ECOLOGY OF BLUE SUCKER AND GRAY REDHORSE IN THE LOWER PECOS RIVER, NEW MEXICO 2000—2006

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INTRODUCTION

Fishes of the sucker family Catostomidae have suffered from a legacy of societal disregard. Competition and predation from introduced species, habitat degradation, and "rough fish" eradication programs have reduced the distribution and abundance of many catostomids (Cooke et al. 2005). Although recent years have brought increased attention to conservation of imperiled fishes, most suckers are relatively under-studied and required information on their life history and ecology is lacking.

The native fish assemblage of the Pecos River drainage in New Mexico historically consisted of at least 38 species, including five catostomids: river carpsucker *Carpiodes carpio*, white sucker *Catostomus commersoni*, blue sucker *Cycleptus elongatus*, smallmouth buffalo *Ictiobus bubalus*, and gray redhorse *Moxostoma congestum* (Sublette et al. 1990). The native fish fauna in the Pecos drainage has declined over the past century to the extent that eighteen fishes are considered "Species of Greatest Conservation Need" in the New Mexico Comprehensive Wildlife Strategy (2006), eight are listed as threatened or endangered in New Mexico, two are federally listed, and three species are considered extirpated (NMGF 2006). Meanwhile, species introductions have resulted in the contemporary presence of about 25 nonnative fishes in the drainage (Sublette et al. 1990; Propst 1999). Among native catostomids, the river carpsucker and white sucker remain fairly common, whereas blue sucker, gray redhorse, and smallmouth buffalo have become increasingly rare (Sublette et al. 1990, Propst 1999).

Blue sucker occur across much of North America east of the continental divide. The genus has recently been subject to taxonomic revision as a result of morphological and genetic analyses identifying distinctions at the species level within historical *C. elongatus*. The form native to Gulf of Mexico drainages east of the Mississippi River has been designated *C. meridionalis* (Burr and Mayden 1999), and recognition of the Rio Grande basin blue sucker may also be warranted (Burr and Mayden 1999; Buth and Mayden 2001; Bessert 2006).

Although relatively few studies of *Cycleptus* ecology have been published, available information indicates strong association with large rivers, swiftly flowing water, and hard substrates (Moss et al. 1983; Dettmers et al. 2001; Morey and Berry 2003; Eitzmann et al. 2007). Blue suckers are typically found in or near riffles and rapids, along reinforced shorelines, or in reservoir tailwaters. In the Kansas River, Kansas, abundance of blue suckers was similar among logjam, mud bank, and riprap habitats, but was higher in upstream reaches and below a dam than in channelized or above-dam reaches (Eitzmann et al. 2007). Spawning has been reported to occur in riffles over cobble-bedrock substrate during spring (April through June) at temperatures of 16 to 20º C and around periods of increased flow (Moss et al 1983; Vokoun et al. 2003). Larvae and small juveniles (16 to 39 mm TL) have been captured in off-channel habitats adjacent to the main channel in late May and early June (Fisher and Willis 2000; Adams et al 2006) and at high-velocity areas downstream from dams in July (McInerny and Held 1991). In the lower Rio Grande near Big Bend, Texas, young-of the-year blue suckers were abundant at creek mouths during April (20 mm SL) and May (40 mm) (Hubbs and Wauer 1973; Hubbs et al. 1977). Juveniles grow rapidly, reaching 173 to 250 mm TL during their first year (Moss et al.1983; Hand and Jackson 2003); however, typical sampling methods tend to produce few fish smaller than about 400 mm (Moss et al 1983;

Peterson et al. 2000; Hand and Jackson 2003; Eitzmann et al. 2007). Reports of age and growth vary widely, possibly an artifact of sampling bias or differential accuracy among ageing methodologies (Burr and Mayden 1999; Eitzmann et al. 2007). Sampled fish typically range between 400 and 700 mm in length and 4 to 12 years in age, as estimated using scales and pectoral rays (Rupprecht and Jahn 1980; Moss et al. 1983; Hand and Jackson 2003; Eitzmann et al. 2007), although a mean age of 15 years was obtained in one study using scales (Vokoun et al. 2003). Pectoral rays generally yield higher age estimates than scales for fish older than age 7 (Rupprecht and Jahn 1980; Eitzmann et al. 2007), and *C. meridionalis* has been aged to 33 years using opercular bones (Peterson et al. 1999). Blue suckers consume a variety of aquatic invertebrates, especially those concentrated in high-velocity habitats (Moss et al. 1983).

Although widely distributed, blue sucker has declined over much of its range (Williams et al. 1989). In New Mexico, blue sucker historically occupied the Rio Grande River and the Pecos River upstream to Roswell (Sublette et al. 1990), but in recent years, populations have been found only in the Pecos River below Brantley Dam and in the Black River. It has apparently been extirpated from Rio Grande in New Mexico. Populations in the Mexican portions of the Rio Grande drainage have also experienced recent declines (Edwards et al. 2002; Miller 2006). The state of New Mexico listed blue sucker as endangered in 1976 (19 NMAC 33.1), and the U.S. Fish and Wildlife Service classified blue sucker as a Category 2 species (listing may be warranted but insufficient data available to make determination) before abolishing that listing category (Elstad and Werdon 1993).

Gray redhorse is native to the Rio Grande basin in New Mexico, Texas, and Mexico, and to smaller drainages from the Brazos River south to Rio Soto la Marina (Hubbs 1957; Jenkins 1980; Sublette et al. 1990, Miller 2006). Specific nomenclature has alternated between *M. congestum* and *Scartomyzon congestus* in recent decades, coincident with efforts to resolve the taxonomy of the tribe Moxostomatini (Harris and Mayden 2001; Nelson et al. 2004). Although congeners are widely distributed across North America east of the continental divide, the gray redhorse has a fairly restricted range and has received limited attention from researchers. Gray redhorse reportedly prefer habitat having firm substrate and some current, but may be found in pools, backwaters, runs, and reservoirs (Edwards 1997). In the Devil's River, Texas, gray redhorse were generally associated with pool edges, but occupied shallow, narrow reaches during winter (Valdes Cantu and Winemiller 1997; Robertson and Winemiller 2003). One study reported gray redhorse to co-occur in mesohabitats with Rio Grande darter *Etheostoma grahami*, manantial roundnose minnow *Dionda argentosa* and Rio Grande perch *(Cichlasoma cyanoguttaum)* (Valdes Cantu and Winemiller 1997), but a subsequent study found no strong association with any other fish species (Robertson and Winemiller 2003). Gray redhorse were most common in relatively quiet and deep portions of clear, perennial streams in the Little River drainage, Texas (Rose and Echelle 1981). Gray redhorse move upstream to spawning sites, where they aggregate in early spring (Martin 1986; Tomelleri and Eberle 1990). Spawning occurs over gravel substrate at the downstream end of pools during March through May at temperatures of about 18º C or warmer (Martin 1986). Small juveniles are rarely sampled, but individuals < 36 mm SL have been captured during May through July (Hubbs and Wauer 1973; Edwards 1997). Gray redhorse forage in shallow areas between pools, consuming algae and various invertebrates (Cowley and Sublette 1987a; Edwards 1997). Adults may exceed 400 mm TL and live to at least age 5 (Little 1964b; Edwards 1997).

Like blue sucker, gray redhorse historically occupied the Rio Grande and Pecos River upstream to Roswell in New Mexico, but have been extirpated from the Rio Grande and from the Pecos River above Brantley Dam (Sublette et al. 1990; Propst 1999). Gray redhorse remain common over much of their distribution in Texas (R.J. Edwards, University of Texas-Pan American, personal communication) but have declined considerably in recent decades in the Texas portion of the Rio Grande (Linam and Kleinsasser 1996). The state of New Mexico has listed the gray redhorse as threatened since 1976 (19 NMAC 33.1); federal listing has not been evaluated.

Downward trends in population status of blue sucker and gray redhorse have elevated the need to implement effective conservation measures. This is particularly true given emerging awareness of the uniqueness of blue sucker in the Rio Grande basin (Buth and Mayden 2001; Bessert 2006). Detailed information on species biology is essential to management planning, and this investigation was conducted to determine current distribution and abundance, habitat use, and movements of blue sucker and gray redhorse in New Mexico.

Study Area

The Pecos River flows approximately 800 km from its origins in the Sangre de Cristo Mountains of northern New Mexico to the Texas state line and an additional 645 km to the Rio Grande at Amistad, Texas. After descending from the mountains, the Pecos occupies a wide, shallow, sand-bed channel that traverses the plains of eastern New Mexico, generally losing surface flow until entering the Roswell artesian basin. Downstream from Roswell, springs and seepage recharge the largely channelized river to Brantley Lake. Travertine bedrock and alluvium dominate the river channel downstream of Brantley Lake. Because prior surveys indicated that blue sucker and gray redhorse were restricted to the Pecos drainage downstream of Brantley Dam, the study area included the lower 125-km portion of the Pecos River (5th order stream, sensu Strahler 1952) from Brantley Dam to the Texas state line, including the Black River (4th order) (**Figure 1**). The study area lies within the northern Chihuahuan Desert ecotome. Maximum daily air temperature at Carlsbad, NM averages 14.8º C (58.6º F) in January and 35.4º C (95.8º F) in July, while precipitation averages 32.3 cm (12.7”) annually and falls primarily during summer rainstorms (WRCC 2007). Mountain snowmelt runoff and summer monsoon storms drive the natural hydrology of the basin. Mean daily water temperatures downstream from Brantley Dam range from about 6º C in January to 26º C in July (**Table 1**). The river descends from about 975 m at Brantley Dam to 866 m near the state line.

The ecology of the Pecos River has been dramatically altered as a consequence of agricultural development in the basin. The study reach holds five dams, including one large storage project (Brantley: 1,255 ha; 42,000 af), a smaller storage and diversion project (Avalon: 4,466 af) and four run-of-the-river diversion dams that create small impoundments (Carlsbad Municipal, Bataan, Six Mile, and Ten Mile lakes) (**Figure 1**). None of the structures provides upstream fish passage, and the Pecos River within the study area has been effectively fragmented since the construction of Avalon Dam in 1888. Discharge from Brantley Lake is regulated to satisfy irrigation demands from

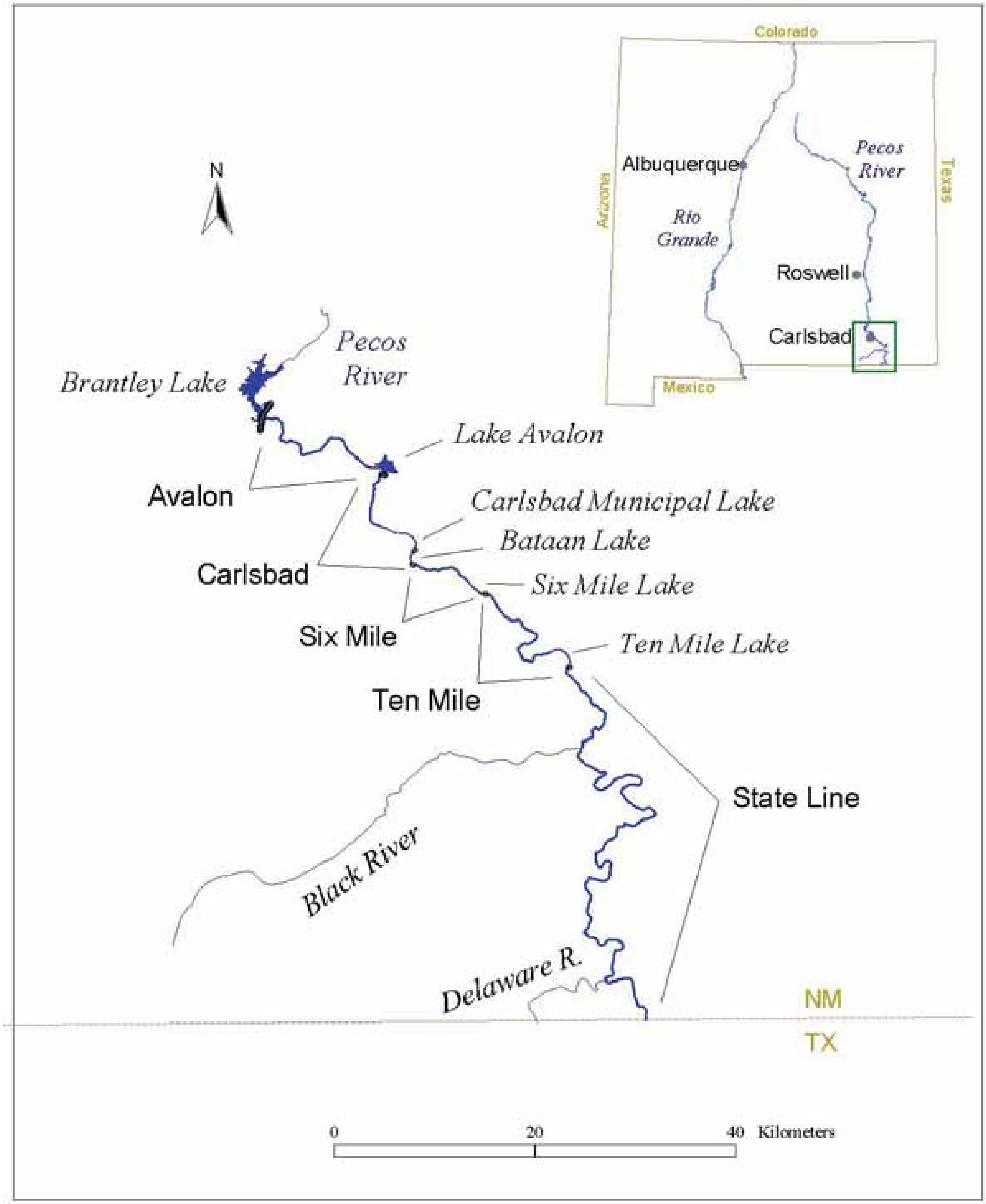

Figure 1. Map of lower Pecos River study area within New Mexico, including designated river segments (bold; named for defining feature at downstream end of segment), impoundments (italics), and locator (inset).

Table 1. Temperature data for selected study sites. Thermograph data collected during April 2001 through February 2002 in the reach between Brantley Dam and Lake Avalon. Point measurements collected at USGS "below Brantley" gage during 1990 through 1997 and at USGS "Black River above Malaga" gage during 1960 through 1976.

Segment / source / metric	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Avalon lotic / thermograph / mean daily max	9.4	10.2	-	19.1	24.0	26.1	29.0	29.4	25.0	18.7	14.3	8.8
Avalon lotic / thermograph / daily mean	5.7	7.4	-	15.4	20.4	23.8	26.4	26.3	23.3	17.2	13.4	5.8
Avalon lotic / USGS / point meas. mean	7.6	9.2	13.9	15.0	18.5	23.0	26.2	24.5	25.8	-	11.6	9.8
Black R. / USGS / point meas. mean	6.3	10.1	12.8	17.3	21.2	23.9	27.3	24.7	23.7	19.1	12.0	9.4

1 April through 31 October and to send block deliveries of water to Texas, resulting in extreme fluctuations in flows between Brantley Dam and Lake Avalon (**Figure 2**). A minimum release of 20 cfs (0.57 cms) from Brantley Dam is required as mitigation for fish and wildlife uses (USBR 1982), and inflow of water for irrigation maintains Lake Avalon; however, the entire lake is silted and shallow (depth < 1 m) except for two small holes near the dam. During the irrigation season, water is diverted at Avalon Dam into the Carlsbad Irrigation District (CID) canal system, the main line of which runs about 38 km to the Black River above Malaga. The diversion lacks a fish screen and large numbers of fish are stranded upon closure of canal in November. Lack of flow below Avalon Dam disrupts the continuity of the Pecos River, and, except during brief periods around water deliveries to Texas, about 5 km of river channel typically consists of isolated ephemeral pools or dry channel bed. The river regains perennial flow underneath the CID flume at the north end of Carlsbad, where seepage and spring flow contribute to Carlsbad Municipal Lake and Bataan Lake. Downstream from Carlsbad, free-flowing reaches consist of a stair-step pattern of large natural pools connected by short, high gradient stream sections. Six Mile and Ten Mile dams create lentic conditions that extend about 3 km upstream of each. Exacerbated by surface and groundwater withdrawals, portions of the river occasionally experience stagnation during the summer low-flow period. Below Malaga, spring flow from the Rustler Formation drastically increases the salinity of the Pecos River and probably limits suitability for many freshwater fishes. As a consequence of human activities as well as natural sources, the river has a legacy of water quality problems and is presently considered impaired according to biological criteria, metals, sediment, and temperature (NMED 2007).

The Black River originates in the Guadalupe Mountains and flows east to the Pecos River near Malaga, NM. The upper drainage consists of perennial and ephemeral

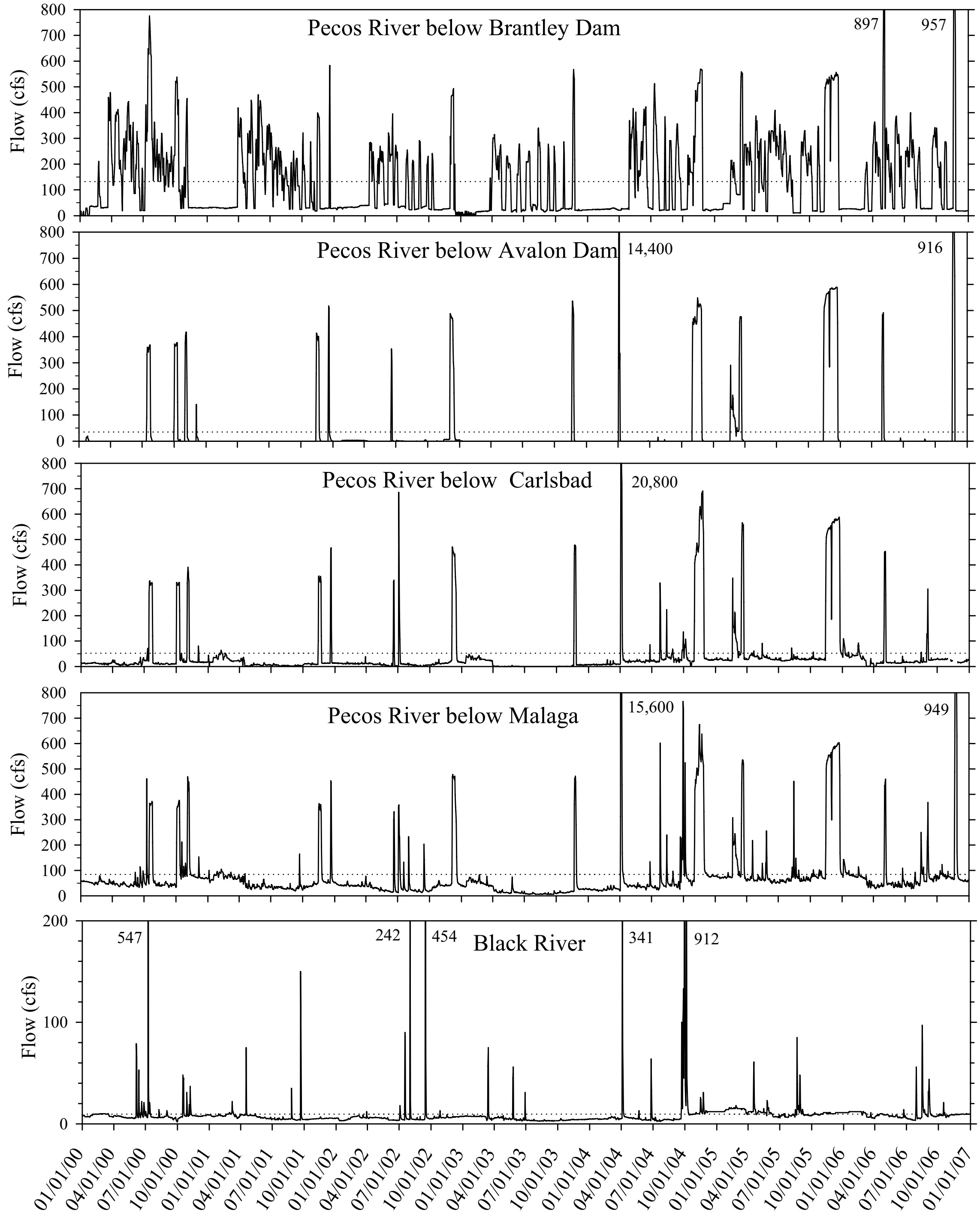

Figure 2. Mean daily discharge during 2000 through 2006 at four USGS gauging stations on the Pecos River and one on the lower Black River. Dotted horizontal line indicates overall mean for period shown. Pattern below Brantley Dam (top) reflects operations conducted to provide irrigation water for CID canal. Flow events below Avalon Dam indicate block deliveries to Texas. Peaks at Black River reflect storm events in the drainage. Maximum values provided for extreme flow events.

reaches, but the river goes subsurface for several kilometers below Rattlesnake Springs. Perennial surface flow emerges above Blue Spring and the river demonstrates a stair-step morphology comprised of large pools with interspersed riffles within a narrow, incised valley. Human population density is fairly low within the watershed, the riparian zone is generally well vegetated, and no major dam or reservoir occurs on the main stem. Although the Black River is more ecologically intact than the Pecos River, small diversion dams at the CID canal inflow and near Black River Village may act as partial barriers to migration. Inflow of Pecos River irrigation water degrades water quality below the CID canal return and may act as a source of nonnative organisms, including fishes (Cowley and Sublette 1987a; Lang 2001). Irrigated agriculture, cattle grazing, and an increasing amount of oil and gas development occur in the Black River drainage.

More than 60 fish species have been documented within the Pecos drainage, although many inhabit specific habitats such as springs or are restricted to upstream locales (Sublette et al. 1990). Within the study area, the assemblage of large-bodied fishes consists primarily of members of Catostomidae, Centrarchidae, Cyprinidae, Clupeidae, Ictaluridae, and Lepisosteidae (Sublette et al. 1990). The New Mexico Department of Game and Fish maintains an intensive stocking program focused on rainbow trout *Oncorhynchus mykiss*, channel catfish *Ictalurus punctatus*, largemouth bass *Micropterus salmoides*, and walleye *Sander vitreus*. Brantley Lake, Carlsbad Municipal Lake, Bataan Lake, and Higby Hole on the Black River receive the majority of stocked fish.

METHODS

Distribution and Abundance

Fish surveys were conducted during 2000 through 2006 to assess distribution and abundance of blue sucker and gray redhorse across the study area (**Table 2**). Sampling during 2001 through 2004 was focused on six core sites: Brantley Dam stilling basin, the lotic reach above Lake Avalon, Carlsbad Municipal Lake, Six Mile Lake, Ten Mile Lake, and the pool at the confluence of the Pecos and Black rivers. In 2004 and 2005, efforts were concentrated downstream from Carlsbad at sites where capture of target species was deemed most likely. All sites previously containing gray redhorse or blue sucker were re-sampled in 2006 to assess changes in distribution since the beginning of the study. Fish sampling was also conducted in the project area for two concurrent studies (Texas hornshell mussel biology and Pecos River warmwater fish community monitoring), and pertinent elements of these data are included herein. Additionally, six tag-recapture sessions consisting of 2 to 4 successive days of trammel net sets were conducted to obtain population estimates of gray redhorse in Six Mile Lake.

Sampling methods varied according to site conditions and targeted fish size (**Table 2**). A raft-mounted Smith-Root 5.0 GPP electrofishing system was used to sample the Pecos River between Brantley Dam and Lake Avalon, but wider application of this technique was restricted by high specific conductance (> 3,000 μS/cm near Carlsbad, > 10,000 μS/cm downstream from Malaga), limited effectiveness in large, deep pools, and limited navigability of many river reaches. Trammel nets (30.5 m x 1.5 m; 30-cm outer panel and 13-cm inner panel; typically set for 1 to 4 hours) were used in lentic habitats to capture large-bodied fishes (i.e., deep-bodied fishes > 100 mm TL, slender-bodied fishes

> 200 mm TL). Seines (2 x 3 m; 0.5-mm mesh) were used to capture small-bodied fish in lotic habitats and along reservoir shorelines. On a few occasions, hoop nets, hand nets, and backpack electrofishing were used. Total length, standard length, and mass of each fish were determined, and condition (e.g., maturation status, presence of parasites) was noted. Spawning condition and sex were determined by presence of gametes or external characteristics such as prominent nuptial tubercles (Moss et al. 1983). Gray redhorse and blue sucker larger than 200 mm TL were implanted with Passive Integrated Transponder (PIT) tags inserted into the ventral portion of the abdominal cavity posterior to the pelvic insertion.

Catch data was summarized according to catch-per-unit-effort (CPUE), relative abundance, and diversity metrics. CPUE was standardized as number of fish per 100 feet of trammel net per hour (f/nh) or as number of fish per hour of electrofishing (f/h). Abundance patterns were assessed by constructing plots of CPUE by year and site. Population estimates for gray redhorse in Six Mile Lake were made using an open capture model (POPAN) in the program MARK (White and Burnham 1999).

Size structure was compared among sites, among seasons at individual sites, and between sexes. Differences in size structure were tested using *t*-tests or Mann—Whitney *U*-tests for comparisons between two sites, and ANOVA (Tukey's post-hoc comparisons) or Kruskal—Wallis tests for comparisons among three or more sites. Parametric tests were used only if assumptions of normality and homoscedasticity were met. Because sampling was conducted over the course of the growing season, statistical tests of length differences among sites were performed only for restricted sets of surveys conducted at about the same date in a given year.

Growth of gray redhorse was assessed using scale analysis, mark-recapture data, and length-frequency analysis. Gray redhorse scales were collected in 2006 from midway between the lateral line and dorsal fin insertion. Most scale samples were obtained from fish from the Black River ($N = 48$) and Six Mile Lake ($N = 61$); a few ($N = 8$) were collected in the lotic reach upstream from Six Mile Lake and at the Pecos—Black confluence pool ($N = 4$). Scales were pressed between two glass slides and aged, without knowledge of fish size or capture date, on two occasions. If an ageing discrepancy was not readily resolved, the sample was omitted. Annuli were identified as crossing-over of multiple circuli in both lateral fields, whereas crossing-over in only one lateral field constituted a check (Meyer 1962; Bowman 1970; Rupprecht and Jahn 1980). Distances from the focus to each annulus were measured in the lateral field along the ventro-medial axis using a digital image analysis system. Length at age was back-calculated using the direct proportion method because a regression of scale radius on body length (TL = -3.7 + 754.1 * RADIUS; $r^2 = 0.92$; $N = 110$) indicated the intercept was not different from zero ($P = 0.67$). Differences in length at age between gray redhorse from Black River and Six Mile Lake were tested with Mann—Whitney *U*-tests, and mean length at age was used to calculate Von Bertalanffy growth curves for each site. Growth curves and length—weight relations were calculated using the program FAST (Slipke and Maceina 2000), and simple linear regression was used to calculate standard length–total length relations for gray redhorse as well as for blue sucker.

Fish condition was calculated using the formula $K_{TL} = (WT*10^6) / (TL*10^3)$. To assess sub-annual differences and site differences in condition, subsets of fish were compared using ANOVA or *t*-tests. Condition of blue sucker in the Avalon lotic reach was compared among fish captured in March, April, and May using ANOVA (general linear model) including body length (TL) and month as factors. Condition of redhorse was compared between Six Mile Lake and the Black River and among months (Six Mile Lake in June, August, and December of 2006; Black River in late May—early July and December 2006).

Habitat Characteristics and Spawning Areas

Habitat-use data were obtained through sonic telemetry, surface observation, and assessment of capture location characteristics. Telemetry was conducted using hydroacoustic tags (Sonotronics™, model CT82-2, 14-month, 8 grams) because high conductivities of study waters precluded use of radio tags. Blue sucker and gray redhorse larger than 390 mm TL were captured for tagging in spring of 2002 and 2003 by electrofishing or in trammel nets in the Avalon (18 fish) and Six Mile (3 fish) segments. Fish were anaesthetized in tricaine methanesulfonate and a transmitter was inserted into the peritoneal cavity anterior to the left pelvic fin. The incision was closed using sutures and monofilament and disinfected with betaine, and fish were released near the point of capture after resuscitation. A total of eight blue suckers and 13 gray redhorse were tagged during the study. Tracking was conducted from inflatable kayaks on a weekly basis in March through May of 2002 and 2003, monthly from June through September in 2002, and otherwise irregularly until April 2004. Tagged fish were located using a hydrophone (Sonotronics ™, Model DH-4) and receiver (Sonotronics ™, Model USR-96), and the position was recorded with a handheld GPS. Upon resolving the position of a tag, an effort was made to ascertain whether the tag was still implanted in a living fish (e.g., movement when approached). Habitat measurements collected at fish locations included depth, water velocity at 0.6 of maximum depth (m/sec), dominant substrate, and presence or absence of cover. Distances between fish locations were measured using a geographic information system (GIS).

Fish Species Associations / Community Characteristics

Catch-per-unit-effort and diversity metrics were used to characterize fish assemblages. Species richness (number of species captured) and diversity were calculated for each sampling event (i.e., one-day electrofishing run through a reach or one set of trammel nets at a site). A modification of the Shannon-Weiner formula [exp (H')] was used to provide an index of diversity because of its more intuitive interpretability relative to the standard formula (Jost 2006).

Table 2. Number of sampling events (i.e., individual days or disjunct sites on same day) conducted during 2000 through 2006 according to gear type. Asterisk indicates total excluding additional fish sampling conducted for Texas hornshell mussel study on the Black River.

Locality	Gear	2000	2001	2002	2003	2004	2005	2006	Total
				Avalon Segment					
Brantley Dam Stilling Basin	Trammel		4	2	1			1	8
Lotic reach (> Lake Avalon)	Electrofish		2	2				2	6
	Hoop net			1			1		2
	Seine	4	2	2	2	2	2	5	19
	Trammel		1	4	7	1	1	4	18
Lake Avalon	Trammel	2						1	3
				Carlsbad Segment					
Lotic reach (> Carlsbad)	Seine		1						1
Carlsbad Municipal Lake	Trammel	1		2	1			2	5
				Six Mile Segment					
Lotic reach (> Six Mile L.)	Seine		1					3	3
Thompson Pool	Trammel							1	1
Six Mile Lake	Trammel	1	5	2	4	10		6	28
				Ten Mile Segment					
Lotic reach (> Ten Mile L.)	Seine							2	2
Pool < Six Mile Dam	Trammel					1	1		2
Ten Mile Lake	Trammel	1	5	2	1	1	1	1	12
				State Line Segment					
Lotic reach (> state line)	Seine		6	3	4	2	3	3	21
Fisherman's Lane Pool	Trammel							1	1
Pecos–Black Confluence Pool	Trammel	2	5	2	1			1	11
				Black River					
Black River	Seine				1		*	2 *	3*
	Trammel	1			3		*	1 *	5*
	Electrofish						*	0 *	0*
	Hoop net							0 *	0*
Blue Spring	Seine	2							2
Castle Spring	Seine				1				1
Rattlesnake Spring	Electrofish							1	
	Minnow trap							1	1
				Carlsbad Canal System					
	Seine	1	2					1	4
Total	Electrofishing	0	2	2	0	0	0*	3 *	7*
	Hoop net	0	0	1	0	0	1	0 *	2*
	Seine	7	12	5	8	4	5*	16*	57*
	Trammel net	8	20	14	18	13	3*	19*	95*

RESULTS

Distribution, Abundance, and Growth

Distribution and abundance of blue sucker and gray redhorse drastically declined during the study period. Extensive fish kills on the Pecos River were reported in May 2002 through June 2003 at various locations between Brantley Lake and the NM—TX state line and were associated with blooms of golden algae *Prymnesium parvum* (pers. comm., S. R. Denny, New Mexico Department of Game and Fish, Roswell). Numbers of dead fish counted at individual sites ranged from ten to several thousand. During site visits in February through April of 2003, numerous dead fish, including blue sucker and gray redhorse, were encountered in the lotic reach between Brantley Dam and Lake Avalon. The kills appeared to affect all large-bodied species (i.e., fish > about 100mm TL); dead small-bodied fishes were not observed.

Blue Sucker

Blue suckers (*N* = 51) were captured at five study locations (**Table 3**). However, most (78%, *N* = 38) were caught in the Avalon lotic reach between the Hwy 30 bridge and Lake Avalon during 2000 through 2003. Raft-mounted electrofishing through this reach in 2000 and 2001 produced 2.3 to 4.9 blue suckers per electrofishing hour (3 to 13 individuals per sampling event). Numerous additional fish were observed but evaded capture because gear efficiency was limited in narrow, high velocity chutes where they were often encountered. Despite the prior fish kills, eight blue suckers were captured on 6 March 2003 using trammel nets in this reach (CPUE = 1.6 f/nh). Small numbers of blue sucker were also found in the Black River in 2000, 2003, 2005, and 2006. Only one individual was caught in each Carlsbad Municipal Lake (512 mm; 13 May 2003) and Six Mile Lake (585 mm; 14 July 2004). Six small blue suckers (about 150 to 200 mm SL) were seined in the CID canal on a single occasion (7 November 2000) after conclusion of the irrigation season when only a few pools of water remained.

Comprehensive sampling of all core sites in 2006 produced blue suckers from only the Black River. On 30 May 2006, one fish was captured in a trammel net, and four blue suckers were observed at the head of a pool in August 2006. The capture of only

Table 3. Total catch and CPUE for blue sucker from 2000 through the last year in which blue sucker were collected at each locality. CPUE indicates number of fish per 100 net feet per hour (trammel) or per hour of effort (electrofishing). Asterisk indicates calculation of CPUE and number of events includes only years 2000 through 2003; different sampling protocols prevent inclusion of Black River data from 2005 and 2006.

Locality	Period	Gear	Events	Blue sucker	CPUE Mean	CPUE Min	CPUE Max
Black River	2000-2006	Trammel	4*	5	0.25*	0.00*	0.57*
Avalon (lotic)	2001-2002	Electrofish	4	29	3.78	2.31	4.94
	2001-2003	Trammel	10	9	0.18	0.00	1.60
Crlsbd. Mun. L.	2000-2003	Trammel	4	1	0.03	0.00	0.12
Six Mile Lake	2000-2004	Trammel	22	1	0.00	0.00	0.03
CID canals	2000	Seine	1	6	-	-	-

one blue sucker in 21 days sampling at the Black River suggests low abundance, although most sampling was conducted to capture fish for a mussel study (only one trammel net deployed, fish immediately removed upon entanglement) and not designed to assess fish abundance. In the lotic reach above Lake Avalon, where blue suckers were historically abundant, six trammel netting events (25.4 net hours "nh") and two electrofishing runs through the reach failed to produce blue sucker after 2003. No blue sucker was caught during 2006 in Carlsbad Municipal Lake (14.2 nh effort), Six Mile Lake (113.2 nh), or in pools or stream reaches within the Six Mile segment (5.7 nh plus intensive seining).

Nearly all blue suckers captured in this study were large, adults. Those captured in the Pecos and Black rivers were 485 to 850 mm TL (mean = 638 mm TL, SD = 70 mm; $N = 44$) (**Figure 3**). Twenty-five were obviously ripe (tuberculate and emitting milt or ova) and all but one was male. The relationship between total and standard length for these large fish was SL = 0.929 * TL -57.96 ($N = 43$, $r^2 = 0.97$), the length—mass relationship was (MASS = -6.78 * TL $^{3.617}$; $r^2 = 0.92$; $N = 43$), and K_{TL} averaged 0.89 ± 0.02 (mean ± SE). Variance in the length—mass relationship increased with length exceeding about 350 mm TL but was not readily attributable to sex or maturation status. Total length was similar among fish captured during March, April, and May (ANOVA: $F = 0.886$, df = 2, $P = 0.42$), but condition differed according to month and fish length (general linear model; length: $F = 17.307$, df = 1, $P < 0.001$, month: $F = 4.713$, df = 2, $P = 0.016$), being highest in April and positively related to fish length. Fish length was

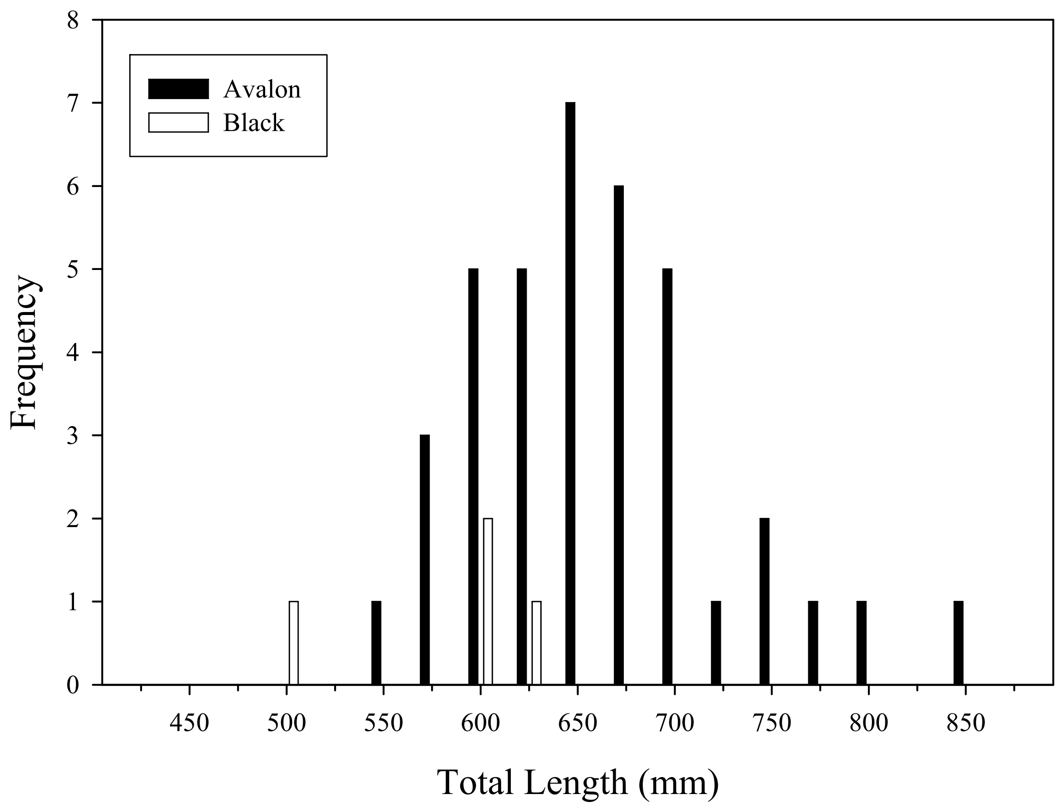

Figure 3. Length frequency distributions for blue suckers caught in the lotic reach above Lake Avalon ($N = 38$) during 2000 through 2003 and in the Black River ($N = 4$) during 2000 through 2006.

similar between electrofished and trammel-netted fish in the Avalon lotic reach (Mann-Whitney test, $P = 0.45$). Electrofishing and seining efforts failed to produce any juvenile blue suckers from the Black or Pecos rivers. However, six juvenile blue suckers 150—200 mm TL were collected in the CID canal on 7 November 2000.

Gray redhorse

Gray redhorse was widely distributed across the project area, but its range diminished during the study period (**Figure 4**). Sampling with trammel nets produced gray redhorse from all river segments and from all core sites except Lake Avalon. After 2003, gray redhorse was found only in the Black River and in the Pecos River downstream from Bataan Lake (**Figure 5**). Absence of gray redhorse after 2003 in the Avalon lotic reach, Lake Avalon, and Carlsbad Municipal Lake, suggests that fish kills during 2002 through 2004 resulted in a severe decline in abundance and contraction of the species' range.

Catch rates using trammel nets ranged from 0.06 to 8.16 f/nh for events in which gray redhorse was captured ($N = 72$ events, mean CPUE ± SE = 1.33 ± 0.19) and was less than 1.4 f/nh for most events (74%). Overall, CPUE was highest at the Black River and Six Mile Lake (5 of 6 years >1 f/nh) (**Figure 6**; **Figure 7**). High longitudinal variability

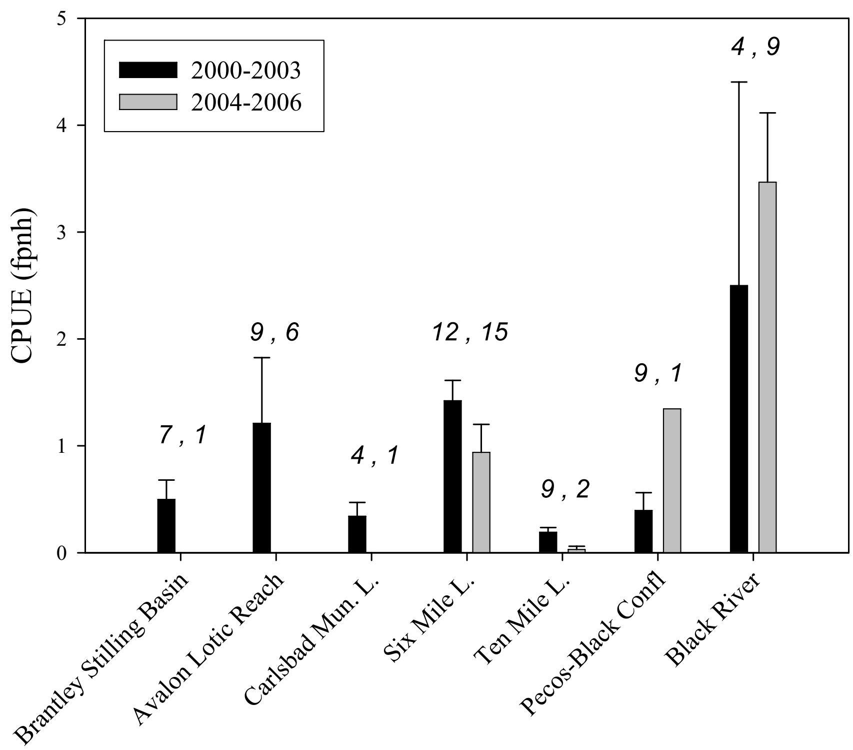

Figure 4. Gray redhorse CPUE (mean + SE) at core sites, comparing first and second halves of study period. Number of sampling events provided above bars. December 2006 sample from Black River and Six Mile Lake omitted to reduce bias. No gray redhorse was captured at Lake Avalon.

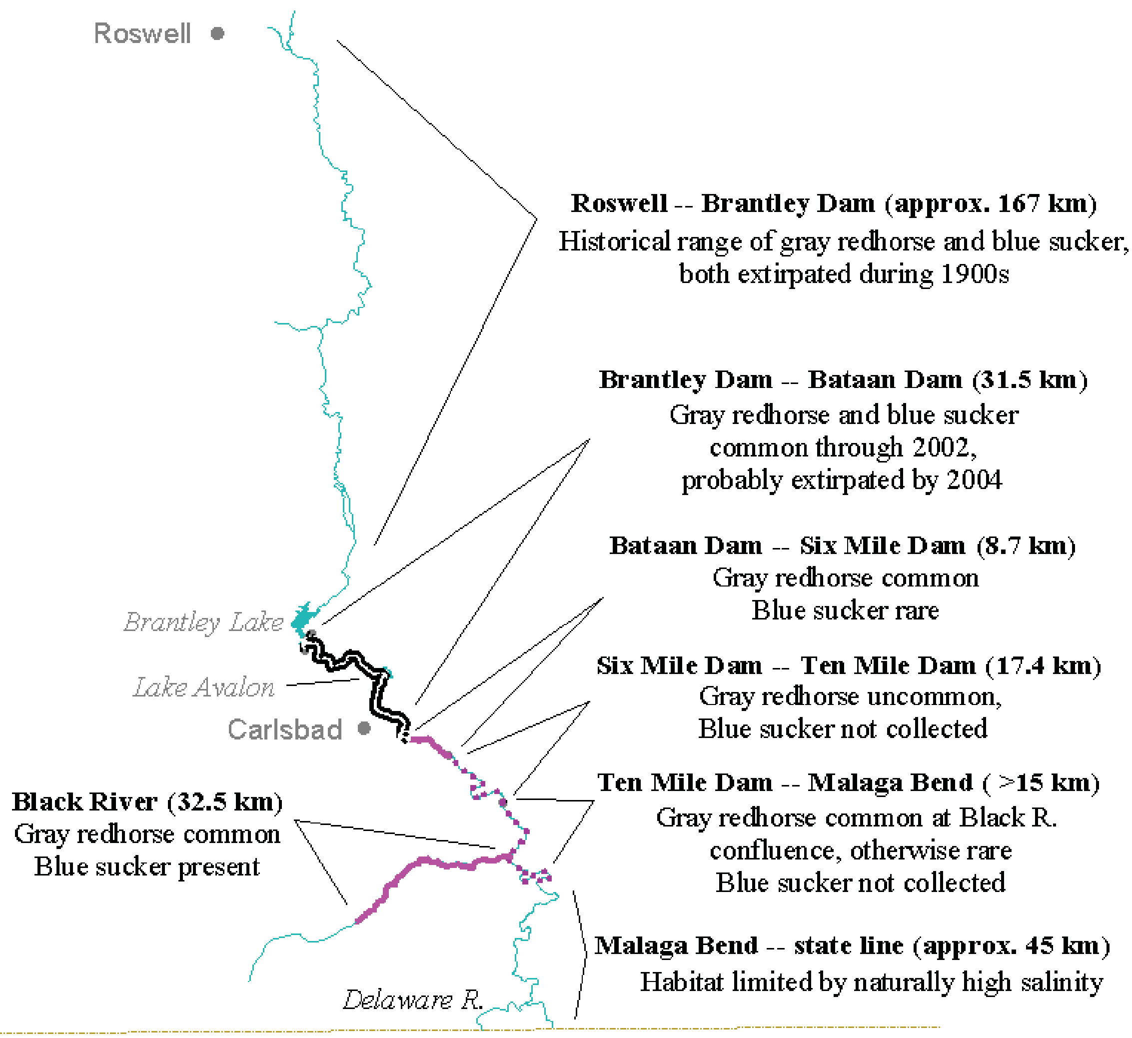

Figure 5. Map of blue sucker and gray redhorse historical range in the Pecos River basin of New Mexico, and current distribution inferred from sampling conducted in 2004 through 2006.

in fish abundance contributed to the variation in CPUE at the Avalon lotic reach and the Black River. Raft-mounted electrofishing in the Avalon lotic reach produced CPUE ranging from 3.1 to 42.8 f/h during 2001 and 2002. Abundance was lower through 2003 (mean CPUE = 0.25 to 0.39 f/nh) at Brantley Stilling Basin, Carlsbad Municipal Lake, and the Pecos—Black confluence pool. Of these three sites, only the confluence yielded gray redhorse in 2006, and CPUE (1.34 f/nh) was somewhat greater than in previous sampling events. Ten-Mile Lake produced only a few gray redhorse (CPUE < 0.33 f/nh) in 5 of 6 sampled years and none in 2005.

Low recapture rates precluded calculation of reasonably precise estimates of gray redhorse population size for Six Mile Lake. Twenty sampling events were conducted during 2001 through 2004. Recaptured fish comprised as much as 36.8 % of the catch for a sampling event; however, this represented a maximum of only 7.7 % of all gray redhorse marked since the earliest tagging date of the fish recaptured during that event. An open capture model (POPAN) for 2004, during which 10 sampling events occurred, provided a point estimate of 505 individuals, but the 95 % confidence interval ranged

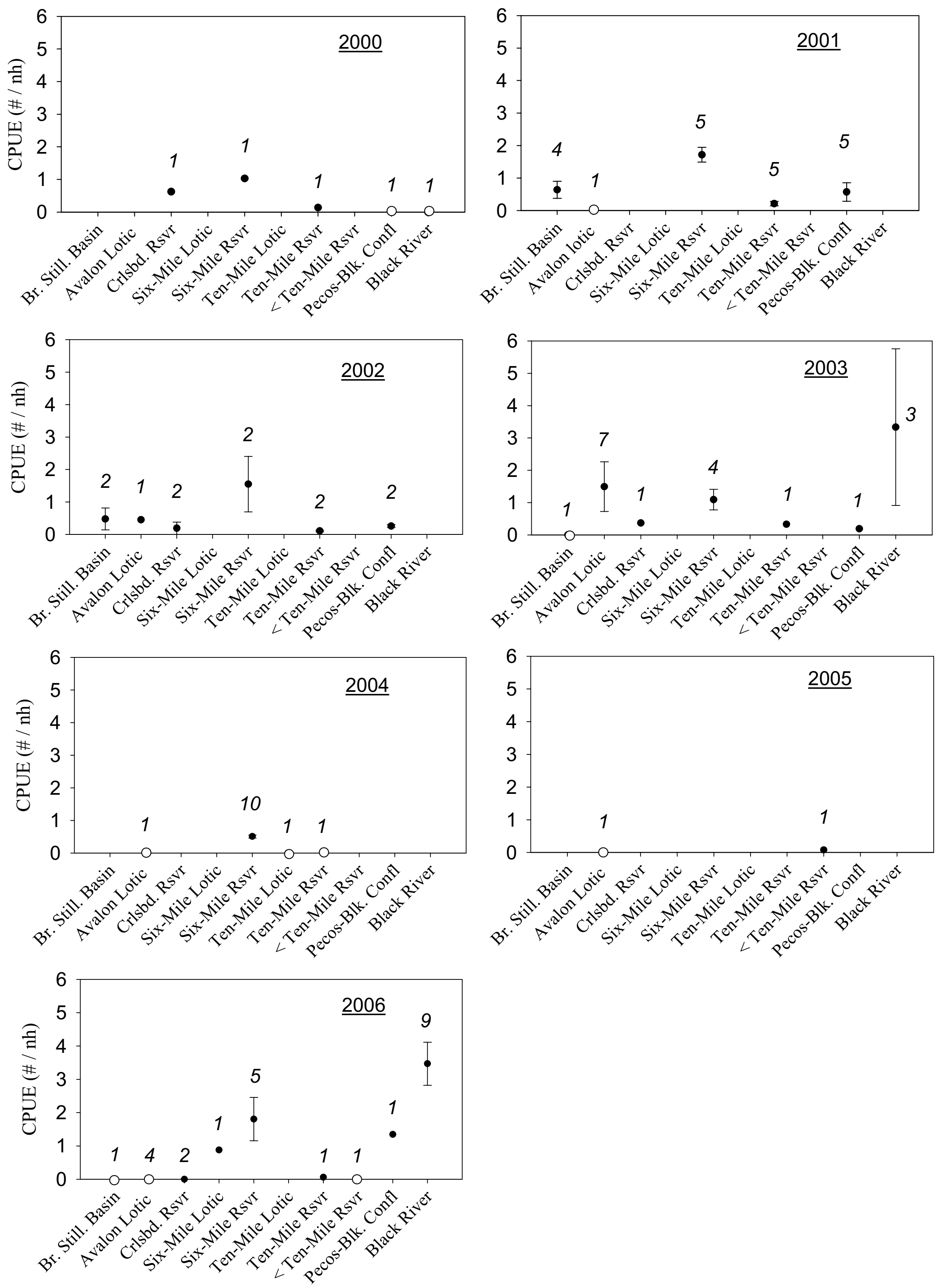

Figure 6. Gray redhorse CPUE (mean, range) for each year of the study. Open circles indicate zero redhorse captured. Number of sampling events provided above bars. December 2006 sample from Black River and Six Mile Lake omitted to reduce bias from seasonal effects. No gray redhorse was captured in Lake Avalon during the study period.

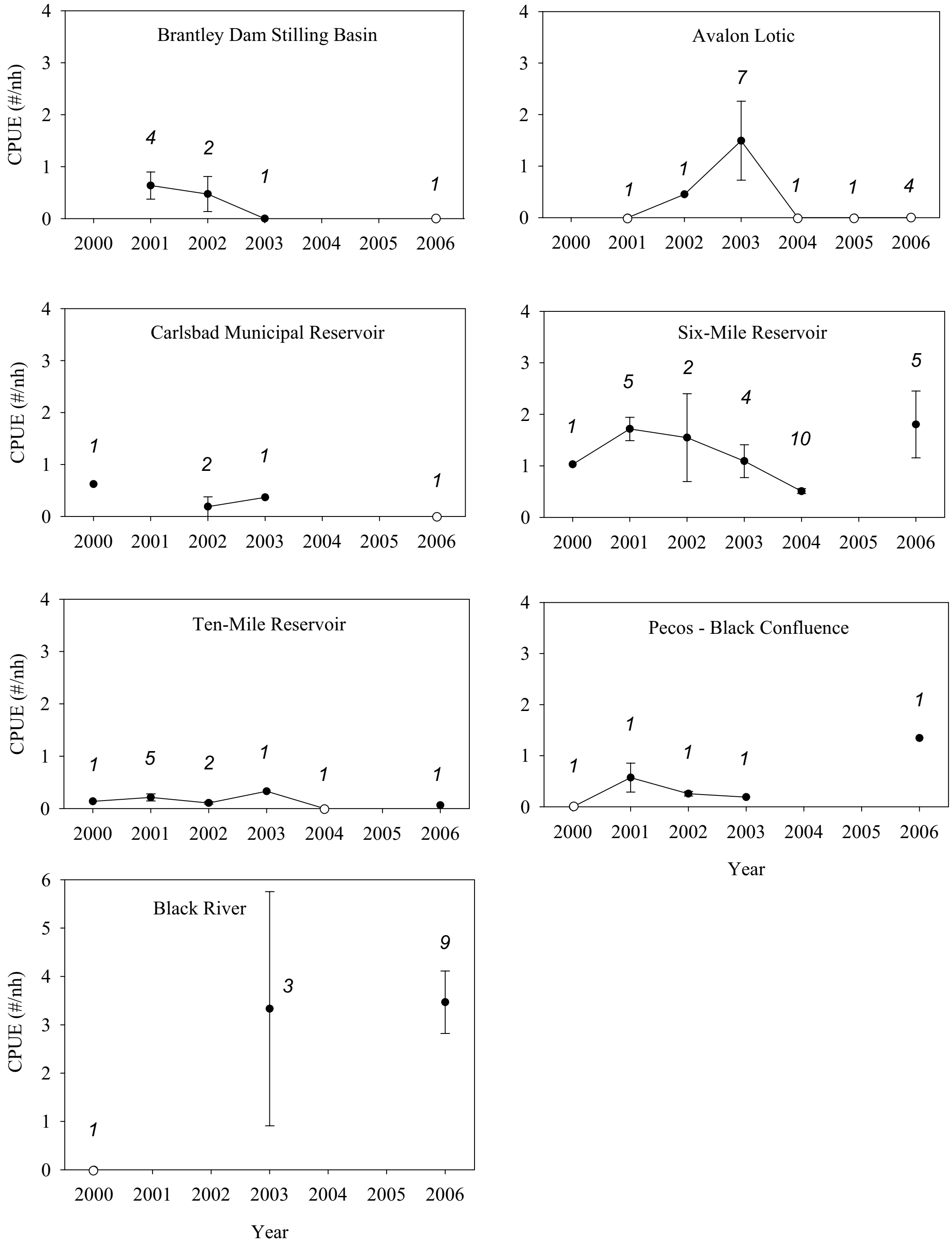

Figure 7. Gray redhorse CPUE (mean ± SE) at each core site. Number of sampling events provided above bars. December 2006 sample from Black River and Six Mile Lake omitted to reduce bias from seasonal effects. No gray redhorse was captured at Lake Avalon during the study period.

from 171—839 individuals. In 2006, only one gray redhorse was recaptured during a four-day tag—recapture session on Six Mile Lake.

Size of captured gray redhorse ranged from 34 to 509 mm TL (mean ± SE = 383.4 ± 2.4; **Figure 8**) but varied according to sampling gear, sex, and location. Relatively few gray redhorse (*N* = 24) were captured by seining, but specimens ranged from 34 to 459 mm. Juvenile gray redhorse less than 200 mm TL were caught during only 4 of more than 55 seining events and only in the Black River or below its confluence in the Pecos River (Pecos River at Malaga Bend and at the Black River confluence on 15 October 2001, Black River on 24 May 2006 and 4 December 2006). Trammel nets captured a wide size range of gray redhorse (195 to 509 mm TL), but the mesh size was probably too large to effectively entangle those smaller than about 200 mm TL. All but two (201, 290 mm) of the 80 gray redhorse captured by raft-mounted electrofishing exceeded 380 mm TL. However, raft-mounted electrofishing was limited to the Avalon lotic reach, where electrofishing and trammel nets produced similar size distributions during the one year (2002) both gears were used (t = 2.00, df = 59, P = 0.88). Across all study sites, ripe females (N = 60, range = 350 to 509 mm, mean ± SE = 445 ± 4) were larger than males (N = 81, range = 317 to 467 mm, mean ± SE = 412 ± 3; t = 6.224, df = 148, P < 0.001). Restricting comparisons to the two locations where > 15 individuals of both sexes were captured (Avalon segment and Six-Mile Lake) produced similar results (general linear model, site: F = 11.705, df = 1, P = 0.001; sex: F = 38.388, df = 1, P < 0.001; **Figure 9**).

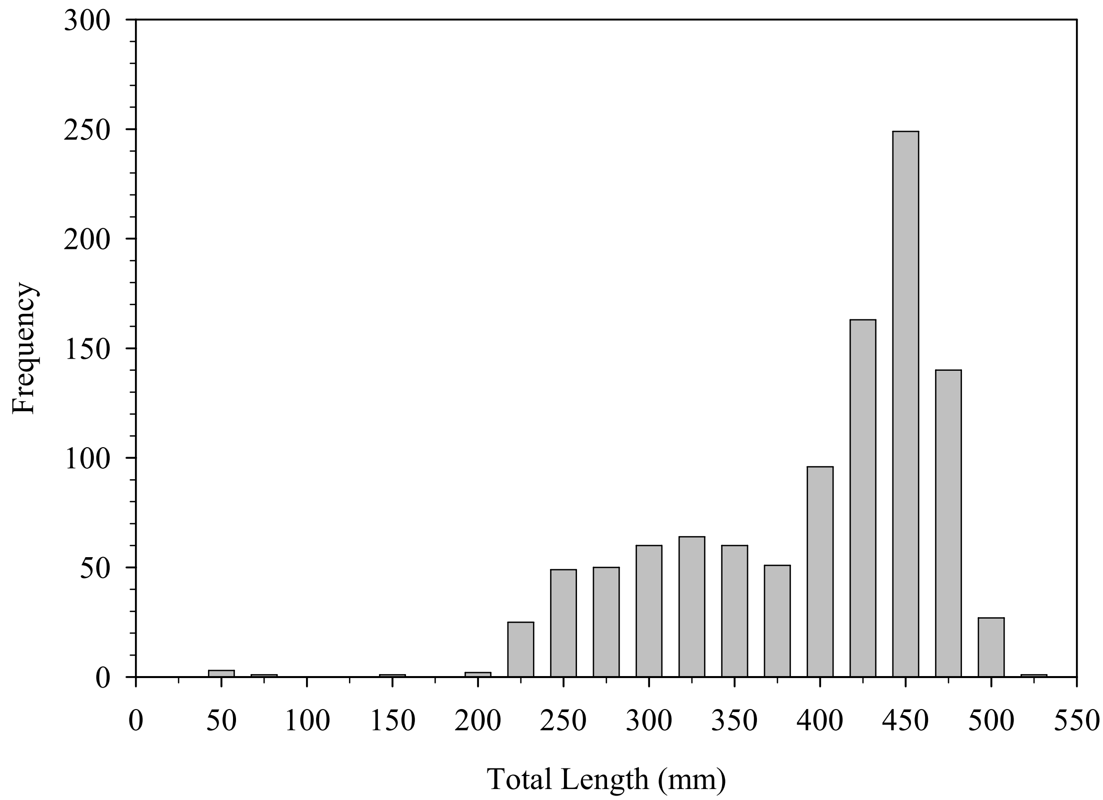

Figure 8. Length distribution of all measured gray redhorse captured during the study.

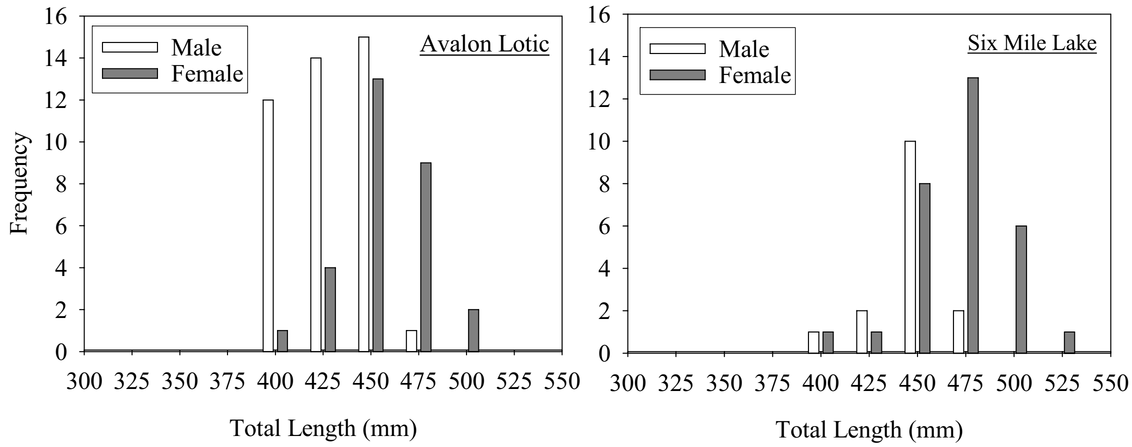

Figure 9. Length distributions of ripe female and male gray redhorse captured in the Avalon lotic reach (left) and in Six Mile Lake (right).

Overall, prior to 2004, gray redhorse were larger in Six Mile Lake and the Avalon segment than in Carlsbad Municipal Lake, the Black River, or the Pecos—Black confluence pool, whereas in 2006 fish were larger in the Black River than in Six Mile Lake or the confluence pool (**Table 4**).

Size structure varied temporally during the study period. Prior to 2004, impoundments and the Avalon lotic reach produced mainly large (> 375 mm) gray redhorse (**Figure 10**). The Black River produced a more diverse but overall smaller size structure. After 2004, the size structure in Six Mile Lake shifted toward much smaller fish, whereas large gray redhorse made up a greater portion of the catch from the Black River. Size structure at the Pecos—Black confluence was inconsistent across years, and the sample size exceeded five gray redhorse only in 2001 and 2006.

Relatively high sampling intensity at Six Mile Lake, combined with persistence of a sizeable gray redhorse population, indicated three patterns of variation in population size structure. First, every sampling event during 2000 through 2004 produced primarily large gray redhorse (event means = 416 to 449 mm TL), whereas mainly smaller redhorse and few large individuals were caught in 2006 (event means = 251—307 mm) (**Figure 10**). Length in 2006 was significantly less than in 2000, 2001, 2002, 2003, and 2004 (ANOVA, $F = 407$, df = 5, $P < 0.001$; Tukey's pair-wise comparisons, all $P < 0.001$), but lengths were otherwise similar among years, with the exception that lengths in 2004 exceeded those in 2001 ($P = 0.01$). Second, for 2000 through 2004 in aggregate, length distributions were smaller in summer (June through August) than in spring (March through May) or autumn (September through October) (ANOVA, $F = 4.691$, df = 2, $P = 0.01$; **Figure 11**). The difference was significant between summer and spring (Tukey: $P = 0.03$), but marginally non-significant between summer and autumn ($P = 0.06$), whereas lengths in spring and autumn were highly similar ($P = 1.00$). Third, substantial intra-annual growth was apparent from June through December for the class of smaller gray redhorse (i.e., < 386 mm TL) during 2006 (**Table 5**).

Table 4. Comparisons of gray redhorse length distributions among sites. Comparisons restricted to events less than one month apart to minimize effect of intra-annual growth.

Date	Compared Sites and Findings (*N*)	Test	Parameters
Sep 2000	Six Mile Lake (19) > Carlsbad Mun. Lake (11)	*t*-test	$t = 3.63$, df = 28, $P = 0.001$
Apr 2001	Avalon Lotic Reach (10), Six Mile Lake (20), Pecos-Black Confl. (13)	ANOVA	$F = 11.76$, df = 2, $P < 0.001$
	- Six Mile Lake = Avalon Lotic Reach	Tukey	$P = 0.71$
	- Six Mile Lake > Pecos-Black Confl.	Tukey	$P < 0.001$
	- Avalon Lotic Reach > Pecos-Black Confl.	Tukey	$P = 0.006$
May 2001	Six Mile Lake (29) = Avalon Lotic Reach (20) = Brantley Stilling Basin (10)	ANOVA	$F = 0.90$, df = 2, $P = 0.41$
Jul/Aug 2002	Six Mile Lake (28) = Brantley Stilling Basin (10)	*t*-test	$t = 1.78$, df = 36, $P = 0.08$
Mar 2003	Six Mile Lake (8) > Avalon Lotic Reach (47)	M-W	$U = 334.50$, $P < 0.001$
May/Jun 2006	Six Mile Lake (83), Black R. (52), Pecos-Black Confl. (13)	K-W	KW = 50.18, df = 2, $P < 0.001$
	- Black R. > Pecos-Black Confl.	M-W	$U = 585.50$, $P < 0.001$
	- Black R. > Six Mile Lake	M-W	$U = 664.50$, $P < 0.001$
	- Six Mile Lake = Pecos-Black Confl.	M-W	$U = 689.50$, $P = 0.108$

Condition of the smaller length-class of gray redhorse in Six Mile Lake during 2006 varied among months but not according to length (ANOVA; length: $F = 0.14$, df = 1, $P = 0.714$; month: $F = 7.17$, df = 2, $P = 0.001$), declining from June (mean ± SE = 1.26 ± 0.01) to August (1.19 ± 0.01) and December (1.17 ± 0.01). Gray redhorse in Six Mile Lake had higher condition than gray redhorse of similar length in the Black River both in June (included length range 205 to 293 mm TL; Black River: $N = 14$, mean K ± SE = 1.11 ± 0.03; $t = -7.16$, df = 95, P <0.001) and December (length range 256 to 397 mm TL; Black River: $N = 29$, mean K ± SE = 1.06 ± 0.01; December: $t = -7.16$, df = 95, P <0.001). However, condition of gray redhorse in the Black River was similar between June and December (included length range 256 to 408 mm TL; $t = -0.08$, df = 32, P = 0.94).

Analysis of scales indicated that gray redhorse grow rapidly during their first three years and slowly thereafter. Most scales clearly showed up to four annuli (**Figure 12**). However, after the fourth annulus, scales usually showed an abrupt reduction in the number of circuli, and annuli were exceedingly difficult to identify according to objective criteria (**Figure 13**). Also, scales from large gray redhorse were more likely regenerated or eroded at the outer edge. Thus, confidence in the accuracy of discerning age 3 and older was low. Back-calculation using scales produced overall mean incremental growth of 157 mm during age 0; 113 mm during age 1; 85 mm during age 2; and 61 mm during age 3. Gray redhorse grew faster in Six Mile Lake than in the Six Mile lotic reach or in the Black River (**Table 6**), and back-calculated lengths at age were significantly greater for Six Mile Lake than Black River fish (age classes grouped; Mann—Whitney *U*-tests; age 1: $P = 0.000$; age 2: $P = 0.007$; age 3: $P = 0.001$; age 4: $P = 0.047$). Back-calculated lengths in this study were similar to those previously reported by Little (1964b) for gray

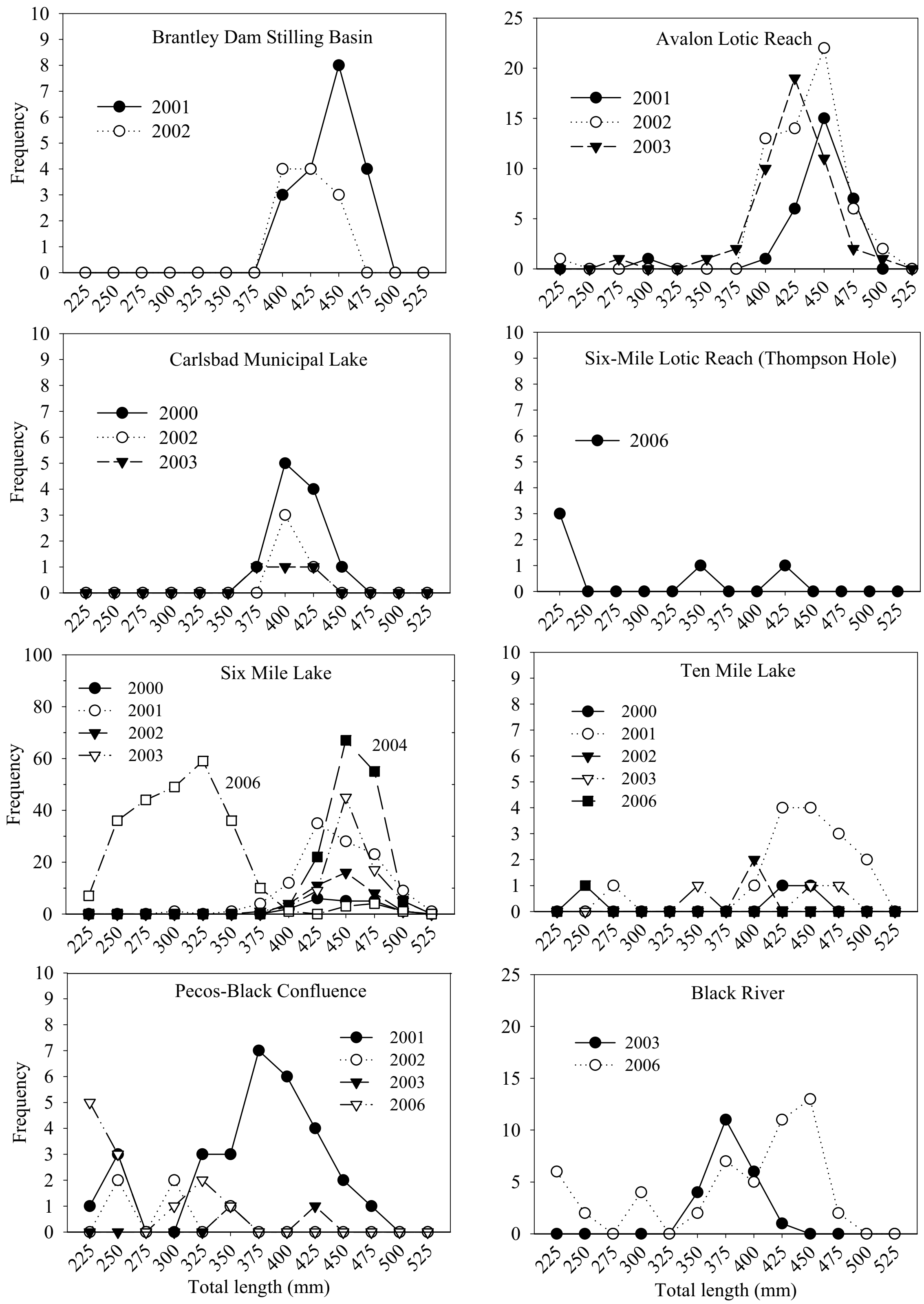

Figure 10. Length distributions of gray redhorse at each study site.

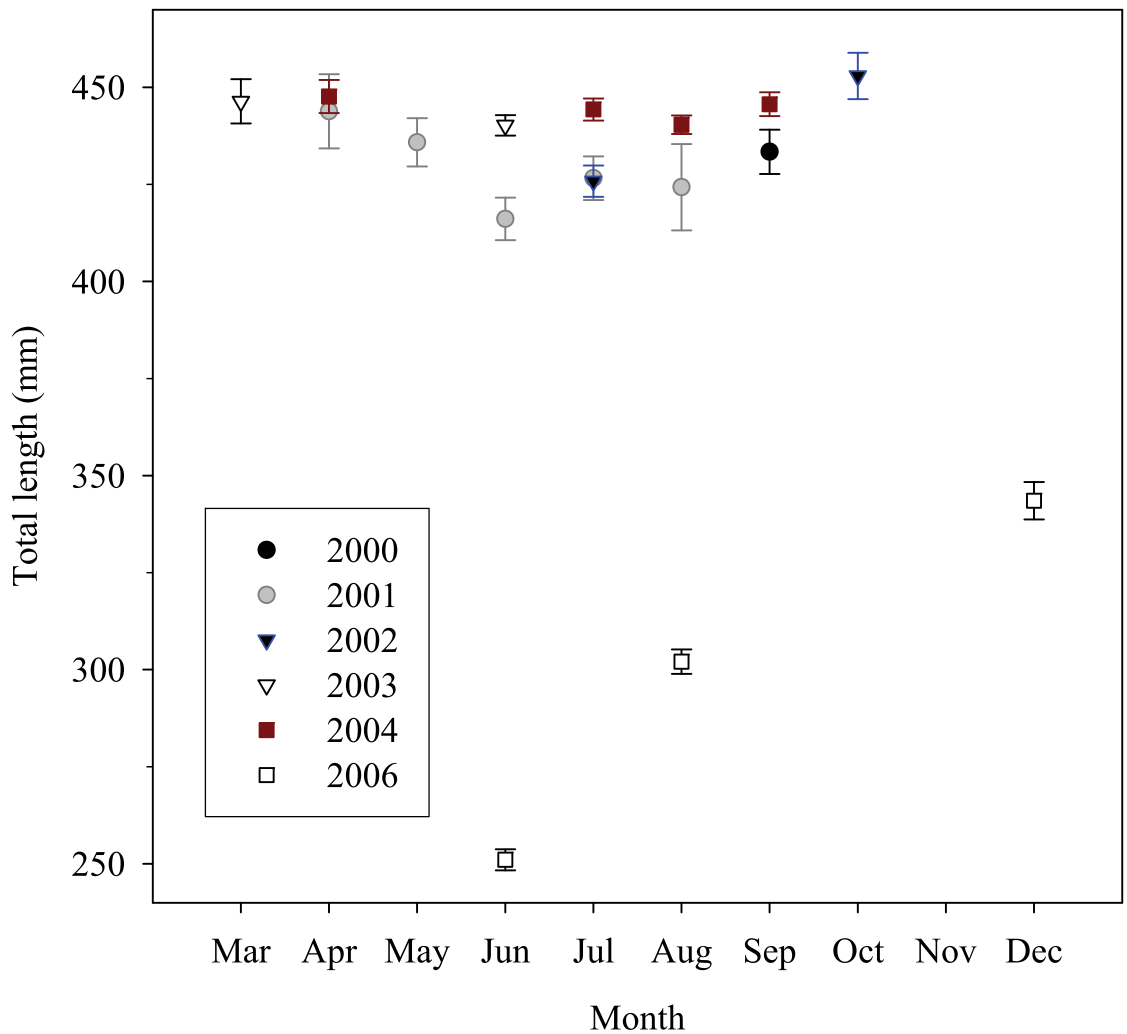

Figure 11. Mean monthly length of gray redhorse (mean ± SE) caught in trammel nets at Six Mile Lake during each year of the study.

Table 5. Comparisons of length distributions for gray redhorse collected in various months within individual years at Six Mile Lake.

Year	Compared Events and Findings	Test	
2001	Apr, May, Jun, Jul, Aug	ANOVA	$F = 3.673$, df = 4, $P = 0.008$
	- Apr > Jun	Tukey	$P = 0.004$
2002	Oct > Jul	*t*-test	$t = -3.711$, df = 38, $P = 0.001$
2004	Apr, Jul, Aug, Sep	ANOVA	$F = 1.705$, df = 3, $P = 0.168$
2006	Jun, Aug, Dec	ANOVA	$F = 625.021$ df = 2, $P < 0.001$
	- Dec > Aug	Tukey	$P < 0.001$
	- Aug > Jun	Tukey	$P < 0.001$

Table 6. Total length (mm) at capture (mean ± SE) and back-calculated lengths at age (BCLAA) for gray redhorse at three sites in 2006 and 2007 and as previously reported for the Pecos River below Carlsbad. Sample size in parentheses; cells having $N < 3$ omitted.

	Age				
Month	0	1	2	3	4
			Black River		
Jun	48 ± 7 (4)	227 ± 3 (6)		374 ± 5 (4)	425 ± 5 (6)
Dec		270 ± 7 (4)		374 ± 5 (14)	
BCLAA		136 ± 3 (36)	263 ± 4 (26)	344 ± 4 (24)	406 ± 10 (6)
			Six Mile Lake		
Jun		250 ± 2 (27)			
Aug		298 ± 4 (8)			
Dec		333 ± 8 (10)			
BCLAA		174 ± 3 (55)	287 ± 26 (9)	400 ± 14 (7)	430 ± 9 (4)
			Six Mile segment lotic reach		
Aug		214 ± 2 (3)			
Feb		229 ± 6 (3)			
BCLAA		138 ± 9 (9)	260 ± 23 (3)		
			Little (1964) – Pecos R. BCLAA		
		137 (19)	282 (18)	380 (13)	410 (8)

redhorse captured south of Carlsbad (**Table 6**). Von Bertalanffy growth curves fit using mean back-calculated lengths calculated theoretical average maximum lengths (L_∞) of 539 mm TL for Six Mile Lake and 525 mm for the Black River (**Figure 14**); however, the largest gray redhorse caught at Six Mile Lake during the study was 509 mm (age 7, based on growth curve) and at the Black River was 455 mm (age 5), possibly indicating underestimation of age using scales from large fish (> 400 mm).

Length-frequency data for Six Mile Lake in 2006 and tag—recapture data for previous years corroborate interpretation of scale data suggesting rapid early growth followed by an abrupt slowing in growth. In 2006, length frequencies were unimodal, excluding a few large fish. Mean length (± SE) for this class increased from 248.8 ± 13.7 mm TL in June to 299.1 ± 12.2 mm in August and 335.1 ± 20.5 mm in December, roughly similar to mean back-calculated values of 250 mm at age 1 and 330 mm at age 2. Recaptured gray redhorse from Six Mile Lake were all in the larger size range when tagged (≥ 390 mm), but a 237-mm fish at the confluence pool grew a comparable 95 mm in about a year (336 days). Large, PIT-tagged gray redhorse recaptured in Six Mile Lake typically grew slowly (**Table 7**). Fish recaptured after 1 to 5 months at liberty showed little overall growth, and declines were measured in total length for 1/3 of individuals and in standard length for 1/6. Gray redhorse recaptured one or more years after tagging grew at rates of 2.5 ± 1.7 mm TL or 11.7 ± 2.4 mm SL per year (mean ± SE), although total length declined for 1/3 and standard length for 1/10 of individuals. Growth was poorly predicted by number of days at liberty ($N = 39$; TL = 0.028 * days - 4.934, $r^2 = 0.45$; SL = 0.024 * days + 7.500, $r^2 = 0.22$) and size at tagging ($N = 38$; growth rate (mm/d) = -0.0011 * TL + 0.495, $r^2 = 0.16$; growth rate (mm/d) = -0.0005 * SL + 0.2636, $r^2 = 0.00$). Two large gray redhorse (mean = 445 mm TL at tagging) were recaptured two years after release and two others (mean = 412 mm TL) three years after release, supporting the assertion that some redhorse probably attain at least age 5.

Growth data from the few gray redhorse recaptured at other study locations were similar to those for Six Mile Lake. In the Brantley Dam stilling basin, two gray redhorse (398, 443 mm TL) recaptured after 29 and 106 days were measured to be 2—6 mm smaller in both TL and SL, whereas a 420-mm TL fish grew 14 mm in TL and 15 mm in SL over 437 days. In the Avalon segment lotic reach, a 418-mm fish lost 3 mm in TL but grew 25 mm in SL over 321 days, and a 412-mm fish grew 3 mm in TL and 26 mm in SL over 217 days. Measurements of redhorse recaptured within two days of release indicated that precision in measurement of lengths was reasonably high (**Table 7**).

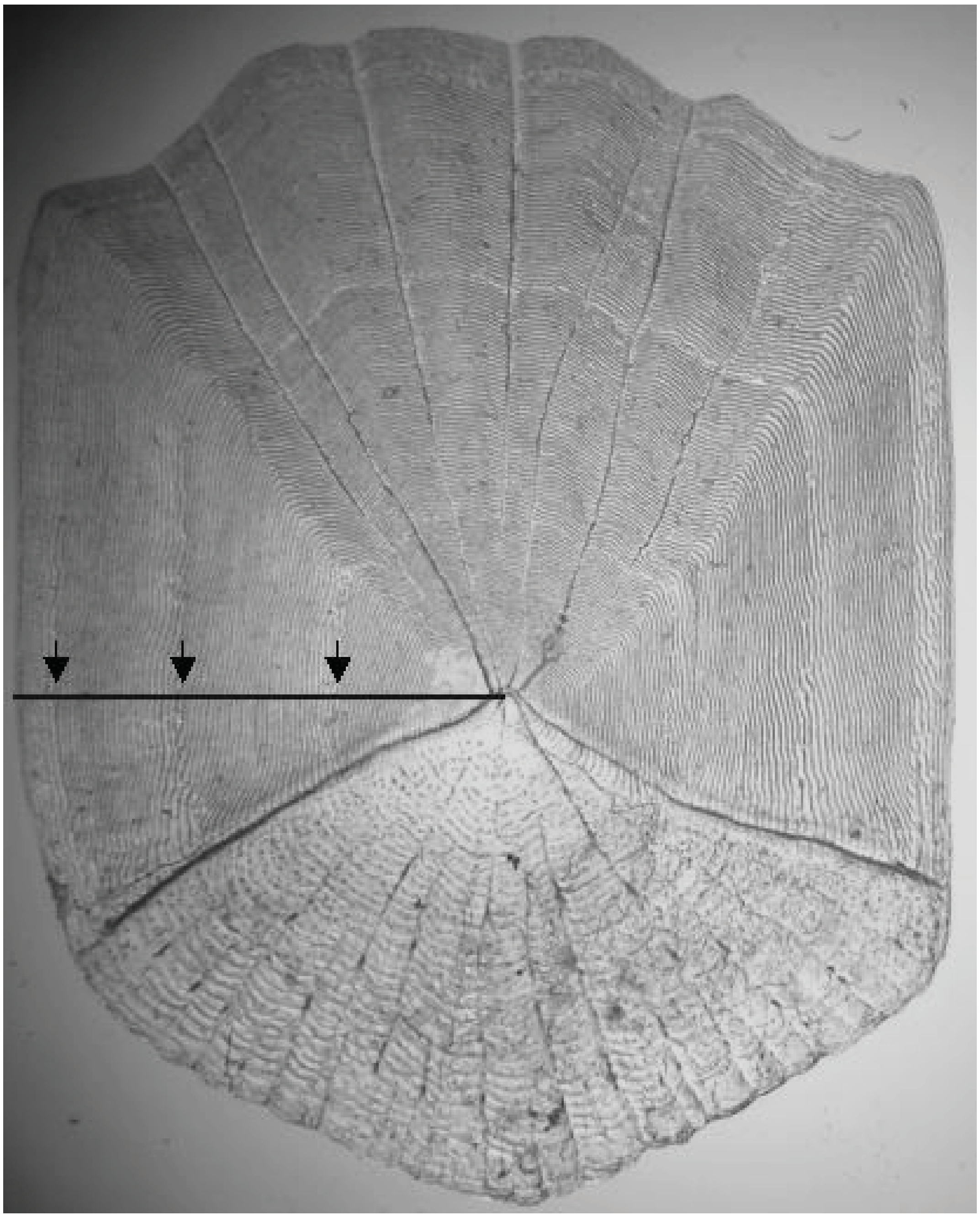

Figure 12. Scale from a 397-mm gray redhorse, estimated to be age 3, collected from the Black River on 4 December 2006. Arrows indicate annuli along axis of measurement.

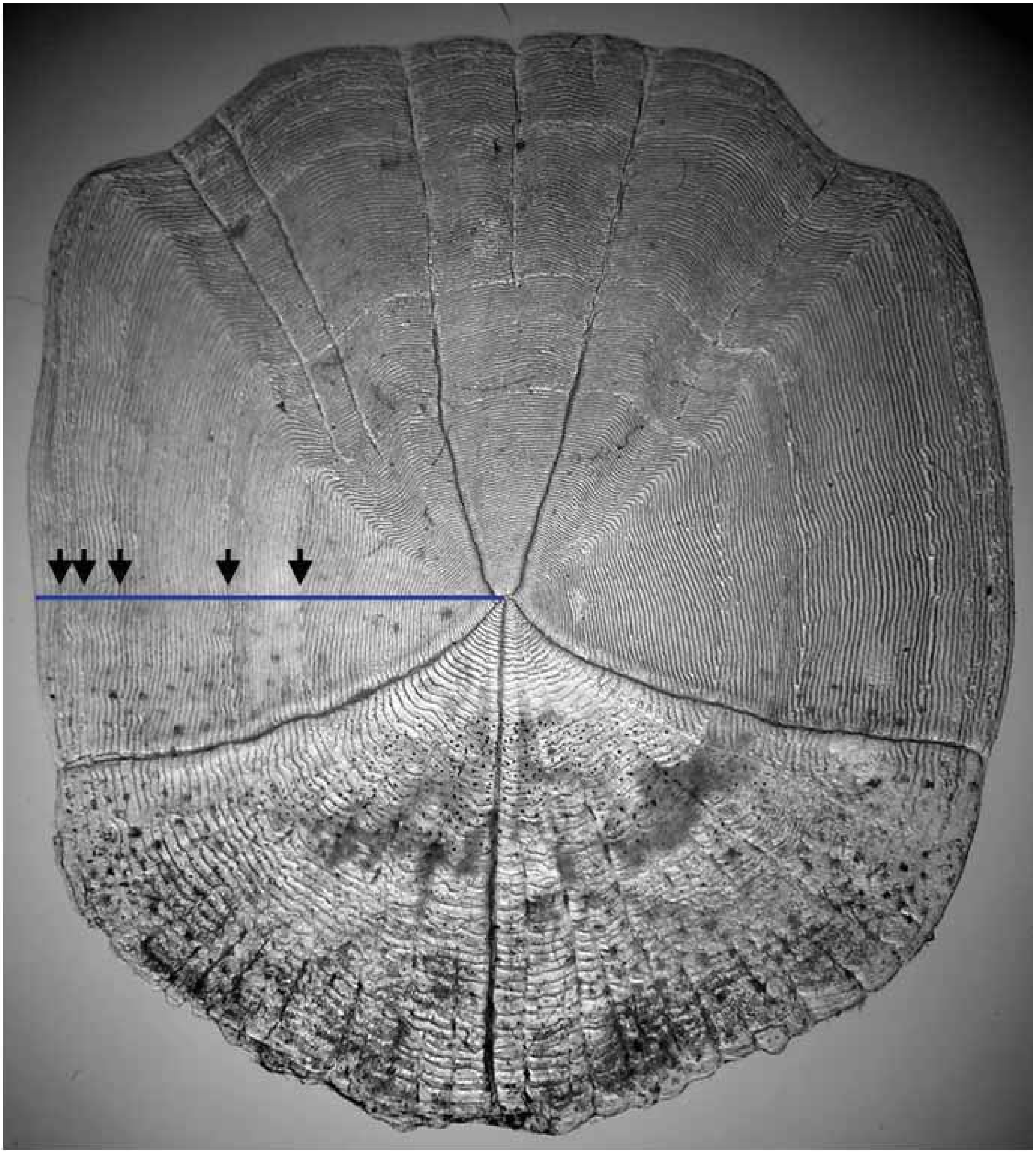

Figure 13. Scale from a 418-mm TL gray redhorse, estimated to be age 5, collected from Six Mile Lake on 18 August 2006. Arrows indicate annuli along axis of measurement.

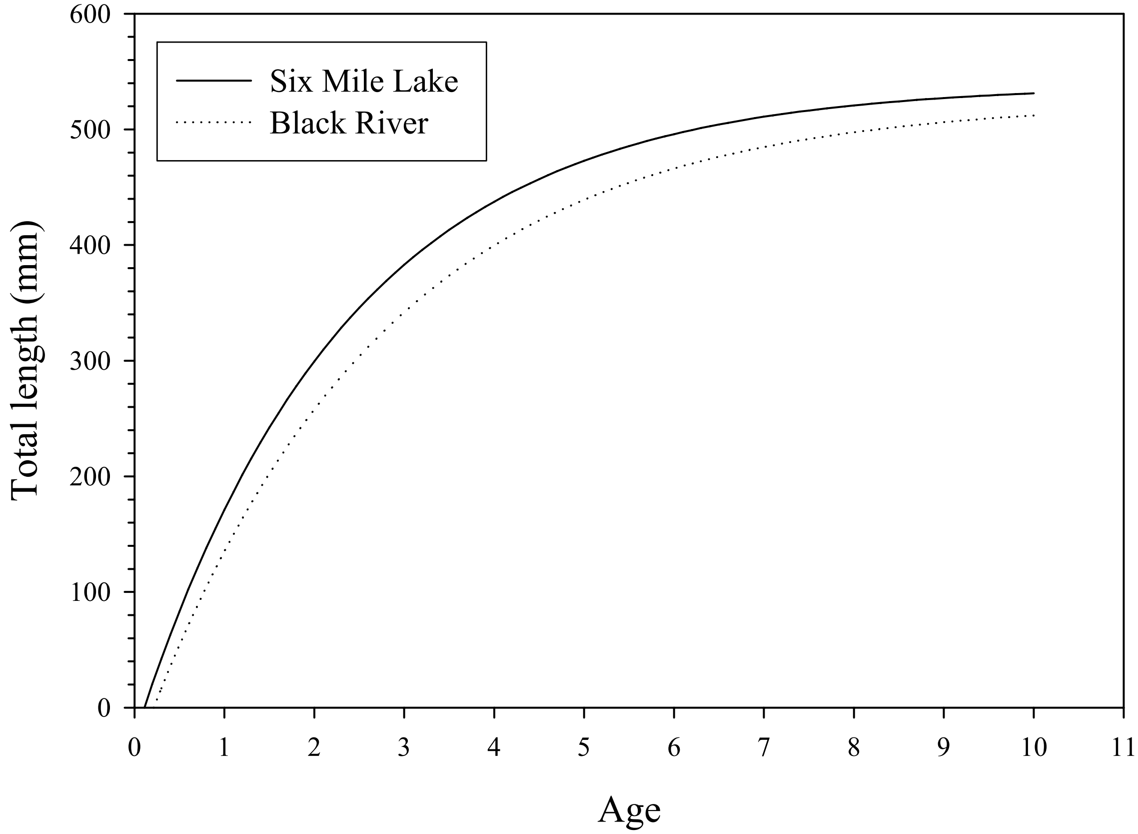

Figure 14. Growth curves (VBGF) for gray redhorse caught in 2006.

Table 7. Measured growth (mean ± SE) of recaptured PIT-tagged gray redhorse, categorized by amount of time at liberty.

		Size at tagging (mm)			Change in size (mm)		
Days at liberty	N	TL	SL	WT	TL	SL	WT
0—2	15	435.0 ± 6.3	360.2 ± 6.2	991.0 ± 64.0	0.1 ± 1.6	-1.5 ± 1.0	11.0 ± 15.7
27—48	6	442.2 ± 7.6	356.8 ± 6.2	891.6 ± 52.7	-1.7 ± 1.9	6.8 ± 4.9	-22.5 ± 45.4
75—78	5	452.8 ± 8.4	363.2 ± 9.7	1080.0 ± 131.5	1.8 ± 2.0	17.8 ± 6.9	-14.0 ± 138.4
97—104	4	438.7 ± 16.9	350.7 ± 15.9	1137.5 ± 234.6	3.8 ± 2.4	10.0 ± 3.9	-137.5 ± 157.6
152—154	3	457.3 ± 5.4	366.3 ± 11.3	1016.6 ± 44.1	-0.3 ± 3.9	23.6 ± 6.4	3.3 ± 48.4
239—463	15	443.4 ± 3.9	359.4 ± 3.5	1265.0 ± 64.0	0.7 ± 2.4	13.9 ± 3.5	-137.0 ± 61.2
716—764	3	445.3 ± 26.0	360.3 ± 21.5	1073.3 ± 146.8	12.3 ± 6.2	21.6 ± 6.0	126.7 ± 122.0
1120—1175	2	412.5 ± 7.5	333.0 ± 2.0	825.0 ± 125.0	40.0 ± 0.0	38.0 ± 3.0	162.5 ± 112.5

The relationship between total and standard lengths of gray redhorse in this study was described by the equation: SL = 1.2219 * TL - 1.935 (N = 1033, r^2 = 0.979). The length—mass relationship for all gray redhorse was: Mass = -4.93 * $TL^{3.0017}$ (r^2 = 0.954; N = 1023). Variance in the relation was not readily attributable to sex or maturation status.

Habitat Characteristics and Spawning Areas

Blue sucker

Patchy distribution of blue suckers in the Pecos River – Avalon segment indicated an association with relatively high gradient reaches. Most blue suckers were caught below the Hwy 30 bridge, below Rocky Arroyo, and near Soapberry Draw in high-velocity chutes, riffles, and interspersed deep pools. However, this species appeared to avoid the long, low-velocity stretches between high gradient areas. By contrast, blue suckers in the much smaller Black River were captured in large, deep pools or observed at the heads of these pools, but none was captured while seining or electrofishing the narrow, high-velocity stream sections. Habitat use of juvenile blue suckers could not be assessed because almost none was found. Six were seined from the CID canal on a single occasion.

Telemetry provided little insight into blue sucker habitat use or movement patterns. Valid locations were obtained for two blue suckers (**Figure 15**), but only for a period of two weeks after tagging. A 620-mm fish was relocated 1.06 km downstream of its release location six days subsequent to tagging. This fish seemed to be moving about a large, low-velocity pool downstream of the rapid at Soapberry Draw. A 664-mm fish exhibited little movement and was located three times within a two-week period in the braided "Three-Channel Area" near Rocky Arroyo. This fish was located in a fast run and in a deep pool along a bedrock outcrop, immediately below a small rapid where numerous blue suckers were observed during electrofishing runs. No valid locations were obtained for the other six telemetered blue suckers.

Spawning by blue suckers was not observed, but corollary evidence suggested its occurrence in high-gradient sections of the Avalon lotic reach. A ripe female (850 mm TL) was captured on 6 March 2003 when water temperature was 12.3º C, and one ripe male (688 mm TL) was captured on 4 March 2001 when water temperature was 14.4 º C. Numerous additional tuberculate males were handled during March, April, and May of 2001 through 2003. Blue suckers were observed in groups of as many as ten individuals occupying narrow, high-velocity riffles and runs during these occasions. In 2001, the April mean daily mean temperature was 15.4º C and the mean daily maximum was 19.1º C (**Table 1**).

Gray redhorse

Gray redhorse occupied a wide variety of habitats across the study area. Relatively high abundances occurred in lentic habitats such as the Brantley Dam stilling basin, Six Mile Lake, the large pools of the Black River, and the confluence pool of the Pecos and Black rivers. However, small numbers of gray redhorse were also captured by seining in high-velocity lotic portions of these same river segments, and gray redhorse were concentrated in the same high gradient sub-reaches as blue suckers in the Avalon lotic reach.

Catch data suggested higher abundance at the upstream portions of impoundments. The upper end of Carlsbad Municipal Lake, where gray redhorse was concentrated, has numerous large boulders, substantial spring inflow, and lower turbidity than the lower lake. In Six Mile Lake, the upper portion of the lake tended to produce more gray redhorse than the lower or middle portions, although greatest effort was expended at the upper end of the reservoir during 2000 through 2004 (**Figure 16**). In 2006, June and August sampling produced gray redhorse from throughout the lake, although the middle and upper portion most consistently produced high catch rates (**Figure 17**). The uppermost portion of the lake, from the island up to the Pecos River inlet, produced notably high catch rates (to 8.7 f/nh) in some nets, indicating concentrations of fish in these holes. Few gray redhorse were captured at Ten-Mile Lake, but they occurred in the upper lake during five events in which nets were set throughout the lake. Based on the longitudinal location of fish entangled in trammel nets set perpendicular from shore during daylight hours, gray redhorse were not associated with proximity to shore or presence of submerged shoreline brush (i.e., *Tamarix spp.*) but tended to be caught anywhere from about 5 to 30 m from shore. High catch rates using trammel nets in December 2006 (to 32.8 f/nh in one net) at Six Mile Lake and the Black River indicated that gray redhorse remain active in winter, when conspicuously few fish of other species were captured.

Small juvenile gray redhorse (i.e., < 100 mm) were only found at the Black River during June in the downstream portions of large, deep (> 1.5 m) pools having little current (< 0.25 m/s). These pools had cut banks with overhanging vegetation, and substrates comprised of a mixture of sand, silt, travertine boulders, and rubble. No small gray redhorse was caught in the adjacent high-gradient riffles or chutes. A few larger juveniles (150-200 mm) were seined from small pools and runs within swifter portions of the Pecos River downstream of the Black River confluence, and two larger juveniles (211—216 mm) were caught with trammel nets in the upper portion of a large pool (Thomason Hole) upstream of Six Mile Lake.

Telemetry efforts provided limited data on habitat use of six of the thirteen tagged gray redhorse (**Figure 18** through **Figure 22**). Tagged gray redhorse were relocated 2 to 7 times over contact periods of 29 to 269 days after tagging. In the Avalon lotic reach, gray redhorse were found at mean (± SD) depth of 1.04 ± 0.21 m, mean water velocity of 0.11 ± 0.09 meters per second, and over various substrates. Fish moved at a mean rate of 16.9 ± 0.8 meters per day; however, movements were highly variable among individuals. Three fish were located near the Hwy 30 bridge for several weeks during spring of 2002 before moving downstream, whereas one fish remained near the point of release (three-channel area) for the duration of contact. Three of these individuals died or expelled their tags, and only one (tag 77 – 4.12) survived into summer. Most locations were within areas of relatively high channel heterogeneity, although one fish (tag 77 – 4.12) was located on multiple occasions in flat reaches with overhanging tamarisk. The two gray redhorse in Six Mile Lake that moved after tagging both moved about halfway up the lake and subsequently remained in localized areas through the final contact in December of 2003. These fish occupied slack water at a mean (± SD) distance of 8.3 ± 6.7 m from shore (range = 3 to 15 m) at mean depth of 1.43 ± 0.48 m and substrate comprised of silt and sand.

Gravid female gray redhorse were captured on 17 April 2002 in the Avalon lotic reach, in Six Mile Lake on 25 March 2003, and 5 April 2001 at the Pecos—Black confluence pool. Spent females were captured at the confluence pool on 5 April 2001 and in Six Mile Lake on 29 April 2004. Ripe males were caught from 3 April to 19 June 2001 in the Avalon lotic reach, 13 May 2003 at Carlsbad Municipal Lake and Ten Mile Lake, late March to mid-May at Six Mile Lake, and on 13 and 14 May 2003 in the Black

River. Several gray redhorse were observed above patches of gravel that appeared to be cleaned of algae and vegetation in Six Mile Lake below the inflow of the Pecos River holding on 3 April 2003. On 11 April 2002, an aggregation of about ten redhorse was observed working upstream over a cobble bar in the Avalon lotic reach, apparently feeding, then drifting back to the original position. Aggregations of gray redhorse and common carp *Cyprinus carpio* were observed on 9 June 2000 in a riffle, where individuals would move laterally and occasionally tilt to the side.

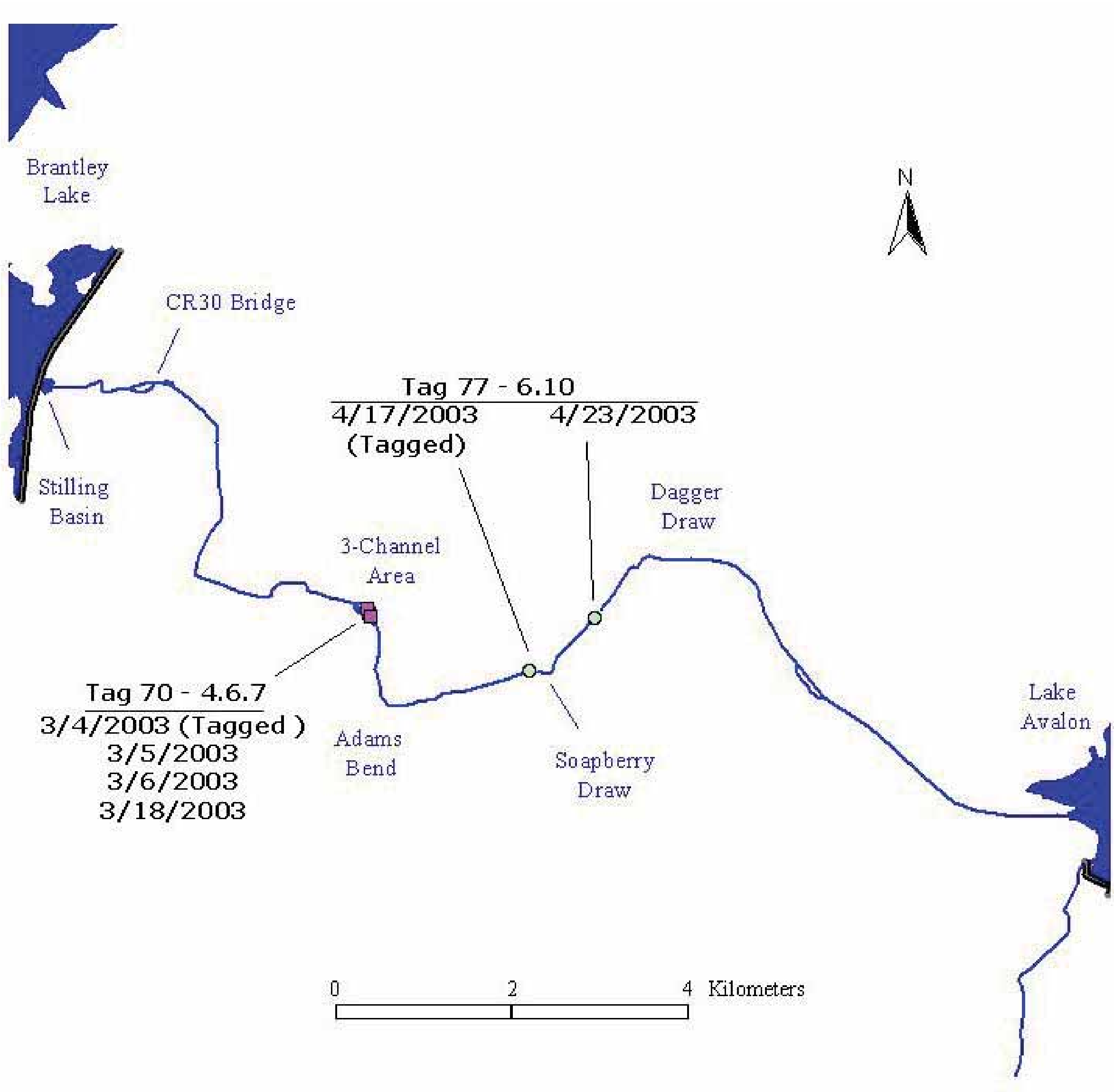

Figure 15. Blue sucker tagging and relocation points obtained by sonic telemetry in the Pecos River, Avalon segment. Relocation points for other tagged blue suckers excluded because of inconclusive evidence for attachment to living fish.

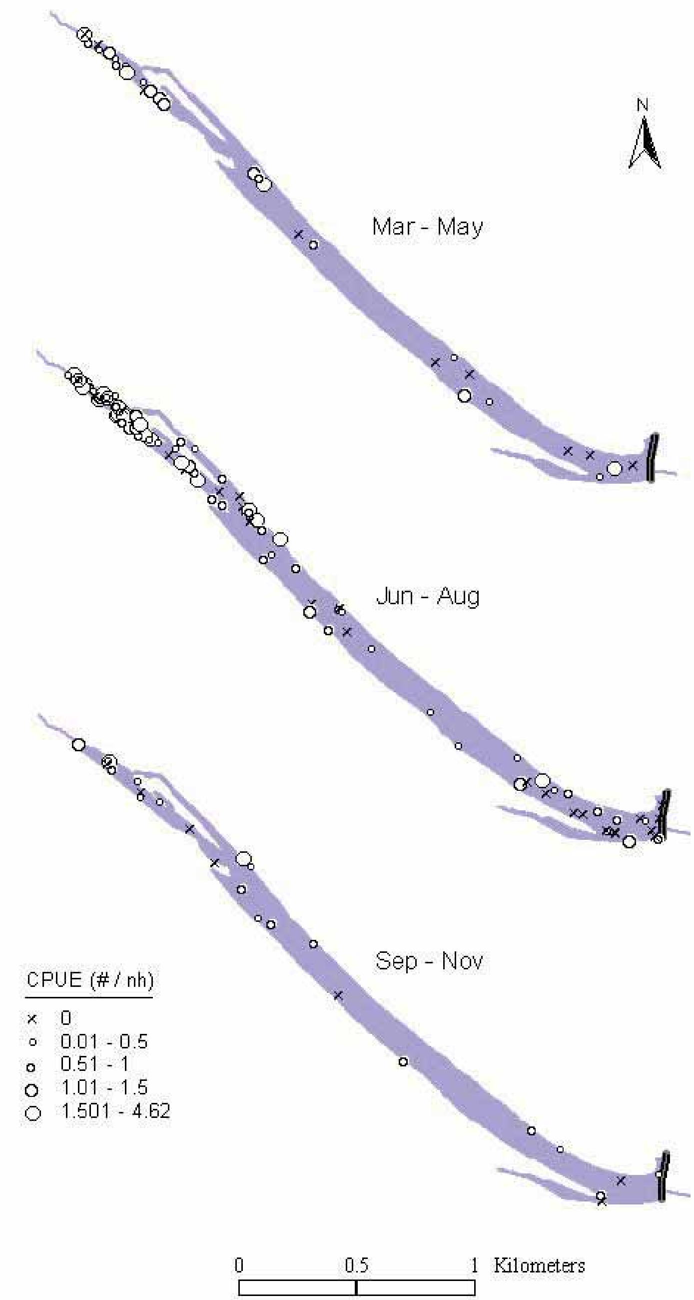

Figure 16. Gray redhorse CPUE for individual trammel nets at Six Mile Lake during spring (top), summer (middle), and autumn (bottom) of 2000 through 2005.

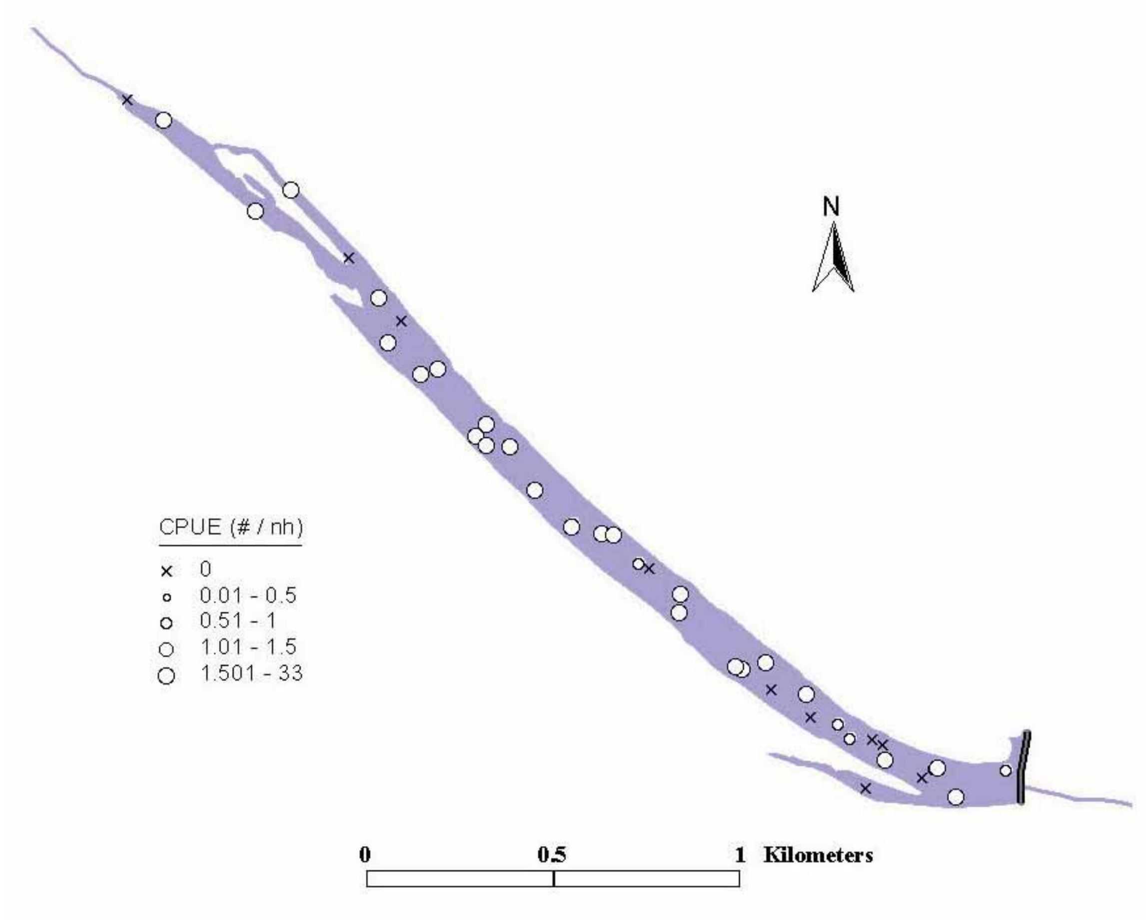

Figure 17. Gray redhorse CPUE for individual trammel nets at Six Mile Lake during 2006. Five upstream-most locations (top left) sampled in December; remainder sampled in June and August.

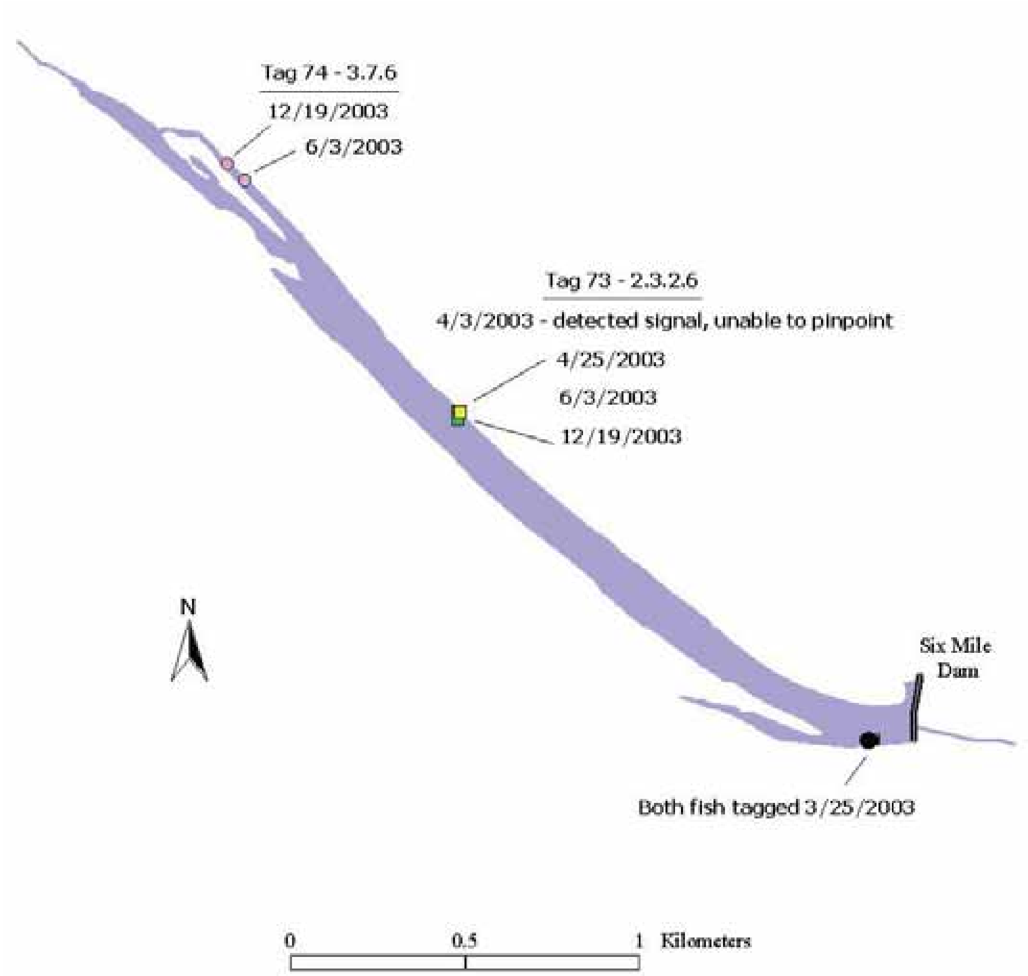

Figure 18. Gray redhorse tagging and relocation points obtained by sonic telemetry in Six Mile Lake. Relocation points for one additional tagged redhorse excluded because of inconclusive evidence for attachment to living fish (twice relocated at release point).

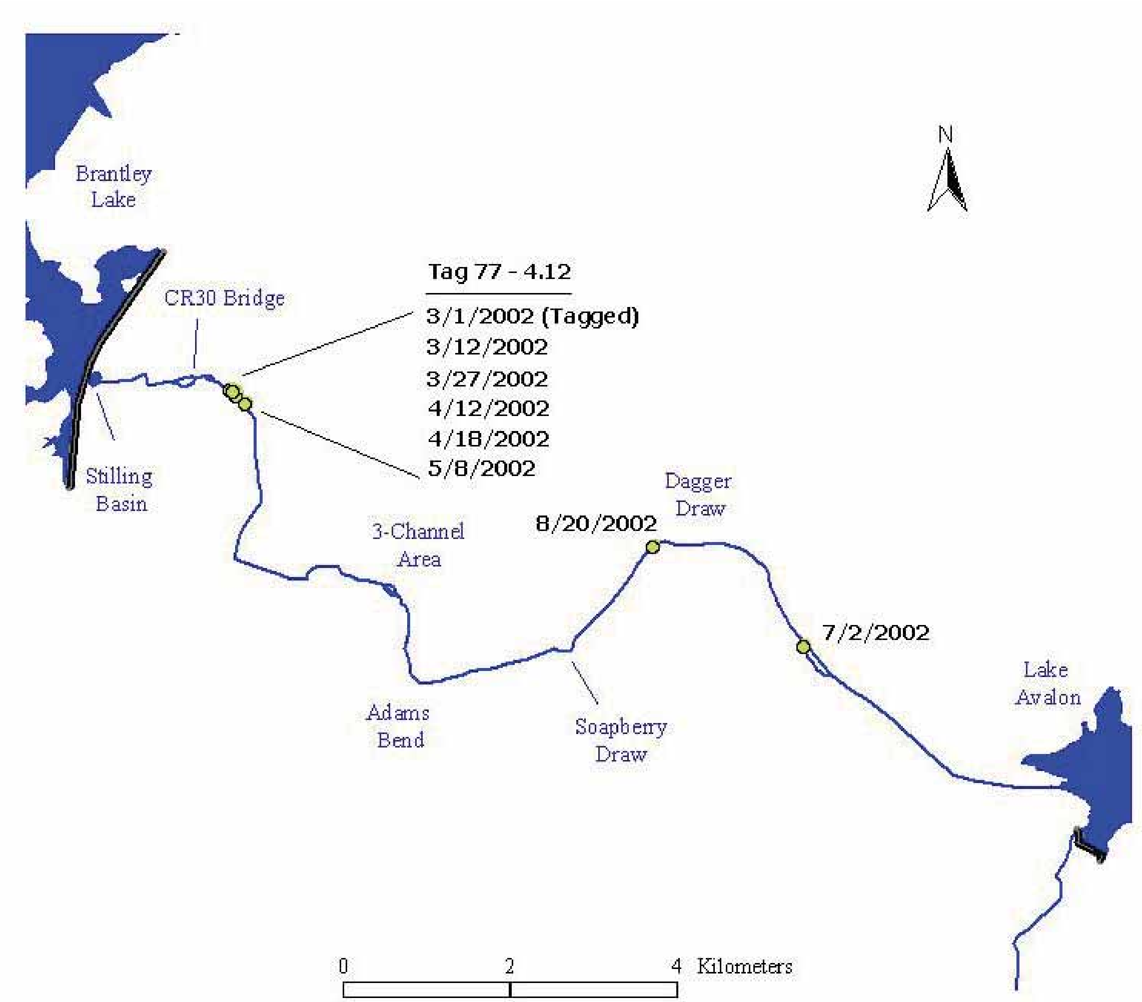

Figure 19. Gray redhorse (tag 77 – 4.12) tagging and relocation points obtained by sonic telemetry in the Pecos River, Avalon segment.

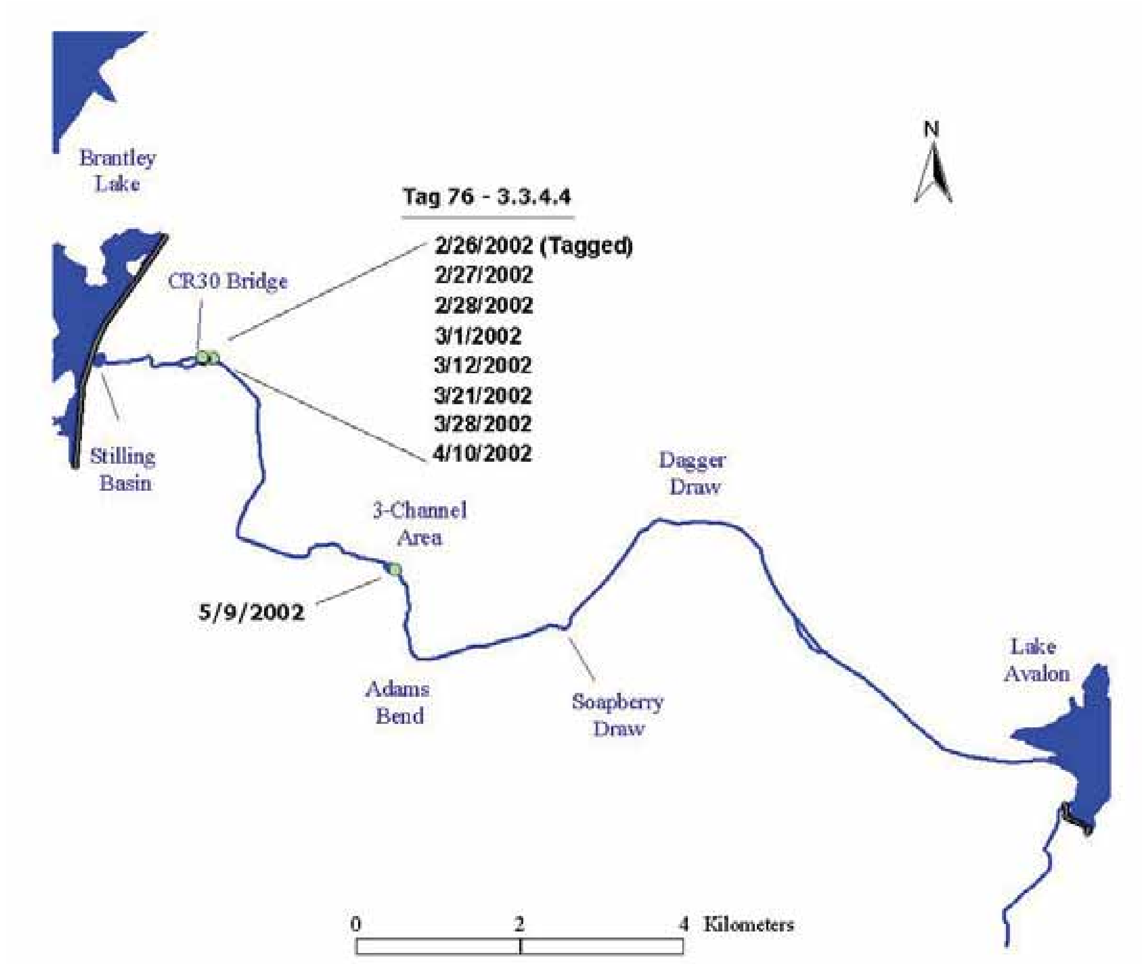

Figure 20. Gray redhorse (tag 76 – 3.3.4.4) tagging and relocation points obtained by sonic telemetry in the Pecos River, Avalon segment. Tag was subsequently located 7 times through June 2003 at exactly the same point in a deep pool, suggesting expulsion.

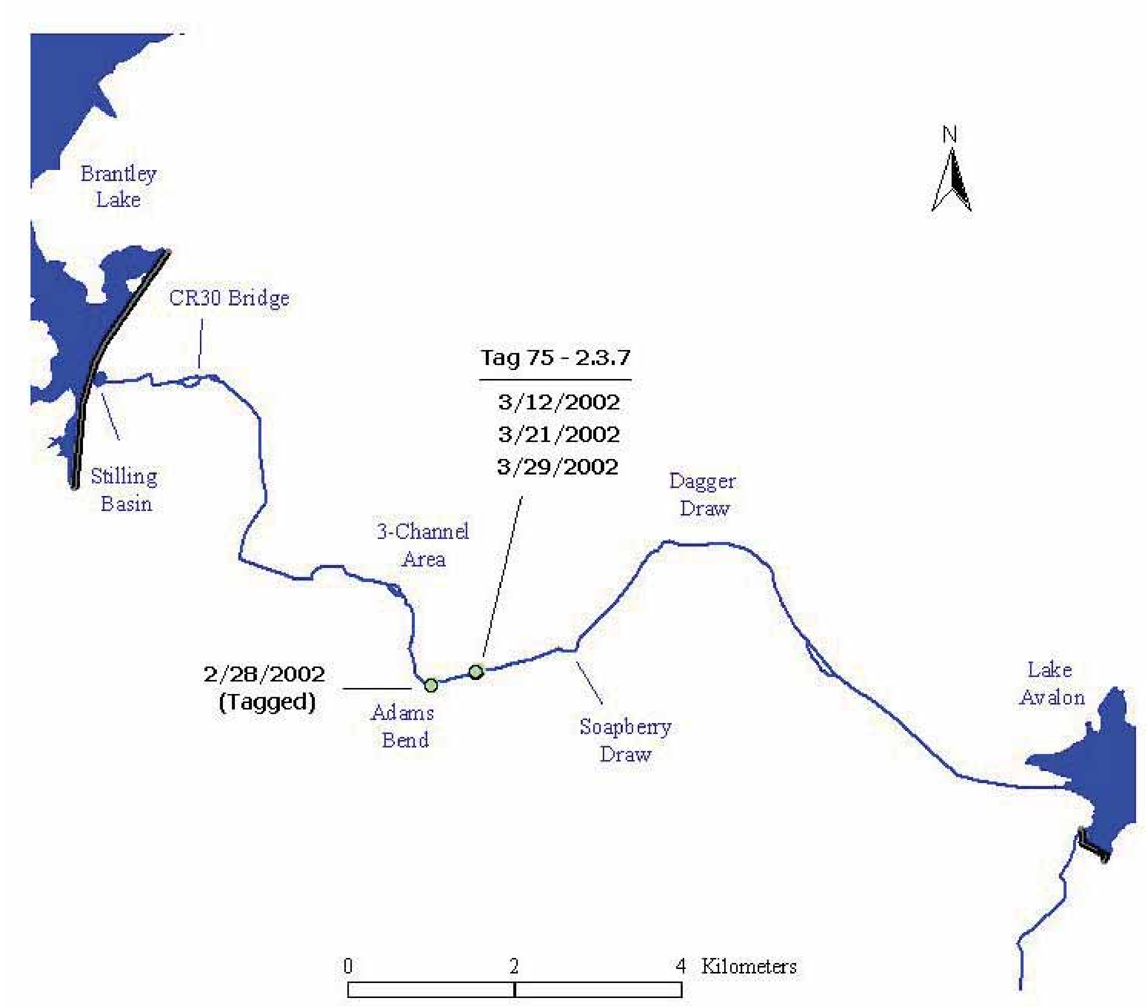

Figure 21. Gray redhorse (tag 75 – 2.3.7) tagging and relocation points obtained by sonic telemetry in the Pecos River, Avalon segment.

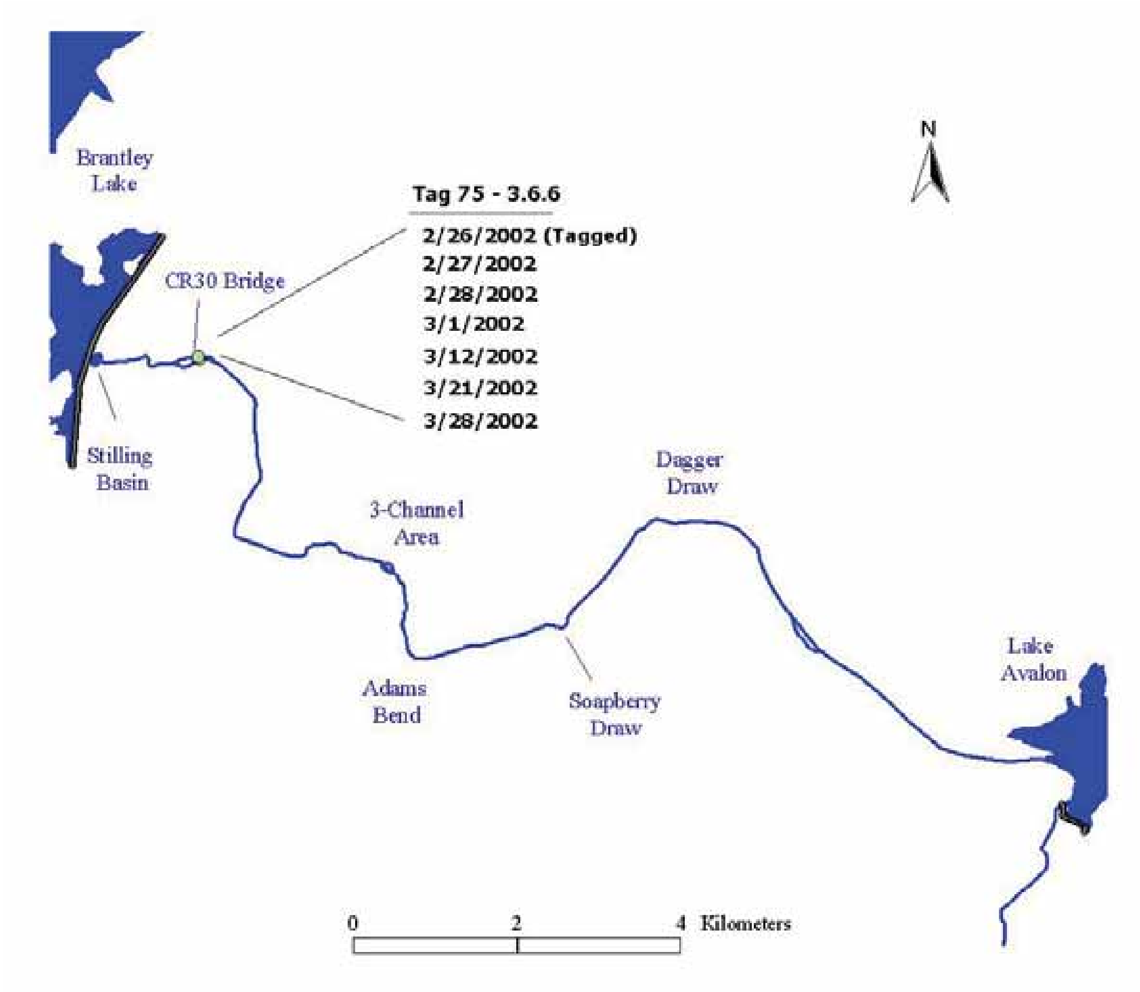

Figure 22. Gray redhorse (tag 75 – 3.6.6) tagging and relocation points obtained by sonic telemetry in the Pecos River, Avalon segment. Tag was subsequently detected on six occasions through July 2002 at a debris pile downstream of Adams Bend, indicating probable expulsion.

Fish Species Associations / Community Characteristics

Thirty-four fish species were sampled across the study area. The five most abundant large-bodied fishes, gizzard shad *Dorosoma cepedianum*, common carp *Cyprinus carpio*, gray redhorse, river carpsucker, and bluegill *Lepomis macrochirus* collectively comprised 80 % of the total excluding young of the year specimens (**Table 8**). Longnose gar *Lepisosteus osseus*, largemouth bass *Micropterus salmoides*, and *Ictalurus spp.* catfish were also commonly captured. Nine additional large-bodied species each comprised less than 1.5 % of the total catch. For those sampling events producing blue sucker (N = 10, excluding CID canal in 2000 and Black River in 2005 and 2006), the fish assemblage most frequently included gray redhorse (90 % of events), river carpsucker (90 %), common carp (70 %), *Ictalurus spp.* (70 %), and gizzard shad (60 %). Longnose gar, six

Table 8. Large-bodied fishes captured during the study and their overall abundance. Channel *I. punctatus* and headwater *I. lupus* catfishes and their hybrids grouped as "Catfish" because of impracticality of field identification. Many small-bodied young of the year fish not enumerated during exploratory seining and excluded from totals (primarily centrarchids and catfishes).

Scientific name	Common name	Code	Count	Relative abund.	Rank abund.
Carpiodes carpio	River carpsucker	CARCAR	756	0.123	4
Cycleptus elongatus	Blue sucker	CYCELO	51	0.008	14
Ictiobus bubalus	Smallmouth buffalo	ICTBUB	16	0.003	16
Moxostoma congestum	Gray redhorse	MOXCON	1090	0.178	2
Lepomis cyanellus	Green sunfish	LEPCYA	92	0.015	9
Lepomis gulosus	Warmouth	LEPGUL	62	0.010	12
Lepomis macrochirus	Bluegill	LEPMAC	750	0.122	5
Lepomis megalotis	Longear sunfish	LEPMEG	75	0.012	11
Micropterus punctulatus	Spotted bass	MICPUN	77	0.013	10
Micropterus salmoides	Largemouth bass	MICSAL	261	0.043	7
Pomoxis annularis	White crappie	POMANN	5	0.001	19
Dorosoma cepedianum	Gizzard shad	DORCEP	1211	0.197	1
Cyprinus carpio	Common carp	CYPCAR	1079	0.176	3
Ameiurus melas	Black bullhead	AMEMEL	54	0.009	13
Ictalurus spp.	Catfish	ICTSPP	243	0.040	8
Pylodictus olivaris	Flathead catfish	PYLOLI	6	0.001	18
Lepisosteus osseus	Longnose gar	LEPOSS	280	0.046	6
Morone chrysops	White bass	MORCHR	19	0.003	15

centrarchid species, and white bass *Morone chrysops* occurred in fewer than six samples. For the 66 events producing gray redhorse, co-occurring species most often included river carpsucker (90 % of events), gizzard shad (81 %), *Ictalurus spp.* (79 %), bluegill (76 %), largemouth bass (66 %), and common carp (66%). Ten additional species co-occurred with redhorse in less than 50 % of gray redhorse collection events. Seine hauls and hoop net sets produced 17 small-bodied species (**Table 9)**, primarily of the families Cyprinidae and Cyprinodontidae, in addition to juvenile individuals of some large-bodied fishes. Red shiner *Cyprinella lutrensis*, inland silversides *Menidia beryllina*, fathead minnow *Pimephales promelas*, and western mosquitofish *Gambusia affinis* were most abundant and widespread overall. Gulf killifish *Fundulus grandis* and rainwater killifish *Lucania parvo* also occurred in all study segments of the Pecos River. Six cyprinids, including Arkansas River shiner *Notropis girardi*, golden shiner *Notemigonus chrysoleucas*, plains minnow *Hybognathus placitus*, Pecos bluntnose shiner *Notropis pecosensis*, Rio Grande minnow *Notropis jemezanus*, and speckled chub *Macrhybopsis aestivalis* were found only in the Avalon lotic reach. Other than golden shiner, these species were also common in the Pecos River upstream of the project area.

Fish assemblage composition shifted substantially during the course of the study in some study segments (**Figure 23** through **Figure 29**). The Avalon segment provided a dramatic example, as seven species captured before 2004 were absent from all subsequent collections in the segment. In the Brantley Dam stilling basin, twelve species were sampled in 2001 and 2002, but only three in 2003 and 2006. Common carp, river

Table 9. Small-bodied fish species collected in seine hauls in the Pecos River between Brantley Dam and the Texas state line (specimens <100 mm TL of large-bodied fishes not listed).

Scientific name	Common name
Menidia beryllina	Inland silversides
Astyanax mexicanus	Mexican tetra
Cyprinella lutrensis	Red shiner
Hybognathus placitus	Plains minnow
Macrhybopsis aestivalis	Speckled chub
Notemigonus crysoleucas	Golden shiner
Notropis girardi	Arkansas River shiner
Notropis jemezanus	Rio Grande shiner
Notropis simus	Pecos bluntnose shiner
Notropis stramineus	Sand shiner
Pimephales promelas	Fathead minnow
Cyprinodon pecosensis x variegatus	Pecos pupfish x sheepshead minnow hybrid
Fundulus grandis	Gulf killifish
Gambusia affinis	Western mosquitofish
Gambusia nobilis	Pecos gambusia
Lucania parva	Rainwater killifish
Percina macrolepida	Bigscale logperch

carpsucker, and green sunfish dominated samples in the Avalon segment after 2003, and the catch otherwise included only a single specimen of each bluegill, gizzard shad, largemouth bass, and longnose gar. Sampling at Carlsbad Municipal Lake produced no blue sucker or gray redhorse after 2003. Game fishes were stocked in Carlsbad Municipal Lake subsequent to the occurrence of extensive fish kills beginning in 2003. Golden algae induced fish kills did not eliminate common carp and river carpsucker, unless the lake was repopulated by downstream movement of fishes during block deliveries. Fish diversity at Ten Mile Lake was sharply reduced from previous years and included only river carpsucker in 2004, but diversity and abundances increased in 2005 and 2006. Only one sampling event (Fisherman's Lane pool east of Loving, NM) targeting large-bodied fish was conducted in the state line segment at a location other than the Pecos—Black confluence pool, and that event produced only river carpsucker, common carp, and gizzard shad. Longnose gar was absent from all samples collected downstream of Six Mile Dam after 2003, whereas it was previously common in Ten Mile Lake and at the Pecos—Black confluence pool.

Large-scale changes in fish assemblage composition were not detected at Six Mile Lake and the Black River. Catch rates for most species were roughly similar at Six Mile Lake before and after fish kills began to occur in the area, and 7 to 11 species were collected each year from 2001 through 2006. In 2002, gizzard shad abundance was notably higher than in other years in Six Mile Lake. Gray redhorse were relatively abundant in Six Mile Lake during all years of sampling but shifted to a much smaller size structure between 2004 and 2006. The Pecos—Black confluence also retained high diversity across sampled years, although lack of sampling during 2004 and 2005 precluded detection of perturbations that may have occurred.

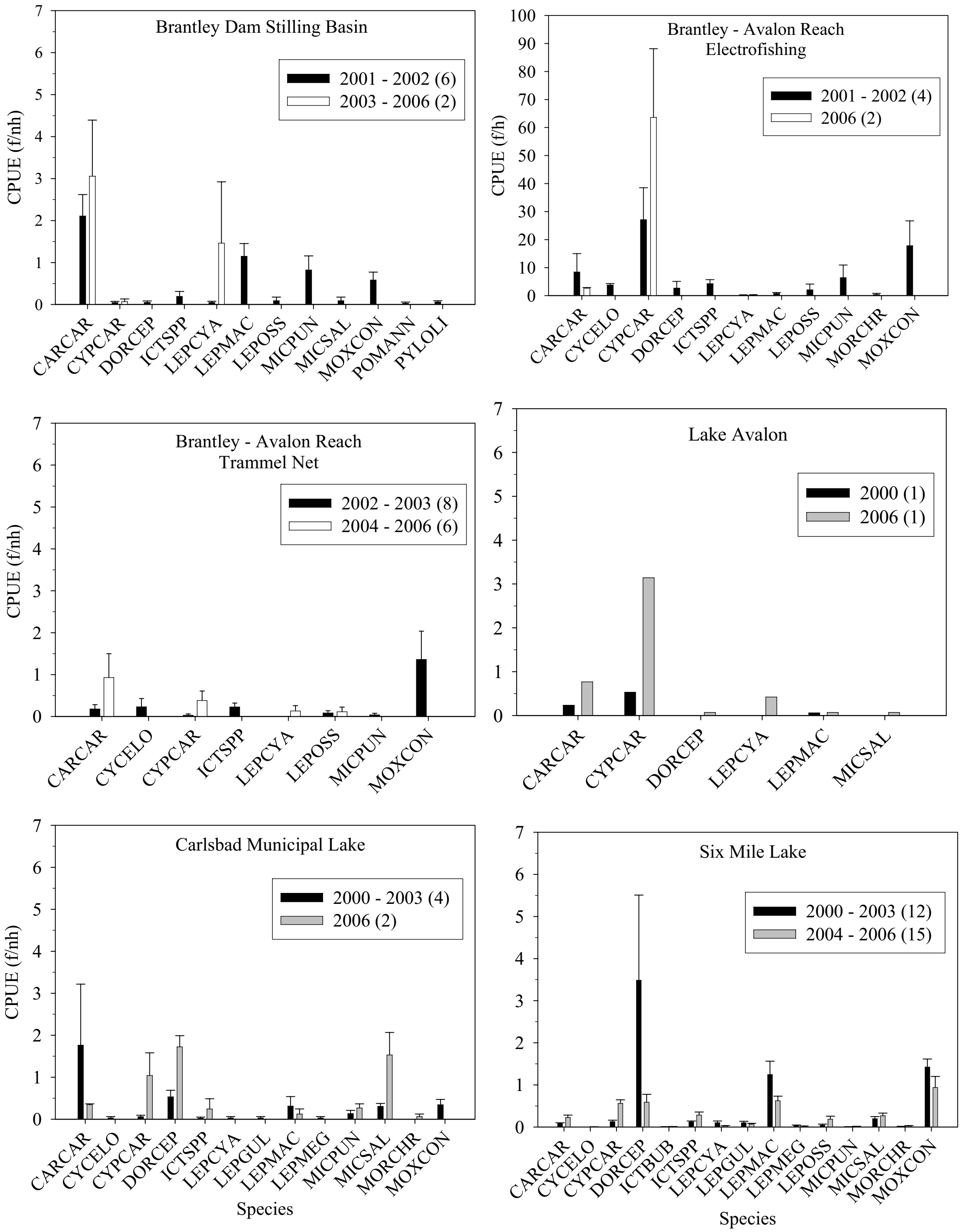

Figure 23. CPUE (mean ± SE) at sites between Brantley and Six Mile dams, comparing periods before and after large-scale fish kills. Temporal division is between 2003 and 2004 except for Brantley Dam stilling basin, where fish assemblage showed marked change between 2002 and 2003 and large fish kills were reported prior to population assessments in 2003. All captured species included. Scale of y-axis constant except for Avalon electrofishing.

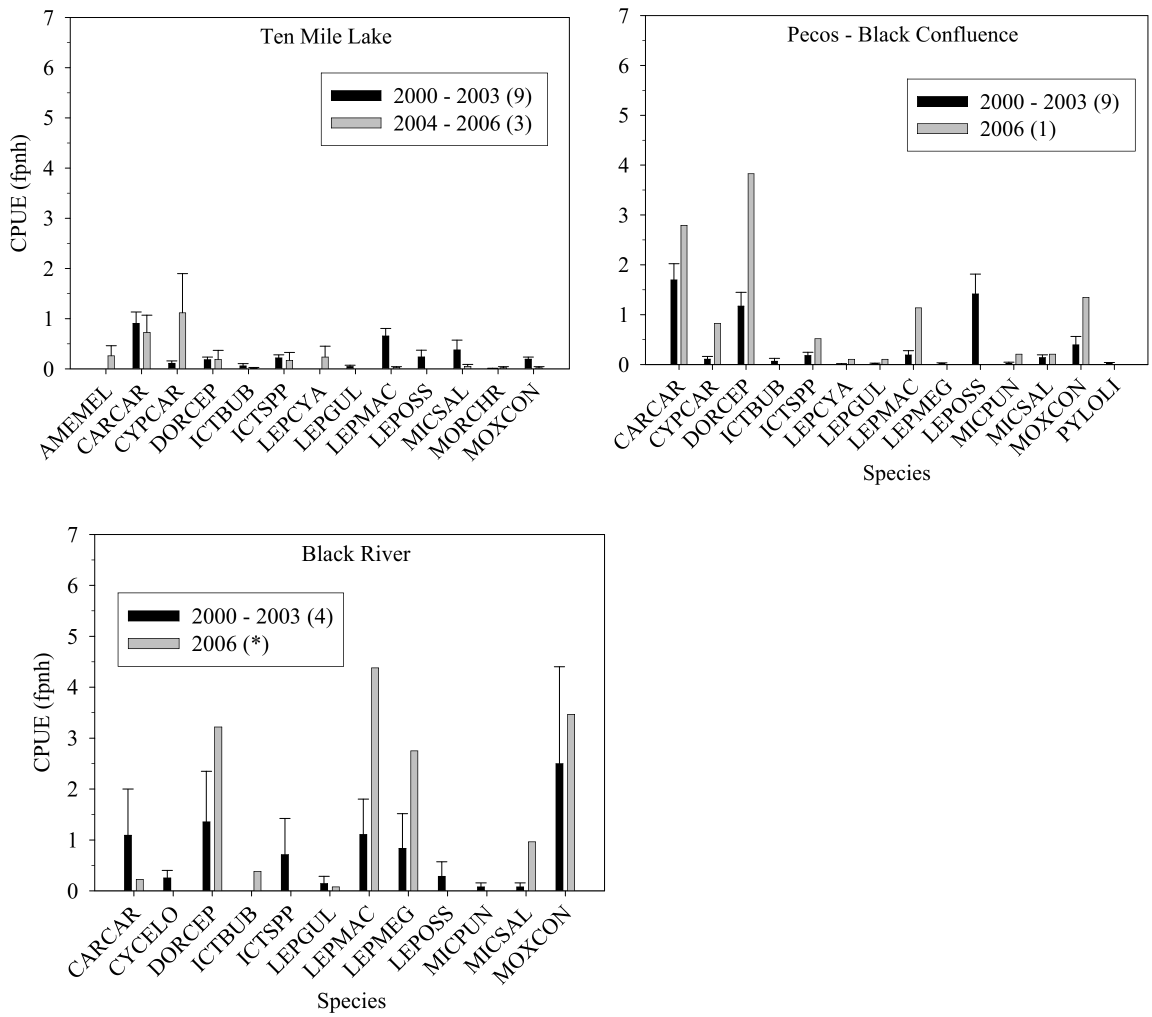

Figure 24. CPUE (mean ± SE) for sites downstream of Six Mile Dam, comparing periods before and after large-scale fish kills. Temporal division is between 2003 and 2004. Number of sampling events in parentheses. Asterisk indicates calculation of number of events precluded because of varying methodology for trammel netting at the Black River. All captured species included. Scale of y-axis constant except for Avalon electrofishing.

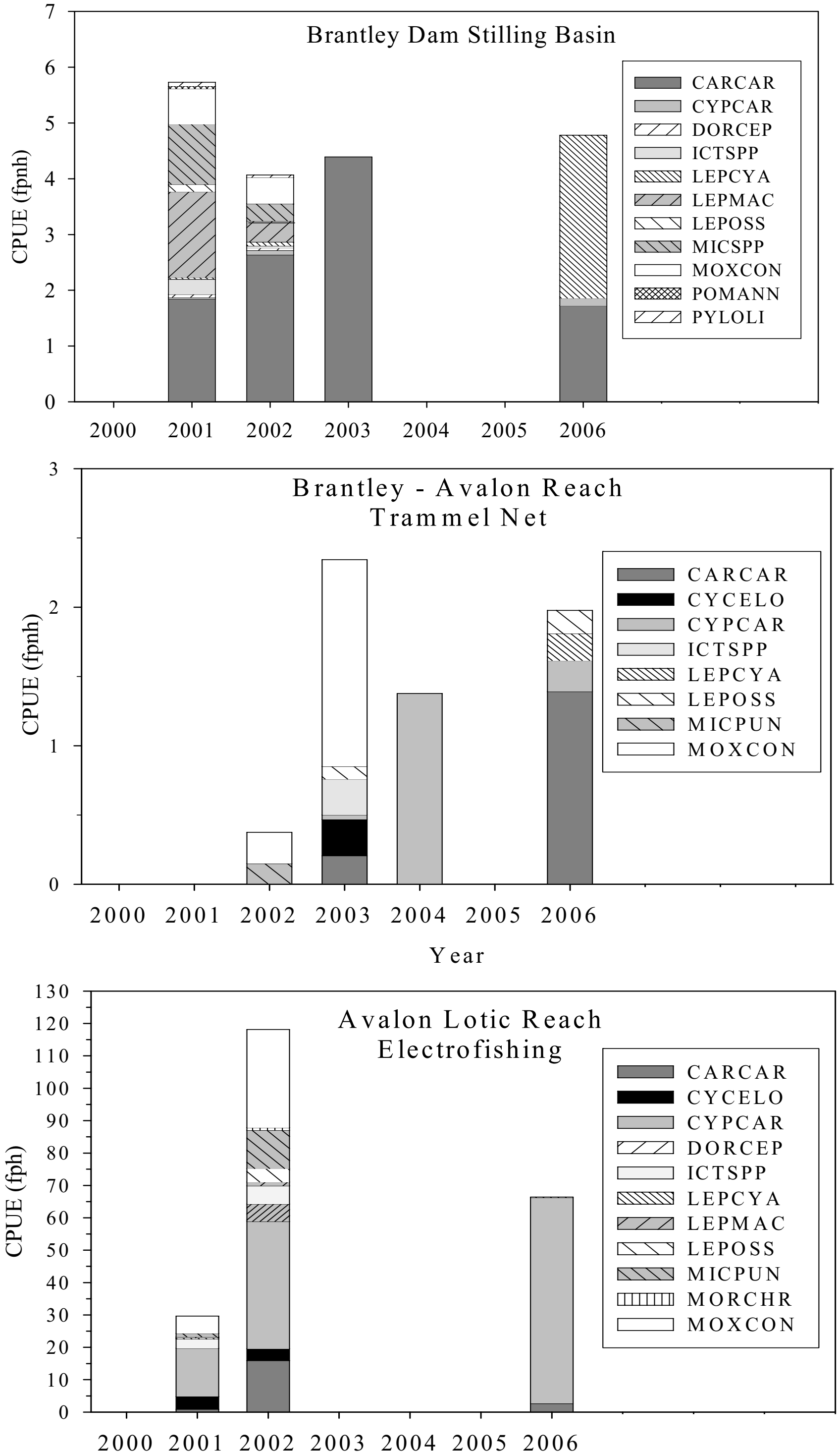

Figure 25. Annual CPUE (annual mean) for each species by year at sites above Lake Avalon. Species excluded for clarity if few captured (CPUE < 0.015 f/nh).

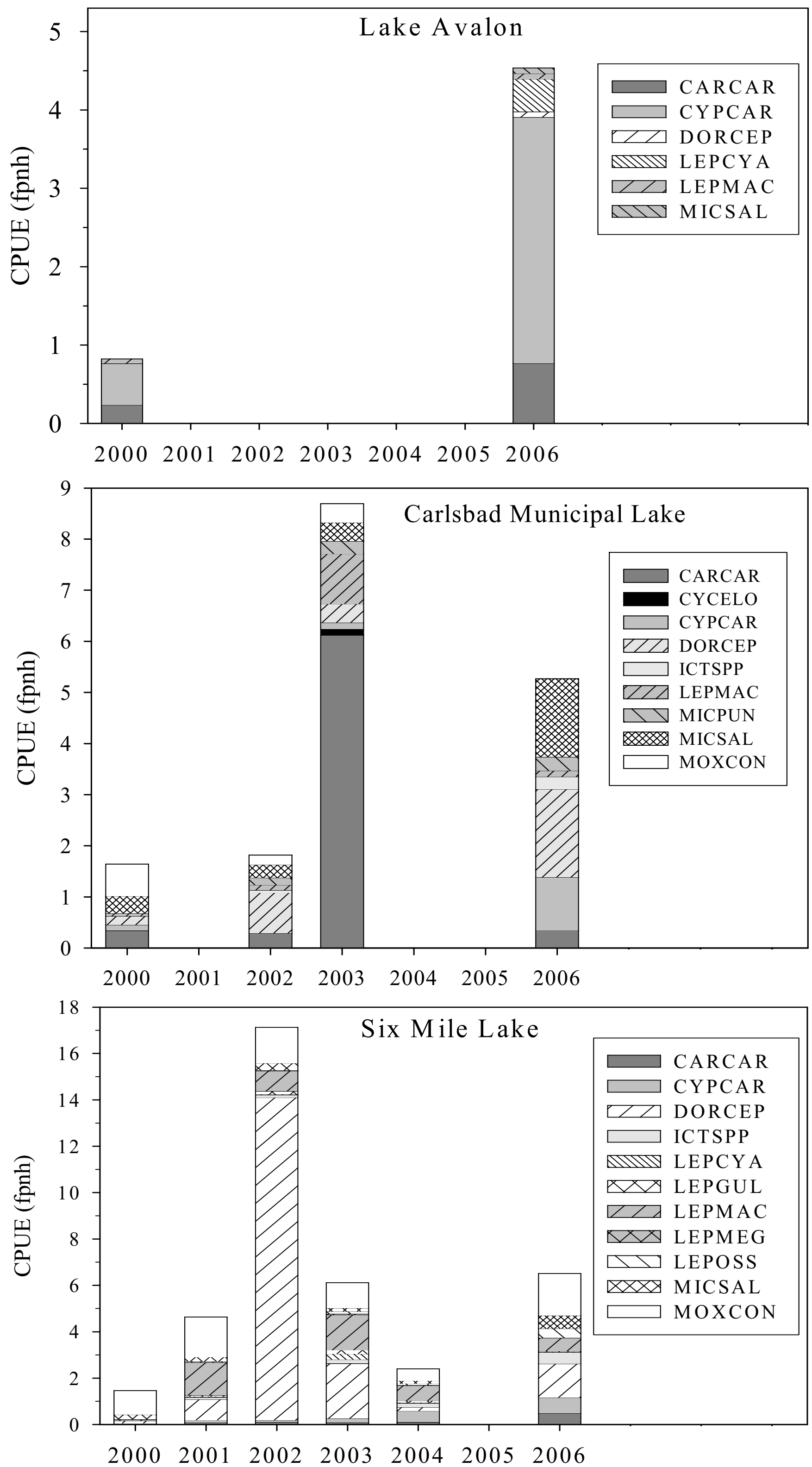

Figure 26. Annual CPUE (annual mean) for each species by year at Lake Avalon, Carlsbad Municipal Lake, and Six Mile Lake. Species excluded for clarity if few captured (CPUE < 0.015 f/nh).

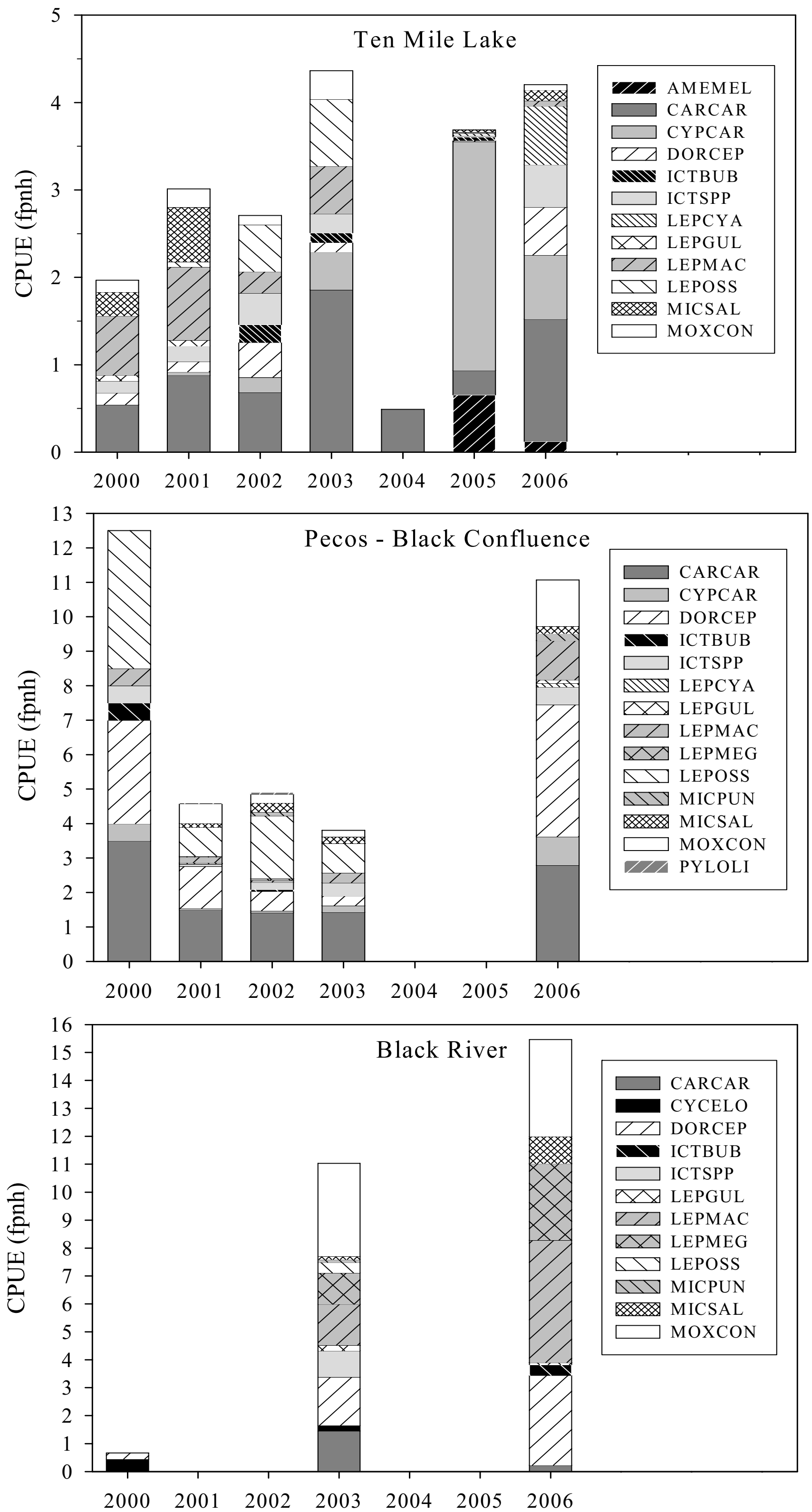

Figure 27. Annual CPUE (annual mean) for each species by year at core sites downstream of Six Mile Dam. Species excluded for clarity if few captured (CPUE < 0.015).

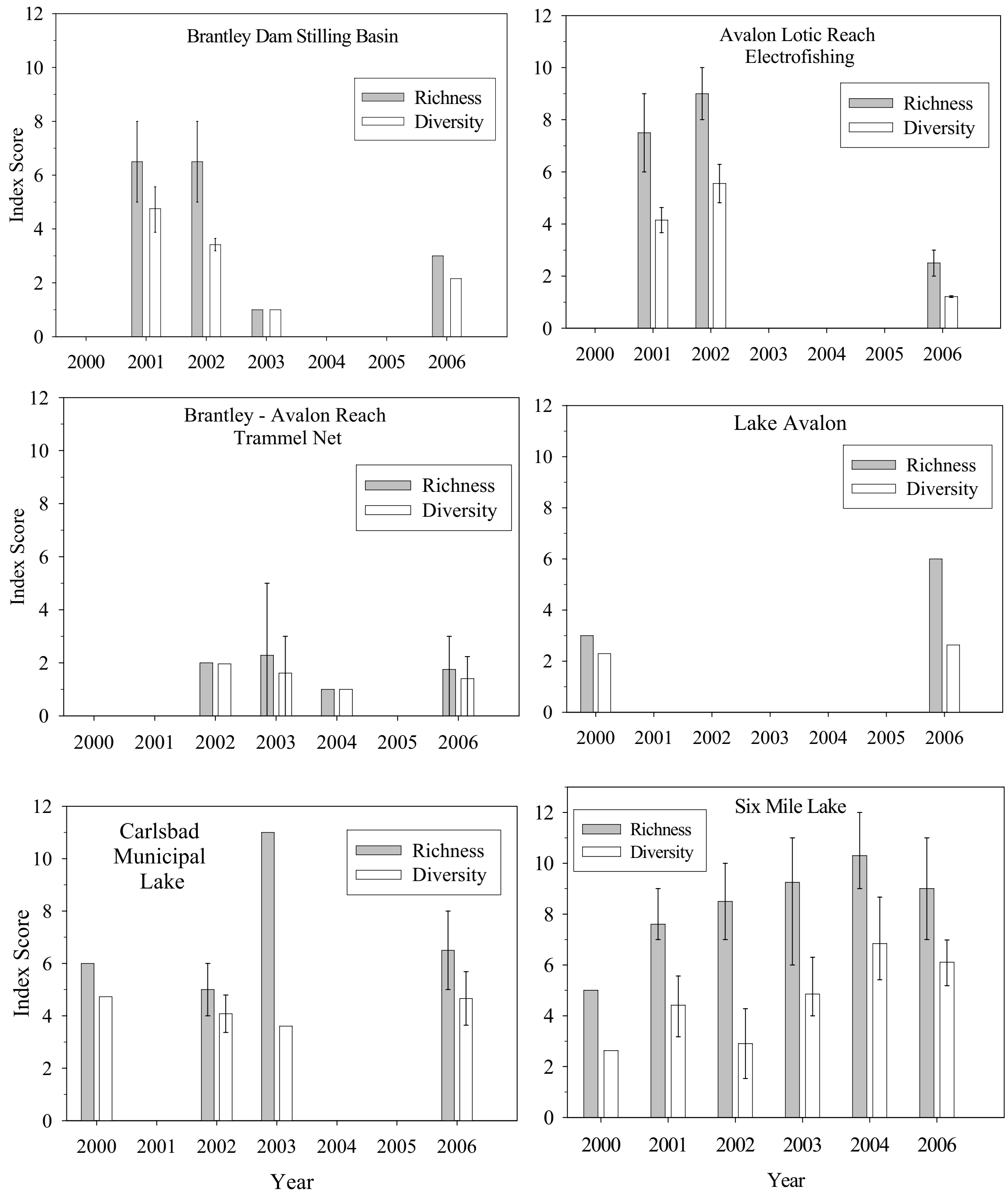

Figure 28. Richness and diversity [exp(H')] for sites between Brantley and Six Mile dams during each year. Error bars denote maximum and minimum for years with multiple sampling events.

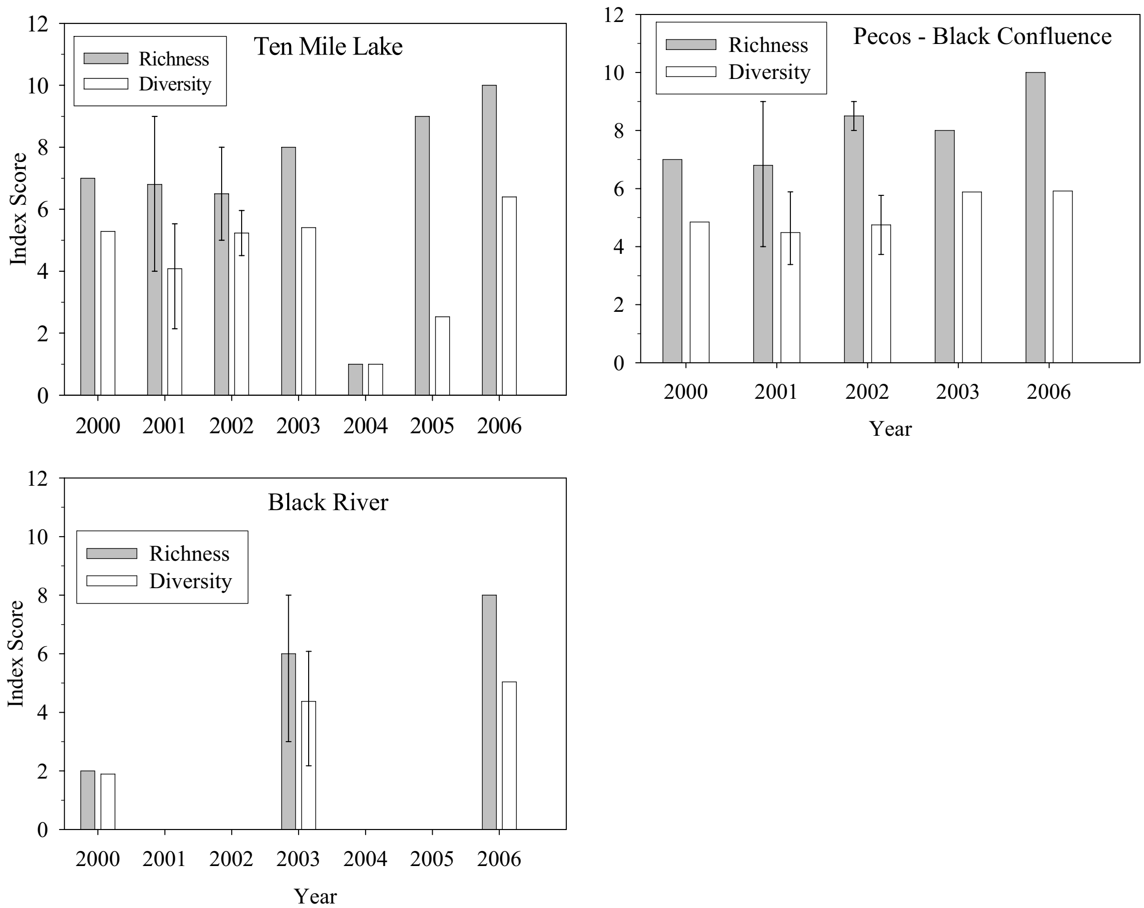

Figure 29. Richness and diversity [exp(H')] for sites below Six Mile Dam during each year. Error bars denote maximum and minimum for years with multiple sampling events.

SUMMARY

The results of this investigation reflect the dominant influence of toxic algae blooms on distribution and abundance of fishes in the study area. During the study period, fish kills apparently eliminated blue sucker and gray redhorse populations from the portion of river between Brantley Dam and Carlsbad and may have effectively extirpated blue sucker from the New Mexico portion of the Pecos River. The absence of both species after 2003 in two electrofishing passes through the Pecos River reach between Brantley Dam and Lake Avalon and 61.5 trammel net hours in the Brantley Dam stilling basin, Avalon lotic reach, Lake Avalon, and Carlsbad Municipal Lake, in combination with massive, repeated fish kills, casts doubt on persistence of blue sucker or gray redhorse populations in this portion of the river. Further, all large-bodied fishes, other than river carpsucker and common carp, were dramatically reduced in abundance if not extirpated from these same areas. Despite an intensive "rough" fish removal program in the 1950s (Navarre 1960), populations of blue sucker, gray redhorse, river carpsucker, smallmouth buffalo, gizzard shad, longnose gar, and common carp survived, and these species were routinely collected in electrofishing and trammel net surveys through the 1990s (Little 1960; Little 1963; Little 1964a; NMGF files; US Fish and Wildlife Service -

Fishery Resource Office, Albuquerque, NM files) and during this study in 2001 and 2002. Although sampling was patchy during 2004 through 2005 and large portions of the main stem Pecos River below Carlsbad were not sampled, failure in 2006 to catch blue sucker anywhere in the Pecos River or gray redhorse above the Six Mile segment suggests the absence of viable populations. Assuming this assessment is correct, range of each species in New Mexico contracted considerably over the past few years.

Fish kills in the Pecos River caused by golden algae beginning in 2002 were unprecedented in extent. Massive kills were previously reported in the lower Pecos River in Texas (James and De La Cruz 1989), and a near-complete kill occurred from Malaga, NM to Imperial, TX in 1988 (Rhodes and Hubbs 1992). It is doubtful golden algae caused massive fish kills in the upper portion of the study area prior to 2002 because of the lack of reported die-offs. Fish kills were reported in previous decades (e.g., on 25 April 1964) downstream of Carlsbad, but the causes were identified as pollution, low flow, and low dissolved oxygen (Little 1965).

If fish populations in affected areas recover, it will be partially a consequence of the hydrologic complexity of and diversity of habitats in the lower Pecos River drainage. The Black River has not experienced fish kills caused by golden algae and may serve as a refuge during golden algae blooms in the Pecos River and provide a source of fish for subsequent colonization of depopulated habitats. The abundant and diverse fish fauna at the Pecos-Black confluence pool in 2006, in contrast to the sparse populations sampled at the Pecos River Fisherman's Lane pool near Loving crossing, suggested the influence of the Black River. Unidentified factors that limit the toxicity of golden algae make Six Mile Lake a potential source for repopulating downstream locations. At Ten Mile Lake, only three river carpsuckers were captured in 2004, but species diversity and abundance in 2006 were similar to levels prior to golden algae blooms. However, golden algae blooms are a recurring problem, and small-scale fish kills were reported in Brantley Lake, Bataan Lake, Ten Mile Lake, and in the Pecos River below Malaga in 2006. Elimination of blue sucker and gray redhorse from the Avalon segment represents the loss of a source of these fishes to the entire project area. Prior to the recent golden algae blooms, the Avalon lotic segment was the population center of blue sucker in New Mexico.

Mortality caused by golden algae was a likely reason for limited success of the telemetry component of this study. Some difficulty was encountered making incisions and suturing during initial surgeries because of thick abdominal scales and dermal tissue, but this was subsequently resolved through equipment modifications and nearly all fish appeared to be in adequate condition when released. Stress caused by the procedure may have increased susceptibility to effects of toxins, but regardless of handling, all blue sucker and gray redhorse in the Avalon segment either died or moved downstream. Sonic tags in dead fish that were deposited on shore by high flows or pulled up by scavengers would have been undetectable with the hydrophone, and deposition of lost tags in the substrate might explain why some signals seemed aberrant in quality and their locations difficult to resolve. Tracking success was somewhat better in Six Mile Lake, where toxic effects of golden algae were minimal. As such, sonic telemetry may be useful in future studies, although additional methodological refinement is necessary.

Attributes of the blue sucker population in the Avalon lotic reach prior to 2004 were similar to those reported in other studies. The prevalence of fish 550 to 700 mm TL in a population was noted in other reports, although the maximum size of individuals in this study (850 mm) was comparatively large (Moss et al. 1983; Hand and Jackson 2003; Morey and Berry 2003). Condition (mean ± SE = 0.89 ± 0.02) of Pecos River blue sucker was slightly higher than values reported for the James River (0.79 ± 0.07) and Big Sioux River (0.73 ± 0.07) populations in South Dakota (Morey and Berry 2003). In the Pecos River, New Mexico blue suckers were concentrated in or near high velocity areas, as reported for the species elsewhere. Although one blue sucker was captured in lentic habitat in each Carlsbad Municipal Lake and Six Mile Lake, the Carlsbad segment provided no lotic habitat and the Six Mile segment produced no additional blue sucker, despite intensive sampling. The inferred April spawning time is earlier than reported for the Neosho River (Moss et al. 1983). No juvenile was captured by electrofishing, although fish in the 50 to 300 mm range are rarely found (Moss et al. 1983; Eitzmann et al. 2007). Loss of the population of blue sucker in the Avalon lotic reach early in the study prohibited comprehensive definition of behavior, movements, and life history of this species in New Mexico.

The numerical dominance of the 250 to 350 mm TL length class of gray redhorse at Six Mile Lake in 2006 was unusual in that collections from previous years consisted almost entirely of large fish (400 to 500 mm). Scale analyses indicated that the dominant cohort in 2006 hatched in 2005, and low success of the previous one or two year classes could account for the low numbers of larger fish in 2006. Such an interpretation has merit given the low flow conditions and golden algae blooms in the area during 2002 through 2004. Gray redhorse in Six Mile Lake in 2006 had higher condition values and, based on scales, were faster growing than gray redhorse in the Black River, indicating greater productivity at Six Mile Lake. The Black River contained a more even representation of multiple age classes and more consistent flow throughout the study period, and it is a substantially smaller body of water.

Comparison of results of this study on gray redhorse in the Pecos River to those for other systems is limited by the paucity of published studies on this species. Although individuals were occasionally seined in riffle habitats, gray redhorse abundance was not high at such sites, in contrast to the association with shallow, swift areas at the Devil's River, Texas (Cantu and Winemiller 1997). Gray redhorse was most common in relatively quiet and deep areas, as was reported in the Little River drainage, Texas (Rose and Echelle 1981). An association with relatively clear streams was reported for the Little River drainage (Rose and Echelle 1981), but water clarity was low throughout our study area except during winter. Relative to other members of the genus, gray redhorse in this study grew more rapidly as juveniles, but growth slowed at an earlier age (Meyer 1962; Bowman 1970). Maximum age was higher for other moxostomids, but possibly because of better definition of later annuli than observed in this study (Meyer 1962; Bowman 1970). The occurrence of gray redhorse on clean patches at the head of Six Mile Lake during the spawning period is similar to that reported for shorthead redhorse *M. macrolepidotum* (making circular depressions in the substrate while spawning; Burr and Morris 1977).

Gray redhorse scales may be used to estimate age and growth for individuals up to age 3, but have little value for ageing older fish. Studies on other catostomids have reported similar results, with structures such as fin rays or otoliths providing better accuracy and precision for larger, older fish (Beamish and Harvey 1969; Rupprecht and

Jahn 1980; Braaten et al. 1999; Eitzmann et al. 2007). Scales would be suitable for comparing early growth among sites or years by isolating individual growth increments and comparing the results to biotic or abiotic factors that might influence growth (Gutreuter 1987; Quist and Guy 2001). Back-calculated values for multiple age classes were grouped in this study because of sample size limitations, but separate analysis of individual cohorts would serve to avoid obfuscating effects of size-dependant mortality (e.g., Lee's phenomenon) and environmental variability. Also, fish less than 200 mm TL were underrepresented in this study, and their inclusion might improve accuracy of growth determinations (Carlander 1985). Validation of ageing or back-calculation has not been reported for gray redhorse and was not attempted in this study. Future collection of scales or rays from tagged and recaptured redhorse, and collection of samples throughout the year, could enable validation of annual increment formation (Campana 2001).

Research Needs and Management Implications

1) Factors responsible for causing toxic blooms of golden algae. Golden algae is a primary limiting factor on fish survival in the study area. Although NMDGF is currently monitoring golden algae occurrence and water quality, the potential for additional studies to improve management of golden algae should be investigated. One question of interest is why fish populations in Six Mile Lake have been relatively unaffected by golden algae while die-offs have occurred at sites immediately above and below.

2) Blue suckers in the Black River. Little is known about the population of blue suckers in the Black River, but a pressing need exists for information on population size, demographic characteristics, and potential limiting factors. Research efforts should address: (A) occurrence of reproduction; (B) survival, habitat use, and movements of juveniles, sub-adults, and adults; and (C) spawning habitat requirements. Collection of a pectoral or pelvic ray sample and a few scales from each handled fish would allow estimation of age structure and growth rates. Completion of this work would require development of sampling protocols specific to blue sucker, a notoriously difficult fish to capture, while addressing logistical challenges arising from high longitudinal heterogeneity and private land ownership.

3) Captive rearing, propagation, and stocking. Loss of source populations necessitates some level of stocking to restore populations to historical, but currently unoccupied, habitats. Documented declining population trends and increased frequency of golden algae outbreaks provide impetus to maintain captive populations of both species, but particularly blue sucker. Re-establishment in upstream reaches would provide a source of fish to naturally augment or repopulate downstream reaches. However, no amount of stocking will surmount recurring lethal conditions caused by golden algae. Thus, repatriation of gray redhorse and blue suckers should be evaluated for the reach of the Pecos River from Brantley Dam to Roswell, which is within the historical range for both species. Physiochemical conditions upstream of Brantley Lake differ from those in the lower river, possibly limiting the potential for toxic golden algae blooms to occur in the upper reach. Repatriation to the Rio Grande in New Mexico should also be considered.

4) Habitat use and movements of gray redhorse in the Black River and in the Six Mile segment of the Pecos River. Habitat requirements and movement of gray redhorse remain poorly defined, particularly with regard to New Mexico populations. Whether the gray redhorse in Six Mile Lake ascend the river to spawn, a behavior typical of the genus, or spawn within the reservoir remains unknown but holds relevance for conservation efforts. Do these species have particular seasonal or life-stage related requirements? Movements of gray redhorse in the Six Mile segment and Black River could be investigated through directed sampling, additional telemetry efforts, or possibly through installment of PIT tag detection stations at key locations (e.g., the stream reach above Six Mile Lake or the last riffle in the Black River above the confluence with the Pecos River).

5) Monitoring and assessment of distribution and abundance. Continued monitoring of large-bodied fishes between Brantley Dam and Carlsbad is necessary to verify extirpation of blue sucker and gray redhorse, assess status of other native fishes, and investigate effects of future management actions. Below Carlsbad, long reaches of the river have not been sampled and the existence of blue sucker or gray redhorse in these reaches is possible. Raft-mounted electrofishing provides a means to effectively sample substantial lengths of river, particularly the swift habitats occupied by blue suckers, and lotic portions of all river segments contain navigable reaches (except the Carlsbad segment). Reservoir environments and large pools should be monitored at regular intervals using trammel nets, although considerable effort (e.g., 15—25 nets in Six Mile Lake) may be necessary to obtain population estimates of target species. Occurrence of fish in the CID canal system should also be monitored. The canal system represents a historical source of considerable mortality, an ecological trap (Battin 2004), and modifications may be warranted at the head of the system (e.g., fish screens) and at the southern outlet, where effects on the water quality and ecology of the Black River may be deleterious. Alternatively, the canal system may offer value as seasonal habitat for fishes such as blue sucker provided they can access suitable overwintering habitat after flows cease in November. Regardless, native fishes should be rescued annually from the canals immediately following end of irrigation season (1 November).

6) Restoring connectivity. Range fragmentation and highly modified hydrological conditions are a common cause of decline in catostomid populations (Cooke et al. 2005), and populations of native fishes would ideally be capable of volitional movement among segments. Such capability would potentially increase short-term survival by allowing access to favorable habitat and would reduce long-term genetic-loss risks. Development of fish passage facilities should be considered around each Avalon, Carlsbad Municipal, Bataan, Six-Mile, and Ten-Mile dams. Also, fish populations, and the ecological integrity of the lower Pecos River drainage as a whole, would benefit from a more natural flow regime. A long-term goal for the lower Pecos includes water operations that enhance ecological functions.

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