Status review of the razorback sucker, *Xyrauchen texanus*

by

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submitted to

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INTRODUCTION

The razorback sucker, Xyrauchen texanus (Abbott), is an endemic species of the Colorado River Basin (Miller 1946, 1959). It was once widespread and common in warmwater reaches of many medium and large-sized streams and rivers of the Colorado River Basin from Wyoming south to Mexico. Razorback suckers have been used extensively as food by aboriginal cultures (Ellis 1914, Miller 1955, Moyle 1976); marketable quantities were caught in Arizona as recently as 1949 (Minckley 1973).

Current distribution and abundance of the razorback sucker is much reduced. In the Lower Colorado River Basin (LCRB), the razorback sucker is common only in Lake Mohave, Arizona and Nevada; these fish probably represent the largest remaining concentration (Minckley 1983, Marsh and Minckley 1989a). Smaller numbers of razorback suckers are present in Lake Mead, Senator Wash Reservoir, California, and below Hoover Dam, Arizona and Nevada (Minckley 1983, Ulmer 1987, Mueller 1989, pers. comm., J. Sjoberg, Nevada Department of Wildlife); the species is rare or incidental in other reservoirs and in the mainstream Colorado River and its associated canals (Maddux et al. 1987, Marsh and Minckley 1989b). Razorback suckers in Lake Mohave are presumed very old (McCarthy and Minckley 1987).

In the Upper Colorado River Basin (UCRB), razorback suckers are found regularly only in the upper Green River, Utah, and lower Yampa River, Colorado (Tyus 1987, Lanigan and Tyus 1989) and occasionally in the Colorado River near Grand Junction, Colorado. The razorback sucker is rare or incidental throughout remaining warmwater reaches of the mainstream Green and Colorado rivers. Small concentrations are also present in the Dirty Devil, San Juan, and Colorado river arms of Lake Powell, Utah (Persons and Bulkley 1982, Meyer and Moretti 1988, pers. comm., R. D. Williams, U.S. Bureau of Reclamation). These concentrations are composed almost exclusively of large, and presumably, old adults (McAda and Wydoski 1980, Tyus 1987, Lanigan and Tyus 1989).

To facilitate recovery of rare fishes in the Upper Colorado River Basin, the Recovery Implementation Program (RIP) for Endangered Fish Species in the Upper Colorado River Basin (U.S. Fish and Wildlife Service 1987) was developed. This group is composed of many state and federal agencies, and private organizations that have a mutual interest in how UCRB water resource development activities affect the well-being of rare fish species (U.S. Fish and Wildlife Service 1987). One of the goals of this recovery program is to recover and delist three endangered fish species (bonytail, humpback chub, Colorado squawfish) and manage a fourth species, the razorback sucker, so that it does not need the protection of the Endangered Species Act (U.S. Fish and Wildlife Service 1987). The razorback sucker has been proposed as an endangered species (U.S. Fish and Wildlife Service, Federal Register Vol. 15, No. 156, 15 August 1989). Research and management projects such as this one are funded through the RIP process to provide information necessary to achieve the goals of the program.

This status review provides a comprehensive compilation of information throughout the range of the species that may be useful for more effective management of razorback suckers. Although this report provides a biological summary and basis for a management or recovery plan, several unanswered questions remain such as: 1) implications of proposed federal listing of the razorback sucker as endangered; 2) mechanisms and procedures for implementing recovery actions in both the Upper and Lower Colorado River basins; and 3) long-term management and recovery goals. Treatment of non-technical or non-biological issues are beyond the scope of this project.

The objectives of this report are to: 1) document the historic and present status of the razorback sucker; 2) summarize available life history information for the species; 3) assemble information on potential causes for decline of the razorback sucker throughout its range; and 4) outline present research and management efforts directed at recovery of the razorback sucker. Recommendations are also given for future research and management activities that may expedite recovery of the razorback sucker. These recommendations were developed through fulfilling the aforementioned report objectives, from discussions with the Colorado River Endangered Fishes Recovery Team, and from comments received on numerous draft report reviews.

DESCRIPTION

Xyrauchen is one of three monotypic genera in the family Catostomidae. The razorback sucker was originally described in 1860 as _Catostomus texanus_ from a mounted specimen collected from the "Colorado and New rivers", Arizona (Abbott 1861). Eigenmann and Kirsch (Kirsch 1889) subsequently described _Xyrauchen_ and placed the humpback sucker (=razorback sucker), _Xyrauchen texanus_, in this genus. Jordan (1891) described the Uncompahgre humpback sucker, _Xyrauchen uncompahgre_ Jordan and Evermann, from a single specimen collected from the Uncompahgre River near Delta, Colorado, in 1889. This form was re-examined, and Hubbs and Miller (1953) concluded that the Uncompahgre sucker represented a hybrid of flannelmouth sucker, _Catostomus latipinnis_, and razorback sucker. More complete synonomies for razorback sucker were provided by LaRivers (1962) and Minckley (1973).

Descriptive meristic and morphological characters presented by Abbott (1861), Ellis (1914), Hubbs and Miller (1953), Minckley (1973, 1983), Moyle (1976), Snyder (1981), and Snyder and Muth (1990) are summarized here. The razorback sucker is distinguished from all other catostomids by an abruptly rising, bony, dorsal keel immediately posterior to the occiput. Body shape is elongate, fairly robust, and somewhat laterally compressed, and the caudal peduncle is short and deep. Enlarged interneural bones form the distinctive keel-like nape; hence the common vernacular, razorback sucker. The ventral mouth is moderate-sized with a cleft lower lip, lateral margins of the lips are continuous and rounded. Head is elongate, with a somewhat flattened dorsal surface and a well developed fontanelle. Primary dorsal fin rays are usually 14-15 (12-17), primary anal fin rays 7, total vertebrae 45-47, scales in lateral series 68-87, and gill rakers 44-50 (1st arch). Body coloration is dark brown to olivacious on upper dorso-lateral surfaces and yellow to white on lower ventro-lateral surfaces. Adults grow to a total length (TL) of 1 m and weigh 5-6 kg but are more commonly 400-700 mm TL and less than 3 kg (McAda and Wydoski 1980, Minckley 1983).

Razorback suckers exhibit sexual dimorphism. Breeding males are dark dorsally and bright yellow and orange laterally and ventrally. Breeding females are less strongly colored. Tuberculation associated with breeding condition is more pronounced in males, especially on the anal and caudal fins, and on the ventral surface of the caudal peduncle. Pelvic and anal fin lengths are generally longer in males than in females, whereas the reverse was true for length of the urogenital papillae. Females are generally longer and heavier than males (McAda and Wydoski 1980, Minckley 1983, Meyer and Moretti 1988), and may exhibit a low, broad, dorsal keel similar to that described for some hybrid razorback sucker specimens (Minckley et al. in press). More details describing sexual dimorphism can be found in Minckley (1983).

Eastman (1977, 1980) described the pharyngeal bones, teeth, and caudal skeleton of the razorback sucker. Like most other catostomid genera, *Xyrauchen* is characterized by an intermediate number of moderately compressed pharyngeal teeth arranged in a comb-like fashion, presumably an adaption benthic feeding (Eastman 1977). The razorback sucker caudal skeleton is relatively heavily ossified, and caudal rays are thickened and foreshortened. Eastman (1980) presumed that these features were adaptions to the strong currents present in rivers occupied by this species.

No studies have been attempted to determine if intraspecific variation occurred in the formerly extensive geographic range of the razorback sucker. A qualitative comparison of the few meristic data presented by Hubbs and Miller (1953) indicated that Upper Colorado River and Gila River specimens were similar.

DISTRIBUTION AND STATUS

The 1922 Colorado River Compact divided the Colorado River Basin into upper (UCRB) and lower (LCRB) portions (Fig. 1) at Lee Ferry, Arizona (review by Carlson and Muth 1989). This provides a convenient point of division for discussion of status and biology of the razorback sucker.

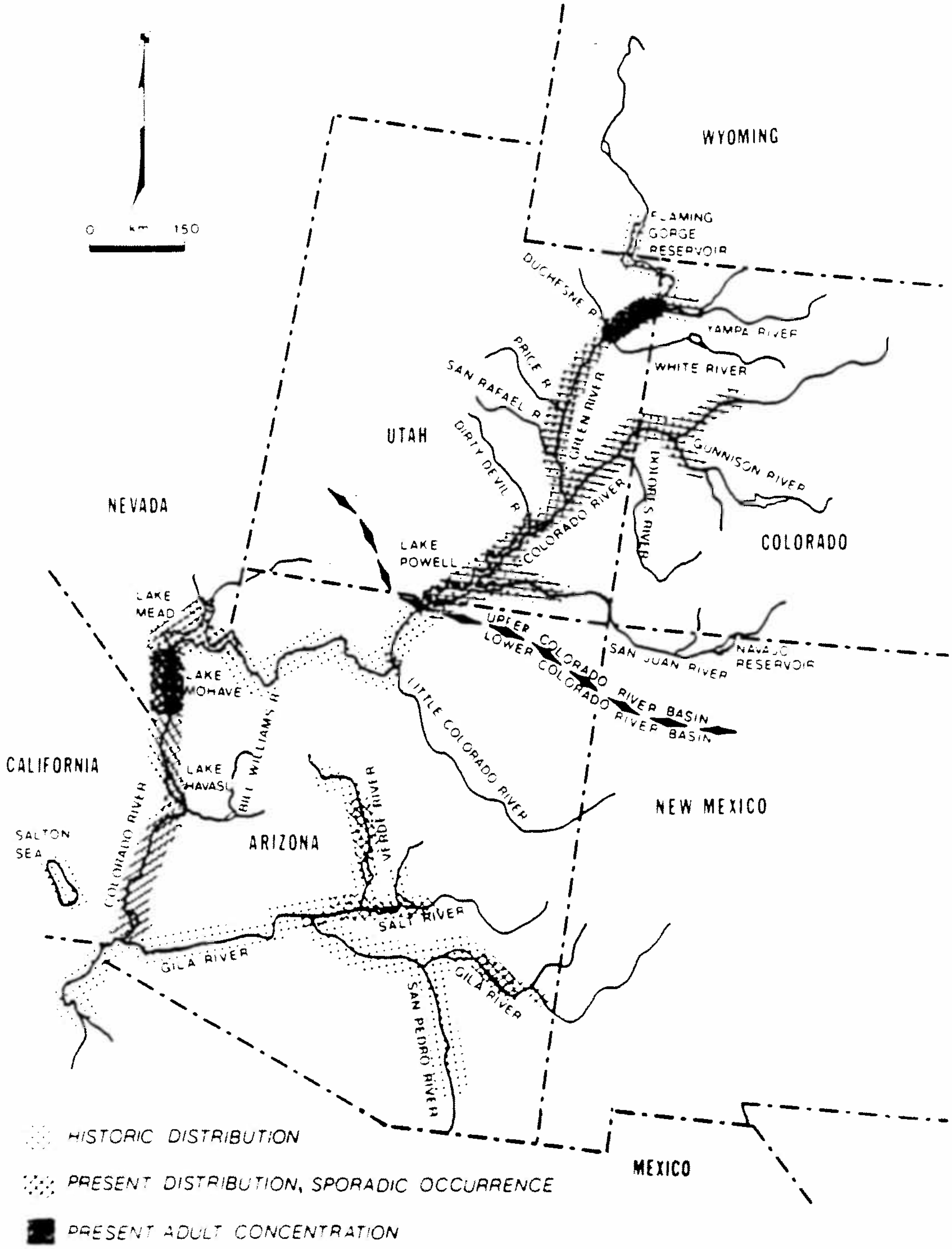

Figure 1. **Historic and present distribution and status of the razorback sucker, *Xyrauchen texanus*, in the Colorado River Basin. Concentration area is an estimated population of > 500 fish.**

Lower Colorado River Basin

Primary drainage units of the LCRB are the mainstream Colorado River and four major tributaries, the Little Colorado, Virgin, Bill Williams, and Gila rivers. Razorback suckers in the LCRB historically occurred in the mainstream Colorado River and the Gila River drainage.

Colorado River--Historic distribution of razorback suckers in the mainstream Colorado River (LCRB) extended from the Colorado River delta in Mexico upstream to present-day Lake Powell. It was most abundant downstream of present-day Lake Mead, and particularly so around Yuma (Gilbert and Scofield 1898). Few records exist for razorback sucker in Grand and Marble canyons, Arizona, (Smith 1959), and lack of extensive surveys (Miller 1946) made historic estimates of abundance in that reach difficult. Razorback suckers may have been historically uncommon in turbulent canyon reaches of the LCRB. Razorback suckers in the Green River (UCRB) are typically found in calm, "flatwater" river reaches, not in turbulent canyons (Tyus 1987, Lanigan and Tyus 1989).

Archeological remains of razorback suckers were common in the Salton Sea area, and a reproducing population apparently existed there in primeval times (Minckley 1983, Minckley et al. in press). Increasing water salinity due to evaporation rendered habitat for freshwater fishes marginal after 1929 and razorback suckers disappeared (Evermann 1916, Coleman 1929).

Decline of the razorback sucker in the Colorado River was noted as early as 1930, and Dill (1944) reported that they were rare and primarily restricted to reservoirs. Dill (1944) also noted an increased abundance of non-native fishes and suggested that they may be negatively impacting native fishes. Moffet (1942) recorded razorback suckers from below Lake Mead but did not report their abundance. Wallis (1951) stated that most native fishes in the region were declining in abundance but suggested that large numbers of razorback suckers had adjusted to the lacustrine conditions in Lake Mead.

Razorback suckers in the Colorado River (LCRB) are now limited primarily to man-made lentic habitats. These include Mead, Mohave, and Havasu reservoirs on the Colorado River mainstream and Senator Wash Reservoir, California (Medel-Ulmer 1980, Minckley 1983, Bozek et al. 1984, Loudermilk 1985, Marsh and Papoulias 1989). The largest concentration of razorback suckers is in Lake Mohave, the newest of the mainstream lower Colorado River reservoirs. Razorback suckers in Lake Mohave have been the subject of long-term study (Minckley 1983, Bozek et al. 1984), and probably represent the largest remaining razorback sucker population in the entire Colorado River Basin. A multiple census population estimate in spring 1989 suggested that about 60,000 (range of 15,000 to 120,000) razorback suckers occurred in Lake Mohave (Marsh and Minckley 1989a).

The unique morphometry and hydrology of Lake Mohave produce patchily distributed areas where large numbers of razorback suckers annually congregate for spawning (Bozek et al. 1984). During spawning, razorback suckers are often the most common fish collected in these habitats (Bozek et al. 1984). Catch/effort and proportion of total catch statistics for razorback suckers from 1983 to 1989 in Lake Mohave were similar to or higher than those for the 1975 to 1982 period (Minckley 1983). Marsh and Minckley (1989a) suggested that the number of razorback suckers in Lake Mohave was stable, and assumed that there was little or no mortality and no recruitment to this stock.

In Lake Mead, groups of up to 20 razorback suckers were observed near the inflow of the Colorado River near Pierce Ferry as recently as 1978 (pers. comm., J. E. Brooks, U. S. Fish and Wildlife Service). Congregations were observed near the boat landing area in late-winter or early spring when spawning might be expected. Four razorback suckers were captured in May 1990 at Vegas Wash Marina, this after earlier observations of 18-20 fish in shallow water in the same area (pers. comm., J. Sjoberg, Nevada Department of Wildlife).

Razorback suckers persist in other LCRB reservoirs, but populations are apparently small and declining in size (Minckley 1983, Marsh and Papoulias 1989). These reservoir populations were presumably produced at times consistent with, or shortly after, reservoir closure (Minckley 1973, McCarthy and Minckley 1987, Minckley et al. in press). Razorback suckers in some LCRB reservoirs live to at least 20 and perhaps 50 years (McCarthy and Minckley 1987), and it was hypothesized that populations will eventually disappear because of lack of recruitment to older age classes (Minckley 1983).

Razorback sucker larvae are annually abundant in Lake Mohave and samples of more than 100 specimens are easily obtained during and just after the reproductive season (Bozek et al. 1984, Marsh and Langhorst 1988). Thirty-seven razorback sucker larvae were collected from Lake Havasu in 1985 and 1986 (Marsh and Papoulias 1989). These larvae were apparently offspring of resident adult razorback suckers and were not transported into Lake Havasu from upstream (Marsh and Papoulias 1989).

Large numbers of razorback sucker larvae are produced annually in Lake Mohave but disappear soon after emergence; juveniles have been extremely rare in collections since the early 1950's (Minckley et al. in press). Three hypotheses were forwarded to explain the absence of razorback sucker larvae larger than 12 mm TL in Lake Mohave (Minckley et al. in press). Larvae may move downstream through the reservoir and into the Colorado River, but available evidence does not support this hypothesis. A food deficiency hypothesis was indirectly tested by comparing growth and survival of razorback sucker larvae in hatchery ponds with differing invertebrate food densities (Papoulias 1988) to the density of food items found in Lake Mohave. It was concluded that starvation of Lake Mohave razorback sucker larvae could occur but only rarely (Minckley et al. in press). Predation on larvae was determined to be the factor most likely limiting successful recruitment of razorback suckers in Lake Mohave. However, Bozek et al. (1984) questioned whether sampling techniques used in Lake Mohave studies were adequate to document presence of juvenile razorback suckers, especially in heavily vegetated littoral zones, and also questioned whether all adult individuals were old. Four small juvenile razorback suckers captured in 1987 at the upstream end of Lake Mohave indicated at least limited survival of this life stage (Marsh and Minckley 1989b).

Razorback suckers are also found occasionally in LCRB canals, tributaries, and the mainstream Colorado River (Minckley 1973, Marsh and Minckley 1989b, Mueller 1989). These were usually one or a few large individuals caught incidentally by fishermen or survey crews (Minckley 1983, Marsh and Minckley 1989b). These areas include the Paria River (Minckley and Carothers 1979), and the mouth of the Little Colorado River (Maddux et al. 1987, pers. comm., D. A. Hendrickson, Arizona Game and Fish Department). Suttkus and Clemmer (1979) collected three razorback x flannelmouth sucker hybrids in the Grand Canyon. Mueller (1989) also reported that spawning razorback suckers were common (50 to 75 annually) in riverine habitat below Hoover Dam and he recorded production of viable eggs and larvae. Marsh and Minckley (1989b) summarized the scattered occurrence of larval, juvenile, and adult razorback suckers from the lower Colorado River downstream of Lake Mohave, most of which were collected from irrigation canals. Although some could have been recently stocked, hatchery-produced individuals, some were thought to be naturally produced (Marsh and Minckley 1989b, Minckley et al. in press).

Gila River--Most warmwater reaches of the Gila River drainage in Arizona historically supported razorback suckers. Records for the species in the Gila River downstream of the Gila-Salt River confluence were uncommon probably because of dewatering and a lack of collections prior to 1960 (Minckley 1973). In the Gila River upstream of the Salt River, and in the San Pedro River (a tributary of the Gila River), historic collections of razorback suckers were also uncommon, perhaps due to low collecting effort prior to 1940 (Minckley 1973). The few reports available, however, suggested that it was common in the Gila River nearly to the New Mexico border (Kirsch 1889) and was available in marketable quantities upstream in the San Pedro River (Miller 1955, 1961).

Razorback suckers were abundant in the lower Salt River downstream of present-day Roosevelt Lake, and also occurred in the Verde River to near Perkinsville, Arizona (Minckley 1973), and in lower Tonto Creek (Hubbs and Miller 1953). Historically, razorback suckers "ran" up irrigation ditches and canals in Arizona, and were so common that they, and the federally endangered Colorado squawfish, *Ptychocheilus lucius*, were pitchforked onto agricultural fields for fertilizer (Minckley 1973). The upstream distribution of razorback suckers in the Salt River may have been limited by extensive canyon habitat. Razorback suckers also used smaller streams, especially in spawning season (Hubbs and Miller 1953, Minckley 1973, Minckley and Carothers 1979).

Habitat degradation and changes in streamflow patterns began in the Gila River drainage in 1905 (Hastings 1959, Miller 1961), and likely reduced razorback sucker habitat. The last substantiated collection of young razorback suckers in the Gila River drainage was in 1926 (Hubbs and Miller 1953, Minckley 1983). Razorback suckers disappeared from Roosevelt Reservoir, Salt River drainage, before the 1930's, but the species persisted in large numbers in other reservoirs in that drainage until the mid-1950's. Since that time, the only known razorback sucker captures from the Gila River drainage were hatchery-produced fish stocked after 1981 (Minckley et al. in press).

Upper Colorado River Basin

Major drainage units of the UCRB are the San Juan-Colorado, upper mainstem Colorado, and Green river sub-basins (Iorns et al. 1965). All of these drainage units historically supported razorback suckers.

San Juan-Colorado River Sub-basin--The San Juan River is the southernmost major drainage of the UCRB and has only one major tributary, the Animas River (Colorado and New Mexico). Other major Colorado River tributaries of the San Juan River sub-basin include Dirty Devil and Escalante rivers. The San Juan-Colorado sub-basin has received the least survey and research effort among the UCRB sub-basins, and the historic status of rare species, including the razorback sucker, is largely unknown. The occurrence of rare fishes in the San Juan River was reviewed by Platania (1990) and Platania et al. (in press). Early records indicated that razorback suckers and other "large-river forms" (including Colorado squawfish) "ran" up the Animas River near Durango, Colorado (Jordan 1891). However, these were based on undocumented evidence; Holden (1980) did not list any collection localities for the razorback sucker in the San Juan River drainage, and Tyus et al. (1982) listed a single locality, presumably from the San Juan River arm of Lake Powell. The only other San Juan River sub-basin records were those of Smith (1959), who reported two small (3.75 cm) razorback suckers from the Colorado River in Glen Canyon prior to inundation by Lake Powell.

There are no specimen-substantiated records for the razorback sucker in the San Juan or Animas rivers in New Mexico or Colorado, although local fishermen accurately described fish similar to razorback suckers (Koster 1960). If razorback suckers existed in the San Juan River, New Mexico, construction and operation of Navajo Reservoir may have reduced their numbers. No razorback suckers were observed in the extensive pre-impoundment fish kill associated with closure of the reservoir (Olsen 1962), indicating that razorback suckers may not have occurred in that area.

Fishery surveys of the San Juan River following closure of Navajo Reservoir (Sublette 1977, VTN Consolidated 1978, Minckley and Carothers 1979, summary in Platania 1990) did not report razorback suckers. The often erroneously quoted account (correctly attributed to personal communication to N. B. Armantrout, U. S. Bureau of Land Management) of a large concentration razorback suckers near Bluff, Utah, in 1976, was clarified by Platania (1990). Only two adult razorback suckers were seined from a small irrigation pond in 1976 near Bluff, Utah (pers. comm., N. B. Armantrout, 1990, in Platania 1990). Several weeks prior to that collection, an unknown source indicated that 100-150 non-adult razorback suckers of various sizes were stranded and died when a second, adjacent pond was drained. These ponds maintained a connection to the San Juan River via an irrigation canal headgate. Contrary to other reports, there were no records of razorback suckers taken from the mainstream at that time.

Surveys in New Mexico (Platania and Bestgen 1988a, Platania and Bestgen 1988b), and Utah (Meyer and Moretti 1988, Roberts and Moretti 1989, Platania 1990), strongly suggest that razorback suckers are rare in the San Juan River. A ripe male razorback sucker collected in the San Juan River in April 1988 near Bluff, Utah (Roberts and Moretti 1989) is the only known mainstream record.

All other razorback sucker records from the San Juan River drainage are from Lake Powell (San Juan River arm). Gustavsen (pers. comm., in Minckley et al. in press) reported capture of eight male razorback suckers from the San Juan River arm of Lake

Powell between 1982 and 1985. U.S. Bureau of Reclamation and Utah Division of Wildlife personnel captured, tagged, and released 12 razorback suckers near the Piute Farms Marina boat ramp in spring 1987 (Meyer and Moretti 1988, Roberts and Moretti 1989). Six of these fish were recaptured in that same season. No additional specimens were captured in fall 1987 sampling efforts. Spring 1988 collections produced four additional razorback suckers and six recaptures from 1987. Recaptures in both years suggested that the concentration was small and many non-native predator species were found at this location (Meyer and Moretti 1988, Roberts and Moretti 1989). Fourteen more razorback sucker adults were captured in April 1990 in the San Juan arm of Lake Powell (pers. comm., D. Knight, Utah Division of Wildlife Resources). Eleven of these specimens were transported to the Colorado River Fishes Propagation and Experiment Station at Ouray, Utah, for brood stock, two fish died, and one escaped. All of the males (n=10) were ripe (pers. comm., H. M. Tyus, U. S. Fish and Wildlife Service). Many of the razorback suckers collected in spring 1987 in the San Juan arm were also ripe males, and this area may be used on an annual basis for reproductive staging or spawning (Meyer and Moretti 1988, Roberts and Moretti 1989).

Other San Juan River sub-basin records included seven razorback suckers (including one recapture) collected in spring 1984 in the Dirty Devil arm of Lake Powell (U.S. Bureau of Reclamation 1984). Four more were collected in spring 1990 in

Lake Powell just downstream of the Dirty Devil River and Colorado River confluence and were taken to the Colorado River Fishes Propagation and Experiment Station at Ouray, Utah (pers. comm., R. D. Williams, U. S. Bureau of Reclamation). Sixteen razorback suckers were collected in the Colorado River arm of Lake Powell in 1981-82 (Persons and Bulkley 1982).

Colorado River Sub-basin--In the Colorado River sub-basin (the mainstream Colorado River and its major tributaries, the Dolores and Gunnison rivers), razorback suckers historically occurred from present-day Lake Powell upstream to near Rifle, Colorado. Razorback suckers were also found in the Gunnison River upstream to at least the confluence with the Uncompahgre River near Delta, Colorado (Hubbs and Miller 1953, Wiltzius 1978, Holden 1980). No records exist for razorback suckers in the Dolores River (Holden and Stalnaker 1975b).

Historic accounts noted that the razorback sucker was moderately abundant in the Colorado River sub-basin prior to about 1950 and Jordan (1891) suggested they were common in larger mainstream sections. Razorback and flannelmouth suckers were marketed for food in Grand Junction, Colorado (Ellis 1914), and a local fisherman stated that from 1930 to 1950, his small commercial fishery on the Gunnison River near Delta, Colorado, supplied fish for mink food and caught "50 squawfish and large numbers of razorback suckers in one of the better years" (Kidd 1977, Wiltzius 1978). Other accounts in the 1940's suggest that thousands of razorback suckers could be seen in the spring, perhaps spawning, in a flooded pasture near Clifton, Colorado (RM 175.6)(in Osmundson and Kaeding 1989a). No accounts of abundance are available for the Colorado River in Utah.

Reductions in distribution and abundance of razorback suckers in the Colorado River sub-basin were evident by the early 1940's and by 1945, razorback suckers were apparently common only in the lower Gunnison River (Wiltzius 1978). Razorback suckers accounted for only about 1% of all catostomids collected in 1946 by W. P. Knoch from the Colorado River at the mouth of the Gunnison River (Hubbs and Miller 1953). By the 1950's, Beckman (1952) considered the razorback sucker a rare species in Colorado. Eight razorback sucker juveniles comprised less than 0.5% of the fish collected (n=2,785) from the Colorado River near Moab, Utah, in 1962-1964 (Taba et al. 1965). These specimens ("90-115 mm long") were the last verified razorback sucker juveniles documented from the Colorado River.

Razorback suckers are currently rare in their historic range in the Colorado River, and remaining individuals are scattered. Only five razorback suckers were collected in three surveys of fishes of Cataract Canyon, Utah, since 1979 (Persons et al. 1982, Valdez et al. 1982a, Valdez 1990). The relatively large concentration of razorback suckers in the Colorado River near Grand Junction, Colorado, has declined dramatically in recent years. From 1974 to 1976, Kidd (1977) collected 234 adult razorback suckers; most (n=210) were from Walker Wildlife Area gravel pit-ponds and other backwaters, near Grand Junction, Colorado. McAda and Wydoski (1980) also sampled the Walker Wildlife Area from 1974-1976 (Table 1); 66 razorback suckers captured comprised 3.4 % of all fish caught. Razorback sucker captures reported by Kidd (1977) and McAda and Wydoski (1980) were not duplicated in their respective reports (pers. comm., C. McAda, U. S. Fish and Wildlife Service), as was suggested by Minckley et al. (in press). Some of these fish represent recaptures; the exact number is unknown.

From 1979 to 1982, 86 razorback suckers were collected in the Colorado River from Rifle, Colorado, to Lake Powell (Valdez et al. 1982a, summary in Osmundson and Kaeding in review); 69 were collected from the Grand Valley, Grand Junction, Colorado and most of those from the Walker Wildlife Area and another gravel pit near Clifton, Colorado. From 1985 to 1988, only 12 razorback suckers were collected in a 53-km reach of the Colorado River in the Grand Valley (Osmundson and Kaeding 1989a, in review), where it was less common than the federally endangered Colorado squawfish. The Walker and Clifton area gravel pit ponds in the Grand Valley, Colorado, which formerly held large numbers of razorback suckers (Kidd 1977), were altered by floods in 1983 and 1984 (Osmundson and Kaeding 1989a). These habitats now consist of small backwaters, secondary channels, or have been diked from the river and are not accessible. The fate of razorback suckers that formerly occupied these gravel pit ponds is unknown. Only one adult razorback sucker (555 mm TL)

Table 1.--Comparison of trammel net catch rates of razorback suckers and other fish species in the Colorado River Basin. Trammel net catch data for razorback sucker are from Kidd (1977), McAda and Wydoski (1980) and Minckley (1983), and Bozek et al. (1984). Trammel net catch-per-unit-effort (CPUE) is number of fish/100m^2 of net/24hr.

Locality and Investigator	*Xyrauchen texanus*	*Ptychocheilus lucius*	*Catostomus latipinnis*	*Cyprinus carpio*
COLORADO RIVER				
Walker Wildlife Area, CO				
Kidd*				
1974	5.00	2.50	--	--
1975	5.40	2.00	--	--
1976	4.57	0.57		
McAda and Wydoski				
April 1975	5.95	6.52	18.97	25.60
May 1975	1.25	0.91	13.37	6.40
June 1975	0.46	0.57	8.80	7.10
GREEN RIVER, UT				
McAda and Wydoski				
Sand Wash December 1974	1.14	1.26	116.59	98.30
Island Park April 1975	0.23	--	4.57	--
Echo Park May 1975	0.24	--	6.63	1.71
LAKE MOHAVE, AZ-NV				
Minckley 1975-1981	2.17	--	--	10.79
Bozek et al. Nov. to April 1982-1983	>10-104.6	--	--	--

*Range of 2 to 8 net hours/day given, catch rates here calculated on 8 hour net-day.

has been collected from the Colorado River, Colorado (1988, RM 146.7) during the standardized monitoring program collections from 1986 to 1990 (pers. comm., P. J. Martinez, Colorado Division of Wildlife); none are known from the Colorado River in Utah. Razorback suckers formerly occurred at the diversion to Highline Canal (Kidd 1977, pers. comm., P. J. Martinez). Two adult razorback suckers (495 and 545 mm TL) were captured in Highline Reservoir near Grand Junction, one on 5 April 1988 and one on 28 September 1989, and another may have been sighted there (pers. comm., P. J. Martinez). During April 1990, four more adult razorback suckers in breeding condition were collected along with ripe and presumably spawning, white and flannelmouth suckers. Highline Reservoir is a drain-water collection reservoir that has a source canal from the Colorado River just upstream of the Grand Valley Diversion.

Recent collections indicate that the formerly large Gunnison River razorback sucker population is much reduced. Only two specimens are known from there since 1970 (Kidd 1977, Wiltzius 1978, Valdez et al. 1982b, McAda 1987).

Green River Sub-basin--The Green River sub-basin consists of the mainstream Green River and its major tributaries, the Price, Duchesne, White, and Yampa rivers. Historic distribution of the razorback sucker in the Green River extended from the confluence of the Green and Colorado rivers upstream to Green River, Wyoming (Jordan 1891, Evermann and Rutter 1895, Simon 1946, Sigler and Miller 1963, Baxter and Simon 1970, Vanicek et al. 1970).

Razorback suckers have been collected from the Duchesne River (Tyus 1987) and but are uncommon in the White River (Sigler and Miller 1963). The historic distribution and status of the razorback sucker in the Yampa River is difficult to assess because of lack of collections. The few recent captures in the Yampa River suggest that razorback suckers occurred in the lower Yampa River and rarely upstream to the Little Snake River, Colorado (McAda and Wydoski 1980, Lanigan and Tyus 1989, pers. comm., E. J. Wick, Colorado State University).

Jordan (1891) stated that large razorback suckers were very abundant in the Green River at Blake City, Utah (Green River Station), and were generally common in the Colorado River Basin, but gave no specific data. Razorback suckers were apparently rare in upstream reaches of the Green River in Wyoming, even prior to the impoundment of Flaming Gorge Reservoir (Simon 1946, Hubbs and Miller 1953, Smith 1959, Gaufin et al. 1960, Smith 1960, Sigler and Miller 1963, Banks 1964, Vanicek et al. 1970, Holden and Staknaker 1975a). Smith (1959) stated that razorback suckers were "common in the lower part, but comparatively rare in the upper section of the Green River." Poisoning of the Green River prior to closure of Fontanelle Dam (Flaming Gorge Reservoir), provided subsequent observations of fishes in the Green River downstream of there. Banks (1964) collected ten razorback suckers during studies of the effects of fish poisoning in the Green River in Dinosaur National Park. Accounts of larger numbers of specimens (up to 60) were also related (in Minckley et al. in press), but

Binns (1965, 1967) suggested that the razorback sucker was the rarest fish observed during this operation. Concentrations regularly occurred in the mouth of the Yampa River near the Green River confluence (Holden and Stalnaker 1975a, Holden and Stalnaker 1975b, Seethaler et al. 1979, McAda and Wydoski 1980).

Pre- and post-impoundment Flaming Gorge Reservoir studies documented the disappearance of the razorback sucker and some other native fishes from the Green River upstream of the Yampa River after closure of Flaming Gorge Reservoir in 1962 (Banks 1964, Vanicek et al. 1970, Stalnaker and Holden 1973, Holden and Crist 1979). Sigler and Miller (1963) also noted declining abundance of the razorback sucker throughout its range in the UCRB.

Razorback sucker presently occupy a portion of their former range in the Green River from the Green-Colorado River confluence upstream into the lower 21 km of the Yampa River (Tyus 1987, Tyus and Karp 1989). Razorback suckers remain rare in the upstream reaches of the Yampa River; only two specimens were captured among many thousands of adults of other fish species collected since 1977 (Wick et al. 1979, Wick et al. 1981, Wick et al. 1982, Wick et al. 1985, Wick et al. 1986). Small concentrations of razorback suckers are still present at the mouth of the Yampa River (Tyus 1987, Lanigan and Tyus 1989, Tyus and Karp in press). In the upper Green River, Utah, the razorback sucker is most abundant from the mouth of the Duchesne River upstream to the Yampa River. Tyus (1987) captured 323 specimens from 1979 to 1986 in this area.

Razorback suckers in the upper Green River, Utah, represent the largest remaining concentration in the UCRB but are rarer in this area than the federally endangered Colorado squawfish (Tyus 1987, Tyus et al. 1987, Lanigan and Tyus 1989). Lanigan and Tyus (1989) estimated that 948 razorback suckers (95% confidence interval, 758-1,138) occurred in the Upper Green River, based on capture-recapture data from 1980 to 1988. In the same period, only 13 razorback suckers were captured (1 recapture) in the Green River downstream of the Duchesne River, a population estimate was not attempted for that area.

Young razorback suckers were very rare in collections from the Green River. Holden (1980) reported collecting young razorback suckers in the Green River, Utah, but did not preserve any specimens. Tyus et al. (1987) reported capture of larval suckers (tentatively identified as razorback suckers by D.E. Snyder, Larval Fish Laboratory, CSU) near a spawning area in the Green River in 1984.

Recent records of razorback suckers in tributaries of the Green River are also rare. Surveys of the White River (Carlson et al. 1979, Lanigan and Berry 1981, Martinez 1986, Chart 1987) and San Rafael River (McAda et al. 1980) failed to reveal razorback suckers, although one hybrid razorback x flannelmouth sucker was collected in the White River (Lanigan and Berry 1981). Records of razorback suckers in tributaries and other seasonally flooded, off-channel habitats, were often associated with springtime spawning movements (Tyus 1987, Tyus and Karp in press).

LIFE HISTORY

Habitat

Razorback suckers occupy a wide variety of habitats. Mainstream portions of moderate-to-large streams and rivers, and associated low-velocity habitats (backwaters, sloughs, oxbow lakes), were integral elements of the historic riverine habitat occupied by most life stages of the razorback sucker (Holden and Stalnaker 1975a, Minckley 1983, Lanigan and Tyus 1989, Tyus and Karp 1989, Minckley et al. in press, Osmundson and Kaeding in review). Other habitats which were used by razorback suckers included nearshore runs and shallow to deep channels adjacent to, or over, mid-stream sandbars (Holden and Stalnaker 1975a, Tyus 1987, Tyus and Karp 1989). Prior to construction of mainstream dams, dampening of high springtime flows, and channelization, off-channel habitat was more commonly available than now (Beland 1953, Tyus and Karp 1989, Osmundson and Kaeding in review); absence of seasonally flooded shorelines and bottomlands may be a factor limiting recruitment of young razorback suckers (Tyus and Karp 1989, Osmundson and Kaeding in review). Springtime congregations of razorback suckers found in off-channel impoundments and tributaries (McAda and Wydoski 1980, Valdez et al. 1982a, Tyus 1987, Tyus and Karp 1989, Tyus and Karp in press, Osmundson and Kaeding in review) demonstrate the importance of these habitats.

Thermal regimes of streams and rivers throughout the extensive geographic and altitudinal range of the razorback sucker vary widely. In the northern portion of its range, razorback suckers may overwinter in ice-covered riverine environments, and in summer, water temperatures often exceed 25 C. In downstream reaches of the mainstream Colorado River near Yuma, Arizona, where razorback suckers were formerly abundant, winter water temperatures were rarely below 10 C, but summer temperatures often approached 32 C (Dill 1944). Bulkley and Pimentel (1983) reported that optimal summer water temperatures for razorback suckers were 22-25 C, based on temperature preference and avoidance experiments. Estimated upper temperature range avoidance (27.4-31.6 C) depended upon acclimation temperature, but lower avoidance temperatures (8.0-14.7 C) were independent of acclimation temperature.

Little is known of the habitat associations of larval razorback suckers in riverine habitats. Sigler and Miller (1963) and Tyus (1987, identification tentative, pers. comm., D. E. Snyder, Colorado State University) collected larval razorback suckers in shallow, quiet shoreline areas in the lower Colorado River, Arizona, and upper Green River, Utah, respectively. Razorback sucker larvae in the lower Colorado River were concentrated on the stream margin in water that was substantially warmer (21.1-24.4 C vs. 15.5 C) than mainstream temperatures (Sigler and Miller 1963). Presumably, these life stages also inhabited backwaters and other off-channel habitats that offered refuge from high water velocities.

Razorback sucker larvae observed or captured in reservoirs occupied nearshore environments over a variety of substrate types and were generally found in the vicinity of spawning areas (Sigler and Miller 1963, Minckley 1983, Bozek et al. 1984, Marsh and Langhorst 1988). Marsh and Langhorst (1988) collected only one larval razorback sucker in deepwater trawls in Lake Mohave, indicating that larvae did not use these habitats extensively. Larvae in Lake Mohave were generally in shallow water (0.3-1.0 m deep), but have been collected at the surface in water as deep as 4.9 m (Bozek et al. 1984). Gently-sloping terraces of wave-sorted gravel and cobble substrate where adults spawn also provides larval habitat. Larvae spend most of the day in the substrate (Bozek et al. 1984) and sediment-free interstitial spaces that are well-oxygenated may be important.

Habitat of juvenile razorback suckers is even less known than that of larval life stages. Taba et al. (1965) collected several juveniles ("90-115 mm long") in a shallow backwater over mud substrate in the Colorado River near Moab, Utah.

During most seasons, adult razorback suckers in lotic environments occupied nearshore and mid-channel habitats, including slow runs, deep eddies, pools, and backwaters over silt and sand substrate, and were sometimes associated with instream cover (Minckley 1973, McAda and Wydoski 1980, Tyus et al. 1982, Valdez et al. 1982a, Tyus 1987, Osmundson and Kaeding 1989a, Tyus and Karp 1989). During spring and early summer, adult razorback suckers have been captured in large numbers in warm, low-velocity backwaters (Kidd 1977, McAda and Wydoski 1980, Valdez et al. 1982a), but sometimes moved into faster, shallower habitats, presumably to spawn (McAda and Wydoski 1980, Tyus and Karp 1989, Tyus and Karp in press). In winter, razorback suckers in the Colorado River, Colorado, used deep (> 1.3 m), low-velocity (0.3 m/s) habitat with silt and sand substrate (Osmundson and Kaeding 1989a). In the Green River, Utah, overwintering adults were found over silt and cobble substrate where water was less than 1 m deep and current velocity was less than 0.3 m/sec (Valdez and Masslich 1989).

Movement

Transport and movement of razorback sucker larvae in riverine environments is poorly understood. In studies of other catostomid larvae, low-velocity stream habitats such as backwaters and stream margins were used extensively (Minckley 1973, Scott and Crossman 1973). Downstream transport of larvae can occur when current velocity exceeds swimming ability. Movement distance downstream probably depended on size and developmental state of larvae, stream size, current velocity, turbidity, channel morphology, and perhaps water temperature (Bestgen et al. 1987). In a laboratory experiment, two-week-old razorback sucker larvae were tested for response to varying flow and light conditions (pers. comm., H. M. Tyus, U. S. Fish and Wildlife Service). Most downcurrent movement occurred during darkness in the fastest flow conditions, but decreased as age, and presumably, size, increased.

In reservoirs, razorback sucker larvae may be susceptible to involuntary movement caused by wave action and currents in near-shore habitats but this has not been studied. Larvae in reservoirs moved from the substrate into the water column, especially at night when attracted to a strong, artificial surface light (Bozek et al. 1984). Larvae were not observed by divers during the day but were common in the same areas at night.

Hatchery-produced razorback sucker juveniles introduced into some streams in the Gila and Verde river drainages showed a marked tendency for downstream dispersal (Brooks 1985, Marsh 1987). Mass downstream movements at night were documented while very little upstream movement was noted.

Springtime movements of adult razorback suckers have been described from observations, tag-recapture data, and radiotelemetry. Early observers described "springtime runs" of razorback suckers and other large-river fishes from mainstream environments into smaller tributaries, presumably for spawning (Minckley 1973). Other observers recorded springtime movements associated with spawning in lentic systems from deeper offshore areas into shallow water zones adjacent to rocky shorelines (Douglas 1952, Jonez and Sumner 1954, Minckley 1983). The annual springtime appearance of razorback suckers below diversions (Kidd 1977), in gravel pits (McAda and Wydoski 1980, Valdez et al. 1982a), and downstream of larger dams also suggested movements associated with spawning (Mueller 1989).

Razorback sucker movements were studied in the Green River with both mark-recapture and radiotelemetry methods (McAda and Wydoski 1980, Valdez and Masslich 1989, Tyus and Karp in press). Data suggested a mostly sedentary population with a component of migratory individuals that have a strong fidelity for the same spawning areas each year (Tyus and Karp in press). Movements were associated with spring spawning and centered around a few areas, the confluence of the Yampa and Green River and the Jensen area between Ashley Creek and the downstream boundary of Dinosaur National Monument. Five male razorback suckers radiotagged and tracked for two weeks at the mouth of the Yampa River in May 1975 (McAda and Wydoski 1980) stayed within 1 km upstream of the release site. Contact was lost with all fish within two weeks; all were moving downstream at that time.

From 1987 to 1989, 66 of 88 razorback suckers recaptured or radiotracked in the upper Green River remained or were recaptured within a restricted river reach and were classed as local (Tyus and Karp in press). Most of these fish used the Jensen area, but six used a reach from Island Park upstream to the mouth of the Yampa River. Migratory razorback suckers included 19 individuals which ranged 53 to 190 km (Tyus and Karp in press). Some of these fish moved between the Yampa River and the Jensen area (n=4, mean one way distance = 49.6 km), and from Jensen to a composite area including Old Charley Wash and lower Duchesne River (n=13, mean one way distance = 94.4 km). Four fish exhibited round trip migrations, one from upstream of Jensen and three from Jensen to

Old Charley Wash. Long distance movements were presumably associated with spawning; all movements occurred during the spawning season, and the majority of fish were ripe when captured.

Other mark-recapture studies in rivers and associated habitats also suggests both movement and sedentary existence for razorback suckers (Vanicek 1967, McAda and Wydoski 1980, Valdez et al. 1982a). Most fish were recaptured within 2 km of their release sites, however, many of these were marked and recaptured within the same gravel pit-ponds. Razorback suckers were formerly attracted in springtime to off-channel gravel-pit habitats of the Colorado River in the Grand Valley (McAda and Wydoski 1980, Valdez et al. 1982a). Most of the razorback suckers tagged and released in the gravel pit ponds stayed there for varying periods. However, Valdez et al. (1982a) recaptured two fish that moved from the Walker Wildlife Area pond to a gravel pit pond and a backwater 22.7 km and 26 km upstream, respectively. Repeated sampling at tagging localities, without equal effort at non-tagging localities, increases the probability that sedentary patterns will be observed.

Other telemetry information suggests that some razorback suckers were sedentary while others showed some movement (McAda and Wydoski 1980, Osmundson and Kaeding 1989a). Three razorback suckers radiotagged in autumn moved short distances but only within the Walker Wildlife Area gravel pit (McAda and Wydoski 1980). Diel movements of one fish were greatest in late evening and late morning, and fish did not school. Three razorback suckers radiotagged in the mainstream Colorado River near Grand Junction in spring 1987 showed some movement (Osmundson and Kaeding 1989a). Two of these fish moved downstream 17.1 and 19.2 km, respectively, and stayed there the remainder of the year while a third moved upstream 11.2 km from its release site within about a 3-week period and subsequently moved downstream to near its release site.

Telemetry information for razorback suckers was also collected in the Gila River, near Safford, Arizona (Marsh and Minckley 1989c). Fourteen wild (Lake Mohave) and hatchery-reared adults were implanted and released 24 May 1988, and nine more were implanted, held for recovery, and later released on 12 October 1988. Movements of fish were mostly downstream; only three fish moved upstream. Most were thought to have died in a short time (32 days or less) as indicated by recovery of transmitters near fish remains. Some fish may have moved downstream to San Carlos Reservoir where transmitter signals were undetectable in deeper water (Marsh and Minckley 1989c).

In winter, razorback suckers in the Green River remained within 5 km study sections and exhibited no distinct diel pattern of movement (Valdez and Masslich 1989). Local movements occurred between closely-spaced microhabitats, but fish often remained sedentary for several hours within a microhabitat.

Movements of razorback suckers in Lake Mohave were evaluated with mark and recapture data (Marsh and Minckley 1989a). Of twenty-five fish recaptured two to seven years after tagging

(Bozek et al. 1984), only four remained in the same locality. The remainder moved up, down or across the lake 4 to 26 km. Of 24 razorback suckers tagged in 1988 and recaptured in 1989, 12 were stationary and 12 moved up, down or across lake 6.4 to 25 km (Marsh and Minckley 1989a). Most fish tagged in 1988 and 1989 and recaptured in the same year showed little movement. However, in 1989, two razorback suckers moved 6.4 km across Lake Mohave, and one fish moved uplake 8 km in less than two days (Marsh and Minckley 1989a).

Reproduction

Some aspects of the reproductive biology of razorback suckers are relatively well-known (Douglas 1952, Jonez and Sumner 1954, McAda and Wydoski 1980, Minckley 1983, Bozek et al. 1984, Loudermilk 1985, Tyus 1987, Tyus and Karp in press). Razorback suckers are highly visible in shallow coves of some reservoirs at the onset of spawning season (Minckley 1983, Bozek et al. 1984). Specific spawning habitat in reservoirs consists of shallow (usually 0.3-2 m), flat or gently sloping offshore areas over gravel, cobble, or mixed substrate types (Douglas 1952, Minckley 1973, Minckley 1983, Bozek et al. 1984, Mueller 1989). These areas are located adjacent to gently sloping shorelines, at the mouths of washes, or over terraces of wave-sorted gravel. Razorback sucker spawning depressions (termed redds by some investigators) overlay bands of offshore wave-sorted gravel and cobble in Lake Mohave (pers. comm., G. Mueller, U. S. Bureau of

Reclamation). The bands are parallel to the shore; depths depend upon previous reservoir drawdown levels and degree of subsequent submergence. Ripe razorback suckers were collected from Highline Reservoir, Colorado, over a wave-washed shoal of gravel and shale in water that was 0.6 to 1.3 m deep (pers. comm., P. J. Martinez, Colorado Division of Wildlife).

Spawning behavior has been extensively documented in some LCRB reservoirs (Douglas 1952, Medel-Ulmer 1980, Bozek et al. 1984). Generally, several males (2-8) accompany a single female over the spawning area. The female apparently selects the precise spawning location and settles near the bottom with a male on each side. All fish convulse rapidly while in contact with each other, and eggs and sperm are simultaneously released. Fertilized eggs settle into spaces between substrate particles in the depression caused by spawning activity. Number of eggs deposited in a single spawning act is apparently a small portion of the total female complement, because few eggs or larvae were observed in depressions following spawning (Bozek et al. 1984, Mueller 1989). Fractional spawning or deposition deep in the substrate may partially explain the small number of eggs observed. Spawning activity was noted throughout the day during the peak of the reproductive season, but was most intense at dusk (Bozek et al. 1984).

Razorback suckers in Lake Mohave had an extended spawning season from late winter to early summer (Minckley 1973). In 1982 and 1983, razorback suckers spawned from late November into May, but peak spawning occurred between January and March (Bozek et al. 1984). Water temperature and photoperiod were declining toward annual minima when razorback suckers first moved into spawning areas. Peak spawning activity took place when water temperature was stable at 10 to 12 C (pers. comm., J. E. Brooks, U. S. Fish and Wildlife Service) or was rising and in the range of 10 to 15 C (Bozek et al. 1984). Water temperature reached 20 C by the end of the spawning period in May (Bozek et al. 1984). Douglas (1952) reported spawning temperatures of 12-18 C for razorback suckers in Lake Havasu.

Male/female ratios of razorback suckers in Lake Mohave during the spawning season ranged from 1.2 to 3.6:1 (Minckley 1983, Bozek et al. 1984). Males generally outnumbered females on the spawning grounds, and ripe males were present for a longer period than females (Bozek et al. 1984). Bozek et al. (1984) reported that during spawning peaks, about 80% of the males and less than 65% of the females were ripe. Decreases in mean size of male and female razorback suckers and catch rates of ripe individuals later in the season (May) were noted (Bozek et al. 1984). Also, individual razorback suckers were recaptured in spawning areas from one day to one month after tagging, and indicated abbreviated residence time at these locations. These data suggest that annual spawning by the population occurred over several months, but that individual razorback suckers completed spawning in a relatively short time (Bozek et al. 1984).

Razorback suckers are sometimes found in tributaries or off-channel habitats prior to, or during, presumed spawning season (McAda and Wydoski 1980, Tyus 1987, Osmundson and Kaeding 1989a, Tyus and Karp in press). These off-channel habitats are often warmer than the mainstream, especially in spring (Tyus and Karp in press, Osmundson and Kaeding in review). The precise role of such habitats in the life history of the razorback sucker is unknown but may be related to feeding, resting, egg maturation, spawning, or other activities associated with reproduction.

Razorback suckers have never been directly observed spawning in turbid river environment of the UCRB, but some data describing presumed reproductive activity were obtained from capture of ripe fish. In riverine habitats of the UCRB, the spawning season of razorback suckers was generally later in the year and shorter in duration than in Lake Mohave. Ripe razorback suckers were generally collected from mid-April to mid-June (McAda and Wydoski 1980, Valdez et al. 1982a, Tyus 1987, Osmundson and Kaeding 1989a, Tyus and Karp 1989, Tyus and Karp in press), but within any year only over a 4-5 week period (Tyus and Karp in press). Similar to Lake Mohave, spawning males outnumber spawning females by 2.5:1 in the Green River. Similar male:female ratios (2.7:1 and 2.9:1 in different years) have been observed for a closed spawning population of white suckers (Quinn and Ross 1985). This was due, however, to a higher incidence of non-annual spawning by females, as the male:female sex ratio for the entire population was 1:1

(spawning and non-spawning individuals). Whether razorback suckers exhibit non-annual spawning is unknown.

Ripe razorback suckers in the Green River were captured when water temperatures were 14 to 16 C (range 9-20 C) and springtime flows were increasing toward their peak (Tyus 1987, Tyus and Karp 1989, Tyus and Karp in press). When springtime flows were high enough, many ripe razorback suckers moved from the cooler (15-16.5 C) main channel of the Green River, into warmer (17-21 C), flooded lowlands (Tyus and Karp in press).

Razorback suckers typically move from deeper habitats to shallower, swifter riffles and runs over gravel and cobble substrate during the spawning season. McAda and Wydoski (1980) radiotracked one adult that twice moved from quiet water into shallow, swift water adjacent to a gravel bar in May 1975. Water depth at the presumed spawning area ranged from 0.3 to 1.0 m, water velocity from 0.4 to 1.0 m/sec, and substrate was 20-50 mm in diameter. Osmundson and Kaeding (1989a) found an increased use of shallower, faster run habitat, and flooded backwaters and gravel-pits, by two razorback suckers in May. Tyus and Karp (1989, in press) captured ripe razorback sucker adults in runs over cobble, gravel, and sand substrate, mean water depth was 0.63 m, and mean water velocity was 0.74 m/sec. Most ripe fish (91%, n=177) were captured near Jensen, while 14 fish (7%) were captured near the mouth of the Yampa River; specific riffles where spawning presumably occurred were identified (Tyus and Karp in press). Ripe flannelmouth and bluehead suckers were captured in large numbers with ripe, and presumably spawning, razorback suckers at these same localities. Ripe male and female razorback suckers were observed cruising shallow shorelines in the Walker Wildlife Area gravel pit pond, but spawning was never observed (McAda and Wydoski 1980).

In the Colorado River below Hoover Dam, Mueller (1989) found razorback sucker spawning depressions with eggs and larvae in a backwater created by flood input of cobble and gravel from a dry side-canyon wash. Spawning depressions were 0.25 to 1 m^2 in area, and occurred at depths of 1.2 to 2.0 m. Water column velocity ranged from 0.0-0.37 m/sec, water velocity 10 cm above the substrate was 0.15 m/sec. Smaller, unarmored substrate in the backwater may have attracted razorback suckers to spawn in that area (Mueller 1989).

Age at maturity for the razorback sucker is variable. Minckley (1983) reported that Age VI hatchery-reared razorback suckers 35 to 39 cm TL were sexually mature, while individuals from the same cohort < 35 cm TL were immature. Growth rates of wild razorback suckers from Lake Mohave declined after seven years of life and might have been an indicator of time of sexual maturity (Minckley 1983). Hatchery-reared male razorback suckers matured at Age II and at lengths < 350 mm TL, while females matured at Age III and were > 390 mm TL (Hamman 1985). Age 0 razorback suckers stocked in a pond near Clifton, Colorado, averaged 462 mm TL after 2.5 years (time when experiment was terminated). These fish were developing gonads in October and could probably have spawned as age III fish the following spring (Osmundson and Kaeding 1989b). Age at maturity is apparently habitat specific and based on differences in food availability, water temperature, and subsequent growth rates.

Ovary mass in five ripe female razorback suckers averaged 10.1% (9.2-11.5%) of somatic body mass (Minckley 1983). Fecundity showed weak or no relationships with fish length (McAda and Wydoski 1980, Minckley 1983). Minckley (1983) calculated average fecundity of 1,812 ova/cm standard length (SL) (1,680-1908 ova/cm SL) for five razorback suckers (391-570 mm SL) from Lake Mohave; total fecundity averaged 100,800 (74,600-144,000). McAda and Wydoski (1980) calculated mean fecundity of 46,740 ova (27,614-76,576) for 10 Green River razorback suckers (mean TL = 507, range 466-534 TL). Their data, recalculated by Minckley (1983) yielded an average fecundity of 1,166 ova/cm SL (600-2,000 ova/cm SL). Differences in fecundity between Lake Mohave and Green River razorback suckers were probably due to incomplete egg development in fall collected fish from the latter area.

The relationship between water temperature and hatching time of razorback sucker eggs is generally inverse. At incubation temperatures of 10 C (three trials), 15 C, and 20 C (two trials each), average hatching time was 19.4, 11.1, and 6.8 days, respectively (Bozek et al. 1984). Toney (1974) found that eggs incubated at 16.6-17.2 C hatched within 5-6 days, and eggs incubated at 14 C hatched in 5.2-5.5 days (Minckley and Gustafson

1982). Marsh (1985) found that eggs incubated at 15 and 25 C hatched in 9 and 3.5 days, respectively.

Effects of incubation temperature on embryo hatching success and survival were less clear and hatching success at various incubation temperatures varied widely. Toney (1974) estimated a 95 % hatch rate at water temperatures of 14.4-17.2 C, but found high mortality for eggs incubated at 11.7 C. In three separate trials at 10, 15, and 20 C incubation temperatures, Bozek et al. (1984) reported average hatching rates of 39, 46, and 45 %, respectively. For two trials, they reported no hatching at 8 C. Marsh (1985) reported highest hatching success at 20 C (35 %) and 25 C (29 %), with only 15 % success at 15 C and no hatch at 5, 10, and 30 C.

Water temperatures at which ripe razorback sucker adults were collected, and subsequent water temperatures in which eggs were fertilized and developed may be related to hatching success, as was alluded to by Marsh (1985). Bozek et al. (1984) captured razorback suckers from Lake Mohave (11 C water temperature), stripped and fertilized eggs, and maintained them at ambient water temperatures of 11.0-13.0 C, prior to acclimation to test temperatures in the lab. Marsh (1985) obtained eggs from females that were held in 17.5-18.0 C water, and eggs were fertilized in water of the same temperature. In both studies, eggs that were fertilized and subsequently subjected to water more than 3-5 C below that of fertilization temperature, hatched at much lower rates or did not hatch at all. Eggs incubated at temperatures higher than those at fertilization exhibited relatively high hatching success in both experiments, with the exception of a 30 C treatment (Bozek et al. 1984, Marsh 1985).

Other possible reasons for differences in hatching success might have been methods of acclimation, incubation, disease, or water quality. Sudden reductions in water temperature may have resulted in excessive cooling of embryos and caused mortality. Extended development time due to cold water temperatures may increase exposure time to predators, disease, and other sources of mortality.

Eggs spawned in nearshore areas of reservoirs or rivers might be subjected to desiccation if water levels suddenly drop. In Lake Mohave, Bozek et al. (1984) estimated that 70 % of eggs in spawning areas may have been destroyed by drawdowns of several days duration during peak spawning activity. Less obvious, but as potentially damaging, were water level fluctuations that move the location of the spawning site nearer or further from shore. In Lake Mohave, wave erosion caused by high winds was thought to be a major source of egg mortality due to silt deposition over spawning sites (Bozek et al. 1984). Egg suffocation due to silt deposition was also observed in hatchery ponds (Inslee 1982). High mainstream flows and nearshore wave action might induce egg abrasion or destruction due to scouring.

Predation on early life history stages of razorback sucker is thought to be a major factor limiting recruitment to the juvenile life stage (Minckley 1983, Tyus 1987, Minckley et al. in press).

Predation by common carp and channel catfish on razorback sucker eggs and larvae in redds has been documented (review by Minckley 1983, Bozek et al. 1984). Extent of predation on eggs and larvae is unknown and may vary within a habitat and individual redds dependent on substrate conditions, the kind and density of predators, water temperature, and subsequent rates of egg and larval development.

Bozek et al. (1984) found that potential non-native predators were generally uncommon in razorback sucker spawning areas in Lake Mohave. Four of sixty-three channel catfish stomachs contained razorback sucker eggs, and none were found in 201 common carp stomachs (Bozek et al. 1984). Thirty-four percent of the non-native predators captured were in close proximity to razorback sucker spawning sites. Razorback sucker larvae were not found in any potential predator stomachs examined, including 75 largemouth bass. However, identifiable eggs or larvae may be difficult to find in predator stomachs because of mastication, rapid digestion, or regurgitation (Bozek et al. 1984, Langhorst 1988, Marsh and Langhorst 1988, Langhorst 1989). Large numbers of razorback sucker larvae present following spawning suggested that if egg predation was occurring, it may not be substantial (Bozek et al. 1984). Razorback sucker eggs were difficult to find in spawning depressions and may have fallen into interstitial spaces in the substrate or were buried in the spawning act (Bozek et al. 1984).

Hybridization

Hybridization between native, sympatric catostomid species is not uncommon (Hubbs et al. 1943). Hybrids between the razorback sucker and two other catostomids, flannelmouth sucker and Sonora sucker <u>Catostomus insignis</u> (Gila River drainage), were first described from specimens collected in 1889 and 1926, respectively (Hubbs and Miller 1953). Hybrid razorback x flannelmouth suckers have been recorded throughout most of the known sympatric range of the two species including Lake Mohave (Minckley 1983, Bozek et al. 1984), the Colorado River in Grand Canyon (Suttkus and Clemmer 1979), and throughout the UCRB (Banks 1964, Holden 1973, Holden and Stalnaker 1975a, McAda and Wydoski 1980, Lanigan and Berry 1981, Valdez et al. 1982a, Tyus and Karp in press). Holden (1973) collected nearly as many razorback x flannelmouth sucker hybrids (n=40) as pure adults (n=53), and reported that the incidence of razorback x flannelmouth sucker hybrids was increasing in the UCRB. Ripe razorback suckers have been documented with aggregations of ripe and presumably spawning flannelmouth, white, and bluehead suckers (Tyus and Karp in press, pers. comm., P. J. Martinez). Ripe razorback x flannelmouth sucker hybrids have also been collected with ripe razorback suckers (McAda and Wydoski 1980, Tyus and Karp in press).

Minckley et al. (in press) discussed the possibility that some hybrid specimens would be easy to misidentify. It was apparently recently discovered that some female razorback suckers have low, broad, predorsal keels, characteristics that may cause those individuals to be mis-classified as hybrids. Eighteen Lake Mohave razorback sucker specimens used in the electrophoretic analysis of Buth et al. (1987) were selected specifically because they were suspected as hybrids. Of these 18 specimens, only one was identified as a hybrid, and that was an introgressed individual. Evidence for hybridization throughout the Colorado River Basin may be due, in part, to mis-identification of low-keeled razorback suckers as hybrids.

The natural rate of hybridization in catostomids, and the role of gene introgression in pristine Colorado River habitat is unknown and poorly understood. Buth et al. (1987) found low levels of presumably introgressed flannelmouth sucker genes in hatchery and Lake Mohave stocks of razorback sucker. They also found reciprocal low-level introgression of razorback sucker genes in flannelmouth suckers. It is unknown if these were natural levels of introgression or were induced through changes in habitat, flow regimes, or other man-caused events.

The relatively high abundance of other native suckers and potentially high incidence of hybridization in some catostomid communities may pose problems for remaining small razorback sucker populations. Reproductive isolation and incidence of hybridization between all native catostomids may be important in assessing recovery methodologies, reintroduction sites, and habitat and flow recommendations. Reintroduction efforts everywhere will need to evaluate the existing native fish fauna and natural incidence and potential for hybridization in catostomids.

Age and growth

Growth information for younger life stages of wild razorback suckers is scant because of the paucity of these life stages in collections (McAda and Wydoski 1980, Minckley 1983, McCarthy and Minckley 1987, Tyus 1987, Marsh and Minckley 1989b, Minckley et al. in press). Most data were derived from growth rates of hatchery-produced razorback suckers. Razorback suckers spawned at Dexter National Fish Hatchery in late February or early March were 7-9 mm TL at hatching. Growth rates of individuals in hatchery-cohorts were highly variable. Razorback suckers stocked into Arizona streams on 22 May 1985 averaged 40 mm TL (Brooks 1985). Specimens recaptured later that year at two localities in the Carrizo Creek drainage, Arizona (Brooks 1985) grew an average of 43.4 (0.71 mm/day) and 47.5 mm TL (0.78 mm/day) by 23 July 1985. Size ranges were 82-94 mm TL (n=4) and 54-121 mm TL (n=12). Size ranges of similar cohorts of razorback suckers stocked in the Gila River were also variable (Marsh and Brooks 1989). Razorback suckers (mean TL = 75 mm) stocked into three isolated backwaters of Bonita Creek, Arizona, on 8 July 1985, increased by an average of 6 (n=30 specimens), 10 (n=1), and 36 mm (n=29) TL by 15 October 1985. Fastest growth of razorback suckers was obtained in a backwater devoid of native catostomids (Brooks 1985). Other ancillary growth information for recaptured razorback suckers from several habitats in the Gila River drainage are given by Minckley et al. (in press).

Lack of accurate aging techniques hindered early interpretation of life history and recruitment patterns of captured adult razorback suckers. Minckley and Deacon (1968) commented on the size distribution of razorback suckers in Lake Mohave and suggested that the population might be composed primarily of large, old fish. Scales were extremely variable in size, worn, and useful only for early growth estimates (Minckley 1983). Minckley (1983) also found extremely slow growth (0.5 cm/yr) for razorback suckers from Lake Mohave (1964 to 1982) as estimated by changes in length frequency distributions. More recent length frequency data (1988 and 1989) indicate that mean lengths of razorback suckers from Lake Mohave are no longer increasing (Marsh and Minckley 1989a).

McCarthy and Minckley (1987) evaluated seven structures for usefulness in evaluating age-growth characteristics of razorback suckers. Only otoliths gave consistent resolution and were used to evaluate the age structure of razorback suckers from Lake Mohave; all other structures tended to underestimate ages or did not yield consistent readings. Minimum and maximum ages were 24 and 44 years, respectively, for specimens collected from 1981-1983. Of 70 specimens analyzed, 62 (89%) were thought to have been hatched in the period prior to, or during, construction and filling of Lake Mohave (McCarthy and Minckley 1987). A razorback sucker captured in the Grand Canyon of the Colorado River, near the Little Colorado River, in 1989, was thought to be about 16 years old, based on otolith examination (pers. comm., D. A. Hendrickson, Arizona Game and Fish Department.

Age of adult razorback suckers collected in the Green and Colorado rivers was estimated to be 4-9 years (McAda and Wydoski 1980), but accuracy of age assignments was questioned because scales were difficult to read. Slow or no growth of two recaptured razorback suckers in the UCRB and otolith analysis of two LCRB specimens indicated extremely slow growth, old age, and probable errors in scale-derived age estimates (McAda and Wydoski 1980). Four Green River razorback suckers were thought to be at least 12, 16, 19, and 26 years, based on vertebrae and otolith analysis (Tyus 1987, Lanigan and Tyus 1989). Ages of all specimens may have been underestimated because vertebrae were used (McCarthy and Minckley 1987) and the ages of most Green River razorback suckers were thought to predate construction and closure of Flaming Gorge Reservoir in 1962 (Tyus and Karp 1989).

The only growth information available for young life stages of razorback suckers from the UCRB are from hatchery reared stocks. Eggs were stripped and fertilized from wild adult fish collected from the Colorado River near Grand Junction, Colorado (Valdez et al. 1982a), and cultured at Colorado State University. Larvae reared in sugar-fertilized tanks grew to 100 mm TL by September and were up to 150 mm TL in a year (pers. comm., E. J. Wick, Colorado State University). Razorback suckers were also cultured at the Colorado River Fishes Propagation and

Experimental Station at Ouray, Utah. Pond-reared razorback suckers stocked in ponds as larvae in May grew to 127 mm TL (49-205), and 156 mm TL (40-271), in four months, in 1987 and 1988, respectively (pers. comm., H. M. Tyus, U. S. Fish and Wildlife Service). Survival was 93 % in 1987 and 89 % in 1988.

Growth rates of hatchery derived razorback suckers stocked into ponds are very rapid. Marsh (in press) stocked juvenile razorback suckers (80-200 mm TL) in a variety of ponds, with and without other fish species, and, within a year, observed growth to over 300 mm TL. Osmundson and Kaeding (1989b) stocked 430 razorback suckers (mean TL = 54.8 mm) from Dexter National Fish Hatchery on 17 June 1987 into a 5.4 ha pond near Clifton, Colorado. These fish grew rapidly and achieved a mean length of 307 mm TL six months later; after two years and seven months (October 1989), mean length and weight was 422 mm TL and 1,088 g, respectively (Osmundson and Kaeding 1989b). Osmundson and Kaeding (1989b) and Marsh (in press) suggested that razorback suckers could be reared in ponds to a size that should be immune to fish predation in a year.

Growth estimates of known-age (hatchery-reared) and wild Lake Mohave razorback suckers showed similarities for the first 6 years of life (Minckley 1983). Back-calculated lengths for Age VI hatchery-reared and Lake Mohave razorback sucker were 33 and 37 cm TL, respectively. Based on scale analysis, back-calculated lengths of razorback suckers through the first 6 years of life indicated rapid growth (7.0 cm/yr), but growth slowed substantially after that. Using back-calculated growth information, McCarthy and Minckley (1987) found that wild female razorback suckers were 140 mm SL and 276 mm SL after one and five growing seasons, respectively. Growth of wild male razorback suckers was slower, achieving lengths of 103 mm SL and 214 mm SL at their first and fifth annulus. Growth rate information from marked and recaptured razorback suckers from Lake Mohave indicated negligible or no growth among this presumably old stock (Marsh and Minckley 1989a).

Growth rates inferred from size changes during recapture intervals and changes in the mean size of some local populations (Table 2) indicated that wild adult razorback suckers grew very slowly in the UCRB. Valdez et al. (1982a) reported little or no change in length for five razorback suckers recaptured up to one year later. Tyus (1987) found slow growth (average of 2.2 mm/year) for 39 razorback suckers with recapture intervals of 1-8 years. Mean growth rate (3.1 mm TL, n=6) of razorback sucker adults recaptured after one year in the San Juan River arm of Lake Powell, corroborate the pattern of slow growth (Roberts and Moretti 1989).

Razorback suckers from the UCRB may also be an aging group of fish as lengths of male and female as indicated by increased average size since 1974. Razorback suckers from the San Juan River arm of Lake Powell were larger than individuals from other populations in the UCRB and were closer in mean length, and perhaps age, to those in Lake Mohave (Bozek et al. 1984).

Table 2.--Mean size (TL), range (parenthetically), and sample size of razorback suckers from the Green-Yampa and Colorado River systems, 1974-1989.

Source and period	Green-Yampa River Male	Green-Yampa River Female	Colorado River[1] Male	Colorado River[1] Female
McAda and Wydoski (1980) 1974-1976	487 (442-515) n=17	510 (461-539) n=10	511 (485-561) n=9	569 (499-618) n=32
Valdez et al. (1982) 1979-1981	---	---	529 (500-557) n=7	567 (522-604) n=17
Tyus (1987) 1979-1986	503 n=37	544 n=23	---	---
Tyus and Karp (in press) 1987-1989	507 (405-576) n=141	547 (485-608) n=45	---	---
San Juan River arm, Lake Powell 1987-1988	---	---	572 (546-605) n=10	633 (595-675) n=4
Bozek et al. 1984 Lake Mohave 1983	---	---	556 (450-610) n=131	624 (525-705) n=81

[1]Razorback sucker data from the San Juan River arm of Lake Powell (Meyer and Moretti 1988 and Roberts and Moretti 1989).

Gradual increases in mean length of razorback suckers captured in the UCRB since 1974 (2-3 mm TL/yr) resembles the pattern revealed by Minckley (1983) for the aging razorback suckers in Lake Mohave.

Diet

Razorback sucker diet varies depending on life stage, habitat, and food availability. The gut of razorback sucker larvae is short (less than one body length) and the mouth is terminal, in contrast to the long (several body lengths), coiled gut and subterminal or ventral mouth position of juveniles and adults.

Gut analysis of larval razorback suckers stocked into and collected one week later from a backwater in the Salt River, Arizona, indicated that chironomid larvae were the dominant food (pers. comm., J. E. Brooks, U. S. Fish and Wildlife Service). No other information is available regarding food habits of larval razorback suckers in lotic ecosystems. Larvae of other southwestern catostomid species (flannelmouth sucker, Sonora sucker, desert sucker *Pantosteus clarki*, bluehead sucker) in streams feed almost exclusively on benthic larval Chironomidae and early instar Ephemeroptera (Maddux et al. 1987, pers. comm., R. T. Muth, Colorado State University).

Razorback sucker larvae in lentic habitats (hatchery ponds and reservoirs) begin feeding following yolk absorption at about 9-10 mm TL. Larvae feed mostly on phytoplankton and small zooplankton (Cladocera, Copepoda, Rotifera), but diet can vary (Marsh and Langhorst 1988, Papoulias 1988). Lake Mohave razorback sucker larvae avoided Copepoda, whereas larvae from an isolated Lake Mohave backwater avoided Rotifera (Marsh and Langhorst 1988). Larvae from both habitats selected Bosmina spp. The high incidence of midwater zooplankton in gut contents suggested that razorback sucker larvae in lentic habitats feed very little on benthos.

Diet of juvenile razorback suckers is largely unknown. Digestive tract contents of eight juvenile ("90-115 mm long") razorback suckers from a Colorado River backwater contained "algae and bottom ooze" (Taba et al. 1965).

Diets of lacustrine populations of adult razorback suckers are dominated by planktonic crustaceans (Cladocera); lesser amounts of algae and detritus are also ingested (Minckley 1973, Marsh 1987). This suggests a planktivorous existence for razorback suckers, with occasional benthic feeding (Marsh 1987). Numerous, fuzzy gill rakers of the razorback sucker (Hubbs and Miller 1953) may aid this mode of feeding. Benthic and planktivorous feeding behavior in lentic environments has been observed (Minckley 1973, Marsh 1987).

Diet of adult razorback suckers in rivers is different than in reservoirs. Riverine specimens consumed mostly benthos including immature Ephemeroptera, Trichoptera, and Chironomidae, along with algae, detritus, and inorganic material (Jonez and Sumner 1954, Banks 1964, Vanicek 1967). Midwater zooplankton communities are probably depauperate in the fluctuating and often turbid upper Colorado River mainstream environments.

Disease

In Lake Mohave, Minckley (1983) found that 14 % of the razorback suckers were blind in one eye and 6.8 % were blind in both eyes. Bozek et al. (1984) found that male razorback suckers had injury or disease in one and both eyes at a rate of 28 % and 8.8 %, respectively. Injury or disease in one or both eyes occurred in 32.3 % and 14.3 % , respectively, of all females collected in the wild. Differences in occurrence of injury or disease between the two studies were inexplicable but may be due to methods of assessment for blindness (Minckley 1983) versus injury or disease (Bozek et al. 1984). Valdez et al. (1982a) noted a high incidence of blindness in one or both eyes of razorback suckers collected in the Colorado River near Grand Junction, Colorado, but the cause of blindness was unknown. Minckley (1983) suggested that blindness may be caused by bacterial or protozoan infections. Other common afflictions included infestations of a parasitic copepod, *Lernaea cyprinacea*, and vertebral deformations; nematode, cestode, trematode, and protozoan infections were less common. Incidence of bacterial infections and external lesions was higher in females than in males and occurred at higher frequency during the height of the reproductive season, when abrasions due to contact with substrate during spawning were more common.

Flagg (1982) surveyed diseases and parasites of fishes in the UCRB and found three pathogens associated with five razorback sucker adults examined. These included a bacterium, a protozoan, and a parasitic copepod, but none of these were considered a factor in the demise of the species.

Importance

Razorback suckers were apparently an important food fish of early civilizations in the American Southwest; accounts of its use and occurrence of bones in excavated aboriginal refuse are common (Ellis 1914, Miller 1955, Miller 1961). The large size of adult razorback suckers probably made them a valuable source of protein, and springtime spawning aggregations were vulnerable to harvest by a primitive type of hoop-net (references in Minckley et al. in press). In modern times, commercial fishermen throughout the Colorado River Basin have caught this species in large numbers for human, furbearer, and livestock consumption and fertilizer (Ellis 1914, Minckley 1973, Wiltzius 1978, Valdez et al. 1982a and b, Minckley 1983, Minckley et al. in press). A razorback sucker fishery existed in Saguaro Lake of the Salt River drainage as recently as 1949 (Minckley 1973). Sportfishing potential for this species is probably minimal. The razorback sucker has high intrinsic value as an endemic of the Colorado River Basin fish assemblage and is also a scientifically interesting species because of its unique morphology and variable life history.

Native Predators

In the evolutionary history of the Colorado River, native fishes that could prey upon razorback suckers include roundtail chub, _Gila robusta_, bonytail, _G. elegans_, and Colorado squawfish. Roundtail chub and bonytail are omnivorous and occasionally consume fish (Vanicek and Kramer 1969, Minckley 1973). Relatively small body size of adult roundtail chubs probably limited predation on razorback suckers to small juveniles or younger life stages. Distribution and habitat of Colorado squawfish and razorback suckers were historically similar, and predatory interaction was likely. Colorado squawfish is large-bodied and preys on catostomids and other fishes (Koster 1960, Vanicek and Kramer 1969, Minckley 1973). The large size of adult razorback suckers probably limited predation on that life stage.

Incidence of avian predation in the wild is unknown, but may be somewhat limited in a turbid river environment. Bird predation is a significant source of mortality for razorback suckers in hatcheries (pers. comm., J. E. Brooks, U. S. Fish and Wildlife Service, pers. comm., H. M. Tyus, U. S. Fish and Wildlife Service). Cormorant predation was responsible for a 70 % decline in numbers of young-of-the-year (YOY) razorback suckers held in ponds in 1988 at the Colorado River Fishes Propagation and Experiment Station in Ouray, Utah. Avian predators annually consume large numbers of fish in ponds at Dexter National Fish Hatchery.

LIFE HISTORY SUMMARY

The razorback sucker was formerly widespread in a variety of environments throughout the Colorado River Basin. The LCRB was thought to have supported the largest number of razorback suckers (Minckley 1973, Minckley 1983); reports indicate moderate to high abundance of razorback suckers throughout most warmwater reaches of the UCRB (McAda and Wydoski 1980). This large, long-lived, potentially migratory species has life history traits that allow for persistence in a historically fluctuating riverine environment. These traits include ability to spawn in a variety of flow conditions ranging from torrential springtime runoff, to standing water in impoundments, early and extended spawning (in impoundments), and high fecundity. Large adult size and longevity presumably would allow this species to persist through several consecutive seasons of no or low reproduction and recruitment, conditions that may have been realized in pristine habitats of the highly fluctuating and unpredictable Colorado River Basin.

Growth to adult size is rapid in food-rich environments of appropriate temperatures (Osmundson and Kaeding 1989b, Marsh in press) and diets are varied. Razorback sucker larvae consume a variety of phytoplankton and invertebrates in lentic habitats. Minckley et al. (in press) suggested that starvation is not a factor limiting survival of razorback sucker larvae in Lake Mohave, but this hypothesis has not been directly tested.

Limited data suggests that chironomid larvae are included in diets of larvae in lotic habitats. Adult razorback suckers appear to be omnivorous and capable of benthic or planktonic feeding depending upon habitat and food availability.

Injuries that result from spawning are common, but generally non-lethal. Adult razorback suckers are capable of long-term survival and successful spawning with a high incidence of disease, physical injury, and blindness in one or both eyes (Minckley 1983).

Razorback suckers show a tendency that is somewhat unique among the native Colorado River mainstream fishes in that seasonal and perhaps year-round use of lentic and backwater environments is common. In historic times and presently, these kinds of habitats are probably important for pre-reproductive staging, spawning, and larval habitat.

REASONS FOR DECLINE

Reasons for decline of most native fishes in the Colorado River Basin have been attributed to habitat loss due to construction of mainstream dams and subsequent interruption or alteration of natural flow and physico-chemical regimes, inundation of river reaches by reservoirs, channelization, water quality degradation, introduction of non-native fish species and resulting competitive interactions or predation, and other man-induced disturbances (Miller 1961, Joseph et al. 1977, Behnke and

Benson 1983, Carlson and Muth 1989, Tyus and Karp 1989). These factors are almost certainly not mutually exclusive, therefore it is often difficult to determine exact cause and effect relationships.

Water development projects in the Colorado River Basin were initiated in the early part of this century to supply water to an expanding population in the naturally arid American Southwest (review by Carlson and Muth 1989). Large-scale modifications are numerous high dams on the mainstream Colorado River and its tributaries. The effects of mainstream dams on riverine habitat and biota are generally known (contributors in Ward and Stanford 1979, Carlson and Muth 1989, Ward and Stanford 1989), and reviews specific to the Colorado River Basin are reviewed here (summaries in Holden 1979, Minckley 1979, contributors in Spofford et al. 1980, Stanford and Ward 1986a, Stanford and Ward 1986b, Carlson and Muth 1989). The pristine Colorado River system fluctuated widely in discharge, exhibiting high spring and early summer flows concurrent with snowmelt. High streamflows and runoff were erosive and resulted in high water turbidity and sediment transport. Seasonal water temperatures ranged from cold to warm, dependent primarily on season and altitude, but in a specific reach, were generally controlled by ambient conditions. Chemical characteristics of the aquatic environment were also highly variable and dependent on stream origin and drainage basin geology, discharge, water temperature, and many other interacting parameters. The native aquatic biota was evolutionarily adapted to this highly fluctuating and unpredictable environment. Large dams on mainstreams moderated the formerly fluctuating conditions by high flow reduction and supplementation of low flows. Declines in mean annual discharge of many mainstream reaches were realized through evaporative loss from reservoirs and irrigated agriculture, extra-basin transport, and consumptive municipal use. Hypolimnetic discharge from dams was generally cold and clear, and the physical and chemical characteristics of water releases were dictated by autochthonous reservoir processes.

Numerous modifications throughout the Colorado Basin disrupted native fish habitat to such an extent that few free flowing semi-natural river reaches persist (Carlson and Muth 1989). The Serial Discontinuity Concept predicts that regulated rivers tend to ecologically reset below dams to conditions that more nearly resemble those in headwater areas, and that mainstream native species will re-establish some distance downstream (Ward and Stanford 1983). In the Colorado River basin, introduced trout communities now thrive in cold-water habitat below many dams and native fishes are reduced or excluded (Vanicek et al. 1970, Holden and Stalnaker 1975a and 1975b, Maddux et al. 1987). As a consequence, native species in much of the Colorado River Basin may have be excluded by extreme habitat alteration (Molles 1980, Sheldon 1988) and interruption of re-establishment mechanisms such as downstream transport of larvae and migration of adults to the affected reach. Large-scale fish poisoning operations prior to closure and filling of some impoundments (e.g., Navajo and Flaming Gorge reservoirs) may have also had negative effects on native aquatic biota (Olsen 1962, Binns 1967).

Channelization of mainstream and other habitat in the Colorado River Basin has been extensive, especially in valley regions where human population centers and agricultural areas are located. This has resulted in restricting natural river meandering and overflow conditions required for maintenance of off-channel habitats used by razorback suckers (Beland 1953, Tyus and Karp 1989, Osmundson and Kaeding in review). Off-channel habitats were among the first to be modified and reduced in number in the Colorado River Basin. Flow regime alterations due to dam construction and operation or water diversion eliminated over-bank flow conditions and denied razorback suckers access to warm, seasonally flooded areas and other off-channel habitats (McAda and Wydoski 1980, Tyus and Karp 1989, Tyus and Karp in press). Invasion of non-native riparian plants like saltcedar, Tamarix chinenesis, and Russian olive, Eleagnus angustifolia, has altered riverine aquatic ecosystems throughout the West including the Colorado River basin. Dense, sometimes nearly impenetrable stands of these introduced plants stabilize banks and constrain and degrade formerly meandering river channels (Graf 1985), but their impacts on fish habitat have not been quantified and are rarely discussed (Carlson and Muth 1989, Osmundson and Kaeding in review). Channel straightening, levees, and arroyo cutting also eliminate over-bank flows and decreases the amount of in-channel, slow-water habitat. Such areas are presumably rich in food, are seasonally warmer because of standing water conditions, and permit fast development of larval and juvenile razorback suckers; they may also be important for pre-reproductive egg development in adults.

The largest remaining razorback sucker population is found in Lake Mohave, an artificially-created environment which also supports non-native fish populations. Small populations of adult razorback suckers in riverine reaches, combined with lack of habitat data and specimens of early life stages, preclude an "historic knowledge" of optimal habitat requirements for most life stages. The precise role and mechanisms of habitat loss in the decline of razorback suckers are unknown. Unfortunately, habitat that is presumed important for early life stages of the razorback sucker also provides habitat for many introduced species.

Other modifications to the Colorado River system include construction of smaller dams that are used for diversion of irrigation water. Such dams are thought to be barriers to upstream movements and migration of resident fishes. Substantial volumes of Colorado River Basin water are lost through evaporation, consumptive use, and inter-basin transfer. Detrimental land use practices, especially in the LCRB in the early part of the century, reduced the amount and quality of habitat.

Sport fisheries composed solely of non-native species were established before or concurrently with water development projects in southwestern streams and reservoirs to provide recreation opportunity for the expanding human population. Over 50 non-native fish species have been introduced into the Colorado River Basin (Tyus et al. 1982, Stanford and Ward 1986b, Carlson and Muth 1989). Most of these species were intentionally stocked bait and game fish and, in some areas, now support economically valuable recreational fisheries in streams and reservoirs. Many of these fishes are piscivorous, highly adaptable, and capable of inhabiting nearly all riverine and lacustrine habitats in the Colorado River Basin. In most of the Colorado River Basin, non-native fish assemblages are more diverse and numerically more abundant than the native fauna. Non-native fishes are widely assumed to have deleterious predatory and competitive impacts on native species like the razorback sucker (Miller 1961, Minckley and Deacon 1968, Minckley 1973, Behnke and Benson 1983, Minckley 1983), but substantive evidence (e.g., razorback suckers in predator stomachs) is difficult to obtain.

Experimental stocking of razorback suckers using control habitats or closely monitored populations provided evidence that predation was a major factor suppressing recruitment. In Lake Mohave, razorback sucker larvae in the reservoir hatched, grew to 10-12 mm TL, but then disappeared; however, razorback sucker larvae in cages free of predators grew to 30 mm TL or more (Langhorst 1987). In a predator-free backwater isolated from

Lake Mohave, razorback sucker larvae survived longer and grew to larger sizes than in the main lake, where predators were common (Marsh and Langhorst 1988). Predators later invaded the backwater through a breach, and extensive predation by green sunfish and other predators was documented (Langhorst 1987, Marsh and Langhorst 1988). Brooks (1985) and Marsh and Brooks (1989) documented extensive predation by channel catfish and flathead catfish, *Pylodictus olivaris*, on hatchery-reared juvenile (45-156 mm SL) razorback suckers in the Gila River, Arizona. Predation rates of resident ictalurids were high enough to eliminate stocked fish. Density of green sunfish and survival of YOY razorback suckers in experimentally stocked earthen ponds at Dexter National Fish Hatchery were inversely related (pers. comm., J. E. Brooks, U. S. Fish and Wildlife Service). Growth and survival of razorback sucker larvae and juveniles is generally observed in habitats where predator fishes do not exist (Osmundson and Kaeding 1989b, Marsh in press) giving further evidence that recruitment may be negatively impacted by predation.

The effects of predation by non-native fishes on survival of early life stages of razorback suckers in the UCRB are unknown and largely unstudied. In summer, carp and channel catfish are nearly exclusive occupants of backwaters in the Colorado River, near Grand Junction, Colorado, and may be detrimental to survival of young razorback suckers (pers. comm., T. Nesler, Colorado Division of Wildlife). Green sunfish and channel catfish are widespread piscivores (Smith 1959, Taba et al. 1965, Tyus et al. 1982, Lemly 1985), but the extent of their predatory interaction with razorback suckers is unknown. Based on reproductive condition of adult fish and on tentative identification of larvae, razorback suckers are thought to spawn in the Green River, Utah (Tyus et al. 1987, Tyus and Karp in press). Reasons for a lack of recruitment there are unknown, but predation may be at least partially responsible. Lack of diagnostic characters for identification of catostomid proto- and mesolarvae in the UCRB (Snyder and Muth 1990) renders determination of the effects of predation and early life history interactions very difficult. Cold water temperatures have also been implicated in the lack of successful reproduction and recruitment of razorback suckers (Marsh 1985).

Severe declines of razorback suckers occurred prior to, and after, construction of mainstream Colorado River Basin dams, suggesting that several factors may be responsible for the species demise. Habitat alterations may have restricted razorback suckers to a small subsets of the formerly available habitat, where non-native predator or competitor species were especially well adapted to such habitats. Inundation of river reaches by reservoirs, and associated downstream impacts of cold water releases and flow alterations on habitat further reduced razorback sucker populations. Dams and other barriers may have also prevented immigration to depleted reaches. Dams and reservoirs also enhance populations of non-native species by providing a source population and moderating habitat conditions. The inherent variation in the system, once a trademark of the habitat and the co-evolved fish assemblage, was removed, and the native fish fauna, including razorback suckers, declined.

CURRENT RESEARCH AND MANAGEMENT

Local extirpation of razorback suckers from some localities and severe reductions in populations in most other areas prompted research programs to study the species. In the UCRB, research efforts for razorback suckers have attempted to define distribution and abundance patterns of razorback suckers, habitat use, movement patterns, flow needs, reproductive biology (Green River), and fish culture techniques and protocols. Ongoing and future research efforts will include expanded versions of the aforementioned activities, and will also focus on brood stock development, refugia populations, and material for studies of genetic diversity, experiments to examine predator-prey interactions at early life stages, evaluation of the importance of seasonally inundated river floodplains, effects of variable and low temperature on hatching and survival of razorback suckers, chemoreception, and other flow and habitat related investigations.

Brood stock are being collected from the Colorado River drainage, Colorado, and Lake Powell (San Juan and Dirty Devil arms). These fish could be used as refugia populations in the event that natural populations in these areas disappear, and could also serve as brood stock to produce young fish for experimentation and reintroduction. Razorback suckers from the Green River are also under propagation at the Colorado River Fishes Propagation and Experimental Station at Ouray, Utah. Strict control of parentage identity of 10 lots of brood fish is being maintained (pers. comm., H. M. Tyus, U. S. Fish and Wildlife Service). To date, 18,635 larvae have been produced in four years since 1987. Optimal rearing conditions and diet experiments have also been conducted (Tyus and Severson in press). Reintroduction of hatchery-reared razorback suckers in the UCRB has been limited to the Green River where about 2,000 juveniles were stocked in 1988, and about 5,000 in 1990.

In the LCRB, research and management activities for razorback suckers have centered around two major themes, 1) research on the abundant population of razorback suckers in Lake Mohave, and 2) a propagation and reintroduction program and associated research and monitoring. Research on the Lake Mohave population has attempted to define reproductive, age-growth and longevity parameters, population size, movements, and causes of larval and juvenile mortality of razorback suckers. Other research has been conducted in Senator Wash Reservoir, and in other impoundments and ponds. Surveys for razorback suckers in Lake Mead are planned for spring 1990 (pers. comm., J. Sjoberg, Nevada Department of Wildlife).

The propagation and reintroduction approach was taken in the LCRB because it was thought that the species would soon be extirpated and that establishment of a refugia population and a brood stock were necessary to save the species from extirpation (Minckley et al. in press). Most razorback sucker propagation have been conducted at Dexter and Willow Beach National Fish hatcheries (Brooks 1985, Johnson 1985, Minckley et al. in press). Widespread stocking of resulting progeny with limited monitoring was decided upon as a logical management action given the restraints on manpower, time, and funding (Minckley et al. in press). A 10-year program of stocking was initiated in 1981 by the state of Arizona; the state of California instituted a 10-year program in 1986 to re-establish razorback suckers in the lower Colorado River (Ulmer 1987, Langhorst 1988, Langhorst 1989). A variety of sizes of razorback suckers have been stocked throughout former habitats with a goal of local re-establishment, reproduction, and self-sustaining populations. Initially, larvae were stocked, but in later years larger YOY and juveniles were used. Stocking in upstream tributaries in some Arizona streams where few predators existed was also attempted. In the lower Colorado River, larvae and juveniles were stocked into a variety of natural backwater habitats and in "grow-out" ponds (Langhorst 1988, Langhorst 1989). Limited numbers of adults have also been stocked.

Few razorback sucker recaptures of any life stage have been reported following stocking in these or other studies (Brooks

1985, Langhorst 1988, Langhorst 1989, Marsh and Brooks 1989). Through 1988, only 118 fish have been recovered from over 12,000,000 stocked razorback suckers of all sizes stocked in the Gila River, and most of these were recovered shortly after stocking (Minckley et al. in press). Predation on stocked fish was substantial (Marsh and Brooks 1989), thereby reducing the chance for large numbers of recaptured fish. The size of the reintroduction area in which razorback suckers were stocked precluded more intensive monitoring efforts that may have detected more stocked razorback suckers (Minckley et al. in press).

Research associated with the reintroduction program has been directed at assessing movements of stocked fish of all life stages, post-stocking survival, diet and nutrition, predation on stocked fish by non-native fishes, and feasibility of rearing razorback suckers to adult size in grow-out ponds. Post-stocking downstream dispersal has been extensive, and predation in most habitats is considerable. Production of large razorback suckers in predator-free grow-out ponds has proven successful and growth rates approach or exceed those realized in the hatchery (Langhorst 1989, Marsh and Brooks 1989). Large adults would presumably be immune to most predators, thereby enhancing chances for establishing a resident population (Langhorst 1989, Marsh and Brooks 1989, Marsh, paper presented at the 20th Annual Meeting, Desert Fishes Council). Wider use of non-traditional habitats such as canals and drains has also been suggested as a potential means of increasing survival of stocked razorback suckers (Marsh and Minckley 1989b).

A study to assess genetic structure of existing razorback sucker stocks is being funded by the Recovery Implementation Program (RIP) (pers. comm., J. H. Williamson, U. S. Fish and Wildlife Service). These studies are expected to provide data regarding genetic diversity of various razorback sucker stocks in the Colorado River Basin.

Several research and management activities and objectives suggested by Wick et al. (1982) and Loudermilk (1985) to recover the razorback sucker have been met. Razorback sucker larvae have been described and all but proto- and early mesolarvae can be accurately identified. Spawning habitats have been identified and described, and much information has been gathered regarding the reproductive biology of razorback suckers, especially in reservoirs. Predation by non-native species has been identified as a major factor supressing recruitment to the juvenile and adult life stage. Efficient propagation techniques have been developed and some limitations on growth and survival of early life stages of razorback suckers are known.

Minckley et al. (in press) suggested that future activities to benefit razorback suckers should be directed at improving the survival of reintroduced fish and increasing exchange of information regarding razorback sucker management. Enhancing survival of stocked fish could be effected through physical habitat manipulations, reduction of non-native fishes in candidate reintroduction habitats, stocking larger fish, establishing additional refugia populations and broodstock, and conditioning stocked fish to reintroduction habitats. Increasing the database and exchange of information resulting from razorback sucker management activities could be accomplished through concentration of effort in limited, accessible reaches, public participation, and establishment of a central repository for pertinent information (Minckley et al. in press). They suggested that research activities be limited to those "necessary if recovery is to be effected". Detailed study suggestions were made pertinent to resolution of the recruitment problem, movement ecology, and genetics.

RECOMMENDATIONS

In spite of the endangered status of the razorback sucker in the Colorado River Basin, aspects of its reproductive biology could be used advantageously to recover the species. The razorback sucker is a long-lived species, spawns in a variety of habitats, produces a large number of young which can grow quickly to adult size, and is easily propagated in the hatchery. Because of the extensive work conducted throughout the Colorado River Basin, the current status of razorback sucker has been reasonably well defined and several factors have been suggested as reasons for the decline of the species. Current obstructions in life history patterns indicate a need to explain and bridge the larval-to-large-juvenile recruitment gap and to provide habitat and flows for all life stages. Results of LCRB research and management activities in lotic and lacustrine habitats (Minckley et al. in press) demonstrate that simply stocking large numbers of razorback suckers in a variety of existing habitats and monitoring their progress will not recover the species. Controlled experimentation that strives to identify one or a few critical limiting factors is needed to solve problems associated with recruitment and habitat needs of razorback suckers throughout their range. Once specific problems have been identified, solutions appropriate to the habitat and conditions must be found and implemented.

Research Recommendations

1) Resolve genetic diversity question. This information is necessary to guide decision-making processes regarding the roles that razorback sucker propagation and refugia are to play in recovery of the razorback sucker, and may also dictate many options for management and research. Studies to address this issue have been recently initiated. Consideration should be given to maintenance of existing individual stocks even if current molecular genetics techniques indicate that all razorback suckers constitute a single, genetically homogeneous population. Similar to some salmonid populations, discrete life history attributes may be operational in razorback suckers that may not be detectable by current methodologies. To identify genetic

changes resulting from selective breeding or directional selection for certain hatchery survival attributes, annual genetic assessment of progeny prior to stocking activities may be required. Specific breeding strategies should also be developed to preserve the genetic integrity of captive populations.

2) Resolve causes of recruitment failure. Lack of survival of larvae razorback suckers has been identified as the single most important factor in its decline. Predation by non-native fish species on young razorback suckers has been identified as the most important cause of recruitment failure in the LCRB. Causes of recruitment failure of razorback suckers may also be related to predation and competition with other non-native fishes in the UCRB. Habitat alterations (e.g., lack of seasonally inundated river floodplains caused by reduction of high spring flows, cold water releases from dams, lack of large, warm backwaters for larval growth and development) have also been proposed as reasons for lack of razorback sucker recruitment. It is likely that a combination of these factors is causing recruitment failure in both the LCRB and the UCRB, however, very few specific experiments have been designed and conducted to specifically test such hypotheses.

3) Define movements, migration, and habitat use. It is especially important to relate these parameters to reproduction, flows, migratory barriers, and the habitat needs of all life

stages of razorback suckers. Once movement patterns and habitat needs are defined, flows and habitats could be manipulated and managed to provide missing elements. Because relatively large concentrations of razorback suckers exist only Lake Mohave and in the upper Green River, experiments may need to be conducted in those places. The use of hatchery fish of life stages not found in the wild in other habitats where razorback suckers are rare or absent may also be necessary. Studies of movement patterns could also be used to evaluate the effectiveness of habitat manipulation such as seasonal inundation of river floodplains and creation of off-channel habitats and spawning areas. Such studies could also examine the phenomenon of downstream migration of stocked fish. Efforts to acclimate, retain, and recruit fish in certain river reaches would be a useful means of establishing populations in habitats suited to, or modified for, razorback suckers.

4) Investigate other life history parameters. Because of the rarity of razorback suckers, more basic life history data, especially for riverine populations, is needed. If fish are reintroduced into habitats, comparative life history data collection would be a good way to evaluate the effectiveness of the introductions. Comparison of the biology of the razorback sucker, especially of early life stages, with a relatively successful species like the flannelmouth sucker, may also be worthwhile. Research to date on the effects of altered water

temperature regimes on the reproductive biology (timing of spawning, egg development, hatching success) of the razorback sucker is somewhat contradictory (e.g., temperature versus hatching success) and should be a high priority research area.

Management Recommendations

1) Broodstock and refugia population development. Brood stock must be captured from all areas of known occurrence so that genetic diversity can be preserved and studied, and so that refugia populations are established in case wild stocks become extinct. Capture of such specimens will provide material for resolution of the genetic diversity question, and if necessary, will also provide progeny that could be used for experimentation and reintroduction. Associated issues to be resolved include: (1) collection and transport protocol; (2) responsibility for maintenance and propagation; (3) importance of identity of individuals and groups of animals; and (4) from where and how many of these animals should be collected. Brood stock collection began in spring 1988 in the Colorado River drainage, Colorado, with three fish sent to Dexter National Fish Hatchery; in spring 1990 an additional four fish were captured and sent there. Razorback sucker brood stock were also collected from below the Dirty Devil arm and the San Juan River arm of Lake Powell, and from the Green River, Utah, and are now being held at the Colorado River Fishes Propagation and Experiment Station, Ouray, Utah. Progeny from wild fish (about 300 fish) are now

being raised for future brood stock. The feasibility of initiating additional hatchery programs for endangered fishes is currently under study.

2) Refine reintroduction strategies to enhance survival. The experiences of biologists in the LCRB suggest that different stocking and augmentation strategies must be developed, if and where continued reintroduction of hatchery fish is appropriate. Size of fish to be stocked, number, timing, consideration of habitat or fish community alterations prior to stocking, and other questions must be answered. Some of these may be best addressed in coordination with some of the research activities outlined above.

3) Identify locations for reintroduction experiments. If reintroduction of hatchery fish is deemed necessary, and if fish of the most appropriate genetic stock are available for stocking, reintroduction sites must be found. Ideally, these sites would be (1) free of predators (or have predators removed from them), (2) fulfill the habitat needs of the fish being stocked, and (3) permit careful and extensive monitoring so that the success of the introduction(s) can be tracked. The possible sizes of such habitats could range from single backwaters to extensive reaches of larger rivers. Obviously the latter would be more difficult to accomplish, but this may be a future goal of a

recovery plan and would provide for a large scale experiment on which to base future recovery efforts.

4) Monitor populations. There is still a need to monitor existing populations and habitats of remaining wild fish. Natural and man-caused alterations are potentially catastrophic, especially for restricted and small populations. There is also a need to survey additional habitats (Gunnison River, Colorado River upstream of Grand Valley Diversion) for remnant razorback sucker populations that may contribute to recovery of the species. Recent rediscovery of Colorado squawfish in the San Juan River suggests that relict populations of endangered fishes may exist in the Colorado River Basin. Such studies would also offer an opportunity to survey habitats that may be appropriate for reintroduction of endangered fishes.

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