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Assessment of Potential Augmentation and Management Strategies for Razorback Sucker *Xyrauchen texanus* in Lake Mead and Grand Canyon: A 2021 Science Panel Summary

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Contents

EXECUTIVE SUMMARY

Razorback Sucker *Xyrauchen texanus* is a large-bodied, long-lived species endemic to the Colorado River Basin. This species historically ranged throughout the basin from the Colorado River delta in Mexico to Wyoming and Colorado. Currently, the species persists ,in a small portion of its historical range with the help of intensive management efforts including augmentation. Recruitment to adult life stages is extremely limited in the wild, but is documented consistently in Lake Mead. Research and monitoring efforts in Lake Mead are ongoing since 1996 and have recently expanded to include the Colorado River inflow area and portions of lower Grand Canyon. Despite evidence of recruitment, the current population size in Lake Mead and Grand Canyon is believed to be small (<400 adults based on long-term mark-recapture data) and susceptible to stochastic effects. This raised interest in the potential to augment the population to prevent loss of genetic diversity and increase abundance and distribution in general, as well as explore recruitment bottlenecks. To address critical uncertainties surrounding this management option and to brainstorm other potential options, a Planning Committee and Steering Committee made up of representatives of state (Arizona, Nevada), tribal (Hualapai Tribe, Navajo Nation), and federal (Bureau of Reclamation, National Park Service, and U.S. Fish and Wildlife Service) management agencies convened an Expert Science Panel (ESP; 2021), to consider augmentation and management strategies for Razorback Sucker in Lake Mead and Grand Canyon. The purpose of this report is to summarize those findings.

The ESP considered the overarching question, *"Is the current population of Razorback Sucker in Lake Mead and Grand Canyon sustainable, and should it be augmented?"* The ESP also included many sub-questions specific to each area and potential sub-population. With regard to the current status of the population in Lake Mead, many on the ESP considered the current population numbers to be unsustainable over long time periods because of low population numbers, ongoing megadrought, and potential changes in reservoir water level management. However, there is large uncertainty in how this population will respond over the long-term. The likely small number of individuals contributing to spawning and lower genetic diversity relative to the Lake Mohave population is cause for concern because this could elevate genetic issues, such as inbreeding effects. The ESP hypothesized that while the limiting factors remain unknown, it appears likely to be predation by nonnative fish –this was identified as a critical uncertainty. Clarification was provided on how the minimum population viability number of 5,800 was originally arrived at in the Razorback Sucker Recovery Goals (USFWS 2002), and the ESP agreed that 5,800 fish is a reasonable starting goal. Other critical uncertainties included: 1) concern with the population being so small that it is hard to be confident in population estimates and trends, 2) hypotheses about factors/conditions contributing to successful recruitment are largely untested in the field, and 3) the effect of augmentation and genetic drift on potential local adaptation. Two-thirds of the ESP recommended experimental augmentation of Lake Mead to increase genetic diversity and bolster the small population size, but one-third of panelists thought augmentation should not occur because it would confound the ability to understand what factors are contributing to natural wild recruitment in Lake Mead.

With regard to the role that Grand Canyon plays in the greater metapopulation viability and dynamics, the ESP considers the populations of Razorback Sucker in Lake Mead and Grand Canyon to represent core (Lake Mead) and satellite (Grand Canyon) populations rather than a metapopulation, because currently Grand Canyon appears to be reliant on fish in Lake Mead moving upstream to recolonize. The Grand Canyon population could be contributing to the Lake Mead core population (e.g., via larvae drifting downstream), but this contribution is likely minimal because the number of adult fish in Grand Canyon appears low. In terms of conditions needed to establish and maintain a population in Grand Canyon, the ESP thought habitat improvements in the form of creating off-channel rearing habitats in western Grand Canyon may be necessary prior to augmentation in the mainstem Colorado River, and the ESP expressed concern that cold water temperatures in the mainstem might limit habitat suitability for all life stages of Razorback Sucker. Additional critical uncertainties for the Grand Canyon satellite population included adding to existing hybridization by abundant Flannelmouth Sucker with Razorback Sucker.

With regard to connectivity between Lake Mead and Grand Canyon, the ESP agreed that two-way connectivity seems limited, temporally variable, and (mostly) biased downstream based on data presented to the ESP. Upstream movement past Pearce Ferry Rapid seems limited under current flow conditions, while downstream movement is likely unimpeded. Critical uncertainties regarding connectivity included: 1) the suitability of spawning and rearing habitat in Grand Canyon, 2) the location of where Razorback Suckers are spawning in Grand Canyon, and 3) how future flow and reservoir conditions could impact connectivity between Lake Mead and Grand Canyon.

Logistically, if augmentation in Lake Mead were to occur, panelists in favor of augmentation recommended: 1) fish should be stocked in multiple locations to better understand if any site-specific features contribute to post-stocking survival, 2) the number of augmented fish should be 600 fish total per year, 300 from Lake Mead stock and 300 from Lake Mohave stock, 3) survival of augmented fish < 300 mm likely would be low but could improve our understanding of early life stage survival and recruitment bottlenecks, 4) all fish should be PIT-tagged and sampled for genetics prior to stocking, and 5) all additional information, such as length, weight, sex, source, etc., should be deposited in existing databases for the lower Colorado River basin (e.g., database maintained by Marsh & Associates). Lastly, the panel attempted to prioritize management activities based on the ideas presented above. Experimental augmentation (over 3 years) of Lake Mead and subsequent monitoring was deemed the top priority for the Lake Mead core population. Experimental augmentation of Grand Canyon tributaries using juvenile fish (100-150 mm total length) was the top priority identified for the Grand Canyon. The ESP also identified multiple knowledge gaps that should be addressed.

In summary, the ESP generally agreed if any augmentation is implemented it should be done on a limited basis and in an experimental framework to allow critical uncertainties to be addressed. However, some panelists questioned the urgency of needing to augment because augmenting the population could confound the ability to determine what is allowing recruitment of wild fish to occur in Lake Mead, but nowhere else. If augmentation were to occur, the goals of augmentation should be to alleviate potential negative genetic consequences of a small population while maximizing the potential to fill in critical knowledge gaps pertaining to Razorback Sucker early life history and recruitment in Lake Mead and Grand Canyon. There was complete consensus by the ESP that augmentation efforts should not turn into into a sustained stocking program.

1.0 INTRODUCTION

1.1 Background

Razorback Sucker *Xyrauchen texanus* is a large-bodied, long-lived species endemic to the Colorado River basin. This species historically ranged throughout the basin from the Colorado River delta to Wyoming and Colorado (Minckley et al. 1991). Currently, the species persists , in a small portion of its historical range with the help of intensive management efforts including augmentation (Schooley and Marsh 2007; Marsh et al. 2015; Franssen et al. 2021).

Although spawning is common, recruitment to adult life stages is extremely limited in the wild, and is documented most consistently in Lake Mead despite abundant nonnative predators (Albrecht et al. 2010; Albrecht et al. 2017). Factors hypothesized to contribute to recruitment success in Lake Mead include turbid river inflows and submerged vegetation, which might provide cover to Razorback Sucker and limit predation by nonnative fishes (Albrecht et al. 2010). Historically, there were limited captures of Razorback Sucker in the Grand Canyon, leading scientists to believe the species was extirpated since the mid-1990s (U.S. Bureau of Reclamation 2017). However, researchers documented the presence of Razorback Sucker larvae in 2014 and 2015 (Kegerries et al. 2017), suggesting the species was spawning in the Grand Canyon.

As water levels recede in Colorado River basin reservoirs, connectivity between reservoirs and upstream river habitats becomes severed. Declines in reservoir water level, combined with years of sediment deposition at river-reservoir inflows, is leading to the formation of impediments or complete barriers to fish movement, such as Pearce Ferry Rapid on the Colorado River upstream of Lake Mead and the Piute Farms Waterfall on the San Juan River upstream of Lake Powell (Cathcart et al. 2018). Razorback Suckers congregate at river-reservoir inflows in Lake Mead and Lake Powell (Albrecht et al. 2017; Pennock et al. 2021), and display different movement strategies whereby some fish remain in the reservoir while others make upstream movements during spawning season and later in summer (Cathcart et al. 2018; Pennock et al. 2020a; Bogaard 2021). This species can be highly mobile. For example, some Razorback Suckers captured in Lake Powell were later detected on PIT tag antennas 600 km upstream in the Green River (Pennock et al. 2020b). While movement barriers at river-reservoir inflows might prevent upstream movement of nonnative fishes from reservoirs, these barriers also prevent movement of Razorback Sucker and other native fishes into upstream rivers to access spawning and other potentially important habitats (Pennock et al. 2020b; Bogaard 2021).

Research and monitoring efforts in Lake Mead are ongoing since 1996 and in 2010 expanded to include the Colorado River inflow area and portions of lower Grand Canyon. Despite evidence of recruitment, the current population size in Lake Mead and Grand Canyon is believed to be less than 400 individuals and susceptible to stochastic effects (Rogers et al. 2019). Historically, populations of Razorback Sucker in Lake Mohave and Lake Mead overlapped considerably in genetic structure (Dowling et al. 1996; Dowling et al. 2012a); currently, fish in Lake Mead have lower genetic variation and a lower effective population size than fish in Lake Mohave (T. Dowling, personal communication; Dowling et al. 2012b). This has raised interest in the potential to augment the population to reduce negative genetic effects of a small population (i.e., inbreeding effects) and increase abundance and distribution in general, as well as explore recruitment bottlenecks (USFWS 2007; Dowling et al. 2012a,b). For the purposes of this report, augmentation is defined as the intentional movement and release of fish into an existing population, and is synonymous with the terms reinforcement, supplementation, and restocking (e.g., IUCN/SSC 2013). To address critical uncertainties surrounding this management option and brainstorm additional options, a Steering Committee made up of representatives of state (Arizona, Nevada), tribal (Hualapai Tribe, Navajo Nation), and federal (Bureau of Reclamation, National Park Service, and U.S. Fish and Wildlife Service) management agencies convened an Expert Science Panel (ESP) to consider augmentation and management strategies for Razorback Sucker in Lake Mead and Grand Canyon. The purpose of this report is to summarize those findings.

1.2 Summary of Previous Science Panels

A Science Panel was convened in 2010 to develop three independent reports consisting of 1) habitat use of Razorback Sucker throughout the Colorado River system (Valdez et al. 2012a), 2) potential habitat for Razorback Sucker in lower Grand Canyon and the Colorado River inflow to Lake Mead (Valdez et al. 2012b), and 3) an augmentation strategy for Razorback Sucker in lower Grand Canyon (Valdez et al. 2012c). The 2010 Science Panel suggested continuing monitoring and research on Razorback Sucker throughout Lake Mead and at the Colorado River inflow, not to force augmentation of Lake Mead, to integrate all information on fish and the food base in Grand Canyon and the Colorado River inflow, and to expand fish surveys for Razorback Sucker in lower Grand Canyon, including larval fish surveys to identify if spawning was occurring.

In 2017, a second Science Panel was convened to review the ongoing work focused on Razorback Sucker in Lake Mead and Grand Canyon, revisit recommendations made by the 2010 Science Panel, and reassess if augmentation of Lake Mead and Grand Canyon should take place (U.S. Bureau of Reclamation 2017). The 2017 Science Panel recommended Razorback Sucker monitoring and research in Lake Mead and the Colorado River inflow should continue and was providing important baseline data. The 2017 Science Panel also identified ongoing knowledge gaps pertaining to the status of the Lake Mead population and the number of fish contributing to spawning and integration of data on fish and the food base in Grand Canyon and the Colorado inflow. The 2017 Science Panel recommended that concerted efforts should begin to collect samples for genetic evaluation and continue to collect fin clips from adults, but once again the panel did not recommend augmentation of Lake Mead, the Colorado River inflow, or Grand Canyon.

Following recommendations of both previous science panels, monitoring efforts for adults and larval Razorback Sucker continue in Lake Mead and Grand Canyon. Both previous science panels identified the need to integrate data on fish and the food base in Grand Canyon and the Colorado River inflow to Lake Mead, but we are unaware of any efforts to address this knowledge gap. Samples continue to be collected for genetic evaluation including larval fish and fin clips from adults. Whereas both previous science panels recommended against augmenting

Razorback Sucker in Lake Mead or Grand Canyon, more recent genetic analyses suggest a small effective population size and concerns of inbreeding effects (T. Dowling, Wayne State University, unpublished data), and long-term mark-recapture data suggests a relatively small population size (<400 adults; Rogers et al. 2019); although, the population size appears to have increased since the mid-1990s (BIOWEST, Inc., and C. Pennock, Utah State University, unpublished data).

1.3 Purpose of the 2021 Science Panel

This Expert Science Panel (ESP) was convened in December 2021 to consider augmentation and management strategies for Razorback Sucker in Lake Mead and Grand Canyon. The ESP was presented available information in the form of a summary of relevant literature, past science panel reports, and data presentations (Table 1) from research and monitoring projects in Lake Mead and Grand Canyon and the opportunity for long, open discussions among panelists.

Table 1: List of data presentations provided to the 2021 Expert Science Panel.

Presenter & affiliation	Presentation title
Julie Stahli, U.S. Fish and Wildlife Service	Brief overview of recovery plan and goal development for Razorback Sucker
Brandon Albrecht & Ron Rogers, BIO-WEST, Inc.	Long-term monitoring in Lake Mead and Grand Canyon
Steve Platania, American Southwest Ichthyological Researchers	Larval fish monitoring in lower Grand Canyon
Charles Yackulic, Grand Canyon Monitoring and Research Center	Monitoring of western Grand Canyon and potential changes in habitat
Dave Rogowski, Arizona Game and Fish Department	Fish assemblage monitoring in western Grand Canyon and above and below Pearce Ferry Rapid
Thomas Dowling, Wayne State University	Current genetic status and trends in razorback sucker in Lake Mead and Grand Canyon
Matt Bogaard, Kansas State University	Razorback Sucker movement behavior in river-reservoir inflows of Lake Powell
Casey Pennock, Utah State University	Demographics and population viability analysis of Lake Mead Razorback Sucker

1.4 Members of the 2021 Science Panel

A list of prospective panelists was compiled by a Steering Committee consisting of representatives from federal, state, and tribal agencies with direct management responsibilities of Lake Mead and Grand Canyon, including from Bureau of Reclamation, National Park Service, U.S. Fish and Wildlife Service, Arizona Game and Fish Department, Nevada Department of Wildlife, Navajo Nation, and Hualapai Tribe. Prospective panelists were selected based on their subject matter expertise and availability. It was desirable to have experts with a diversity of experience and expertise in the lower and upper sub-basins of the Colorado River system. Additionally, some panelists with extensive knowledge and experience in large-river fish conservation, management and research, but with active research programs focused outside of the Colorado River basin, were chosen to provide an independent, outside perspective. Members of the science panel, steering committee and Utah State University scientists involved in this project are listed in Table 2.

Table 2: Experts serving on the Science Panel associated with the assessment of Razorback Sucker in Lake Mead and Grand Canyon, Steering Committee members (alphabetical order) from resource management agencies that guided the formation of the Science Panel, and scientists from Utah State University that facilitated the project.

Science Panel	**Affiliation**
Scott Bonar	U.S. Geological Survey, Arizona Cooperative Fish and Wildlife Research Unit & University of Arizona
Thomas Dowling	Wayne State University
Keith Gido	Kansas State University
Eliza Gilbert	U.S. Fish and Wildlife Service
Brian Kesner	Marsh & Associates LLC
Craig Paukert	U.S. Geological Survey, Missouri Cooperative Fish and Wildlife Research Unit & University of Missouri
Michael Quist	U.S. Geological Survey, Idaho Cooperative Fish and Wildlife Research Unit & University of Idaho
Julie Stahli	U.S. Fish and Wildlife Service
Thomas Turner	University of New Mexico
David Ward	U.S. Geological Survey, Southwest Biological Science Center
Steering Committee	
Winkie Crook	Hualapai Tribe
Chase Ehlo	U.S. Fish and Wildlife Service
Sky Hedden	Arizona Game and Fish Department
Mark McKinstry	Bureau of Reclamation
Emily Omana Smith	National Park Service
Brandon Senger	Nevada Department of Wildlife
Jim Stolberg	Bureau of Reclamation
Kim Yazzie	Navajo Nation
Facilitators	
Phaedra Budy	U.S. Geological Survey, Utah Cooperative Fish and Wildlife Research Unit & Utah State University
Casey Pennock	Utah State University

2.0 DISCUSSION

2.2 Questions for the 2021 Science Panel

Below is a summary of ESP answers and discussion of questions presented by the Steering Committee. At the end is a “Menu of Management Options” the ESP was asked to discuss and develop, and largely summarizes the ESP’s recommendations on future management actions.

Overarching question: Is the current population of Razorback Sucker in Lake Mead and Grand Canyon sustainable, and should it be augmented?

Lake Mead focused questions

What is the current status of the population(s) in Lake Mead and Grand Canyon?

The majority of the ESP considered the current population numbers to be unsustainable over the long-term. The likely small number of individuals contributing to spawning is cause for concern because this could lead to reduced genetic diversity compared to a larger population of spawning adults, such as the population in Lake Mohave. Estimates of the effective population size range from 81-287 females in samples from 2014-2019 (T. Dowling, Wayne State University, unpublished data). These estimates are an order of magnitude lower than estimates in Lake Mohave over the same time period.

A few members of the ESP thought some of the data suggests the population increased since the mid-1990s, although slightly and with large uncertainty (Figure 1). It is unknown what is limiting the population; although, some members of the ESP suggested it is unequivocally predation by nonnative fish as the species will recruit in lentic habitats devoid of predators. This was identified as a critical uncertainty to be addressed.

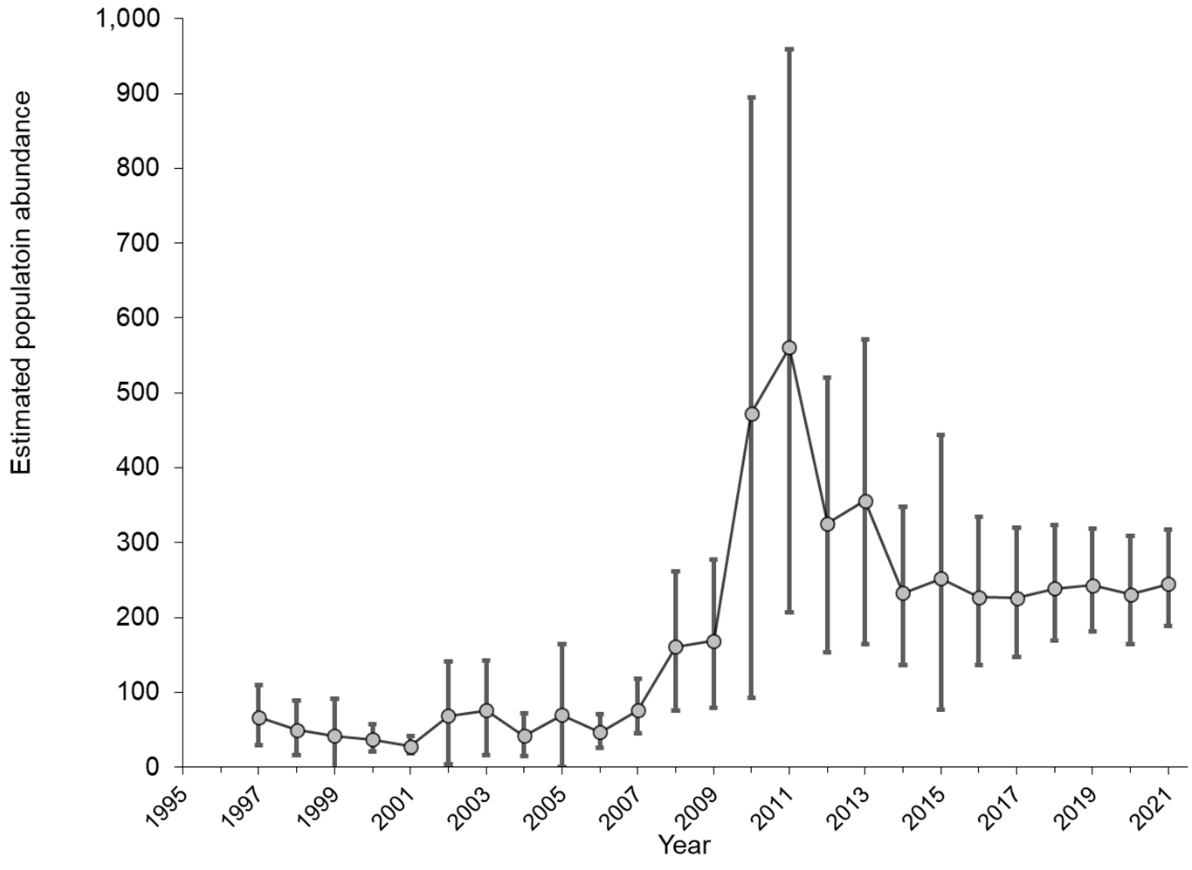

Figure 1: Model-averaged population size estimates for Razorback Sucker captured at five study areas across Lake Mead. The number of areas sampled increased over time (Rogers et al. 2019). Error bars represent 95% confidence intervals. Detections from submersible or shore-based passive integrated transponder (PIT) antennas were included from 2016-2021.

Discussion points: There was thorough discussion about the current status and sustainability of the Lake Mead population. Some panelists questioned the urgency of augmenting a population that appears to be doing something no other population is doing in the Colorado River basin—recruiting to adulthood in consistently detectable numbers. While the ESP was generally in agreement the population seems to be able to sustain itself around 200-500 fish in the short-term with some recruitment and longevity of the species, there is much uncertainty about longer-term dynamics of this population. The lack of small Razorback Suckers (<200 mm) in capture efforts was raised as a red flag, and there was discussion about sampling bias. Age-structure data provided by BIO-WEST suggest there is some consistent, but low-level recruitment occurring. The ESP also inquired about the goal of potential augmentation. If the goal is to learn precisely what the limiting factor is for Razorback Sucker in Lake Mead, then augmentation could confound the ability to identify drivers of natural recruitment. For example, untagged Razorback Sucker are captured in the inflow areas to Lake Powell, but the proportion of untagged to stocked, tagged fish either matches that from upstream rivers (e.g., tag loss; Zelasko et al. 2010), or age estimates of untagged fish overlap with year classes of hatchery fish being stocked without PIT-tags (e.g., San Juan River inflow; Furr 2016; Pennock et al. 2020). If the goal is to alleviate genetic and demographic concerns of a small population, then augmentation should be considered, but at low levels. If the goal is to achieve the stated recovery goal of 5,800 fish (e.g., USFWS 2002) as quickly as possible, then augmentation would be necessary because the population will likely not increase to this abundance on its own without identifying and alleviating limiting factors. There was further discussion about tradeoffs of learning precisely what is limiting the population versus reaching a recovery goal of 5,800 fish, both options have repercussions. For instance, if augmenting confounds the ability to determine limiting factors to Razorback Sucker in Lake Mead, then that opportunity would be lost. Augmenting the population is not likely to lead to a self-sustaining population without alleviating limiting factors. Some panelists expressed concern if augmentation is the only management strategy and suggested any augmentation should be combined with additional management actions (e.g., habitat improvement, predator control; *see section 2.3.1 below*). This is because augmentation alone does not address factors that limit recruitment in the wild.

Is the current level of 5,800 fish a suitable starting goal towards recovery?

Clarification was provided on how the number 5,800 was originally arrived at in the Razorback Sucker Recovery Goals (USFWS 2002). The number of 5,800 fish is based on an evolutionarily argued basis on how large a population theoretically needs to be to maintain itself with environmental perturbations, and not based on any system's carrying capacity per se. The goal of 5,800 fish was meant to be interpreted as the effective number of breeders, not a census target.

The ESP agreed that 5,800 sexually mature fish is a reasonable starting goal.

Discussion points: The ESP discussed how the number 5,800 was determined as well as past efforts to estimate recovery goals. The Lake Mohave program was discussed, where current population estimates are just over 5,000 fish, so getting to 5,800 fish would be difficult. As part of efforts in Lake Mohave, the Lower Colorado River Multi-Species Conservation Program expends a large effort to protect early life stages of Razorback Sucker from predators by collecting wild larvae and growing them large enough to reduce predation.

What evidence exists for conditions allowing for successful recruitment of Razorback Sucker in Lake Mead?

Turbidity at river inflows and lateral washes (e.g., Las Vegas Wash) along with submergent and flooded vegetation with variation in reservoir water level is predicted to contribute to successful recruitment (Albrecht et al. 2010; Ward and Vaage 2019). In laboratory experiments, high turbidity (500 nephelometric turbidity units; NTUs) was effective at reducing predation of juvenile razorback suckers (mean total length = 74 mm) by Largemouth Bass *Micropterus salmoides*, but increased predation by Black Bullhead *Ameiurus melas* (Ward and Vaage 2019). The ESP also discussed warmer water temperatures in lower basin reservoirs relative to Lake Powell as a potential contributor.

Discussion points: There was some additional discussion, and it was pointed out that hypothesized mechanisms are untested in the wild. Very little demographic data exist for survival of Razorback Sucker between age 0 and age 3. These data are likely the most difficult to acquire, but are very important to understanding population dynamics.

What do you predict are the limiting factors for a larger population in Lake Mead?

This is a critical uncertainty, but most of the ESP thought predation by nonnative fishes was limiting the population.

Discussion points: The ESP discussed other potential limiting factors to the population including bottom-up effects and changes in habitat with Lake Mead water level. There have been some attempts to correlate abiotic and biotic factors with Razorback Sucker population dynamics. While data on potential correlates do exist, for at least the more recent portion of Razorback Sucker monitoring, attempts to link Razorback Sucker dynamics with covariates have failed to identify clear patterns. Researchers at BIO-WEST, Inc. assessed potential links between Razorback Sucker recruitment and water level in Lake Mead (Albrecht et al. 2010; Rogers et al. 2019), as well as turbidity and vegetation cover from 2000-2002 (Albrecht et al. 2010). They hypothesized draw-downs in the early 1990s contributed to establishment of vegetation in the previously inundated littoral zone that aided recruitment after the reservoir filled again in the late 1990s. They also hypothesized turbid inflows, regardless of vegetation, could provide cover from predators for early life stage fish, a result supported for sight-feeding predators in a laboratory experiment (Ward and Vaage 2019). However, turbidity does not appear to provide protection for juvenile fish from catfish predators that can feed efficiently in turbid water (Ward and Vaage 2019; Hedden et al. 2020), particularly with an anti-predatory response by juvenile Razorback Sucker to reduce movement and sit on the bottom (Ward and Figiel 2013). Long-term sampling of zooplankton and phytoplankton in Lake Mead began in 2007 (Beaver et al. 2018) and although there is substantial inter-annual variation in zooplankton density, there are no obvious links to suspected strong year classes of Razorback Sucker reported in Rogers et al. (2019). Finally, the facilitators investigated potential correlates between nonnative fish captures and Razorback Sucker between 2005 to 2021, but no clear negative patterns emerged (C.

Pennock, Utah State University, unpublished data), and nonnative fish captures have generally declined since 2005 (Rogers et al. 2019; C. Pennock, Utah State University, unpublished data). Generally, the limited capture data for early life stage Razorback Sucker makes detecting patterns with potential abiotic and biotic correlates difficult.

Based on our current level of knowledge in Lake Mead, do you think augmenting the population would increase the population size of recruiting fish?

Without understanding the factors limiting recruitment or contributing to relatively strong year classes, the ESP thought it would be difficult to say with any certainty that augmenting would create a self-sustaining population.

Discussion points: There was additional discussion about the tradeoffs of augmenting Lake Mead. Some panelists were concerned augmenting the population would reduce the ability to determine which factors are contributing to relatively strong recruitment events; others pointed out the small population size could make it difficult to make inference even if data on other biotic and abiotic factors were consistently available. The ESP also discussed the consequences of continuing to study the Lake Mead population without augmenting. If the population were to go extinct, it could be re-established with fish from Lake Mohave. Concerns were also expressed about the loss of potential local adaptation, if augmentation were to occur; however, it was pointed out that loss of genetic variability could occur naturally (e.g., genetic drift), regardless of augmentation, due to the likely small number of individuals contributing to spawning (effective population size: 81-287; T. Dowling, unpublished data). While about 2/3^{rds} of panelists were in favor of augmenting the Lake Mead population to reduce potential negative genetic effects and reduce risk of extinction, 1/3rd of panelists were not in favor of augmenting Lake Mead. Regardless of whether panelists thought augmentation was currently warranted or not, there was consensus that augmentation alone would not lead to a long-term, self-sustaining population without knowing, and mitigating, the factors limiting the current population (see below).

What are critical uncertainties with regard to this overarching question—Is the current population of Razorback Sucker in Lake Mead and Grand Canyon sustainable, and should it be augmented?

The ESP conveyed concern with the population being small enough that it is hard to be confident in population estimates. The population could be declining, could be stable, or could be slowly increasing.

Because hypothesized conditions contributing to successful recruitment are largely untested in the wild, it is unclear what factors allow for consistent recruitment in Lake Mead. Hypothesized conditions include turbid inflows and submerged vegetation that provide a refuge from predation. Razorback Sucker larvae have a propensity to drift, and might require low-velocity habitats with warmer temperatures in riverine habitats. For instance, growth and survival of early life stage Razorback Sucker are substantially reduced at temperatures <20°C (Marsh 1985; Bestgen 2008). It is also unclear if bottom-up effects play some role in recruitment of fish in Lake Mead and Grand Canyon.

<u>Grand Canyon focused questions</u>

What role does the Grand Canyon play in greater metapopulation viability and dynamics?

The ESP considers the populations of Razorback Sucker in Lake Mead and Grand Canyon to represent core (Lake Mead) and satellite (Grand Canyon) populations rather than a metapopulation, because Grand Canyon appears to be reliant on fish in Lake Mead moving upstream to recolonize. The Grand Canyon population could be contributing to the Lake Mead core population (e.g., via larvae drifting downstream), but this contribution is likely minimal because the number of adult fish in Grand Canyon appears low and all recently tested larvae (n = 14) were hybrids with Flannelmouth Sucker *Catostomus latipinnis* (T. Dowling, unpublished data). The connectivity between Lake Mead and Grand Canyon could change if flows were altered in the future under different reservoir filling actions such as Pearce Ferry Rapid being inundated and becoming more passable, or if the rapid becomes more passable naturally through erosion or lateral movement of the river channel.

Discussion points: The ESP discussed the limited and sporadic upstream connectivity between Lake Mead and Grand Canyon. Although documented movement of four stocked, telemetry-tagged fish moving upstream of River Mile 23 (River Mile 0 is Glen Canyon Dam) suggests the potential for broad-scale distribution exists, whether that is representative of more fish is unclear. The ESP also discussed the potential of providing selective fish passage at Pearce Ferry Rapid to allow native fish access to Grand Canyon while limiting dispersal of nonnative fish from Lake Mead, such as the efforts at the Piute Farms Waterfall and Public Service Company of New Mexico weir on the San Juan River (e.g., Cathcart et al. 2018; Pennock et al. 2020b; Bogaard 2021).

Should Lake Mead and Grand Canyon be considered one population or a metapopulation?

The ESP considers the population in Grand Canyon (satellite population) dependent on fish moving upstream from Lake Mead (core population; see above).

Could Grand Canyon contribute to the greater metapopulation viability?

There is potential for larval drift from Grand Canyon into Lake Mead from spawning by adults moving upstream out of Lake Mead (see above).

What conditions would be needed to establish and maintain a population in Grand Canyon?

The ESP thought habitat improvements in the form of creating off-channel rearing habitats in western Grand Canyon to increase the likelihood of entraining larvae would be necessary to improve habitat for early life stages of Razorback Sucker prior to any augmentation in the mainstem Colorado River in Grand Canyon, if the goal is to establish a naturally recruiting population. The ESP also expressed concerns that cold water temperatures in the mainstem might limit habitat suitability for Razorback Sucker.

Discussion points: The ESP discussed how current low abundance of nonnative fish in lower Grand Canyon could make habitat suitable for early life stages of Razorback Sucker. However, the relatively cold water temperature of the mainstem Colorado River is likely not suitable for Razorback Suckers (the panel did note temperatures have been increasing steadily with declining levels of water in Lake Powell). While spawning can still occur, growth and survival of early life stage Razorback Sucker are substantially reduced at temperatures <20°C (Marsh 1985; Bestgen 2008). Given the high abundance of Flannelmouth Suckers in Grand Canyon, there was also concern about hybridization effects with augmented Razorback Suckers or fish moving upstream from Lake Mead to spawn. For instance, every larval "Razorback Sucker" sampled for genetics from Grand Canyon to date has some evidence of introgression with Flannelmouth Sucker (n = 14; T. Dowling, unpublished data).

What are critical uncertainties with regard to the overarching question and Grand Canyon?

The ESP was unclear how much of a concern the potential hybridization with Flannelmouth Suckers should be if augmentation of Razorback Sucker occurs on top of an abundant Flannelmouth Sucker population. Hybridization is already occurring and occurred throughout the species evolutionary history, but if consistent large numbers of hybrids move into Lake Mead, this could become a problem.

The ESP wondered if the limited number of Razorback Sucker larvae in Grand Canyon was due to limited spawning adults, limited spawning habitat, larval drift, or low survival. Razorback Sucker larvae are known to drift (Marsh and Minckley 1989; Hedrick et al. 2009), and would likely be carried downstream into Lake Mead by river flows without sufficient low-velocity, backwater habitat present in Grand Canyon. Backwater and floodplain habitats are thought to be important for Razorback Sucker recruitment (Bestgen et al. 2011).

<u>Connectivity</u>

To what degree is Pearce Ferry Rapid a barrier to movement of fish between Lake Mead and Grand Canyon?

The ESP agreed that two-way connectivity seems limited, temporally variable, and downstream-biased based on data presented to the ESP. Upstream movement past Pearce Ferry Rapid seems limited under current flow conditions, whereas downstream movement is likely not impeded (see above).

Discussion points: The panelists were in complete agreement about current connectivity between Lake Mead and Grand Canyon. Upstream connectivity appears temporally limited and flow dependent. Downstream connectivity appears to be a non-issue.

Should Lake Mead and Grand Canyon be currently considered one or separate sub-populations? Why or why not?

The ESP agreed Razorback Sucker in Lake Mead and Grand Canyon are currently functioning as one population. Movement of four fish from lower Grand Canyon upstream to near Lee's Ferry suggests there is potential for exchange throughout the system. However, the population in Lake Mead is not likely dependent on Grand Canyon, whereas the Grand Canyon seems dependent on adult fish from Lake Mead for recolonization. Any augmentation to mainstem habitat in Grand Canyon would functionally be augmenting Lake Mead (see above).

What are critical uncertainties with regard to connectivity?

The suitability of habitat in lower Grand Canyon is unknown. The river is cutting into incised reservoir sediments, which might make it difficult to maintain constructed backwaters or off-channel habitats.

The location where Razorback Suckers are spawning in Grand Canyon is unknown.

Future flow and reservoir conditions could impact connectivity between Lake Mead and Grand Canyon; although, Pearce Ferry Rapid is not likely to be inundated if current climate and flow projections hold true and consumptive water use is not decreased (Bruckerhoff et al. 2022).

<u>Other general questions</u>

How might the ongoing and future water shortages in Lake Mead impact the success or failure of Razorback Sucker and potentially augmentation?

There are several potential impacts of ongoing and future water shortages, including changes in inflow turbidity levels, the role of Pearce Ferry Rapid as a barrier, water temperatures in Grand Canyon and the inflows to Lake Mead, and even the ability of Nevada Department of Wildlife (NDOW) to rear fish at their hatchery due to low water levels. Over the last 20+ years, Razorback Sucker in Lake Mohave have spawned in the same four to five locations, and water level during spawning season is similar from year to year (B. Kesner, Marsh & Associates, LLC, personal communication). Declining water level in Lake Mead could be forcing fish to find new spawning locations; there is some evidence of this occurring based on telemetry and re-capture data (e.g., Rogers et al. 2019). Turbidity dynamics could change as inflows change, which could impact recruitment dynamics if turbidity is playing a large role. Depending on water level in Lake Powell, water temperatures in Grand Canyon could increase, decrease, or become highly variable from year to year, which could impact growth, survival, habitat suitability of the mainstem river, and expansion of nonnative fishes in Grand Canyon (negatively or positively). Reductions in water level in Lake Mead could impact fish production at the NDOW hatchery and possibly reduce the amount of suitable habitat in the reservoir for Razorback Sucker through the loss of littoral habitat and clean gravels and cobbles.

Discussion points: The ESP discussed fluctuations in water temperature from Glen Canyon Dam outflows, and how a more stochastic environment (e.g., interannual variation in water temperatures) might not hinder native fishes, but could disadvantage nonnative fishes because native fishes are adapted to a stochastic environment. However, colder water temperatures are likely not suitable for Razorback Sucker (see above). Also, many currently established nonnative fishes are generalists (e.g., Green Sunfish *Lepomis cyanellus*), and so might be tolerant to changes in conditions.

Are current monitoring efforts adequate in Lake Mead and Grand Canyon?

For Lake Mead, the ESP thought experimenting with some different gear types to target younger age classes for which data are minimal would be worth investigating. Particularly, discussion focused on the use of smaller benthic trawls (e.g., Neebling and Quist 2011; Fischer and Quist 2014; Dunn and Paukert 2020). The ESP agreed this could be a good method and could also help sample putative predator assemblages in potential recruitment areas and across different habitats.

The ESP also agreed that data on co-occurring nonnative fishes in Lake Mead would be beneficial to understand how nonnative fish assemblages are changing relative to Razorback Sucker.

ESP members suggested documentation and standardization of the remote PIT tag detection efforts in Lake Mead would be useful. If augmentation were to occur, standardized PIT tag detection effort should be expanded to ensure enough data is collected on augmented fish to evaluate individual and population responses.

For Grand Canyon, the ESP agreed that while the current sampling efforts for small-bodied fishes provide useful information on native fishes, they are labor-intensive and juvenile Razorback Sucker have not been captured. One suggestion was to use a larval trigger to inform whether to sample for small-bodied fishes. For instance, crews could sample for small-bodied (juvenile) fish only if Razorback Sucker larvae are captured in a given year or in the year prior. There was also a suggestion to experiment with other methods in lower Grand Canyon where possible to improve efficiency, such as benthic trawls.

How should the Lake Mead and Grand Canyon population be prioritized within the context of the rest of the Colorado River basin?

Because it is unknown if the Lake Mead population has some level of local adaptation, it was difficult for the ESP to prioritize the population within the context of the rest of the Colorado River basin. However, some members of the ESP stated the consequences of losing the Lake Mead population entirely or mixing the genetics with Lake Mohave are not as dire as something such as Devil's Hole Pupfish *Cyprinodon diabolis*, for instance (Hausner et al. 2014).

Discussion points: There was ample discussion on the urgency to augment the Lake Mead population. While two-thirds of the ESP thought augmentation should take place to bolster numbers and genetic diversity, the other third of the ESP members expressed reserve. Those in reserve were concerned about losing the ability to determine factors contributing to successful recruitment of wild fish since Lake Mead currently hosts the only wild-recruiting population of Razorback Sucker.

If the ESP thinks augmentation should occur in Lake Mead and/or Grand Canyon:

The majority, but not all, of the ESP thought augmentation should occur in Lake Mead, and below is an outline of recommended logistics for a focused, limited augmentation effort from members of the ESP that did support augmentation:

Where should fish be augmented?

The ESP recommended that fish should be augmented in multiple locations in Lake Mead (e.g., Las Vegas Bay, Echo Bay, Colorado River inflow) to better understand if any site-specific features contribute to post-stocking survival.

How many?

The ESP recommended that the number of augmented fish should be 600 fish total per year, 300 from Lake Mead stock and 300 from Lake Mohave stock (e.g., Spurgeon et al. 2015).

How often?

The ESP agreed that stocking should occur on a limited basis perhaps starting with once per year for three years, and then reevaluate.

What size classes?

The panel generally agreed that fish <300 mm total length would have very low survival, and augmented fish should be >300 mm. Although stocking fish of smaller sizes would allow information to be gathered on early life survival and recruitment bottlenecks.

What genetic source should fish come from?

The panel agreed that any augmented fish should come from a 50:50 mix of Lake Mead and Lake Mohave stock. This would allow for maintenance of any potential local adaptation by Lake Mead fish as well as provide an influx of genetic diversity from Lake Mohave. Stocked fish should be PIT-tagged and sampled for genetics prior to stocking to allow for monitoring outcomes. Data on stocked individuals should be maintained in a centralized database. Some panelists in favor of augmentation suggested that availability of larvae from different stocks should not hinder augmentation efforts. For instance, if only one source of fish is available (e.g., Lake Mohave), then augmentation is more important than guaranteeing a 50:50 mix.

2.3 Summary of recommended management actions (Menu of management options), critical uncertainties, and knowledge gaps

Following the discussion on questions provided to the ESP by the Steering Committee, the ESP was asked to have a general discussion and brainstorm a potential menu of management options that could be taken. The recommended actions are presented below in order of priority determined by the ESP and largely relate to or are summaries from answers to questions described above.

2.3.1 Recommended management actions (menu of management options) in order of priority:

Lake Mead

Management option 1: Augmentation of Lake Mead to bolster population size and genetic diversity

Two-thirds of the ESP agreed experimental augmentation of Lake Mead should be considered a priority action. Still, some panelists were hesitant, and indicated the urgency to augment was not quite apparent, and that augmentation would confound the ability to understand factors contributing to natural recruitment in Lake Mead. However, all panelists agreed that should augmentation occur, it should not be done simply to reach 5,800 fish contributing to spawning as quickly as possible. Instead, any augmentation should have a clear purpose or question to be addressed (e.g., to increase genetic diversity), and should follow clear management goals with the logistics of augmentation designed around those goals. Conducting augmentation in an experimental fashion could allow some critical knowledge gaps to be filled, but will likely confound the ability to identify factors contributing to successful recruitment in Lake Mead.

If augmentation were to occur in Lake Mead, the ESP recommended using a mixture of Lake Mead and Lake Mohave stock, and placing fish into the system at turbid inflows using soft-release techniques (Mueller et al. 2003). These fish would be larvae captured from the wild and raised in isolation of predators to a target size. The ESP recommended augmenting with a minimum of two size classes to promote gaining information on early life stages. Whereas survival of augmented fish <300 mm would likely be low based on apparent survival estimates from other systems (e.g., Zelasko et al. 2022), augmentation using older age classes would not provide information on factors limiting recruitment of age-0, age-1, or age-2 fish. One suggestion was to couple augmentation of smaller fish (<200 mm) with some type of localized nonnative fish reduction. The ESP was clear that any augmented fish should be fin clipped for genetic analysis and PIT tagged prior to stocking. These data would be critical to survival analysis of different sizes and origins, assessment of contribution to differential spawning success by origins, and would allow for continued detection of wild recruitment. The ESP recommended augmenting fish at multiple locations including Las Vegas Bay, Echo Bay, and the Colorado River inflow. Six hundred fish per year (300 from Lake Mead stock and 300 from Lake Mohave stock) could be augmented, and augmentation should start with one event per year for three years, followed by a re-evaluation.

Potential questions to be answered:

- What is survival of younger age classes?
- Does recruitment success differ among fish from different origins (i.e., Lake Mead vs Lake Mohave stock), and is the difference large enough to impact long-term population dynamics?

Management option 2: Localized reduction of select nonnative fishes at turbid inflows during spawning-rearing season

Experimentation with different methods of targeted removal or reduction near known Razorback Sucker spawning areas during spawning season might be useful.

Management option 3: Other fine-scale experiments at sites throughout the reservoir to test limiting factors to recruitment, such as turbidity or nonnative fish predation

Management option 4: System-wide nonnative fish eradication to aid recruitment of Razorback Sucker

Management option 5: Evaluate creation of localized turbid zones with pumps

Management option 6: Evaluate predator-free areas by chemically treating localized areas of the reservoir, such as coves using turbidity curtains

While experimental augmentation or other management actions are under way, attempts should be made to address the following knowledge gaps:

What factors/conditions are contributing to successful recruitment of Razorback Sucker in Lake Mead?

Potential approaches:

- Use fin ray microchemistry to discriminate among major inflows to Lake Mead where recruited fish might have originated
- Vegetation cover-isolation experiments
- Turbidity experiments
- Identify environmental correlates with spikes in juvenile Razorback Sucker captures

Do Lake Mead Razorback Sucker larvae display some form of local adaptation compared to Lake Mohave Razorback Sucker larvae?

Potential approaches:

- Behavioral assays of larval suckers
- Feeding efficiency trials under different levels of turbidity

What happens between the larval phase and the adult phase?

Related questions:

- Where is mortality the highest between those phases?
- How, when, where, and why is predation happening?

What are nonnative fish dynamics in Lake Mead as they relate to long-term trends of Razorback Sucker?

Potential approaches/related questions:

- Is there a correlation between Razorback Sucker and nonnative fishes in Lake Mead?
- What are the temporal trends in nonnative fish predators in Lake Mead?
    - Preliminary analysis of nonnative fish catch per unit effort data from sampling conducted by BIO-WEST, Inc. suggests a general decline in nonnative fish catch between 2005 and 2021 that coincides with declines in Lake Mead water level (C. Pennock, unpublished data).

Grand Canyon

Management option 1: Experimental augmentation of Grand Canyon tributaries using juvenile fish (100-150 mm).

The ESP was generally in greater consensus to trying experimental augmentation in Grand Canyon than in Lake Mead, particularly in tributary habitats where nonnative fish are less abundant and water temperatures are warmer. Tributaries and augmentation sites within tributaries could be selected based on some assessment of habitat, such as stream gradient and perennial water.

a. To increase chances of re-encountering fish, larger numbers of augmented juvenile fish would be needed, and should not be less than 300 per event.
    i. Larger numbers of juvenile fish would increase chances of re-encountering fish
b. Start with augmentation for three years and reassess
c. Use a mixture of Lake Mead and Lake Mohave stock
d. Use existing monitoring in Grand Canyon to assess experimental augmentation including established antenna arrays to detect PIT-tagged fish.
e. Introduce fish post-monsoon season; augmenting over multiple years could be important because of environmental variation and flooding
f. PIT tag and fin clip (for genetics) all augmented fish
g. Potentially prioritize tributaries based on habitat conditions and ability to monitor with existing PIT tag antennas

Management option 2: Habitat improvements in lower Grand Canyon

a. Augment adult Razorback Sucker into the mainstem Colorado River following improvement/construction of off-channel rearing habitats to increase potential entrainment of larvae
b. Use a mixed stock of Lake Mead and Lake Mohave fish similar to augmentation plan for Lake Mead
c. Inject fish with hormones to promote immediate spawning
d. PIT tag and fin clip all augmented fish

Management option 3: Temperature control device on Glen Canyon Dam, to get to pre-dam temperatures, drawing from the appropriate depths accordingly.

While experimental augmentation or other management actions are under way, attempts should be made to address the following knowledge gaps:

How suitable is the mainstem Colorado River in Grand Canyon for Razorback Sucker?

Related questions:

- Are current and future water temperatures warm enough to allow for a resident population to establish and persist?
- Are food resources abundant enough to support a resident population?

Will juvenile fish introduced into Grand Canyon remain to become resident, or move downstream into Lake Mead?

3.0 CONCLUSION

Two-thirds of the ESP agreed experimental augmentation of Lake Mead should be considered a priority action. Still, the other third of panelists were hesitant, and indicated the urgency to augment was not quite apparent, and that augmentation could confound the ability to understand factors contributing to natural recruitment in Lake Mead. Thus, there are trade-offs between augmenting the population to increase genetic diversity and bolster population numbers and trying to understand why Razorback Sucker are able to recruit in Lake Mead despite abundant non-native predators. The ESP was clear that any augmentation should be on a limited basis and under an experimental framework to address critical knowledge gaps. The goals of any augmentation should be to alleviate potential negative genetic consequences of a small population size while maximizing the potential to answer critical knowledge gaps pertaining to Razorback Sucker early life history and recruitment in Lake Mead and Grand Canyon. There was complete consensus by the ESP that augmentation efforts should not turn into a sustained stocking program, such as exists elsewhere in the basin. All members of the ESP were open to trying experimental augmentation in Grand Canyon tributaries with PIT-tagged juvenile fish (100-150 mm total length). Lack of suitable habitat to entrain early life stage Razorback Sucker and water temperatures below 20°C were the main concern with augmenting the mainstem Colorado River in Grand Canyon. Potential negative consequences of elevated levels of hybridization with Flannelmouth Sucker in Grand Canyon were also a concern, regardless of where augmentation occurred.

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