Decline of the Razorback Sucker in Lake Mohave, Colorado River, Arizona and Nevada

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Abstract.—The razorback sucker Xyrauchen texanus is an endangered fish endemic to the Colorado River basin in the western United States. Once widely distributed and common throughout the basin, the species has been eliminated from most of its former range by establishment of nonnative fishes and water development, and remaining numbers have dwindled precipitously from historical levels. Although Lake Mohave, Arizona and Nevada, supports the largest and genetically most diverse remaining population, razorback sucker abundance in the lake plummeted from historical numbers in the hundreds of thousands to only 44,000 in 1991 and fewer than 3,000 in 2001. This population is limited primarily to large, old adults because predation on their larvae by nonnative fishes has precluded measurable recruitment for nearly half a century. At the current rate of decline, extinction is anticipated within this decade because, at this time, there is no practicable method to remove the continuing threat of nonnative predators to razorback sucker larvae. As such, the persistence of razorback suckers in Lake Mohave depends on a repatriation program begun in 1991, which uses wild-produced larvae that are reared in captivity and returned to the lake at a size that is less susceptible to predation.

The razorback sucker Xyrauchen texanus is among a suite of now-endangered, endemic “big-river” fishes of the Colorado River basin of the western United States. Historically, it was widely distributed and abundant to common in the mainstream and major tributaries from Wyoming south through Colorado, Utah, and Nevada, into Arizona and California, and to the Gulf of California in Sonora and Baja, Mexico (Minckley 1973). Federal listing in 1991 was a result of population declines and range contractions due largely to impacts of nonnative (introduced) fishes and habitat alterations associated with regional water development (USFWS 1998). Riverine populations persist only in the upper Colorado River basin upstream from Glen Canyon Dam, but these are small and isolated (McAda and Wydoski 1980; Modde et al. 1996). Populations in all but one lower-basin reservoir also are small, while a few individuals are occasionally encountered in other highly modified lower Colorado River reaches (Marsh and Minckley 1989; Minckley et al. 1991; Holden et al. 2001). The largest remaining razorback sucker population occurs in Lake Mohave, a mainstream impoundment in Arizona and Nevada.

The long-term effective female population of razorback suckers in Lake Mohave was estimated via molecular techniques to be in the hundreds of thousands (Garrigan et al. 2002; Minckley et al. 2003), and these fish likely were derived from a historical population that numbered in the millions of individuals basinwide. The Lake Mohave population today consists of fish that were produced in the riverine environment during the early 1950s, when young were abundant (Winn and Miller 1954). In the present impoundment, most remaining adults are estimated to exceed 50 years old (McCarthy and Minckley 1987). Natural recruitment into the population is precluded by predation on early life stages by nonnative fishes (Marsh and Langhorst 1988): juveniles are absent from collections, and there is only one record of natural recruitment since the early 1950s (Marsh and Minckley 1989). Abundance estimates for the Lake Mohave razorback sucker population declined dramatically from 60,000–75,000 in the 1980s to fewer than 25,000 in the mid-1990s (Marsh, unpublished data), and extirpation was anticipated by the early 2000s (Minckley 1983; Minckley et al. 1991; Pacey and Marsh, in press).

We present the most recent population abundance estimate and trend data, plus a population viability analysis (PVA) for razorback suckers in Lake Mohave, based on mark-recapture records for the 12-year period, 1991–2002.

Methods

Razorback sucker population abundance monitoring was conducted in Lake Mohave, a 105-km-long, 11,400-ha, run-of-the-river reservoir impounded on the mainstream Colorado River between Hoover Dam to the north and Davis Dam to the south. Recent work was part of a regional management and recovery effort by an ad-hoc Native Fish Work Group (NFWG; Mueller 1995) and...
volunteers. Sampling sites were identified through observation of adult razorback suckers consistently visiting specific areas of shoreline to stage and spawn in springtime. Primary sampling sites and their approximate river kilometer (RK) upstream of Davis Dam on the Arizona side of Lake Mohave included Owl Cove (RK 45), Yuma and Gold coves (RK 39), Arizona Bay (RK 38), Carp Cove (RK 32), and Cottonwood Cove East (RK 32), while sites on the Nevada side included the area between Cottonwood Cove West and Tequilla Cove (RK 35), Hog Farm Cove (RK 31), Six Mile Cove (RK 30), the area between Nine Mile and Half-way coves (RK 27), and Nine Mile Cove (RK 26).

Annual spring (March) sampling occurred in the above-mentioned coves and inlets along shallow shorelines, reefs, and spits, with variously sized trammel nets (20–100 m long × 3 m deep, 2.5–3.8-cm inner mesh, and 25.4–30.5-cm outer mesh) and boat-mounted electrofishers. Gill nets and hoop nets were used infrequently. Overnight net sets were in water 2–6 m deep, with nets cleared of fishes at 4–6-h intervals. Electrofishing was typically performed at night over similar depths. Razorback suckers were placed into on-board live tanks or into floating live enclosures until assessment. With minimal handling, fish were measured to the nearest millimeter (total length [TL]) and examined for sex, parasites, disease, deformity, injury, and general health. Sex categories were defined as juvenile (a young fish that has not attained sexual maturity and does not exhibit external secondary characters that allow reliable sex determination), male, female, and unknown (an adult fish whose sex could not be reliably determined). All razorback suckers were electronically scanned for passive integrated transponder (PIT) tags (Biomark, Inc., Meridian, Idaho). Most fish captured unmarked were injected with a PIT tag, but occasionally fish were released unmarked, although their TL, sex, and physical data were recorded. Approximately 100 fish were removed from the population during the last decade for their reproductive services at national fish hatcheries or for their participation in telemetry and other studies (e.g., Minckley et al. 1991; Mueller et al. 2000; Marsh, unpublished report).

Annual single-census population estimates were determined for razorback suckers by using an adjusted Peterson-method formula (i.e., \( N^* \), the single-census Chapman modification; Ricker 1975):

\[
N^* = \frac{([M + 1] \times [C + 1])}{(R + 1)},
\]

where \( N^* \) is the annual single-census population estimate for the marking or previous year, \( M \) is the number of fish marked during the marking year, \( C \) is the combined number of marked and unmarked fish captured in the sampling or current year, and \( R \) is the number of marked fish captured in the sampling year that were originally marked in the marking year. \( C \) and \( R \) do not include multiple captures of the same marked fish during the same sampling year. Mortality was assumed to be greater than zero and recruitment was assumed to be zero, so \( N^* \) was calculated for the marking year rather than the sampling year (Seber 1973). Confidence limits (CLs) of \( N^* \) were based on a Poisson frequency distribution with \( R \) as the entering variable \( x \) in the distribution table; if \( R \) was greater than 50, Pearson’s formula was used (Ricker 1975):

\[
x + 1.92 \pm 1.960 \cdot (x + 1.0)^{0.5}.
\]

Linear regression was used to determine whether \( M \) and \( R \) were significantly related to time. All statistical analyses were based on a significance level of 0.05.

Our study followed three basic assumptions, generalized by Pollock et al. (1990) for the adjusted Peterson estimate: (1) the population is closed, with no additions or deletions; (2) all animals have a similar likelihood of capture in each sampling year; and (3) marks are not lost or overlooked. The first assumption is less stringent if mortality is random and does not differ between marked and unmarked fish. Fish in our study were subjected to two processes, capture and handling. Razorback suckers that were found dead in nets or that were observed dead after handling were a rarity; however, results indicate occasional substantial annual losses, and a zero-mortality assumption for the adjusted Peterson method was clearly violated. The second assumption requires that the capture probability for individuals is homogenous throughout the population and that fish do not exhibit a “trap response.” Homogeneity was assumed for our study population for several reasons, the first of which was based on the similar age and size of individuals in the population (McCarthy and Minckley 1987). Also, sampling was focused on spawning sites, and all adults were assumed to participate in spawning behavior. Further, razorback suckers have been shown in the past to disperse great distances after release (Mueller et al. 2000) as well as to randomly mix into the population. Finally, the possibility of a trap response is rejected because trammel nets are not baited;
Table 1.—Annual single-census population estimates (Chapman modification of the Peterson method; Ricker 1975) of razorback suckers captured during annual springtime sampling in Lake Mohave, Arizona and Nevada, 1991–2002. Abbreviations are as follows: \( N^* \) is the annual single-census population estimate for the marking or previous year, CL stands for confidence limit, \( M \) is the number of fish marked during the marking year, \( C \) is the combined number of marked and unmarked fish captured in the sampling or current year, and \( R \) is the number of marked fish captured in the sampling year that were originally marked in the marking year.

<table>
<thead>
<tr>
<th>Marking year</th>
<th>( N^* )</th>
<th>Lower</th>
<th>Upper</th>
<th>( M )</th>
<th>( C )</th>
<th>( R )</th>
<th>Sampling year</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>2,698</td>
<td>1,573</td>
<td>5,081</td>
<td>284</td>
<td>122</td>
<td>13</td>
<td>2002</td>
</tr>
<tr>
<td>2000</td>
<td>2,872</td>
<td>1,965</td>
<td>4,392</td>
<td>239</td>
<td>310</td>
<td>26</td>
<td>2001</td>
</tr>
<tr>
<td>1999</td>
<td>8,161</td>
<td>1,458</td>
<td>81,601</td>
<td>33^a</td>
<td>239</td>
<td>1</td>
<td>2000</td>
</tr>
<tr>
<td>1998</td>
<td>4,506</td>
<td>2,627</td>
<td>8,489</td>
<td>226</td>
<td>257^b</td>
<td>13</td>
<td>1999</td>
</tr>
<tr>
<td>1997</td>
<td>5,355</td>
<td>3,190</td>
<td>9,735</td>
<td>310</td>
<td>240</td>
<td>14</td>
<td>1998</td>
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<td>1996</td>
<td>6,678</td>
<td>4,780</td>
<td>9,661</td>
<td>657</td>
<td>344</td>
<td>34</td>
<td>1997</td>
</tr>
<tr>
<td>1995</td>
<td>9,322</td>
<td>7,049</td>
<td>12,653</td>
<td>645</td>
<td>706</td>
<td>49</td>
<td>1996</td>
</tr>
<tr>
<td>1994</td>
<td>13,517</td>
<td>10,281</td>
<td>17,774</td>
<td>988^c</td>
<td>696</td>
<td>51</td>
<td>1995</td>
</tr>
<tr>
<td>1993</td>
<td>16,932</td>
<td>13,549</td>
<td>21,162</td>
<td>1,222^d</td>
<td>1,065^e</td>
<td>77</td>
<td>1994</td>
</tr>
<tr>
<td>1992</td>
<td>20,853</td>
<td>17,060</td>
<td>25,491</td>
<td>1,502^f</td>
<td>1,317^g</td>
<td>95</td>
<td>1993</td>
</tr>
<tr>
<td>1991</td>
<td>44,333</td>
<td>30,118</td>
<td>68,415</td>
<td>709</td>
<td>1,560^h</td>
<td>25</td>
<td>1992</td>
</tr>
<tr>
<td>Mean</td>
<td>12,293</td>
<td>619</td>
<td>620</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(SD)</td>
<td>(12,124)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>6,808</td>
<td>7,192</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\^a Does not include 211 fish that were released unmarked.
\^b Includes 211 fish that were released unmarked.
\^c Includes one fish that was released with an unknown PIT tag mark.
\^d Includes five fish that were released with unknown PIT tag marks.
\^e Includes 33 fish that were released unmarked and 5 fish released with unknown PIT tag marks.

Therefore, a “trap-happy” response is not likely, and a “trap-shy” response would only serve to increase population estimates. Multiple captures of the same marked fish during the same sampling year were removed from analysis because our primary concern was capture of marked fish over the course of a year and not within the same sampling year. The final assumption can be adjusted for tag loss if it is known (Seber 1973). Although PIT tags are considered permanent marks (Prentice et al. 1990), there are instances when they become defective, are lost, or are overlooked during scanning, all of which bias the estimate. There is little information on retention and long-term losses of PIT tags, although in some instances tag loss may be significant (Buzby and Deegan 1999). Care was taken to ensure all injected PIT tags were functional by scanning newly marked fish prior to their release.

Population viability analysis was performed on \( N^* \) to determine the mean and median times to extinction for the razorback sucker population in Lake Mohave. First, linear regression was used to determine the suitability of PVA to estimate the population parameters \( \mu \) and \( \sigma^2 \). We then calculated the cumulative distribution function (CDF) of conditional extinction time, and viability curves were generated from the adjusted Peterson estimate of the population size from marking year 2002 for extinction thresholds of 50, 100, and 500 individuals. Calculations followed the methodology outlined in Morris and Doak (2002) and were based on 95% confidence.

Our study needed to meet four major PVA assumptions in order to estimate razorback sucker population viability. First, capture data represent estimates of total population size based on an assumption that all adult razorback suckers have equal opportunity for capture. Second, there were a sufficient number of years with capture data, such that year-to-year variation in capture data reflected environmentally driven variations and not study error (our study had 11 years of data, with relatively constant fishing effort each year). Third, there have been no extreme environmental changes, either positive or negative (Lake Mohave is a relatively stable, closed environment). And fourth, razorback sucker population growth rate was not affected by density and has not changed as the population size has decreased (population growth rate is assumed constant and negative, as there is mortality and no recruitment).

Results

Razorback suckers have declined more than 94% over the past decade (Table 1). The greatest decline occurred between 1991 and 1992; however, this decline may be attributed to the small
The regression analysis was nonsignificant for remaining suckers. Only in both the marking and sampling year 2000 was C equal to M, which was probably due to the absence of captures of fish marked in 1999. This was likely a result of marking only 33 of a possible 244 fish, which also was reflected in R from the 2000 sampling year.
Natural populations elsewhere in the Colorado River system are non-sustaining and small or have been extirpated. Fish are encountered only occasionally in other portions of the lower Colorado River (Marsh and Minckley 1989; Minckley 1991) and, except for a few repatriates, the species has been extirpated from the Gila River system, Arizona, for nearly 50 years (Minckley 1973, 1983). Only about 100 fish are thought to persist in the Green River, the largest remaining population in the upper Colorado River basin (Bestgen et al. 2002), and that population is also declining (Modde et al. 1996; Bestgen et al. 2002). The razorback sucker population of Lake Mohave, which historically may have been derived from a source that numbered in the millions (Garrigan et al. 2002; Minckley et al. 2003), is now considered the last remaining storehouse of genetic diversity for the species (Dowling et al. 1996a, 1996b). As this adult population dwindles, the genetic variability of the species also declines.

As a proactive effort consistent with recovery goals for razorback suckers (USFWS 1998, 2002), and with a comprehensive conservation plan for native fishes in the lower Colorado River (Minckley et al. 2003), the NFWG captures larval razorback suckers, rears them to a size relatively safe from predation (30 cm or longer), and returns them to Lake Mohave. The goal of this program, initiated in 1991, is to establish a population of at least 50,000 repatriated razorback suckers, in order to replace the aging and nearly extirpated adult stock. To date, approximately 70,000 fish have been released back into the system, but there have been only 811 recaptures. This result may reflect the time needed for the fish to grow to maturity and become available for capture on the spawning grounds (McCarthy and Minckley 1987; Pacey and Marsh, unpublished data).

It is hoped that the intensive conservation effort based upon repatriated fish will contribute toward perpetuation of the razorback sucker and its genetic variability until such time as threats to the species' survival can be ameliorated or removed. Only then can self-sustaining populations be re-established into historical habitats and thus put this critically imperiled species on the road to biological recovery.

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