THE STATUS OF *MOAPA CORIACEA* AND *GILA SEMINUDA* AND STATUS INFORMATION ON OTHER FISHES OF THE MUDDY RIVER, CLARK COUNTY, NEVADA

G. GARY SCOPPETTONE, PETER H. RISSLER, M. BRIDGET NIELSEN, AND JAMES E. HARVEY

U.S. Geological Survey, Biological Resources Division, Western Fisheries Research Center, Reno Field Station, 1340 Financial Blvd., Suite 161, Reno, Nevada 89502

ABSTRACT—*Moapa coriacea* is endemic to the headwaters (Warm Springs area) of the Muddy River, Clark County, Nevada. The Warm Springs area was snorkeled and *Moapa coriacea* and *Gila seminuda* enumerated in August 1994 after a fire, and in May 1997 after a diversion dam had been removed from the downstream end. *Gila seminuda* had been reported in greatest abundance downstream from the Warm Springs area and we estimated the population there through mark and recapture from January to March 1995. There was a dramatic reduction in native fishes in the Warm Springs area between 1994 and 1997, coinciding with the invasion of *Oreochromis aurea*. Downstream from the Warm Springs area *Gila seminuda* was the most frequently netted species while *O. aurea* was relatively scarce. The fish population (native and non-native) decreased in a downstream direction; the causative factor(s) have not been identified.

RESUMEN—*Moapa coriacea* es endémica de las aguas principales (área de manantiales) del río sucio en Clark County, Nevada. El área de manantiales fue buceada y *Moapa coriacea* y *Gila seminuda*, enumeradeas en agosto de 1994 después de un fuego y en mayo de 1997 después de la desviación de una presa, han sido removidas río abajo. *Gila seminuda* ha sido reportada en gran abundancia río abajo del área de los manantiales y hemos estimado la población a través de marcaje y recaptura de enero a marzo de 1995. Hubo una dramática reducción en peces nativos en al área de los manantiales entre 1994 y 1997, coincidiendo con la invasión de *Oreochromis aurea*. Rió abajo del área de los manantiales *Gila seminuda* fue la especie capturada con mayor frecuencia mientras que *O. aurea* fue relativamente escaza. La población de peces (nativos y no nativos) disminuyo en dirección rio abajo; el factor(es) causante no ha sido identificado.

The Muddy River (a.k.a Moapa River) is Nevada's only perennial tributary to the Colorado River. Yet, while connected to a large river system, its fish assemblage is characteristic of an isolated southwestern desert habitat, comprising few species, and harboring endemic forms. Contributing to species isolation is the thermal nature of the Muddy River (Hubbs and Miller, 1948; La Rivers, 1962), originating from a series of thermal springs emanating from a deep paleozoic carbonaceous aquifer (Eakin, 1964). Two of the river's four native fish species, *Moapa coriacea* (Moapa dace) and *Crenichthys baileyi moapae* (Moapa White River springfish), are thermophilic and endemic to the headwaters (Warm Springs area) typically in water temperatures ranging from 26.0 to 32.0°C (Hubbs and Miller, 1948). Because the Muddy River cools as it flows downstream, these fish are restricted to the Warm Springs area (Cross, 1976). *Rhinichthys osculus moapae* (Moapa speckled dace), also endemic (Williams, 1978), occupies the cooler water downstream from the Warm Springs area (Deacon and Bradley, 1972; Cross, 1976). The Moapa roundtail chub (*Gila robusta* sp.) was recently synonymized with Virgin River chub (*Gila seminuda*; DeMarais et al., 1992) and now it is the only one of the four natives not found exclusively in the Muddy River, but occurs in the Virgin River (Utah, Arizona, and Nevada) as well. In the Muddy River, *G. seminuda* does occur in the Warm Springs area, but its greatest concentration is downstream (Deacon and Bradley, 1972; Cross, 1976)

Symptomatic of fishes of the southwest desert, Muddy River native fish populations have declined due to habitat alteration and introduction of non-native fishes (Deacon and Bradley, 1972; Scoppettone, 1993). There have been previous Muddy River fish surveys (Deacon and Bradley, 1972; Cross, 1976; Scoppettone et al., 1992), but since then there have been additional habitat alterations and the introduction of at least one new fish species (*Oreochromis aurea*; blue tilapia), warranting an update in species status. *Moapa coriacea* is federally listed as endangered (U.S. Department of Interior, 1973), and *C. b. moapae* and *R. o. moapae* were category 2 species, considered for listing (U.S. Department of the Interior, 1991) until the designation was eliminated. *Gila seminuda* was federally listed as endangered in 1989 in the Virgin River (U.S. Fish and Wildlife Service, 1989), but listing of the Muddy River population is predicated, in part, upon its distribution and abundance (U.S. Fish and Wildlife Service, 1995). Thus, in this paper we investigate the status of *G. seminuda* and, additionally, *M. coriacea* because *M. coriacea* is the most susceptible to extinction and there had been recent perturbations to its very limited habitat. A flash fire swept through a tributary previously documented as containing almost one-third of the adult *M. coriacea* population. Also, a 1.5 m high dam was installed at the lower reach of the Warm Springs area, effectively impounding water to 1.5 km upstream. We surveyed the Warm Springs area in August 1994, six weeks after the fire and six years after the dam installation, and again in May 1997, two years after the dam had been removed.

DESCRIPTION OF AREA—More than 20 springs and seeps emerge within a 2 km radius and unite in the upper Moapa Valley to form the Muddy River (Fig. 1). Cumulative discharge is about 1.1 m^3/s (Eakin, 1964). Most springs are warm, between 32.0–33.0°C (Garside and Schilling, 1979). We define the stream systems upstream of a 0.6 m high concrete U.S. Geological Survey (USGS) gaging weir at Warm Springs Road (Fig. 1) as the "Warm Springs area." From its origin, here defined as the junction of the South and North forks, the Muddy River flows more than 40 km and discharges into the Overton Arm of Lake Mead. Despite its high mineral content, the Muddy River serves as a potable water source, is used to irrigate pasture and hay crops, and is a water source for a coal-fired power plant (Reid Gardner Station). Agricultural return flows add salt from mineral laden soils (U.S. Department of Agriculture, 1993); thus water conductivity increases markedly downstream (Deacon and Bradley, 1972).

The Muddy River system has been greatly altered by human activity. In the Warm Springs area, spring-fed tributaries have been excavated and natural channels replaced by concrete or earthen ditches. Approximately 30 m upstream of the USGS gaging weir, a 1.5 m high gabion dam was installed in 1988 to divert water to Reid Gardner Station, 9 km downstream. The dam was removed in February 1995 and replaced by a no-head diversion system. Several springs have been pooled for recreational purposes and others have been capped and pumped. Reaches of the main stem have been channelized and straightened. There are several concrete diversion dams along its course, which supply water for irrigation.

Native riparian vegetation is being replaced by non-native species. In the Warm Springs area, non-native fan palm (*Washingtonia filifera*) is the predominant riparian species along two small tributary streams, and has become established throughout watercourses of the upper Moapa Valley. Non-native tamarisk (*Tamarisk* sp.) is the predominant riparian vegetation occurring along the length of the river system, and patches of native mesquite (*Prosopis* sp.), arrow weed (*Pluchea sericea*) and ash (*Franzinua* sp.) persist along the upper to middle reaches.

In addition to four native fish species, 13 non-native fishes are known from the Muddy River (Deacon and Bradley, 1972; Cross, 1976). The most recent introduction *O. aurea*, native of Asia, was first observed immediately downstream from the high USGS gaging weir, in 1991 (Don Sada, Biological Consultant, Bishop, California, pers. comm.).

To protect *M. coriacea, C. b. moapae,* and Warm Springs area endemic invertebrates from the negative effects of non-native species and habitat destruction, the Moapa National Wildlife Refuge (MNWR) was established at one of the Warm Springs area spring provinces contributing to the flow of the Muddy River. Cumulative refuge spring flow was 0.09 m^3/s. About 500 m in length, the stream within the confines of the refuge has supported up to 500 *M. coriacea* and over 10,000 *C. b. moapae* adults with no non-native fishes (primary author, unpublished), and its native fish population is isolated by a 0.75 m high barrier. Downstream from the refuge the stream extends an addi-

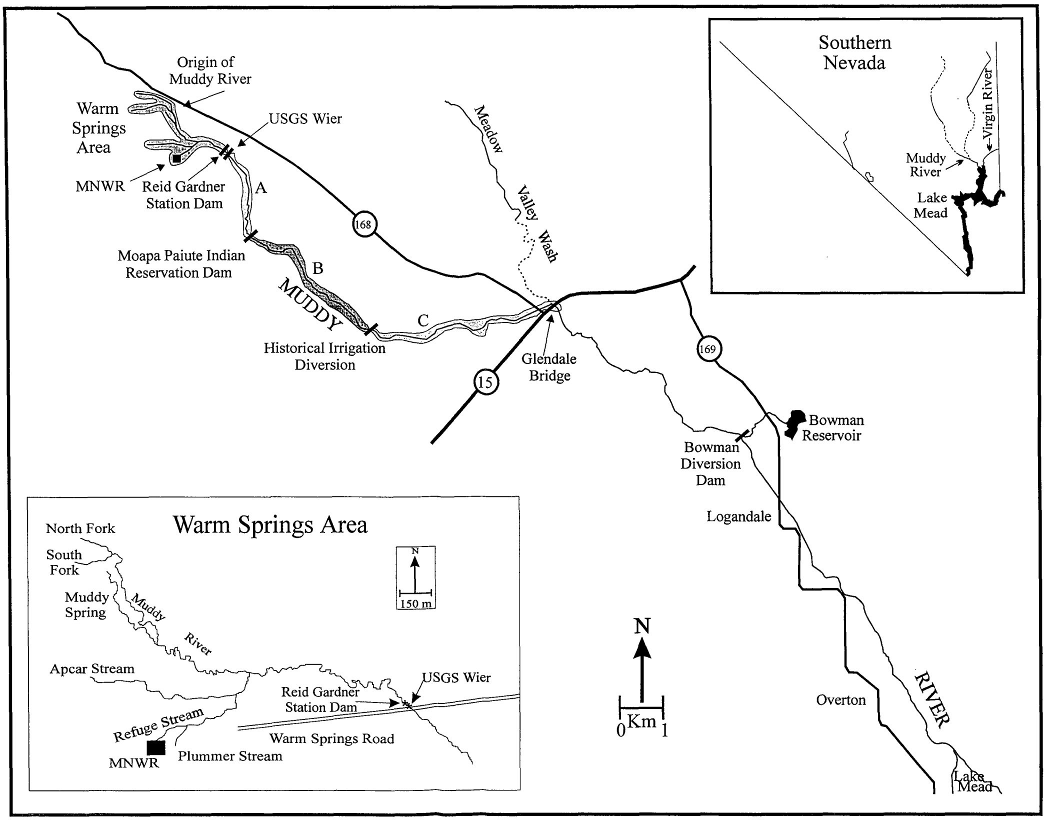

FIG. 1—Map of the Muddy River including Warm Springs area and three sections sampled with hoop nets.

tional 700 m before discharging into the Muddy River. The riparian corridor was predominated by fan palms downstream to the Apcar Stream and then deciduous trees predominated. In June 1994 a flash fire burned through the Refuge Stream to the Muddy River, leaving charred palms without fronds. The palms were not killed and sprouted fronds within several weeks.

MATERIALS AND METHODS—*Warm Springs Area Counts*—In the Warm Springs area, we used mask and snorkel to enumerate *M. coriacea* and *G. seminuda* greater than or equal to 40 mm FL. This method was used because the water generally runs clear and *M. coriacea* and *G. seminuda* (of this size) were in open water and patchy in distribution. *Crenichthys baileyi moapae* was much more numerous and more frequently associated with more complex habitat, so we estimated its relative abundance and distribution rather than conduct enumeration. Two surveys were made, each over a three-day period; one during August 9–11, 1994 and the other May 8–10, 1997. The snorkel survey began about 200 m downstream from the USGS weir at Warm Springs Road Bridge and continued upstream to include the main stem Muddy River and its five primary tributaries, a total distance of 5.9 km (Figure 1). Only *M. coriacea* was targeted for counting downstream of the USGS weir. Two pairs of snorkelers surveyed the mainstem, and one snorkeler the five tributaries.

In this paper, river kilometer (rk) is measured downstream from the Muddy River origin.

Downstream from Warm Springs Area-Mark and Recapture—Downstream from the Warm Springs area we used mark and recapture to estimate the *G. seminuda* population. Hoop nets were used for capture; they were 6.35 mm stretch- mesh, 1.60 m long, with a 0.66 m opening and set with the mouth oriented downstream.

We focused our efforts on the 17.1 km of stream immediately downstream from the Warm Springs are (rk 3.1–20.2), which had previously been documented as having the greatest concentration of *G. seminuda* (Deacon and Bradley, 1972; Cross, 1976; authors unpublished). We divided this reach into three sections, each defined by an impediment to

TABLE 1—Number of *Moapa coriacea* and *Gila seminuda* counted, and estimated number of *Oreochromis aurea* in the Warm Springs area.

	Moapa coriacea		*Gila seminuda*		*Oreochromis aurea*	
Location	1994	1997	1994	1997	1994	1997
North Fork	426	106	1,200	0	0	>40
South Fork	355	28	950	0	0	>30
Muddy Spring	236	28	346	0	0	2
Apcar Stream	407	528	871	1	0	>400
Refuge Stream	313	595	330	0	0	>200
Plummer Stream	0	20	0	0	0	0
Muddy River	2,088	260	4,359	1	0	>300
Total	3,841	1,565	8,056	2	0	>970

fish movement. Section A was 4.0 km long with the 0.6 m high USGS concrete weir upstream, and a 2.0 m high concrete diversion dam downstream. Section B began at the diversion dam and extended downstream 5.3 km to a 2.5 m high relic diversion dam at rk 12.4. Section C extended 7.8 km from the relic dam to Glendale Road Bridge (rk 20.2). There was no physical barrier at the downstream end of Section C.

To capture *G. seminuda* for marking, hoop nets were fished from January 17, 1995, to March 12, 1995. As many as 30 hoop nets were set at 40 m intervals; nets were fished overnight and then moved downstream, until the entire section had been sampled. For each net set, captured *G. seminuda* were measured, scanned for PIT (Passive Integrated Transponder) tag presence, and PIT-tagged in the abdominal cavity if the fish was ≥120 mm FL and had not been previously tagged. Five to seven days after marking had been completed, nets were set in the lower, mid, and upper reach of the section to sample for marked and unmarked *G. seminuda*. Population estimates were made using a modified Petersen estimator (Ricker, 1975), which is predicated upon a closed system, and fish randomly mixing. To test for random movement and whether fish remained within the section where they had been tagged, fish movement was tracked by giving each net an identification number and approximate location, using a Global Position System and scaled aerial photograph. A chi-square was used to test the hypothesis that recaptured fish would disperse upstream and downstream with equal frequency.

RESULTS—*Warm Springs Area Counts*—There was a reduction in the number of native fish between 1994 and 1997. Most notable the *G. seminuda* population dropped from over 8,000 to 2 individuals (Table 1). *Moapa coriacea* went from 3,800 to fewer than 1,600 adults. Although we did not enumerate *C. b. moapae,* in 1994 they were virtually 100% sympatric with *M. coriacea,* and they appeared numerous throughout the Warm Springs area. However, in 1997 *C. b. moapa* was rare in most of its range. Coinciding with native fish reduction in the Warm Springs area was the invasion of *O. aurea:* none were observed upstream of the USGS weir in 1994, but in 1997 more than 900 were sighted, many larger than 150 mm FL. *Oreochromis aurea* may have accessed the Warm Springs area when the Reid Gardner Station diversion dam was removed (April 1994) providing sufficient flow to allow passage over the USGS weir.

In 1997 over 65% of the remaining *M. coriacea* were in areas which *O. aurea* had apparently not invaded. In the Refuge Stream, 552 of its 595 *M. coriacea* were found upstream of a series of falls where *O. aurea* had not been sighted. Likewise, in the Apcar Stream, *M. coriacea* inhabited an area of dense *Vallisneria,* conditions which large (>70 mm FL) *O. aurea* appeared to avoid or not yet invaded. *Crenichthys baileyi moapae* followed a similar pattern of distribution and were most abundant in those areas where *M. coriacea* was most abundant and *O. aurea* were absent or few.

In our 1994 survey of the MNWR it was apparent that the flash fire had killed or cause to relocate almost all the fish inhabitants. Only 34 *M. coriacea* and fewer than 150 *C. b. moapae* were accounted for. Except for several shortfin molly (*Poecilia mexicana*), the Refuge Stream immediately downstream of MNWR was devoid of fish life downstream to the Apcar Stream. Most of the *M. coriacea* counted (296) along the Refuge Stream in 1994 were downstream from the Apcar Stream.

TABLE 2—Number and percent of total of fish of each species captured.

Species	Section A	Section B	Section C	Total
Gila seminuda	56.1% (806)	78.7% (1,921)	86.0% (671)	73.0% (3,398)
Rhinichthys osculus moapae	13.7% (197)	19.0% (457)	6.9% (54)	14.8% (708)
Moapa coriacea	0% (0)	0% (0)	0% (0)	0% (0)
Cyprinus carpio	0% (0)	0.2% (5)	0.5% (4)	0.9% (9)
Crenichthys baileyi moapae	0.7% (10)	0% (0)	0% (0)	0.3% (10)
Poecilia mexicana	21.1% (303)	0.8% (18)	0.5% (4)	6.8% (325)
Gambusia affinis	0% (0)	0% (0)	0% (0)	0% (0)
Oreochromis aurea	8.5% (122)	1.4% (33)	1.3% (10)	3.5% (165)
Ameiurus melas	0% (0)	0% (0)	4.7% (37)	0.8% (37)

Downstream from Warm Springs Area-Mark and Recapture—*Gila seminuda* was the most frequently netted species (3,398) representing 73.0% of the total captures, followed by *R. o. moapa* (708) representing 14.1%, and then *O. aurea* (Table 2). Fish captures declined in Section C. *Gila seminuda* captures dropped substantially at rk 16, and remaining consistently low at downstream net sets (Fig. 2). *Rhinichthys osculus moapae* captures were almost nil at and downstream from rk 14.

Movement of PIT-tagged *G. seminuda* indicated that they mixed randomly and did not leave the section in which they had been marked. Fish moved in Sections A, B, and C an average distance of 446, 927, and 993 m respectively, and there was no significant difference in directional movement ($x^2 = 1.03$, $P = 0.30$).

There was an estimated 15,684 *G. seminuda* along the 17.1 km reach sampled (Table 3). The most was in Section B (11,123) and the fewest in section C (2,234). Captured *G. seminuda* tended to be smallest ($\bar{X} = 115$ mm FL; $SD = 21$ mm) in Section B and largest ($\bar{X} = 143$ mm FL; $SD = 25$ mm) in Section C, and intermediate in length in Section A ($\bar{X} = 124$ mm FL; $SD = 24$ mm).

DISCUSSION—*Oreochromis aurea* is the only non-native fish species to have become established in the Warm Springs area since *Poecilia mexicana* (short fin molly) in the early 1960s (Hubbs and Deacon, 1964), and we anticipate *O. aurea* will become a much greater threat to native fish persistence than have previous invaders. Where it has become established in Florida, *O. aurea* has replaced natives and become the predominant fish species (Shafland, 1979; Kohler and Courteney, 1986). Our 1997 survey suggested that in less than three years, *O. aurea* had already reduced the number and distribution of Warm Springs area natives. At the time of our survey *O. aurea* may still have been expanding in number and range, and the full negative effect on Warm Spring area native fish may not have occurred.

The invasion of *O. aurea* has elevated the importance of MNWR as a safe haven for the thermophilic *M. coriacea* and *C. b. moapae,* even though the June 1994 flash fire reduced the *M. coriacea* refuge population from about 500 individuals to 34. Fire, with abundant fuel, has been documented to kill fish and cause local extinction in small streams (Rinne, 1996; Rieman and Clayton, 1997). MNWR fish were probably killed by fire before they could escape. Dried palm fronds were an abundant, highly flammable fuel source, which cloaked the stream with ashes causing bank overflow. Within days after the fire, the remaining fish were concentrated near the spring source, and we speculate that they had survived by holding within spring sources at the time of the fire, and thus escaping the heat and chemical changes associated with highly fueled fires (Rinne, 1996; Rieman and Clayton, 1997). Our survey results prompted the removal of the highly flammable, albeit, fire resistant palms. Uprooting the large palms necessitated stream rehabilitation because hydraulic conditions conducive to all life stages of *M. coriacea* and *C. b. moapae* (Scoppettone et al., 1992; Scoppettone, 1993) were greatly reduced, and the documented invasion of *O. aurea* into the Warm Springs area required that this rehabilitation be expedited. Additional *M. coriacea* and *C. b. moapae* have already begun to be re-

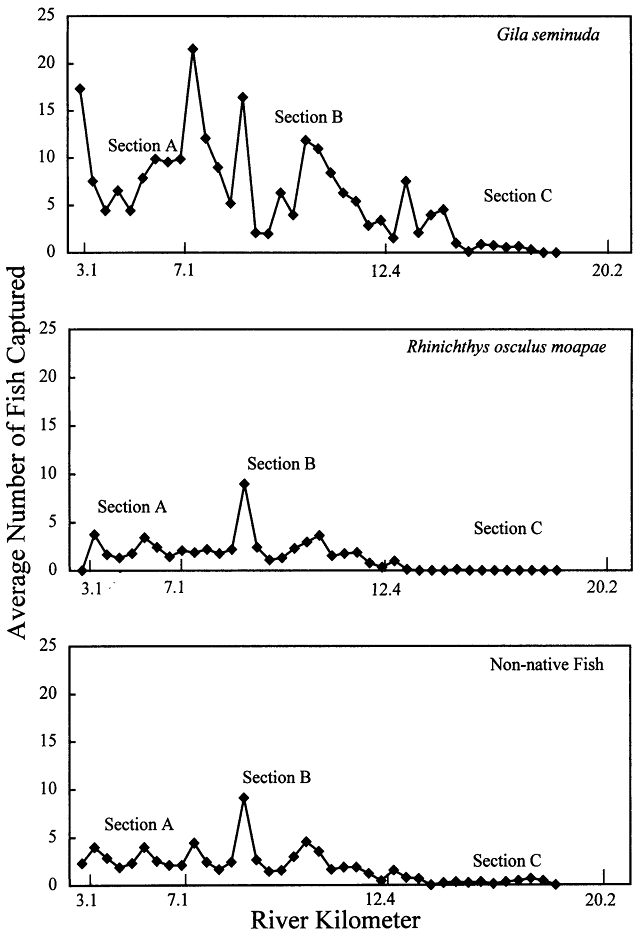

FIG. 2—The average number of fish captured at specific river kilometers throughout each of the three sample sections along the Muddy River.

leased onto the refuge from other parts of the Warm Springs area.

Before our 1994 survey, *G. seminuda* had been reported as less abundant than other fishes in the Warm Springs area, including *M. coriacea* (Hubbs and Miller, 1948; Deacon and Bradley, 1972; Cross, 1976; Scoppettone et al., 1986); for example, in 1986 only 415 were counted compared with over 2,800 *M. coriacea*. *Gila seminuda* distribution was also more localized than *M. coriacea* and was primarily confined to the main stem Muddy River; they were sympatric with *M. coriacea* in only about 50% of the *M. coriacea* range. In the summer of 1994, the *G. seminuda* population was greater than 8,000, most of which were <100 mm FL. It had spread to regions of the Warm Springs area where it had not been previously reported and sympatry incorporated about 90% of the *M. coriacea* range. We suspect that the impounded water created by the Reid Gardner Station power diversion dam encouraged the increase by creating suitable reproductive habitat. Whatever the cause, the increase of *G. sem-*

TABLE 3—Population estimates for *Gila seminuda* along a 17.1 km reach of the Muddy River, Nevada.

Section	Population estimate	95% confidence interval	
		Lower	Upper
A	2,327	1,481	3,173
B	11,123	7,219	15,027
C	2,234	2,186	2,283
Total	15,684	13,235	18,133

inuda in this vicinity probably contributed to downstream recruitment.

Results of our 1995 estimate indicated that *G. seminuda* was reasonably abundant downstream from the Warm Springs area. Catch rate in our hoop-nets suggested *G. seminuda* was much more numerous than *O. aurea,* which had established in the region by 1991. Although our hoop-nets were selective for larger fish, *R. o. moapa* was captured more frequently than *O. aurea*. Thus, *O. aurea* did not appear an immediate threat to replace native fishes downstream. We have renewed concerns, however, for *G. seminuda* and *R. o. moapa* since the Warm Springs area now probably contributes *O. aurea* rather than *G. seminuda* recruits. Such changes the Muddy River should be monitored. The environmental phenomena leading to a marked decline in fishes approximately 14 km downstream from the origin of the Muddy River also merits attention, since some of the apparently least disturbed and favorable native fish habitat harbored few or no fish. Deacon and Bradley (1972) found natives to decrease and non-native increase in a downstream direction, but we found a decrease in number of all species in a downstream direction. We conducted supplementary sampling three months prior to our hoop-net survey and found there were few fish downstream to Bowman Reservoir diversion dam (rk 25; Fig. 1), and the stream seasonally dry and without native fishes downstream of Bowman Reservoir.

Alteration of the Muddy River system has already greatly reduced native fish habitat, but now non-native species threaten to replace native fishes in the Warm Spring area, and the likelihood of fire from spread of fan palms in the basin is growing. Extraordinary measures may be needed to prevent extinction of the Muddy River native fishes.

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