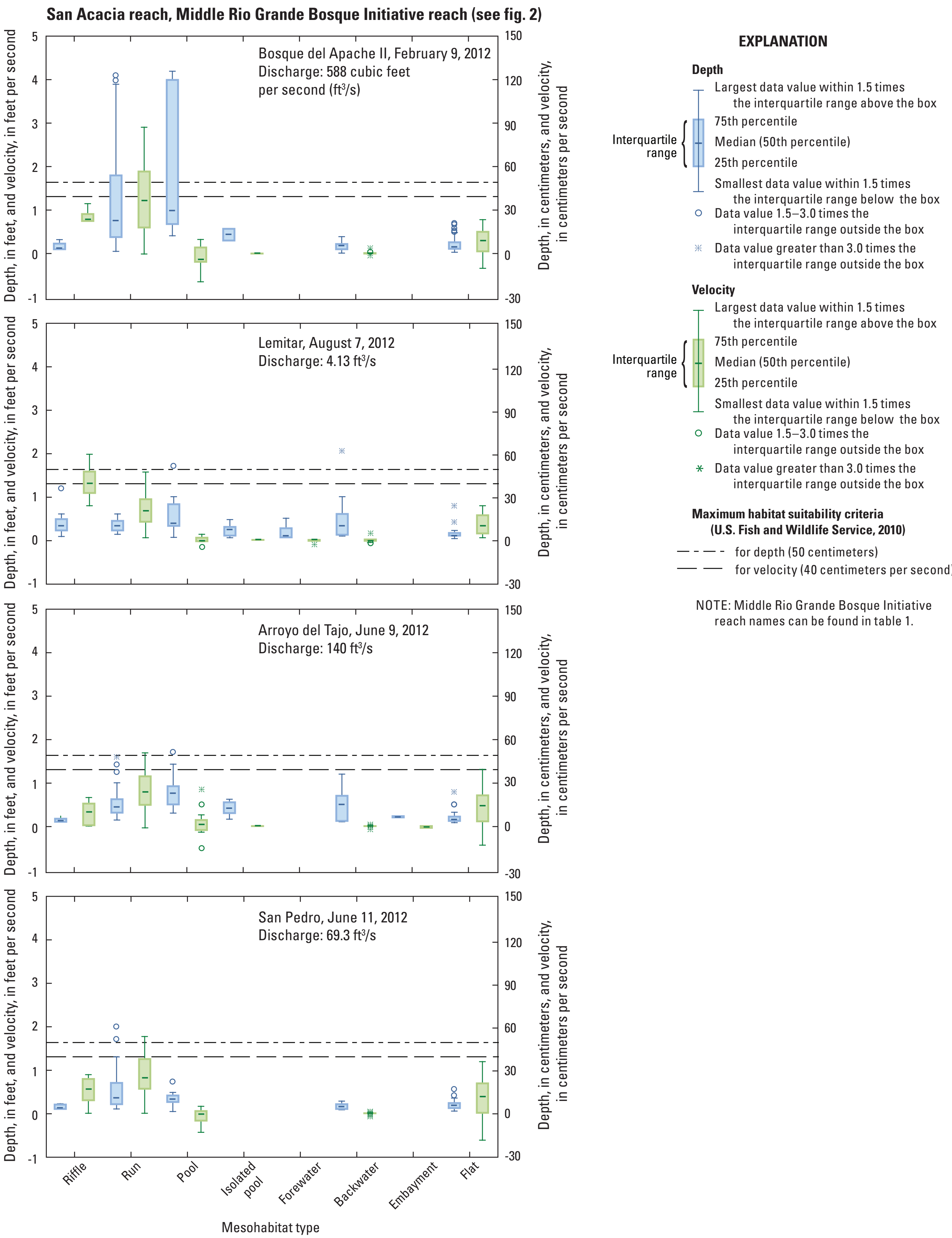

Figure 10. Depth and velocity in different mesohabitat types at 15 sites on the Middle Rio Grande, New Mexico, winter 2011–12 and summer 2012.—Continued

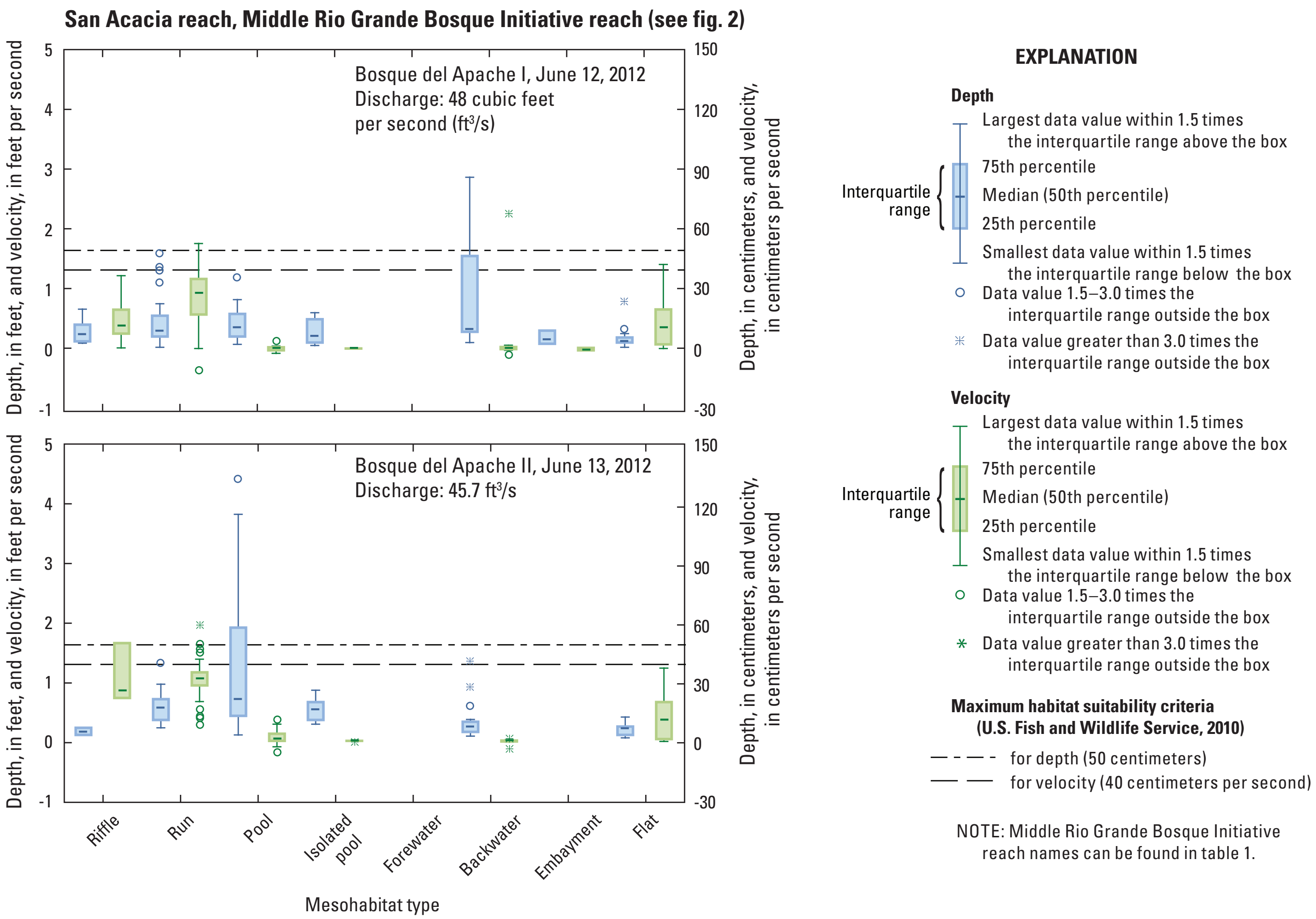

Figure 10. Depth and velocity in different mesohabitat types at 15 sites on the Middle Rio Grande, New Mexico, winter 2011–12 and summer 2012.—Continued

Streambed sediments at the Peña Blanca and Bernalillo sites were predominantly coarse gravels and cobble (fig. 12). Downstream from these two sites, the Rio Grande is characterized by a broader, lower gradient channel dominated by smaller grained bed materials, primarily sand with some silt and clay. Streambed sediments with large amounts of silt and clay were prevalent at the midreach sites (Los Lunas I and II, Abeytas, La Joya, and Rio Salado). The increase in silts and clays at these sites compared to the Peña Blanca and Bernalillo sites could be the result of finer grained contributions from two large tributaries to the Rio Grande, the Rio Puerco and Rio Salado, both of which join the Rio Grande downstream from Albuquerque (fig. 2).

Mean values were also computed for the water-quality properties (temperature, dissolved oxygen, specific conductance, and pH) measured at each site during summer 2012. Mean temperatures ranged from 21.47 °C at the San Pedro site to 29.03 °C at the Lemitar site. In contrast to the mean temperatures calculated for each site, the lowest temperature measured in any given mesohabitat was 16.16 °C in an isolated pool at the Arroyo del Tajo site, and the highest temperature measured in any given mesohabitat was 36.96 °C in an isolated pool at the Lemitar site (listed in the geospatial database attribute table tbl_water_quality). As a primary constituent element of critical habitat, the U.S. Fish and Wildlife Service (2003, p. 8117) has established that "water of sufficient quality to maintain natural, daily, and seasonally variable water temperatures in the range of greater than 1 °C and less than 30 °C" is needed to provide for the "physiological, behavioral, and ecological requirements of the [Rio Grande] silvery minnow." The largest ranges in temperature were typically measured in isolated pools, but other low-velocity mesohabitats, such as backwaters and embayments, also tended to have large temperature ranges (fig. 13). Mean site temperatures tended to be higher at the sites that were sampled in August (25.57 °C) compared to June (24.61 °C) (table 3). The highest mean temperature (29.03 °C) was measured at the Lemitar site on August 7, 2012, coincident with the lowest measured discharge (4.13 ft^3/s) in summer 2012 (table 3). Temperature was affected by the time of day when it was measured; temperature measurements made early in the day tended to be lower than those made in the afternoon. Temperature variation also tended to be largest in mesohabitats with low velocities because they had little to no streamflow, and these mesohabitats also tended to be shallower, which reduced their capacity to moderate heat through mixing or thermal advection.

Dissolved oxygen concentrations ranged from 1.16 mg/L in a backwater at the Lemitar site to 14.52 mg/L in an isolated pool at Los Lunas II (fig. 13). Matthews and Maness (1979) determined that a dissolved oxygen concentration higher than 3.3 mg/L (fig. 13) is preferred by cyprinids, but dissolved oxygen concentrations as low as 1.5 mg/L may be tolerable. The largest ranges in dissolved oxygen concentrations tended to be measured in mesohabitats associated with low velocities, particularly isolated pools, backwaters, embayments, and, to a lesser extent, forewaters. The four most downstream sites in downstream order—Arroyo del Tajo, San Pedro, Bosque del Apache I, and Bosque del Apache II—tended to have narrow ranges in dissolved oxygen concentrations across all mesohabitat types (aside from isolated pools at Bosque del Apache I) relative to the more upstream sites (fig. 13). Mean dissolved oxygen concentrations tended to be lower in August (7.46 mg/L) compared to June (8.33 mg/L) (table 3). The highest mean dissolved oxygen concentration (9.13 mg/L) was measured at the Lemitar site on August 7, 2012, and the lowest mean dissolved oxygen concentration (6.23 mg/L) was measured at the Los Padillas site on August 10, 2012 (table 3). The three sites in and near Albuquerque, La Orilla (7.19 mg/L), Barelas (6.79 mg/L), and Los Padillas (6.23 mg/L), in addition to the next downstream site, Los Lunas I (6.91 mg/L), tended to have lower mean dissolved oxygen concentrations than the remaining sites other than Rio Salado, which had a mean dissolved oxygen concentration of 7.07 mg/L (table 3).

Appreciable diel fluctuations in dissolved oxygen concentrations (larger from midafternoon to late afternoon and decreasing through the night) are likely in shallow, low-velocity mesohabitats (isolated pools, forewaters, backwaters, and embayments), where large amounts of periphytic algae were observed (Huggins and Anderson, 2005). Higher dissolved oxygen concentrations were measured in shallow, low-velocity mesohabitats (fig. 13) compared to higher velocity mesohabitats (riffles, runs, and flats), despite higher water temperatures in the low-velocity mesohabitats, most likely as a result of the relative abundance of periphyton in the low-velocity mesohabitats compared to the higher velocity mesohabitats. The dominance of sand (fig. 12) in most mesohabitats and a shifting streambed that was characteristic in riffles, runs, and flats may account for the lack of periphyton in these higher velocity mesohabitats, and consequently, the smaller dissolved oxygen concentrations measured. Also, dissolved oxygen and the other mesohabitat measurements were measured between 9 a.m. and 4 p.m. each day, when dissolved oxygen concentrations would be at or near their peak daily value.

Specific conductance ranged from 175 µs/cm at 25 °C in an isolated pool at the La Orilla site to 2,246 µs/cm at 25 °C in an isolated pool at the La Joya site (fig. 13). The broadest ranges in specific conductance within a mesohabitat type were typically measured in isolated pools, particularly at the Los Lunas I, La Joya, and Lemitar sites, where specific conductance values were the highest. Elevated specific conductance in isolated pools may be caused by either the evaporative concentration of solutes (Stephens and others, 1996) or by the mixing of less saline surface water with more saline groundwater from the hyporheic zone. Additional mesohabitats where low velocities and relatively large ranges in specific conductance were measured were backwaters (at the La Joya site) and embayments (at the Los Lunas I and Abeytas sites).

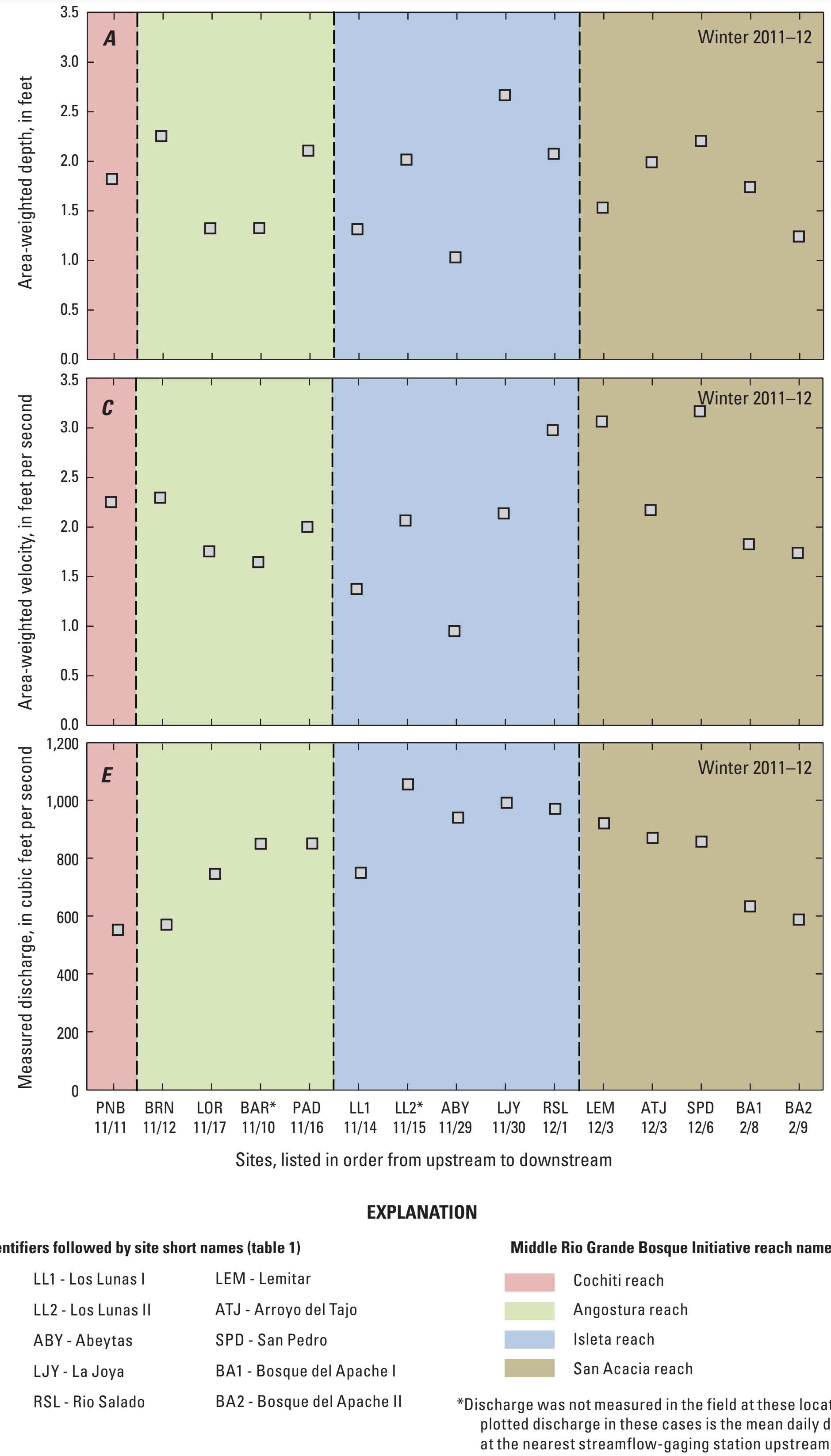

Figure 11. Area-weighted depths by mesohabitat in *A*, winter 2011–12 and *B*, summer 2012; area-weighted velocities by mesohabitat in *C*, winter 2011–12 and *D*, summer 2012; and measured discharge in *E*, winter 2011–12 and *F*, summer 2012.

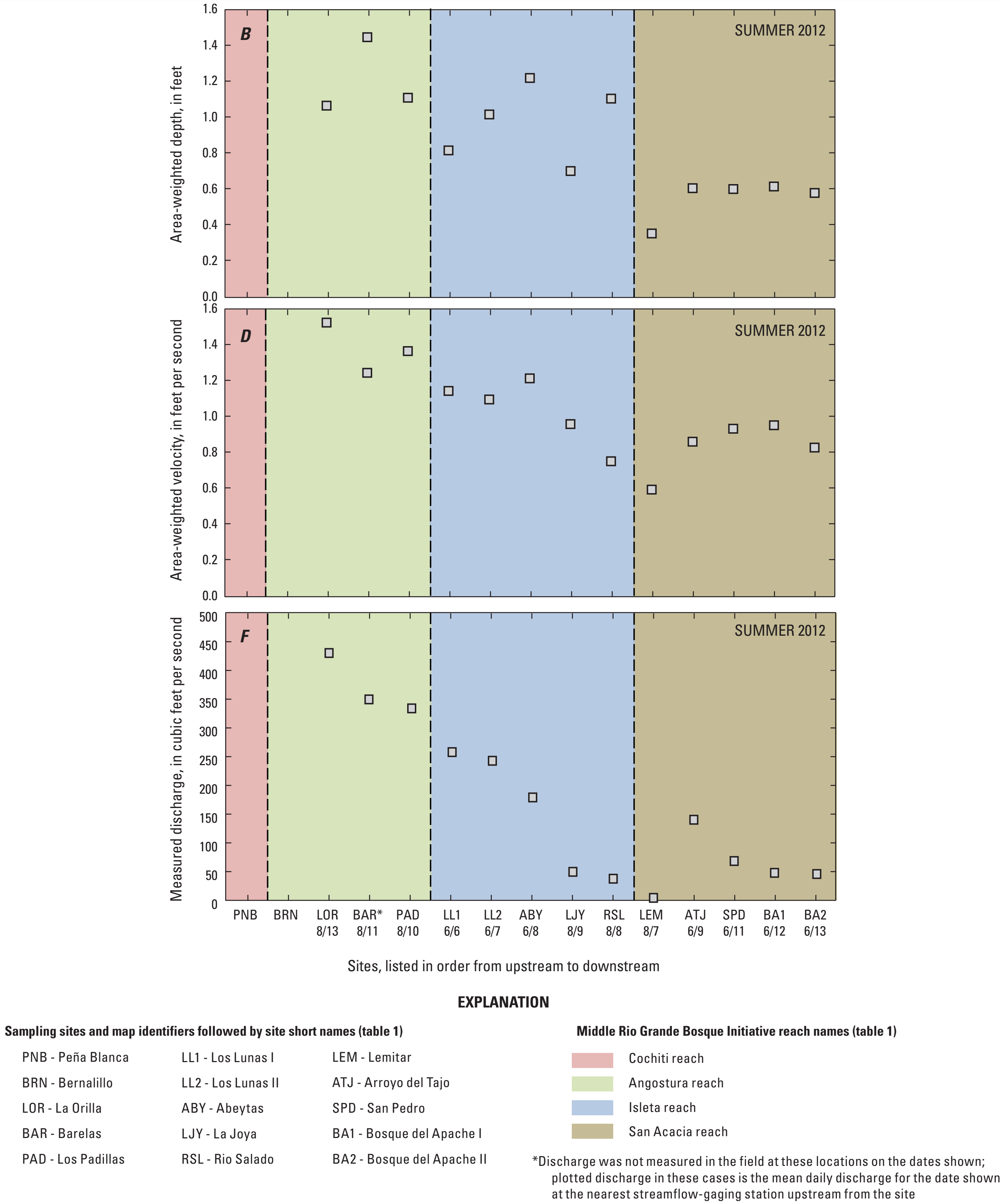

Figure 11. Area-weighted depths by mesohabitat in *A*, winter 2011–12 and *B*, summer 2012; area-weighted velocities by mesohabitat in *C*, winter 2011–12 and *D*, summer 2012; and measured discharge in *E*, winter 2011–12 and *F*, summer 2012.—Continued

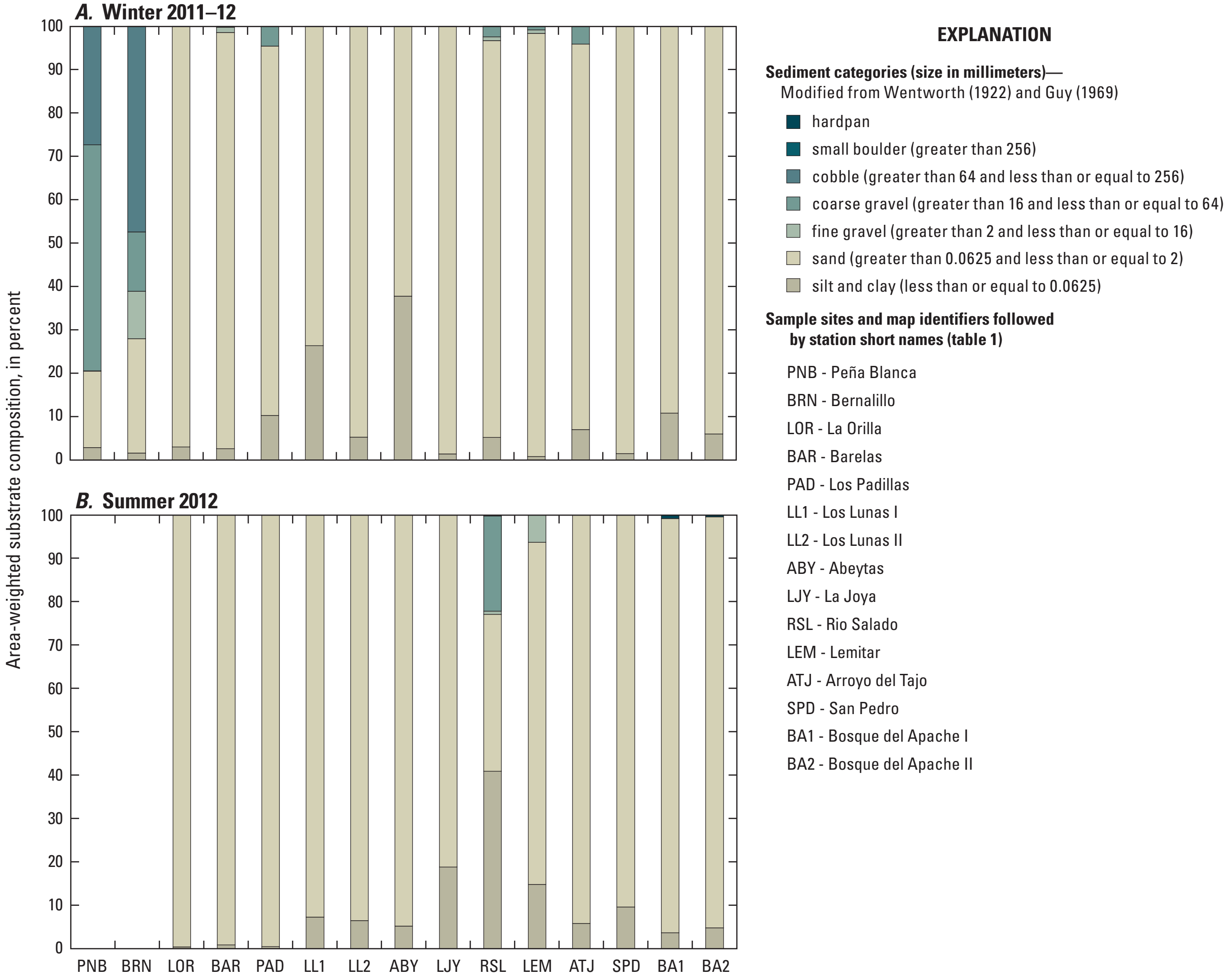

Figure 12. Area-weighted substrate composition in *A*, winter 2011–12 and *B*, summer 2012.

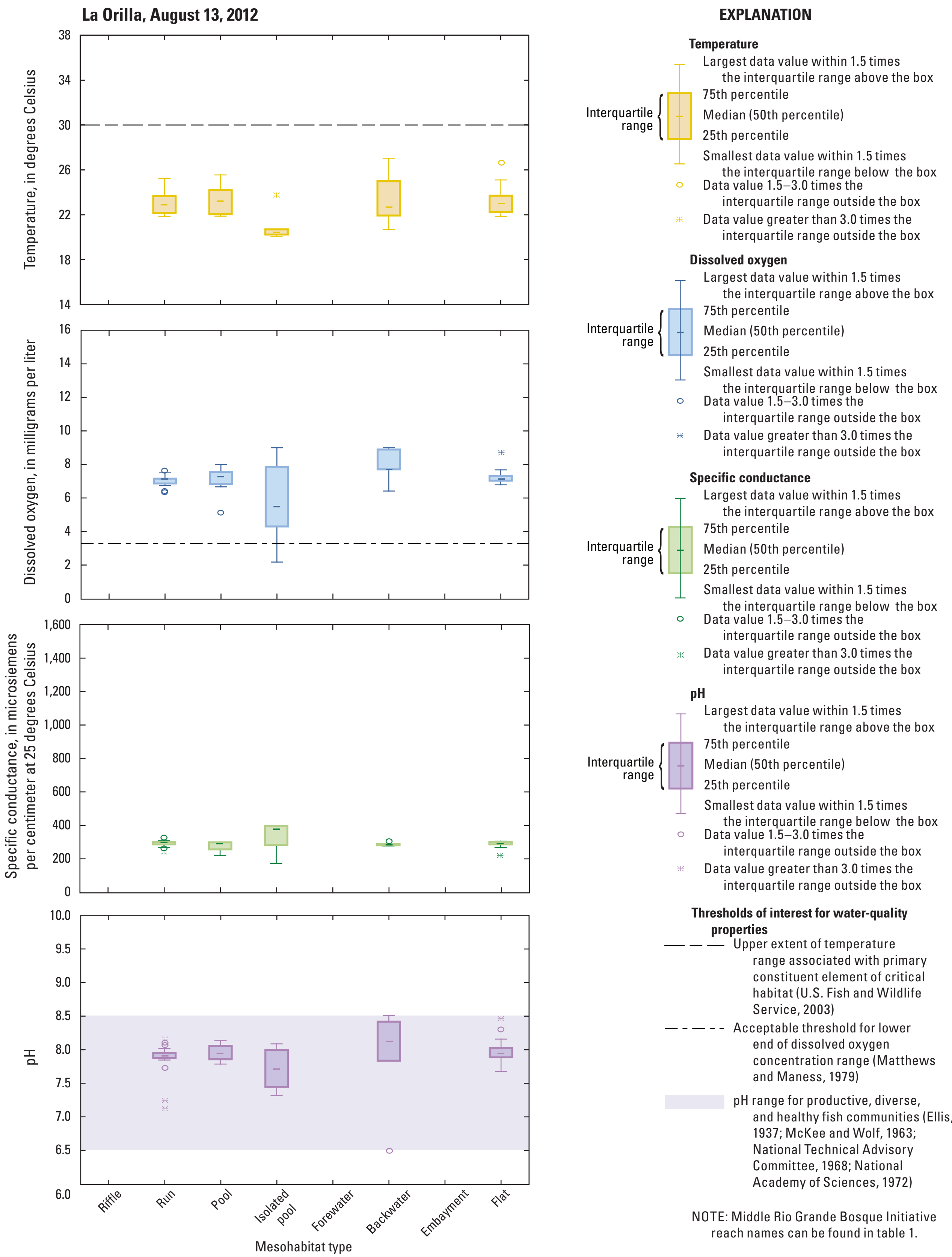

Figure 13. Temperature, dissolved oxygen, specific conductance, and pH in different mesohabitat types at 13 sites on the Middle Rio Grande, New Mexico, summer 2012.

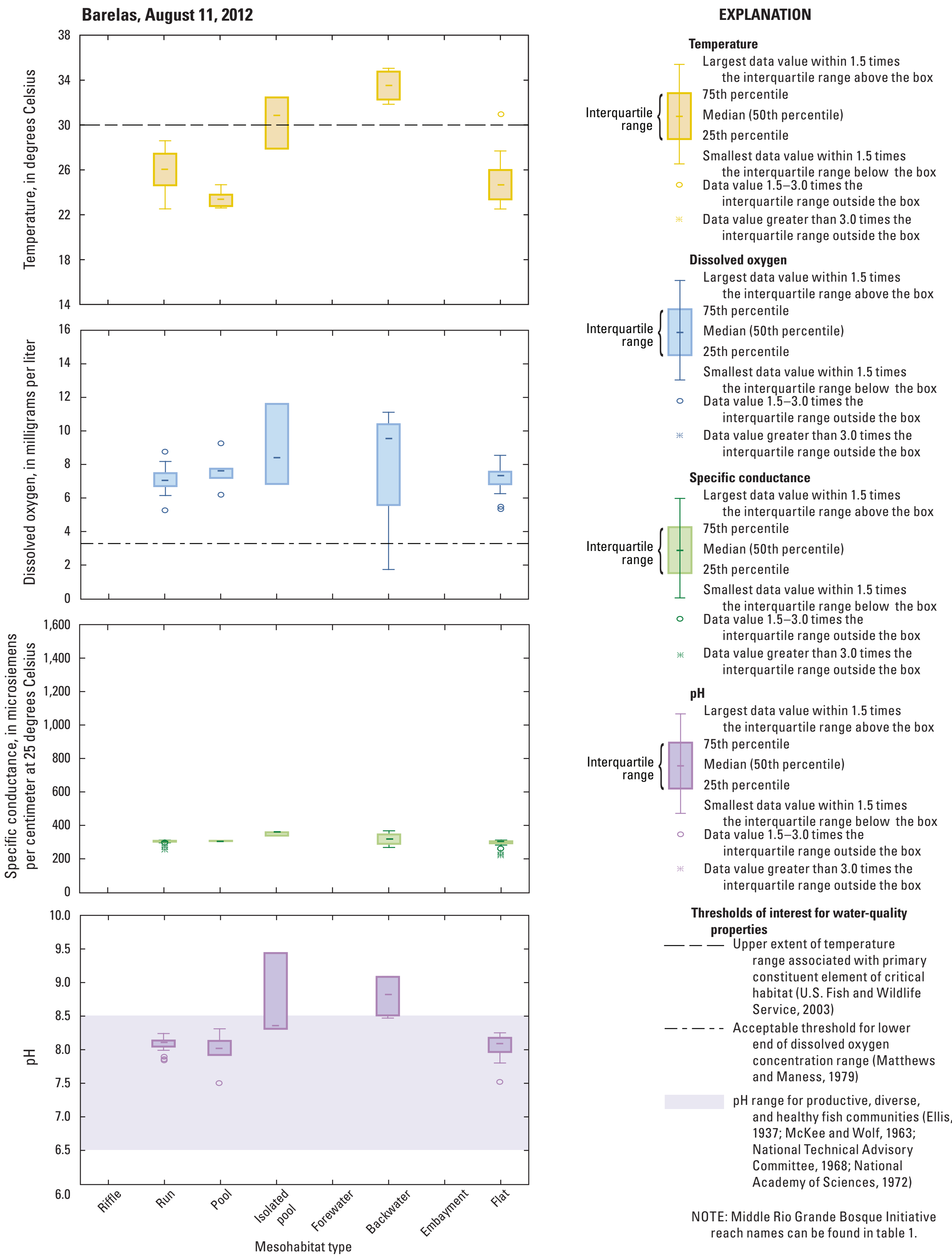

Figure 13. Temperature, dissolved oxygen, specific conductance, and pH in different mesohabitat types at 13 sites on the Middle Rio Grande, New Mexico, summer 2012.—Continued

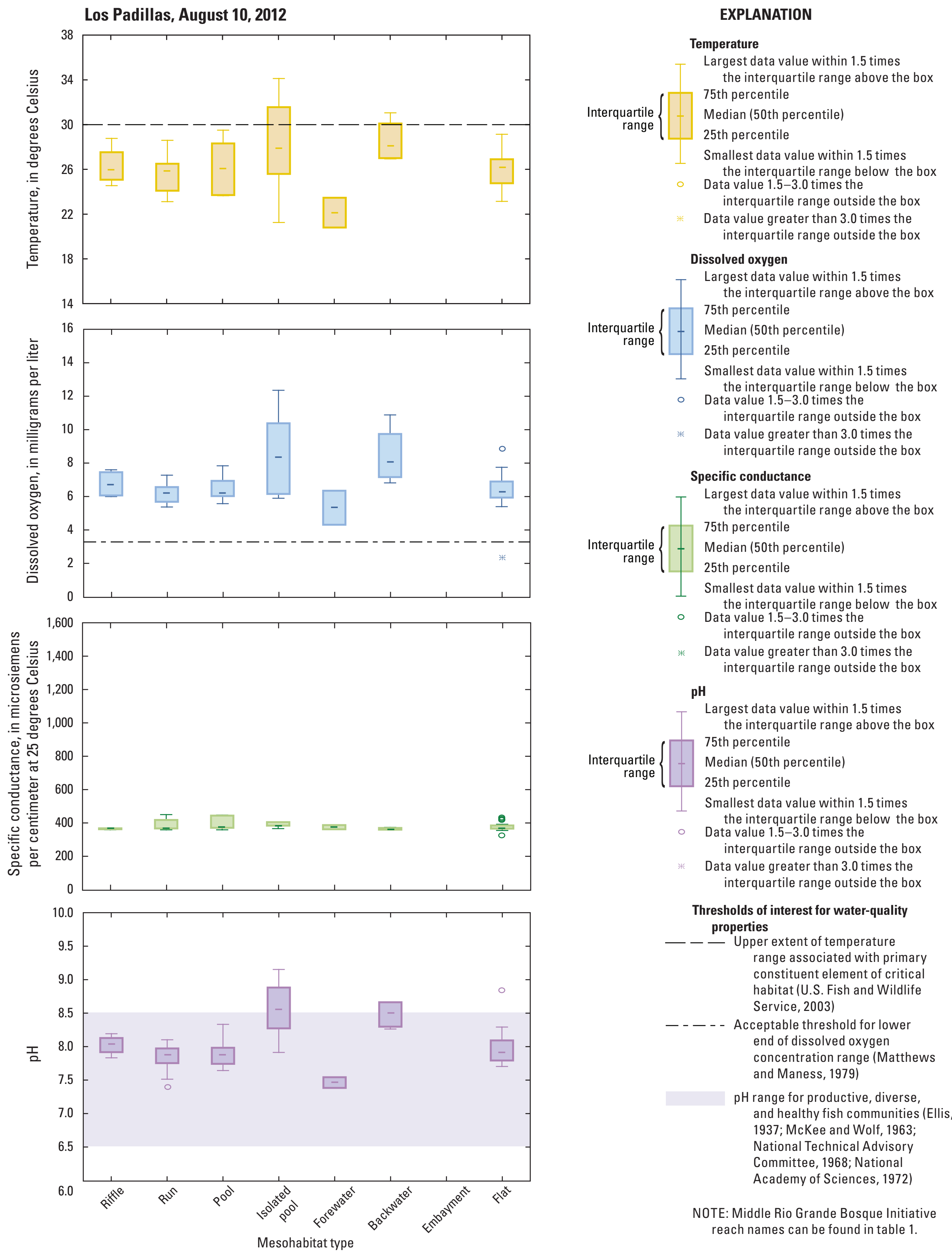

Figure 13. Temperature, dissolved oxygen, specific conductance, and pH in different mesohabitat types at 13 sites on the Middle Rio Grande, New Mexico, summer 2012.—Continued

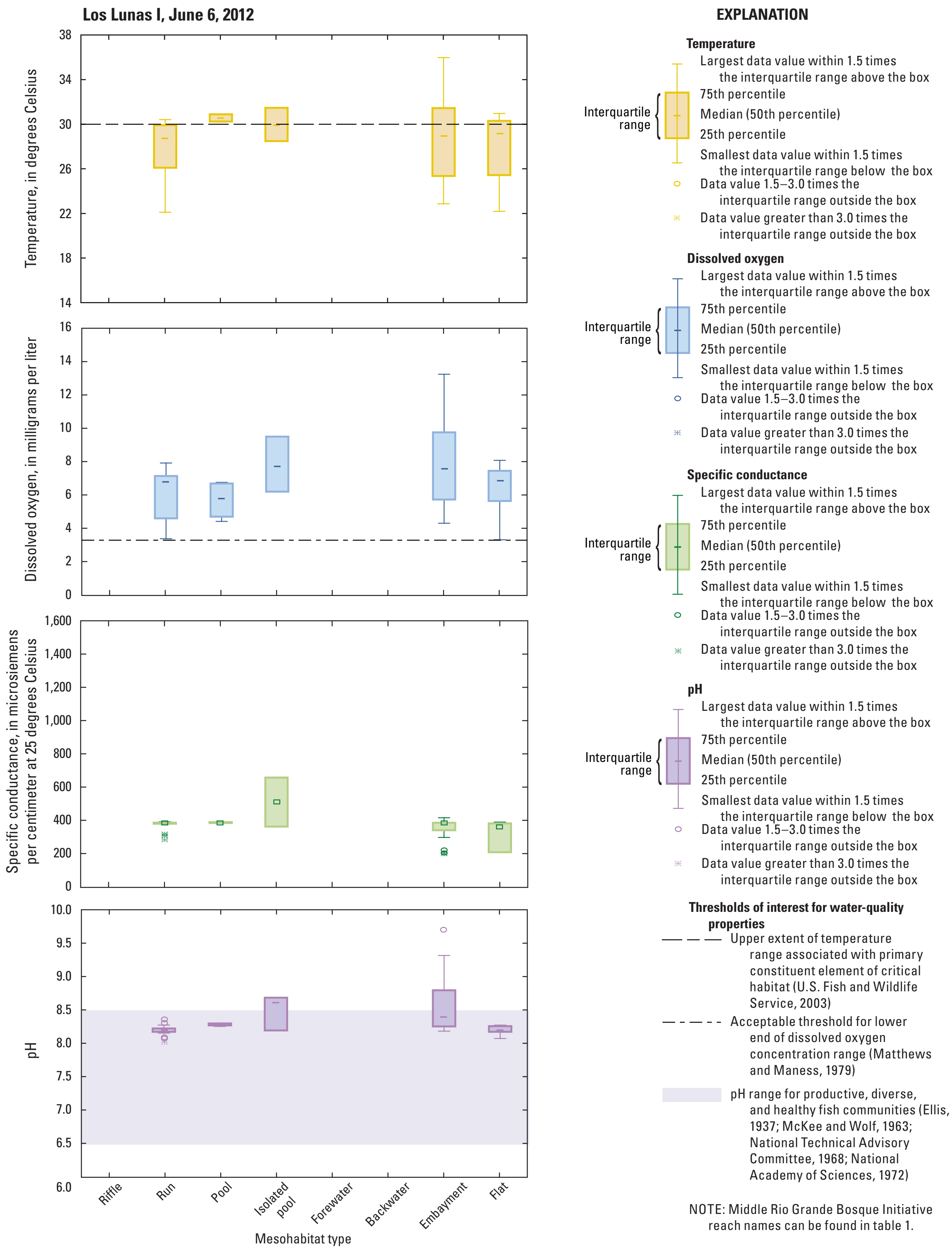

Figure 13. Temperature, dissolved oxygen, specific conductance, and pH in different mesohabitat types at 13 sites on the Middle Rio Grande, New Mexico, summer 2012.—Continued

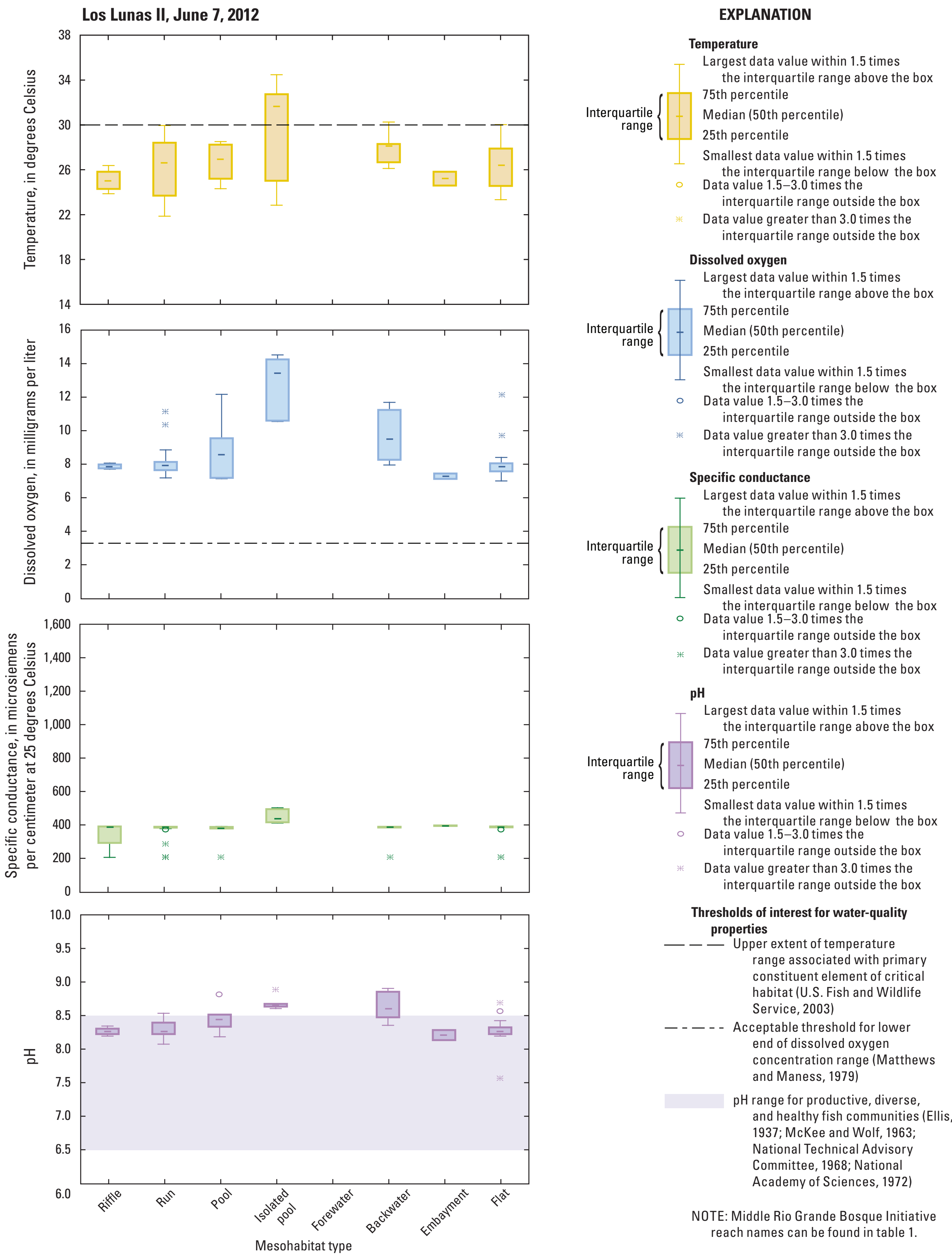

Figure 13. Temperature, dissolved oxygen, specific conductance, and pH in different mesohabitat types at 13 sites on the Middle Rio Grande, New Mexico, summer 2012.—Continued

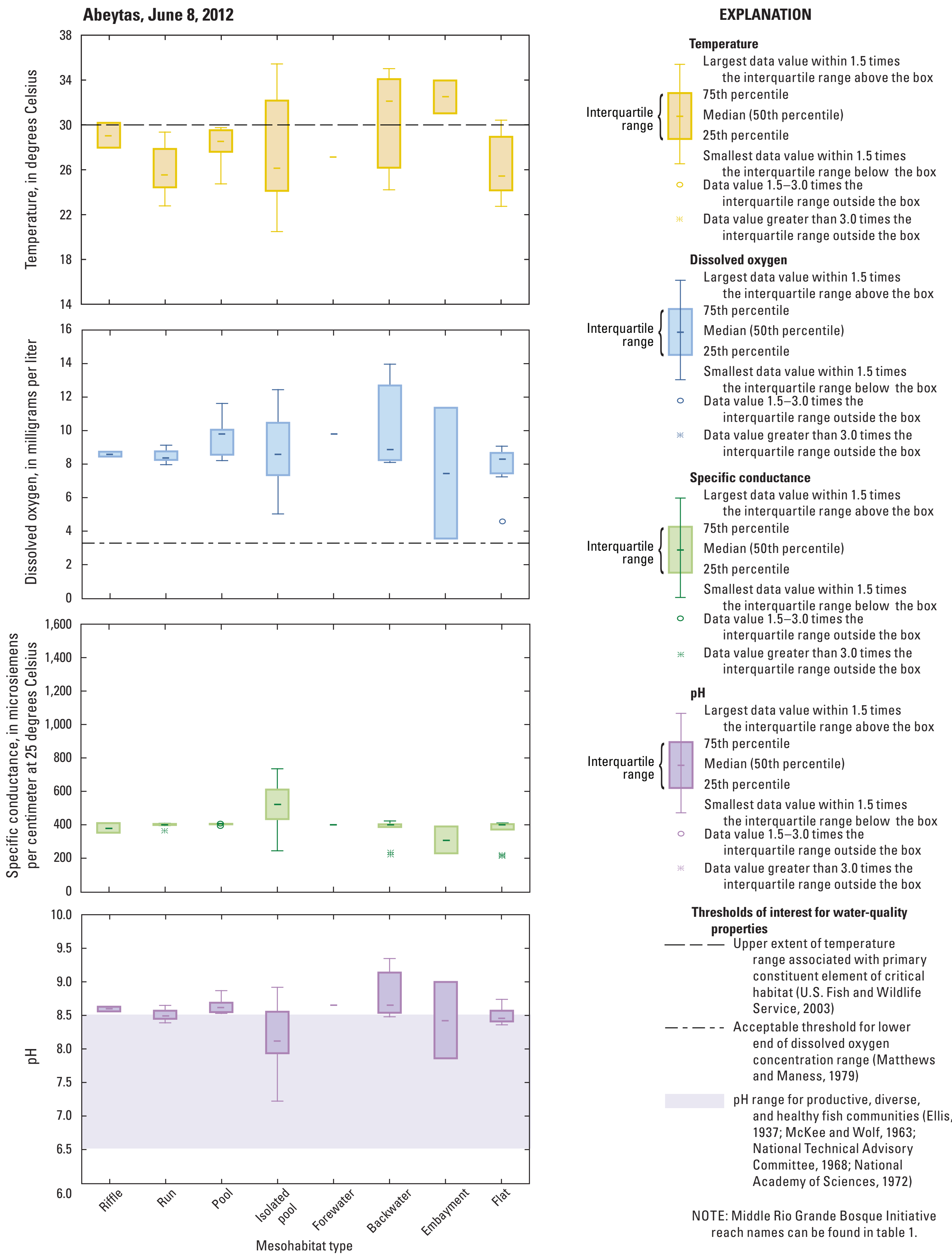

Figure 13. Temperature, dissolved oxygen, specific conductance, and pH in different mesohabitat types at 13 sites on the Middle Rio Grande, New Mexico, summer 2012.—Continued

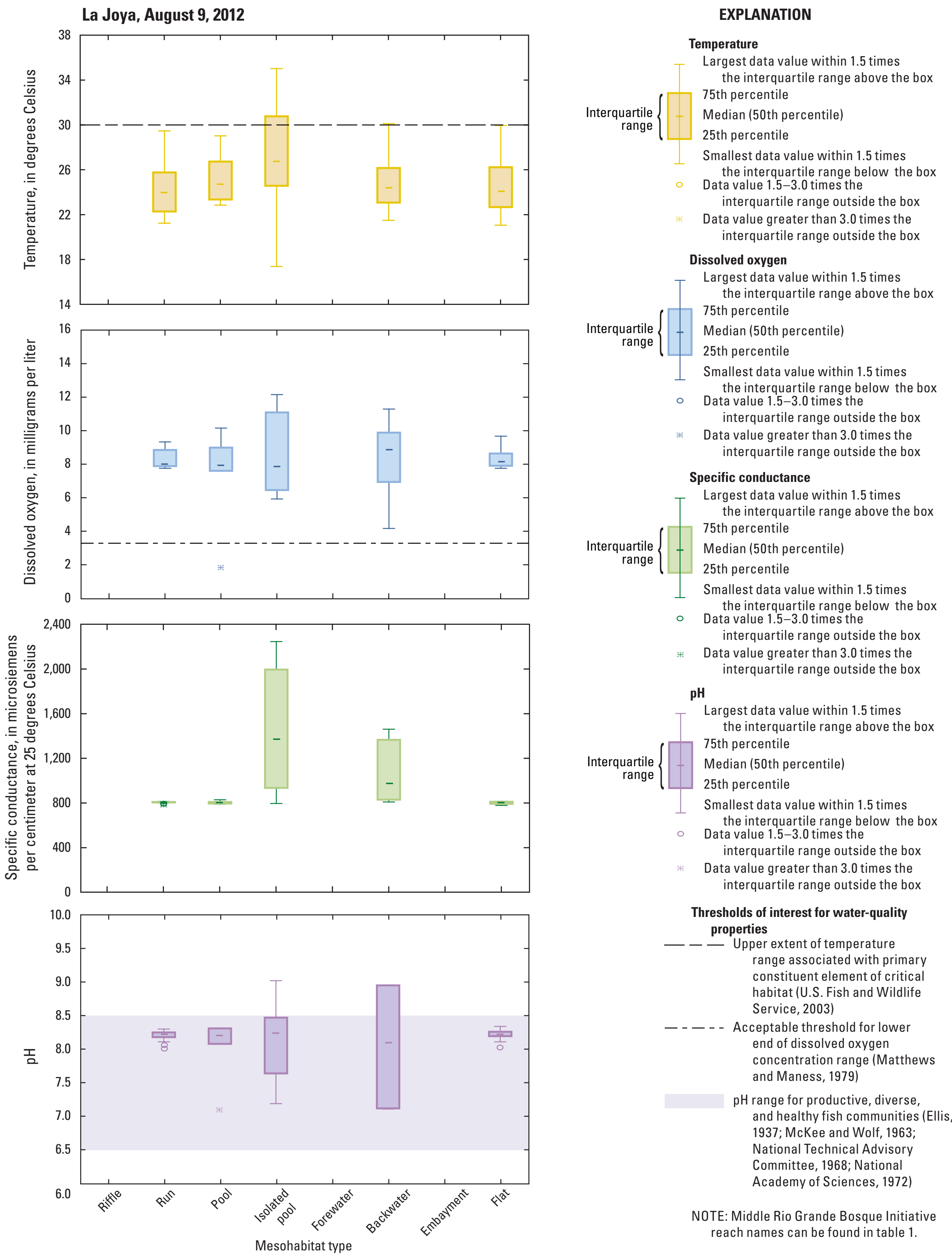

Figure 13. Temperature, dissolved oxygen, specific conductance, and pH in different mesohabitat types at 13 sites on the Middle Rio Grande, New Mexico, summer 2012.—Continued

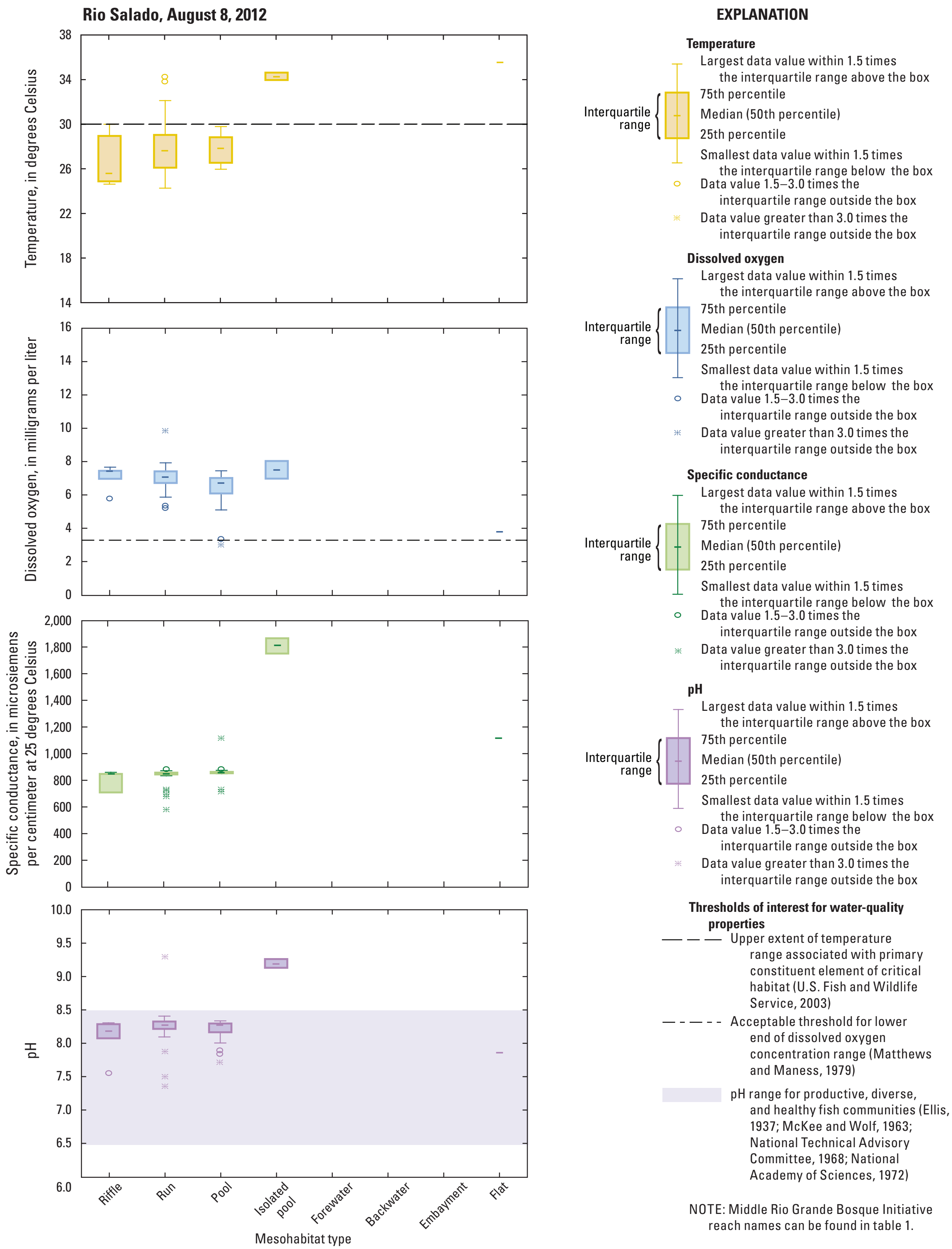

Figure 13. Temperature, dissolved oxygen, specific conductance, and pH in different mesohabitat types at 13 sites on the Middle Rio Grande, New Mexico, summer 2012.—Continued

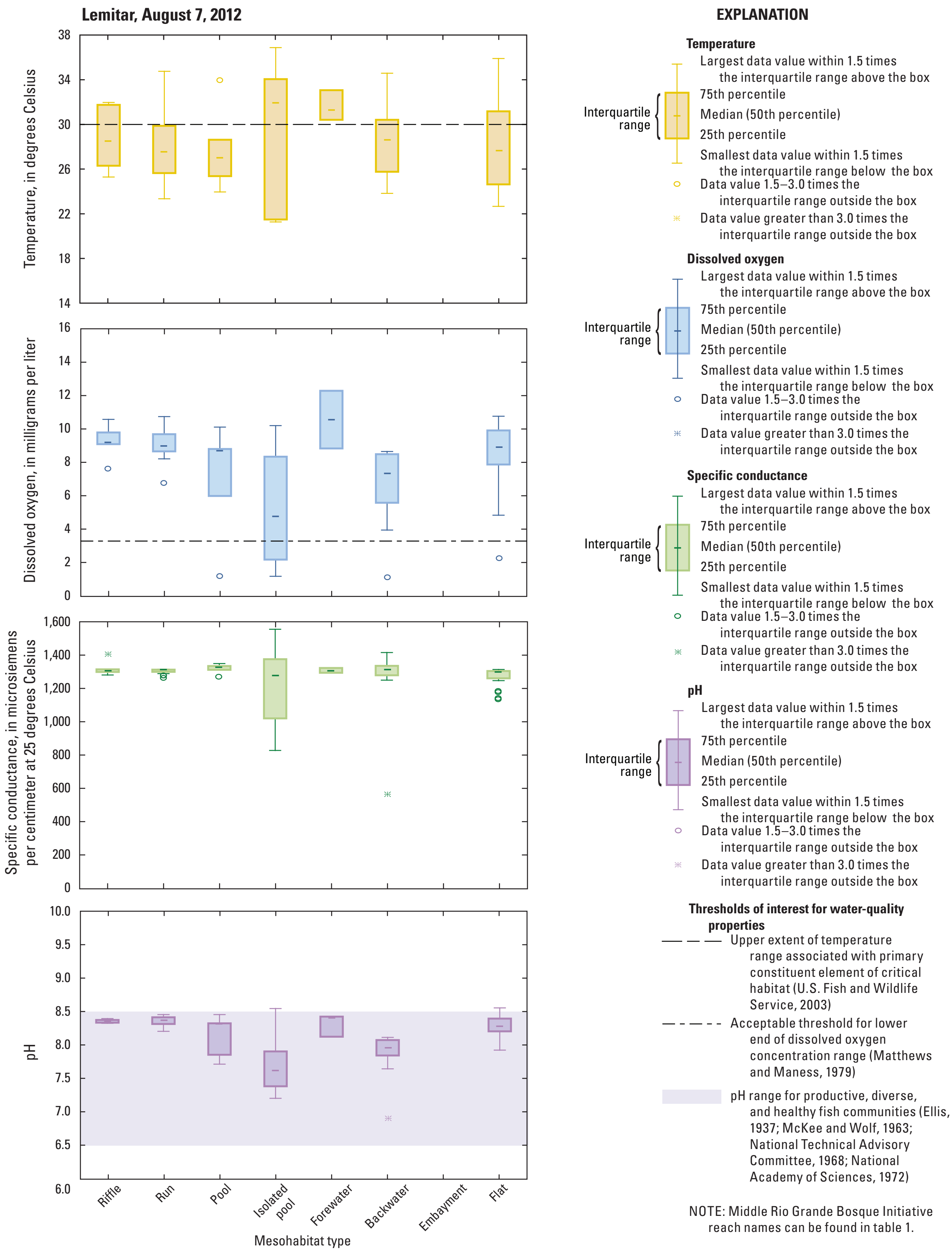

Figure 13. Temperature, dissolved oxygen, specific conductance, and pH in different mesohabitat types at 13 sites on the Middle Rio Grande, New Mexico, summer 2012.—Continued

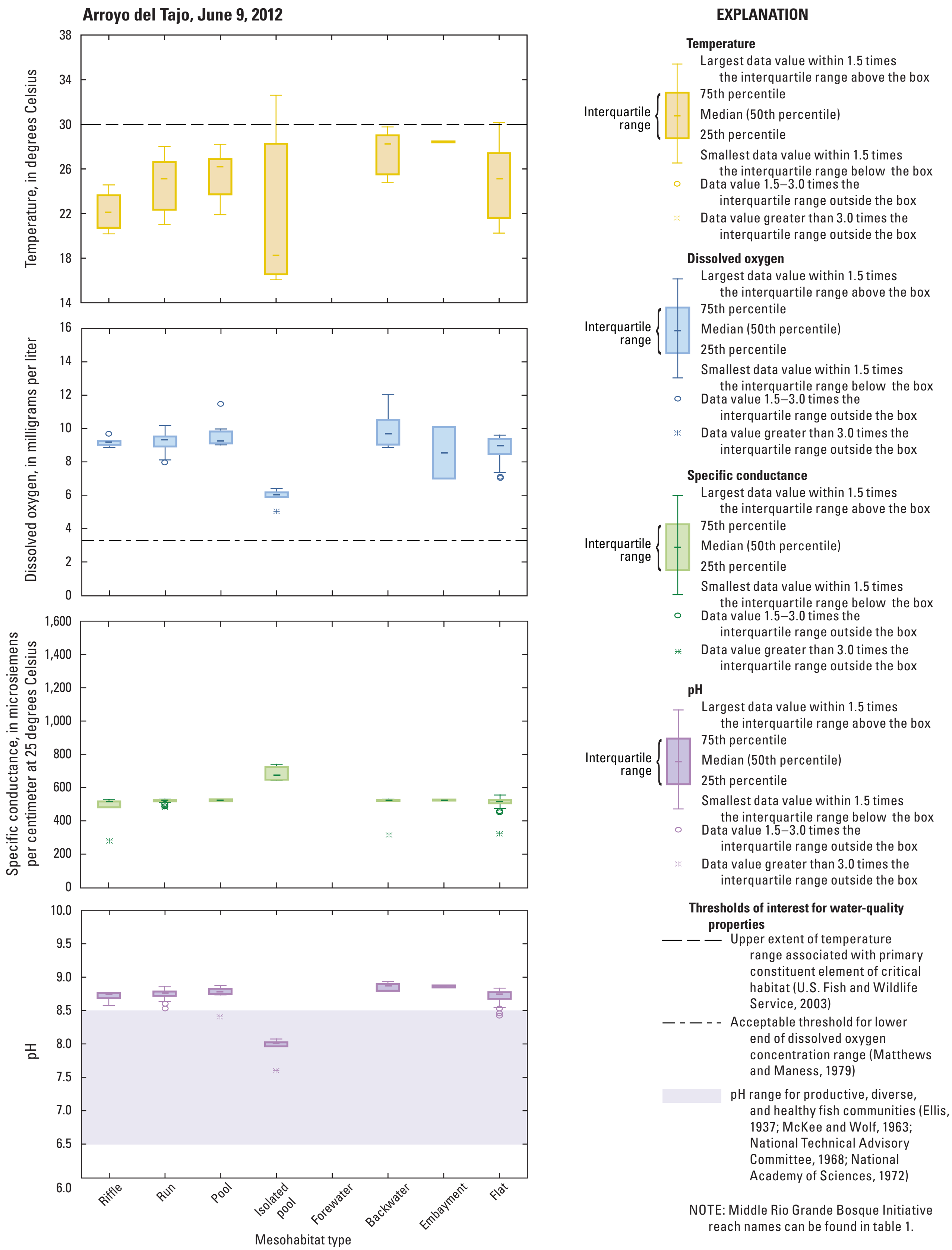

Figure 13. Temperature, dissolved oxygen, specific conductance, and pH in different mesohabitat types at 13 sites on the Middle Rio Grande, New Mexico, summer 2012.—Continued

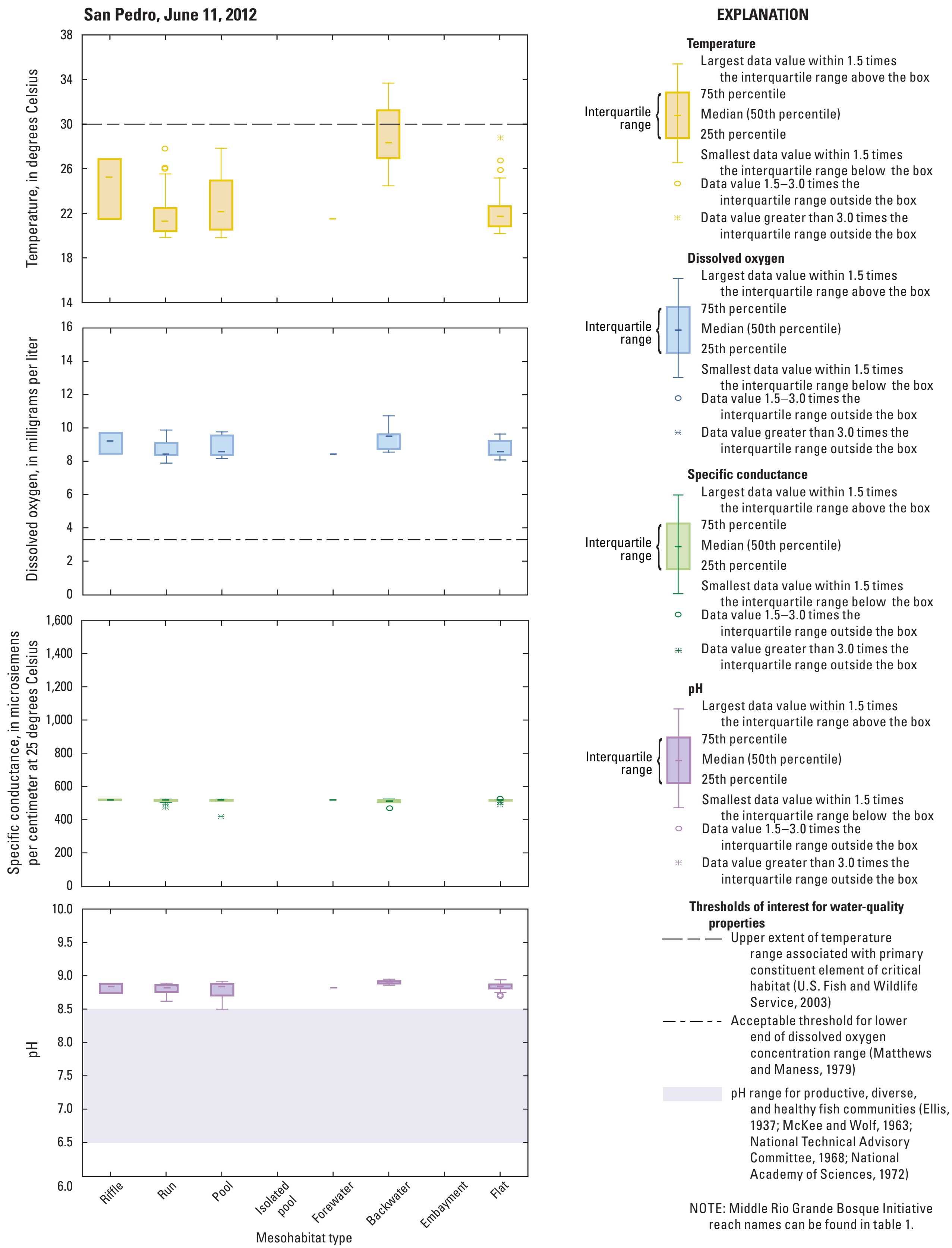

Figure 13. Temperature, dissolved oxygen, specific conductance, and pH in different mesohabitat types at 13 sites on the Middle Rio Grande, New Mexico, summer 2012.—Continued

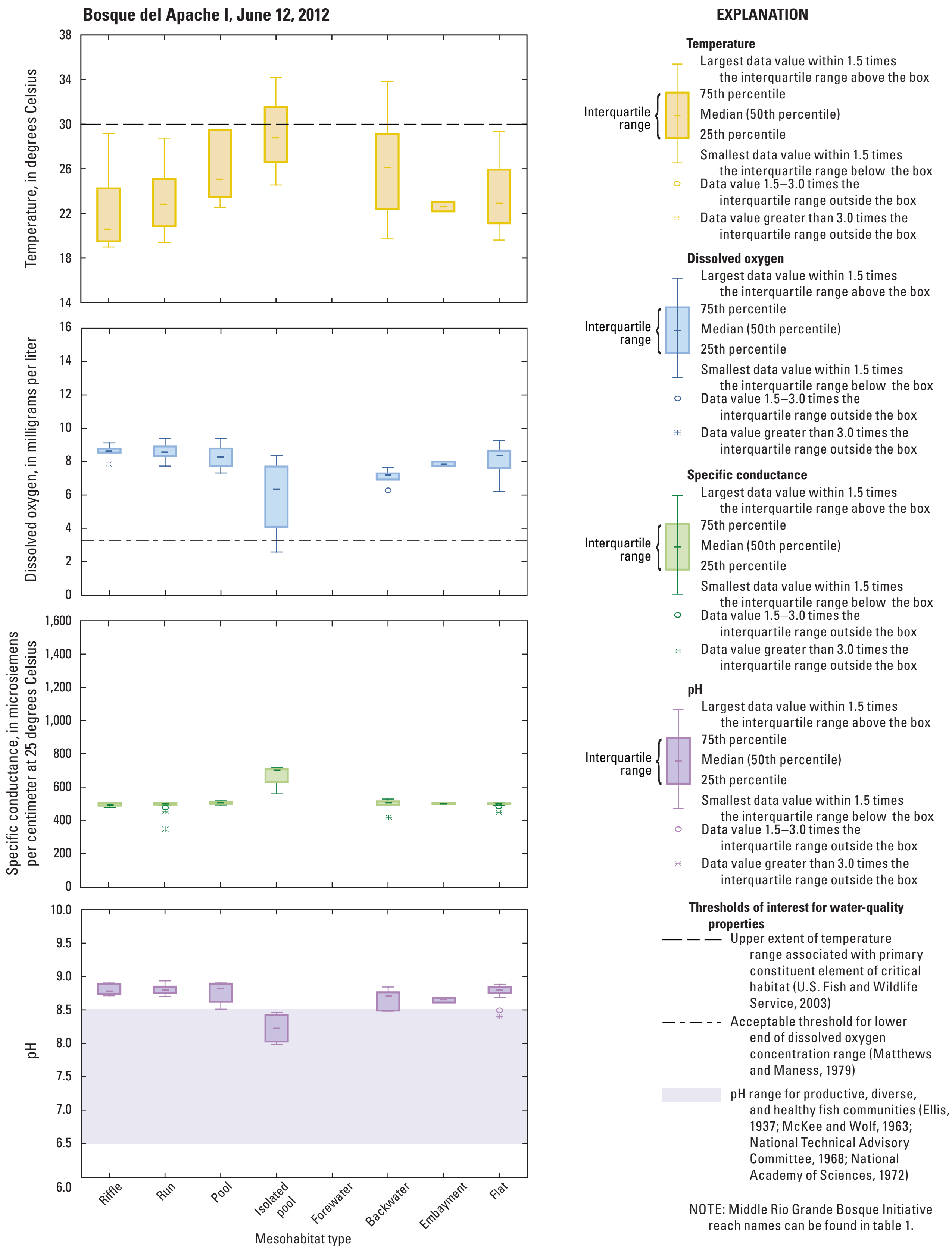

Figure 13. Temperature, dissolved oxygen, specific conductance, and pH in different mesohabitat types at 13 sites on the Middle Rio Grande, New Mexico, summer 2012.—Continued

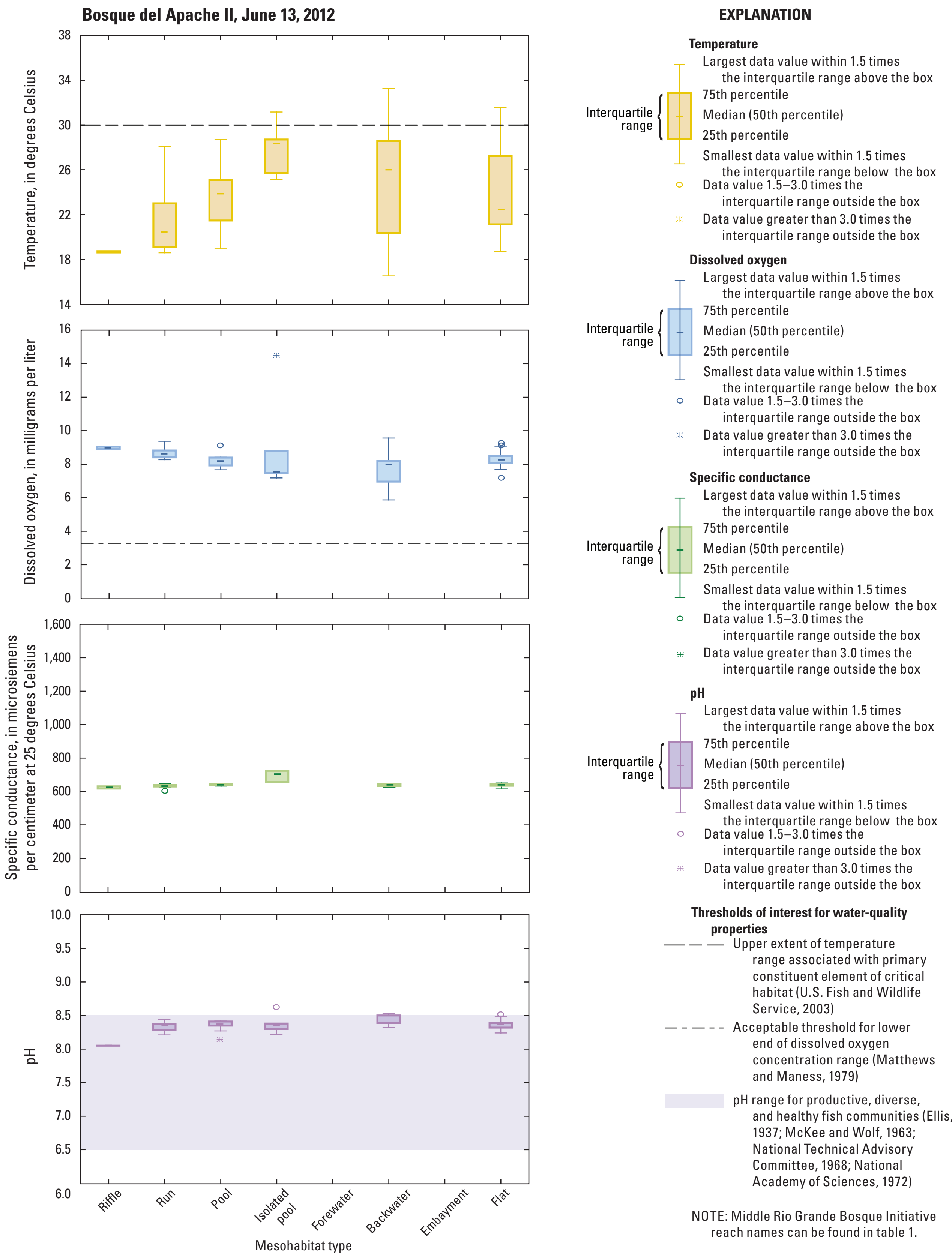

Figure 13. Temperature, dissolved oxygen, specific conductance, and pH in different mesohabitat types at 13 sites on the Middle Rio Grande, New Mexico, summer 2012.—Continued

Table 3. Area-weighted mean values of the water-quality properties measured at 13 sites on the Middle Rio Grande, New Mexico, summer 2012.

[°C, degrees Celsius; µS/cm at 25 °C, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; ft³/s, cubic feet per second]

Short name for sampling site (sites are listed in downstream order)	Date sampled	Temperature (°C)	Specific conductance (µS/cm at 25 °C)	Dissolved oxygen (mg/L)	pH (standard units)	Discharge (ft³/s)
La Orilla	8/13/2012	23.31	299	7.19	7.98	430
Barelas	8/11/2012	25.70	312	6.79	8.08	93.0
Los Padillas	8/10/2012	25.33	395	6.23	7.81	334
Los Lunas I	6/6/2012	26.68	366	6.91	8.22	258
Los Lunas II	6/7/2012	26.46	386	8.05	8.30	243
Abeytas	6/8/2012	26.46	400	8.60	8.50	179
La Joya	8/9/2012	22.86	837	8.34	8.14	49.5
Rio Salado	8/8/2012	27.19	857	7.07	8.32	37.9
Lemitar	8/7/2012	29.03	1,300	9.13	8.32	4.13
Arroyo del Tajo	6/9/2012	24.95	518	9.03	8.70	140
San Pedro	6/11/2012	21.47	514	8.74	8.79	68.3
Bosque del Apache I	6/12/2012	22.57	501	8.60	8.78	48
Bosque del Apache II	6/13/2012	23.66	640	8.41	8.37	45.7
Area-weighted mean values[1] for sites sampled in June		24.61	475	8.33	8.52	140
Area-weighted mean values[1] for sites sampled in August		25.57	666	7.46	8.11	158
Area-weighted mean values[1] for all sites excluding La Joya, Rio Salado, and Lemitar		24.66	433	7.86	8.35	184
Overall area-weighted mean values[1]		25.05	563	7.93	8.33	149

[1]Area-weighted values for water-quality properties by site were made by summing the products of the areal extent of each mesohabitat where water-quality properties were measured and the value for that water-quality property within that mesohabitat for all mesohabitats where water-quality properties were measured. The resulting sum was then divided by the sum of the areal extents for all mesohabitats where water-quality properties were measured.

Area-weighted specific conductance in the sites upstream from La Joya did not exceed 400 µs/cm at 25 °C, and the mean specific conductance values at the La Joya, Rio Salado, and Lemitar sites (837, 857, and 1,300 µs/cm at 25 °C, respectively) were appreciably higher compared to the overall mean specific conductance measured for the other 10 sites (433 µs/cm at 25 °C; table 3). It is unclear if the disparity in mean specific conductance between these three sites (La Joya, Rio Salado, and Lemitar) and the remaining sites is based on local geology, an influx of surface water with elevated specific conductance (from agricultural returns or wastewater-treatment plant effluent, for example), or evapotranspiration effects; however, groundwater sources along the western margin of the Middle Rio Grande Basin in the area around the Rio Puerco, which flows into the Rio Grande just upstream from La Joya, tend to have the highest specific conductance values (greater than 2,000 µs/cm at 25 °C) in the Middle Rio Grande Basin (Plummer and others, 2004). In addition, the highest mean specific conductance values (measured at the La Joya, Rio Salado, and Lemitar sites) were measured (table 3) downstream from the confluence of the Middle Rio Grande and the Rio Puerco following 32 consecutive days with streamflow recorded at USGS streamflow-gaging station 08353000 Rio Puerco near Bernardo, N. Mex. (U.S. Geological Survey, 2014), about 3 miles upstream from the confluence with the Rio Grande, and the inflows from the Rio Puerco were likely more saline compared to the native streamflow in the Middle Rio Grande. The four remaining sites downstream from Lemitar (Arroyo del Tajo, San Pedro, Bosque del Apache I, and Bosque del Apache II) were sampled following more than 3 weeks without streamflow in the Rio Puerco; this may help explain the substantially lower specific conductance values at these 4 sites relative to the 3 sites immediately upstream (La Joya, Rio Salado, and Lemitar). La Joya, Rio Salado, and Lemitar also had some of the lowest measured discharges (49.5, 37.9, and 4.13 ft³/s, respectively) (table 3), so evaporative enrichment likely contributed to the elevated specific conductance measured at these sites.

The pH typically ranges from about 6.5 to 8.5 in waters supporting productive, diverse, and healthy macroinvertebrate and fish communities (Ellis, 1937; McKee and Wolf, 1963; National Academy of Sciences, 1972). In establishing water-quality criteria for pH, the Ohio River Valley Water Sanitation Commission (1955) stated that although fish had been found at pH levels ranging between 4 and 10, the safe range was between 5 and 9, and maximum productivity generally occurred at a pH maintained between 6.5 and 8.5. A pH range between 6.5 and 8.5 is highlighted in the box plots associated with pH in figure 13.

The pH ranged from 6.5 in a backwater at the La Orilla site to 9.72 in an embayment at the Los Lunas I site. The largest ranges in pH within a mesohabitat type tended to be associated with low-velocity mesohabitats, particularly isolated pools, backwaters, and embayments. A small range in pH values was measured across all mesohabitat types in the downstream part of the study area (with the exception of the isolated pools at the Bosque del Apache I site), particularly at the Rio Salado, Arroyo del Tajo, San Pedro, Bosque del Apache I, and Bosque del Apache II sites. At three of these sites (Arroyo del Tajo, San Pedro, and Bosque del Apache I), the mean pH values were often outside of the range associated with productive, diverse, and healthy macroinvertebrate and fish communities (6.5 to 8.5; fig. 13). The mean pH was lower at the sites sampled in August (8.11) compared to the sites sampled in June (8.52) (table 3). The largest mean pH (8.79) was measured at the San Pedro site on June 11, 2012, and the smallest mean pH (7.81) was measured at the Los Padillas site on August 10, 2012. Lower mean pH values were measured at the three sites in and near Albuquerque (La Orilla [7.98], Barelas [8.08], and Los Padillas [7.81]) compared to any of the 10 remaining sites, which had an overall mean pH of 8.44 (table 3). Lower pH associated with the more urban sites near Albuquerque may be caused in part by more acidic stormwater runoff.

Fish Assemblage Composition at the Site Scale

Nineteen species of fish were collected among the 15 sites and four reaches over both sampling periods (table 4). Fish-species richness (number of species) among sites that were sampled during both sampling periods ranged from 6 at Rio Salado to 12 at La Orilla; only four species of fish were collected at Peña Blanca during winter 2011–12 (table 4). Fish were most abundant at the Lemitar site (1,786 individuals) and least abundant at the San Pedro site (275 individuals) (table 4). Total CPUE (combined from both sampling periods, except at the Peña Blanca and Bernalillo sites, which were only sampled during winter 2011–12) at each site ranged from 13.4 at San Pedro to 211 at Peña Blanca (table 4). The number of individuals and the number of fish species collected were generally larger at sites in the Angostura and Isleta reaches (table 4) compared to the San Acacia reach, with the exception of the Lemitar site. Periods of river fragmentation in much of the San Acacia reach because of irrigation withdrawals during the summer and fall probably account for the fewer individuals, fewer fish species, and smaller CPUEs in the San Acacia compared to the more upstream reaches during the entire year.

Ten of the 19 species (53 percent) collected during winter 2011–12 and summer 2012 were introduced species (table 4). More introduced than native species were also found in the Middle Rio Grande between near Bernalillo, N. Mex., and Elephant Butte Reservoir from 1987 to 1990 (Platania, 1993). In this study, the native *Cyprinella lutrensis* (red shiner) was the most abundant species collected among all of the sites, accounting for about 42 percent of fish collected (table 4), followed by the introduced *Gambusia affinis* (western mosquitofish) at about 24 percent and native *Carpiodes carpio* (river carpsucker) at about 11 percent. All other species of fish had relative abundances of less than 10 percent (table 4). Red shiner was also the most common native species collected in the Middle Rio Grande between Bernalillo and Elephant Butte Reservoir from 1987 to 1990 (Platania, 1993) and again from 2002 to 2004 (Remshardt and Tashjian, 2003). Only 1 or 2 individuals were collected across all sites during both sampling periods for six species: (1) *Ameiurus melas* (black bullhead), (2) *Dorosoma cepedianum* (gizzard shad), (3) *Lepomis cyanellus* (green sunfish), (4) *Morone chrysops* (white bass), (5) *Micropterus salmoides* (largemouth bass), and (6) *Lepomis macrochirus* (bluegill). About 61 percent of fish collected were members of the family Cyprinidae (table 4), and 69 percent of these fish were accounted for by one cyprinid, red shiner (table 4).

Fish-species richness was used in this investigation as a standard diversity metric (Ludwig and Reynolds, 1988) to compare the fish assemblage among sites at differing streamflows during winter 2011–12 and summer 2012 (table 4). Fish-species richness differed more among sites during winter 2011–12 than during summer 2012. The fish-species richness varied considerably during winter 2011–12, ranging from 1 species at the Los Lunas II site to 9 at the Abeytas site (fig. 14; table 4). A much smaller range in fish-species richness was found during summer 2012, when a minimum of 5 species were collected at the Rio Salado site and a maximum of 10 species were collected at the Los Lunas I site (fig. 14; table 4). Fish-species richness was higher during summer 2012 compared to winter 2011–12 at all sites that were sampled during both periods, with the exception of the Abeytas site, where 9 species were collected during both periods, and the Los Padillas site, where 7 species were collected during both periods (fig. 14; table 4).

The CPUE per sampling period was highest at the Peña Blanca site (211 in winter 2011–12) and lowest at the Los Lunas II site (0.15 in winter 2011–12) (table 4, fig. 15). In fact, CPUE per sampling period at Peña Blanca was at least double the CPUE at all other sites, with the exception of Lemitar, which had a CPUE of 151 during summer 2012. The CPUE

Table 4. Fish species, number of individuals collected, number of species of fish, and catch per unit effort from 15 sites distributed among four reaches of Middle Rio Grande, New Mexico, winter 2011–12 and summer 2012.

[MRGBI, Middle Rio Grande Bosque Initiative; I, Introduced; N, Native; m², square meters; CPUE, catch per unit of seining effort (number of individuals caught per 100 square meters; no., number)]

MRGBI reach name	Site short name	Sampling period	Family	Cyprinidae					
			Species	*Cyprinus carpio*	*Cyprinella lutrensis*	*Hybognathus amarus*	*Rhinichthys cataractae*	*Pimephales promelas*	*Platygobio gracilis*
			Species common name	Common carp	Red shiner	Rio Grande silvery minnow	Longnose dace	Fathead minnow	Flathead chub
			Species abbreviation	CYPCAR	CYPLUT	HYBAMA	RHICAT	PIMPRO	PLAGRA
			Species status	I	N	N	N	N	N
Cochiti	Peña Blanca	winter 2011–12	Number of individuals	0	0	0	2	0	0
			CPUE	0.00	0.00	0.00	0.30	0.00	0.00
Angostura	Bernalillo	winter 2011–12	Number of individuals	0	402	2	2	4	5
			CPUE	0.00	75.71	0.38	0.38	0.75	0.94
	La Orilla	winter 2011–12	Number of individuals	0	43	21	0	8	1
			CPUE	0.00	5.78	2.82	0.00	1.08	0.13
		summer 2012	Number of individuals	1	124	0	18	0	223
			CPUE	0.09	11.39	0.00	1.65	0.00	20.48
		total	Number of individuals	1	167	21	18	8	224
			CPUE	0.05	9.11	1.15	0.98	0.44	12.22
	Barelas	winter 2011–12	Number of individuals	0	2	13	0	0	4
			CPUE	0.00	0.16	1.03	0.00	0.00	0.32
		summer 2012	Number of individuals	2	98	1	0	34	38
			CPUE	0.16	7.81	0.08	0.00	2.71	3.03
		total	Number of individuals	2	100	14	0	34	42
			CPUE	0.08	3.98	0.56	0.00	1.35	1.67
	Los Padillas	winter 2011–12	Number of individuals	0	9	7	1	1	1
			CPUE	0.00	1.42	1.10	0.16	0.16	0.16
		summer 2012	Number of individuals	1	297	0	41	0	303
			CPUE	0.08	25.06	0.00	3.46	0.00	25.57
		total	Number of individuals	1	306	7	42	1	304
			CPUE	0.05	16.82	0.38	2.31	0.05	16.71
Isleta	Los Lunas I	winter 2011–12	Number of individuals	0	24	4	0	0	0
			CPUE	0.00	3.46	0.58	0.00	0.00	0.00
		summer 2012	Number of individuals	30	781	5	0	22	0
			CPUE	2.08	54.16	0.35	0.00	1.53	0.00
		total	Number of individuals	30	805	9	0	22	0
			CPUE	1.41	37.70	0.42	0.00	1.03	0.00
	Los Lunas II	winter 2011–12	Number of individuals	0	1	0	0	0	0
			CPUE	0.00	0.15	0.00	0.00	0.00	0.00
		summer 2012	Number of individuals	8	248	4	0	34	2
			CPUE	0.69	21.47	0.35	0.00	2.94	0.17
		total	Number of individuals	8	249	4	0	34	2
			CPUE	0.44	13.79	0.22	0.00	1.88	0.11
	Abeytas	winter 2011–12	Number of individuals	3	149	0	0	1	0
			CPUE	0.42	20.78	0.00	0.00	0.14	0.00
		summer 2012	Number of individuals	4	562	0	0	53	0
			CPUE	0.34	47.79	0.00	0.00	4.51	0.00
		total	Number of individuals	7	711	0	0	54	0
			CPUE	0.37	37.56	0.00	0.00	2.85	0.00

Table 4. Fish species, number of individuals collected, number of species of fish, and catch per unit effort from 15 sites distributed among four reaches of Middle Rio Grande, New Mexico, winter 2011–12 and summer 2012.—Continued

[MRGBI, Middle Rio Grande Bosque Initiative; I, Introduced; N, Native; m^2, square meters; CPUE, catch per unit of seining effort (number of individuals caught per 100 square meters; no., number]

MRGBI reach name	Site short name	Sampling period	Family	Cyprinidae					
			Species	*Cyprinus carpio*	*Cyprinella lutrensis*	*Hybognathus amarus*	*Rhinichthys cataractae*	*Pimephales promelas*	*Platygobio gracilis*
			Species common name	Common carp	Red shiner	Rio Grande silvery minnow	Longnose dace	Fathead minnow	Flathead chub
			Species abbreviation	CYPCAR	CYPLUT	HYBAMA	RHICAT	PIMPRO	PLAGRA
			Species status	I	N	N	N	N	N
Isleta—Continued	La Joya	winter 2011–12	Number of individuals	0	209	1	0	0	5
			CPUE	0.00	37.06	0.18	0.00	0.00	0.89
		summer 2012	Number of individuals	4	523	0	0	1	10
			CPUE	0.43	56.60	0.00	0.00	0.11	1.08
		total	Number of individuals	4	732	1	0	1	15
			CPUE	0.27	49.19	0.07	0.00	0.07	1.01
	Rio Salado	winter 2011–12	Number of individuals	0	38	14	0	0	20
			CPUE	0.00	4.29	1.58	0.00	0.00	2.26
		summer 2012	Number of individuals	0	227	0	0	0	23
			CPUE	0.00	29.10	0.00	0.00	0.00	2.95
		total	Number of individuals	0	265	14	0	0	43
			CPUE	0.00	15.92	0.84	0.00	0.00	2.58
San Acacia	Lemitar	winter 2011–12	Number of individuals	0	32	13	0	0	12
			CPUE	0.00	6.05	2.46	0.00	0.00	2.27
		summer 2012	Number of individuals	5	1,461	10	0	2	18
			CPUE	0.44	127.93	0.88	0.00	0.18	1.58
		total	Number of individuals	5	1,493	23	0	2	30
			CPUE	0.30	89.35	1.38	0.00	0.12	1.80
	Arroyo del Tajo	winter 2011–12	Number of individuals	0	48	75	0	0	2
			CPUE	0.00	6.58	10.29	0.00	0.00	0.27
		summer 2012	Number of individuals	37	26	1	0	16	50
			CPUE	2.61	1.84	0.07	0.00	1.13	3.53
		total	Number of individuals	37	74	76	0	16	52
			CPUE	1.72	3.45	3.54	0.00	0.75	2.42
	San Pedro	winter 2011–12	Number of individuals	0	1	5	0	0	0
			CPUE	0.00	0.14	0.68	0.00	0.00	0.00
		summer 2012	Number of individuals	196	4	1	0	0	15
			CPUE	14.92	0.30	0.08	0.00	0.00	1.14
		total	Number of individuals	196	5	6	0	0	15
			CPUE	9.55	0.24	0.29	0.00	0.00	0.73
	Bosque del Apache I	winter 2011–12	Number of individuals	0	1	2	0	0	0
			CPUE	0.00	0.14	0.27	0.00	0.00	0.00
		summer 2012	Number of individuals	324	16	0	0	11	33
			CPUE	32.34	1.60	0.00	0.00	1.10	3.29
		total	Number of individuals	324	17	2	0	11	33
			CPUE	18.65	0.98	0.12	0.00	0.63	1.90
	Bosque del Apache II	winter 2011–12	Number of individuals	0	0	6	0	0	0
			CPUE	0.00	0.00	0.82	0.00	0.00	0.00
		summer 2012	Number of individuals	511	29	0	0	16	21
			CPUE	40.56	2.30	0.00	0.00	1.27	1.67
		total	Number of individuals	511	29	6	0	16	21
			CPUE	25.61	1.45	0.30	0.00	0.80	1.05
			Total no. of individuals	1,126	5,355	185	64	203	786
			Relative abundance	8.87	42.21	1.46	0.50	1.60	6.19

Table 4. Fish species, number of individuals collected, number of species of fish, and catch per unit effort from 15 sites distributed among four reaches of Middle Rio Grande, New Mexico, winter 2011–12 and summer 2012.—Continued

[MRGBI, Middle Rio Grande Bosque Initiative; I, Introduced; N, Native; m^2, square meters; CPUE, catch per unit of seining effort (number of individuals caught per 100 square meters; no., number)]

MRGBI reach name	Site short name	Sampling period	Family	Catostomidae		Ictaluridae				Poeciliidae	Clupeidae
			Species	*Carpiodes carpio*	*Catostomus commersonii*	*Ameiurus melas*	*Ictalurus punctatus*	*Pylodictis olivaris*	*Ameiurus natalis*	*Gambusia affinis*	*Dorosoma cepedianum*
			Species common name	River carpsucker	White sucker	Black bullhead	Channel catfish	Flathead catfish	Yellow bullhead	Western mosquitofish	Gizzard shad
			Species abbreviation	CARCAR	CATCOM	AMEMEL	ICTPUN	PYLOLI	AMENAT	GAMAFF	DORCEP
			Species status	N	I	I	I	N	I	I	N
Cochiti	Peña Blanca	winter 2011–12	Number of individuals	0	19	1	0	0	0	1,372	0
			CPUE	0.00	2.87	0.15	0.00	0.00	0.00	207.56	0.00
Angostura	Bernalillo	winter 2011–12	Number of individuals	0	6	0	2	0	0	27	0
			CPUE	0.00	1.13	0.00	0.38	0.00	0.00	5.08	0.00
	La Orilla	winter 2011–12	Number of individuals	5	0	0	0	0	0	29	0
			CPUE	0.67	0.00	0.00	0.00	0.00	0.00	3.90	0.00
		summer 2012	Number of individuals	0	0	0	39	19	5	0	0
			CPUE	0.00	0.00	0.00	3.58	1.74	0.46	0.00	0.00
		total	Number of individuals	5	0	0	39	19	5	29	0
			CPUE	0.27	0.00	0.00	2.13	1.04	0.27	1.58	0.00
	Barelas	winter 2011–12	Number of individuals	0	0	0	3	0	1	0	0
			CPUE	0.00	0.00	0.00	0.24	0.00	0.08	0.00	0.00
		summer 2012	Number of individuals	38	2	0	40	0	0	277	0
			CPUE	3.03	0.16	0.00	3.19	0.00	0.00	22.09	0.00
		total	Number of individuals	38	2	0	43	0	1	277	0
			CPUE	1.51	0.08	0.00	1.71	0.00	0.04	11.02	0.00
	Los Padillas	winter 2011–12	Number of individuals	4	0	0	11	0	0	0	0
			CPUE	0.63	0.00	0.00	1.74	0.00	0.00	0.00	0.00
		summer 2012	Number of individuals	0	0	0	87	13	0	0	0
			CPUE	0.00	0.00	0.00	7.34	1.10	0.00	0.00	0.00
		total	Number of individuals	4	0	0	98	13	0	0	0
			CPUE	0.22	0.00	0.00	5.39	0.71	0.00	0.00	0.00
Isleta	Los Lunas I	winter 2011–12	Number of individuals	1	0	0	0	0	0	0	0
			CPUE	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		summer 2012	Number of individuals	503	46	0	1	0	0	98	0
			CPUE	34.88	3.19	0.00	0.07	0.00	0.00	6.80	0.00
		total	Number of individuals	504	46	0	1	0	0	98	0
			CPUE	23.61	2.15	0.00	0.05	0.00	0.00	4.59	0.00
	Los Lunas II	winter 2011–12	Number of individuals	0	0	0	0	0	0	0	0
			CPUE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		summer 2012	Number of individuals	267	16	0	0	0	0	237	0
			CPUE	23.12	1.39	0.00	0.00	0.00	0.00	20.52	0.00
		total	Number of individuals	267	16	0	0	0	0	237	0
			CPUE	14.78	0.89	0.00	0.00	0.00	0.00	13.12	0.00
	Abeytas	winter 2011–12	Number of individuals	4	0	0	1	0	0	3	1
			CPUE	0.56	0.00	0.00	0.14	0.00	0.00	0.42	0.14
		summer 2012	Number of individuals	99	0	0	0	0	1	494	1
			CPUE	8.42	0.00	0.00	0.00	0.00	0.09	42.01	0.09
		total	Number of individuals	103	0	0	1	0	1	497	2
			CPUE	5.44	0.00	0.00	0.05	0.00	0.05	26.25	0.11

Table 4. Fish species, number of individuals collected, number of species of fish, and catch per unit effort from 15 sites distributed among four reaches of Middle Rio Grande, New Mexico, winter 2011–12 and summer 2012.—Continued

[MRGBI, Middle Rio Grande Bosque Initiative; I, Introduced; N, Native; m^2, square meters; CPUE, catch per unit of seining effort (number of individuals caught per 100 square meters; no., number]

MRGBI reach name	Site short name	Sampling period	Family	Catostomidae		Ictaluridae				Poeciliidae	Clupeidae
			Species	*Carpiodes carpio*	*Catostomus commersonii*	*Ameiurus melas*	*Ictalurus punctatus*	*Pylodictis olivaris*	*Ameiurus natalis*	*Gambusia affinis*	*Dorosoma cepedianum*
			Species common name	River carpsucker	White sucker	Black bullhead	Channel catfish	Flathead catfish	Yellow bullhead	Western mosquitofish	Gizzard shad
			Species abbreviation	CARCAR	CATCOM	AMEMEL	ICTPUN	PYLOLI	AMENAT	GAMAFF	DORCEP
			Species status	N	I	I	I	N	I	I	N
Isleta—Continued	La Joya	winter 2011–12	Number of individuals	0	0	0	2	0	0	1	0
			CPUE	0.00	0.00	0.00	0.35	0.00	0.00	0.18	0.00
		summer 2012	Number of individuals	9	0	0	57	0	0	187	0
			CPUE	0.97	0.00	0.00	6.17	0.00	0.00	20.24	0.00
		total	Number of individuals	9	0	0	59	0	0	188	0
			CPUE	0.60	0.00	0.00	3.97	0.00	0.00	12.63	0.00
	Rio Salado	winter 2011–12	Number of individuals	0	0	0	2	0	0	0	0
			CPUE	0.00	0.00	0.00	0.23	0.00	0.00	0.00	0.00
		summer 2012	Number of individuals	0	0	0	20	0	1	146	0
			CPUE	0.00	0.00	0.00	2.56	0.00	0.13	18.72	0.00
		total	Number of individuals	0	0	0	22	0	1	146	0
			CPUE	0.00	0.00	0.00	1.32	0.00	0.06	8.77	0.00
San Acacia	Lemitar	winter 2011–12	Number of individuals	0	0	0	0	0	0	0	0
			CPUE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		summer 2012	Number of individuals	26	0	0	85	0	0	122	0
			CPUE	2.28	0.00	0.00	7.44	0.00	0.00	10.68	0.00
		total	Number of individuals	26	0	0	85	0	0	122	0
			CPUE	1.56	0.00	0.00	5.09	0.00	0.00	7.30	0.00
	Arroyo del Tajo	winter 2011–12	Number of individuals	0	0	0	0	0	0	0	0
			CPUE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		summer 2012	Number of individuals	130	1	0	0	0	0	29	0
			CPUE	9.18	0.07	0.00	0.00	0.00	0.00	2.05	0.00
		total	Number of individuals	130	1	0	0	0	0	29	0
			CPUE	6.06	0.05	0.00	0.00	0.00	0.00	1.35	0.00
	San Pedro	winter 2011–12	Number of individuals	0	0	0	0	0	0	0	0
			CPUE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		summer 2012	Number of individuals	47	2	0	0	0	0	4	0
			CPUE	3.58	0.15	0.00	0.00	0.00	0.00	0.30	0.00
		total	Number of individuals	47	2	0	0	0	0	4	0
			CPUE	2.29	0.10	0.00	0.00	0.00	0.00	0.19	0.00
	Bosque del Apache I	winter 2011–12	Number of individuals	0	0	0	0	0	0	0	0
			CPUE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		summer 2012	Number of individuals	143	0	0	0	0	0	1	0
			CPUE	14.27	0.00	0.00	0.00	0.00	0.00	0.10	0.00
		total	Number of individuals	143	0	0	0	0	0	1	0
			CPUE	8.23	0.00	0.00	0.00	0.00	0.00	0.06	0.00
	Bosque del Apache II	winter 2011–12	Number of individuals	0	0	0	0	0	0	0	0
			CPUE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		summer 2012	Number of individuals	84	4	0	0	0	0	5	0
			CPUE	6.67	0.32	0.00	0.00	0.00	0.00	0.40	0.00
		total	Number of individuals	84	4	0	0	0	0	5	0
			CPUE	4.21	0.20	0.00	0.00	0.00	0.00	0.25	0.00
			Total no. of individuals	1,360	96	1	350	32	8	3,032	2
			Relative abundance	10.72	0.76	0.01	2.76	0.25	0.06	23.90	0.02

Table 4. Fish species, number of individuals collected, number of species of fish, and catch per unit effort from 15 sites distributed among four reaches of Middle Rio Grande, New Mexico, winter 2011–12 and summer 2012.—Continued

[MRGBI, Middle Rio Grande Bosque Initiative; I, Introduced; N, Native; m², square meters; CPUE, catch per unit of seining effort (number of individuals caught per 100 square meters; no., number)]

MRGBI reach name	Site short name	Sampling period	Family	Centrarchidae					Number of individuals	Fish-species richness	Seined area (m²)	CPUE
			Species	*Lepomis cyanellus*	*Pomoxis annularis*	*Morone chrysops*	*Micropterus salmoides*	*Lepomis macrochirus*				
			Species common name	Green sunfish	White crappie	White bass	Largemouth bass	Bluegill				
			Species abbreviation	LEPCYA	POMANN	MORCHR	MICSAL	LEPMAC				
			Species status	I	I	I	I	N				
Cochiti	Peña Blanca	winter 2011–12	Number of individuals	0	0	0	0	0	1,394	4	661	211
			CPUE	0.00	0.00	0.00	0.00	0.00				
Angostura	Bernalillo	winter 2011–12	Number of individuals	0	0	0	0	0	450	8	531	84.7
			CPUE	0.00	0.00	0.00	0.00	0.00				
	La Orilla	winter 2011–12	Number of individuals	0	0	0	0	0	107	6	744	14.4
			CPUE	0.00	0.00	0.00	0.00	0.00				
		summer 2012	Number of individuals	0	50	0	0	0	479	8	1,089	44.0
			CPUE	0.00	4.59	0.00	0.00	0.00				
		total	Number of individuals	0	50	0	0	0	586	12	1,833	32.0
			CPUE	0.00	2.73	0.00	0.00	0.00				
	Barelas	winter 2011–12	Number of individuals	0	0	0	0	0	23	5	1,259	1.83
			CPUE	0.00	0.00	0.00	0.00	0.00				
		summer 2012	Number of individuals	0	0	0	0	0	530	9	1,254	42.3
			CPUE	0.00	0.00	0.00	0.00	0.00				
		total	Number of individuals	0	0	0	0	0	553	10	2,513	22.0
			CPUE	0.00	0.00	0.00	0.00	0.00				
	Los Padillas	winter 2011–12	Number of individuals	0	0	0	0	0	34	7	634	5.36
			CPUE	0.00	0.00	0.00	0.00	0.00				
		summer 2012	Number of individuals	0	28	0	0	0	770	7	1,185	65.0
			CPUE	0.00	2.36	0.00	0.00	0.00				
		total	Number of individuals	0	28	0	0	0	804	10	1,819	44.2
			CPUE	0.00	1.54	0.00	0.00	0.00				
Isleta	Los Lunas I	winter 2011–12	Number of individuals	0	0	0	0	0	29	3	693	4.18
			CPUE	0.00	0.00	0.00	0.00	0.00				
		summer 2012	Number of individuals	0	3	1	0	0	1,490	10	1,442	103
			CPUE	0.00	0.21	0.07	0.00	0.00				
		total	Number of individuals	0	3	1	0	0	1,519	10	2,135	71.1
			CPUE	0.00	0.14	0.05	0.00	0.00				
	Los Lunas II	winter 2011–12	Number of individuals	0	0	0	0	0	1	1	651	0.15
			CPUE	0.00	0.00	0.00	0.00	0.00				
		summer 2012	Number of individuals	0	0	0	1	0	817	9	1,155	70.7
			CPUE	0.00	0.00	0.00	0.09	0.00				
		total	Number of individuals	0	0	0	1	0	818	9	1,806	45.3
			CPUE	0.00	0.00	0.00	0.06	0.00				
	Abeytas	winter 2011–12	Number of individuals	1	2	0	0	0	165	9	717	23.0
			CPUE	0.14	0.28	0.00	0.00	0.00				
		summer 2012	Number of individuals	0	1	0	0	1	1,216	9	1,176	103
			CPUE	0.00	0.09	0.00	0.00	0.09				
		total	Number of individuals	1	3	0	0	1	1,381	11	1,893	73.0
			CPUE	0.05	0.16	0.00	0.00	0.05				

Table 4. Fish species, number of individuals collected, number of species of fish, and catch per unit effort from 15 sites distributed among four reaches of Middle Rio Grande, New Mexico, winter 2011–12 and summer 2012.—Continued

[MRGBI, Middle Rio Grande Bosque Initiative; I, Introduced; N, Native; m², square meters; CPUE, catch per unit of seining effort (number of individuals caught per 100 square meters; no., number]

MRGBI reach name	Site short name	Sampling period	Family	Centrarchidae					Number of individuals	Fish-species richness	Seined area (m²)	CPUE
			Species	*Lepomis cyanellus*	*Pomoxis annularis*	*Morone chrysops*	*Micropterus salmoides*	*Lepomis macrochirus*				
			Species common name	Green sunfish	White crappie	White bass	Largemouth bass	Bluegill				
			Species abbreviation	LEPCYA	POMANN	MORCHR	MICSAL	LEPMAC				
			Species status	I	I	I	I	N				
Isleta—Continued	La Joya	winter 2011–12	Number of individuals	0	0	0	0	0	218	5	564	38.7
			CPUE	0.00	0.00	0.00	0.00	0.00				
		summer 2012	Number of individuals	0	0	0	0	0	791	7	924	85.6
			CPUE	0.00	0.00	0.00	0.00	0.00				
		total	Number of individuals	0	0	0	0	0	1,009	8	1,488	67.8
			CPUE	0.00	0.00	0.00	0.00	0.00				
	Rio Salado	winter 2011–12	Number of individuals	0	0	0	0	0	74	4	885	8.36
			CPUE	0.00	0.00	0.00	0.00	0.00				
		summer 2012	Number of individuals	0	0	0	0	0	417	5	780	53.5
			CPUE	0.00	0.00	0.00	0.00	0.00				
		total	Number of individuals	0	0	0	0	0	491	6	1,665	29.5
			CPUE	0.00	0.00	0.00	0.00	0.00				
San Acacia	Lemitar	winter 2011–12	Number of individuals	0	0	0	0	0	57	3	529	10.8
			CPUE	0.00	0.00	0.00	0.00	0.00				
		summer 2012	Number of individuals	0	0	0	0	0	1,729	8	1,142	151
			CPUE	0.00	0.00	0.00	0.00	0.00				
		total	Number of individuals	0	0	0	0	0	1,786	8	1,671	107
			CPUE	0.00	0.00	0.00	0.00	0.00				
	Arroyo del Tajo	winter 2011–12	Number of individuals	0	0	0	0	0	125	3	729	17.1
			CPUE	0.00	0.00	0.00	0.00	0.00				
		summer 2012	Number of individuals	0	0	0	0	0	290	8	1,416	20.5
			CPUE	0.00	0.00	0.00	0.00	0.00				
		total	Number of individuals	0	0	0	0	0	415	8	2,145	19.3
			CPUE	0.00	0.00	0.00	0.00	0.00				
	San Pedro	winter 2011–12	Number of individuals	0	0	0	0	0	6	2	738	0.81
			CPUE	0.00	0.00	0.00	0.00	0.00				
		summer 2012	Number of individuals	0	0	0	0	0	269	7	1,314	20.5
			CPUE	0.00	0.00	0.00	0.00	0.00				
		total	Number of individuals	0	0	0	0	0	275	7	2,052	13.4
			CPUE	0.00	0.00	0.00	0.00	0.00				
	Bosque del Apache I	winter 2011–12	Number of individuals	0	0	0	0	0	3	2	735	0.41
			CPUE	0.00	0.00	0.00	0.00	0.00				
		summer 2012	Number of individuals	0	0	0	0	0	528	6	1,002	52.7
			CPUE	0.00	0.00	0.00	0.00	0.00				
		total	Number of individuals	0	0	0	0	0	531	7	1,737	30.6
			CPUE	0.00	0.00	0.00	0.00	0.00				
	Bosque del Apache II	winter 2011–12	Number of individuals	0	0	0	0	0	6	1	735	0.82
			CPUE	0.00	0.00	0.00	0.00	0.00				
		summer 2012	Number of individuals	0	0	0	0	0	670	7	1,260	53.2
			CPUE	0.00	0.00	0.00	0.00	0.00				
		total	Number of individuals	0	0	0	0	0	676	8	1,995	33.9
			CPUE	0.00	0.00	0.00	0.00	0.00				
			Total no. of individuals	1	84	1	1	1	12,688	19	50,696	25.0
			Relative abundance	0.01	0.66	0.01	0.01	0.01				

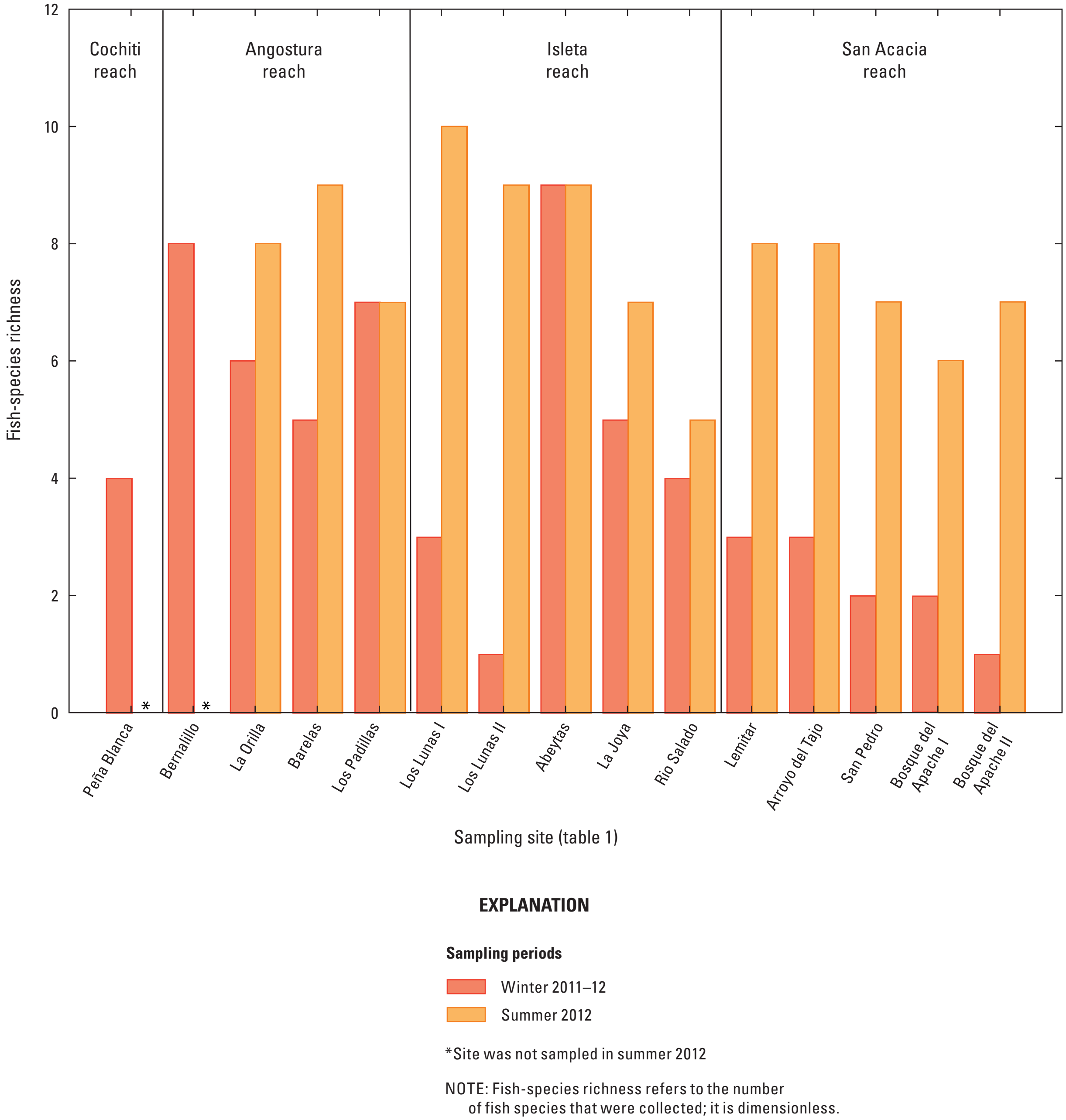

Figure 14. Fish-species richness (number of fish species) collected from 15 sites on the Middle Rio Grande distributed among four reaches of the Middle Rio Grande, New Mexico, winter 2011–12 and summer 2012.

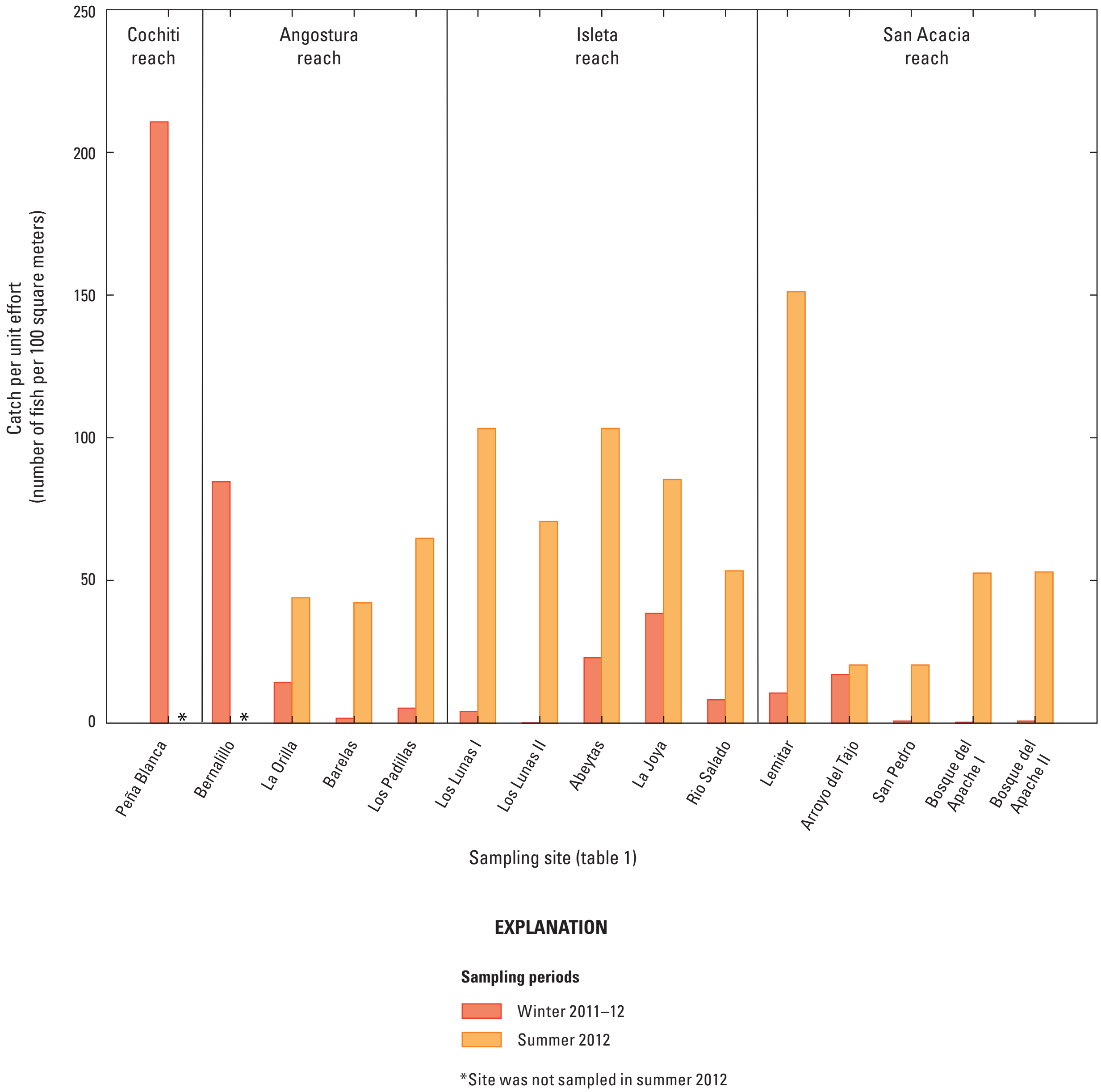

Figure 15. Catch per unit effort from 15 Middle Rio Grande sites distributed among four reaches of the Middle Rio Grande, New Mexico, winter 2011–12 and summer 2012.

was lower in winter 2011–12 relative to summer 2012 at all of the sites that were sampled during both sampling periods. The higher CPUEs during summer 2012 at the majority of sites that were sampled during both sampling periods can be explained, at least in part, by improved sampling efficiency with respect to easier access to specific mesohabitats within the river channel during the summer 2012, when depths were shallower and streamflows were lower compared to winter 2011–12 (fig. 11). One other factor contributing to higher CPUEs in summer 2012 relative to winter 2011–12 is that summer is the reproductive season for most fish species, so their numbers and densities tend to be higher in summer.

Fish Assemblage Composition at the Mesohabitat Scale

The relations between fish assemblage composition (that is, total abundance, which refers to the number of individuals of each species that were collected) and selected environmental variables (physical characteristic data collected at the mesohabitat scale [depth, velocity, and substrate particle size] and mesohabitat types) were explored by using CCA (figs. 16 and 17). Each orange triangle in the CCA represents a species' central tendency related to environmental variables graphically displayed on ordination gradients (axes 1 and 2 in figs. 16 and 17). Species that plotted in close proximity to one another 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 the number of individuals of each species (total abundance) in the CCA models, data were logarithmically transformed (base 10), 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), and species with fewer than 10 individuals were removed from the CCA model output. 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 are collected. As a result, species that are collected infrequently tend to be overemphasized in the CCA model, and downweighting was used to correct this overemphasis (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 8 percent ($p=0.48$) of the variability in the Middle Rio Grande fish assemblage during winter 2011–12 (fig. 16). Environmental variables strongly associated with axis 1 were forewater mesohabitats (0.47), cobbles substrates (0.45), sand substrates (-0.53), and run mesohabitats (-0.50). Environmental variables strongly associated with axis 2 were pool mesohabitats (0.58), riffle mesohabitats (0.45), and depth (-0.40). Among fish associated with axes 1 and 2, western mosquitofish was weakly associated with pool and forewater mesohabitats with clay, silt, and cobble substrates; *Platygobio gracilis* (flathead chub) and *Ictalurus punctatus* (channel catfish) were weakly associated with relatively high velocities (qualitative descriptors are derived from synthetic gradients extracted from CCAs) and run mesohabitats, and Rio Grande silvery minnow were weakly associated with sand substrates, relatively moderate velocities, and relatively shallow depths.

Environmental variables explained 14 percent ($p<0.01$) of the variability in the Middle Rio Grande fish assemblage during summer 2012 (fig. 17). Environmental variables strongly associated with axis 1 were velocity (0.94), run habitats (0.63), sand substrates (0.58), silt and clay substrates (-0.61), backwater habitats (-0.40), and pool habitats (-0.38). Environmental variables strongly associated with axis 2 were gravel substrates (0.50), riffle habitats (0.36), embayment habitats (-0.53), and depth (-0.52). Among fish associated with axes 1 and 2, channel catfish, *Pylodictis olivaris* (flathead catfish), and Rio Grande silvery minnow were associated with run mesohabitats, relatively high velocities, sand substrates, and relatively moderate depths. *Rhinichthys cataractae* (longnose dace) and flathead chub were associated with riffle and flat mesohabitats, relatively high velocities, and sand and gravel substrates at relatively shallow depths. *Cyprinus carpio* (common carp), western mosquitofish, *Pimephales promelas* (fathead minnow), and river carpsucker were associated with backwater and pool mesohabitats, relatively low velocities, silt and clay substrates, and relatively shallow to moderate depths.

Aside from a single pool at the Los Lunas I site in which 7 fish species were collected, no more than 4 fish species were collected in any other mesohabitat of any type during winter 2011–12 (fig. 18*A*). Fish-species richness per mesohabitat ranged from 0 to 4 in riffles, runs, and isolated pools and was slightly less in flats (0 to 3) and margin pools (0 to 2). Mean fish-species richness during winter 2011–12 was highest in pools (1.23), and only two of the mesohabitat types sampled (pools and isolated pools) had a mean fish-species richness of at least 1 (fig. 18*A*). In contrast, during summer 2012, all mesohabitat types except for riffles had mean fish-species richness values greater than 1, and two mesohabitat types (pools and isolated pools) had mean fish-species richness values greater than 2 (fig. 18*B*). The mean fish-species richness was 2.33 in pools and 2.08 in isolated pools during summer 2012 (fig. 18*B*). The ranges of fish-species richness were larger in summer 2012 than in winter 2011–12 for 4 of the 6 mesohabitat types (runs, isolated pools, margin pools, and flats), and the upper end of the ranges for the 2 remaining mesohabitat types (riffles and pools) during winter 2011–12 were each represented by a single mesohabitat and include a riffle at the La Orilla site and the previously mentioned single pool at the Los Lunas I site. The mean fish-species richness was greater in summer 2012 than in winter 2011–12 for each mesohabitat type (fig. 18), and the overall fish-species richness

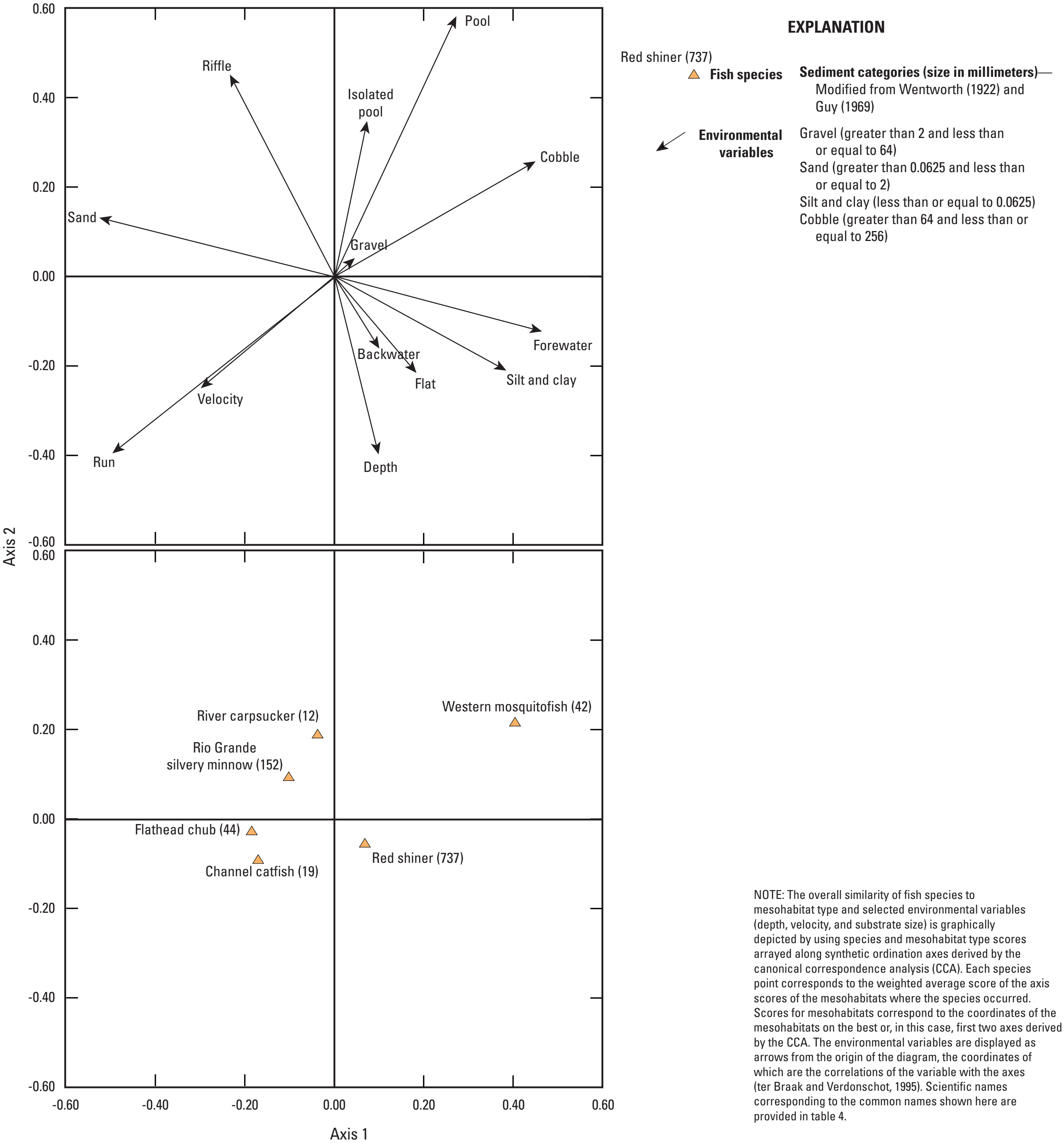

Figure 16. Correlation between fish species and a combination of mesohabitats and environmental variables at 15 sites distributed among four reaches of the Middle Rio Grande, New Mexico, winter 2011–12.

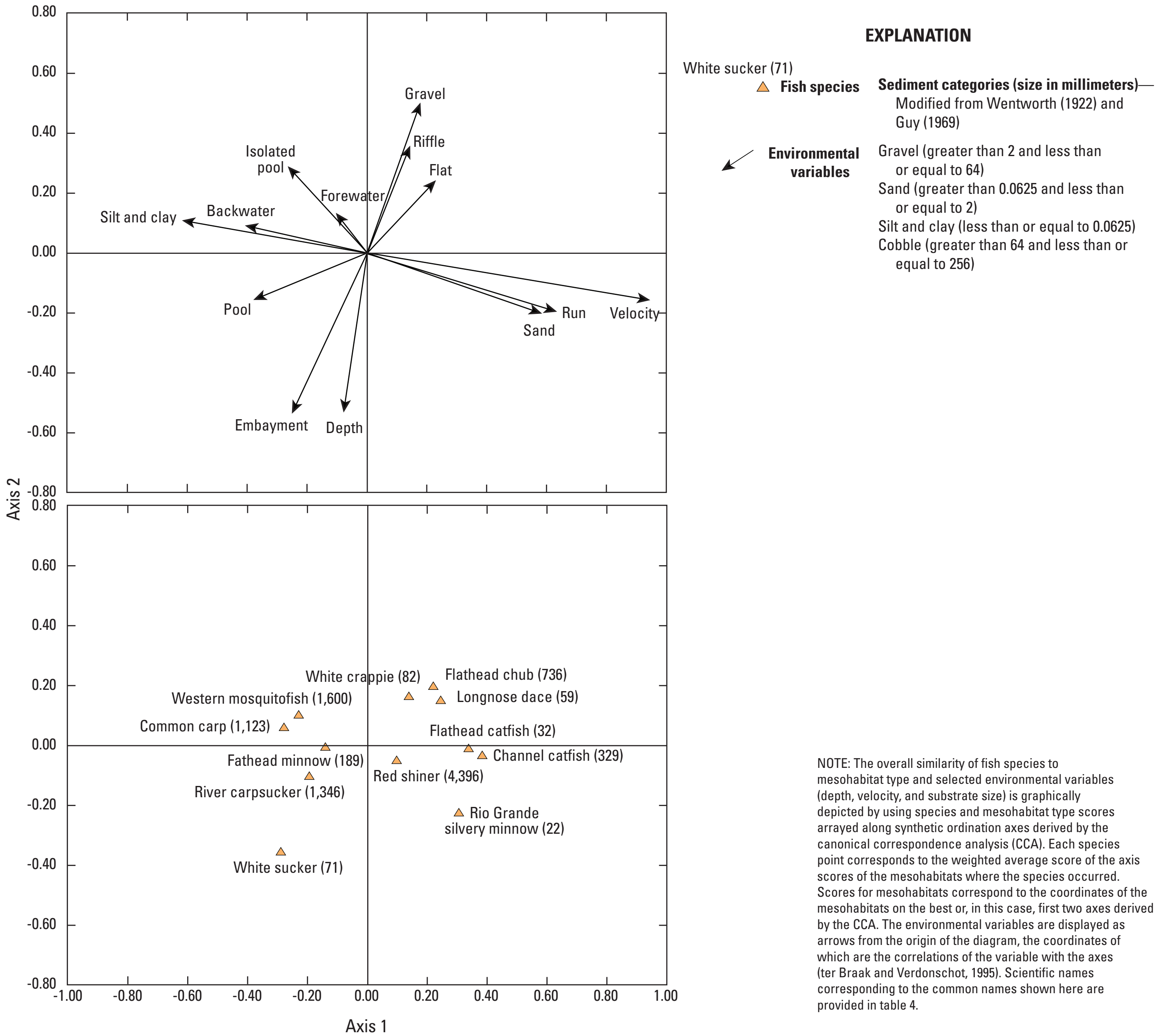

Figure 17. Correlation between fish species and a combination of mesohabitats and environmental variables at 13 sites distributed among four reaches of the Middle Rio Grande, New Mexico, summer 2012.

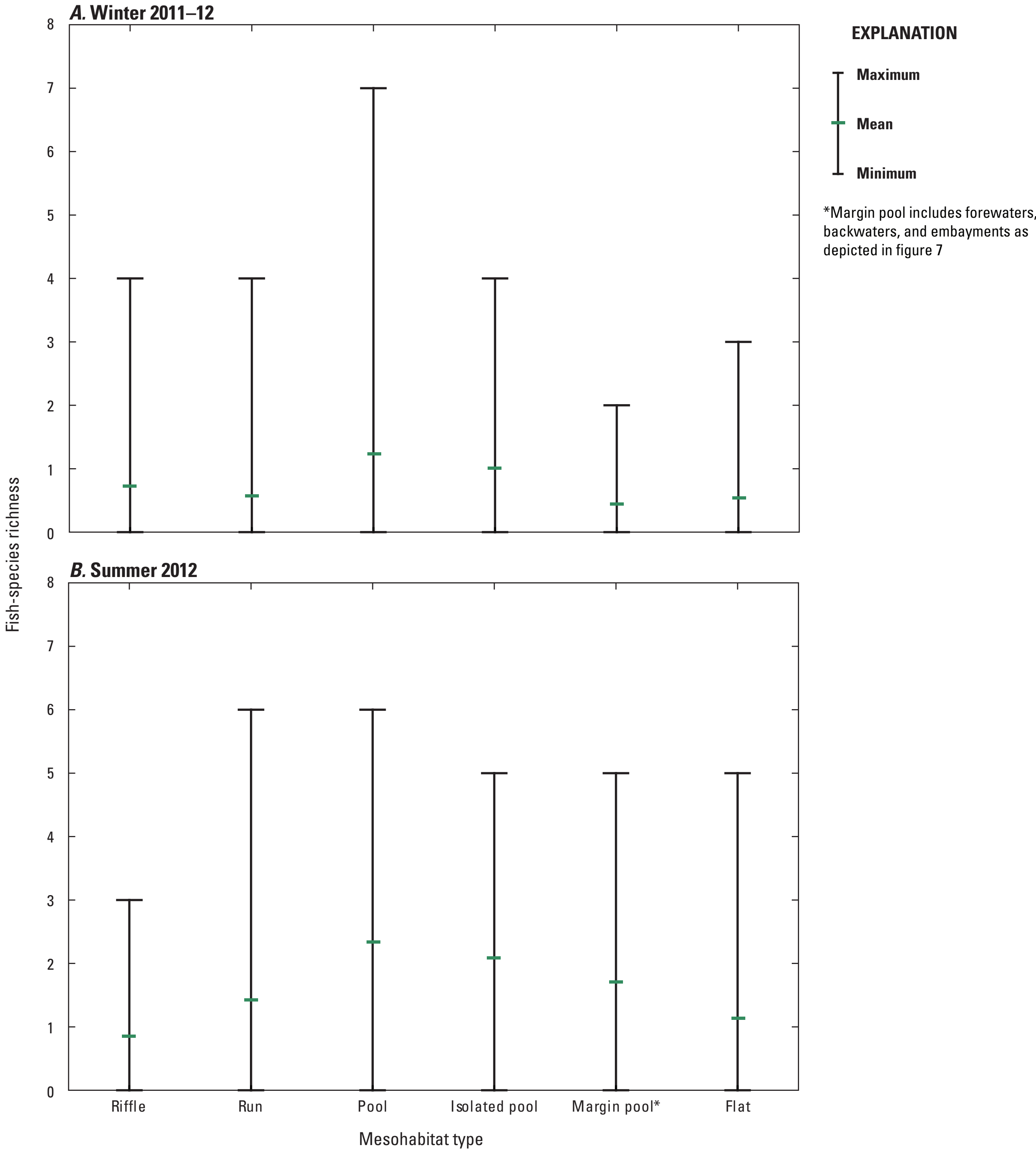

Figure 18. Fish-species richness by mesohabitat type measured at 15 Middle Rio Grande sites distributed among four reaches of the Middle Rio Grande, New Mexico during, *A*, winter 2011–12, and *B*, summer 2012.

across all mesohabitat types was 0.62 during winter 2011–12 compared to 1.49 during summer 2012. In other words, almost one additional fish species, on average, was collected per mesohabitat sampled during summer 2012 compared to winter 2011–12.

Catch per unit effort ranged from zero to less than 380 fish per 100 m^2 in 5 of the 6 mesohabitats (riffles, pools, isolated pools, margin pools, and flats) sampled during winter 2011–12 (fig. 19*A*). Only runs had a maximum CPUE range that exceeded 380 fish per 100 m^2, reaching as high as 1,478 fish per 100 m^2 in a run at the Bernalillo site (fig. 19*A*), but the fact that runs made up 58 percent of the mesohabitats sampled during winter 2011–12 may provide some justification for this disparity in CPUE between the different mesohabitat types. The highest mean CPUE during winter 2011–12 was in isolated pools (54.3 fish per 100 m^2), whereas the lowest was in flats (18.9 fish per 100 m^2) (fig. 19*A*). Ranges in CPUE were higher in summer 2012 relative to winter 2011–12 in each mesohabitat type sampled, reaching as high as 4,333 fish per 100 m^2 in a run at Rio Salado (fig. 19*B*). As in winter 2011–12, the highest mean CPUE during summer 2012 was in isolated pools (233 fish per 100 m^2), whereas the lowest was in flats (29.6 fish per 100 m^2) (fig. 19*B*). Overall mean CPUE per mesohabitat across all mesohabitat types was 29.1 fish per 100 m^2 during winter 2011–12 compared to 85.3 fish per 100 m^2 during summer 2012. In other words, almost three times as many fish, on average, were collected per unit sampling effort during summer 2012 compared to winter 2011–12.

Four species of minnows (red shiner, Rio Grande silvery minnow, fathead minnow, and flathead chub) (referred to hereinafter as the “four minnow species of interest”) were selected to compare preferred mesohabitat characteristics because all are small-bodied minnows and because more than 200 individuals (a sufficient sample size for evaluating preferences for mesohabitat physical characteristics) of each of these species were collected. Comparisons were made with regards to depth, velocity, and dissolved oxygen concentration among the Angostura, Isleta, and San Acacia reaches. Depth, velocity, and dissolved oxygen values used in this comparison were from measurements collected from the center of each seine haul. The 163 Rio Grande silvery minnow individuals collected during winter 2011–12 were distributed as 43 individuals from the Angostura reach, 19 individuals from the Isleta reach, and 101 individuals from the San Acacia reach. The 22 Rio Grande silvery minnow individuals collected during summer 2012 were distributed as 1 individual from the Angostura reach, 9 individuals from the Isleta reach, and 12 individuals from the San Acacia reach. The number of individuals of the different species shown above each of the box plots in figures 20–22 does not necessarily match the number of individuals of those same species listed in table 4 and in the geodatabase; this is because depth, velocity, and dissolved oxygen data were not collected at all locations where fish were collected. If depth, velocity, and dissolved oxygen data could not be linked to a fish, then that fish could not be included in figures 20–22.

During winter 2011–12, red shiner were collected across the largest range of depths (0.02–4.31 ft) of the four minnow species of interest across the study area, and fathead minnow were collected in the narrowest range of depths (0.34–0.70 ft), most likely the result of the comparatively small sample size (n=8) in winter 2011–12 for this species (fig. 20). The broad range of depths associated with the collections of red shiner are probably the result of both the large sample size for this species (n=626 when associated depth and velocity data were also collected) in conjunction with the fact that red shiners are generalists (U.S. Geological Survey, 2002), which means that they can thrive in a wide array of environmental conditions. The largest ranges in depths for each of the four minnow species of interest occurred in the Isleta reach, with the exception of the fathead minnow, which had only a single individual collected in the Isleta reach during winter 2011–12. Red shiner were collected across the largest range of depths (0.05–3.4 ft) of the four minnow species of interest during summer 2012. Rio Grande silvery minnow were collected in the narrowest range of depths (0.30–2.1 ft), most likely as a result of the comparatively small sample size (n=22) in the summer of 2012 for this species (fig. 20). As in winter 2011–12, the broad range of depths associated with the collections of red shiner are probably the result of a large sample size (n=4,396) for this species and its status as a generalist.

During winter 2011–12, red shiner were collected in the broadest range of velocities (0.0–4.31 ft/s) across the study area of the four minnow species of interest (fig. 21). Only the magnitudes of velocity measurements were considered in terms of fish preferences with respect to velocity (fig. 21); Rio Grande silvery minnow had the narrowest range (0.0–3.18 ft/s). During summer 2012, the flathead chub was collected in the largest range of velocities (0.0–3.44 ft/s) across the study area (not including the Peña Blanca and Bernalillo sites) of the four minnow species of interest (fig. 21). Rio Grande silvery minnow had the narrowest range (0.02–1.51 ft/s), again most likely the result of the small sample size for this species in the summer of 2012. Median velocity preferences were highest for all four minnow species of interest in the Angostura reach relative to the Isleta and San Acacia reaches.

The range of velocities associated with the collection of Rio Grande silvery minnow in this study is at the upper end of the distribution of velocities for this species, as determined in previous studies (Dudley and Platania, 1996, 1997). More than 95 percent of Rio Grande silvery minnows collected as part of the first of these Dudley and Platania studies (1996) were collected at velocities less than or equal to 1.00 ft^3/s (fig. 21*G*), and approximately 95 percent of Rio Grande silvery minnows collected as part of the second of these Dudley and Platania studies (1997) were collected at velocities less than or equal to 0.67 ft^3/s (fig. 21*H*). In contrast, the overall median velocity at which Rio Grande silvery minnows were collected as part of this investigation was 1.01 ft^3/s. The median velocity at which Rio Grande silvery minnows were collected in winter 2011–12 was 1.21 ft^3/s, whereas the median velocity in summer 2012 was 0.91 ft^3/s.

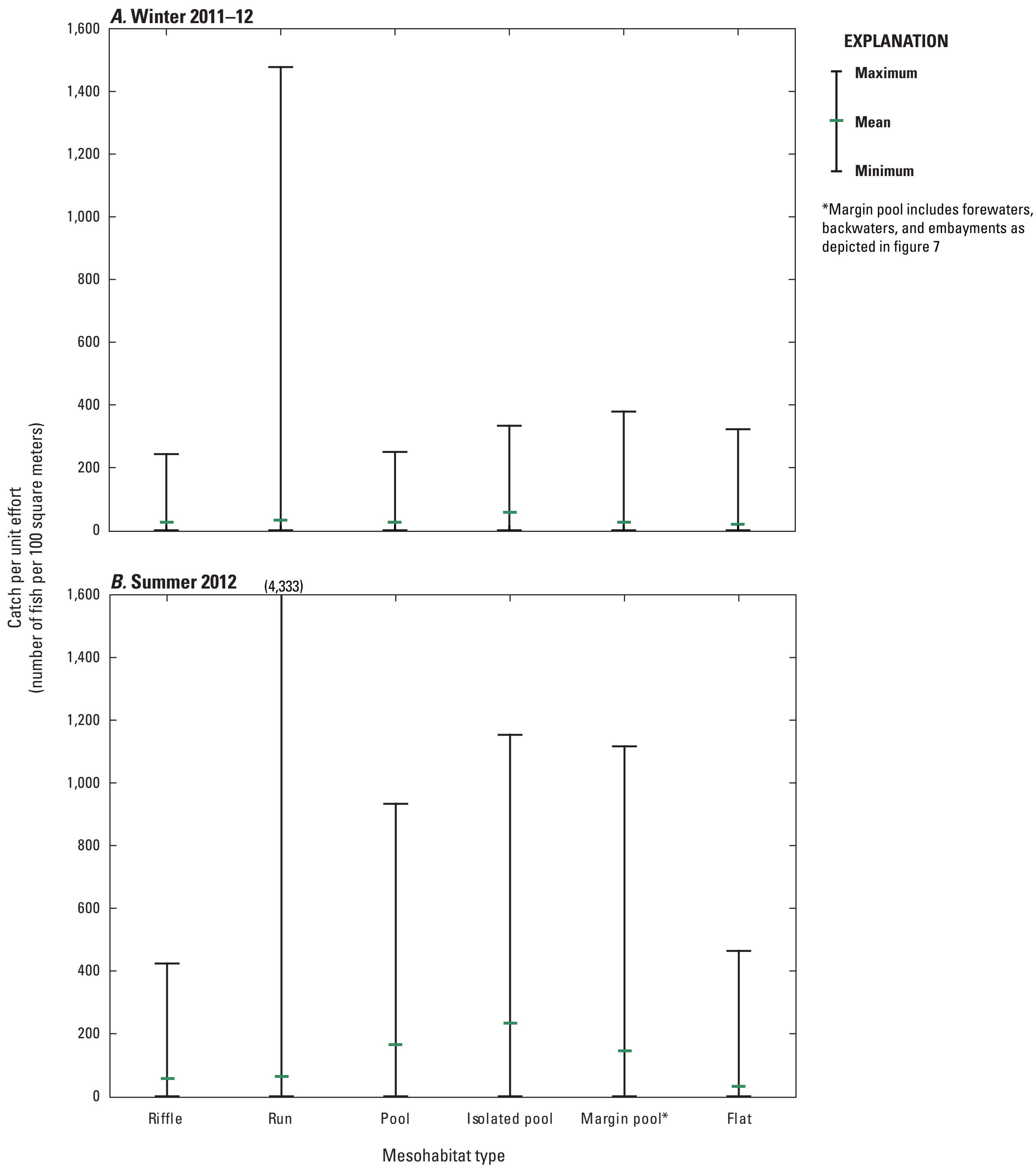

Figure 19. Catch per unit effort by mesohabitat type from 15 Middle Rio Grande sites distributed among four reaches of the Middle Rio Grande, New Mexico, *A*, winter 2011–12, and *B*, summer 2012.

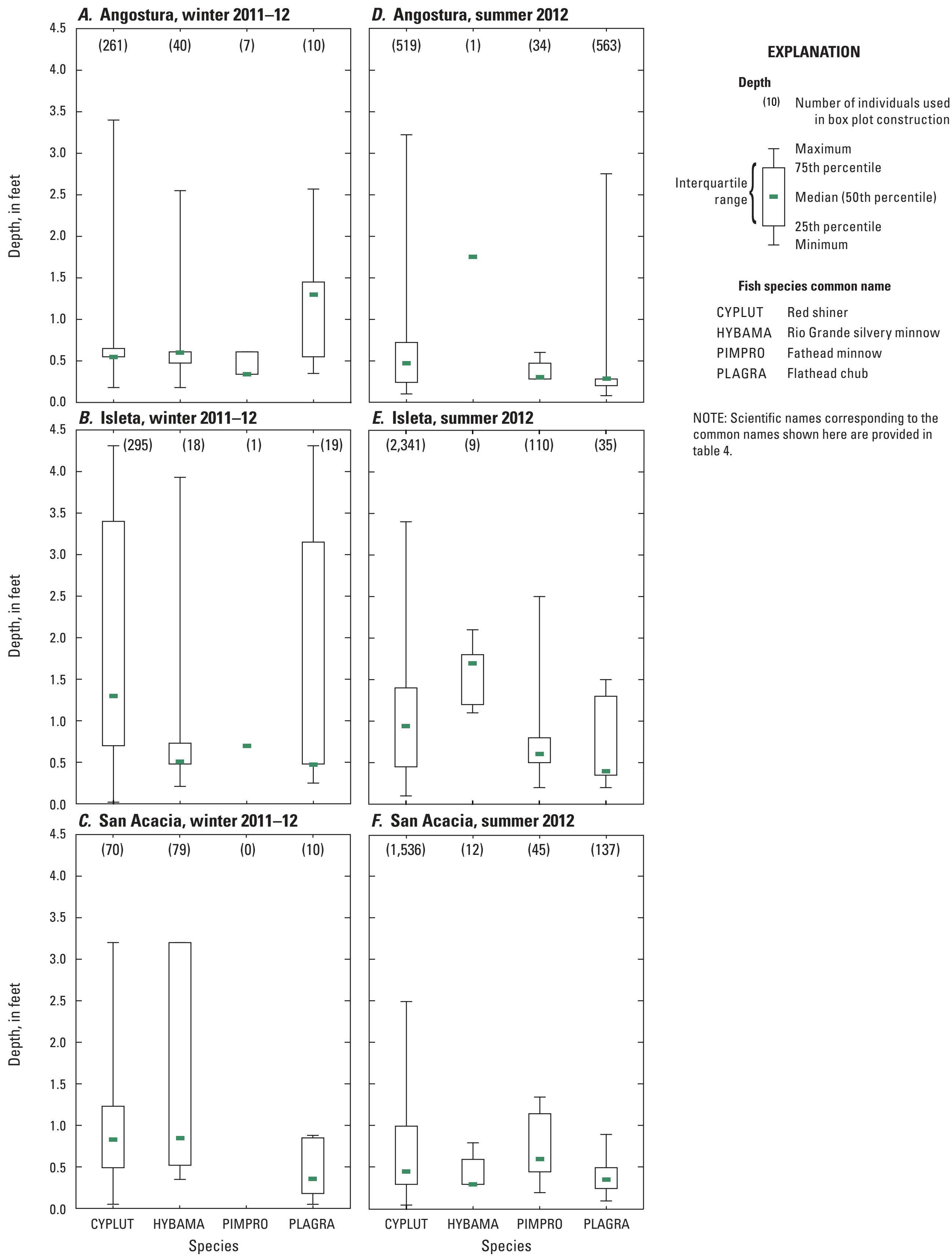

Figure 20. Depths associated with the collection of selected minnow species from three reaches of the Middle Rio Grande, New Mexico, during winter 2011–12 *A*, Angostura; *B*, Isleta; and *C*, San Acacia; and during summer 2012 *D*, Angostura; *E*, Isleta; and *F*, San Acacia.

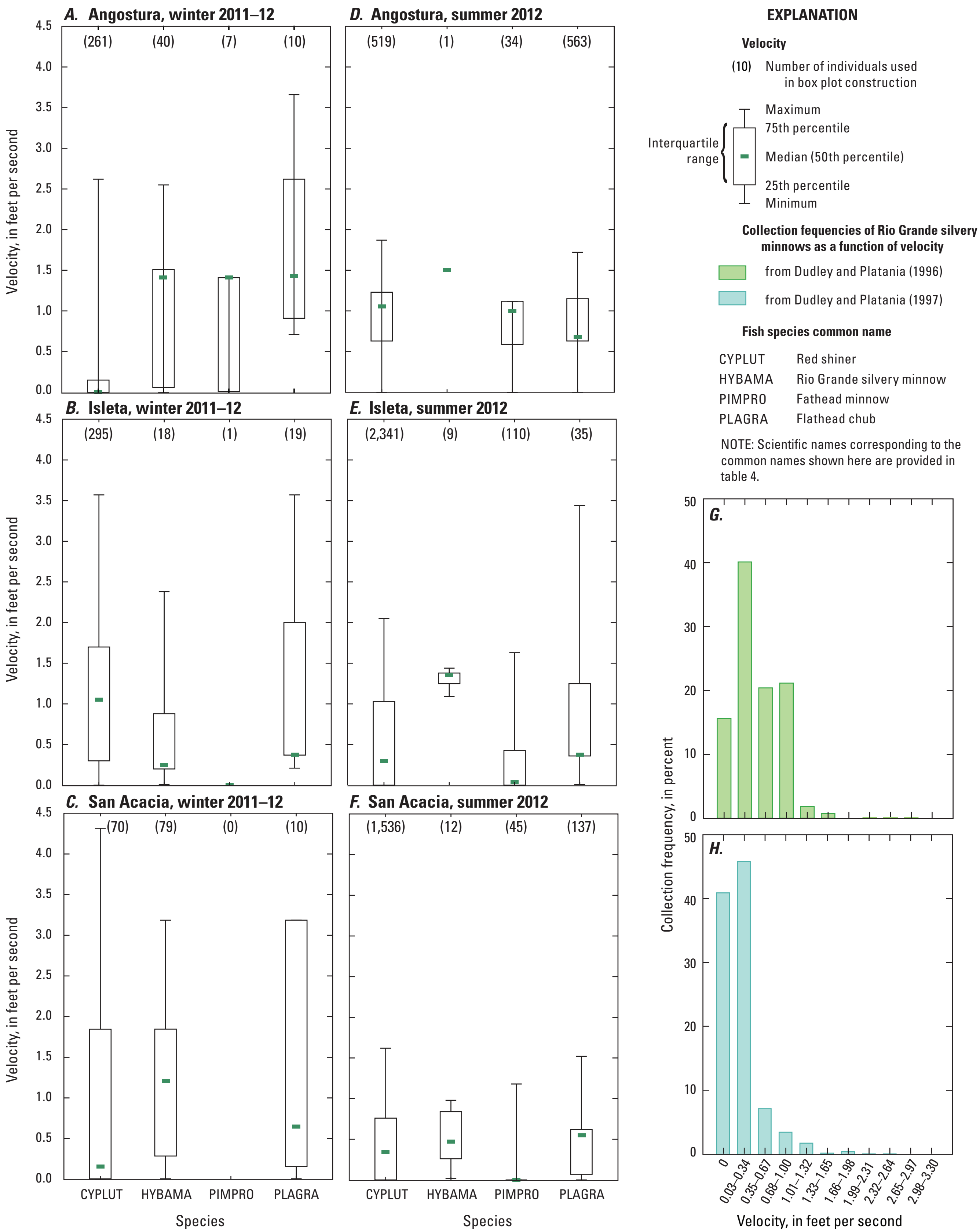

Figure 21. Velocities associated with the collection of selected minnow species from three reaches of the Middle Rio Grande, New Mexico, during winter 2011-12, *A*, Angostura; *B*, Isleta; and *C*, San Acacia and during summer 2012; *D*, Angostura; *E*, Isleta; and *F*, San Acacia; and collection frequencies of Rio Grande silvery minnows as a function of velocity from *G*, Dudley and Platania (1996); and *H*, Dudley and Platania (1997).

Like depth and velocity, dissolved oxygen was collected at the center of each seine haul at the midpoint of the water column. Median dissolved oxygen concentrations for the four minnow species of interest exhibited a general upward pattern in a downstream direction from the Angostura reach to the San Acacia reach (fig. 22). Median dissolved oxygen concentrations for the four minnow species of interest ranged from 6.32 to 7.08 mg/L in the Angostura reach, from 7.14 to 8.83 mg/L in the Isleta reach, and from 7.72 to 9.05 mg/L in the San Acacia reach. This is most likely the result of the comparatively large number of shallow, low-velocity mesohabitats including margin pools and isolated pools in the San Acacia reach that contained a large amount of algae when the sites were sampled in summer 2012. Although the ranges of dissolved oxygen concentrations associated with the collection of red shiner and Rio Grande silvery minnow were quite different because red shiners were more widespread, median dissolved oxygen concentrations were similar (particularly in the Isleta and San Acacia reaches) for both species on a reach basis. It should also be noted that because the water-quality monitoring methodology did not capture the diel minima and maxima, it was not possible to accurately quantify the species-specific range of preferred dissolved oxygen concentrations.

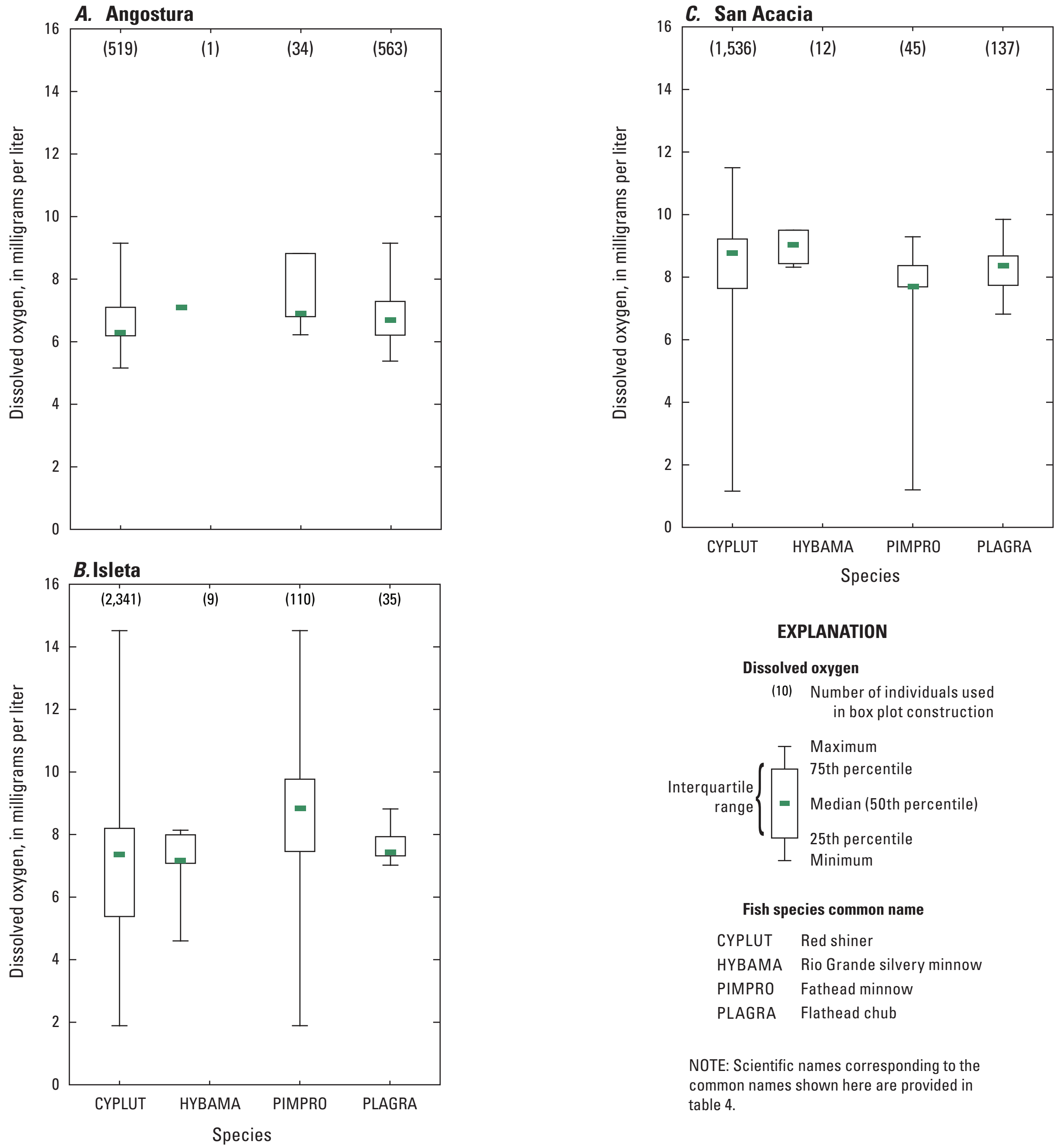

Figure 22. Dissolved oxygen concentrations associated with the collection of selected minnow species during summer 2012 from three reaches of the Middle Rio Grande, New Mexico, *A*, Angostura, *B*, Isleta, and *C*, San Acacia.

Summary

In winter 2011–12 and summer 2012, the U.S. Geological Survey (USGS), in cooperation with the U.S. Army Corps of Engineers, Albuquerque District and the U.S. Fish and Wildlife Service New Mexico Fish and Wildlife Conservation Office in Albuquerque, N. Mex., evaluated the physical characteristics and fish assemblage composition of available mesohabitats over a range of streamflows at 15 sites on the Middle Rio Grande in New Mexico. The fish assemblage of the Middle Rio Grande includes several minnow species adapted to hydrologically variable but seasonably predictable rivers, including the *Hyboganthus amarus* (Rio Grande silvery minnow). Gaining a better understanding of habitat usage by the Rio Grande silvery minnow, a federally listed endangered species, was the impetus for studying physical characteristics and fish assemblages in the Middle Rio Grande during different streamflow conditions. Data were collected at all 15 sites during winter 2011–12 (moderate streamflow), and a subset was collected at the 13 most downstream sites in summer 2012 (low streamflow). Sites were grouped into four river reaches separated by diversion dams listed in downstream order (names of the diversion dams are followed by short names of the sites nearest each dam in parentheses, listed in downstream order): (1) Cochiti (Peña Blanca), (2) Angostura (Bernalillo, La Orilla, Barelas, Los Padillas), (3) Isleta (Los Lunas I, Los Lunas II, Abeytas, La Joya, Rio Salado), and (4) San Acacia (Lemitar, Arroyo del Tajo, San Pedro, Bosque del Apache I, and Bosque del Apache II). Stream habitat was mapped in the field by using a geographic information system in conjunction with a Global Positioning System. Fish assemblage was determined during both streamflow regimes, and fish were collected by seining in each mesohabitat where physical characteristic data (depth, velocity, dominant substrate type and size, and percent embeddedness) and water-quality properties (temperature, dissolved oxygen, specific conductance, and pH; during summer 2012 only) were measured.

Measured depths and velocities varied greatly by mesohabitat type, site, and sampling period (winter 2011–12 or summer 2012). When an area-weighting factor was applied to the depth and velocity, the sites that were investigated in both winter 2011–12 and summer 2012 tended to have smaller mean depths and mean velocities during summer 2012, when discharges tended to be lower, compared to winter 2011–12. Discharge measurements that were made in the field ranged from 552 cubic feet per second (ft^3/s) at Peña Blanca on November 11, 2011, to 991 ft^3/s at La Joya on November 30, 2011, in winter 2011–12, and ranged from 4.13 ft^3/s at Lemitar on August 7, 2012, to 430 ft^3/s at La Orilla on August 13, 2012. Streambed sediments at Peña Blanca and Bernalillo were predominantly coarse gravels and cobble. Downstream from these two sites, the Rio Grande is characterized by a broad, low-gradient channel dominated by smaller grained bed materials, primarily sand with some silt and clay.

Water-quality properties were only collected during summer 2012, when low-streamflow conditions existed and water-quality properties were thought to be potentially most limiting to aquatic life. Area-weighted mean water temperatures tended to be higher at the sites that were sampled in August (25.57 degrees Celsius [°C]) compared to June (24.61 °C). The highest area-weighted mean water temperature at a given site (29.03 °C) was measured at the Lemitar site on August 7, 2012, coincident with the lowest measured discharge (4.13 ft^3/s). Area-weighted mean dissolved oxygen concentrations tended to be lower in August (7.46 milligrams per liter [mg/L]) compared to June (8.33 mg/L). The highest area-weighted mean dissolved oxygen concentration (9.13 mg/L) was measured at the Lemitar site on August 7, 2012, and the lowest area-weighted mean dissolved oxygen concentration (6.23 mg/L) was measured at the Los Padillas site on August 10, 2012. Specific conductance ranged from 175 microsiemens per centimeter [µs/cm] at 25 °C in an isolated pool at the La Orilla site to 2,246 µs/cm at 25 °C in an isolated pool at the La Joya site. Elevated specific conductance in isolated pools may be caused by either the evaporative concentration of solutes or by the mixing of less saline surface water with more saline groundwater from the hyporheic zone. Area-weighted specific conductance in the sites upstream from La Joya did not exceed 400 µs/cm at 25 °C, whereas the area-weighted mean specific conductance at La Joya (837 µs/cm at 25 °C), Rio Salado (857 µs/cm at 25 °C), and Lemitar (1,300 µs/cm at 25 °C) were all well above the average of the area-weighted means for the 10 remaining sites (433 µs/cm at 25 °C). The pH ranged from 6.5 in a backwater at the La Orilla site to 9.72 in an embayment at the Los Lunas I site. Lower area-weighted mean pH values were measured at the three sites in and near Albuquerque (La Orilla [7.98], Barelas [8.08], and Los Padillas [7.81]) compared to any of the 10 remaining sites, which had an overall mean pH of 8.44.

Nineteen species of fish were collected among the 15 sites and four reaches over both sampling periods; 10 of these 19 species are introduced. Fish-species richness (total number of fish species collected at each site during each sampling event) among sites that were sampled during both sampling periods ranged from 6 at Rio Salado to 12 at La Orilla. Fish were most abundant at the Lemitar site (1,786 individuals) and least abundant at the San Pedro site (275 individuals). The native *Cyprinella lutrensis* (red shiner) was the most abundant species collected among all of the sites, accounting for about 42 percent of fish collected. Fish-species richness and catch per unit effort (CPUE) were higher (or equivalent) at all sites during summer 2012 compared to winter 2011–12.

The relations between fish assemblage composition (that is, total abundance, which refers to the number of individuals of each species that were collected) and selected environmental variables (physical characteristic data collected at the mesohabitat scale [depth, velocity, and substrate particle size], and mesohabitat types) were explored by using canonical correspondence analysis. Environmental variables explained 8 percent (p=0.48) of the variability in the Middle

Rio Grande fish assemblage during winter 2011–12, and Rio Grande silvery minnow were weakly associated with sand substrates, relatively moderate velocities (qualitative descriptors are derived from synthetic gradients extracted from CCAs), and relatively shallow depths. Environmental variables explained 14 percent ($p<0.01$) of the variability in the Middle Rio Grande fish assemblage during summer 2012, when Rio Grande silvery minnow were associated with run mesohabitats, relatively high velocities, sand substrates, and relatively moderate depths.

Aside from a single pool at the Los Lunas I site in which 7 fish species were collected, no more than 4 fish species were collected in any other mesohabitat of any type during winter 2011–12. The mean fish-species richness was greater in summer 2012 than in winter 2011–12 for each mesohabitat type, and the overall fish-species richness across all mesohabitat types was 0.62 during winter 2011–12 compared to 1.49 during summer 2012. In other words, almost one additional fish species, on average, was collected per mesohabitat sampled during summer 2012 compared to winter 2011–12.

The highest mean CPUE during winter 2011–12 was in isolated pools (54.3 fish per 100 square meters [m^2]), whereas the lowest was in flats (18.9 fish per 100 m^2). Ranges in CPUE were higher in summer 2012 relative to winter 2011–12 in each mesohabitat type sampled, reaching as high as 4,333 fish per 100 m^2 in a run at Rio Salado. As in winter 2011–12, the highest mean CPUE during summer 2012 was in isolated pools (233 fish per 100 m^2), whereas the lowest was in flats (29.6 fish per 100 m^2). Overall mean CPUE per mesohabitat across all mesohabitat types was 29.1 fish per 100 m^2 during winter 2011–12 compared to 85.3 fish per 100 m^2 during summer 2012. In other words, almost three times as many fish, on average, were collected per unit sampling effort during summer 2012 compared to winter 2011–12.

Four species of minnows (red shiner, Rio Grande silvery minnow, *Pimephales promelas* [fathead minnow], and *Platygobio gracilis* [flathead chub]) were selected to compare preferred mesohabitat characteristics because all are small-bodied minnows and because more than 200 individuals of each these species were collected. Red shiner were collected across the largest range of depths in both winter 2011–12 (0.02–4.31 feet [ft]) and summer 2012 (0.05–3.4 ft), as well as the largest range of velocities (0.0–4.31 feet per second [ft/s]) during winter 2011–12 among the four minnow species of interest. Rio Grande silvery minnow occurred in the narrowest range of depths (0.30–2.1 ft) during summer 2012, as well as the narrowest range of velocities in both winter 2011–12 (0.0–3.18 ft/s) and summer 2012 (0.02–1.51 ft/s). Median dissolved oxygen concentrations for the four minnow species of interest exhibited a general upward pattern in a downstream direction from the Angostura reach to the San Acacia reach, which is most likely the result of the comparatively large number of shallow, low-velocity mesohabitats including margin pools and isolated pools in the San Acacia reach that contained a large amount of algae when the sites were sampled in summer 2012. Although the ranges of dissolved oxygen concentrations associated with the collection of red shiner and Rio Grande silvery minnow were quite different because red shiners were more widespread, median dissolved oxygen concentrations were similar (particularly in the Isleta and San Acacia reaches) for both species on a reach basis.

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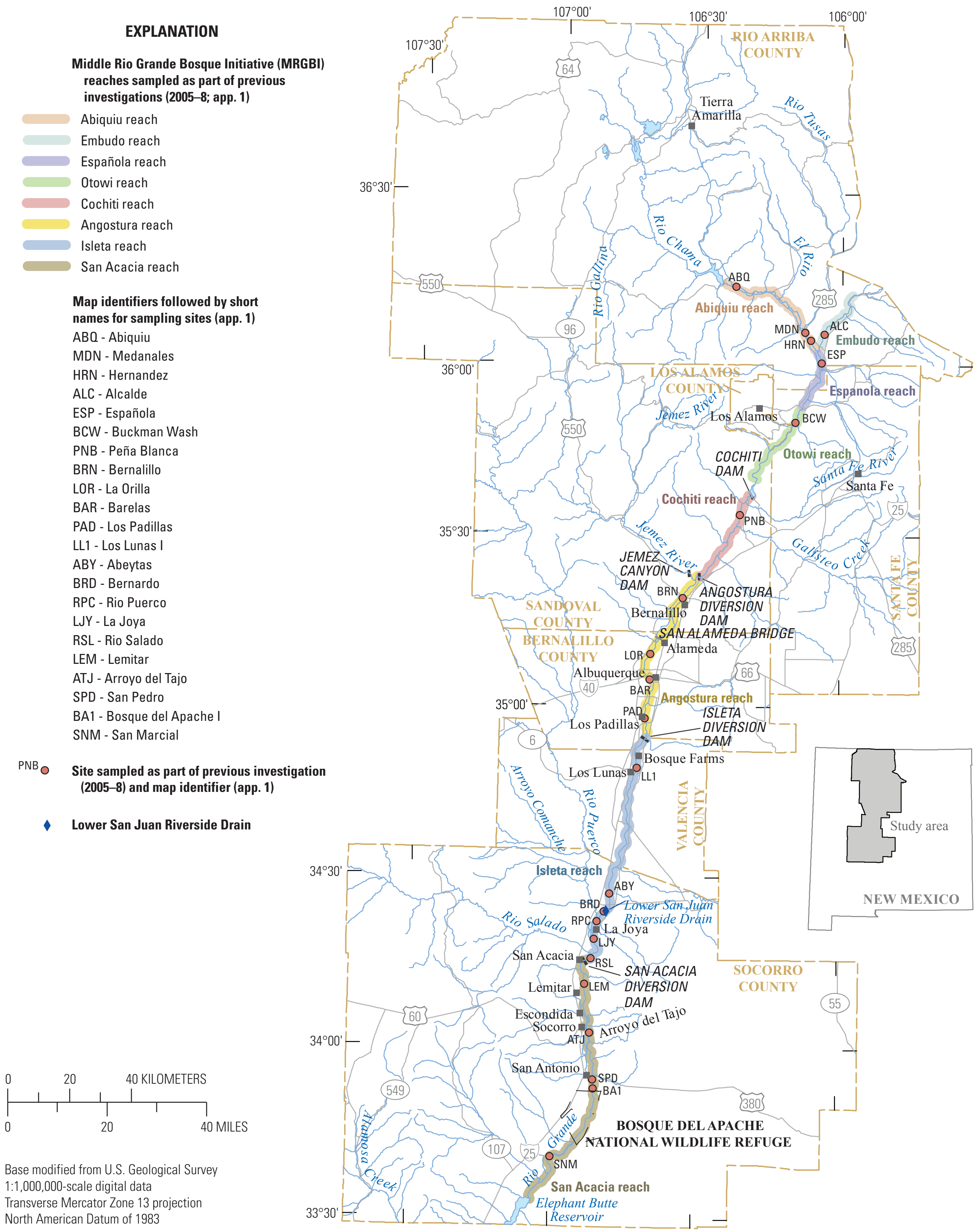
Appendixes 1–4

Appendix 1. Study sites from previous investigations in the Middle Rio Grande, New Mexico 2005–8 (Middle Rio Grande Bosque Initiative reach names are from U.S. Fish and Wildlife Service, 2014).

[MRGBI, Middle Rio Grande Bosque Initiative; USGS, U.S. Geological Survey; USACE, U.S. Army Corps of Engineers; --, no data were collected during indicated time period; H, hydraulic measurements (depth and velocity) were made; HM, hydraulic measurements (depth and velocity) were made in conjunction with mesohabitat features; IFIM, systematic hydraulic measurements (depth and velocity) were calibrated to flow]

MRGBI reach names	USGS station number	USGS station name	Short name	Map identifier (fig. 2)	River mile[1]	Previous investigations: Remshardt and Tashjian (2003)	Buntjer and Remshardt (2005)	USACE and others (2007)	Torres and others (2008)	Bovee and others (2008)
Abiquiu	--	Rio Chama downstream from Abiquiu Dam	Abiquiu	ABQ	271.6 + 29.6	--	--	H	--	--
Abiquiu	--	Rio Chama upstream from Highway 285 bridge	Medanales	MDN	271.6 + 5.3	--	H	H	--	--
Abiquiu	--	Rio Chama upstream from Highway 233 bridge	Hernandez	HRN	271.6 + 3.3	--	H	--	--	--
Embudo	--	Rio Grande upstream from Española	Alcalde	ALC	280.6	--	H	--	--	--
Española	--	Rio Grande at Española	Española	ESP	269.0	--	H	--	--	--
Otowi	--	Rio Grande in White Rock Canyon	Buckman Wash	BCW	254.0	--	H	--	--	--
Cochiti	353330106213500	Rio Grande near Peña Blanca, N. Mex.	Peña Blanca	PNB	227.5	--	--	H	HM	--
Angostura	351848106333400	Rio Grande downstream from Highway 550 at Bernalillo, N. Mex.	Bernalillo	BRN	203.6	--	--	H	--	--
Angostura	350859106402600	Rio Grande upstream from Montano Road northwest at Albuquerque, N. Mex.	La Orilla	LOR	189.0	HM	--	--	--	--
Angostura	350432106400500	Rio Grande upstream from Highway 314 at Albuquerque, N. Mex.	Barelas	BAR	183.0	HM	--	H	--	--
Angostura	345732106410800	Rio Grande upstream from Interstate Highway 25 near Los Padillas, N. Mex.	Los Padillas	PAD	173.0	HM	--	--	--	--
Isleta	344852106424200	Rio Grande upstream from Highway 6 at Los Lunas, N. Mex.	Los Lunas I	LL1	162.5	HM	--	--	--	--
Isleta	342644106481300	Rio Grande upstream from Highway 60 near Contreras, N. Mex.	Abeytas	ABY	133.0	HM	--	--	--	--
Isleta	--	Rio Grande downstream from Highway 60 Bridge	Bernardo	BRD	130.4	--	--	H	--	--
Isleta	--	Rio Grande downstream from San Juan Drain and Rio Puerco	Rio Puerco	RPC	126.0	--	--	--	--	IFIM
Isleta	341842106511100	Rio Grande near La Joya, N. Mex.	La Joya	LJY	122.0	HM	--	--	--	IFIM
Isleta	341542106520700	Rio Grande downstream from Arroyo Rosa de Castillo, San Acacia, N. Mex.	Rio Salado	RSL	117.5	--	--	--	--	IFIM
San Acacia	341044106530300	Rio Grande near Lemitar, N. Mex.	Lemitar	LEM	109.0	HM	--	--	--	--
San Acacia	340215106515500	Rio Grande downstream from Arroyo del Tajo near Socorro, N. Mex.	Arroyo del Tajo	ATJ	97.0	HM	--	--	--	--
San Acacia	335403106505800	Rio Grande downstream from Highway 380 near San Antonio, N. Mex.	San Pedro	SPD	86.5	HM	--	--	--	--
San Acacia	335229106505800	Rio Grande north of Bosque del Apache, San Antonio, N. Mex.	Bosque del Apache I	BA1	84.5	HM	--	H	--	--
San Acacia	--	Rio Grande below San Marcial Railroad Bridge	San Marcial	SNM	68.6	--	--	H	--	--

[1]Confluence of Rio Grande and Rio Chama is at river mile 271.6; number of miles following "+" correspond to the distance upstream from the confluence along the Rio Chama.



Appendix 2. Map of sites from previous investigations in the Middle Rio Grande, New Mexico, 2005–8.

Appendix 3. Data tables and definitions of data elements associated with the project geodatabase.

tbl_discharge – Discharge data

Field code	Field name	Definition	Codes (if applicable)
site_nm	Site name	Long site name for sampling location	Rio Salado Arroyo del Tajo La Joya Abeytas Lemitar San Pedro La Orilla Los Padillas Barelas Los Lunas 2 Los Lunas 1 Bernalillo Peña Blanca Bosque del Apache 2 Bosque del Apache 1
date_va	Date value	Discharge measurement date	
time_va	Time value	Discharge measurement time	
discharge_cfs_va	Discharge value	Discharge value in cubic feet per second	

tbl_fish – Fish assemblage data

date_va	Date value	Fish collection date	
site_nm	Site name	Long site name for sampling location	Rio Salado Arroyo del Tajo La Joya Abeytas Lemitar San Pedro La Orilla Los Padillas Barelas Los Lunas 2 Los Lunas 1 Bernalillo Peña Blanca Bosque del Apache 2 Bosque del Apache 1
site_abv	Site abbreviation	Site abbreviation for sampling location	RSL – Rio Salado ATJ – Arroyo del Tajo LJY – La Joya ABY – Abeytas LEM – Lemitar SPD – San Pedro LOR – La Orilla PAD – Los Padillas BAR – Barelas LL2 – Los Lunas 2 LL1 – Los Lunas 1 BRN – Bernalillo PNB – Peña Blanca BA2 – Bosque del Apache 2 BA1 – Bosque del Apache 1

tbl_fish – Fish assemblage data—Continued

date_va	Date value	Fish collection date	
sample_id	Sample identifier	Sampling event identifier	1 – November or December 2011 2 – June or August 2012 3 – February 2012
mesohab_id	Mesohabitat identifier	Mesohabitat identifier	
mesohab_com	Mesohabitat comments	Mesohabitat comments	
unique_id	Unique identifier	Unique identifier composed of site_abv+sample_id+mesohab_id	
HYBAMA	*Hybognathus amarus*	Fish count for species	
HYBAMA_SL	*Hybognathus amarus* standard length	Standard length(s) for Rio Grande silvery minnow(s)	
CYPCAR	*Cyprinus carpio*	Fish count for species	
CYPLUT	*Cyprinella lutrensis*	Fish count for species	
CARCAR	*Carpiodes carpio*	Fish count for species	
RHICAT	*Rhinichthys cataractae*	Fish count for species	
CYCELO	*Cycleptus elongatus*	Fish count for species	
CATCOM	*Catostomus commersonii*	Fish count for species	
AMEMEL	*Ameiurus melas*	Fish count for species	
ICTPUN	*Ictalurus punctatus*	Fish count for species	
PYLOLI	*Pylodictis olivaris*	Fish count for species	
PLAGRA	*Platygobio gracilis*	Fish count for species	
AMENAT	*Ameiurus natalis*	Fish count for species	
GAMAFF	*Gambusia affinis*	Fish count for species	
DORCEP	*Dorosoma cepedianum*	Fish count for species	
LEPCYA	*Lepomis cyanellus*	Fish count for species	
POMANN	*Pomoxis annularis*	Fish count for species	
PIMPRO	*Pimephales promelas*	Fish count for species	
MORCHR	*Morone chrysops*	Fish count for species	
MICSAL	*Micropterus salmoides*	Fish count for species	
LEPMAC	*Lepomis macrochirus*	Fish count for species	
Unknown	Unknown species	Fish count for unknown species	
Total_fish	Total fish	Total number of fish collected	

tbl_fish_habitat – Fish habitat data

Field code	Field name	Definition	Codes (if applicable)
date_va	Date value	Fish collection date	
site_nm	Site name	Long site name for sampling location	Rio Salado Arroyo del Tajo La Joya Abeytas Lemitar San Pedro La Orilla Los Padillas Barelas Los Lunas 2 Los Lunas 1 Bernalillo Peña Blanca Bosque del Apache 2 Bosque del Apache 1
site_abv	Site abbreviation	Site abbreviation for sampling location	RSL – Rio Salado ATJ – Arroyo del Tajo LJY – La Joya ABY – Abeytas LEM – Lemitar SPD – San Pedro LOR – La Orilla PAD – Los Padillas BAR – Barelas LL2 – Los Lunas 2 LL1 – Los Lunas 1 BRN – Bernalillo PNB – Peña Blanca BA2 – Bosque del Apache 2 BA1 – Bosque del Apache 1
sample_id	Sample identifier	Sampling event identifier	1 – November or December 2011 2 – June or August 2012 3 – February 2012
mesohab_id	Mesohabitat identifier	Mesohabitat identifier	
mesohab_com	Mesohabitat comments	Mesohabitat comments	
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 7 – backwater 8 – isolated pool 10 – run 13 – flat 14 – embayment 15 – forewater
mesohabitat_cd	Mesohabitat code	Mesohabitat class as defined by the fish crew	
lat_va	Latitude	Latitude in decimal degrees	
lon_va	Longitude	Longitude in decimal degrees	
seine_lg	Seine length	Length of seine haul, in meters	
depth_va	Depth value	Water depth, in feet	
velocity_va	Velocity 1	Water velocity, in feet per second	
velocity2_va	Velocity 2	Water velocity, in feet per second	
temp_C	Temperature	Temperature, in degrees Celsius	
cond_µS	Specific conductance	Specific conductance, in microsiemens per centimeter	
DO_mL	Dissolved oxygen	Dissolved oxygen concentration, in milligrams per liter	
pH	pH	pH value measured using the pH scale	
comments	Comments	Comments	

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	
transect_id	Transect identifier	Transect identifier for each mesohabitat sampled (1–5 transects per unit)	
dom_sub_cd	Dominant substrate code	Dominant substrate type	CB – cobble FN – fines GC – gravel coarse GF – gravel fine HP – hardpan NA – not applicable NR – not recorded SA – sand
sub_dom_sub_cd	Subdominant substrate code	Subdominant substrate type	CB – cobble FN – fines GC – gravel coarse GF – gravel fine HP – hardpan NA – not applicable NR – not recorded SA – sand SB – small boulder
fil_algae_pc	Filamentous algae	Presence of filamentous algae along transect, in percent	0 – absent (0 percent) 1 – sparse (1–10 percent) 2 – moderate (11–40 percent) 3 – heavy (41–75 percent) 4 – very heavy (>75 percent) NA – Not applicable NR – Not recorded
macrophytes_pc	Macrophytes	Presence of macrophytes along transect, in percent	0 – absent (0 percent) 1 – sparse (1–10 percent) 2 – moderate (11–40 percent) 3 – heavy (41–75 percent) 4 – very heavy (>75 percent) NA – Not applicable NR – Not recorded
woody_deb_pc	Woody debris	Presence of woody debris (<0.3 meters in diameter) along transect, in percent	0 – absent (0 percent) 1 – sparse (1–10 percent) 2 – moderate (11–40 percent) 3 – heavy (41–75 percent) 4 – very heavy (>75 percent) NR – Not recorded
lg_woody_deb_pc	Large woody debris	Presence of large woody debris (>0.3 meters in diameter) along transect, in percent	0 – absent (0 percent) 1 – sparse (1–10 percent) 2 – moderate (11–40 percent) 3 – heavy (41–75 percent) 4 – very heavy (>75 percent) NR – Not recorded
overhang_veg	Overhanging vegetation	Presence of overhanging vegetation along transect, in percent	0 – absent (0 percent) 1 – sparse (1–10 percent) 2 – moderate (11–40 percent) 3 – heavy (41–75 percent) 4 – very heavy (>75 percent) NA – Not applicable NR – Not recorded

tbl_fish_cover – Fish cover data—Continued

Field code	Field name	Definition	Codes (if applicable)
undercut_bnk	Undercut bank	Presence of undercut bank along transect, in percent	0 – absent (0 percent) 1 – sparse (1–10 percent) 2 – moderate (11–40 percent) 3 – heavy (41–75 percent) 4 – very heavy (>75 percent) NA – Not applicable NR – Not recorded
art_struct	Artificial structures	Presence of artificial structures along transect, in percent	0 – absent (0 percent) 1 – sparse (1–10 percent) 2 – moderate (11–40 percent) 3 – heavy (41–75 percent) 4 – very heavy (>75 percent) NR – Not recorded
comments	Comments	Comments	

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	
transect_id	Transect identifier (margin)	Transect identifier for each margin mesohabitat sampled (1–5 transects per unit)	
lmargin_w_m	Left margin width	Left margin width, in meters	NA – not applicable NR – not recorded
lmargin_d_m	Left margin depth	Left margin depth, in meters	E – estimate < – less than > – greater than NA – not applicable NR – not recorded
lmargin_v_fts	Left margin velocity	Left margin velocity, in feet per second	E – estimate < – less than NA – not applicable NR – not recorded
lmargin_subs	Left margin substrate type	Left margin dominant substrate type	CB – cobble FN – fines GC – gravel coarse GF – gravel fine HP – hardpan NA – not applicable NR – not recorded SA – sand
lmargin_subs_per_cov	Left margin substrate percent cover	Left margin dominant substrate coverage, in percent	NA – not applicable NR – not recorded
lmargin_subs_sz	Left margin substrate size	Left margin substrate size, in millimeters	NA – not applicable NR – not recorded
lembed_pct	Left margin embeddedness	Left margin substrate embeddedness, in percent	NA – not applicable NR – not recorded

tbl_margin – Margin habitat data—Continued

Field code	Field name	Definition	Codes (if applicable)
lmargin_subdom	Left margin subdominant substrate type	Left margin subdominant substrate type	CB – cobble FN – fines GC – gravel coarse GF – gravel fine NA – not applicable NR – not recorded SA – sand
lmargin_subdom_per_cov	Left margin subdominant substrate percent cover	Left margin subdominant substrate coverage, in percent	NA – not applicable NR – not recorded
lmargin_subdom_sz	Left margin subdominant substrate size	Left margin subdominant substrate size, in millimeters	NA – not applicable NR – not recorded
lmargin_peri_pct	Left margin periphyton	Left margin periphyton cover, in percent	NA – not applicable NR – not recorded
lmargin_densi	Left margin densiometer	Left margin densiometer measurement (0–17)	NA – not applicable NR – not recorded
lbank_angle	First left margin bank angle	First left margin bank angle, in degrees	NA – not applicable NR – not recorded
lbank2_angle	Second left margin bank angle	Second left margin bank angle, in degrees	NA – not applicable NR – not recorded
lbank3_angle	Third left margin bank angle	Third left margin bank angle, in degrees	NA – not applicable NR – not recorded
lbank4_angle	Fourth left margin bank angle	Fourth left margin bank angle, in degrees	NA – not applicable NR – not recorded
lbank5_angle	Fifth left margin bank angle	Fifth left margin bank angle, in degrees	NA – not applicable NR – not recorded
rmargin_w_ft	Right margin width	Right margin width, in feet	< – less than NA – not applicable NR – not recorded
rmargin_d_ft	Right margin depth	Right margin depth, in feet	< – less than > – greater than E – estimate NA – not applicable NR – not recorded
rmargin_v_ft	Right margin velocity	Right margin velocity, in feet per second	> – greater than < – less than ≤ – less than or equal to E – estimate NA – not applicable NR – not recorded
rmargin_subs	Right margin substrate type	Right margin dominant substrate type	CB – cobble FN – fines GC – gravel coarse GF – gravel fine HP – hardpan NA – not applicable NR – not recorded SA – sand

tbl_margin – Margin habitat data—Continued

Field code	Field name	Definition	Codes (if applicable)
rmargin_subs_per_cov	Right margin substrate percent cover	Right margin dominant substrate coverage, in percent	E – estimate NA – not applicable NR – not recorded
rmargin_subs_sz	Right margin substrate size	Right margin substrate size, in millimeters	NA – not applicable NR – not recorded
rembed_pct	Right margin embeddedness	Right margin substrate embeddedness, in percent	E – estimate NA – not applicable NR – not recorded
rmargin_subdom	Right margin subdominant substrate type	Right margin subdominant substrate type	CB – cobble FN – fines GC – gravel coarse GF – gravel fine HP – hardpan NA – not applicable NR – not recorded SA – sand
rmargin_subdom_per_cov	Right margin subdominant substrate percent cover	Right margin subdominant substrate coverage, in percent	E – estimate NA – not applicable NR – not recorded
rmargin_subdom_sz	Right margin subdominant substrate type	Right margin subdominant substrate size, in millimeters	NA – not applicable NR – not recorded
rmargin_peri_pct	Right margin periphyton	Right margin periphyton cover, in percent	E – estimate NA – not applicable NR – not recorded
rmargin_densi	Right margin densiometer reading	Right margin densiometer measurement (0–17)	E – estimate NA – not applicable NR – not recorded
rbank_angle	First right margin bank angle	First right margin bank angle, in degrees	E – estimate NA – not applicable NR – not recorded
rbank2_angle	Second right margin bank angle	Second right margin bank angle, in degrees	E – estimate NA – not applicable NR – not recorded
rbank3_angle	Third right margin bank angle	Third right margin bank angle, in degrees	NA – not applicable NR – not recorded
rbank4_angle	Fourth right margin bank angle	Fourth right margin bank angle, in degrees	NA – not applicable NR – not recorded
comments	Comments	Comments	

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	
transect_id	Transect identifier (mesohabitat)	Transect identifier for each mesohabitat sampled (1–5 transects per unit)	NR – not recorded
transect_w_m	Transect width	Transect width, in meters	E – estimate NR – not recorded
depth_ft	Depth	Depth, in feet	E – estimate NR – not recorded
velocity1	First velocity	First velocity, in feet per second (may include multiple measurements)	E – estimate NR – not recorded
velocity2	Second velocity	Second velocity (if necessary), in feet per second (may include multiple measurements)	E – estimate
velocity(final)	Final velocity	Final velocity, in feet per second (average of velocity measurements if multiple measurements were made)	E – estimate NR – not recorded
subs_cd	Substrate type	Substrate type	CB – cobble FN – fines GC – gravel coarse GF – gravel fine HP – hardpan NR – not recorded SA – sand
subs_size	Substrate size	Substrate size, in millimeters	NA – not applicable NR – not recorded
embed_pct	Embeddedness	Substrate embeddedness, in percent	NR – not recorded

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	
transect_id	Transect identifier (mesohabitat)	Transect identifier for each mesohabitat sampled (1–5 transects per unit)	
cond_µS	Specific conductance measurement	Specific conductance, in microsiemens per centimeter	NR – not recorded
temp_C	Temperature	Temperature, in degrees Celsius	
DO_mL	Dissolved oxygen measurement 2	Dissolved oxygen, in milligrams per liter	
pH	pH measurement	pH value measured by using the pH scale	

Appendix 4. Federal Geographic Data Committee-compliant metadata record.

Identification_Information

Citation: mesohab_11092011

Citation_Information:

Originator: U.S. Geological Survey

Publication_Date: 20141215

Title: Physical Characteristics and Fish Assemblage Composition at the Site- and Mesohabitat-Scale over a Range of Streamflows in the Middle Rio Grande, New Mexico, Winter 2011–12, Summer 2012.

Geospatial_Data_Presentation_Form: vector digital data

Description:

Abstract: In winter 2011–12 and summer 2012, the U.S. Geological Survey (USGS), in cooperation with the U.S. Army Corps of Engineers, Albuquerque District and the U.S. Fish and Wildlife Service New Mexico Fish and Wildlife Conservation Office in Albuquerque, New Mexico, evaluated the physical characteristics and fish assemblage composition of available mesohabitats over a range of streamflows at fifteen sites on the middle Rio Grande in New Mexico. Data were collected at all 15 sites during winter 2011–12 (moderate streamflow) and a subset, the 13 most downstream sites, in summer 2012 (low streamflow). Sites were grouped into four river reaches separated by diversion dams listed in downstream order (names of the diversion dames are followed by short names in parentheses of the sites nearest each dam, listed in downstream order): Cochiti (Peña Blanca), Angostura (Bernalillo, La Orilla, Barelas, Los Padillas), Isleta (Los Lunas I, Los Lunas II, Abeytas, La Joya, Rio Salado), and San Acacia (Lemitar, Arroyo del Tajo, San Pedro, Bosque del Apache I, and Bosque del Apache II). Stream habitat was mapped in the field by using a geographic information system in conjunction with a Global Positioning System. Fish assemblage was determined during both streamflow regimes, and fish were collected by seining in each mesohabitat where physical characteristic data (depth, velocity, dominant substrate type and size, and percent embeddedness) and water-quality properties (temperature, dissolved oxygen, specific conductance, and pH; during summer 2012 only) were measured.

Time_Period_of_Content:

Time_Period_Information:

Single_Date/Time:

Calendar_Date: 2011

Currentness_Reference: 2011

Status:

Progress: Complete

Maintenance_and_Update_Frequency: None Planned

Spatial_Domain:

Bounding_Coordinate:

West_Bounding_Coordinate: -107.097605

East_Bounding_Coordinate: -106.131221

North_Bounding_Coordinate: 35.568157

South_Bounding_Coordinate: 33.809107

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: Middle Rio Grande

Place_Keyword: New Mexico

Place_Keyword: Albuquerque

Place_Keyword: Sandoval County

Place_Keyword: Bernalillo County

Place_Keyword: Valencia County

Place_Keyword: Socorro County

Use_Constraints: These data are for informational purposes only. These data have not received Bureau approval and as such are provisional and subject to revision. The data are released on the condition that neither the U.S. Geological Survey, its cooperators, nor the U.S. Government may 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 Windows 7 Version 6.1 (Build 7601) Service Pack 1; Esri ArcGIS 10.2.1.3497

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 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: 20141124

Spatial_Data_Organization_Information:

Direct_Spatial_Reference_Method: Vector

Point_and_Vector_Object_Information:

SDTS_Terms_Description:

SDTS_Point_and_Vector_Object_Type: GT-polygon composed of chains

Point_and_Vector_Object_Count: 809

Spatial_Reference_Information:

Horizontal_Coordinate_System_Definition:

Planar:

Map_Projection_Name: Albers Equal-Area Conic USGS CONUS NAD83

Albers:

Standard_Parallel: 29.5

Standard_Parallel: 45.5

Longitude_of_Central_Meridian: -96.0

Latitude_of_Projection_Origin: 23.0

False_Easting: 0.0

False_Northing: 0.0

Planar_Coordinate_Information:

Planar_Coordinate_Encoding_Method: coordinate pair

Coordinate_Representation:

Abcissa_Resolution: 0.0001
Ordinate_Resolution: 0.0001

Planar_Distance_Units: meters

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_11092011

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_cl
Attribute_Definition: Mesohabitat type.
Attribute:
Attribute_Label: X
Attribute_Definition: Longitude in decimal degrees.
Attribute:
Attribute_Label: Y
Attribute_Definition: Latitude in decimal degrees.
Attribute:
Attribute_Label: mesohab_lg
Attribute_Definition: Approximate midchannel length of mesohabitat (meters)
Attribute:
Attribute_Label: Shape_Length
Attribute_Definition: Perimeter of feature in meters.
Attribute_Domain_Values:
Unrepresentable_Domain: Positive real numbers that are automatically generated.
Attribute:
Attribute_Label: Shape_Area
Attribute_Definition: Area of feature in meters squared.
Attribute_Domain_Values:
Unrepresentable_Domain: Positive real numbers that are automatically generated.
Distribution_Information:
Resource_Description: Downloadable Data
Metadata_Reference_Information:
Metadata_Date: 20141124
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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