CATASTROPHIC DECLINE OF THE MUSSEL FAUNA OF THE BLUE RIVER, OKLAHOMA

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The Blue River is considered one of Oklahoma's most pristine and scenic streams. The river begins in Pontotoc County near Roff and flows 236 km in a southeasterly direction to its confluence with the Red River near Wade in Bryan County (Oklahoma Water Resource Board, 1990). The Blue River basin is long and narrow with a maximum width of about 22 km and a total drainage area of 1,750 km^2. The upper reaches of the river lie within the Arbuckle Uplift and are primarily spring-fed (Fairchild et al., 1990); the lower reaches flow across the coastal plain before entering the Red River.

The Blue River was known historically for its rich and unusual mussel fauna. The fauna was first described by Isely (1924). Isely traversed lower sections of the river by boat during the summer of 1910, and visited upper reaches in 1912. At that time local fishermen described the river to Isely as "being full of mussels." Isley described the mussel fauna from three sites on the river (Fig. 1, Table 1), a site on the lower Blue River (site 1), a site 8 km north of Durant (site 2), and a site 3 km north of Milburn (site 4). He described the lower river to be "deep and muddy". *Potamilus purpuratus* and *Amblema plicata plicata* were abundant in the lower reaches. He found many species at the site near Durant. Particularly common was *Fusconaia flava*, many of which were quite small averaging 14 to 20 mm in length. *Quadrula pustulosa* was also quite abundant. The area north of Milburn was described as "a shallow, clear water, sandy bottomed stream with good current." Mussels were abundant although they were not distributed in extensive beds.

Valentine and Stansbery (1971) sampled two sites on the river in the summer of 1967, including the site north of Durant (site 2) previously sampled by Isely. In the intervening years a small dam had been constructed directly upstream from this site. The site is located immediately below the spillway of the dam in a large gravel shoal. Valentine and Stansbery found "800 naiads of 19 species" on their first trip to the Durant site, and located two additional species on a subsequent trip (Table 1). Valentine and Stansbery (1971) also sampled a site (site 3) 0.4 km north of Milburn at the Oklahoma route 48A bridge (Fig. 1). Here they discovered "348 naiads of eight species" (Table 1). The mussels were described as being scattered with no major concentrations and were all in the deepest part of the river. The number of mussels increased with distance downstream from the bridge.

I revisited the sites sampled by Isely and Valentine and Stansbery, and sampled additional sites (Figure 1, Table 1), during the summers of 1991–1993. Sections of the river from its confluence with the Red River to north of Milburn were traversed by canoe. Reconnaissance snorkel searches were conducted in areas where shells were observed and in areas in which the habitat looked appropriate for mussels. When live mussels were found, quantitative sampling was done following Vaughn et al. (1997). Voucher specimens were deposited with the Oklahoma Biological Survey, University of Oklahoma.

Unionids have been extirpated from much of the Blue River. I found no live mussels in lower stretches of the river (Fig. 1, between sites 1 and 2, and from site 1 all the way to the confluence with the Red River). The lower most site still harboring unionids is the area below the spillway north of Durant (Fig. 1, site 2). Above this lowhead dam, live mussels are extirpated until the site at Connerville (site 6). Thus, with the exception of the Durant site, mussels have been extirpated from the lower 75% of the river. This massive decline has occurred during the past 30 years, as mussels were still abundant in middle reaches of the river when Valentine and Stansbery sampled in 1967. When I visited sites 3 and 4 in 1992 the river bottom was literally paved with dead shell (Table 1).

What caused these mass extirpations? Major

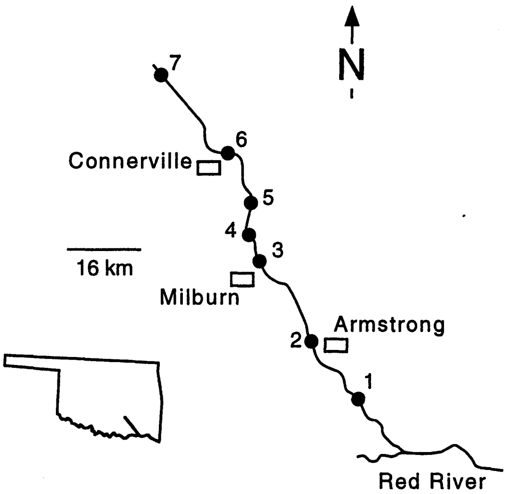

FIG. 1.—Approximate location of sampling sites on the Blue River. 1 = Lower Blue, 2 = Below dam, 8 km north of Durant, 3 = 0.4 km north of Milburn, 4 = 3 km north of Milburn, 5 = ODWC Public Fishing Area 9.7 km east of Reagan, 6 = HW 377 bridge 1.6 km north of Connerville, 7 = 4.8 km east of Roff.

declines of mussel populations and species diversity have occurred world-wide over the last century (Bogan, 1993; Mehlhop and Vaughn, 1994) and 50% of the remaining species are threatened with extinction (Neves, 1993). This decline has been linked to degradation and loss of essential habitat, particularly through large scale impoundment and channelization of major rivers (Bogan, 1993; Mehlhop and Vaughn, 1994) and poor land use practices causing siltation (Anderson et al., 1991; Williams et al., 1993).

Mussels are sedentary filter-feeders that are rooted to approximately the same spot for their entire 40 to 50 year life span. Because of this they are among the most sensitive organisms to siltation (Ellis, 1936; Simmons and Reed, 1973). A heavy layer of silt can cause suffocation of an entire mussel bed, and siltation has contributed to massive extirpations of mussels in other rivers (Anderson et al., 1991). Sources of increased siltation in rivers include

TABLE 1—Historical and current occurrences of mussels in the Blue River. Numbers refer to collecting sites shown in Fig. 1. I = Isely, V = Valentine and Stansbery, P = present (this study), L = live individuals, D = dead, WD = weathered dead.

	1		2			3		4		5	6	7
	I	P	I	V	P	V	P	I	P	P	P	P
Amblema plicata plicata	L		L	L	L		WD	L	WD	WD	D	
Fusconaia flava	L		L	L	L	L	WD	L	WD	WD		
Lampsilis cardium	L			L	L	L	WD	L	WD	WD		
Lampsilis siliquoidea			L	L	L	L	WD		WD	WD	L	
Lampsilis teres	L		L	L	L	D	WD	L				
Lasmigona complanata	L			L								
Leptodea fragilis	L		L	L		D		L		WD		
Ligumia subrostrata						D					L	
Megalonaias nervosa	L											
Obliquaria reflexa				L	L							
Potamilus ohiensis				L								
Potamilus purpuratus	L			L	L							
Ptychobranchus occidentalis			L		L	D		L	WD	WD	L	
Pyganodon grandis				L								
Quadrula pustulosa	L		L	L	L	L	WD	L	WD	WD		
Quadrula quadrula	L		L	L	L					WD		
Toxolasma parvus	L		L	L		D						
Tritogonia verrucosa	L		L	L	L	D		L	WD	WD		
Truncilla donaciformis	L		L	L				L				
Truncilla truncata	L		L	L								
Uniomerus tetralasmus				L						WD	L	L
Utterbackia imbecillis				L		D					L	
Villosa lienosa											L	
Villosa sp.				L								

head cutting, gravel mining, poor agricultural practices (runoff), cattle grazing, and clearing of riparian vegetation (Bogan, 1993). The erosional processes causing increased silt loads may also lead to shifting, unstable stream bottoms in which mussels cannot survive (Williams et al., 1993). Along the Blue River the riparian vegetation has been cut all the way to the river bank in many areas, soil is intensively tilled for agriculture to the rivers edge, cattle graze at the rivers edge in many areas, and the river bottom is coated with silt (Vaughn, pers. obs).

Most mussel species cannot live in impoundments (Watters, 1996), and do poorly in the altered hydrologic regimes below impoundments (Mehlhop and Vaughn, 1994). Furthermore, larval mussels are ectoparasites on fish (Kat, 1984); thus, mussels are also affected by any environmental impacts on their fish hosts. The distribution and movement patterns of fish hosts play an important role in the distribution of the mussels (Watters, 1992; Vaughn, 1997). Watters (1996) found that the distribution of two unionid species in five midwestern rivers were restricted to areas downstream of lowhead dams, and attributed this to the dams blocking upstream migration of fish hosts. Decline of mussels above the lowhead dam near Durant may in part be linked to the blocked migration of some fish hosts above this structure. Even though this structure was already in place during the Valentine and Stansbery surveys, adult mussels may have still been in abundance upstream because mussels are extremely long-lived invertebrates. A population of adult mussels isolated from their hosts and not reproducing (and thus functionally extirpated) could take decades to die from "old age."

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EXPANDED OCCURRENCE OF GENETICALLY INTROGRESSED PUPFISH (CYPRINODONTIDAE: *CYPRINODON PECOSENSIS* X *VARIEGATUS*) IN NEW MEXICO

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The Pecos pupfish *Cyprinodon pecosensis* (Cyprinodontidae) is endemic to roughly 700 river-km of the Pecos River and associated waters from the vicinity of Roswell, Chaves Co., New Mexico downstream to the mouth of Independence Creek, Texas (Fig. 1). Since the 1950s, the species has been collected only in three general areas (Echelle and Echelle, 1978; Sublette et al., 1990): 1) Roswell vicinity to just south of Artesia, Chaves Co., New Mexico; 2) about 500 river-km of the Pecos river, vicinity of Malaga, Eddy Co., New Mexico to the mouth of Independence Creek, 42 km SE of Sheffield, Terrell Co.; and 3) Salt Creek, a saline tributary of the Pecos River in Reeves Co., from its mouth upstream for more than 30 km (G. Garrett, pers. comm.).

In New Mexico, *C. pecosensis* occurs most abundantly in saline waters of the Pecos River floodplain near Roswell, primarily on the Bitter Lake National Wildlife Refuge and Bottomless Lakes State Park. In this area, *C. pecosensis* is one of the most abundant species in the more saline springs, sinkholes, and artificial lake habitats, but generally has been uncommon in the relatively fresh waters of the Pecos River proper. However, in the more saline reach of river in Eddy Co. from the vicinity of Loving and Malaga downstream to Red Bluff Reservoir on the New Mexico-Texas boundary, collections have occasionally produced large numbers of the species (e.g., 157 specimens in 1990, Museum of Southwestern Biology, MSB, catalog number 8797). In this paper, we report that populations from Loving downstream to Red Bluff Reservoir now contain genetic material from the sheepshead minnow *Cyprinodon variegatus*, a pupfish introduced into the Pecos River sometime between 1980 and 1984 (Echelle and Connor, 1989).

The original introduction of *C. variegatus*, probably in Red Bluff Reservoir (Childs et al., 1996), led to hybridization and rapid genetic introgression of the endemic *C. pecosensis* over most of its historic range in Texas. By the mid 1980s, locally panmictic admixtures of the two species occupied the Pecos River and various peripheral waters (reservoirs and irrigation canals) from Red Bluff Reservoir downstream about 500 river-km (Echelle and Connor, 1989; Wilde and Echelle, 1992). All of these populations showed morphological evidence of introgression, and average frequency of introduced alleles for four allozyme gene loci ranged from about 20% to 80%, depending on locality.

Until 1994, introgression in the New Mexico portion of the range of *C. pecosensis* seemed limited to Red Bluff Reservoir and the Pecos River immediately upstream of the reservoir. The upstream-most extent of introgressed pupfish appeared to be a sidepool associated with the confluence of the Pecos and Delaware rivers (T26S,R29E,S19) in Eddy Co., 4.5 km N of the New Mexico–Texas boundary (Fig. 1). A collection of 337 specimens from this site in 1990 (MSB 8788) showed traits of color pattern (Echelle and Connor, 1989) and belly scalation (complete rather than partially or completely naked belly scalation) indicative of introgression by *C. variegatus*. Collections taken in the same year from two sites upstream of the Delaware-Pecos river confluence revealed no morphological evidence of genetic intro-