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MANAGEMENT OF ENDANGERED SONORAN TOPMINNOW AT BYLAS SPRINGS, ARIZONA: DESCRIPTION, CRITIQUE, AND RECOMMENDATIONS

Paul C. Marsh¹ and W. L. Minckley²

ABSTRACT.—Efforts between 1982 and 1990 have failed to recover and secure three natural populations of endangered Sonoran topminnow (*Poeciliopsis o. occidentalis*) at Bylas Springs, Arizona. Flooding in the Gila River in 1977–78 allowed ingress by predatory mosquitofish (*Gambusia affinis*), and topminnows began to decline. Since that time (1) one stock has been replaced twice and is again nearly gone because of depredations by mosquitofish that resisted two eradication attempts; (2) topminnows at a second spring were extirpated through vegetation encroachment after fencing to protect the habitat from livestock; and (3) a third population was lost to mosquitofish, restocked after the nonnative was removed, and the restocked population is again in jeopardy, or extirpated, since mosquitofish re-invaded. Recommendations for a more intensive program of recovery are based on reassessments of past efforts and new suggestions for eradication and exclusion of mosquitofish.

The Sonoran (Gila) topminnow, *Poeciliopsis o. occidentalis*, is a poeciliid fish endemic to and once widespread in the Gila River basin of Arizona and New Mexico, USA, and the ríos Gila, Concepción, and Sonora basins of Sonora, México (Hubbs and Miller 1941, Minckley 1973, Vrijenhoek et al. 1985). It was listed in 1967 as an endangered species (U.S. Fish and Wildlife Service [USFWS] 1989) because of predation by introduced mosquitofish (*Gambusia affinis*) and habitat degradation in the Gila River basin (Miller 1961, Meffe et al. 1983, Meffe 1985). Most efforts to recover the Sonoran topminnow have emphasized reintroductions within its native range (USFWS 1984). This paper deals only with attempts to maintain its natural populations, which in the USA are now restricted to fewer than 10 sites, all in Arizona.

STUDY AREA

Three natural topminnow populations occupied a series of small springs adjacent to the Gila River on San Carlos Apache Indian Tribal lands near Bylas, Graham County, Arizona. Two were discovered in 1968 (Johnson and Kobetich 1970) and the third in 1981 (Meffe et al. 1983). No other fishes were present. Although collectively known as Bylas Springs, the habitats gained various coined names in the literature. For brevity, we term them S-I (with west and east sources) through S-III, west to east, and provide a synonymy below. Descriptions and/or mention of the springs have appeared in papers noted above and others by Meffe (1983a, 1983b), Meffe and Marsh (1983), Hendrickson and Minckley (1985), Williams et al. (1985), Taylor (1987), and Hershler and Landye (1988).

All the springs are small, with base flows of a few liters (S-II = Middle Spring, which dried temporarily in 1990) to a few tens of liters per minute (S-I, with west and east sources, = Bos and Medicine springs, respectively; S-III = Salt Creek). S-III has the greatest base flow. S-I and S-II rise through alluvial fill along a stony escarpment; they have essentially no surface watersheds other than their immediate surroundings. S-III rises in the channel of an otherwise ephemeral watershed of >50 km² (Burkham 1976a). All are intermittent in their lower reaches, originally isolated from the Gila River either by desiccating on or percolating into the terrace that parallels the river's broad floodplain (S-I and S-II), or by falling over an alluvial escarpment >2.5 m high (S-III).

Unusually high flooding in the Gila River in winter 1977–78 afforded an opportunity for mosquitofish to invade S-I, and that species plus red shiner (*Cyprinella lutrensis*; recorded only once) also colonized S-III. Subsequent declines in topminnow populations

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were immediate and dramatic in both systems, and various management strategies were planned and implemented in attempts to eradicate the introduced fish and restore topminnows. This paper recollects those efforts, provides a status update on topminnows at Bylas Springs, and offers recommendations to perpetuate the stocks.

**THE SEQUENCE OF EVENTS**

Quantitative data are lacking on the abundance of topminnows at the times of their discovery in Bylas Springs, but these fish were present in substantial numbers, especially in summer throughout the systems and in winter in and near the springheads. After invasion of mosquitofish, topminnow in S-I between summer 1980 and spring 1982 remained in the upper reaches of runs (62–72% of all fishes present) but declined to rare or absent downstream where mosquitofish were numerous. A parallel situation existed in S-III. S-II was never invaded by mosquitofish, and topminnows remained common until 1988.

**S-I.**—In March 1982 S-I was poisoned with antimycin-A (Meffe 1983b). No live fish were found three weeks later, and >150 topminnows, along with large numbers of indigenous invertebrates salvaged prior to poisoning, were reintroduced in the springheads. By July 1982 substantial populations of both topminnows and invertebrates were reestablished. At the same time, however, mosquitofish were discovered downstream. Since the Gila River had not again flooded, poisoning must have failed to remove them from the lower part of the system. Meffe (1983b) recommended massive, repeated poisoning combined with construction of barriers as a possible method of maintaining the topminnow. Both strategies were embraced in the species' recovery plan (USFWS 1984).

Barriers intended to prevent upstream movements of mosquitofish were constructed on the runs of all three springs during winter 1983–84. Each consisted of low (0.7–0.8 m), concrete, V-notch weirs with earthen wings at S-I and S-III extending laterally and upstream for 3.5–6.6 m. No berms were constructed lateral to the barrier at S-II. In addition, the western source of S-I and the single source of S-II, plus the areas surrounding each new barrier, were fenced to exclude domestic livestock.

S-I was again poisoned with antimycin-A in April and June 1984 and restocked in July with >200 topminnows and uncounted invertebrates removed prior to poisoning. All native animals soon reestablished in large numbers. However, mosquitofish again survived downstream, to invade above the barrier when it was bypassed by spate-augmented flows in late summer. The introduced species constituted 24% of total fishes caught in December 1985, 69% in September 1986, and 98% by July 1987 (Simons 1987). In January 1989 topminnows (n = 9) in the fenced (west) source of S-I were accompanied by mosquitofish (n = 6), and only mosquitofish were taken downstream; the unfenced (east) source was not sampled. Three topminnows and one mosquitofish were collected from the fenced source in April 1990, while topminnows composed 44% of 189 fish taken from the unfenced source. No topminnows were found in the pool above the barrier or in the stream below, where mosquitofish were abundant.

In summer 1989, in anticipation of another poisoning (which has not yet occurred), the channel of S-I was realigned to again flow over its barrier, and low (<0.5 m high) gabions of wire-constrained and loose rock were extended for 19–24 m on either side to replace the earthen berms. In summer 1990 notches in all the barriers were reshaped from the original "V" to approximately rectangular, doubling their areas to 1500 cm² to accommodate larger flows. The upstream base of the barrier at S-I was also sealed with bentonite to prevent seepage under the structure, which had become substantial, and a large saltcedar (Tamarix chinensis) that threatened damage was removed.

**S-II.**—This spring experienced no discharge that passed over the barrier and remained secure from mosquitofish; nevertheless, topminnows disappeared in 1990 due to surface water depletion. Invasion by cattail (Typha angustifolia) after livestock exclusion, discussed below, resulted in increased evapotranspiration and accumulation of vegetative debris and entrained sediment that dried the system.

**S-III.**—Topminnows were extirpated from S-III by 1984. A flood in the Salt Creek watershed in 1983 incised the lower part of the run.
to destroy the former waterfall. The intermittent, lower part of the spring run now led into the river over a gentle cataract that should have posed no reasonable deterrent to fish passage. Despite this, the reach above the artificial barrier remained fishless from the time mosquitofish were poisoned in April 1984 until 300 topminnows from S-II were stocked in 1986 (Brooks 1986). Topminnows became abundant, and no exotic fish was captured in 1986, 1987, or winter 1988. The run flooded around the barrier sometime in 1988, and mosquitofish again appeared in spring-summer 1989. By April 1990 mosquitofish constituted 76% of all fishes collected above the barrier and were abundant downstream where only a single topminnow was captured. No topminnows were observed in S-III in July 1990.

In 1989, in anticipation of future renovation and as at S-I, lateral gabions of wire-constrained and loose rock were extended 10–11 m on either side of the structure, and the channel of S-III was realigned to again pass over its artificial barrier.

DISCUSSION

The inability to secure populations of the endangered Sonoran topminnow at Bylas Springs is disturbing, given that nearly a decade has passed since management efforts began. Moreover, of the 10 known natural stocks of Sonoran topminnows remaining in the Gila River basin (including S-I and S-II, the latter now extirpated), 6 were sympatric with mosquitofish in 1987 (Simons 1987) and expected to disappear in the near future.

There is little doubt that two of the three populations at Bylas Springs would already be gone had mosquitofish not been partially controlled, but the facts remain that (1) a topminnow stock at S-I, although removed and replaced twice, is again nearing extinction through depredations by mosquitofish that resisted two attempts to remove them; (2) a native stock at S-II has been extirpated through encroachment of vegetation after fencing to protect it from livestock; and (3) one population (S-III) was lost to mosquitofish, necessitating restocking from S-II after the nonnative was removed, and the restocked population is again in jeopardy, or extirpated, since mosquitofish reinvaded.

Major habitat changes occurred as a result of barrier construction and fencing in the Bylas Springs system. All the runs begin at a relatively low gradient, which is reduced even further as they pass onto the gently sloping surface of the Gila River floodplain. This precluded construction of high barriers without extensive concrete work or excavation for long, lateral berms. The structures decided upon were placed as far downflow as practicable (ca 400 and 200 m downstream from the respective west and east sources in S-I, 60 m in S-II, and 575 m in S-III) to protect maximum lengths of spring runs. All barriers are 700 m or more from the Gila floodplain. None spanned the entire flood channel, however, and those at S-I and S-III failed to direct high discharges over the concrete weirs, since surface runoff from one or more precipitation events cut around them. Berm replacement by longer rock gabions in 1989 again failed at S-I, where surface flow bypassed the barrier in July 1990.

The barriers also created small ponds on the low-gradient runs. Concern existed that such ponds might enhance mosquitofish, and the exotic species did, in fact, quickly expand its population as soon as the lentic habitat was achieved. However, because they had already invaded prior to the presence of ponds, the question was moot. The pond habitats were transitory anyway. Sedimentation was extensive, and all three were quickly invaded by cattails. By 1990, emergent vegetation was so dense above the barriers on S-I and S-III that open water scarcely existed. Cattail stands had trapped even more sediment, so that bypassing by floodwaters may have been forced in part by mounding of vegetative debris and silt upstream from the weirs. Given sufficient time, accumulations of cattails became so extensive that we are convinced the barriers would have been clogged and breached without high water.

In January 1989 the barrier pool at S-II held only small pockets of water, 20–30 cm in diameter and scarcely a centimeter deep. Several dozen topminnows had died in these pockets, likely due to combined low temperature and oxygen depletion in the thin layer of water overlying organic sediments. The population had dwindled to a few individuals, and a single adult male was caught. In April and July 1990 the habitat was only moist; no fish were found despite exhaustive examination.
A similar sequence occurred after fencing to exclude cattle from the source of S-II. The headspring and its outflow were rapidly invaded by cattails, and by January 1989 the plants had formed a virtual mound of living and dead vegetative materials, with surface water only along the margins. We speculated that the site would be uninhabitable by fishes the next growing season, and by April 1990 no surface water was present and the topminnow population was gone. Succession had proceeded to include invasion of a large bulrush (Scirpus sp.). In July 1990 water was present but fishless, and the cattail stands here and at the downstream barrier pool were dead for unknown reasons.

Vegetation in the western source of S-I responded differently to livestock exclusion. The marsh and springhead, although <5.0 m in diameter, were avoided by livestock, presumably due to its dangerously spongy, "quaking," organic deposits overgrown by "cienega" vegetation of small sedges (Elodea sp.) and grasses. Only its periphery was heavily grazed. Over the years Minckley (unpublished data) found three dead cattle mired in the center of this tiny marsh. It remains similar today inside its protective fence, although there is a slightly more luxuriant growth of the same low vegetation but no invasion of cattails. Invasion by other than low, especially adapted sedges and grasses may be precluded by water-saturated, reducing hydrosols, as suggested by Hendrickson and Minckley (1985). Interestingly, the spongy marsh has now solidified and no longer appears dangerous to livestock. Currently, the fish habitat comprises only a limnocrene, ca 50 cm long, 25 cm wide, and 25 cm deep, and its outflow.

The eastern source of S-I was always larger than any other spring but Salt Creek, and remains so. It was not fenced and remains an open, flowing limnocrene 1.0 m across, 2.0 m long, and 25 cm deep. The combination of intense watering/graazing/trampling by livestock plus human activities, although unsightly and outwardly appearing to damage the system, precludes overgrowth by semi-aquatic vegetation.

**RECOMMENDATIONS**

Our recommendation is that the U.S. Fish and Wildlife Service make a firm, appropriately funded commitment to maintain the Bylas Springs topminnow stocks. Piecemeal efforts to date have largely failed because hydrologic and vegetational dynamics and complexity were either not understood or taken into account. Habitat responses to management prescriptions were thus unpredicted. A formal plan for recovery must be implemented, followed by programmed, event-responsive monitoring for the foreseeable future.

Next, it is appropriate to define the degree of isolation of the three Bylas Springs. The presence of endemic hydrobiid snails, members of a specialized group restricted to springs in the American West (Taylor 1987, Hershler and Landye 1988), indicates considerable antiquity of the habitat. These animals are essentially unknown in streams, and their presence in large, erosive rivers like the Gila is even less probable. Their presence in S-III, which rises within a channel that floods on occasion, is unusual. Topminnows could have colonized the springs at any time.

Mosquitofish were not locally available to invade Bylas Springs until perhaps the 1930s. Chamberlain (1904) collected none in the Safford area, and the species was found nowhere else in Arizona until 1926, when it appeared in the Colorado River at Yuma and Salt River in Tempe (Miller 1961, Miller and Lowe 1967). Invasion progressed rapidly, and mosquitofish were abundant statewide at low elevations by the 1940s (Minckley 1973). Topminnows were thus protected for about 40 years, until flooding in 1977–78 was sufficient to permit ingress by the nonnative species. Reconstruction of the history of these habitats helps understand how and why mosquitofish were originally excluded.

The Gila River channel, <90 m in width in the period 1875–1903, was eroded to an average of 600 m in width in 1905–17 (Burkham 1972, Turner 1974). The terrace on which Bylas Springs now occur was not present in the latter period, and the springs were much nearer or could have flowed directly into the river.

During 1905–1906 a cone of coarse alluvium was washed into the Gila River channel by flash flooding in Salt Creek (the channel in which S-III rises). By 1914 the river was being deflected southward and threatening the town of Bylas (U.S. Army Corps of Engineers
This was accompanied by deposition on the north side of the channel, downstream of the Salt Creek alluvial cone, as documented by photographic evidence (Burkham 1972) and indirectly by the sizes of mesquite trees (Prosopis sp.; see Gavin 1973) that could only have colonized after the terrace was formed (see also Minckley and Clark 1984). In part because of saltcedar invasion (Burkham 1976b), the channel again narrowed, to average <120 m by 1964–68. The river remained on the south side of its floodplain; thus Bylas Springs were isolated. Flooding in 1977–78 and again in 1983 continued to erode southward, stimulating major engineering attempts to stabilize and control the channel (personal observation).

Since it was unknown whether invasion by mosquitofish in 1977–78 was an isolated event or whether the system was changed enough to assure continued access by exotic fishes, we reexamined it in July 1990. S-I ended, as it did before 1977–78, in a variably wetted sump formed within saltcedar thickets on the terrace. This sump may exceed 0.5 ha in area and was heavily utilized by livestock. Also, as before, there was no apparent outlet to the Gila River, which lay at least a kilometer farther south and considerably lower in elevation (ca. 5.0 m). S-II similarly remained equally as isolated in 1990 as it was in the recorded past. As noted before, the channel into which S-III rises passed unimpeded into the Gila River and was thus accessible to mosquitofish during flood.

As long as mosquitofish exist in the sump of S-I, an artificial barrier will be required, but it must be designed to function under all but the most severe conditions. S-II seems sufficiently isolated without a barrier, assuming fish habitat can again be established. S-III will require a barrier for the foreseeable future, since mosquitofish will continue to occupy the Gila River. Existing weirs, especially the two endemic hydrobiid snails, Tryonia gilae and the monotypic Apachecocclus arizonae (Taylor 1987, see also Hershler and Landye 1988), which have previously been held on-site for no longer than a few days and in aquaria for about three months. If these animals are to be held captive for a longer period, special treatment or facilities may be required. Typically, invertebrates may be reintroduced soon after the poison dissipates, generally a few days after the final application. Numbers of all animals retained for restocking barriers so that upstream ponds and their associated problems will not exist.

Once mosquitofish are eradicated, a barrier should not be needed on S-II. Forty years of protection by natural isolation would seem an acceptable period of time for management of an endangered, short-lived species such as the Sonoran topminnow. We cannot predict the recurrence interval of major floods, but such events, some of which have exceeded 4000 m$^3$·sec$^{-1}$ in a river that averages 14 m$^3$·sec$^{-1}$ at Safford (Burkham 1970, U.S. Geological Survey 1989), cannot be engineered against. Such a flood, directed against the north side of the Gila River floodplain, would destroy the system as it now exists.

Despite these data and pronouncements, mapping of the entire spring complex is clearly in order for future management reference. The effort should include aerial photography at the time of minimum vegetative development in winter, accompanied by extensive ground truth to confirm intricacies of the aquatic system. The extent of aquatic habitat should be determined under both drought and wet conditions to assure an understanding of actual and potential interconnections.

Next, mosquitofish must be eradicated, an operation which must be preceded by removal of substantial numbers of native fish and other animals from each spring to secure refugia. Fortunately, fish from S-II have already been transplanted to a spring in Roper Lake State Park near Safford, Arizona, where they established a large, reproducing population (Arizona Game and Fish Department [AZGFD], unpublished data). A stock from S-I is being similarly maintained at Arizona State University. The stock originally inhabiting S-III is extinct.

Invertebrates may present a problem, especially the two endemic hydrobiid snails, Tryonia gilae and the monotypic Apachecocclus arizonae (Taylor 1987, see also Hershler and Landye 1988), which have previously been held on-site for no longer than a few days and in aquaria for about three months. If these animals are to be held captive for a longer period, special treatment or facilities may be required. Typically, invertebrates may be reintroduced soon after the poison dissipates, generally a few days after the final application. Numbers of all animals retained for restocking
should be large enough to assure maintenance of genetic variability and a reasonable probability for representation of rare alleles (Meffe 1986, 1987, Meffe and Vrijenhoek 1988).

Considering the negative results of previous attempts, piscicide should be applied repeatedly, perhaps three or more times at weekly or longer intervals. Application should be accompanied by physical dewatering of runs, lateral pools, and the downstream sump of S-I, if possible. Footprints of livestock in muds of the sump provide tiny, but effective, life-support sites in which mosquitofish may survive immediately adjacent to toxic water. Temporary exclusion of livestock might well alleviate this problem. Alternatively, water could be retained upstream by temporarily damming the spring run, so the sump could be repeatedly dewatered, at least to a degree, and then flooded to inundate such refugia with poisonous water.

A fishless period of at least a year should be required for the entire system before topminnows are restocked. Presence of mosquitofish in any of the springs allows children (or adults) to inadvertently or intentionally move them from place to place. Humans are attracted to springs in otherwise arid lands, and the Bylas Springs, although reasonably isolated, are periodically used by local residents for recreation.

In order to assure long-term success, the area must be inspected frequently and managed to assure maintenance of habitat integrity and continued exclusion of mosquitofish, and to detect and interdict local land uses that may prove detrimental. We recommend a cooperative agreement with the San Carlos Apache Tribe to perform a quarterly or more frequent schedule of surveillance and monitoring. Biannual, intensive surveys should enlist the assistance of a professional biologist. The entire system is small and may be thoroughly examined in one day.

The activities of domestic livestock, which must have precluded overgrowth by cattail in the past, may be a necessary part of the ecology of these springs. Encroachment by semiaquatic vegetation destroys small, isolated habitats, and this must be avoided. The habitat disruption and apparent degradation by livestock is preferable to loss of the habitats and topminnows. If reliable, close-order surveillance is developed, the existing fences could be gated and opened periodically to allow removal of vegetation by livestock. If not, we recommend the fences be removed from headsprings and barrier pools alike.

Cattail and other emergent plants could also be controlled by cutting, burning, or chemical herbicides; but these methods are labor-intensive and may be more habitat disruptive than livestock, a situation that should be avoided if possible. Experimental manipulations to determine reasonable vegetation control measures might be attempted at S-II, which is now fishless. Once tested, acceptable control techniques could be applied to other sites.

**CONCLUSIONS**

The current and past recovery efforts in behalf of Sonoran topminnows in the Gila River basin (Brooks 1985, 1986, Simons, 1987, Simons et al. 1989) have emphasized introductions and reintroductions within historic range far more than dealing with natural populations, resulting in continuing jeopardy to natural populations. In fact, according to the current recovery plan (USFWS 1984), all natural populations could disappear without influencing the down-listing or delisting criteria. And, since the criteria have been satisfied (Simons et al. 1989), the species could conceivably be down-listed to threatened status. In 1990 the USFWS Desert Fishes Recovery Team recommended against such action (Minckley, unpublished data).

We do not underestimate the difficulties associated with habitat renovation for maintenance of native topminnow stocks, but we suggest a concerted effort be directed toward accomplishing that end at Bylas Springs. If topminnows cannot be secured here, which undoubtedly represents some of the least complex habitats occupied by natural populations of topminnows in the USA, it seems highly unlikely that any natural population threatened by mosquitofish has much hope of persisting. Yet, repeated attempts to eradicate mosquitofish have failed, and other efforts to manage the habitat have had undesirable results. It is more efficient to devote necessary planning, manpower, and material to initial operations, even if the assurance of success is costly, than to expend lesser amounts on repeated, unsuccessful operations.
over time, whereby cumulative costs become exorbitant and the populations are still lost. A new round of effort is clearly needed, and quickly.

ACKNOWLEDGMENTS

Many individuals have been involved in research and management efforts at Bylas Springs. USFWS personnel have included, among others, J. Brooks (formerly AZGFD), J. Hansen, S. Jacks, D. Parker, B. Robertson (deceased), and S. Stefferud. B. Bagley, D. Hendrickson, and L. Simons, AZGFD, provided data and assistance, as did a number of students and others from Arizona State University; D. Langhorst, G. Meffe, R. Timmons, and S. Vives deserve special mention. The San Carlos Apache Indian Tribe permitted access through their Wildlife Department, and tribal wardens physically assisted in many operations. All deserve special thanks. We, of course, take full responsibility for any errors in fact or interpretation.

LITERATURE CITED


Received 26 July 1990
Accepted 6 September 1990