Chapter 7

Adaptive Management of an Imperiled Catostomid in Lake Mohave, Lower Colorado River, USA

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Additional information is available at the end of the chapter

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Abstract

Lake Mohave, a man-made reservoir in the lower Colorado River, USA, was once home to the largest wild population of the endemic and endangered razorback sucker *Xyrauchen texanus*, estimated at 60,000 individuals in the late 1980s. Individuals of this population were 25 years or older because recruitment was precluded by the removal of larval production by introduced centrarchid species. A repatriation program was initiated in the 1990s to replace the aging population with young fish by capturing larvae from the reservoir and raising them in hatcheries and protected lakeside backwaters until they were released back into the reservoir. Although more than 200,000 fish have been repatriated to Lake Mohave, the repatriate population has remained at a few thousand fish. The wild population is now functionally extinct. The program has adapted to new threats to the population, political realities, and technological advances. Management shifted in 2006 to the Lower Colorado River Multi-Species Conservation Program, which has politicized the process. The aim of this chapter is to describe the initial, informal adaptive management strategy for razorback sucker in Lake Mohave, the transition to a formal program, and the inherent pitfalls that formalization entails.

Keywords: endangered species, population dynamics, genetic diversity, razorback sucker, hatchery management

1. Introduction

Razorback sucker *Xyrauchen texanus* is a long-lived catostomid that is endemic to the Colorado River basin of western North America. Historically, it was encountered throughout the basin in the mainstem Colorado River as well as medium to large tributaries [1]. Declines in abundance and range contraction over the last half century are attributed to habitat alteration (e.g., dams and water extraction) and introduction and establishment of more than four dozen nonnative fish species [2]. Razorback sucker was federally (USA) listed as endangered in 1991 [3], and management actions divided the basin into upper and lower units at Lee's Ferry upstream of the Grand Canyon (**Figure 1**). In the lower Colorado River, management actions were initially focused on the largest remnant population of razorback sucker in Lake Mohave, a water regulation reservoir impounded in 1951 by the completion of Davis Dam (**Figure 2**).

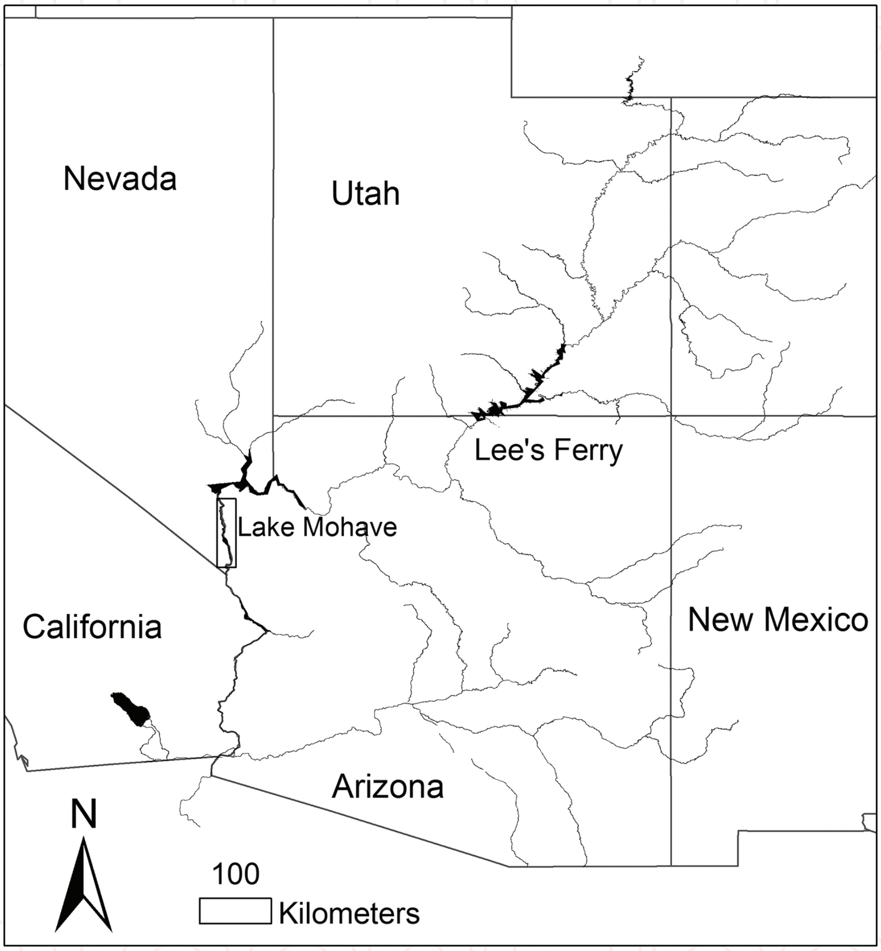

Figure 1. Map of the Colorado River drainage in western USA.

The management of razorback sucker in Lake Mohave began with a single goal, to replace a declining old population likely to become extirpated by the turn of the twentieth century with a young repatriated population [4]. This single goal was established in the early 1990s by the ad hoc Lake Mohave Native Fishes Workgroup (NFWG), an informal group of biologists from state and federal agencies, universities, and private entities. It was seen as a stop-gap measure to buy time until effective, long-term recovery actions could be developed and implemented. Nearly 30 years later, the management strategy has resulted in a genetically diverse repatriate population of approximately 2500 individuals [5], far fewer than the estimated 60,000 wild adults that resided in the lake in the late 1980s. However, without this repatriated population, razorback sucker would have disappeared from the reservoir, as the wild population is now functionally extirpated [5].

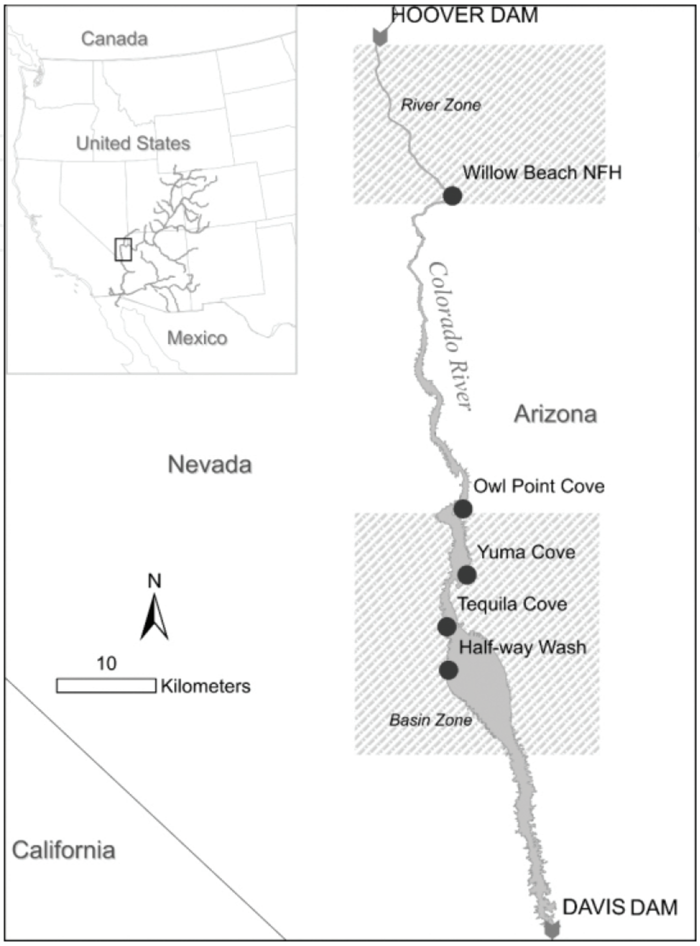

Figure 2. Map of Lake Mohave Arizona and Nevada, USA.

The management strategy for razorback sucker in Lake Mohave has always been adaptive. As is likely with any resource management program that has covered multiple decades, it had to adapt to changing environmental conditions, technological advancements, and periodic political intransigence. Today, adaptive management is at the cornerstone of federal policy regarding endangered species recovery plans [6]. Recently, the informal adaptive management strategy for razorback sucker in Lake Mohave (NFWG) has been replaced by the formal and well-documented adaptive management structure of the Lower Colorado River Multi-Species Conservation Plan (LCR MSCP). This plan seeks to conserve at least 26 plant and animal species in the lower Colorado River corridor while continuing to allow normal Colorado River water and power operations [7]. Applying adaptive management principles to endangered species recovery programs requires striking a delicate balance. The public and elected officials often demand an end date, an exact price in dollars, and time for a recovery program, which can run counter to the adaptive management approach because new data can change predicted outcomes of management practices.

2. Adaptive management of razorback sucker in Lake Mohave

2.1. Population decline and razorback sucker repatriation program

The number of razorback sucker in Lake Mohave was likely in the hundreds of thousands, if not millions in the 1960s and 1970s, but no attempt to estimate their abundance was made until the early 1980s [8]. By the late 1980s, the remnant population was estimated at 60,000 individuals [9]. This was the largest remaining population of razorback sucker in existence, but fish that had been aged through otolith examination were old, between 25 and 45 years old [10]. Most of these adults were representatives of successful cohorts produced in the first few years after impoundment of the reservoir, and no recruitment had been detected for 25 years. If this continued, the population was projected to disappear before the turn of the century [1, 11].

Although the immediate threat to the species within Lake Mohave was simple to identify, no simple solution was available. The complete removal of larval production from the entire reservoir through predation, mainly from introduced centrarchid species, was seemingly improbable, but multiple studies spanning several decades throughout the basin all pointed in the same direction [12, 13]. Data to support alternative hypotheses could not be produced. Resource limitation appeared promising and was carefully investigated but could not be clearly identified as a mortality factor [14, 15]; larval razorback sucker survived and grew inside protective enclosures placed in the reservoir, and razorback sucker grew to adults when placed in a nonnative free environment. Neither the political climate nor the technical knowhow was available at the time or is presently available to remove all nonnative fish species from the reservoir. Therefore, if the population and the species were to be perpetuated, assistance would have to take the form of stocking fish.

Early attempts to produce juveniles took place in an isolated backwater adjacent to Lake Mohave at Yuma Cove where a large aggregation of fish was available during the spawning season [1]. The first attempt in January 1991 was to stock ripe fish captured from the reservoir (33 females and 67 males) directly into the backwater. Larvae were produced but no juveniles survived; at least none was detected, and no mortality factor was identified. A year later in January 1992, 28 females and 60 males were transferred from the lake into the backwater. Larvae again were produced and this time juveniles survived and nearly 300 were captured the following autumn. However, genetic evaluation indicated that the juveniles represented a relatively small number of parents, their variation was less than expected relative to the wild adult population, and this method of propagation was unlikely to preserve the population's genetic diversity [5, 16, 17]. The next iteration in March 1993 involved manually spawning ripe fish on site and stocking about 200,000 embryos thus produced into the backwater. Unfortunately, water level in the backwater lowered unexpectedly and exposed the bottom where most fertilized ova had settled, killing them. Nonetheless, some larvae hatched and a small number of juveniles was captured. At the same time, a number of laboratory-reared fish (metalarvae and juveniles averaging 26 mm long) were stocked into this and other backwaters around the lake. Survival of these fish was variable among sites, but recovery of fewer than 500 juveniles was inadequate to fulfil programmatic goals of stocking thousands of young fish.

The real "aha" moment came with the suggestion to harvest naturally produced larvae directly from the lake and transfer them to protective custody in nonnative-free rearing sites including lakeside backwaters. Larvae were known to be phototactic [8] and easily captured, abundant, and likely to represent the genetic diversity of the wild adult population. Thus, in winter-spring 1994 began the methodical process of nighttime harvest with dip nets of larvae that were attracted to lights, rearing in safe places, and return to the lake as relatively large subadults or adults. One unique aspect of the program was the early use of passive-integrated transponder (PIT) tags. From the beginning, every attempt was made to implant all repatriated razorback sucker with a PIT tag prior to being released into the reservoir. Each tag contained a unique 10-digit hexadecimal code that was used to identify individual fish. With periodic refinements, the same basic protocol is followed today.

Early indications were that the repatriation program was a success. By 1994, repatriated razorback sucker were captured in routine monitoring on the spawning grounds throughout the reservoir. To increase the capacity of the program, the NFWG partnered with golf courses in Boulder City, Nevada, Willow Beach National Fish Hatchery (a federal trout hatchery that was built on the shores of the reservoir downstream of Hoover Dam), and other entities. An average of more than 12,000 razorback sucker was repatriated annually from 1997 to 2005. In 1999, the repatriate population was estimated at more than 1000 fish, based on PIT tag recapture data [18]. However, from 1999 through 2004 the repatriate population appeared to plateau at about 1500 fish (estimates fluctuated between 1000 and 2500) regardless of the number stocked (**Figure 3**). It was clear that the repatriate population was not going to match the previous size of the wild population under the current program. Meanwhile, the wild population had declined from more than 60,000 in 1991 to less than 50 [5], and now is functionally extinct. Concerns over whether genetic diversity could be maintained long term with a population of only a few thousand [19] motivated research into the sources of post-stocking mortality.

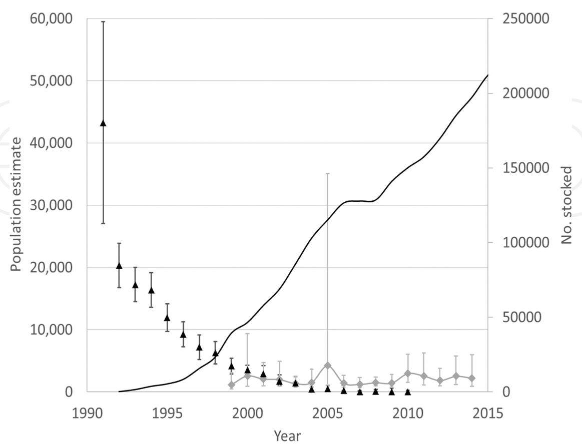

Figure 3. Wild (black triangles) and repatriate (gray diamonds) population estimates and 95% confidence intervals for razorback sucker in Lake Mohave. Estimates are single census mark-recapture estimates derived from captures during annual netting activities in March. The solid line and secondary axes represent the cumulative number of PIT tagged repatriated razorback sucker stocked into Lake Mohave.

Based largely on work in the Gila River, the program originally considered a 250-mm razorback sucker to be free from most predatory threats in Lake Mohave, as the main concerns were channel catfish *Ictalurus punctatus* and centrarchid species common to the reservoir, for example, largemouth bass *Micropterus salmoides* and bluegill *Lepomis macrochirus*. An unexpected population expansion of one of the reservoir's nonnative predatory fishes altered this condition at nearly the same time the repatriation program was initiated. During a season of heavy winter rains in 1983, the spillway was opened on Hoover Dam. Besides releasing water downstream unfettered, this operation allowed the introduction into Lake Mohave of large numbers of the obligate piscivore striped bass *Morone saxatilis*. Although this species already was known to occur in Lake Mohave [20], the influx of individuals and their subsequent reproduction and recruitment led to it becoming a predominant species by 1990. The impact of striped bass was immediate and severe, yet interestingly the phenomenon is largely unstudied except in the context of native fishes. The trout fishery downstream of Hoover Dam was considered to be one of the best in the United States in the 1980s [21], but trout were rarely seen more than a few weeks after stocking by the mid-1990s. Striped bass grew rapidly in Lake Mohave obtaining sizes of up to 1200 mm TL and more than 30 kg in weight. The target-stocking size of 250 mm for razorback sucker was clearly inadequate, but the "right" size to mitigate striped bass predation was unknown.

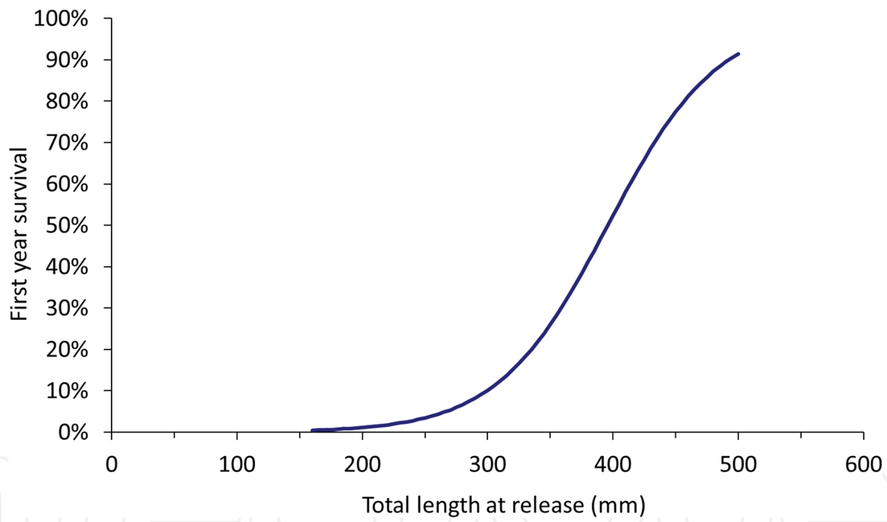

Figure 4. Estimated first-year survival for repatriated razorback sucker released into Lake Mohave based on total length (TL) when released. Survival estimates based on mark-recapture analysis of release and capture data in Lake Mohave from 1993 through 2004.

One of the early attempts to quantify the size-survival relationship for razorback sucker used PIT tag recapture data from annual census data. Sampling trips to monitor populations of native (and endangered) bonytail *Gila elegans* and razorback sucker in Lake Mohave were conducted multiple times per year, but most razorback sucker were captured on sampling trips conducted during the peak of spawning activity in March. These "March Roundup" recapture data were linked to stocking records to derive capture histories for all repatriated fish released in Lake Mohave. TL at release was added as a covariate to first-year survival and the data were assessed within the mark-recapture software MARK. The resulting relationship between first-year survival and TL at release was used as a management tool (**Figure 4**), but there was considerable uncertainty about the relationship due to low survival of stocked fish, less than 2% overall, and low annual recapture rates, less than 10% [18]. Increasing recapture rate would require increasing netting effort during the March Roundup. Members of the NFWG were concerned about increasing stress and potential delayed mortality due to repeated handling of fish. The program needed to adapt to increase survival of stocked fish, and increase recapture rates without increasing handling.

2.2. Research, adaptation, and emerging technology

Prior to the formal publication of the size-survival relationship, incremental increases in stocking sizes were implemented moving to 300 and 350 mm TL from 1999 to 2004. By 2006, the decision was made to produce fish that were nearly immune to predatory threats, which required raising razorback sucker over 500 mm TL. Raising large numbers of razorback sucker to 500 mm TL at the hatchery was going to take additional years of growth and experimentation. In the interim acoustic telemetry studies were performed with small numbers of razorback sucker at the potentially optimal stocking size of 500 mm TL and at the previously common release size of 380 mm TL to test the hypothesis. The results from these studies were unequivocal and confirmed the size-survival relationship, but survival also varied dramatically from year to year [22]. In addition, an acoustic tag that was implanted in a 520-mm TL razorback sucker was recovered from the stomach of a relatively average sized 13-kg striped bass by a fisherman [23], providing evidence that no size was completely safe from predation; the maximum length of razorback sucker is thought to be near a meter [24], but few individuals longer than 700 mm now are encountered [18, 20].

While razorback sucker were being held for additional years of growth at the hatchery, few fish were stocked; only about 500 repatriates were released from the hatcheries between November 2007 and October 2009. The 2007 population estimate, calculated after the 2008 March Roundup, had dropped to near 1000 adult repatriates. Although razorback sucker held at the hatcheries had not reached the target length of 500 mm TL, the NFWG determined that releasing fish at their current size was better than taking the risk that genetic diversity of the population would be compromised due to the low population size. Over the next 18 months, more than 20,000 razorback sucker were stocked from the hatchery system. Although the mean TL of all fish stocked was similar to previous stockings (360 mm), more than 800 razorback sucker at 450 mm TL or longer were released.

Along with a shift in release size, a technological shift also occurred in 2006. PIT tagging all repatriates released into Lake Mohave had been conducted since the program began in 1992 with few exceptions. By 2006, PIT tag technology had progressed significantly. The 400-kHz tags used in Lake Mohave for the previous 14 years were being superseded by 134.2-kHz PIT tags. Some PIT tag readers could detect both tag frequencies, but the newer 134.2-kHz tags were becoming the dominant format in animal tagging. The 134.2-kHz tag had significant advantages over the older frequency. The 400-kHz tags were read by rubbing the PIT tag reader over the tag injection site, the new 134.2-kHz tags could be read from tens of centimeters away.

Not only did this reduce handling time by making it easier during capture to identify fish, it was now possible to detect fish without handling them. After years of favoring methodological continuity over emerging technology, the shift was made to 134.2-kHz tags in 2006. All razorback sucker were now tagged with the new tag prior to repatriation, and any razorback sucker captured during monitoring activities without a tag was given the new tag. Due to the lack of stocking from 2006 through 2008, razorback sucker captured with 400-kHz tags were given a 134.2-kHz tag starting in 2008 (double tagging).

Oversight of the management program also shifted by 2006. Prior to 2006, management of the program was guided by the NFWG. However, in 2005 the Lower Colorado River Multi-Species Conservation Plan was signed. This negotiated agreement between state water resource agencies of the lower Colorado River basin and the federal government is a 50-year agreement for continued operations and conservation actions for at least 26 native plant and animal species. The informal adaptive management approach of the NFWG was replaced with a formal adaptive management strategy when the LCR-MSCP was signed and became the de facto management doctrine for razorback sucker and other native fish species in the lower Colorado River. The LCR MSCP strategy for the conservation of razorback sucker in the lower Colorado River closely followed the concepts developed by Minckley et al. [25]. This paper acknowledged the limited success of the repatriation program, and advocated for a different approach to conserving razorback sucker long term: create self-recruiting populations in off-channel habitats free of nonnative fishes, while maintaining a genetically diverse population of adults in the mainstem Colorado River and its reservoirs. The Lake Mohave razorback sucker population continued to be important as the genetic repository of the species, and understanding the population dynamics of the off-channel and reservoir populations would be fundamental to the success of the program. Remote PIT scanning appeared to be the tool needed to acquire the data upon which to base science-driven management decisions.

The increased reception range of the new 134.2-kHz PIT tag allowed for remote sensing of PIT tags, that is, identifying a tagged fish without capturing it. Elsewhere, portable PIT scanners were used to monitor behavior, movement, and habitat use of fishes in shallow waters of small streams [26, 27], and fish movement has also been monitored in larger streams using units permanently or semi-permanently mounted to the substrate or man-made structure [28, 29]. Initial testing of this technology in Lake Mohave relied on Biomark® flat-plate antennas and FS2001 radiofrequency identification (RFID) scanners. These units were able to detect both 400-kHz and 134.2-kHz tags. Although read range of 400-kHz PIT tags was only a few centimeters or less, razorback sucker were known to remain close to the substrate and the potential to remotely contact at least a portion of 400-kHz tagged fish was important given the small number of 134.2-kHz tagged razorback sucker released by 2008. These PIT scanning units could only be deployed in the calm, lotic waters of the reservoir because they required a floating component to contain the RFID readers and batteries. In 2008, the remote PIT-scanning units on Lake Mohave contacted 176 unique PIT tags and 194 were contacted in 2009 [30]. In 2010, the number of available 134.2-kHz tagged fish increased due to large stocking events. PIT scanning in the reservoir contacted 477 razorback sucker in that year, nearly twice as many as the number encountered during the March Roundup (286 razorback sucker) in the same year. It was clear that this technology would allow for a much larger proportion of the population to be contacted annually than the netting effort once the 134.2-kHz tagged fish made up the majority of the population. This increase in monitoring data also would not require additional handling or netting activities, which could impact survival or spawning behavior. However, the PIT scanners could not alleviate one monitoring issue. Razorback sucker were routinely observed in the swiftly flowing and turbulent riverine section of the reservoir downstream of Hoover Dam, but these fish were generally unmonitored. Trammel nets were ineffective in the fast-flowing river, and boat electrofishing was effective, but potentially harmful to the fish [31]. PIT scanning would likely be effective as well, but the floating systems could not be anchored well enough to remain in place in the river.

In 2010, a PIT scanner design was proposed for use in the riverine sections of Lake Mohave based on systems described in Bond et al. [28]. The design was adapted to allow the unit to be completely self-contained without a floating or a shore-based component. The first fully submersible PIT scanners were developed and deployed in 2011 between Hoover Dam and Willow Beach. Sites of deployment were based on observations of spawning aggregates during the winter and spring months (January through April), and PIT scanner units were typically deployed between 12 and 24 h before being retrieved, downloaded, and redeployed with fresh batteries during week-long sampling trips. In that first year, 670 PIT tags from repatriated razorback sucker were contacted. By 2012, this number nearly tripled to 1832, more than twice the number contacted in the basin by PIT scanners (882). The total number scanned in the river alone nearly matched the 2012 population estimate of 1854. Combined, repatriate PIT scanning contacts in Lake Mohave exceeded the population estimate based on mark-recapture data from netting activities during the March Roundup.

One purpose of extending PIT scanning to the riverine section below Hoover Dam was to determine if the fish in the river and in the basin were of the same population. It was assumed that razorback sucker moved throughout the reach between Davis and Hoover dams, and that population estimates based on netting activities on the spawning grounds in the basin were representative of the lake-wide population. Initial analysis of PIT scanning data from 2011 and 2012 in the basin and river did not support this assumption. More than 80% of the fish contacted in the riverine reach downstream of Hoover Dam had been released (stocked) there, and more than 80% of the fish contacted in the basin had been released in the basin. In year-to-year comparisons, fewer than 10% of the fish contacted in one reach were contacted in the other reach the subsequent year. The partial demographic isolation of the two subpopulations required a rethinking of population estimates and the overall stocking strategy.

Beginning in 2012, year-to-year population estimates based on PIT scanning data supplemented the annual estimates based on annual netting activities. Consistent with the partial demographic isolation demonstrated in the PIT scanning data, population estimates were divided into basin and river subpopulations. In the first few years, the sum of subpopulation estimates based on PIT scanning was similar to estimates from netting activities even though the river subpopulation was not effectively sampled by netting activities. This was likely due to the exclusion of 400-kHz tagged fish in PIT scanning and the lack of complete geographic coverage of the basin area with PIT scanners. Netting activities generally covered four primary spawning aggregates in the basin area: Halfway Wash, Tequila Cove, Yuma Cove, and Owl Point. The majority of PIT scanning in 2011 and 2012 was concentrated in Tequila Cove and Yuma Cove. These two sites had semi-permanent PIT scanners that scanned nearly continuously throughout the spawning season (November through April). As the geographic coverage in the basin improved, and the proportion of 134.2-kHz tagged fish increased, the subpopulation estimate for the basin alone approached the overall estimate based on netting activities. By 2014, each subpopulation was estimated at around 1500 fish each. The discovery of additional razorback sucker in the system was a positive development for the program. However, the river subpopulation did not contribute significantly to the repatriation program. This is because until recently all larvae collected in the lake for the repatriation program were collected more than 10 km downstream of Willow Beach, whereas the majority of the river subpopulation was reproducing upstream reproducing upstream of Willow Beach. Proportional representation of the riverine subpopulation in larval collections would require about half of the 20,000 larvae collected annually to be collected upstream of Willow Beach, and so the program must again adapt to this new paradigm.

3. LCR MSCP and the future of Lake Mohave

The original goal of replacing the wild adult population with a young repatriated population was based on solid scientific evidence available at the time it was formulated. Changes in the fish fauna and lower than expected adult survival resulted in a population of only a few thousand, maintained through annual stocking of more than 10,000 razorback sucker. The NFWG adapted to new data and technologies, and the NFWG recognized the futility of continuing the stocking program indefinitely although a small population of razorback sucker had been established and maintained. Alternative strategies to the repatriation program were under development as early as the late 1990s. The overall strategy for razorback sucker conservation in the lower Colorado River codified in journal publications [5, 25], the US Fish and Wildlife Service (USFWS) implementation plans [32], and the LCR MSCP is one of natural recruitment within protected off-channel habitats. These small populations would be managed with the exchange of adults with the populations maintained in the mainstem and its reservoirs and with each other to maintain genetic diversity. This would eliminate the need for hatcheries and massive stockings and permit nearly natural selective pressures to continue. The LCR MSCP conceptually is in agreement with this strategy, but its formal adaptive management structure spreads limited resources too thin and its political nature creates obstacles to implementation of new strategies when data are acquired.

The basic concept of adaptive management is to treat current management practices as working hypotheses, and the results of such practices are evaluated through monitoring to provide information, which forms the basis of changes in subsequent management practices. The number of knowledge gaps identified by the LCR MSCP conceptual model for razorback sucker [33] that required additional research stretches scant resources to their limit, and does nothing for conserving the species in the short term. The immediate need of optimizing stocking regimes should take precedence over understanding the complete life cycle of the species, especially when most of that research requires experiments with life stages that cannot be found in the natural system. Razorback sucker as a species is still in crisis, the size of the one population with the genetic legacy is too low to secure that legacy. Does it therefore make sense to spend resources answering biological questions that at best will aid razorback sucker recovery which is decades off and likely will not happen at all if current trends continue?

One example of the lack of focus since the LCR MSCP is the size at release for razorback sucker in Lake Mohave. After the release of large fish from the hatchery system from 2009 to 2011, an experiment that began prior to the LCR MSCP, the target released size returned to 300 mm TL. The only large fish released into Lake Mohave have been from lakeside backwaters. This has resulted in almost no razorback sucker stocked in the last 3 years from the hatchery being captured or contacted via PIT scanners. For comparison, out of the 806 fish longer than 450 mm TL that were released during the attempt to grow 500-mm TL fish, 417 were contacted by PIT scanners from 2011 through 2015. More than 22,000 razorback sucker were released in 2012 and 2013 (41 fish over 450 mm TL), and only 169 have been contacted more than 30 days after their release. The complete failure of recently stocked fish to recruit to the adult population has erased any gains in population size that were created from the large fish releases in 2009, 2010, and 2011.

Equally important, the political constraints cause actions that could benefit razorback sucker to not be performed. The LCR MSCP mandates the creation of 360 surface acres of backwater. The most successful backwaters in the system to date are the lakeside backwaters on Lake Mohave. Experiments designed to assess the genetic contribution of one razorback sucker generation to the next in backwater environments are currently being conducted in three lakeside backwaters on Lake Mohave. Two of these backwaters produce young of year razorback sucker annually, but must be harvested each year as the backwaters dry up during reservoir drawdowns. One lakeside backwater at Yuma Cove that is deep enough to retain water year-round has a healthy population of several hundred razorback sucker, some stocked, some self-recruited in the backwater. With the exception of Cibola High Levee Pond [25], there is currently no other location on the lower Colorado River that has proven as effective. However, the LCR MSCP does not give credit to the program for any off-channel habitat created in Lake Mohave, and unfortunately the lakeside backwaters will only be used for experiments or grow-out, and no new backwaters will be created on the reservoir.

4. Conclusions

The real danger of an expensive management program for any endangered species is failure to produce tangible results. A perception that millions of tax dollars were spent without a return on the investment would likely reduce support for future programs. The endangered fish recovery program in the upper basin should be a warning sign for the LCR MSCP. Although the LCR MSCP is very specifically a conservation and not a recovery program, that distinction will likely not save it from public or political scrutiny if it is perceived a failure. A 30- or 50-year time span may seem like a long time to recover a species, but it is within the life span of a single razorback sucker. It is unreasonable to expect that our understanding of the causes of population decline for razorback sucker will reach the level of being able to reverse that decline within the life span of a single fish. The upper basin has had nearly three decades to reach that goal, yet not one population of razorback sucker in that region is doing better now than before the beginning of the program if impacts of stocking are excluded. Although stocking can reduce the probability of extinction, it does nothing to improve the probability of self-sustenance, which is a fundamental requirement of any successful recovery program.

The ultimate fate of the razorback sucker population in Lake Mohave under the LCR MSCP is unknown, but if the NFWG had required that a complete understanding of razorback sucker life history and predator-prey interactions be obtained prior to stocking one fish, there would be no population to conserve. The NFWG was able to focus on a single goal, adapted to new information, and still failed to achieve its goal. The LCR MSCP is attempting to achieve multiple goals, with a 5-year planning cycle, a 54-member steering committee, and an expectation that "program-level adaptive management is not anticipated to occur often over the 50 year term because the HCP conservation direction was developed using the best available information" [34]. There recently has been a refocus on meeting a target release size of near 500 mm TL. If razorback sucker at or near 500 mm TL are released consistently, a substantial increase in the number of individuals in the population is expected. These actions will secure the razorback sucker in Lake Mohave for a number of years; however, conservation and recovery of the species in the lower Colorado River will require successful implementation of the backwater-based program concept [25, 32]. Such a plan already has proven its biological efficacy and we urge the LCR MSCP partners to move forward aggressively to identify, confront, and overcome political and logistical barriers and put that plan into practice.

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References

[1] Minckley WL, Marsh PC, Brooks JE, Johnson JE, Jensen BL. Management toward recovery of the razorback sucker. In: Minckley WL, Deacon JE, editors. Battle Against Extinction: Native Fish Management in the American West. Tucson, AZ, USA: University of Arizona Press; 1991. p. 303–317.

[2] Minckley WL. Native fishes of the Grand Canyon region: an obituary? In: Colorado River Ecology and Dam Management; 24–25 May 1990; Santa Fe, NM. Washington DC: National Academy Press; 1991. p. 124–177. DOI: 10.17226/1832

[3] United States Fish and Wildlife Service. Endangered and threatened wildlife and plants; the razorback sucker (*Xyrauchen texanus*) determined to be an endangered species, final rule. Federal Register. 1991;56:54597–54967.

[4] Mueller GA. A program for maintaining the razorback sucker in Lake Mohave. Bethesde, MD. In: American Fisheries Society Symposium 15; American Fisheries Society; 1995. p. 127–135.

[5] Marsh PC, Dowling TE, Kesner BR, Turner TF, Minckley WL. Conservation to stem extinction: the fight to save razorback sucker *Xyrauchen texanus* in Lake Mohave and its implications for species recovery. Copeia. 2015;103:141–156.

[6] Doremus H. Adaptive management, the Endangered Species Act, and the institutional challenges of new age environmental protection. Washburn Law Journal. 2001;41(1): 50–89.

[7] Lower Colorado River Multi-Species Conservation Program, Volume II: Habitat Conservation Plan. Sacramento, CA; 2004. 506 p.

[8] Bozek MA, Paulson LJ, Deacon JE. Factors affecting reproductive success of bonytail chubs and razorback suckers in Lake Mohave. Report to US Fish and Wildlife Service Contract No. 14-16-0002-81-251. Las Vegas: University of Nevada; 1984. 136 p.

[9] Marsh PC, Minckley WL. Status of bonytail (*Gila elegans*) and razorback sucker (*Xyrauchen texanus*) in Lake Mohave, Arizona-Nevada. Proceedings of the Desert Fishes Council. 1992;23:18–23.

[10] McCarthy MS, Minckley WL. Age estimation for razorback sucker (Pisces: Catostomidae) from Lake Mohave, Arizona and Nevada. Journal of the Arizona-Nevada Academy of Science. 1987;21:87–97.

[11] Marsh PC, Pacey CA, Kesner BR. Decline of the razorback sucker in Lake Mohave, Colorado River, Arizona and Nevada. Transactions of the American Fisheries Society. 2003;132:1251–1256.

[12] Marsh PC, Langhorst DR. Feeding and fate of wild larval razorback sucker. Environmental Biology of Fishes. 1985;21:59–67.

[13] Carpenter J, Mueller GA. Small nonnative fishes as predators of larval razorback suckers. The Southwestern Naturalist. 2008;53:236–242.

[14] Papoulias D, Minckley WL. Food limited survival of larval razorback sucker, *Xyrauchen texanus*, in the laboratory. Environmental Biology of Fishes. 1990;29:73–78.

[15] Horn MJ. Nutritional limitation of recruitment in the razorback sucker (*Xyrauchen texanus*) [dissertation]. Tempe: Arizona State University; 1996. 280 p.

[16] Dowling TE, Minckley WL, Marsh PC. Mitochondrial DNA diversity within and among populations of razorback sucker (*Xyrauchen texanus*) as determined by restriction endonuclease analysis. Copeia. 1996;(3):542–550.

[17] Dowling TE, Minckley WL, Marsh PC, Goldstein E. Mitochondrial DNA diversity in the endangered razorback sucker (*Xyrauchen texanus*): analysis of hatchery stocks and implications for captive propagation. Conservation Biology. 1996;10:120–127.

[18] Marsh PC, Kesner BR, Pacey CA. Repatriation as a management strategy to conserve a critically imperilled fish species. North American Journal of Fisheries Management. 2005;25:547–556.

[19] Dowling TE, Marsh PC, Kelsen AT, Tibbets CA. Genetic monitoring of wild and repatriated populations of endangered razorback sucker. Molecular Ecology. 2005;14(1):123–135.

[20] Minckley WL. Status of razorback sucker, *Xyrauchen texanus* (Abbot), in the lower Colorado River basin. The Southwestern Naturalist. 1983;28:165–187.

[21] Allan RC, Roden DL. Fish of Lake Mead and Lake Mohave. Reno, Nevada: Nevada Department of Wildlife Biological Bulletin No. 7; 1978. 105 p.

[22] Karam AP, Kesner BR, Marsh PC. Acoustic telemetry to assess post-stocking dispersal and mortality of razorback sucker *Xyrauchen texanus*. Journal of Fish Biology. 2008;73:719–727.

[23] Karam AP, Marsh PC. Predation of adult razorback sucker and bonytail by striped bass in Lake Mohave, Arizona-Nevada. Western North American Naturalist. 2010;70:117–120.

[24] Minckley WL. Fishes of Arizona. Phoenix, AZ: Arizona Game and Fish Department; 1973. 293 p.

[25] Minckley WL, Marsh PC, Deacon JE, Dowling TE, Hedrick PW, Matthews WJ, Mueller G. A conservation plan for native fishes of the lower Colorado River. Bioscience. 2003;53:219–234.

[26] Riley WD, Eagle MO, Ives MJ, Rycroft P, Wilkinson A. A portable passive integrated transponder multi-point decoder system for monitoring habitat use and behaviour of freshwater fish in small streams. Fisheries Management and Ecology. 2003;10:265–268.

[27] Roussel JM, Cunjak RA, Newbury R, Caissie D, Haro A. Movement and habitat use by PIT-tagged Atlantic salmon parr in early winter: the influence of anchor ice. Freshwater Biology. 2004;49:1026–1035.

[28] Bond MH, Hanson CV, Hayes SA, Baertsch R, Mcfarlane RB. A new low cost in-stream antenna for tracking passive integrated transponder (PIT) tagged fish in small streams. Transactions of the American Fisheries Society. 2007;136:562–566.

[29] Lucas MC, Mercer T, Armstrong JD, McGinty S, Rycroft P. Use of a flat-bed passive integrated transponder antenna array to study the migration and behaviour of lowland river fishes at a fish pass. Fisheries Research. 1999;44(2):183–191.

[30] Kesner BR, Karam AP, Pacey CA, Marsh PC. Demographics and post-stocking survival of repatriated razorback sucker in Lake Mohave. 2010 annual report. Boulder City, NV: Bureau of Reclamation Agreement No. R09AP30002; 2010. 32 p.

[31] Snyder DE. Electrofishing and its harmful effects on fish. Information and technology report USGS/BRD/ITR-2003-002. Denver, CO: U.S. Government Printing Office; 2003. 149 p.

[32] U.S. Fish and Wildlife Service. Management plan for the big river fishes of the Colorado River basin: amendment and supplement of the bonytail, humpback chub, Colorado pikeminnow, and razorback sucker recovery plans. Albuquerque, NM: Department of the Interior; 2005.

[33] Braun DP, McClure CJW. Razorback sucker (*Xyrauchen texanus*) (RASU) basic conceptual ecological model for the lower Colorado River. Boulder City, NV: Lower Colorado River Multi-Species Conservation Program; 2013. 184 p.

[34] Lower Colorado River Multi-Species Conservation Program. Final Science Strategy. Boulder City, NV: Lower Colorado River Multi-Species Conservation Program; 2007. 71 p.