RECLAMATION

Managing Water in the West

Razorback Sucker *Xyrauchen texanus* Research and Monitoring in the Colorado River Inflow Area of Lake Mead and the Lower Grand Canyon, Arizona and Nevada

2022 FINAL ANNUAL REPORT

US Bureau of Reclamation
Upper Colorado Region
Salt Lake City, Utah

Report prepared for:
US Bureau of Reclamation
Upper Colorado Region
and the Lower Colorado River
Multi-Species Conservation Program

Razorback Sucker *Xyrauchen texanus*
Research and Monitoring
in the Colorado River Inflow Area
of Lake Mead and the Lower Grand Canyon,
Arizona and Nevada

2022 FINAL ANNUAL REPORT

Prepared by:

Ron J. Rogers[1], Brandon Albrecht[1], Justin Handtke[1], Jake G. Mortensen[2], Monika S. Kawski[2], Steven P. Platania[2], Mark McKinstry[3], Kerri Pedersen[3], Brian Healy[4], James Stolberg[5], and Emily Omana Smith[4]

([1] BIO-WEST, Inc.; [2] American Southwest Ichthyological Researchers, LLC; [3] US Bureau of Reclamation, Upper Colorado Region; [4] US National Park Service; [5] Lower Colorado River Multi-Species Conservation Program)

December 2022

ACKNOWLEDGMENTS

This project was funded by the US Bureau of Reclamation and the Lower Colorado River Multi-Species Conservation Program and was a cooperative effort between BIO-WEST, Inc. (BIO-WEST); American Southwest Ichthyological Researchers, LLC (ASIR); US National Park Service; Arizona Game and Fish Department; Nevada Department of Wildlife; and US Fish and Wildlife Service. Sampling, logistics, and planning strategies were conducted jointly between these groups in various capacities. Thank you to Grand Canyon National Park and Lake Mead Recreational Area for providing logistical support, camping facilities, and transportation. We thank all those from Ceiba Adventures for providing safe and well-equipped transportation through Grand Canyon. We also thank all of those who participated in field sampling and even volunteered their time. The participants are too numerous to list, but their efforts were extremely valuable to the success of the project. We would also like to thank those at the Museum of Southwestern Biology, Division of Fishes, and University of New Mexico for curation and processing of larval collections.

COVER PHOTO DESCRIPTIONS

Colorado River in Grand Canyon, Arizona, at sunset, August 2022 (credit: B. Albrecht, BIO-WEST, Inc.).

DISCLAIMER

The opinions and recommendations expressed in this report are those of the authors and do not necessarily reflect the views of the US Bureau of Reclamation or any other agency or organization. The use or mention of trade names, commercial products, or firms and businesses does not constitute endorsements or recommendations for use.

RECOMMENDED CITATION

Rogers, R.J., B. Albrecht, J. Handtke, J.G. Mortensen, M.S. Kawski, S.P. Platania, M. McKinstry, K. Pedersen, B. Healy, J. Stolberg, and E. Omana Smith. 2022. Razorback Sucker *Xyrauchen texanus* research and monitoring in the Colorado River inflow area of Lake Mead and the lower Grand Canyon, Arizona and Nevada. Report prepared by BIO-WEST, Inc., for the US Bureau of Reclamation, Upper Colorado Region, Salt Lake City.

EXECUTIVE SUMMARY

In 2010, the US Bureau of Reclamation, Upper Colorado Region (Reclamation), and the Lower Colorado River Multi-Species Conservation Program (LCR MSCP) initiated a joint project to evaluate Razorback Sucker *Xyrauchen texanus* use of the Colorado River Inflow Area of Lake Mead (CRI). That project was based on Biological Opinions from the US Fish and Wildlife Service (USFWS) on the proposed adoption of *Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead* (USFWS 2007) and the *Operation of Glen Canyon Dam Including High-Flow Experiments and Non-Native Fish Control* (USFWS 2011), which identified conservation measures to examine the potential for, and suitability of, habitat in the lower Grand Canyon for Razorback Sucker, and to institute an augmentation program in collaboration with USFWS, if appropriate. Conservation measures under the latest Biological Opinion for the *Glen Canyon Dam Long-Term Experimental and Management Plan* (USFWS 2016) call for Reclamation to continue to assist the National Park Service (NPS), USFWS, and the Glen Canyon Dam Adaptive Management Program (GCDAMP) in funding larval and small-bodied fish monitoring in order to, (1) determine the extent of hybridization in Flannelmouth Sucker *Catostomus latipinnis* and Razorback Sucker collected in the western Grand Canyon, (2) determine habitat use and distribution of different life-stages of Razorback Sucker to assist in future management of flows that may help conserve the species, and (3) assess the effects that trout-management flows and other dam operations may have on Razorback Sucker. The "lower Grand Canyon" was subsequently defined as Grand Canyon from Lava Falls Rapid downstream, including the inflow portion in Lake Mead and several miles of lake habitat (Leslie Fitzpatrick, USFWS, personal communication). The project was also recommended in a comprehensive report that reviewed 10 years of Razorback Sucker monitoring on Lake Mead (Albrecht et al. 2008a). Several of the recommendations from that report were highlighted by the Lake Mead Work Group (LMWG) for inclusion in its long-term management plan (Albrecht et al. 2009). Investigating the CRI and other unsampled locations for Razorback Sucker presence were some of the first items of that plan to be implemented.

Based on observations of sonic-tagged Razorback Sucker use of Grand Canyon (Kegerries and Albrecht 2013a, 2013b), Reclamation provided additional funding in 2014 to support more-comprehensive Razorback Sucker investigations within Grand Canyon and the CRI. The overall goal of this effort was to identify and document the presence or absence of wild Razorback Sucker within the understudied Grand Canyon and continue to monitor the CRI population.

BIO-WEST, Inc., (BIO-WEST) was selected to lead this study and teamed with American Southwestern Ichthyological Researchers, LLC, (ASIR) as well as personnel from Reclamation and NPS. Larval sampling expertise within Grand Canyon was provided by ASIR. Dr. Rich Valdez and Dr. Paul Holden were added as team members to provide historical context, species expertise, and peer review. Other collaborators include personnel from the LCR MSCP, Arizona Game and Fish Department, USFWS, and Nevada Department of Wildlife (NDOW). These groups are represented on, participate in, and comprise the LMWG, a multiagency group dedicated to conserving Razorback Sucker and contributing to species recovery. This cooperative approach was paramount in providing the means to assess Razorback Sucker use of Grand Canyon and the CRI efficiently and effectively, and this project has benefited from uniting researchers and managers of the upper Colorado River basin, Grand Canyon, and lower Colorado River basin on behalf of the species.

This report contains information from the 2022 field season. Data stemming from the CRI are presented in Chapter 1. Chapter 2 covers small-bodied and larval-fish community sampling conducted within Grand Canyon in 2022. Considering the interconnectedness observed between the lake and river, Chapter 3 presents holistic findings from sonic-telemetry efforts. These three chapters provide evidence of Razorback Sucker interaction between and among the study areas. While this report presents interesting and new information pertaining to the status of Razorback Sucker in Grand Canyon and the CRI, the value of this multiyear study will be found in investigating the relationship between the river and Lake Mead, which was recommended by an independent science panel that reviewed project findings to date (Reclamation 2017).

Colorado River Inflow Area of Lake Mead (CRI)

At the CRI, sonic-telemetry and trammel-netting techniques were used to capture adult and juvenile fish where concentrations of Razorback Suckers were suspected, and fin-ray specimens were obtained from previously unaged Razorback Suckers for aging purposes. In more than 620 trammel net-hours at the CRI in 2022, 1 adult Razorback Sucker and 69 Flannelmouth Suckers were captured.

Using sonic-tagged fish locations and previous knowledge of potential spawning areas to guide sampling for catostomid larvae during the 2022 spawning period (February–May), 36 larval Razorback Suckers from the CRI were captured.

Since 2010, 194 Razorback Suckers and 125 Razorback Sucker × Flannelmouth Sucker hybrids have been captured via trammel netting. Additionally, 822 Razorback Sucker larvae, including recently transformed juvenile fish, have been captured from multiple spawning areas at the CRI.

Long-term investigations involved tagging and releasing hatchery-reared Razorback Suckers into the CRI in 2010 and 2011 and then tracking these fish using sonic-telemetry techniques. In 2013, efforts were initiated to implant wild Razorback Suckers with sonic tags, which resulted in the surgical implantation of one wild fish at the CRI. Thirteen additional wild Razorback Suckers were implanted with sonic tags at the CRI, two in 2014, three in 2015, two in 2016, three in 2018, two in 2021, and one in 2022. Additionally, 10 hatchery-reared fish were successfully implanted with sonic tags in 2013 and released below Separation Canyon. Nine hatchery-reared fish were implanted with sonic tags and released just below Lava Falls in 2014, 10 hatchery-reared fish were implanted with dual radio/sonic tags and released at Diamond Creek in 2016, and 10 hatchery-reared fish were implanted with dual radio/sonic tags and released at Bright Angel Creek in 2018. In 2021, 32 Razorback Suckers were implanted with sonic tags (n=20; Sonotronics CT-05-48 or CT-05-36) and radio tags (n=10; Lotek MCFT2-3FM). Thirty of these fish were taken from NDOW's Lake Mead Fish Hatchery and the other two were wild male fish captured in 2021 at the CRI. Twenty Razorback Suckers were released at Bright Angel Creek, 10 were released at Separation Canyon, and the 2 wild fish were released at their point of capture at the CRI. Lastly, in 2022 one wild male Razorback Sucker was implanted with a sonic tag. Sonic-tagged Razorback Suckers are regularly monitored via manual tracking as well as passive tracking, which uses submersible ultrasonic receiver technology.

Grand Canyon

Monthly fish-collecting efforts began in March 2022 and continued through September 2022. Larval-fish collection began in March and concluded in August; while small-bodied fish community sampling began in April and concluded in September. Grand Canyon sampling in 2022 resulted in the capture of four native and nine nonnative fish species, as well as documentation of young-of-the-year (age-0) catostomid and cyprinid fishes. The native species captured included Bluehead Sucker *Catostomus discobolus*, Flannelmouth Sucker, Humpback Chub *Gila cypha*, and Speckled Dace *Rhinichthys osculus*. Seining results indicated that native species (particularly native suckers) dominate the Grand Canyon fish community, especially below Havasu Creek. No Razorback Suckers were captured during small-bodied fish seining efforts within the Grand Canyon study area in 2022.

Juvenile and adult Humpback Chub were captured during small-bodied fish sampling throughout Grand Canyon. The first individuals were captured in April 2022, and the species' relative abundance appeared highest in July, when Humpback Chub were captured throughout the study area (just below Phantom Ranch to near Pearce Ferry). The collection of additional data throughout Grand Canyon regarding this species added value to the project and to recovery efforts. These findings may warrant discussions about potential Humpback Chub spawning in the mainstem Colorado River. At minimum, these results demonstrate that this species utilizes habitats within Grand Canyon and the full-pool footprint of Lake Mead.

Larval-fish sampling continues to document magnitude and duration of reproduction by members of the ichthyofaunal community (native and nonnative) throughout the lower 191 river miles of the Colorado River within Grand Canyon. For the first 6 years of this project (2014–2019), larval-fish sampling verified Razorback Sucker spawning and larval production in the Colorado River within Grand Canyon National Park. In 2019, larval Razorback Suckers (n=8) were captured only during April and May and were distributed from river mile (RM) 127.3 to RM 279.0. The May 2019 capture of one Razorback Sucker at RM 127.3 is the farthest upstream Razorback Sucker larva has been captured within the expanded study area (2016–2019; RM 88.6–279.0). This finding extended the distribution of age-0 Razorback Sucker 17.5 river miles further upstream than the previously identified most upstream capture of Razorback Sucker in 2018 (n=1, RM 144.8). All except one of the 2019 captured larval Razorback Suckers were collected in May (n=7). The number of larval Razorback Sucker taken per sampling year has continued to decline since the study started in 2014 (2014=462, 2015=81, 2016=46, 2017=27, 2018=10, 2019=8), even though sampling effort has remained relatively consistent throughout this project. While larval Razorback Sucker were not collected in 2020, it is important to note that sampling was not conducted in April or May 2020 (because of national park closures during the COVID-19 pandemic). April and May are the two most important months for collection of these larval fish; consider that from 2014 through 2019, the April and May monthly surveys collectively yielded over 90% of the larval Razorback Suckers collected from the Grand Canyon. Larval fish sampling occurred monthly March–August 2021 (n=6 surveys), yet no Razorback Sucker larvae were positively identified from these collections (n=22 catostomid larvae are pending identification to species; however, there is no certainty any of these specimens are Razorback Sucker larvae).

Larval Razorback Suckers collected during 2014–2019 were represented by two ontogenetic phases (i.e., protolarvae and flexion and postflexion mesolarval subphases). The developmental stages of these few fish combined with their location of capture strongly suggest multiple spawning locations. The range of length-based back-calculated hatching dates encompassed a 5-week period from 30 March to 5 May 2019, a shorter spawning season than previous years. This is further evidence of the importance of April and May samples to the collection of larval Razorback Sucker.

Age-0 Humpback Chubs were captured during four (May–August) of the six monthly larval fish surveys during 2022. Age-0 Humpback Chubs were first captured during May, which is consistent with the 2014–2021 larval fish survey years. During 2022, age-0 Humpback Chubs (n=444) were distributed over approximately 180 river miles (RM 98.7–279.0). Larval Humpback Chubs were represented by several ontogenetic phases (flexion and postflexion mesolarvae and metalarvae) with the majority being mesolarvae; no protolarvae of this species were collected in 2022. Protolarval Humpback Chubs were collected during (2018–2020). Humpback Chubs collected during 2022 showed a trend of increasing abundance and ontogenetic phase progression with distance downstream May–August. Approximately half of age-0 Humpback Chubs (57.2%) were collected downstream of RM 200.1 during 2022. Back-calculated hatch dates for Humpback Chub in 2022 spanned 10 weeks (70 days) from 3 May to 11 July 2022. The distribution of hatch dates suggests multiple peaks in hatching occurred, beginning in early May with the majority occurring late-May to early June and a final hatch occurring in late-June. During the first monthly survey of 2021 (March), relatively few larval fish were collected (n=46) but the vast majority of these specimens (98.3%) were the earliest two ontogenetic stages (protolarvae and mesolarvae) of Flannelmouth Sucker. All the larval Flannelmouth Suckers collected in March 2020, 2021, and 2022 occurred downstream of Havasu Creek (RM 157.3), suggesting this tributary serves an important role in reproduction for the ichthyofaunal community in Grand Canyon. Age-0 Rainbow Trout were collected for the fourth consecutive year (2019–2021) in March or April, indicating the early spawning (prior to initiation of sampling) of this species. Larval catch rates in 2022 showed a continuation of spatial and temporal patterns in the abundance, distribution, and ontogenetic stage distributions of endemic catostomids and Humpback Chub observed in previous survey years (2016–2021). Collectively, native species accounted for 98.6% of age-0 fishes collected during larval-fish community sampling in 2022.

The July 2022 sample yielded six larval Striped Bass (nonnative); a species that had not been previously collected in this study. These six specimens were collected at six separate generalized random tessellation stratified (GRTS) sites between RM 139.6 and RM 220.0 and were 27.0 mm SL to 31.5 mm SL (mean=28.9 mm SL). Striped Bass are broadcast spawners, which produce semibuoyant eggs into the current, where they develop and hatch. It is not known if these larvae were a product of spawning by adult Striped Bass upstream of RM 139.6 or if the eggs were from Lake Powell and were transported through Glen Canyon Dam. Discovery of this nonnative predacious fish in Grand Canyon highlights the value of larval fish sampling for early detection of rare fishes.

Overall Findings

Major findings for this study to date include (1) multiple age-classes of unmarked, wild Razorback Sucker (including juvenile fish) occupy the CRI, and adults spawn there; (2) Razorback Suckers spawn within Grand Canyon or its associated tributaries; (3) young Humpback Chub occur throughout Grand Canyon in relatively higher abundance than perhaps previously suspected; (4) sonic-tagged Razorback Sucker (stocked and wild) utilize both the CRI and Grand Canyon; and (5) native fish are dominating the fish community in Grand Canyon.

Within the study period, the efforts expended and techniques described in this report have allowed us to document the interaction of Razorback Sucker within Grand Canyon and the CRI. This research will hopefully provide a better understanding of Razorback Sucker reproduction and recruitment in this system. Overall, study results suggest that this is an interconnected, recruiting population of Razorback Sucker that demonstrates plasticity sufficient to allow for lentic and lotic habitat use in Lake Mead and Grand Canyon. Future investigations of this species and monitoring of all Lake Mead and Grand Canyon study areas will be crucial to understanding the species and promoting conservation and recovery of Razorback Sucker not only within this particular system but also perhaps basin-wide.

(This space intentionally left blank.)

CONTENTS

Figures

Tables

GENERAL INTRODUCTION AND BACKGROUND

The Razorback Sucker *Xyrauchen texanus* is one of four endemic, big-river fish species of the Colorado River basin and presently is proposed to be downlisted from endangered to threatened by the US Fish and Wildlife Service (USFWS). The other species are the Colorado Pikeminnow *Ptychocheilus lucius*, Bonytail *Gila elegans*, (both of which remain classified as endangered), and the Humpback Chub *Gila cypha*, which was recently downlisted to threatened status (USFWS 1991, US Office of the Federal Register 2020, 2021). The Razorback Sucker was historically widespread and common throughout the larger rivers of the Colorado River basin (Minckley et al. 1991). The current distribution and abundance of Razorback Sucker are greatly reduced from historic levels, mainly because of the construction of mainstem dams and the resultant cool tailwaters and reservoir habitats, which replaced a warm, riverine environment (Holden and Stalnaker 1975; Joseph et al. 1977; Wick et al. 1982; Minckley et al. 1991). Razorback Sucker persisted in several reservoirs constructed in the lower Colorado River basin; however, these populations consisted primarily of adult fish that recruited during the first few years of reservoir formation. Because of a lack of sustained recruitment, the populations of long-lived adults disappeared 40–50 years following reservoir creation (Minckley 1983). Riverine Razorback Sucker populations in the upper Colorado River basin have also declined as recruitment has not occurred at significant levels since the construction of mainstem dams (Bestgen et al. 2011). Under current conditions, which have increased lentic habitats and altered temperature and flow regimes, it is thought that predation by bass *Micropterus* spp., Common Carp *Cyprinus carpio*, Channel Catfish *Ictalurus punctatus*, sunfish *Lepomis* spp., and other nonnative species is the primary reason for the lack of Razorback Sucker recruitment throughout its original distribution (Minckley et al. 1991; Marsh et al. 2003; Albrecht et al. 2020).

It was widely believed that the trends of Razorback Sucker decline observed in the Colorado River occurred in Lake Mead after Hoover Dam was completed in 1935. Razorback Sucker numbers, initially high in Lake Mead, decreased noticeably in the 1970s, and no Razorback Suckers were collected during the 1980s (Minckley 1973; McCall 1980; Minckley et al. 1991; Holden 1994; Sjoberg 1995). However, in the early 1990s, Nevada Department of Wildlife (NDOW) personnel were informed by local anglers that the species was still present in two localized areas of Lake Mead: Las Vegas Bay and Echo Bay. Limited sampling efforts initiated by NDOW soon confirmed the presence of remnant populations of Razorback Sucker in Lake Mead. In 1996, the Southern Nevada Water Authority (SNWA), in cooperation with NDOW, initiated the Lake Mead studies to attempt to identify some of the basic population dynamics of Razorback Sucker in Lake Mead. BIO-WEST, Inc., (BIO-WEST) was contracted to design and conduct the study with collaboration from SNWA and NDOW. Other cooperating agencies included the US Bureau of Reclamation (Reclamation), National Park Service (NPS), Colorado River Commission of Nevada, and USFWS. This work eventually led to the discovery of several groups of wild fish spawning and recruiting in the reservoir, and these groups currently represent the largest-known wild population of Razorback Sucker in the Colorado River basin to consistently demonstrate natural recruitment (Albrecht et al. 2008a, 2010a, 2010b, 2013a, 2013b, 2014a, 2014b, 2017, 2020; Kegerries et al. 2009, 2015a, 2017a; Shattuck et al. 2011; Shattuck and Albrecht 2014; Mohn et al. 2015, Rogers et al. 2017, 2018, 2019, 2020, 2021a, 2022).

Larval Razorback Suckers were found in the Colorado River Inflow Area of Lake Mead (CRI) during 2000 and 2001, but despite opportunistic netting efforts, no adult Razorback Suckers were captured at that time (Holden et al. 2001; Abate et al. 2002; Albrecht et al. 2008a). In 2008, the Arizona Game and Fish Department (AZGFD) captured a large adult Razorback Sucker during annual gill-netting efforts in Gregg Basin, and NDOW captured two adults in the Virgin Basin, near Bonelli Bay (see Figure 1.1 in Chapter 1). These captures suggested the possibility that other Razorback Sucker populations may occur in areas of Lake Mead that were not being sampled under existing Lake Mead Razorback Sucker monitoring efforts.

A comprehensive review to evaluate the entire Lake Mead Razorback Sucker dataset obtained from 1996 to 2007 and summarize the methods and cumulative findings from Lake Mead Razorback Sucker research was conducted in 2008. The review included recommendations for future monitoring and research on Lake Mead (Albrecht et al. 2008a). The recommendations from the evaluation were incorporated into a long-term management plan that is used and updated by the Lake Mead Work Group (LMWG). It also serves as a guide for future Razorback Sucker studies on Lake Mead (Albrecht et al. 2009). The LMWG consists of personnel from several agencies including Reclamation, USFWS, NPS, NDOW, and AZGFD working cooperatively to study Lake Mead's Razorback Sucker population.

One of the major tasks of the management plan is to explore other locations in Lake Mead for existing Razorback Sucker populations. Based on the location of known populations, which occur in areas with some turbidity and (at times) vegetative cover, the CRI was identified as the most logical area to investigate first. In addition, Biological Opinions from the USFWS on the proposed adoption of *Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead* (USFWS 2007) and the *Operation of Glen Canyon Dam Including High-Flow Experiments and Non-Native Fish Control* (USFWS 2011) identified conservation measures to examine the potential for, and suitability of, habitat in the lower Grand Canyon for Razorback Sucker, and to institute an augmentation program in collaboration with USFWS, if appropriate. The LMWG decided to begin investigative efforts in the CRI with the goal of determining whether a population exists within the upper end of Lake Mead. This was the first new task in the management plan to be implemented and is one of the first steps in meeting the conservation measure described in the 2007 Biological Opinion listed above (USFWS 2007; Albrecht et al. 2009). Concurrent with the timing and implementation of the management plan goal (Albrecht et al. 2009) to explore other locations in Lake Mead for Razorback Sucker populations, Valdez et al. produced three reports (2012a, 2012b, 2012c) to provide background information pertaining to the 2007 Biological Opinion (USFWS 2007). Those three reports were (1) a review and summary of Razorback Sucker habitat throughout its range in the Colorado River (Valdez et al. 2012a), (2) a report on the potential habitat within the lower Grand Canyon (LGC) based on expert opinion (Valdez et al. 2012b), and (3) a possible strategy for establishing Razorback Sucker in the LGC/CRI through either natural expansion of the Lake Mead population or possible augmentation (Valdez et al. 2012c). A more recent Biological Opinion for the *Glen Canyon Dam Long-term Experimental and Management Plan* (USFWS 2016) calls for Reclamation to assist the National Park Service (NPS), USFWS, and the Glen Canyon Dam Adaptive Management Program (GCDAMP) in funding larval and small-bodied fish monitoring in order to, (1) determine the extent of hybridization in Flannelmouth Sucker *Catostomus latipinnis* and Razorback Sucker collected in the western Grand Canyon, (2) determine habitat use and distribution of different life-stages of Razorback Sucker to assist in future management of flows that may help conserve the species, and (3) assess the effects of trout-management flows and other dam operations on Razorback Sucker.

In 2009, there was an apparent expansion in Razorback Sucker recruitment, based on an increased number of juvenile fish observed at known spawning areas in Lake Mead (Albrecht et al. 2008a; Kegerries et al. 2009). Due to apparent habitat similarities with other areas in Lake Mead, it was hypothesized that there was a high potential to document Razorback Sucker in the CRI at that time. Given the success of monitoring fish implanted with sonic tags, it was concluded that renewed efforts in the CRI would help clarify whether a spawning population existed within this area of Lake Mead (Albrecht et al. 2008a; Kegerries et al. 2009). Thus, telemetry and limited sampling efforts in the CRI were initiated in 2010. Stocking and tracking of sonic-tagged Razorback Suckers combined with trammel netting and larval sampling increased the potential of finding a new spawning population of Razorback Sucker in the CRI. This multi-method approach confirmed the existence of a newly identified Lake Mead spawning aggregation (Albrecht et al. 2010a). These efforts provided a greater understanding of Razorback Sucker habitat use and movement patterns within Lake Mead; additionally, sampling this population provided even more information regarding the overall recruitment patterns of Lake Mead Razorback Sucker, which has helped and will continue to help in identifying the conditions that are conducive to these unique recruitment events.

Furthermore, information regarding the impact, scale, and magnitude of reservoir-level and habitat changes in relation to Razorback Sucker spawning were learned by investigating the CRI. As a result of fluctuating reservoir levels, Razorback Sucker spawning habitats and locations have changed. Habitat in the CRI has changed during the past decade at a larger spatial scale than at some of the other spawning areas throughout the reservoir (e.g., Las Vegas Bay, Echo Bay, Virgin River/Muddy River inflow area). For example, reservoir elevation dropped from approximately 365 m in 2001 to 317.9 m above mean sea level (amsl) in 2022. With that decline in elevation, the reservoir receded from the confined canyon reach of the LGC to the more-open area of the CRI basin, thereby exposing shallow cobble/gravel shoals and sand bars. This report further describes the declining lake and impacts to Razorback Sucker.

Currently, the lentic portion of Lake Mead begins at Sandy Point (Figure 1.1). Above that interface, several kilometers of once-lentic habitats are now riverine and essentially part of the Colorado River proper. This provided a unique opportunity to evaluate Razorback Sucker use of an area that has been drastically modified and remained dynamic since the river was impounded. Monitoring efforts in the CRI may also provide insight into what can and should be expected in terms of future spawning activity, particularly at the Virgin River/Muddy River inflow area and other known spawning locations within the reservoir—if reservoir levels continue to decline.

Mainstem dams along the Colorado River corridor are recognized as one of the reasons for the failed reproductive success of the Colorado River's big-river fishes (Holden 1979; Minckley et al. 1986). These structures impede migration of adults to spawning grounds and alter or eliminate the historic hydrologic cycle, in which peak discharges were common in spring during snowmelt and again in summer during monsoonal flooding. Hypolimnetic releases from dams drastically alter river temperatures, turbidity, and food bases (Mueller and Marsh 2002; Gloss et al. 2005). Management of mainstem dams to mimic historical flow conditions has been used to maintain cues for activities such as spawning and migration of native fishes, create and maintain nursery habitat for larval fishes, and suppress nonnative fish populations (Nesler et al. 1988; Bestgen and Williams 1994; Poff et al. 1998; Bestgen et al. 2011; LaGory et al. 2012). Natural flow regimes promote downstream displacement or drifting behavior of larval fishes and exploitation of premium feeding and rearing areas (Muth and Schmulbach 1984; Pavlov 1994). In many western river systems, higher spring and early summer flows increase sediment transport and turbidity, which reduce the predation of larvae (Johnson and Hines 1999). Sediment transport during high spring flows also scours substrates, providing critical spawning habitat for native catostomids (Osmundson et al. 2002). These natural river system attributes are largely absent in the Grand Canyon section of the Colorado River. Glen Canyon Dam is operated to produce hydropower, where releases are made in direct accordance with energy demands. The historical hydrologic cycle has been replaced with a daily fluctuation of water, which may have an impact on the survival of the early life-stages of the Colorado River's native fish and fauna in the Grand Canyon.

The life history of the Razorback Sucker is closely linked to the dynamic conditions of the Colorado River system, especially streamflow and channel geomorphology, which differ by river region and have been further modified by human intervention (Bestgen 1990; Muth et al. 2000; USFWS 2002). In the Green River and upper Colorado River regions, where some aspects of natural streamflow remain in undammed reaches, adult Razorback Sucker overwinter in deep pools and migrate to canyons to spawn over clean cobble bars during spring runoff. Spawning occurs in May through June, and the eggs incubate 6–7 days in the spaces between cobble/gravel substrate(s) (Muth et al. 1998). The larvae emerge and are transported downstream, where they become entrained in floodplains, which are inundated during spring runoff and reconnect to the main river channel. These floodplains are rich, productive nursery habitats where the young feed on plankton, insects, crustaceans, and detritus (Muth et al. 1998).

In reservoirs of the lower Colorado River basin, spawning occurs in March and April, and adults congregate to spawn on shallow gravel shorelines where emerging young find food and shelter from predators in complex, rocky shorelines and vegetation (Albrecht et al. 2008a; Kegerries et al. 2009). The number of fish predators in these reservoirs are relatively high, and in some locations, larvae are captured and raised in hatcheries and isolated ponds for release back into the reservoir after they have grown to larger size (Marsh et al. 2003, 2005, 2015; Albrecht et al. 2020). Post-larval Razorback Suckers feed on small invertebrates, so the timing and chronology of zooplankton development in nursery habitats may be vital to the survival of fish in early life-stages (Modde et al. 1996). Abiotic factors, such as water temperature and discharge, act as cues for adult spawning, but they also affect available food supplies for survival and growth rates of their offspring (Miller et al. 1988; Bestgen 2008).

There is little information available regarding the spawning activities of Razorback Sucker in the Grand Canyon reach of the Colorado River in Arizona. From 1944 through 1990, 10 adult Razorback Suckers were documented in Grand Canyon from Lees Ferry (river mile [RM] 0) downstream to Shinumo Creek (RM 109) (Minckley and Carothers 1979; McCall 1980; Carothers and Minckley 1981; Bookstein et al. 1985; Maddux et al. 1987; Valdez and Carothers 1998). Razorback Suckers were detected in the Colorado River in 1990 at the confluence of the Little Colorado River, but the species was thought to be functionally extirpated in Grand Canyon because there was no evidence of reproduction (Clarkson and Childs 2000). Adult Razorback Suckers were not captured or observed in this reach during fisheries investigations in 1992 or 1994, or from 2004 to 2006 (Valdez 1994; Valdez et al. 1995; Ackerman et al. 2006; Ackerman 2007; Rogers et al. 2007). However, one larva collected at Havasu Creek (RM 157) in October 1998 (Douglas and Douglas 2000) was later determined to be a Razorback Sucker. More recently, two adult Razorback Suckers were captured in 2012 and 2013 below Spencer Creek (Bunch et al. 2012; Rogowski and Wolters 2014; Kegerries et al. 2017b), renewing questions about Razorback Sucker habitat use in this section of river.

Research concerning early life history of Razorback Sucker within Lake Mead and the LGC was conducted from 2014 through 2022, and may help determine the current extent and future feasibility of upstream expansion of Razorback Sucker into Grand Canyon. The effects of daily river fluctuations, which are controlled by the operation of Glen Canyon Dam, and the cooler water temperatures from its hypolimnetic releases, are ameliorated in the lower portions of Grand Canyon. Future decreases in Lake Powell elevation and a warming climate may also contribute to more suitable habitats for listed and native fishes and some nonnative species in Grand Canyon.

The goal of the initial project was to determine the presence or absence of a Razorback Sucker population within the CRI. This goal was met by accomplishing the following objectives in 2010 through 2013:

- using sonic-tagged Razorback Suckers to locate and capture wild Razorback Suckers of various life-stages and track movement patterns of any existing population;
- marking captured juvenile and adult Razorback Suckers for individual identification using passive integrated transponder (PIT) tags;
- using a combination of sonic-telemetry data, larval Razorback Sucker capture-location information, and juvenile/adult Razorback Sucker netting data to determine habitat use of this unique population; and
- using nonlethal aging techniques to characterize the age structure and potential recruitment patterns associated with a Razorback Sucker population in the CRI.

Given the findings of wild Razorback Sucker at the CRI in 2010, the study objectives remained the same for 2011 and 2012, but with twice the field effort compared to 2010. This increased effort was meant to (1) capitalize on the sampling opportunity presented by recent Razorback Sucker recruitment, (2) cover more area, and (3) increase the likelihood of capturing more individuals. With this increased effort, more resources were expended in the Colorado River proper trying to understand the relationship between the riverine environment and lentic habitat utilization of Razorback Sucker during the spawning season.

In 2014 at the CRI, all sampling efforts were confined to January–May, and these efforts were similar to the intensive field efforts conducted during the original 2010 study year. As such, field work in 2014–2022 resembled more of a monitoring-type effort.

Based on observations of sonic-tagged Razorback Sucker utilizing portions of the LGC (Kegerries and Albrecht 2013a, 2013b), Reclamation supported Razorback Sucker investigations within the riverine portions of the LGC, as well as the CRI, in a more holistic and comprehensive manner than had been conducted to date. The overall goal of this effort was to quantify the fish community and reproductive success, with a focus on documenting the presence or absence of wild Razorback Sucker within the understudied Grand Canyon area, while continuing to monitor the Lake Mead CRI population by completing the following general tasks:

- conducting larval and small-bodied fish studies to quantitatively assess annual fish reproduction, spawning, and nursery areas in Grand Canyon portions of the Colorado River;
- determining whether wild Razorback Suckers are present in the study area and whether they use habitat in the Grand Canyon; and
- determining habitat use, relative spawning and reproductive efforts, and trends in population abundance and demography of Razorback Suckers in the CRI and Grand Canyon, as appropriate.

To accomplish these goals, BIO-WEST teamed with American Southwestern Ichthyological Researchers, LLC, (ASIR) to provide expertise specific to the larval sampling, as well as personnel from Reclamation, NPS, USFWS, AZGFD, and NDOW for support, expertise and logistics. In addition, Dr. Rich Valdez and Dr. Paul Holden were added as team members to provide historical context, species expertise, and peer review, when needed. This cooperative approach was paramount in providing the means to assess Razorback Sucker use of the LGC and the CRI efficiently and effectively. In summary, we found that various life-stages of Razorback Suckers were indeed utilizing both the CRI and the LGC (Albrecht et al. 2014a; Kegerries et al. 2015a, 2016a, 2017a, 2017b). All goals of the original study were accomplished and are reported by Kegerries et al. (2019, 2020a) and Rogers et al. (2021a). Subsequently, given the successes of the project, and based on findings and review from a science panel, it was recommended that the study continue into the foreseeable future (Reclamation 2017), and in 2022 the study was continued in both Lake Mead and Grand Canyon.

This report contains information from 2022, the 9th year of this comprehensive study of the Lake Mead CRI and the LGC. An effort to place findings into historical context, including comprehensive analysis of data collected since 2014, is included as applicable and appropriate. More specifically, information stemming from sampling in the CRI is presented as Chapter 1, while Chapter 2 covers sampling conducted in Grand Canyon. Because of the interconnectedness between the reservoir and river, Chapter 3 provides telemetry findings in a holistic and seamless manner. While this report presents interesting and new information pertaining to the status of Razorback Sucker in Grand Canyon and CRI, the true value of this multiyear study will be realized as the study progresses.

CHAPTER 1: RAZORBACK SUCKER MONITORING AT THE COLORADO RIVER INFLOW AREA OF LAKE MEAD (CRI)

INTRODUCTION

This chapter presents findings from 2022, the 13th year of study within the Colorado River Inflow Area (CRI), and the 9th year under the current study objectives. The results presented are based on trammel-netting and larval-fish sampling within the reservoir and opportunistic sampling within the Colorado River proper. Following Kegerries and Albrecht (2013b) and subsequent reports, data for the CRI portions of this project are reported from July 1, 2021, through June 30, 2022. The period of reporting is referred to as the 2022 study year.

In addition to this study at the CRI, annual, long-term monitoring (LTM) of Lake Mead Razorback Sucker *Xyrauchen texanus* occurs at Las Vegas Bay, Echo Bay, and the Virgin River/Muddy River inflow area, and the findings from those locations lend critical additional insight into this wild, recruiting population of Razorback Sucker (Rogers et al. 2022). Research on the juvenile life-stage of Razorback Sucker was also conducted during 2013–2016 within Lake Mead in the same general areas as the LTM efforts, with the hope of better understanding this early life-stage and the nearly consistent level of natural recruitment observed in Lake Mead (Albrecht et al. 2013a, 2014b; Shattuck and Albrecht 2014; Kegerries et al. 2015b, 2016a). Current and future study efforts at the CRI and Grand Canyon should provide a more-comprehensive and better-informed understanding of this naturally recruiting population of Razorback Suckers. While the information provided in this report could be particularly important for those managing Lake Mead and Grand Canyon, it may also be insightful for all managers of this species basin-wide.

STUDY AREA

The 2022 CRI study activities occurred within Gregg Basin of Lake Mead and the Colorado River upstream to Pearce Ferry Rapid in the LGC near river mile (RM) 280.0 (Figure 1.1).

Definitions for various portions of the CRI in which the study was conducted are referred to using the following terms:

- *Lake Mead* proper begins where the flooded portion of the river channel widens and velocity is reduced.
- The *Colorado River* proper is simply the flowing river. Depending on conditions, this area may or may not be accessible by large boats.
- The *interface* is the area where the river proper meets the reservoir proper. This area may or may not have flow, is typically turbid, and is transitory and highly dynamic.

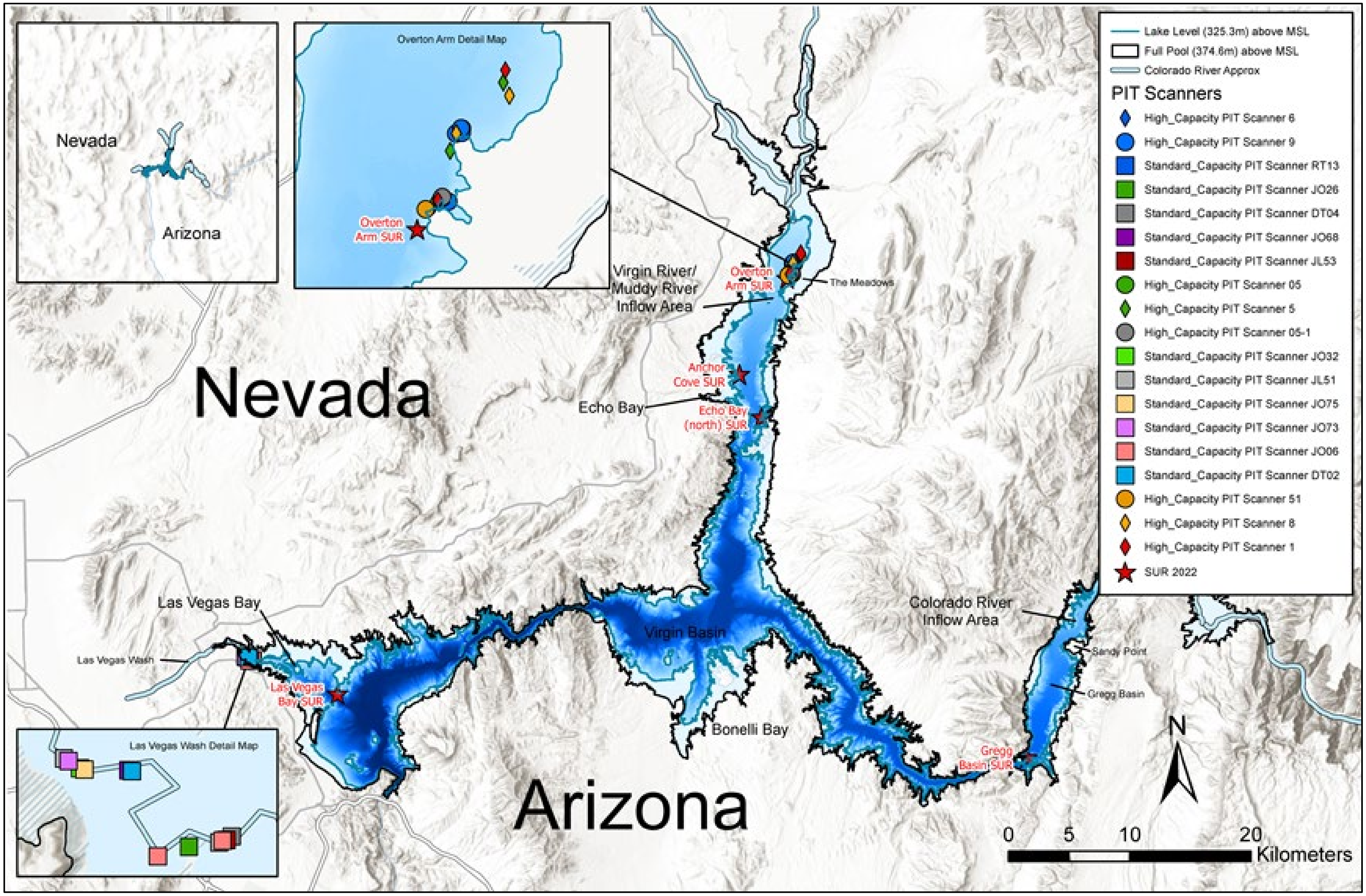

Figure 1.1. General study area and submersible ultrasonic receiver (SUR) location at the Colorado River Inflow Area (CRI) and Bonelli Bay of Lake Mead.

METHODS

Reservoir Elevation

Month-end and projected reservoir elevations (February 1, 1935–June 30, 2022) were reported in meters above mean sea level (amsl) and obtained from Reclamation's Lower Colorado Regional Office website (Reclamation 2022).

Adult Studies

Trammel Netting

Adult fish were captured using trammel nets measuring 91.4 m long by 1.8 m deep, with internal panels of 2.54-cm mesh, and external panels of 30.48-cm mesh. Nets were generally set with one end near shore, with the net stretched out into deeper habitats. Most trammel nets were set in the late afternoon just before sundown and pulled the next morning shortly after sunrise. Netting locations were selected based on the locations of sonic-tagged Razorback Sucker individuals, the presence of concentrated larval fish, and previous knowledge of Razorback Sucker capture locations.

Fish were taken from nets and held in large, 94.6-L coolers filled with reservoir water. Razorback Suckers, Flannelmouth Suckers *Catostomus latipinnis*, and Razorback Sucker × Flannelmouth Sucker hybrids (hybrid suckers) were held in separate live wells. Typically, all but the first five nonnative species were enumerated and returned to the reservoir, while the first five of each nonnative species were identified, measured for total length (TL) and fork length (FL), weighed (g), and released at their capture location. Suspected hybrid suckers were identified in the field following descriptions contained in Hubbs and Miller (1953), primarily using dorsal fin-ray and lateral-line scale counts. Razorback Suckers, Flannelmouth Suckers, and hybrid suckers were scanned for passive integrated transponder (PIT) tags. If the individual was not a recaptured fish, it was PIT-tagged, measured (including TL, FL, and standard length [SL]), weighed, and released at the point of capture. Native sucker species that were selected for age determination were anesthetized with tricaine methanesulfonate (MS-222) and placed dorsal-side down on a padded surgical cradle for support while a 0.5-cm segment of the second pectoral fin ray was surgically removed (see Age Determination section, below). Because of the presence of hybrid suckers at the CRI, as well as other genetic monitoring of Lake Mead Razorback Suckers, genetic material was also removed from wild Razorback Suckers and suspected hybrid suckers and retained. This consisted of obtaining a small piece (0.5 cm) of tissue from the caudal fin, preserving it in 95% ethanol (EtOH), and providing samples to the Lower Colorado River Multi-Species Conservation Program (LCR MSCP) for further laboratory analysis.

Length and Growth

Razorback Sucker annual growth was calculated from recaptured individuals in trammel-netting collections. Recaptured individuals were measured only once during the spawning season to avoid handling stress, and they were used only for annual growth analysis if 1 year had passed between capture occasions. Recently stocked individuals were excluded from the dataset and analyses to account for discrepancies in environmental conditions (e.g., hatchery-reared or pond-reared individuals recently stocked into a wild environment) and to allow for the yearly cycles of gonadal and somatic growth. Additionally, negative growth values were excluded, considered the likely result of field-measurement errors. Annual growth for Razorback Sucker was calculated for each individual using the difference in TL (mm) between capture periods. These data should not be used to assume typical average growth; rather they should be used in conjunction with growth reported during past field efforts on Lake Mead for a more complete understanding of Lake Mead Razorback Sucker growth. Furthermore, Mohn et al. (2015) showed that growth rates did not significantly vary between wild and stocked Razorback Sucker in Lake Mead, so the mean growth rates were calculated by combining data from wild and stocked fish. Length and growth rates were also assessed for the study period from 2010 to 2022. The lengths of all wild Razorback Sucker captured via trammel netting to date and growth rates for recaptured fish are reported.

Remote Passive Integrated Transponder (PIT) Scanning

A 36-inch, round, fully-submersible PIT-scanning antenna was deployed in numerous locations and for varying time periods throughout the CRI from February through April 2022 before the unit was unfortunately stolen. No data were retrieved from the unit before it was stolen.

Larval Sampling

The primary larval sampling method was developed by Burke (1995) and other researchers on Lake Mohave. The procedure uses the positive phototactic response of larval Razorback Suckers to capture them. After sundown, two 12-volt underwater fishing lights were connected to a battery, placed over each side of the boat, and submerged in 10–25 cm of water. Two field personnel equipped with long-handled aquarium dip-nets were stationed to observe the area around the lights. Larval Razorback Suckers that swam into the lighted area were dip-netted out of the water, enumerated, and placed into a holding bucket. Larvae were retained and preserved in 95% EtOH for species verification and genetic analysis. The procedure was repeated for 15 minutes at 2–6 sampling sites on each night attempted.

Because of the vast sampling area, turbidity, flowing water, and the potential for larval drift at the CRI, larval light-traps were also deployed as a method to capitalize on efforts to collect catostomid larvae. The larval light-traps were deployed by tying a lead line to vegetation near shore in suspected spawning areas or in habitats with little-to-no current velocity. A chemical light-stick was inserted into the trap and allowed to float freely. The light-traps were set out overnight and collected the following day. The catch bowls were checked for larval fish and all larvae were retained in 95% EtOH for species verification and genetic analysis.

Because other native sucker species are present at the CRI, preserved larval suckers were retained for laboratory microscopic verification using a key to catostomid fish larvae developed by Snyder and Muth (2004). Only a subset of larvae was collected for verification and genetic analysis. Some preserved specimens were sent to American Southwestern Ichthyological Researchers, LLC, (ASIR) for further identification.

Catch-Per-Unit Effort Data Analysis

In order to be consistent with past annual reports, catch-per-unit effort (CPUE) for adult Razorback Sucker captures via trammel netting (combined 91.4 and 45.7 m nets) was calculated as the mean total number of fish captured per net-hour fished regardless of how many times an individual was captured in a given year. Additionally, CPUE effort for larval Razorback Sucker captures via active light sampling was calculated as the mean number of fish captured per minute. As non-normality and unequal variances are common with datasets related to low-density fish species, a quartile-quartile (Q-Q) plot was examined, and it showed deviation from linearity, indicating the data were not normally distributed (Thode 2002). Data were further tested for normality using a Shapiro-Wilk test. Given that both the Q-Q plots and the results from the Shapiro-Wilk test showed a non-normal distribution of data ($P<0.05$), the data were transformed [Ln(CPUE+1)]. Hereafter, all mentions of CPUE in the context of adult trammel netting and larval sampling represent captures that are log-transformed data. All statistical analyses were performed using the program Statistix 8.1. An analysis of variance (ANOVA), which is considered robust to violations of the normality assumption (Lumley et al. 2002), was used to test for yearly differences in mean CPUE for each sampling site following recommendations of Hubert and Fabrizio (2007). The ANOVA was limited to test for annual differences in mean CPUE from 2015 to 2022 for each individual sampling site as well as amongst the long-term monitoring study areas. When an ANOVA detected significant differences of less than or equal to an alpha value of 0.05, a Tukey's Honestly Significant Difference (HSD) test was used to examine all possible pairwise comparisons.

Spawning-Site Identification

Multiple methods are often needed to identify primary annual Razorback Sucker spawning sites. The basic, most effective spawning site identification procedure has been to track sonic-tagged fish and identify their most frequented areas (see Chapter 3). Typically, once a location is identified as frequently used by sonic-tagged fish, particularly during crepuscular hours, trammel nets are set in an effort to capture Razorback Suckers. Captured fish are then evaluated for signs of ripeness, which are indicative of spawning. After the initial identification of a possible spawning site through habitat use by sonic-tagged Razorback Suckers and other trammel-net captures, larval sampling is conducted to validate whether successful spawning occurred. Examples of the effectiveness of these techniques are evident in the descriptions provided by Albrecht and Holden (2005) regarding the documentation of a new spawning aggregation near Fish Island in the Overton Arm of Lake Mead. This same general approach has also been used effectively at the CRI since 2010 (e.g., Kegerries et al. 2017a).

Age Determination

A nonlethal technique using fin-ray sections to age captured wild Lake Mead Razorback Suckers was developed in 1999 (Holden et al. 2000a). As in past Lake Mead Razorback Sucker studies, the 2022 CRI spawning season efforts involved an emphasis on collecting fin-ray sections from unaged Razorback Suckers, suspected hybrids, and occasionally Flannelmouth Suckers for aging purposes using this technique.

During the 2022 spawning period, new fish captured via trammel nets were anesthetized and a single, approximately 5 mm-long section of the second left pectoral fin ray was surgically removed using custom-made bone snips originally developed by BIO-WEST. This surgical tool consists of a matched pair of finely sharpened chisels welded to a set of wire-stripping pliers. The connecting membrane between rays was cut using a scalpel, and the section was placed in a labeled envelope for drying. All surgical equipment was cold-sterilized with a 10% povidone-iodine and 70% isopropyl alcohol mixture before use, and subsequent wounds were packed with antibiotic ointment to minimize postsurgical bacterial infections and promote rapid healing. All native suckers undergoing fin-ray extraction techniques were immediately placed in a recovery bath of fresh reservoir water containing slime-coat protectant and NaCl, allowed to recover, and released as soon as they regained equilibrium and appeared recovered from the anesthesia. Vigilant monitoring was conducted during all phases of the procedure.

In the laboratory, fin-ray segments were embedded in thermoplastic epoxy resin and heat-cured. This technique allowed the fin rays to be perpendicularly sectioned using a Buhler isomet low-speed saw. Resultant sections were then mounted on microscope slides, sanded, polished, and examined under a stereo-zoom microscope. Three readers independently aged each sectioned fin ray. Sections were reviewed by all readers and in instances in which the assigned age was not agreed upon and, all three readers reviewed the ray and collectively assigned an age to the individual.

Population and Annual Apparent Survival Estimation

Because stocked and wild Razorback Suckers have been observed moving between all study locations within Lake Mead (i.e., Mohn et al. 2016), the population was assessed at the reservoir-wide scale. As such, a population and annual apparent survival estimate specific to the CRI is not included herein. Razorback Sucker capture and recapture data stemming from the CRI were included as part of the reservoir-wide population and annual survival estimates provided in Rogers et al. (2022).

Supplemental Efforts

Colorado River Proper

In addition to weekly research at the CRI, efforts in the lotic section of the Colorado River were conducted from below Pearce Ferry Rapid downstream to the CRI. These efforts were conducted opportunistically, depending on the weekly project goals, weather, and flow conditions, and field schedules. Sonic telemetry was conducted following the methods described in Chapter 3. Electrofishing (17-foot jet drive aluminum electrofishing boat with two 9-inch diameter steel anodes deployed off the bow and two steel cable cathodes towed off the stern of the boat, powered by an ETS MBS 1D-72A control box), was utilized to sample the small-bodied fish community. Native fishes were identified and measured (TL, FL, SL [mm]) and weighed (g), implanted with a PIT tag if they were untagged fish, then released at the point of capture. All nonnative species were measured (TL, FL [mm]), weighed (g), and then released at the point of capture.

Data specific to investigations of Pearce Ferry Rapid as a potential deterrent to upstream use of the Grand Canyon by Lake Mead fishes continued to be collect as a cooperative effort with AZGFD in 2022. As in past years, data were provided to AZGFD, who are responsible for reporting efforts during this portion of the overall project. Please see (Hedden et al. 2022) for additional details regarding Pearce Ferry Rapid sampling.

Bonelli Bay Investigations

At the request of the Lake Mead Workgroup, and in addition to weekly research at the CRI, additional efforts were opportunistically conducted in Bonelli Bay, within the Virgin Basin of Lake Mead, when weather permitted (Figure 1.1). BIO-WEST personnel worked collaboratively with NDOW personnel to sample at this location where sonic-tagged, larval, and adult Razorback Sucker have been documented (Shattuck et al. 2011; Albrecht et al. 2013a; NDOW 2018). All lake methods, as described above, were utilized in this location to better assess Razorback Sucker use of this understudied location within Lake Mead. Razorback Sucker capture data, as pertaining to population estimates, were included as described for the CRI in the reservoir-wide population and annual survival estimates produced by Rogers et al. (2022).

RESULTS

Reservoir Elevation

The elevation of Lake Mead has generally declined since 2000 (Figure 1.2). During the 2021–2022 sampling season, the reservoir elevation appeared relatively stable from July through February, with a peak elevation of 325.5 m amsl in August (Figure 1.2). Since February, the reservoir elevation has declined to its lowest level (317.9 m amsl) since Lake Mead began to fill in the 1930s, and the elevation is predicted to continue to decline (Figure 1.2) (Reclamation 2022). Early in the spawning season, biologists observed the littoral areas drying up relatively rapidly.

Adult Studies

Trammel Netting

During the 2022 field season, 46 nets were set for a total 574.6 net-hours, the majority of which occurred during February and March (Table 1.1). Netting was spread throughout Gregg's Basin in order to locate spawning adults; however, one adult Razorback Sucker was captured off the western shoreline across from South Point (Figure 1.3).

The single Razorback Sucker mentioned above was captured on March 15, 2022 (Table 1.2). At the time of capture, this fish was implanted with a sonic-tag (code 4556) and released at the point of capture. This individual was a recaptured wild male that was originally tagged on February 26, 2020, at the CRI.

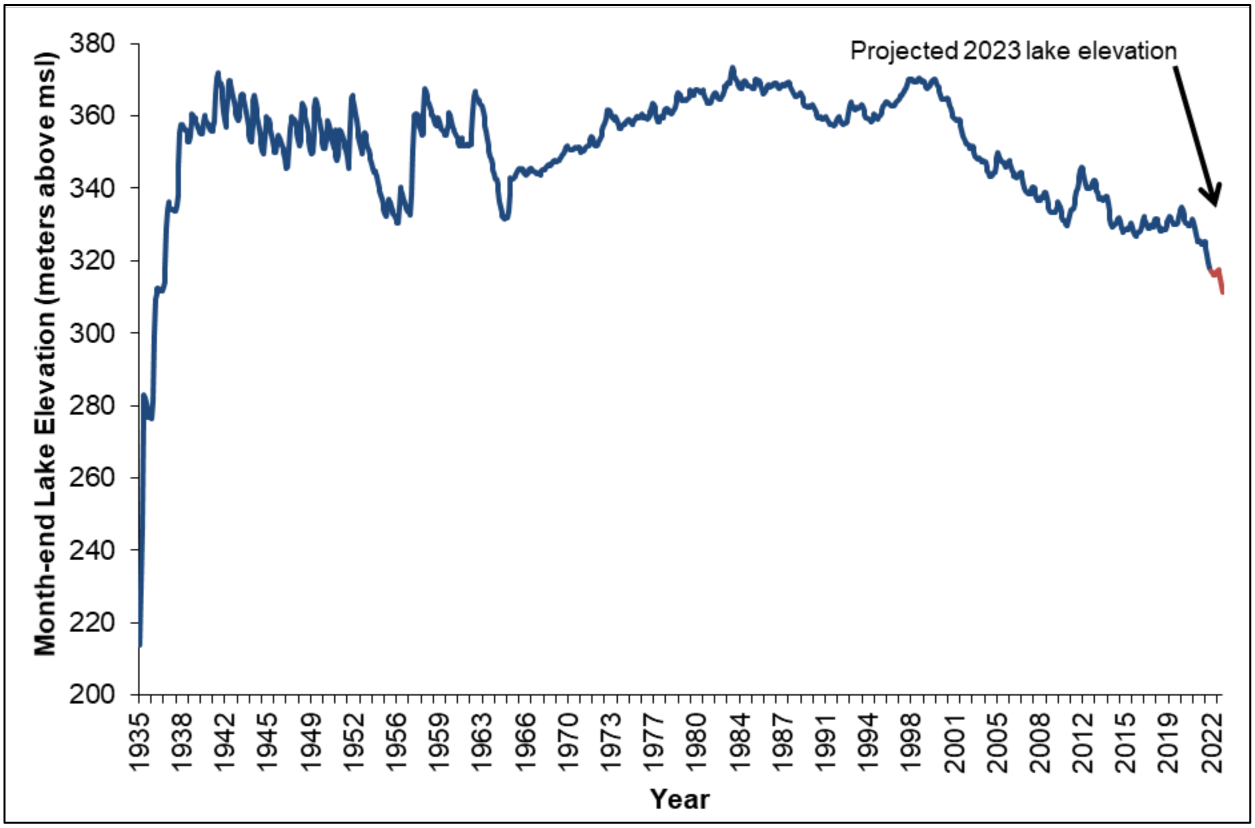

Figure 1.2. Lake Mead month-end elevations (Reclamation 2022) in meters above mean sea level from February 1935 to June 2022 with projected elevations in red. The inset graph depicts reservoir elevations during the study period, (July 2021 to June 2022).

Table 1.1. Trammel netting effort in the Colorado River Inflow Area of Lake Mead (CRI) during 2022, showing total nets set and net-hours by month.

MONTH	TOTAL NET SETS	TOTAL NET-HOURS
February	7	116.5
March	23	262.6
April	12	142.8
May	4	52.7
TOTAL	**46**	**574.6**

Table 1.2. Date, passive integrated transponder (PIT) tag number, size, and status information for Razorback Suckers and Razorback Sucker × Flannelmouth Sucker hybrids captured in the Colorado River Inflow Area of Lake Mead (CRI) during 2022 via trammel nets and electrofishing.

DATE	SPECIES[a]	PIT-TAG NUMBER	SONIC CODE	DATE[b] (ORIG.)	RECAPTURE (STATUS)	TL[c] (mm)	FL[d] (mm)	SL[e] (mm)	WT[f] (g)	SEX[g]	GEAR
3/15/2022	RZ	3dd.003c06f11a	4556	2/26/2020	YES (WILD)	563	520	481	2096	M	TRAMMEL

[a] Species: RZ=razorback sucker, [b] Date originally stocked or originally captured. [c] TL=total length. [d] FL=fork length. [e] SL=standard length. [f] WT=weight. [g] Sex: F=female, M=male, I=immature, U=Unknown.

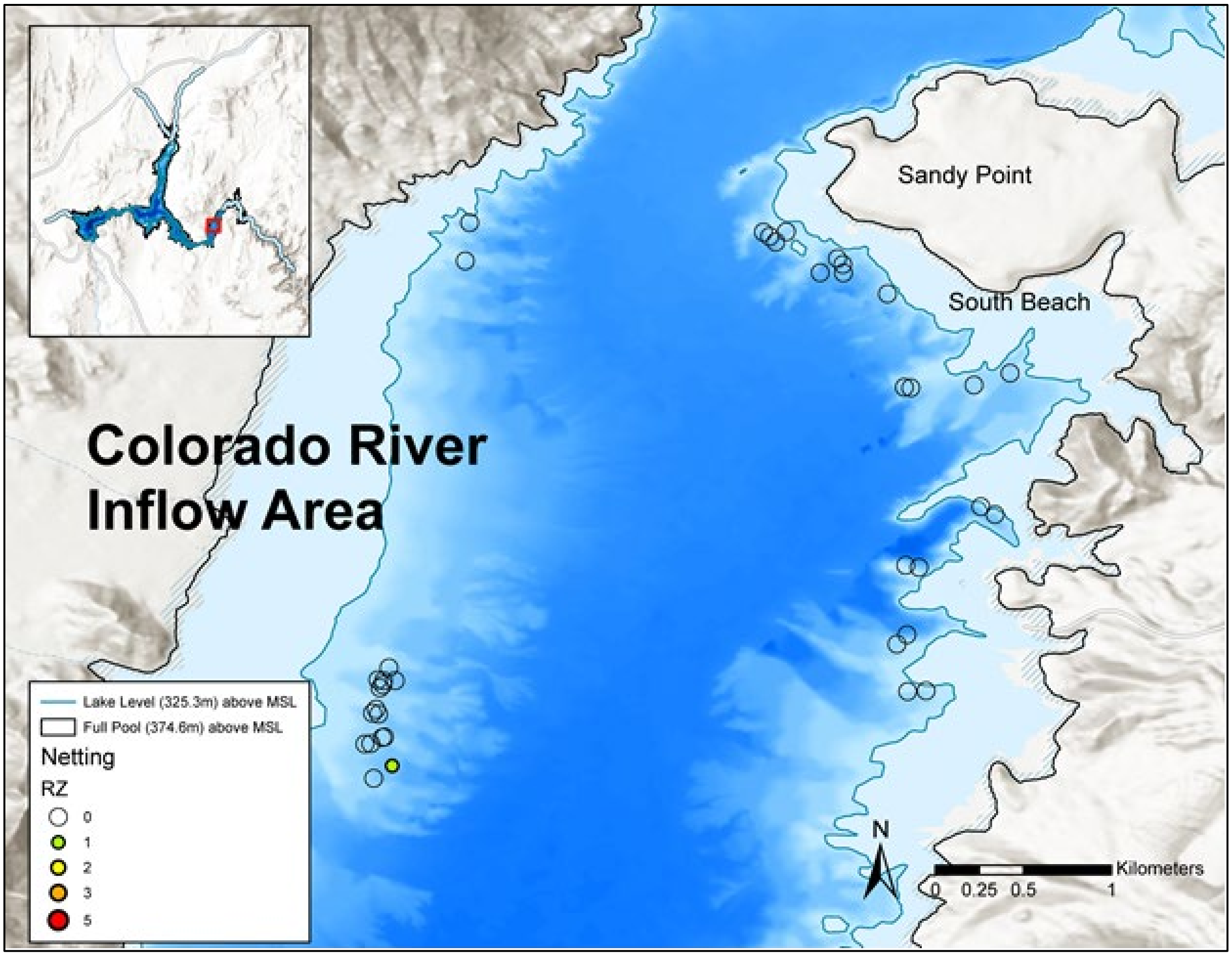

Figure 1.3. Trammel-netting locations and numbers of fishes captured in the Colorado River Inflow Area of Lake Mead (CRI), January–May 2022.

The Razorback Sucker catch rate at the CRI in 2022 was 0.001 fish per net-hour (Table 1.3 and Figure 1.4), the lowest catch rate recorded since the project's inception. A significant difference in mean annual catch rates was detected (ANOVA, $F_{12,1228}$=5.83, P<0.0001), and post-hoc analysis (Tukey's HSD) determined that 2022's catch rate was statistically lower compared to that of 2020 and 2021.

To date, a total of 1,443 Flannelmouth Suckers have been captured at the CRI. In 2022, 69 Flannelmouth Suckers were captured (Appendix A), resulting in a mean catch rate of 0.145 (SE±0.051) (Table 1.3). Please note that nine Flannelmouth Sucker were not measured or tagged due to handling stress. Many of these fish were either immature or their sex was not readily identifiable at the time of capture (Appendix A). One Flannelmouth Sucker was captured via electrofishing in 2022 (Appendix A). While no Bluehead Suckers *Catostomus discobolus* were captured at the CRI in 2022, four Bluehead Suckers have been captured at the CRI since 2010. Lastly, no hybrid suckers were captured in 2022 (Table 1.3).

Table 1.3. Number and catch rate of Razorback Suckers, Flannelmouth Suckers, and hybrid suckers captured from 2010 to 2022.

YEAR	NUMBER RAZORBACK SUCKER CAPTURED	RAZORBACK SUCKER CPUE[a] (±SE)	NUMBER FLANNELMOUTH SUCKER CAPTURED	FLANNELMOUTH SUCKER CPUE[a] (±SE)	NUMBER HYBRID SUCKER CAPTURED	HYBRID SUCKER CPUE[a] (±SE)
2010	3	0.009 (0.007)	51	0.113 (0.023)	3	0.007 (0.005)
2011	15	0.005 (0.002)	110	0.036 (0.004)	9	0.003 (0.001)
2012	33	0.011 (0.002)	191	0.060 (0.007)	1	0.000 (<0.001)
2013	4	0.004 (0.002)	271	0.208 (0.031)	2	0.002 (0.001)
2014	6	0.005 (0.002)	254	0.151 (0.021)	7	0.009 (0.005)
2015	17	0.010 (0.003)	129	0.081 (0.013)	3	0.001 (0.001)
2016	7	0.003 (0.001)	113	0.056 (0.007)	7	0.004 (0.002)
2017	12	0.007 (0.002)	68	0.041 (0.007)	18	0.014 (0.005)
2018	32	0.021 (0.005)	12	0.008 (0.003)	35	0.020 (0.004)
2019	12	0.010 (0.003)	76	0.066 (0.011)	16	0.014 (0.004)
2020	21	0.024 (0.007)	48	0.060 (0.011)	19	0.024 (0.007)
2021	31	0.040 (1.014)	51	0.053 (0.027)	5	0.008 (0.004)
2022	1	0.001 (0.001)	69	0.145 (0.051)	0	0

[a] Catch-per-unit effort (CPUE) expressed as mean ln(1+(number/net-hour)).

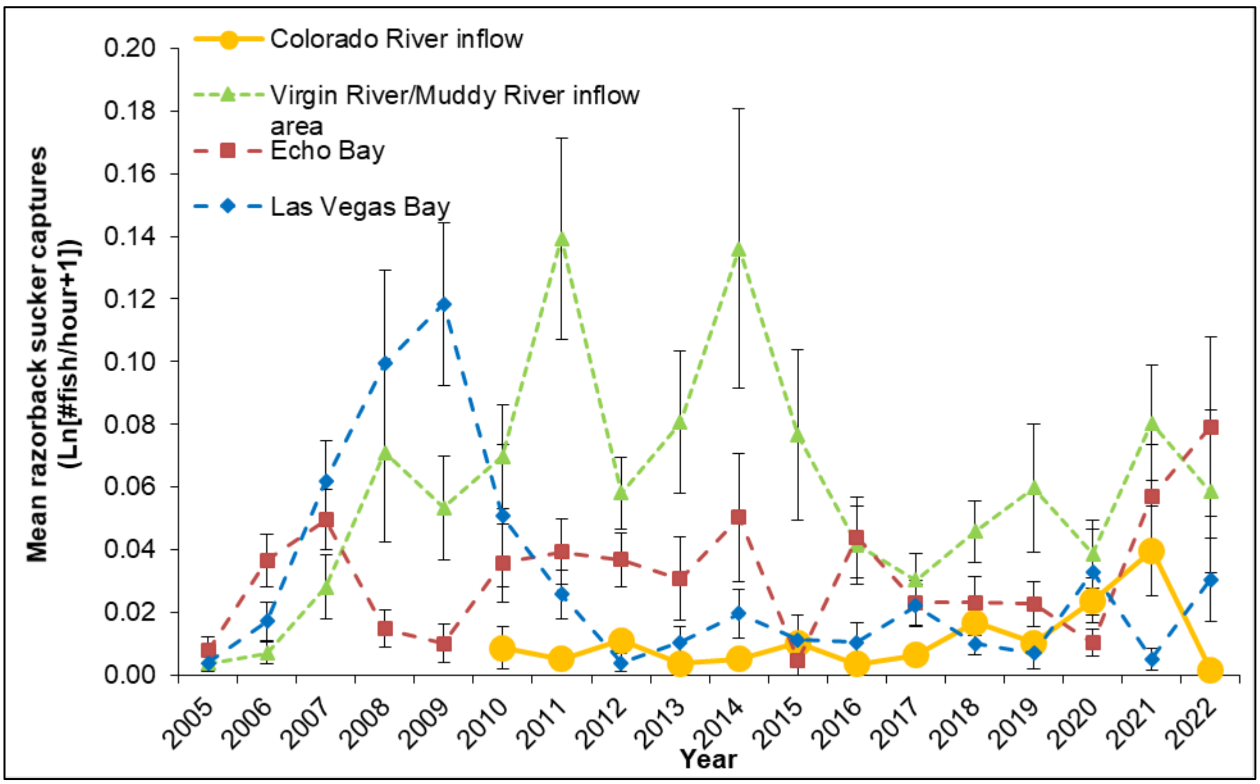

Figure 1.4. Trammel-netting catch-per-unit effort (CPUE) expressed as the mean ln(1+(#Razorback Sucker/net-hour)) (±SE))values from the Colorado River Inflow Area of Lake Mead (CRI) and long-term monitoring (LTM) sites throughout Lake Mead, 2005–2022.

Length and Growth Information

The Razorback Sucker captured in 2022 had a TL of 563 mm (Figure 1.5). The annual growth rate for this fish was 3.4 mm per year (Table 1.4). Flannelmouth Suckers captured in 2022 at the CRI ranged in size from 234 to 559 mm (TL) with a mean TL of 446.7 mm (SE±9.0) (Appendix A).

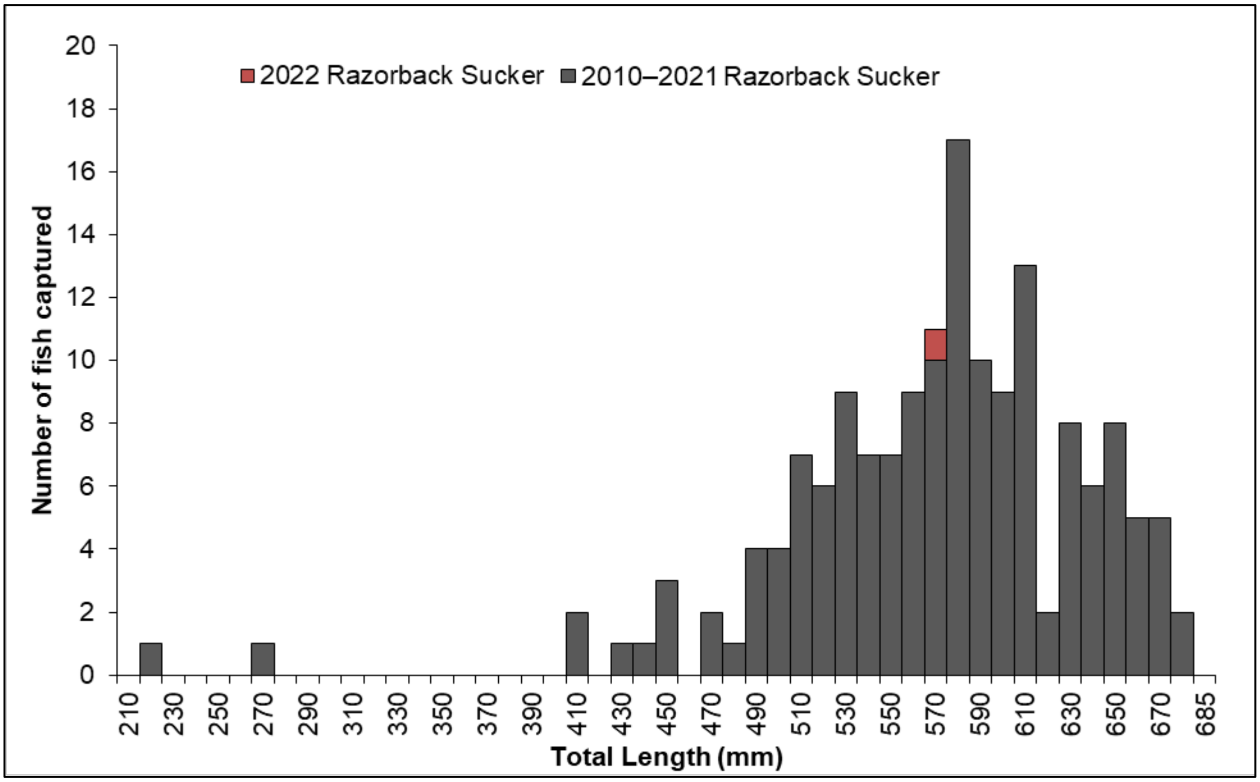

Figure 1.5. Length-frequency (mm total length) distributions for Razorback Suckers captured at the Colorado River Inflow Area of Lake Mead (CRI) in 2022 (red bars) and combined from 2010 to 2021 (gray bars). Data from trammel netting efforts only.

Table 1.4. Growth histories of applicable Razorback Sucker recaptured at the Colorado River Inflow Area of Lake Mead (CRI) in 2022.

PIT TAG NUMBER	ORIGINAL CAPTURE OR STOCK DATE[a]	TL (mm)	LAST DATE RE-CAPTURED	TL (mm)	TOTAL GROWTH (mm)	DAYS BETWEEN MEASUREMENTS	GROWTH/YEAR (mm/365 days)
Wild Fish							
3DD.003C06F11A	02/26/20	556	03/15/22	563	7	748	3.4

[a] The date a fish was stocked into Lake Mead, or the date a wild fish was originally captured.

Remote Passive Integrated Transponder (PIT) Scanning

The remote PIT-scanning unit was deployed from February to April throughout the CRI. It was downloaded periodically throughout the season; however, the unit contacted no PIT-tagged fish. As mentioned, it was then stolen before its data could be downloaded in April.

Larval Sampling

Sampling for Razorback Sucker larvae began on February 16, 2022, and continued through May 4, 2022. Larval fish were captured just south of Sandy Point at the mouth of the river inflow off the eastern shore (Figure 1.6). As such, much of the effort was focused in and around the river/reservoir interface.

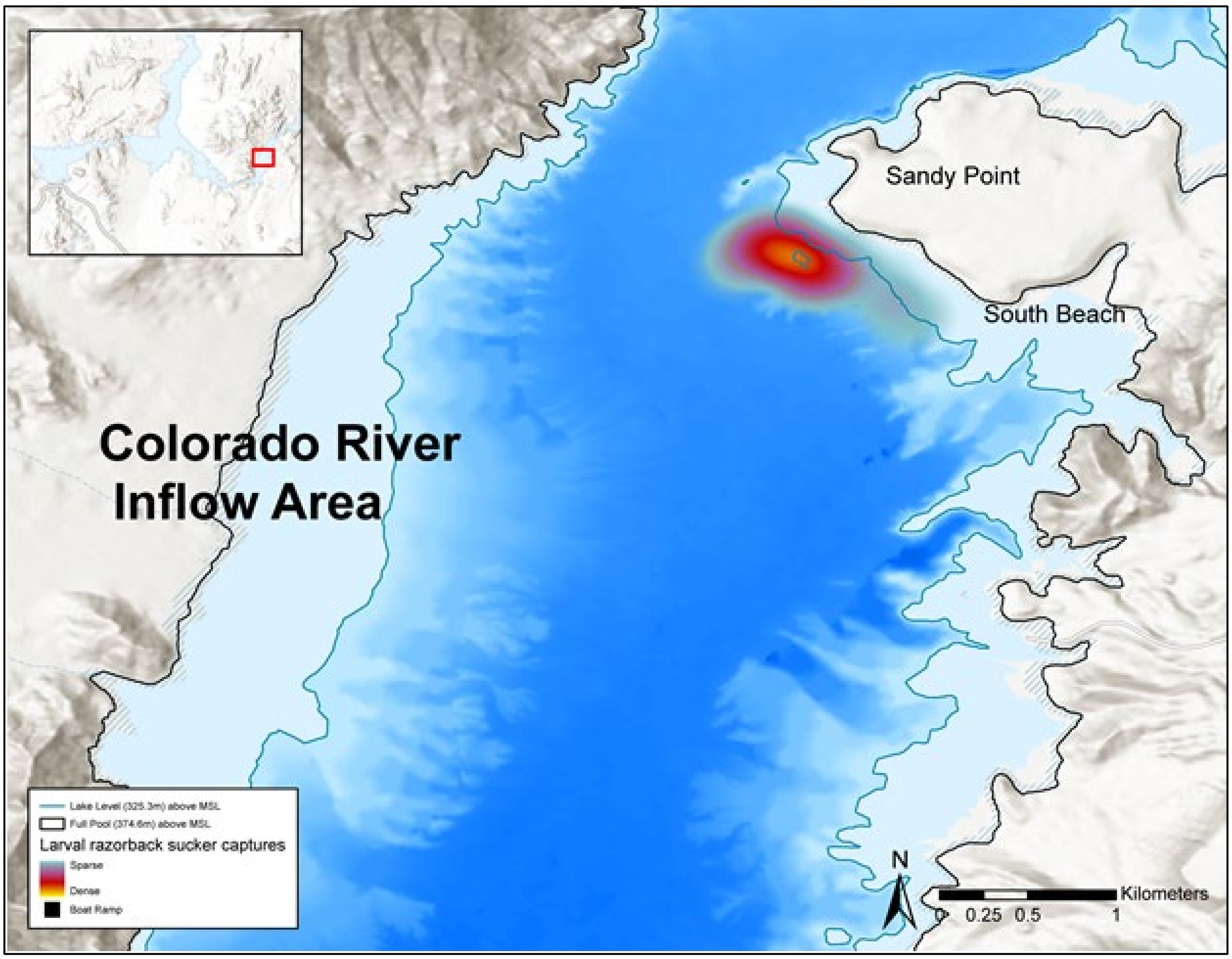

Figure 1.6. Larval Razorback Sucker sample and capture locations in the Colorado River Inflow Area of Lake Mead (CRI), 2022.

Active larval sampling in 2022 resulted in the capture of 36 Razorback Sucker larvae. Most were captured along a shoreline east of the river inflow (Figure 1.6). The first larvae were captured on April 12, 2022, (n=7) at a water temperature of 17.1°C. Larvae were captured through May 4, 2022, at water temperatures ranging from 18.6 to 21.3°C (Figure 1.6).

In 2022, the mean larval Razorback Sucker catch rate was 0.0628 (SE±0.0142), which falls within the historical context of the area; and appears higher than the CPUE at the Virgin River/Muddy River inflow area in 2022 (Figure 1.7). Significant differences in catch rates were found between sample years (ANOVA, $F_{12,1081}$=18.1, P<0.0001). Post-hoc pairwise comparisons confirmed that the mean CPUE in 2022 was lower than it was in 2020 and 2021 (Figure 1.7).

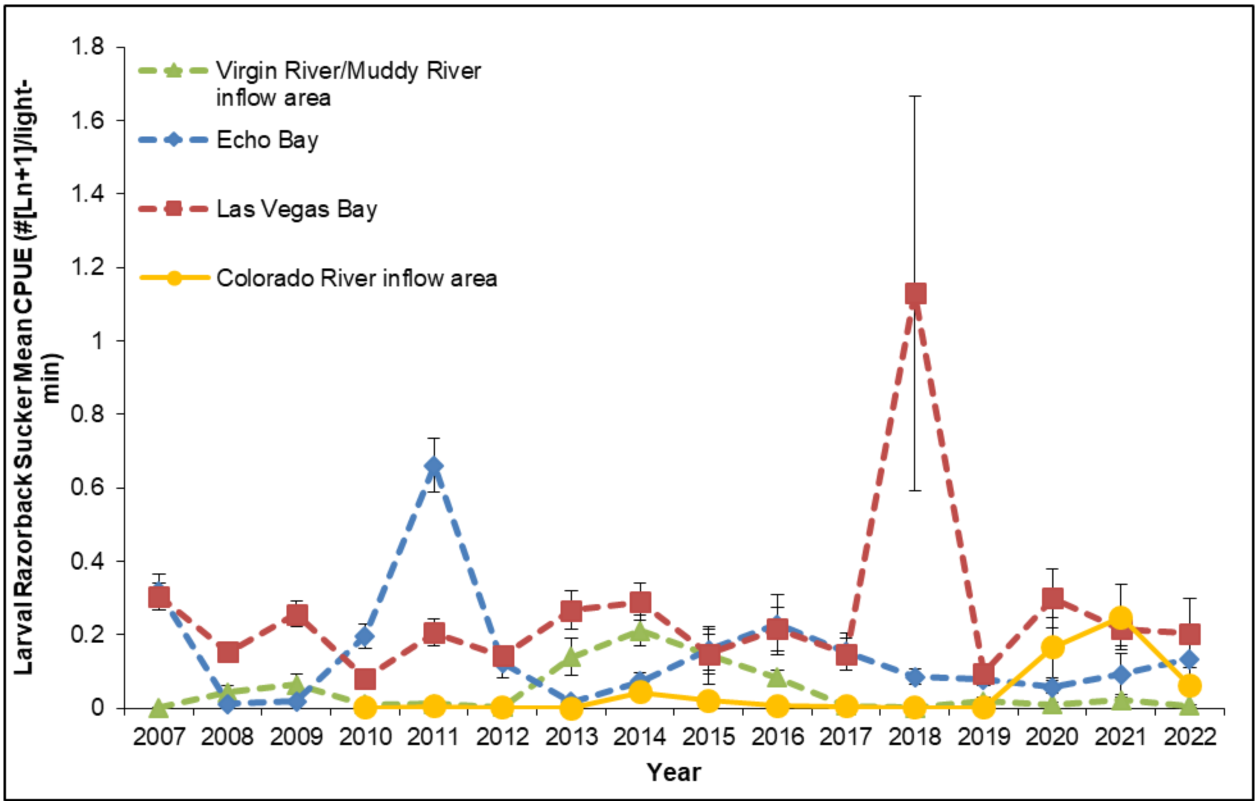

Figure 1.7. Larval Razorback Sucker mean catch-per-unit-effort (CPUE) (ln(1+(number larvae/light-minute sampled))) (±SE) comparisons by primary sampling location on Lake Mead for 2010–2022.

Lastly, to increase larval sampling efforts and cover more area for longer periods of time, 11 passive light traps were deployed in 2022 at the CRI. No larvae were captured during those efforts.

Spawning-Site Identification and Observations

The Razorback Sucker larvae collected at the CRI in 2022 were found off the south end of Sandy Point, east of the river inflow area (Figure 1.6). This area of the CRI is adjacent to the reservoir/river interface and is an area with relatively high turbidity, and it is protected from the direct flow of water from the river. The shoreline is a mix of bedrock shelf, cobbles, and finer sediment. The only adult was captured off the west shore approximately 2 km south of the river-inflow area. Successful spawning occurred at the CRI in 2022; however, pinpointing the location is made difficult by the lack of adult captures. This may suggest that spawning occurred in the flowing portions of the river that were not sampled with trammel nets. Researchers in Las Vegas Bay have observed similar circumstances, in which larvae are found in the eddy of the inflow but few adults (sonic-tagged and/or captured) were detected in the bay. Further research into the interaction of the river/reservoir interactions may lead to additional insights.

Razorback Sucker Aging

No Razorback Suckers were aged from the CRI during the 2022 spawning season. The one fish that was captured had been previously aged.

Razorback Suckers move between spawning locations in Lake Mead and between the reservoir and main stem river. Figure 1.8 presents cumulative Lake Mead Razorback Sucker aging data from all sampling locations (see Rogers et al. 2022). To date, all aged Razorback Suckers were spawned from 1972 to 2020 throughout Lake Mead, with the exception of one fish, which was spawned around 1966 (Figure 1.8) (Appendix B). At the CRI, the most-recent year-class represented in the dataset was 2015. When combined with the LTM data, aged fish captured in the CRI coincide with strong cohorts observed in other areas of the reservoir (Figure 1.8).

Supplemental Efforts

Colorado River Proper (below Pearce Ferry Rapid to Colorado River Inflow Area of Lake Mead [CRI])

Supplemental small-bodied sampling efforts was conducted with electrofishing in the Colorado River below Pearce Ferry Rapid downstream to the CRI from March to April 2022 and resulted in the capture of one Flannelmouth Sucker and several nonnative fish species (Table 1.5). The majority of nonnative fish captured consisted of Gizzard Shad (n=668).

Colorado River Proper (Iceberg Canyon to Colorado River Inflow Area of Lake Mead [CRI])

As the reservoir elevation declined from February 2022 through August 2022, a new rapid developed at the mouth of Iceberg Canyon (Figure 1.1, Figures 1.9a and b). In February this feature was navigable by field personnel when the reservoir elevation was 325.2 m amsl (Figure 1.2). However, it was noted by the authors that this feature was developing, and that it would likely become unnavigable in the near term if the reservoir elevation continued to decline. Throughout much of the winter, the delta was unnavigable, preventing field crews from observing the development of the rapid (Figure 1.9c), and by July 2022 (when the reservoir elevation was 317.9 m amsl) the rapid had indeed become unnavigable (Figure 1.2). This feature was created when the river was confined by bedrock on river left and river right with a bedrock substrate. On August 4, 2022, a reconnaissance trip to determine the size of the rapid was conducted; the feature measured approximately 10 m high, approximately 15 m wide, and remained unnavigable (Figures 1.9a and b).

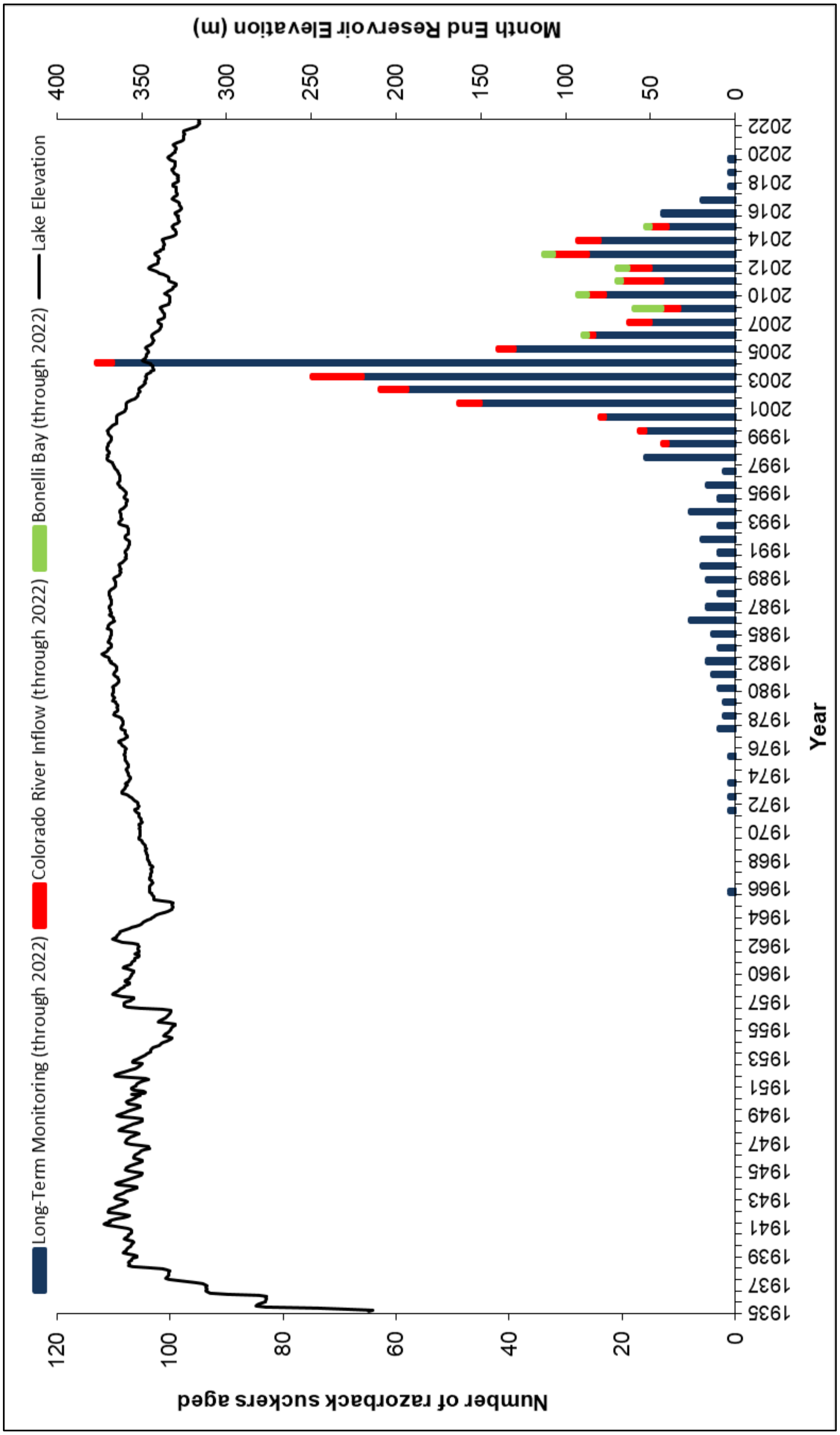

Figure 1.8. Lake Mead hydrograph from January 1935 to June 2022, with the number of aged Razorback Suckers spawned each year through 2020. Red bars denote the Razorback Suckers aged from the Colorado River Inflow Area of Lake Mead (CRI), green bars denote the Razorback Suckers aged from Bonelli Bay, while blue bars denote Razorback Suckers aged from the long-term monitoring (LTM) study.

Table 1.5. Small-bodied and larval fish supplemental sampling between Pearce Ferry Rapid and the Colorado River Inflow Area of Lake Mead (CRI) from March to May 2022.

DATE	GEAR TYPE	NUMBER OF SAMPLES	RAZORBACK SUCKER	FLANNELMOUTH SUCKER	HYBRID SUCKER	BLUEHEAD SUCKER	HUMPBACK CHUB	SPECKLED DACE	AGGREGATE NONNATIVE CATCH
3/8/2022	Electrofishing	1	0	1	0	0	0	0	888
4/27/2022	Electrofishing	1	0	0	0	0	0	0	2
TOTAL FISH			0	1	0	0	0	0	890

Figure 1.9a. Rapid at the mouth of Iceberg Canyon near Devils Cove, on August 4, 2022, at the Colorado River Inflow Area (CRI).

Figure 1.9b. Rapid at the mouth of Iceberg Canyon near Devils Cove, on August 4, 2022, at the Colorado River Inflow Area (CRI).

Figure 1.9c. Delta at the Colorado River Inflow Area (CRI), on August 4, 2022.

Bonelli Bay Investigations

Collaborative sampling between NDOW and BIO-WEST (214.8 total net hours) was conducted within Bonelli Bay, resulting in the capture of one new wild male Razorback Suckers with a TL of 589 mm (Table 1.6, Figure 1.10). The resulting Razorback Sucker CPUE was 0.005. Additionally, one new wild Flannelmouth Sucker (sex unknown) (CPUE=0.005) with a TL of 352 mm was captured in Bonelli Bay (Table 1.6).

Table 1.6. Date, passive integrated transponder (PIT) tag number, size, and status information for Razorback Suckers captured in Bonelli Bay during 2022.

DATE	SPECIES [a]	PIT-TAG NUMBER	SONIC CODE	DATE [b] (ORIG.)	RECAPTURE (STATUS)	TL [c] (mm)	FL [d] (mm)	SL [e] (mm)	WT [f] (g)	SEX [g]	GEAR
2/24/2022	RZ	3DD.003BE66291		2/24/2022	NO (WILD)	589	547	505	2678	M	Trammel
3/9/2022	FM	h		NA	NO (WILD)	352	333	h	380	U	Trammel

[a] Species: RZ=razorback sucker, FM=flannelmouth sucker. [b] Date originally stocked or originally captured. [c] TL=total length. [d] FL=fork length. [e] SL=standard length. [f] WT=weight. [g] Sex: F=female, M=male, U=unknown, I=immature.

The Razorback Sucker captured in Bonelli Bay in 2022 was aged at 7 years (year-class 2015) (Figure 1.8) (Appendix B).

(This space intentionally left blank.)

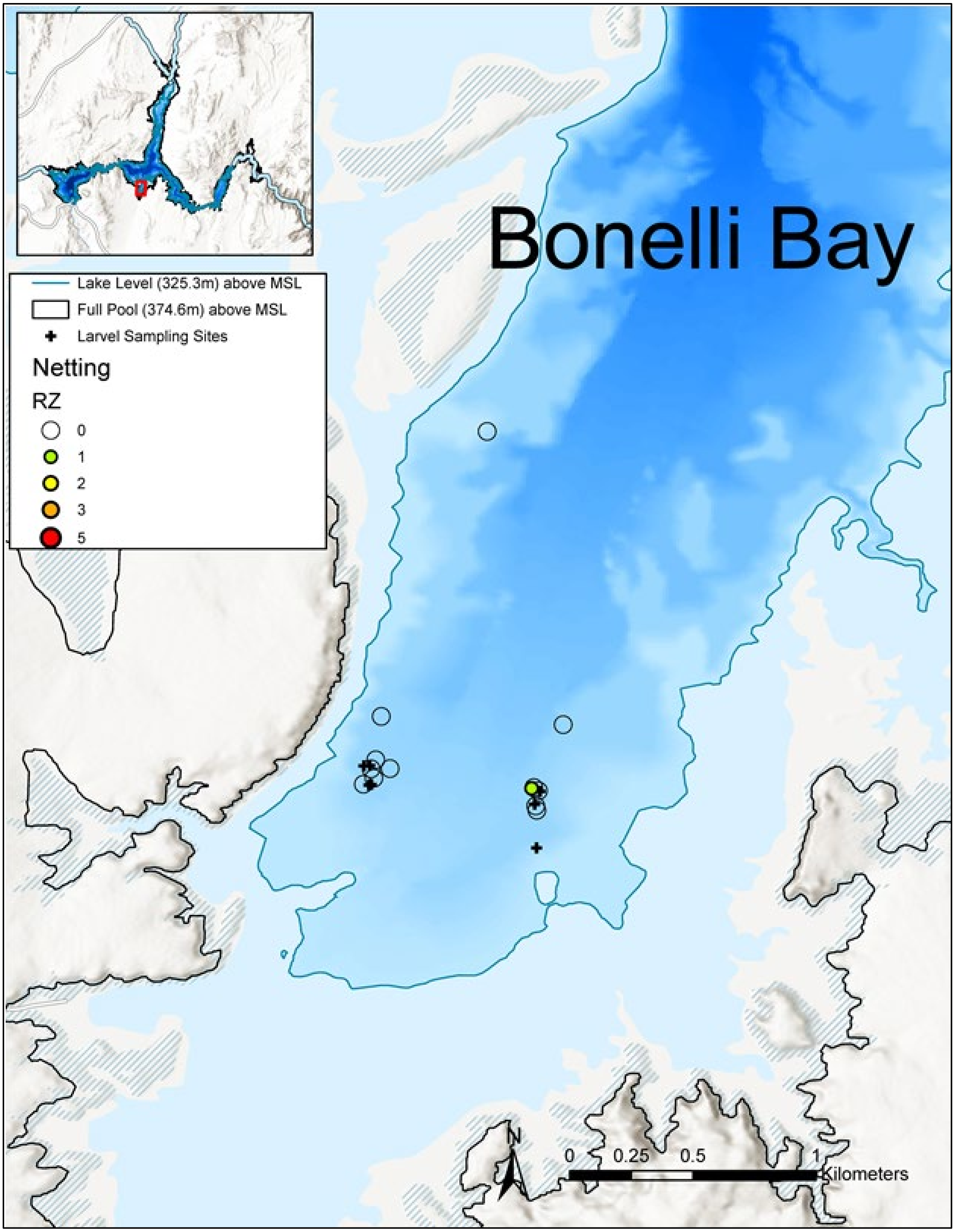

Figure 1.10. Trammel-netting, larval fish sampling, and telemetry contact locations for Razorback Sucker in Bonelli Bay in Lake Mead, January–May 2022.

DISCUSSION AND CONCLUSIONS

Information collected at the CRI since 2010 has added to our knowledge of the Lake Mead Razorback Sucker population's spawning behavior, habitat use, growth, age structure, and recruitment. Combined data from sonic-telemetry (see Chapter 3), trammel-netting, and larval-collection efforts confirm that Razorback Sucker occupy and successfully spawn in CRI habitats. These findings also underscore the apparent and continued importance of inflow habitats to Razorback Sucker as a species (Albrecht et al. 2017). We have documented recruitment within the system with age-0, juvenile (n=2; 23 and 34 mm [TL]) (Albrecht et al. 2014a), age-2 juvenile (Kegerries and Albrecht 2013b), and several younger Razorback and hybrid suckers aged between 3 and 5 years, found occupying CRI and riverine habitat in Iceberg Canyon habitat over the 13-year study period. Recent findings, which are included in this report, continue to link Lake Mead and Grand Canyon and indicate that continued and perhaps additional studies are needed to fully understand Razorback Sucker use of these areas (Kegerries et al. 2020a).

Adult Studies and Spawning-Related Observations

At this stage of our research and monitoring, it seems that fluctuations in the number of Razorback Suckers spawning, number of larval fish collected, and the number of sonic-tagged fish activity are tied, at least in part, to the species' relationship with Grand Canyon. In 2014, spawning was confirmed in the Grand Canyon (below Lava Falls [RM 179]), but limited evidence was found for spawning within the CRI (Albrecht et al. 2014a; Kegerries et al. 2017b). In 2015, spawning evidence was discovered in both Grand Canyon and Lake Mead (Kegerries et al. 2015a), while in 2016 and 2017, spawning was confirmed only within the river (Kegerries et al. 2016b and 2017a). In 2018 and 2019, we captured few Razorback Sucker larvae, but we documented spawning adults at the CRI and observed spawning success within the river (Kegerries et al. 2018, 2019, 2020). In 2021, we documented the highest catch rates of Razorback Sucker larvae and adults at the CRI since 2010 (Rogers et al. 2021b). Although it is intuitive to assume that more adults would result in more larvae captured, that has not been the case based on the 2010–2022 data. Our knowledge of the relationship between the number of adults and spawning success at the CRI would benefit from evaluations of additional spawning seasons. In this report, we documented the lowest CPUE of adult Razorback Suckers since the project's inception. However, the capture of larvae in the lake, adjacent to the mouth of the river, suggests spawning may have occurred at the CRI. Lastly, the sonic fish that was tagged disappeared shortly after it was tagged. These three observations could suggest that spawning occurred in the flowing part of the river that was inaccessible to researchers during the spawning season. This has been observed for several years in Las Vegas Bay, including during the 2022 spawning season (Rogers et al. 2022). This again demonstrates the connection of Lake Mead to the Colorado River in the Grand Canyon.

The number of juvenile Razorback Suckers captured each year has varied since the project began in 2010. In some years, such as 2015, the habitat in the river upstream of the CRI was dominated by a channelized river and consisted of run and instream slackwater habitats; few backwater habitats were available in this section of river. Contrastingly, in 2014, several backwater and slackwater habitats were found in the river upstream of the CRI, which is where two of the age-0 juvenile Razorback Suckers were captured (Albrecht et al. 2014a). It is possible that changes in the river through time has allowed for better-targeted sampling of prime recruitment habitat, such as oxbow-like areas. These periodic, unexpected findings highlight the cryptic nature of juvenile Razorback Sucker behavior and the dynamic, difficult-to-sample habitats they seem to occupy.

Captures of Flannelmouth Suckers and hybrid suckers have been relatively common at the CRI since 2010 (Albrecht et al. 2010a, 2014a; Kegerries and Albrecht 2011, 2013a, 2013b; Kegerries et al. 2015a, 2016, 2017, 2018, 2019, 2020a; Rogers et al. 2021b). Although hybridization between Flannelmouth Suckers and Razorback Suckers has been extensively documented (e.g., Bestgen 1990), the reasons for hybridization between these species at the CRI and within Grand Canyon are not clearly understood. However, at the CRI, habitat alterations could potentially reduce reproductive isolation, thereby increasing the likelihood of hybridization (Muhlfeld et al. 2009). Hybridization between these two species has also been documented on the San Juan River, where Razorback Suckers are stocked into areas where there are large Flannelmouth Sucker populations (Ryden 2006). It is unclear whether hybridization will negatively impact the wild Razorback Sucker population at the CRI or within Lake Mead. Hybrids produce viable gametes, which allow for backcrossing to either species (Douglas and Marsh 1998; Wolters et al. 2019). Flannelmouth and Razorback suckers are both species of concern for the LCR MSCP, and the preservation and conservation of native species is a mission focus of the National Park Service (NPS) (NPS 2013a). With its populations of Flannelmouth Suckers, Razorback Suckers, hybrids, and Bluehead Suckers, the CRI appears to provide key habitats for native catostomids within the lower Colorado River system. Most recently, in Bright Angel Creek in the Grand Canyon, a member of the NPS observed Razorback and Flannelmouth suckers spawning (B. Healy, NPS, personal communication), which demonstrates the continued need to understand the impact of hybridization on both species in both Grand Canyon and Lake Mead.

The Lake Mead reservoir elevation will likely continue to fluctuate over the next several years. If this occurs, Razorback Suckers at the CRI are likely to change spawning site locations to adapt to the variable conditions imposed by these fluctuations and Colorado River dynamics, as they have done in past years throughout the lake (e.g., Rogers et al. 2019, 2022 and previous BIO-WEST reports). Given the relatively large inflow area and the delta formed by the Colorado River proper, as well as the magnitude of change that has occurred at the CRI, shifts in spawning site location may be observed during future field seasons. These changes necessitate continued and careful monitoring of this Razorback Sucker spawning aggregation, both within the reservoir and the river.

The rapid at the mouth of Iceberg Canyon is fairly similar to Pearce Ferry Rapid in size. This may suggest that the newly formed rapid at the mouth of Iceberg Canyon is a deterrent to the upstream migration of some fish species. Native species, which have evolved in the Colorado River system, may be able to navigate this feature. Hedden et al. (2022) observed that while fish passage at Pearce Ferry Rapid is possible, the species composition above the rapid is dominated by native species. The new rapid at the mouth of Iceberg Canyon may serve a similar boundary, giving further refuge for native species in the Colorado River, but continued research will be necessary to determine how this feature functions.

Larval Sampling

Similar to larval capture rates at the other spawning areas in Lake Mead, the larval capture rate at the CRI fluctuate from year to year. The 2022 larval CPUE falls within the historical context of the project; however, is appears lower than it was during the previous 2 years. This may be due to the fluctuation of reservoir elevations during the 2022 spawning period. Spawning in the area may have been reduced because of one of the following reasons: (1) Razorback Suckers could not find suitable habitats, (2) larvae eddied out of the river/delta into areas not accessible to researchers, (3) adults moved upstream and larvae did not drift into the delta/lake, or (4) Razorback Sucker eggs dried out before hatching. While a number of other circumstances are possible, the CRI likely remains an important area for reproduction and nursery habitat for Razorback Suckers in Lake Mead. Perhaps different from the other locations are the relatively low numbers consistently captured at the CRI year to year. Continued monitoring of larvae will help determine spawning variability or trend analysis.

Growth and Aging

Based on data collected from Razorback Suckers captured in the CRI from 2010 to 2022, growth rates at the CRI are higher relative to those observed in other areas of the Colorado River basin (Modde et al. 1996; Pacey and Marsh 1998; Bestgen et al. 2002; Kesner et al. 2012). Growth rates in 2022 appeared lower compared to the other long-term monitoring sites (Rogers et al. 2022). However, higher growth rates reservoir-wide are expected based on the Razorback Suckers being relatively young (<10 years) in Lake Mead (Albrecht et al. 2010b, 2013a, 2013b; Shattuck et al. 2011; Mohn et al. 2015, 2016; Rogers et al. 2017, 2018, 2019, 2020, 2021a, 2021b, 2022). The previous captures of juvenile Razorback Suckers at the CRI suggests that natural recruitment likely occurs at the CRI or at least within Lake Mead or the Colorado River proper. These findings should be considered significant to managers as future research and monitoring efforts evolve.

At the combined study areas in Lake Mead, Razorback Suckers have been aged from 2 to 36 years old (Appendix B). Prior to 2000, the majority of fish aged were spawned during high water levels in the reservoir, while the reservoir was relatively stable around full-pool elevation (Figure 1.8). However, recent data show that fish older than the 2000 year-class, which coincided with an overall, long-term period of declining reservoir elevations and frequent annual fluctuations in the reservoir's level, were readily captured (Figure 1.8). While the 2005 spawning season remains one of the more-abundant year-classes in Lake Mead to date (Kegerries et al. 2009; Albrecht et al. 2010a, 2010b, 2010c, 2013a, 2013b, 2014a, 2014b; Shattuck et al. 2011; Mohn et al. 2015, 2016; Rogers et al. 2017, 2018, 2019, 2020, 2021a, 2022), the year-classes spanning 2001 to 2007 are all well-represented through aging techniques. Additionally, fish that were spawned more recently (2016–2020) are also represented in the dataset (Rogers et al. 2020, 2021a, 2021b, 2022). Based on previous observations, as well as the year-class strength analysis from Rogers et al. (2022), it typically takes at least 4–5 years for Razorback Suckers to be susceptible to the methods and gear used to conduct long-term monitoring on Lake Mead. Although the number of fish captured for a single year-class can allude to the strength and likelihood that that year-class will survive, it does not account for the annual irregularity with which some year-classes are represented (i.e., not all year-classes are captured in the same proportion each year). Additionally, this observation emphasizes the importance of continued research and monitoring to verify recruitment of this unique population (e.g., Rogers et al. 2017, 2018, 2019, 2020, 2021b). Aging the Lake Mead Razorback Sucker population using non-lethal methods remains paramount for tracking continued natural recruitment and elucidating the factors that contribute to recruitment success. Finally, as more specimens are obtained from all areas of Lake Mead, including the CRI, conditions that promote recruitment pulses can be further investigated.

In summary, the sampling conducted at the CRI since 2010 has yielded several interesting results:

1. Juvenile Razorback Suckers (along with juvenile Flannelmouth Suckers and hybrid suckers) are present in the CRI and can be captured with the methods we have used to capture adult Razorback Sucker. Capture of juvenile Razorback Suckers suggests that the CRI may provide important recruitment habitat and function similar to that of the historic oxbow and floodplain habitats where this species once thrived (Minckley 1973; Minckley et al. 1991; Minckley and Marsh 2009; Albrecht et al. 2014a, 2017; Kegerries et al. 2015a, 2017b).

2. Razorback Suckers occur in the CRI and were found in spawning condition during the spawning period. The number of Razorback Suckers at this location varies, and the timing and intensity of spawning appears to be more unpredictable than at other known spawning areas in Lake Mead (e.g., Rogers et al. 2018 and previous BIO-WEST reports). This disparity may arise from one or more of the following factors: (1) annual changes in river and reservoir conditions, including inter-annual and intra-annual river and reservoir elevation fluctuations, which often trigger gains and losses of littoral habitat types at the CRI; (2) temperature differences and variability, (3) overall flow of the Colorado River within Grand Canyon, (4) the addition of river-derived sediment during crucial spawning times, and (5) potential barriers to movement such as Pearce Ferry Rapid. A more-holistic understanding of the importance of this location to Razorback Sucker may be attained through continued efforts at the CRI and within the Colorado River proper.

3. Wild Razorback Suckers have been captured at different locations in the CRI for 13 consecutive field seasons. The exploration of this area demonstrates that unknown aggregates of Razorback Suckers could exist at other locations in Lake Mead or the Colorado River (e.g., Bonelli Bay, as reported herein).

4. Razorback Sucker, Flannelmouth Sucker, and potentially Bluehead Sucker habitat use overlaps at the CRI. Hybridization of Razorback Suckers and Flannelmouth Suckers has been documented by the capture of hybrid suckers at the CRI.

5. Sampling in Bonelli Bay continues to provide insight into the native fish community in Lake Mead. One new wild Razorback Sucker was captured in the bay in 2022. Recaptured Razorback Suckers from previous years at other sites on the lake demonstrates the interconnectedness of Lake Mead.

Future Considerations

Juvenile Razorback Suckers have been documented at the CRI as recently as 2019, and young fish appear to be fairly common at the CRI, which supports the hypothesis, to some degree, that natural recruitment is occurring in this area of Lake Mead. Although many questions have been answered from the 2010–2022 sampling efforts at the CRI, many new questions have arisen. For example, are there unexplored areas of the reservoir or flowing portions of the river that have suitable Razorback Sucker habitat and spawning aggregates? What role does the river play in wild Razorback Sucker recruitment? What is the long-term use of the lower portions of the Colorado River proper during both spawning and non-spawning periods of the year? Does Razorback Sucker use of habitats above (or below) Pearce Ferry Rapid vary depending on overall amounts of water released from Glen Canyon Dam, the timing of those releases, specific reservoir elevations, conditions at the Pearce Ferry Rapid, or some combination of those or additional factors? How will declining reservoir elevations effect Razorback Sucker spawning and recruitment?

Hybridization of Razorback Sucker and Flannelmouth Sucker was undocumented in Lake Mead until research began at the CRI. This finding raises the question, what might hybridization mean for Razorback Sucker recruitment and recovery? Because Flannelmouth Suckers are relatively common at the CRI, we can conclude that the CRI habitat is suitable for native fishes in general. Depending on project scope and overall interest, recruitment patterns of Flannelmouth Suckers and native hybrid suckers could also be investigated and analyzed as more data on those native species are collected during future efforts at the CRI.

Study results from the past 13 years demonstrate similarities in characteristics of habitat used by Razorback Suckers in the CRI compared with other Lake Mead spawning locations, but perhaps there are unidentified differences critical to wild recruitment. We should strive to learn from the apparent natural recruitment success of Lake Mead Razorback Suckers and apply that information to areas throughout the Colorado River basin that are presently or have been historically occupied by the species. This study at the CRI, combined with the LTM study on Lake Mead, has brought us much closer to understanding and identifying wild recruitment, while placing these processes in context within and throughout the historic range of the Razorback Sucker. The primary cause of extirpation in Lake Mohave is thought to be predation (Bestgen 2020). However, the nonnative fish community in Lake Mead and Lake Mohave are similar, and that alone may not explain the extirpation of Lake Mohave wild Razorback Sucker and the success of Lake Mead Razorback Sucker recruitment. With regard to the upper basin, Bestgen et al. (2020) also observed successful wild rearing of larvae to juvenile stage in flood-plain habitats in the presence of nonnative predators. Both Albrecht et al. (2017) and Bestgen et al. (2020) suggest that complex habitats may give Razorback Suckers the advantage to rear from larva to juvenile and possibly recruiting adults. Additionally, at a minimum, the efforts at the CRI have spurred research in Lake Powell and Grand Canyon that employ the technical approach developed at Lake Mead (e.g., Albrecht et al. 2017; Kegerries et al. 2017b; Kegerries et al. 2020a). At this time, it is important to consider how the Razorback Sucker population at the CRI (and Lake Mead in general) fits into conservation and recovery planning for both the lower Colorado River basin and Grand Canyon. Decisions must be made to determine the importance of, and potential strategies for, continued monitoring and research, and perhaps enhancement of this population, which will be needed for long-term understanding and tracking of this

Razorback Sucker population. Determinations of the level and scope of continued research for Razorback Sucker, Flannelmouth Sucker, Bluehead Sucker, Humpback Chub, and perhaps other native (or even nonnative) species, must be considered.

2022–2023 COLORADO RIVER INFLOW AREA OF LAKE MEAD (CRI) STUDY RECOMMENDATIONS

1. Maintain sampling efforts at the CRI and within Grand Canyon as a holistic effort. The telemetry (see Chapter 3), trammel netting, larval-fish sampling, and aging techniques outlined in this report are effective and essential tools for documenting Razorback Sucker habitat use and recruitment in Lake Mead. These techniques, especially telemetry, were also important for determining the extent of Razorback Sucker interactions within the CRI, below Pearce Ferry Rapid, and in Grand Canyon. Therefore, these techniques should be continued and improved through future efforts, as suggested within this report.

   Data stemming from the sampling efforts listed above can be used to assist in understanding the population size and habitat use of Razorback Suckers at the CRI and in Grand Canyon, help document the movement of sonic-tagged fish between sites, identify potential limitations or habitat shifts associated with CRI and Grand Canyon spawning aggregations, identify new spawning locations, identify reservoir-wide recruitment patterns, help characterize the Lake Mead Razorback Sucker habitat use of the Colorado River proper, and ascertain important findings from agency management actions such as future stocking events. All of these items were supported by a science panel, who also suggested that monitoring in its current form should continue, and that the CRI and the LGC should be studied jointly in the future (Reclamation 2017). All of this becomes particularly important as releases from Glen Canyon Dam are adjusted for experimental flows in accordance with the Glen Canyon Dam Long-Term Experimental and Management Plan (e.g., “high-flow,” “bug flows,” “trout management flows”) and the drought currently affecting Lake Powell and Lake Mead.

2. Continue and increase sampling efforts in the riverine habitat located below Pearce Ferry to Lake Mead. Given that young-of-year (YOY) and three sucker species (Razorback, Flannelmouth, and Bluehead) and Humpback Chub have been captured below Pearce Ferry (Kegerries et al. 2017a and 2018; Rogowski et al. 2018) and within the broader study area during past study years (see Chapter 2), larval and small-bodied fish sampling (utilizing methods described in Chapter 2) are certainly warranted and should be continued upstream of the CRI to the extent practical.

3. Consider the use of other capture methods, including electrofishing, to sample for juveniles and adults to better determine if Pearce Ferry Rapid remains a barrier to upstream travel by Razorback Suckers and other native and nonnative fish species. The use of similar methodologies from Separation Canyon downstream to Peace Ferry Rapid may be beneficial by possibly providing insights into the fish community above and below the rapid, but also support management and protection efforts of Razorback Sucker, Humpback Chub, and other native fish species of the Colorado River. These efforts would also serve as an early warning for any changes in the upstream movement of not only native fishes but perhaps more importantly the persistent threat of nonnative fish movements upstream.

4. Identify new potential spawning sites that appear similar to known spawning areas within Lake Mead as described by Albrecht et al. (2009). For example, BIO-WEST fisheries crews could stock and track additional sonic-tagged fish, utilizing remote PIT-tag antennas (as appropriate), trammel netting, and larval sampling to capture unmarked, wild Razorback Suckers in an effort to identify new potential spawning sites. Sonic-tagged Razorback Suckers have demonstrated the ability to integrate into wild populations during the spawning season. By maintaining sonic-tagged Razorback Suckers (after batteries expire) in the areas where sonic-tagged fish have been detected, future research may identify new spawning locations in Lake Mead. Bonelli Bay is of particular interest because sonic-tagged fish were documented there during past and current study years and larval and adult fish were captured there despite minimal sampling efforts (Holden et al. 2000a, 2001; Shattuck et al. 2011; Albrecht et al. 2012; Mohn et al. 2015, 2016; Rogers et al. 2018; Kegerries et al. 2018, 2019, 2020; Rogers et al. 2021b). This effort would require additional time and support, but it also falls under recommendations contained in the current version of the Lake Mead Razorback Sucker Conservation and Management Plan. Given that efforts to find a new Razorback Sucker population at the CRI were successful in this regard (Kegerries et al. 2016a), it may be time to revisit some of the reservoir-wide searches for other Razorback Sucker aggregates.

CHAPTER 2: SMALL-BODIED AND LARVAL FISH COMMUNITY SAMPLING WITHIN GRAND CANYON

INTRODUCTION

This chapter includes findings from small-bodied and larval-fish community sampling conducted during March through September 2022. This chapter also presents results from previous study years (October 2013 through September 2021) within Grand Canyon for comprehensive reporting efforts. Small-bodied fish sampling, larval-fish community sampling, and sonic telemetry were the major efforts conducted within Grand Canyon during six field trips in 2022 (Table 2.1). More specifically, the intent of this study is to help describe the overall fish community within Grand Canyon, allow for the capture of young Razorback Sucker and Humpback Chub, if present, and better understand the reproductive success, habitat use, and movement of (and areas of importance to) Razorback Sucker, Humpback Chub, and the overall Grand Canyon fish community.

Table 2.1. Grand Canyon sampling dates and trip purpose, 2022.

MONTH	SAMPLING DATES	TRIP PURPOSE
March	3/8/2022 through 3/18/2022	Larval-fish community sampling (GRTS[a])
April	4/12/2022 through 4/20/2022	Telemetry, small-bodied, and larval-fish community sampling (GRTS)
May	5/10/2022 through 5/17/2022	Telemetry, small-bodied, and larval-fish community sampling (GRTS)
June	6/7/2022 through 6/14/2022	Telemetry, small-bodied, and larval-fish community sampling (GRTS)
July	7/5/2022 through 7/13/2022	Telemetry, small-bodied, and larval-fish community sampling (GRTS)
August	8/9/2022 through 8/16/2022	Telemetry, small-bodied, and larval-fish community sampling (GRTS)
September	9/01/2022 through 9/8/2022	Telemetry and small-bodied community sampling (GRTS)

[a] Sampling following full generalized random tessellation stratified (GRTS) design (see Methods section).
[b] Sampling conducted outside of GRTS standard sampling locations chosen by the sampling crew.

In 2016, the number of small-bodied and larval fish sampling trips was reduced from seven to six to accommodate the increased sampling area while maintaining the same number of sites sampled in 2014 and 2015. The September sampling trip was eliminated from the larval fish portion of the project because 2014–2015 efforts documented a marked reduction in the catch rate of larval fish in the system during that month. As with the larval fish-sampling effort, the least-informative of the seven monthly trips to sample small-bodied fish was the March trip, and it was therefore eliminated in 2016. In 2022, larval fishing occurred from March through August and small-bodied fish trips were conducted from April to September.

STUDY AREA

The study area encompassed 191.5 river miles, from immediately downstream of the Bright Angel Creek confluence near Phantom Ranch (RM 88.5) to Pearce Ferry (RM 280.0) (Figure 2.1). Sampling locations and other river features, presented in river miles, are unique to Grand Canyon and are most familiar to Grand Canyon researchers.

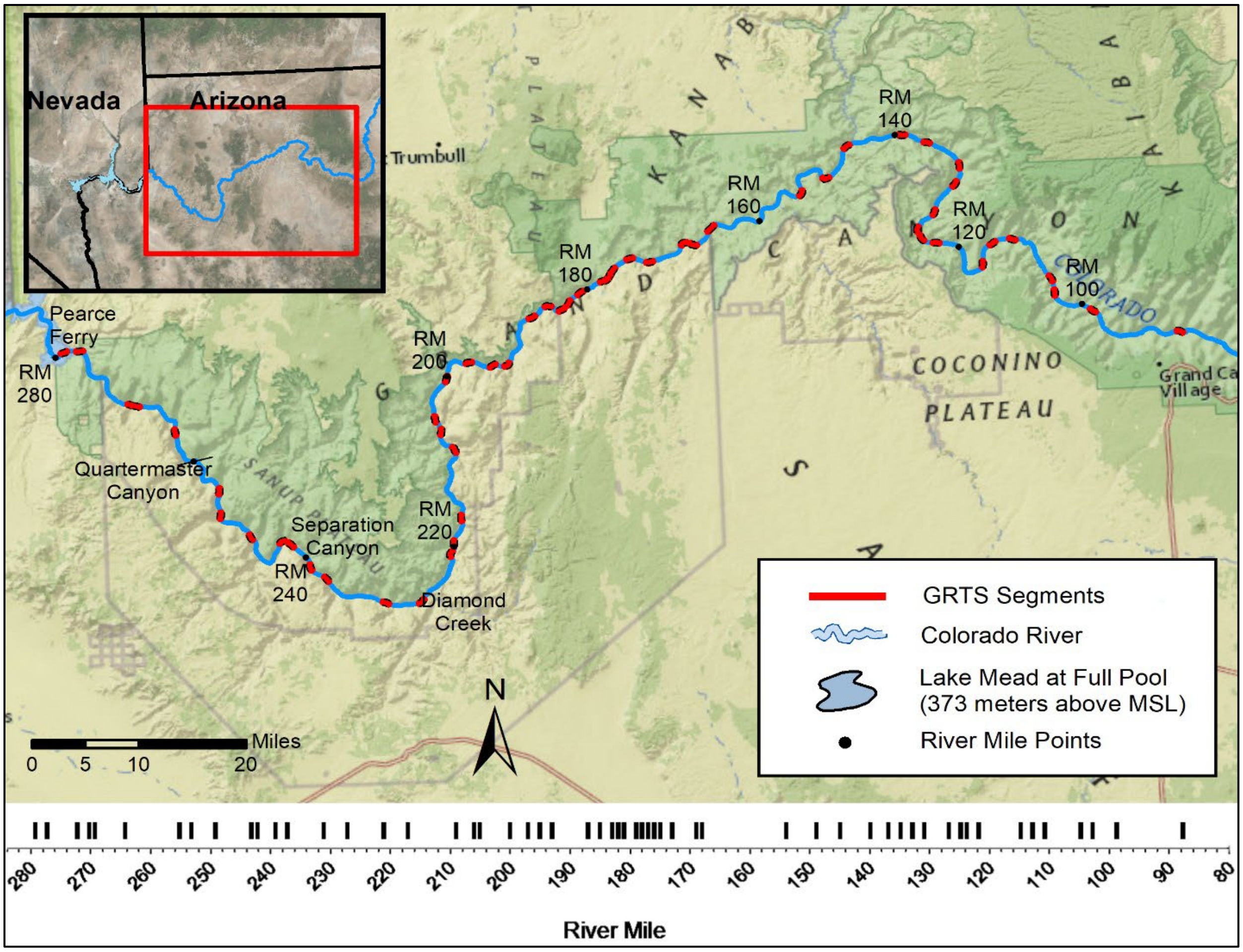

Figure 2.1. The general study area within Grand Canyon and the 56 generalized random tessellation stratified (GRTS) design segments (red) located in the 191.5-river-mile study area from below Phantom Ranch to just above Pearce Ferry in 2022 (some GRTS segments are adjoining). Tick marks denote linear distribution of GRTS segments.

METHODS

Discharge

Colorado River discharge measurements were collected from the US Geological Survey (USGS) gage station above Diamond Creek (#09404200) for the period of October 1, 2021, through September 30, 2022. Discharge information from this gage was chosen to add context to the early life-stage fish-capture data, and the gage was selected due to its centralized location within the Lava Falls to Pearce Ferry reach. Data include both approved and provisional information from USGS, and measurements are presented in cubic feet per second (ft^3/s).

Small-bodied Fish Community Sampling

Sampling sites in Grand Canyon in 2022 for the larval and small-bodied fish surveys were the same as those from 2016–2021. All sites were selected using a generalized random tessellated stratified (GRTS) design to maintain an unbiased probability of sampling at river segments that support differing densities of fishes (Stevens and Olsen 1999, 2003, 2004). The GRTS method is a form of spatially balanced sampling that is a true probability design, as each point has a known, nonzero probability of being included in the sampling effort. This monitoring method yields statistically rigorous data because sites are randomly selected, and it is used by the NPS for monitoring (NPS 2013b).

The advantage of using the GRTS method over simple random sampling is that it ensures spatially balanced samples. This is important because it is necessary to understand the spatial distribution of an organism in order to understand abundance trends over space and time.

The initial step for GRTS segment selection was to determine the appropriate length of the sampling segment in order to determine how many segments would be used in the randomized model. The sampling unit must be long enough to (1) encompass the suite of mesohabitats present for small-bodied and larval-fish community sampling, (2) contain enough area for both sampling methodologies to be used, and (3) adequately represent the fish community in that area. The segment length was determined during an initial study trip conducted in October 2013 from Diamond Creek to Pearce Ferry (Albrecht et al. 2014a). Because many reaches in Grand Canyon are highly channelized, and low-velocity habitats can be infrequent, an 800-m segment length was chosen. This length allowed the greatest number of segments within the study area while also providing opportunities for an adequate location at which to conduct larval fish and small-bodied fish community sampling methods within the segment.

The study area was divided into 385 continuous, 800-m segments. The computer program S-Draw (Western EcoSystems Technology, Inc.—Trent L. McDonald) was used to randomly generate 56 spatially balanced sampling segments (Figure 2.1) (Appendix C). An additional 14 segments were also generated, providing the opportunity to replace any of the 56 original sites if habitat in those segments prohibited sampling.

Within a selected segment, a site was chosen that contained the best available habitats for both larval and small-bodied fish community sampling. Site locations varied within the 800-m segment, depending on river discharge at the time of a sampling trip and availability of appropriate aquatic habitat. When possible, the same site in a segment was sampled across monthly surveys and years.

Each seine haul within a site comprised a sample. Target numbers of and lengths for seine hauls were designated for each gear type (n=4 larval fish seine hauls at approximately 10 m/sample, and up to 10 small-bodied fish seine hauls at approximately 10 m/sample). This protocol helped provide a level of consistency that yielded approximately equal effort at each site in a segment, as well as a nonbiased sampling regime.

In addition to the GRTS-generated segments that were sampled during each trip, specific mesohabitat types were opportunistically sampled with small-bodied and larval-fish community sampling gears in locations that appeared likely to hold young, rare fishes. These included backwaters formed in off-channel lateral canyons, tributary mouths, other locations offering habitat complexity and diversity, and the presence of sonic-tagged Razorback Suckers. For the purposes of analysis, these sites are treated separately from the GRTS sampling segments because there is potential for field crew selection bias. However, documentation of rare fishes is paramount and was one of the primary objectives of these surveys, so at times complex and diverse habitats were targeted to perhaps bolster documentation of the rarest species.

During each sampling trip, varying numbers of segments were sampled daily, depending on their complexity, the number of fish captured, and their distances from each other. The intent was to sample as many types of low-velocity habitat as possible for young Razorback Sucker, Humpback Chub, and other small-bodied fishes. Sampling was conducted using a double-weighted seine, the size of which was either 4.6 m x 1.2 m x 3 mm, or 3.0 m x 1.2 m x 3 mm, depending on habitat type and river conditions.

Information collected at each seining location included river mile, segment number, sample number, habitat type, seine type, water temperature, turbidity, area sampled (length and width), maximum depth, and primary and secondary substrate and cover types (Tables 2.2 and 2.3). All fish collected were identified to the species level and counted. At least five randomly selected individuals of each species captured per seine haul were measured, with the exception of Razorback Sucker and Humpback Chub (of which all were measured). This provided information on the general sizes of the fishes that were collected by seine haul during each sampling trip in various habitats and cover types. All fishes were returned to the habitat alive when conducting small-bodied fish seining. A PIT-tag reader was taken on all monitoring trips, and individual fish larger than 80 mm TL were typically scanned for PIT tags as per Grand Canyon standard protocol (S. Vanderkooi, USGS/Grand Canyon Monitoring and Research Center, personal communication; D. Rogowski, AZGFD, personal communication). In addition, all young Humpback Chub were examined for visual implant elastomer tags. In 2022, all captured Humpback Chub over approximately 80 mm TL were PIT-tagged if no mark was present.

The number of fish collected by species was divided by the area (m^2) of each seine haul to generate CPUE, as appropriate. Those data were examined by total catch (regardless of species) or individual species, as well as spatially (segment) and temporally (trip). Catch data were used to track proportional changes in native and nonnative fishes and habitat occupancy. The program Statistix 8.1 was used for all statistical analysis. Because nonnormality is common with datasets related to low-density fish species, catch-rate data were analyzed using the Shapiro-Wilk test for normality. If residuals were found to be not normally distributed ($P \leq 0.05$), the data were log-transformed (ln[1+CPUE]). An ANOVA was then used to test for yearly differences in mean catch rates (ln[1+CPUE]) following recommendations of (Hubert and Fabrizio 2007) for this type of data.

Table 2.2. Mesohabitat definitions for larval and small-bodied fish collections. A habitat was determined for each sample (seine haul).

CODE	HABITAT	DEFINITION
BW	Backwater	Typically, a body of water off-channel in an abandoned secondary mouth, behind a bar, or in a bank indention, no perceptible flow, and a typically silt or sand and silt substrate. Little or no mixing of backwater and channel water occurs.
PO	Pool	Area within a channel where flow is not perceptible or barely so, with water depth usually ≥30 cm, and a substrate of silt, sand, or silt over gravel, cobble, or rubble.
ED	Eddy	Same as pool except water flow is evident (but slow) and typically circular or opposite that of the channel.
SH	Shoal	Generally shallow (≤25 cm) areas with laminar flow (very slow to slow velocity: ≤5 cm per second) over any substrate.
RN	Run	Typically, moderate- or rapid-velocity water 10–30 cm per second with little or no surface disturbance. Depths are usually 10–74 cm but may exceed 75 cm. Substrate is usually sand but may be silt in slow-velocity runs or gravel or cobble in rapid-velocity runs.
RF	Riffle	Area within a channel where gradient is moderate (5 cm per m); water velocity is usually moderate to rapid (10–31 cm per second), and water surface is disturbed. Substrate is usually cobbles and rubble, and portions of rocks may be exposed. Depths vary but rarely greater than 50 cm.
SW	Slackwater	Low-velocity habitat usually along inside margin of river bends or shoreline invaginations, or immediately downstream of debris piles, bars, or other in-stream features but deeper than shoals (>25 cm).
IP	Isolated pool	Small body of water in a depression, old backwater, or side channel that is not connected to the channel as a result of receding flows.
EB	Embayment	Open shoreline depression similar to a backwater but that faces upstream. Typically they at the top end of abandoned secondary channels or bars.
RP	Rapid	Deep, high-gradient, high-velocity areas, often with standing waves.
PW	Pocket water	Low-velocity water similar to slack water but in boulder fields. These usually occur in channel margins in the canyon reaches.

Table 2.3. Substrate (A) and cover (B) codes determined for each seine haul. Primary and secondary (if available) substrate and cover were assigned. All samples had a substrate recorded; however, cover was not always available for each sample.

A	CODE	SUBSTRATE	DEFINITION	B	CODE	COVER
	SI	silt			IV	inundated vegetation
	SA	sand			RT	roots
	FG	fine gravel	<2.5 cm		SWD	small woody debris
	CG	coarse gravel	2.5–7.6 cm		LWD	large woody debris
	SC	small cobble	7.6–15.2 cm		OV	overhanging vegetation
	LC	large cobble	15.2–25.0 cm		BLD	boulders
	BLD	boulder	>25.4 cm		BRS	bedrock shelves
	BR	bedrock				

Hereafter, all mention of CPUE in the context of small-bodied fish captures will be natural log-normalized data. When significant differences were found, post-hoc analysis was performed using Tukey's HSD all-pairwise comparisons in the program Statistix 8.1 to differentiate homogeneous groups. For all tests, α was set at 0.05. Additionally, a least-squares linear regression was used to compare CPUE longitudinally by river mile throughout the study area.

Length-frequency histograms were also constructed for Humpback Chub in an effort to determine length distribution and temporally compare growth and seasonal recruitment.

Finally, comparisons have been made between historic data and data collected in this study. Results from 2014–2021 and comparisons to historic data are published in Rogers et al. (2021b). In this report, small-bodied fish catch data from 2014–2022 were examined for holistic trends where appropriate. However, most statistical comparisons were limited to data from 2016–2022, when the study area and effort remained relatively consistent.

Larval-Fish Community Sampling

The 2022 study area encompassed 191 river miles from immediately downstream of the Bright Angel Creek-Colorado River confluence (RM 88.5) near Phantom Ranch to Pearce Ferry (RM 280.0). Following the upstream expansion of the study area in 2016, the study reach was again divided into 800-m sampling segments (n=385), from which 56 sampling segments were randomly identified (using GRTS) as permanent sampling segments. In 2022, larval fish surveys were conducted monthly March through August (n=6 surveys). In 2017, two GRTS segments were removed due to unsafe sampling conditions and replaced with the next sequential GRTS segments. Aside from replacement of those sites, all GRTS sampling locations remained the same throughout the 2022 Grand Canyon larval and small-bodied sampling efforts.

Sampling for larval fish was conducted using a short and fine-mesh seine (ca. 1 m x 1 m x 0.8 mm mesh) and primarily occurred in low-to-zero velocity habitats. Four samples, each consisting of one seine haul in a discrete mesohabitat (around 5–10 m in length), were made at each GRTS segment. Fishes that could be accurately identified in the field were enumerated, measured (standard length [SL] mm), and held in a live well. Total length (TL mm) and fork length (FL mm) were recorded for Humpback Chub. Identifiable fishes collected at each site remained in a live well until sampling at the site had been completed. They were subsequently released unharmed into a low-velocity habitat at the site of their capture. Fishes that could not be accurately identified in the field, typically due to small size or limited morphological development, were retained in Whirl-paks® containing fluid fixative (95% ethanol [EtOH]). Starting in 2020, all retained specimens were preserved in 95% EtOH (as opposed to 10% formalin). Whirl-paks® were labeled with a field tag containing a unique alphanumeric code (field number), sample number (1–4), and habitat code corresponding to the individual seine haul in which they were captured. For each seine haul, a discrete suite of data was recorded including presence/absence of fish, length of seine haul (to the nearest 0.1 m), mesohabitat type, secondary habitat descriptor (Table 2.4), substrate, instream cover, maximum depth (cm), and water temperature. Sampling effort (m^2) was determined by multiplying seine width (1 m) by seine haul length.

At each site, at least one digital photograph of the habitat sampled was recorded. Additional data acquired at each site included main-channel water temperature, pH, and conductivity (using a HANNA multi-parameter water quality device), turbidity (Secchi disk), and ambient air temperature. The locations of each predetermined GRTS segment and sampling site were verified using NPS low-elevation aerial photomaps (marked with river mile). Geographic coordinates (UTM Easting and UTM Northing) of sampling sites were obtained with a Garmin *etrex 20* handheld GPS unit using the NAD 83 geodetic reference system. Additional notes regarding river conditions and pertinent observations were also recorded on field data sheets.

Hobo® Tidbit water temperature data loggers, set to record once every hour, were co-located with each SUR (Chapter 3) to document the longitudinal temperature gradient from near Phantom Ranch (RM 89) downstream to Pearce Ferry (RM 280). Data loggers that were in place from the previous year (in this case, August 2021) are typically downloaded and replaced during the following August or September survey (in this case, 2022).

Table 2.4. Additional mesohabitat descriptors determined for each sample (seine haul) in the larval fish surveys.

CODE	MICROHABITAT	DEFINITION
SH	Shore	Area sampled is along shore, up to 1 m off shoreline.
OP	Open	Sample is >1 m off shoreline.
MO	Mouth	The interface of a backwater or embayment with the main channel. The sampled area may include shoreline and open water.
TR	Terminal	The culminating end of the backwater or embayment opposite the mouth. The sampled area may include shoreline and open water.

Retained fish samples were accessioned into the Museum of Southwestern Biology (MSB), Division of Fishes, at the University of New Mexico, immediately after each field survey. At MSB, samples and associated field tags were removed from Whirl-paks®, larval fish were separated from debris, the field fixative was replaced with 95% EtOH and specimens were stored in museum-quality glass jars awaiting identification. After samples were cleaned, ASIR staff with Colorado River Basin larval fish identification expertise identified specimens to species. Stereomicroscopes equipped with transmitted light bases (light and dark fields) and polarized filters that enhance the delineation of larval fish characteristics that differentiate species (myomeres, pterygiophores, and fin rays), were used in the identification process. The following larval fish guides and companion computer interactive keys were used to assist with identification:

- *Guide to the cyprinid fish larvae of the Upper Colorado River Basin, morphological descriptions, comparisons, and computer interactive key* (Snyder et al. 2016).

- *Catostomid fish larvae and early juveniles of the Upper Colorado River Basin, morphological descriptions, comparisons, and computer interactive key* (Snyder 2003; Snyder and Muth 2004).

Only YOY (i.e., age-0) specimens were included in analysis of the larval-fish community sampling effort. The terms YOY and age-0 are synonymous and include both larval and juvenile fishes. These terms refer to any fish, regardless of ontogenetic developmental phase, between hatching or parturition and the beginning of the next calendar year (1 January). Conversely, "larval fish" is a specific developmental (morphogenetic) period between hatch and transformation to juvenile stage (juvenile fish are no longer larval fish). Larval fish developmental terminology used in this report follows Snyder (1981) in recognizing three distinct, sequential larval developmental phases: protolarvae, mesolarvae, and metalarvae. Mesolarvae are further divided into two sequential subphases: flexion mesolarvae and postflexion mesolarvae. Fishes in any of these developmental phases (i.e., proto-, meso-, or metalarvae) were classified as "larval fish." Juvenile fish have progressed beyond the metalarval phase and no longer retain traits characteristic of fish larvae. Scientific and common names of fishes used in this report follow Page et al. (2013).

Larval fishes were enumerated and measured; minimum and maximum length (mm) was recorded for each species in each sample. Standard length was measured and recorded using an electronic caliper or ocular micrometer. A stage micrometer was used to calibrate the ocular micrometer. Standard length (body length excluding the caudal fin) is the preferred body length measurement when identifying larval fish specimens, as Upper Colorado River Basin larval fish identification guides employ morphometric ratios based on SL. Conversions from SL to TL can be easily made using published species-specific ratios (Snyder and Muth 2004, Snyder et al. 2016). Similarly, fishes released in the field were assigned an ontogenetic phase (when appropriate) based on species-specific length at various stages. Additionally, ontogenetic phase was determined for Bluehead Sucker and Flannelmouth Sucker.

Hatching dates were estimated for age-0 Humpback Chub based on body length measurements and date of capture. Hatching dates were calculated using the species-specific polynomic equation:

$$D = \frac{\log_e SL - \log_e 7.2843}{0.0280}$$

where D is the number of days from hatching and SL is the standard length of the specimen (Muth 1990).

Catch-per-unit effort (CPUE) was calculated as the number of fish (n) captured at each site divided by the area sampled (i.e., n/m^2). These data were log-transformed (ln [1 + CPUE]) prior to statistical analysis to help stabilize variance and better approximate normality. Catch-per-unit effort data were also log-transformed for plotting purposes. Analysis of variance (ANOVA) was used to assess differences in mean CPUE across habitats, months, and years. When ANOVA detected a significant difference ($P \leq 0.05$), a Tukey's Honestly Significant Difference (HSD) post-hoc test (α=0.05) was used to further examine all possible pairwise comparisons. All statistical analyses were performed using JMP, Version 16.2 (JMP 2021).

Please note that log scales for Figures 2.13 through 2.17 in most previous annual reports (2016–2020) formerly ranged from 0.1 to 100, but were rescaled from 0.1 to 10 in 2021. These changes in scale provide greater visibility of low monthly species CPUE rates by species in Figures 2.13 through 2.17.

RESULTS

2022 Discharge

Discharge of the Colorado River within Grand Canyon was variable both within and between sampling events. Regulated increases in mean daily discharge and increased daily flow fluctuations were experienced during the April–September trips. Mean daily discharges ranged between 8,330 and 15,300 cubic feet per second (cfs) during sampling events (Figure 2.2). Mean monthly discharge values for August were significantly higher than the other months' samples (ANOVA, $F_{5,177}$=68.0, P<0.0001). Mean monthly hydropeaking (the difference between maximum and minimum discharge) also differed with the lowest daily fluctuations in April, May, and June; while the highest hydropeaking occurred in August. August and July hydropeaking values were significantly higher than those of any of the other month sampled (ANOVA, $F_{5,177}$=16.2, P<0.0001).

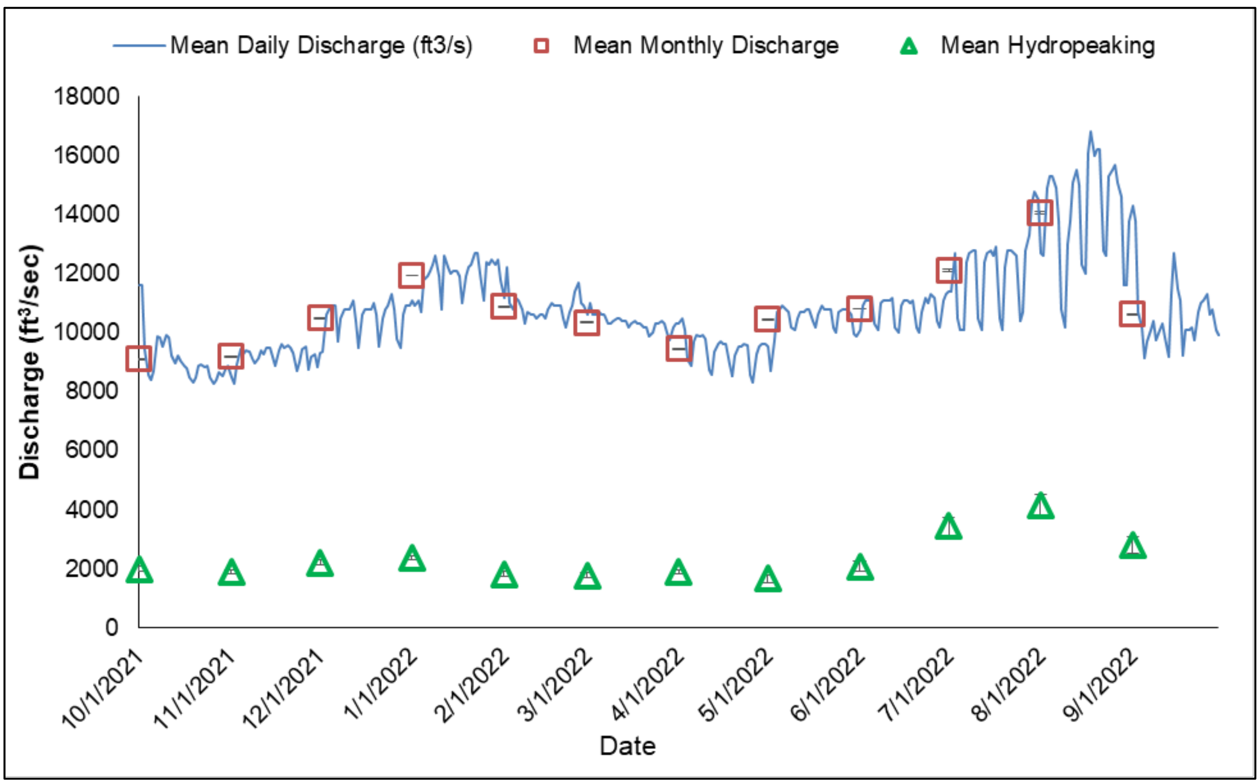

Figure 2.2. Mean daily discharge, mean monthly discharge, and mean monthly hydropeaking in cubic feet per second (cfs) of the Colorado River for the period of October 1, 2021, through September 30, 2022, recorded at the USGS gage above Diamond Creek (#09404200). Error bars are ±1 SE.

Small-bodied Fish Community Sampling

The GRTS segments were sampled from March to September 2022 (Table 2.5). No small-bodied sampling was conducted in March. Monthly effort under the GRTS sampling design ranged from 6,177.0 to 9,820.8 m^2 (228–303 seine hauls) of habitat sampled.

Table 2.5. Sampling effort from 2022 small-bodied fish surveys.

SAMPLING MONTH	DATES OF SAMPLING	NUMBER OF HAULS	EFFORT (m^2) AT GRTS[a] SEGMENTS	GRTS SEGMENTS SAMPLED
March	8–18	Small-bodied sampling was not conducted		
April	12–20	288	8,201.0	56
May	10–17	293	9,820.8	56
June	7-14	238	6,307.0	56
July	5–13	254	6,886.0	56
August	9–16	228	6,177.0	56
September	1–8	303	6,876.0	56

[a] GRTS=generalized random tessellation stratified.
[b] NA=not applicable as all sampling was opportunistic.

During small-bodied fish community sampling efforts in 2022, 16,923 native fishes of four species (Bluehead Sucker [n=239], Flannelmouth Sucker [n=9,066], Humpback Chub [n=1,168], and Speckled Dace [n=6,450] [Appendix D]) were captured in GRTS segments. Native fish dominated Grand Canyon, representing approximately 95.3% of the total catch. Although other catostomid fishes were captured, no Razorback Suckers were captured during small-bodied seining efforts within the study area in 2022.

The following nine nonnative fish species were captured during small-bodied fish community sampling in 2022: Striped Bass *Morone saxatillis* (n=1), Walleye *Sander vitreus* (n=1), Common Carp (n=54), Fathead Minnow (n=293), Plains Killifish *Fundulus zebrinus* (*n*=276), Green Sunfish *Lepomis cyanellus* (n=1), Western Mosquitofish *Gambusia affinis* (n=14), Red Shiner *Cyprinella lutrensis* (n=71), and Rainbow Trout *Oncorhynchus mykiss* (n=132), totaling 843 individuals (Appendix D). The Striped Bass (75 mm TL) was captured on September 4, 2022, at RM 115.4 and the Walleye (190 mm TL) was captured September 8, 2022, at RM 241.9. Although additional nonnative species are present in Grand Canyon, native fishes dominated the catch for the small-bodied fish community, whether evaluated by total numbers (Appendix D) or through catch rates, as reported below.

Small-bodied fish captures at the opportunistic sites represented lower native relative abundance and lower nonnative species diversity as compared to those of the GRTS segments (Appendix D). Native species, consisting of Humpback Chub (n=2), Bluehead Sucker (n=4), Flannelmouth Sucker (n=449), and Speckled Dace (n=59), comprised 99.2% of the small-bodied fish captured during opportunistic sampling. The nonnative catch consisted of Fathead Minnow (n=1), Plains Killifish (n=1), and Rainbow Trout (n=2). Sites sampled opportunistically in 2022 consisted of tributary and tributary mouths.

In addition to the fish readily identifiable in the field and not included in the total counts, 1,975 young-of-year fishes (n=1,964 suckers and n=11 cyprinids) were captured.

Catch Rates

A comparison of mean CPUE ($\ln(1+(\#/m^2))$) of native and nonnative fishes captured at GRTS segments in 2022 demonstrates dominance and significantly higher catch rates of native, small-bodied fish species in Grand Canyon (ANOVA, $F_{1,3206}=507$, $P<0.0001$) (Figure 2.3 and 2.4). When evaluated by trip, significant differences were found in native fish catch rates (ANOVA, $F_{5,1598}=136$, $P<0.0001$) (Figure 2.3). Post-hoc analysis revealed that catch rates for native fish in July 2022 had the highest mean catch rate, while April and May 2022 had the lowest mean catch rates (Figure 2.3).

In comparison with previous data, native catch rates in 2022 were significantly lower compared to 2014, 2017, and 2018, but higher than 2015, 2016, 2019, 2020, and 2021 (ANOVA, $F_{8,14473}=77.1$, $P<0.0001$; Tukey's HSD). Nonnative fish catch rates in 2022 were also significantly lower than those of 2014 and similar to all other years (ANOVA, $F_{8,14473}=9.57$, $P<0.0001$) (Figure 2.4).

Native fish catch rates differed among sampling segments in 2022 (ANOVA, $F_{55,1548}=3.03$, $P<0.0001$) (Figure 2.5). Post-hoc analysis revealed differences in catch rates among sampling segments, but there was no clear pattern or indication that catch rates differed significantly from upstream to downstream. Similar results were found for the combined data from 2016–2022 with differences among segments, but it is difficult to determine where those differences occurred (ANOVA, $F_{64,11472}=16.1$, $P<0.0001$).

To better assess mean catch rates longitudinally for segments, catch rates in the upper half and lower half of the study area for 2016–2022 were compared. Catch rates above Lava Falls were compared with mean catch rates for segments below Lava Falls (RM 179.0). This analysis confirmed that mean catch rates for native fish were significantly higher below Lava Falls than above it (ANOVA, $F_{1,11535}=347$, $P<0.0001$). It appeared that catch rates increased below Havasu Creek (Figure 2.5); thus, 2016–2022 catch rates in segments above Havasu Creek (RM 157.3) versus below were compared. Mean catch rates for native fish were significantly higher below Havasu Creek than above it (ANOVA, $F_{1,11535}=416$, $P<0.0001$), suggesting the tributary is important for native fishes.

In 2022, native fish numbers and their TL varied by sampling trip. Total length ranged from 8 to 430 mm (mean=41.5 mm; SE=0.34). Although a wide range in native fish lengths were found, there is no indication that size class is different throughout the study area and among sampling segments.

An analysis of catch rates for individual native species by sampling trip was also performed to identify relative temporal differences in the native fishes captured in 2022 (Figure 2.6). Relatively high Flannelmouth Sucker and Speckled Dace catch rates were observed throughout sampling trips, while catch rates of age-0 suckers increased through June before becoming more easily identifiable during July–September (Figure 2.6).

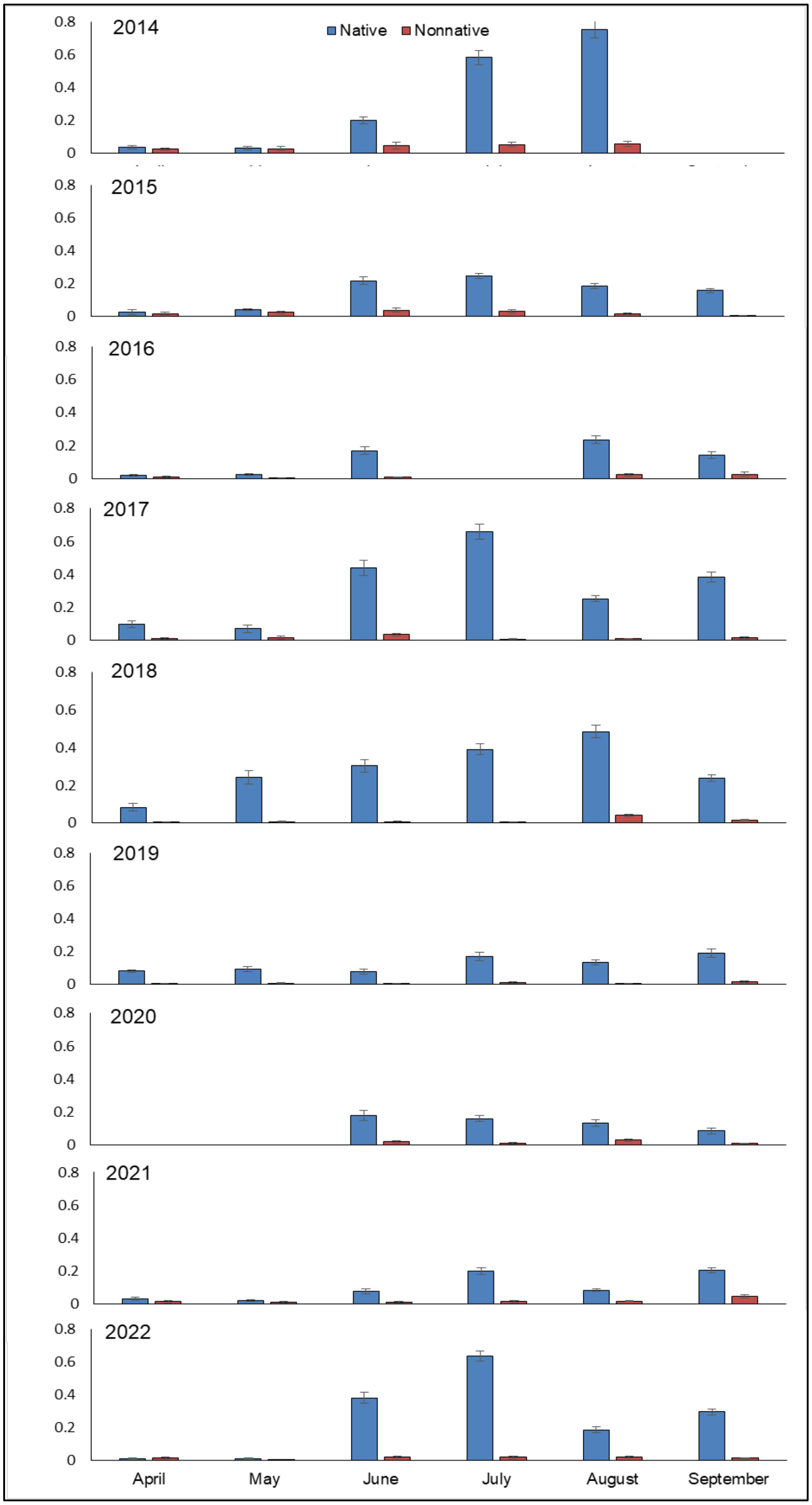

Figure 2.3. Mean native and nonnative fish catch-per-unit effort (CPUE) (ln(1+(#/m²))) by sampling trip for 2014–2022. Error bars are ±1 SE.

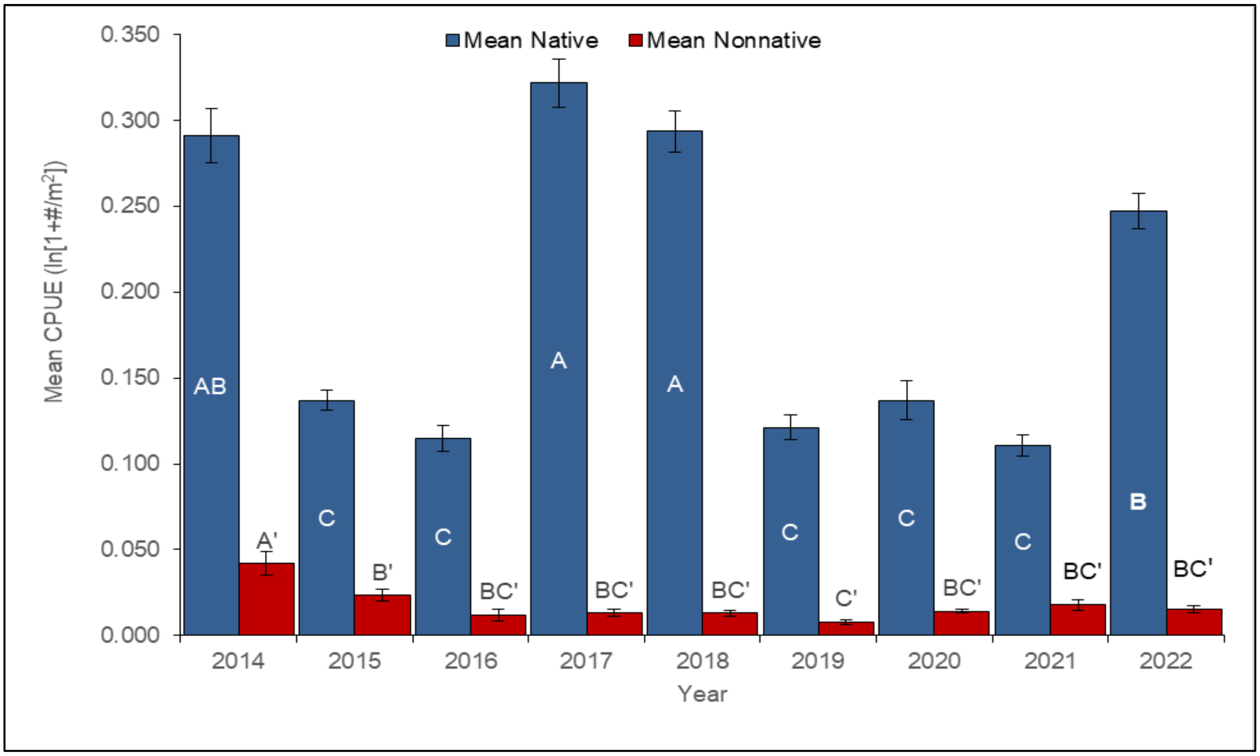

Figure 2.4. Mean native and nonnative fish catch-per-unit effort (CPUE) (ln(1+(#/m^2))) by sampling year for 2014–2022. Error bars are ±1 SE. Letters denote statistically significant groups.

(This space intentionally left blank.)

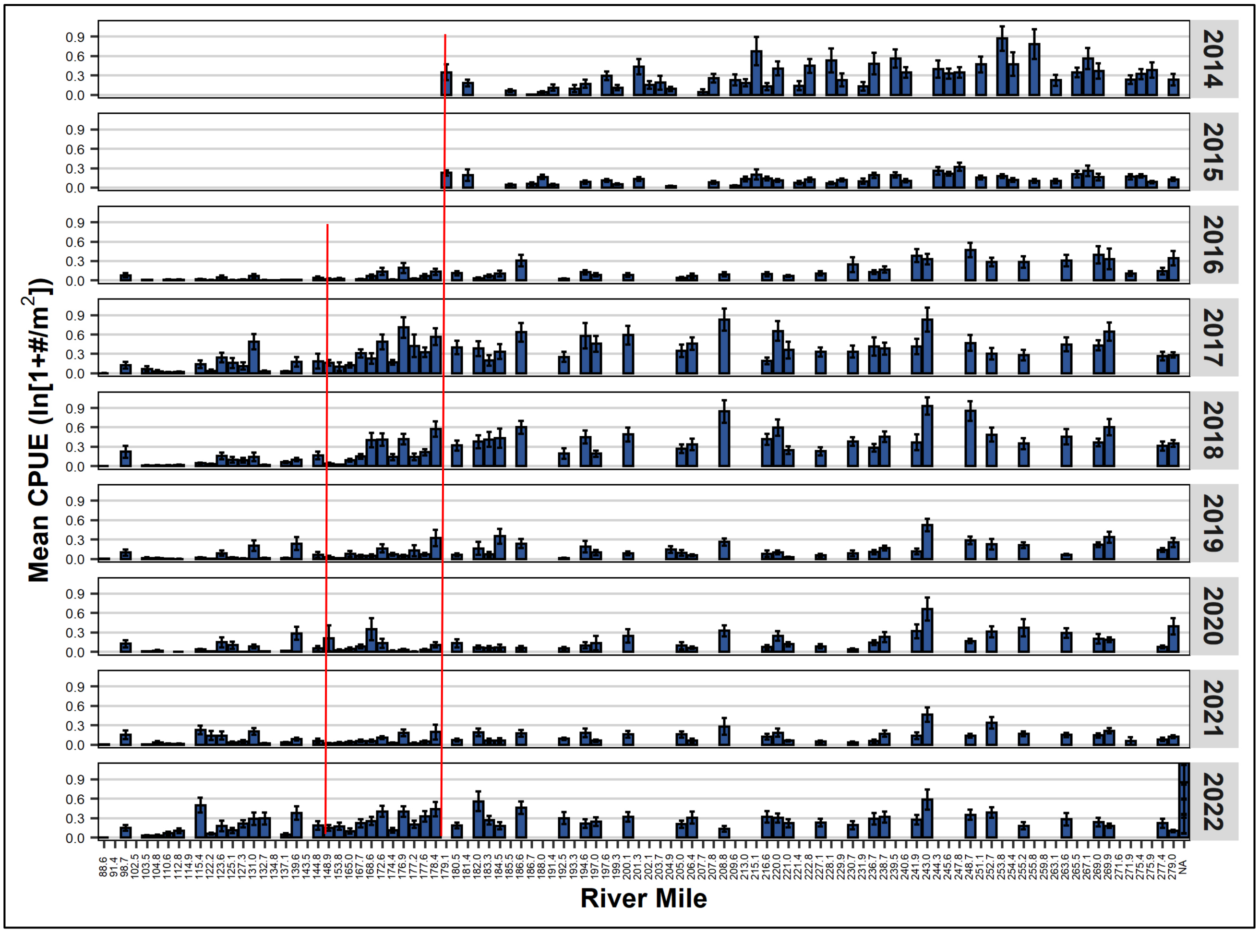

Figure 2.5. Mean native fish catch-per-unit-effort (CPUE) (ln(1+(#/m^2))) by river mile (generalized random tessellation stratified [GRTS] design segment) upstream to downstream separated by sampling year (Red lines designate Havasu Creek and Lava Falls). Error bars are ±1 SE.

(This space intentionally left blank.)

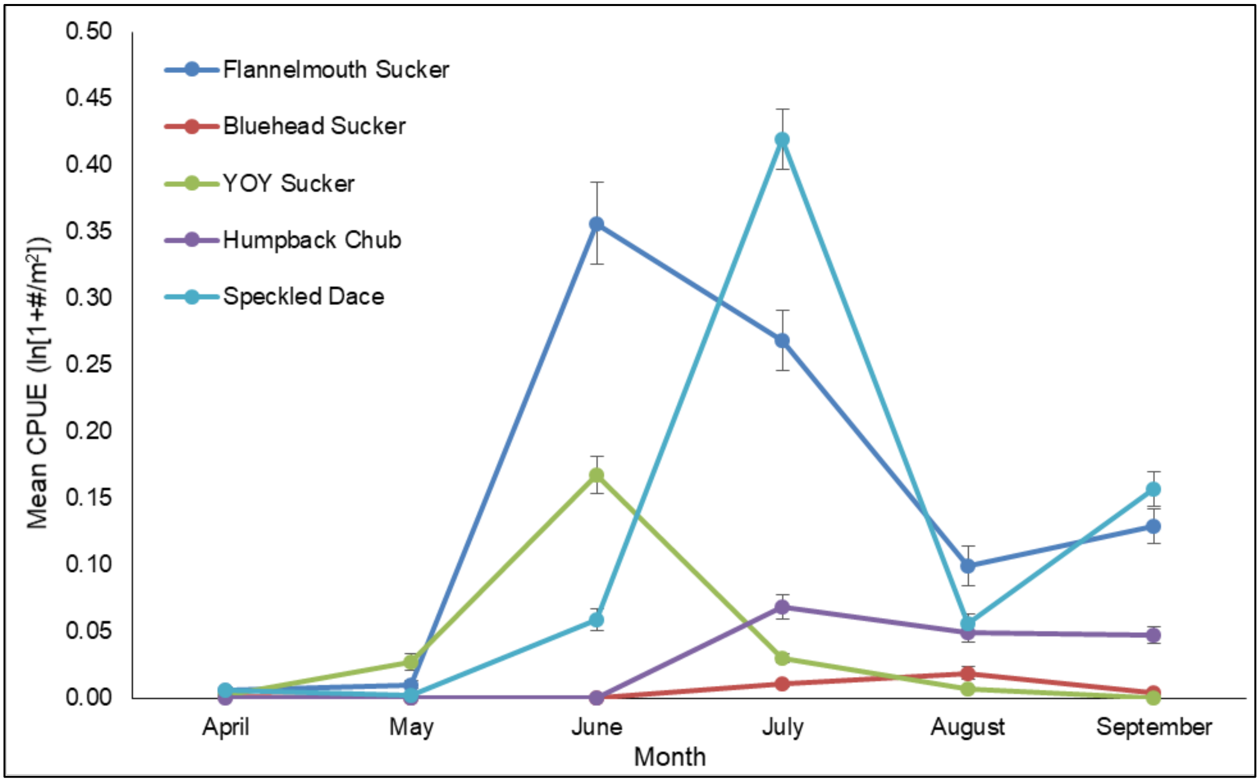

Figure 2.6. Mean native fish catch-per-unit effort (CPUE) (ln(1+(#/m^2))) by sampling trip separated according to species in 2022. Error bars are ±1 SE.

Humpback Chub catch rates differed each year from 2014 to 2022, with 2012 having the highest catch rate and 2016 the lowest (ANOVA, $F_{8,14474}$=23.5, P<0.0001). Since 2014, during small-bodied sampling, a total of 3,528 Humpback Chub have been captured. In 2022 alone, 1,170 Humpback Chub were captured, which represents 33% of the total catch. Humpback Chub catch rates were relatively low from April to June, and peaked in July, then remained relatively stable in August and September (Figure 2.6). Since 2014, Humpback Chub lengths ranged from 10–369 mm TL (mean=48.2 mm; SE=0.61) and were captured throughout the GRTS segments (Figure 2.7).

Habitat

In 2022, most seine hauls (59.7%) were conducted in slackwater habitat, followed by runs and pools (15.7 and 10.3%, respectively). These habitats also provide low-velocity conditions conducive to seining. Fine substrates, such as sand and silt, covered 84.9% of the habitat sampled during all seine hauls. While forms of cover varied, boulders and inundated vegetation were the most prevalent cover types (31.2% and 20.9%, respectively), although 31.7% of the sampling occurred where no cover was present (Figure 2.8).

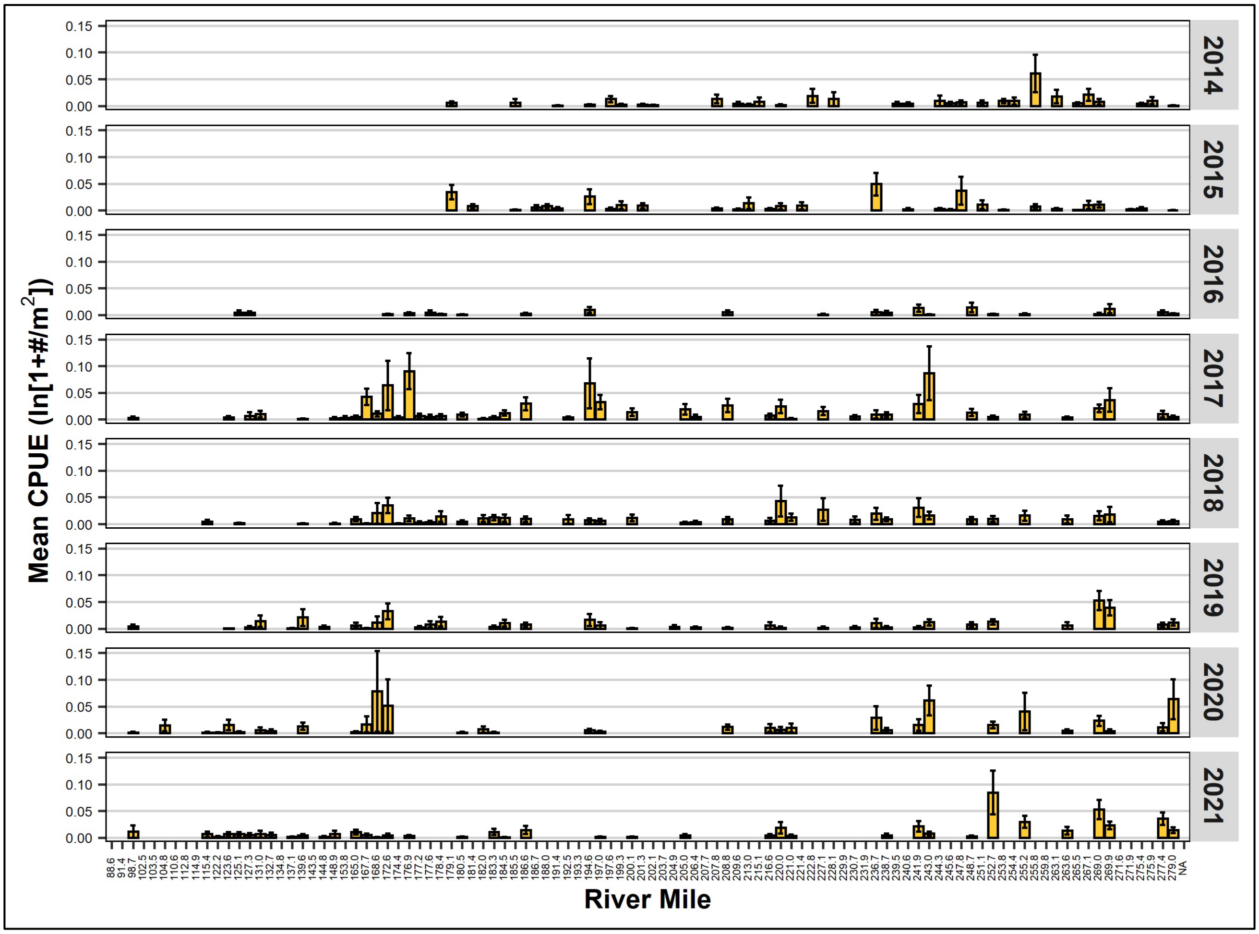

Figure 2.7. **Mean Humpback Chub catch-per-unit effort (CPUE) (ln(1+(#/m^2))) by river mile (generalized random tessellation stratified [GRTS] design segment) upstream to downstream, 2016–2022. Error bars are ±1 SE.**

(This space intentionally left blank.)

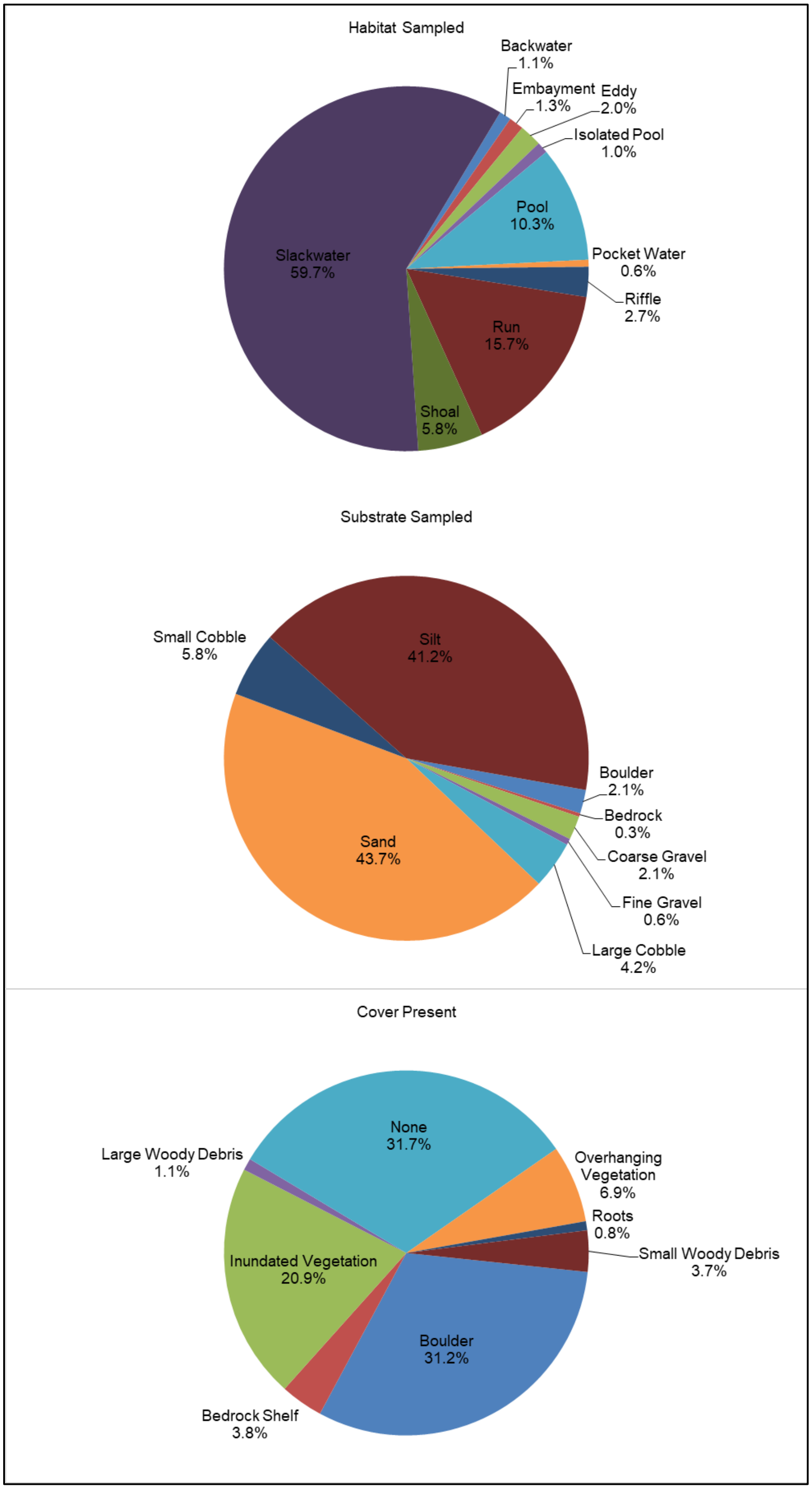

Figure 2.8. Frequency distribution of habitat, substrate, and cover present for samples at generalized random tessellation stratified (GRTS) segments during the 2022 small-bodied fish survey.

Habitat and Catch Rates per Habitat Sampled 2022

Although this study was not intended to describe habitat throughout Grand Canyon, the data collected provided insight into general habitat associations of native and nonnative fish and provided habitat-specific capture rates. Though inferences are made, these data should not be interpreted to imply native and nonnative fish habitat preference or an accurate representation of available habitat for the entire sampling area; rather, these data reflect the habitat associated with native and nonnative fish captured during small-bodied seining at GRST segments in 2022.

During the combined sampling events in 2022, a significant difference in mean catch rates among native fishes in different habitat types was detected (ANOVA: $F_{9,1606}$=6.31, P<0.0001); however, post-hoc analysis showed a complex relationship of catch rates and habitat associations. Testing for differences of mean catch rates of native fishes found mean catch rates in ebayments were different from all habitat types and slackwaters were different from riffles and runs (Figure 2.9). In testing for differences of mean catch rates of nonnative fishes, backwaters were shown to have higher catch rates compared to all other habitat types sampled in 2021 (ANOVA: $F_{9,1606}$=5.11, P<0.0001) (Figure 2.9).

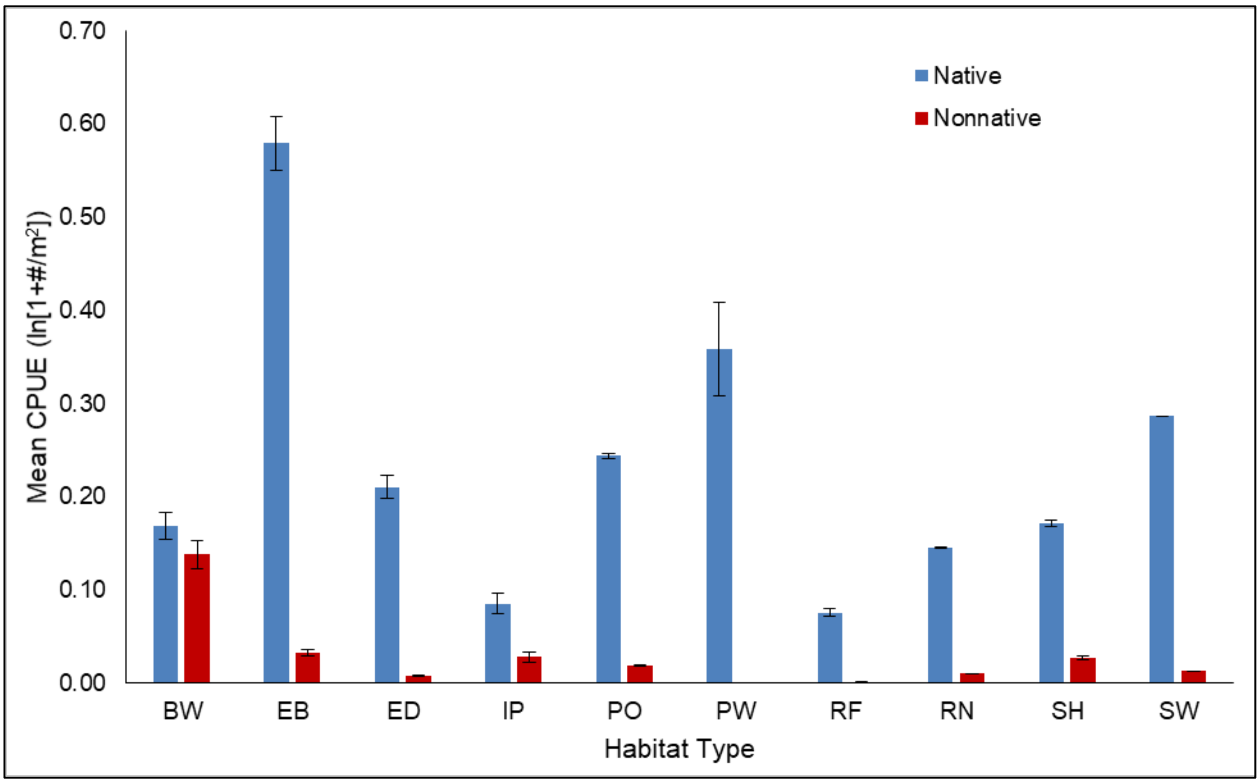

Figure 2.9. Catch-per-unit effort (CPUE) in the habitats sampled in the generalized random tessellation stratified (GRTS) Grand Canyon (RM89.5–279.9) segments in 2022.

Fish Community Composition 2014–2022

The fish community at the GRTS segments sampled during 2014–2022 were dominated by native fish (Figure 2.10). Of the native fishes, Flannelmouth Sucker dominated the catch in 2015, 2017, 2018, 2019, 2020, and 2022, while Speckled Dace dominated in 2014, 2016, and 2021 (Figure 2.10). Bluehead Sucker and Humpback Chub were captured every year but represented a lower percentage of captured species (Figure 2.10). Humpback Chub composition ranged from a low of 0.7% of the catch in 2014, to a high of 6.4% of the catch in 2022 (Figure 2.10). Fathead Minnows, Western Mosquitofish, and Plains Killifish have been the most commonly captured nonnative species, but they've always been captured in lower densities compared to that of native fish (Figure 2.10). In 2022, one Striped Bass (0.006%) and one Walleye (0.006%) were captured for the first time during GRTS sampling in the Grand Canyon. The Striped Bass was captured at RM 115.4 on September 4, 2022. The TL of this individual was 75 mm. The Walleye was captured on September 8, 2022, at RM 241.9 and had a TL of 190 mm. While they represent a small percentage of the catch, these predatory species may pose a risk to the native fish community. Small-bodied sampling has shown to be valuable in detecting rare and elusive fish species in the mainstem river.

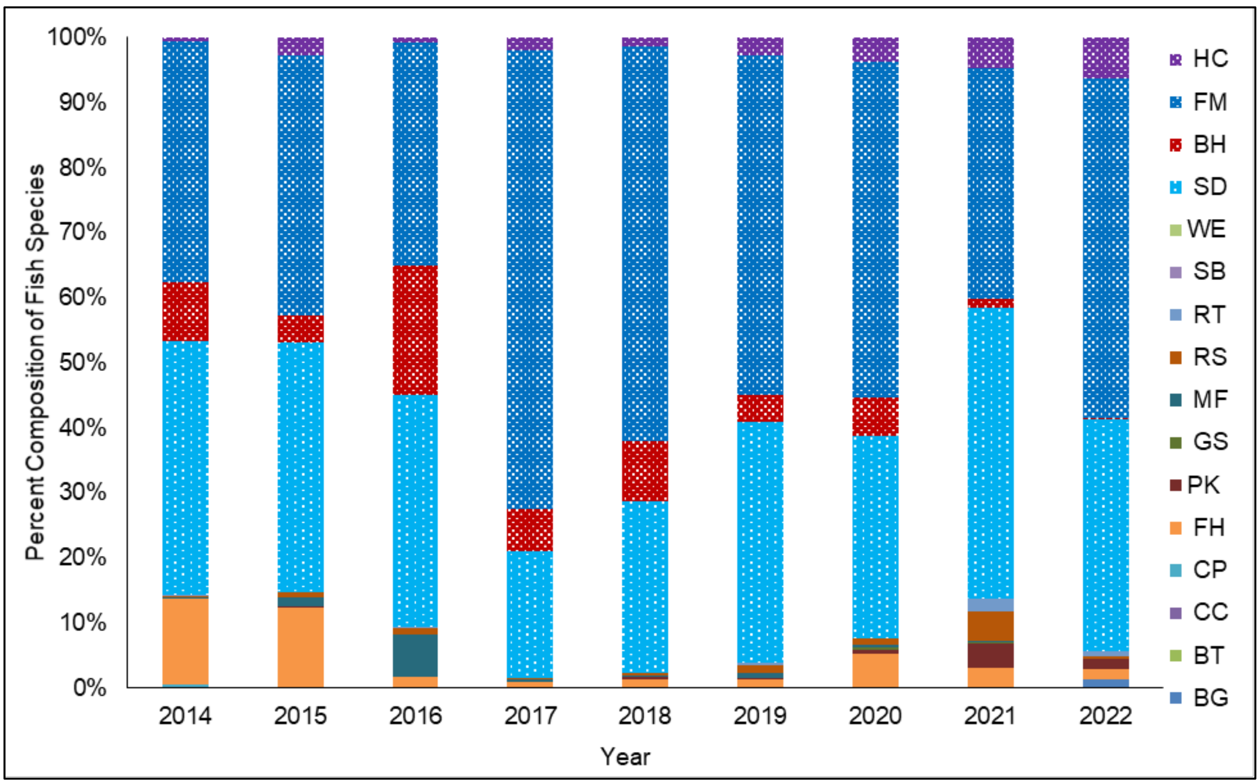

Figure 2.10. Percent composition of the fish community in the generalized random tessellation stratified (GRTS) Grand Canyon (RM 89.5–279.9) segments from 2014–2022.

Larval-Fish Community Sampling

2022 Sampling

Six larval fish surveys were conducted in the Colorado River in the Grand Canyon during 2022. Surveys occurred monthly March through August (Figure 2.11). Sampling design was maintained for consistency with previous larval-fish community sampling efforts—GRTS segments that were systematically sampled 2016–2021 (n=56) were surveyed again during 2022. In each month of 2022, all 56 GRTS segments were sampled (Table 2.6). A total of four seine hauls (i.e., samples) were taken at each GRTS segment with 224 seine hauls per monthly survey, resulting in 1,831–2,136 m^2 of larval fish habitat sampled per month in 2022 (March–August). A total of 23,264 larval fishes (i.e., age-0, YOY), consisting of 11 species, were collected in 2022 (Appendix E.1). Larval fish sampling during 2022 incidentally captured 754 age-1+ fishes consisting of 10 species (Appendix F.1).

Table 2.6. Sampling effort from monthly 2022 larval fish surveys.

SAMPLING MONTH	SAMPLE DATES	NUMBER OF HAULS	EFFORT (m^2) AT GRTS [a] SITES	GRTS SITES SAMPLED
March	8–18 March	224	2,060	56
April	12–20 April	224	2,106	56
May	10–17 May	224	1,881	56
June	6–14 June	224	2,122	56
July	5–13 July	224	2,136	56
August	9–16 August	224	1,831	56

[a] GRTS site=Generalized random tessellation stratified site.

2022 Capture Summary

March: The first larval fish survey in 202*2* (Phantom Ranch [RM 89] to Pearce Ferry [RM 280]) occurred during 8–18 March (Table 2.6). During the sampling period, mean daily discharge measured in the Colorado River just upstream of Diamond Creek (USGS gage 09404200) ranged from 9,752 to 10,088 cfs. Water clarity, as measured with a Secchi disk, was high (over 1 m) from Lee's Ferry downstream and remained >1 m to RM 269.0 where Secchi disc depth declined to 58 cm. Water clarity continued to decrease at the final three downstream GRTS sites, declining to 35 cm, 30 cm, and then 18 cm at RM 279.0 (Pearce Ferry). Mean daily water temperature near the middle of the study area (RM 190.6) was 10.2°C and hourly water temperatures ranged from 9.1 to 11.9°C (Figure 2.11).

The March collection of larval fish consisted of 46 specimens and represented only two taxa (Appendix E.2). March had the lowest catch rate among monthly surveys in 2022 and was significantly lower than catch rates during the April–August surveys (ANOVA, $F_{5,330}=68.55$, $P<0.001$; Tukey's HSD, $P<0.05$) (Figure 2.1*2*). All of the March 2022 specimens were Catostomids, with 31 Flannelmouth Sucker, 9 identified as Bluehead Sucker, and 6 *Catostomus* sp. that could not be confidently identified to species. The first larval specimens collected in 2022 were three Flannelmouth Suckers taken on 14 March at RM 165.3—one protolarvae and two flexion mesolarvae. Larval fish were collected at 12 of 33 sites between RM 165.3 and RM

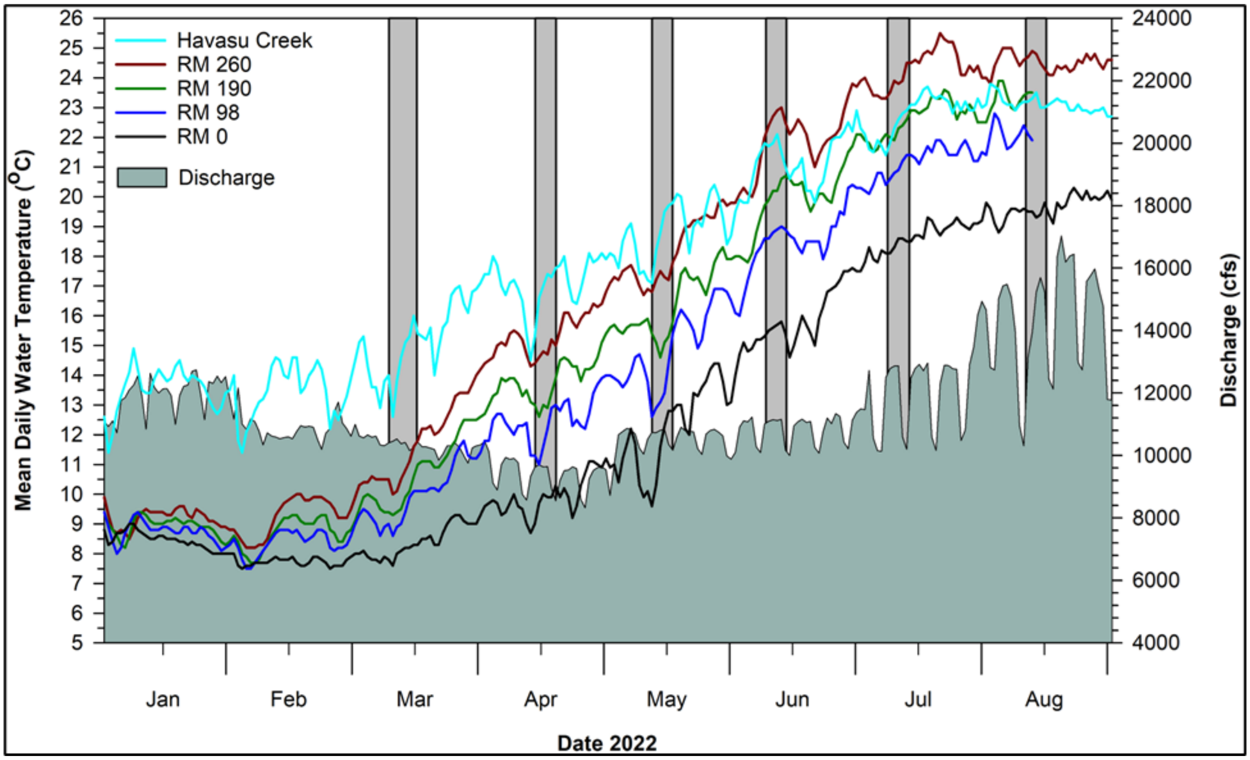

Figure 2.11. Colorado River discharge upstream of Diamond Creek (USGS gage 09404200), water temperatures during 2022 from Lee's Ferry (USGS gage 09380000, RM 0), Havasu Creek above its mouth (USGS gage 09404115, confluence near RM 157.3) and three mainstem Colorado River water temperature loggers. Vertical, gray-filled bars denote larval survey trips.

255.2. While 4 of the 46 larval sucker were yolked protolarvae, the vast majority (n=40, 87%) were flexion mesolarvae. The early ontogenetic stages of these specimens indicate that these fish had recently hatched and initiated the drift phase of their early life history.

Age-1 incidental captures during the March larval fish survey were low (n=38) and were composed of nonnative Red Shiner, Rainbow Trout, and Plains Killifish (Appendix F.2). Only two native Age-1 specimens were collected, Speckled Dace and Bluehead Sucker.

April: The April 2022 survey occurred 12–20 April (Table 2.6), with sampling beginning on 14 April. Hourly discharge in the Colorado River during the April survey (as measured from the USGS gage 09402500 near Grand Canyon, Arizona) ranged from 7,280 to 10,500 cfs, with mean daily discharge ranging from 8,243 to 9,281 cfs (9,003 cfs mean discharge). Water clarity ranged from 60 to 86 cm between RM 112.8 and RM 184.5 (14–17 April). Conversely, water clarity was more than 1 m from RM 186.6 to RM 243.0 (18–19 April). Over the next 20.3 river miles (RM 248.7–RM 269.0), Secchi disc depth ranged from 47 to 77 cm but dropped to 15 cm or less throughout the final 10 river miles of the study area. Mainstem water temperatures recorded at sampling locations ranged from 11.4 to 17.2°C, while the mean daily water temperature near the middle of the study area (RM 190.6) was 13.8°C, ranging from 13.4 to 14.8°C (Figure 2.11).

The distribution and abundance of age-0 fishes increased in April relative to March (Appendix E.3). However, monthly catch rates remained relatively low and was significantly lower than catch rates during the May–July surveys (ANOVA, $F_{5, 330}$=68.55, P<0.001; Tukey's HSD, P<0.05) (Figure 2.12). The upstream-most April capture of larval fish (Flannelmouth Sucker) was at the second GRTS location (RM 165.3) which expanded its distribution 66.6 miles upstream to RM 98.7 relative to the March survey. Catostomidae was the most abundant family collected during April, comprising >90% (n=941) of larval fishes collected that month. Flannelmouth Sucker was the most abundant species captured in April (81.8%) and was distributed between RM 98.7 and RM 279.0. They were collected at 45 of 56 sampling sites and all sites (n=38) downstream of RM 153.8 (near Havasu Creek confluence). Protolarval Flannelmouth Sucker (n=7) were collected from RM 132.7 to RM 248.7 and were collected at every site downstream of RM 165.3. Conversely, flexion mesolarvae, the most numerous ontogenetic phase of Flannelmouth Sucker collected in April (n=592, 69.5%), was present from RM 131.0 to RM 279.0. Post-flexion mesolarvae were the second-most abundant (n=243, 28.5%) ontogenetic Flannelmouth Sucker phase in the April samples and had the widest distribution. They were collected from RM 98.7 to RM 279.0. Bluehead Suckers (n=28) were collected between RM 137.2 and RM 279.0 and were not consistently found until RM 221.0. Like Flannelmouth Sucker, flexion mesolarvae was the most abundant ontogenetic phase (n=79, 90.8%) and widely distributed (RM 172.6 to RM 279.0) ontogenetic phase. The three species of age-0 nonnative larval fishes collected in April 2022 were Common Carp (n=1), Fathead Minnow (n=95), and Rainbow Trout (n=2); nonnative fishes accounted for 9.4% of April larval fish specimens.

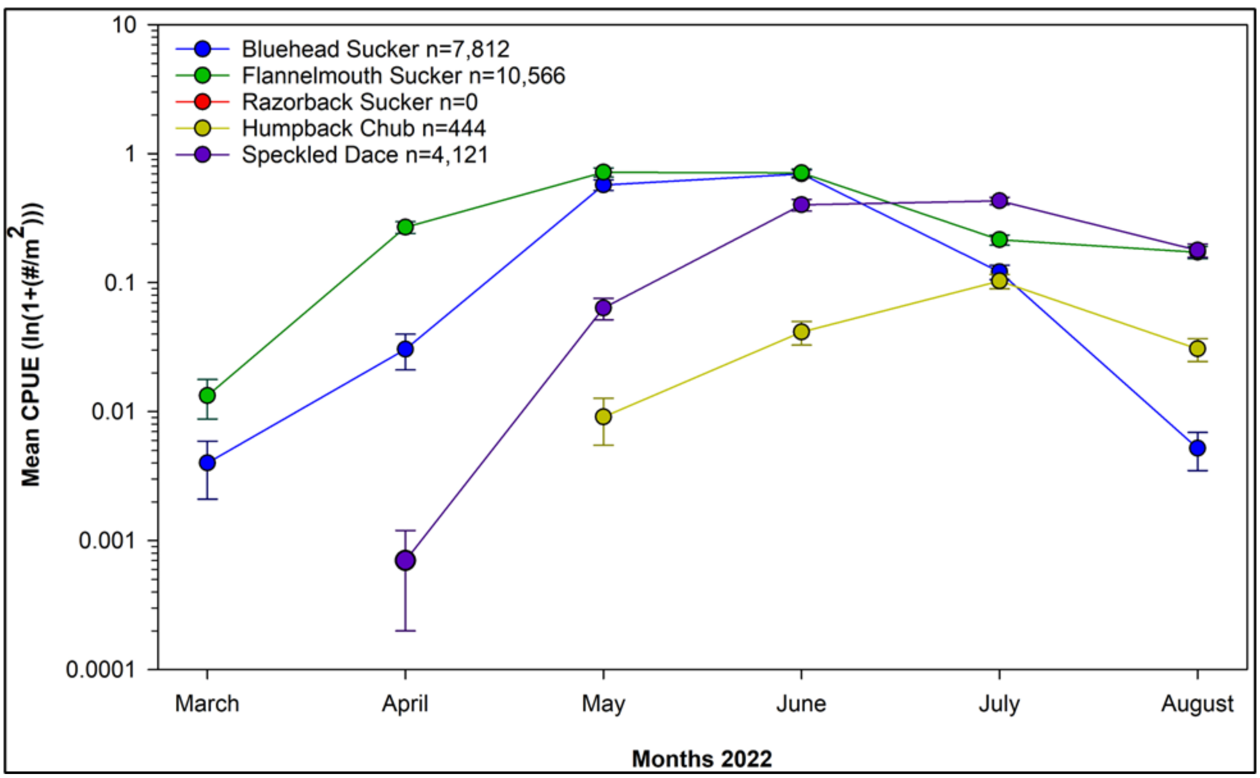

Figure 2.12. Mean CPUE of age-0 native fishes by sampling trip (month) during the 2022 larval fish survey. The *y*-axis scale is $\log_{10}$ and error bars are ± 1 SE.

The species composition of age-1 fishes captured during April 2022 was, as in March, five species (Appendix F.3). The majority of these age-1 fishes were Red Shiner (n=58; 63.0%). The second most abundant age-1 species collected was Plains Killifish represented by 13 specimens. Densities of all five age-1 fishes were all relatively very low during April 2022.

May: The May 2022 survey occurred 10–17 May (Table 2.6). Mean daily discharge in the Colorado River during the sampling period was 10,190 cfs, with mean daily rates ranging from 9,500 to 10,100 cfs. Water clarity was high throughout most of the study area during May; Secchi disk depth was greater than 100 cm at 51 of 56 sites (RM 88.6–255.2). Conversely, water clarity decreased downstream of RM 255.2, where it ranged from 55 to 13 cm between RM 263.6 and RM 279.0 (respectively) throughout the final 16 river miles of the study area (all sampled on 17 May 2022). Mainstem water temperatures recorded at sampling locations ranged from 12.6–23.2°C, while mean daily water temperature recorded at RM 190.6 was 15.5°C and ranged from 15.3 to 15.7°C (Figure 2.11).

The May survey age-0 catch was an eight-fold increase in the abundance relative to the April catch (Appendix E.4). Native fishes (n=8,184) comprised greater than 98.5% of the age-0 fishes collected during May. Catostomids collected were primarily Flannelmouth Sucker (n=4,522; 56.5%) followed by Bluehead Sucker (n=3,489; 43.5%). The distribution of catostomids also increased with collections of Flannelmouth Sucker occurring at all except one GRTS site (n=56; 98.2% frequency of occurrence); Bluehead Sucker was similarly distributed between RM 98.7 and RM 279.0, with collections at 52 of 56 sites. Over 95% of May larval Flannelmouth Sucker were within the three earliest developmental stages (protolarvae n=21, flexion mesolarvae n=1,112, post-flexion mesolarvae n=3,194). Conversely, 99.9% of May larval Bluehead Sucker were within the three earliest developmental stages (protolarvae n=52, flexion mesolarvae n=1,697, post-flexion mesolarvae n=1,738). Native cyprinids (2.6%) collected were Humpback Chub (n=17) and Speckled Dace (n=153). The May survey marked the first collections of age-0 Humpback Chubs during 2022, consistent with previous survey years. This species was taken at seven GRTS segments and was distributed from RM 208.8 to the end of the study area (RM 279.0). The majority of specimens (n=12; 70.6%) were flexion mesolarvae, with the remainder beingwere post-flexion mesolarvae. The protolarval phase in Humpback Chub is very short, and specimens in this earliest developmental stage are rarely collected. The final native age-0 species collected during May was Speckled Dace. They were distributed at 22 GRTS segments between RM 132.7 and RM 279.0. 277.4). Nonnative, age-0 species collected in May were Common Carp (n=53), Fathead Minnow (n=69), and Plains Killifish (n=2), which had limited distribution and occurrence between RM 192.5 and RM 204.8.

May had the lowest catch of age-1 fishes (Appendix F.4). Four species comprised the May age-1 fish catch (n=19). The catch was primarily nonnative Fathead Minnow (n=15), followed by Common Carp (n=2), and Plains Killifish (n=1). A single Speckled Dace was the only native age-1 fish collected during May 2022.

June*:* The June 2022 survey occurred 6–14 June (Table 2.6). Mean discharge during this monthly survey was 10,452 cfs, while mean daily discharge ranged from 9,715 to 10,749 cfs. Water clarity, as measured with a Secchi disk, was 100 cm or greater from RM 86.6–RM 255.2 (7–16 June). Conversely, water clarity decreased downstream of RM 255.2 and ranged from 55 to 13 cm between RM 263.6 and RM 279.0 (respectively) throughout the final 16 river miles of the study area (all sampled on 14 June 2022). Mainstem water temperatures recorded at sampling locations ranged from 18.8 to 24.0°C. Mean daily water temperature recorded near the middle of the study area (RM 190.6) was 20.0°C and ranged from 18.8 to 20.6°C (Figure 2.13).

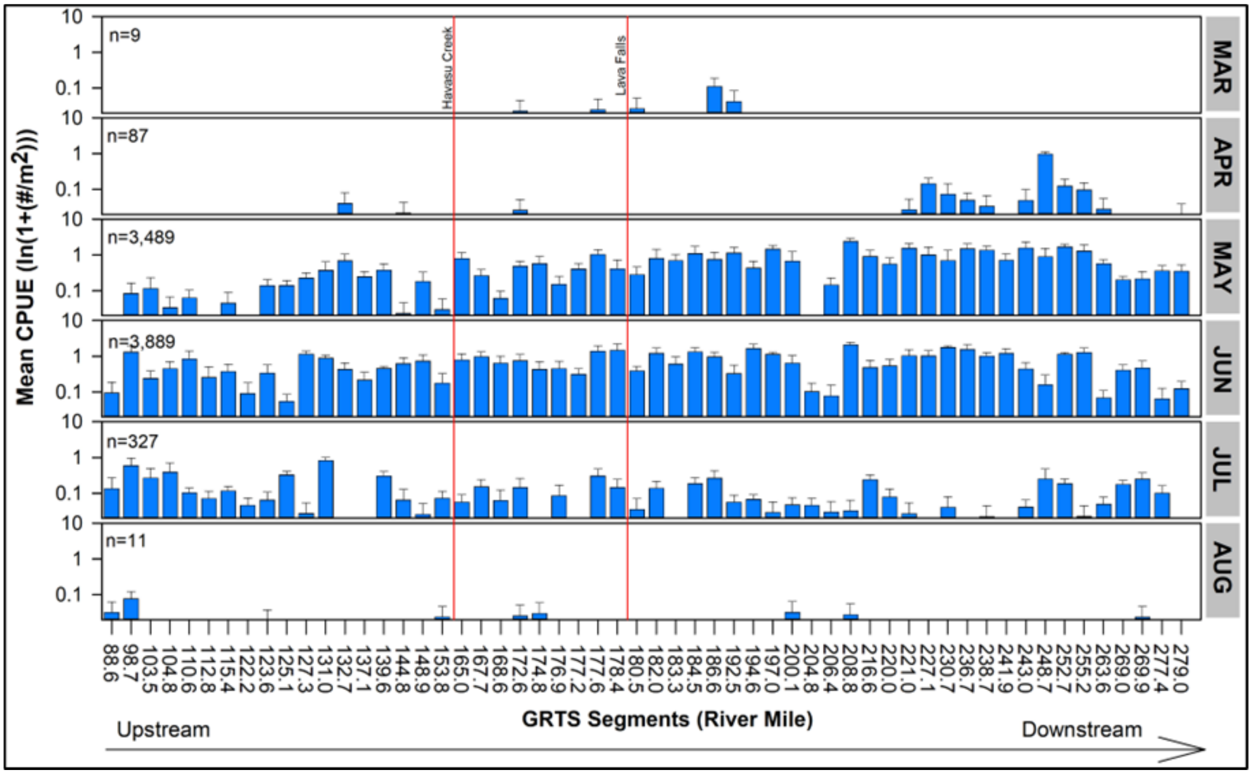

Figure 2.13. Mean CPUE of age-0 Bluehead Sucker by 2022 sampling trip (month) and GRTS segment. The *y*-axis scale is $\log_{10}$ and error bars are ± 1 SE.

June had the highest catch rate of age-0 fishes among the 2022 monthly surveys and was significantly higher than all other months surveyed except May (ANOVA, $F_{5, 330}$=68.55, *P*<0.001; Tukey's HSD, *P*<0.05) (Figure 2.12, Appendix E.5).

Catostomids were distributed throughout the study area and continued to numerically dominate collections consisting of greater than 79.1% (n=7,973) of the total age-0 catch. Flannelmouth Sucker was the most abundant age-0 species collected (n=4,081; 51.2%), followed closely by Bluehead Sucker (n=3,889; 48.8%) (Figure 2.13, 2.14). As during previous monthly trips, Razorback Sucker larvae were not present in June samples (Figure 2.15).

Native cyprinids composed a smaller portion of the age-0 catch in June (20.8%). Speckled Dace was the most abundant native cyprinid (n=1,997) and was distributed over most of the study area (RM 98.7–279.0) (Figure 2.17). This was the second monthly sample that yielded Humpback Chub with the distribution of Humpback Chub expanded nearly 60 miles upstream (upstream of Havasu Creek) between the May and June effort (from RM 148.9 to RM 208.8) (Figure 2.16). These fish (n=101) were distributed between RM 98.7 (the second downstream GRTS site) and RM 279.0 (Figure 2.18).

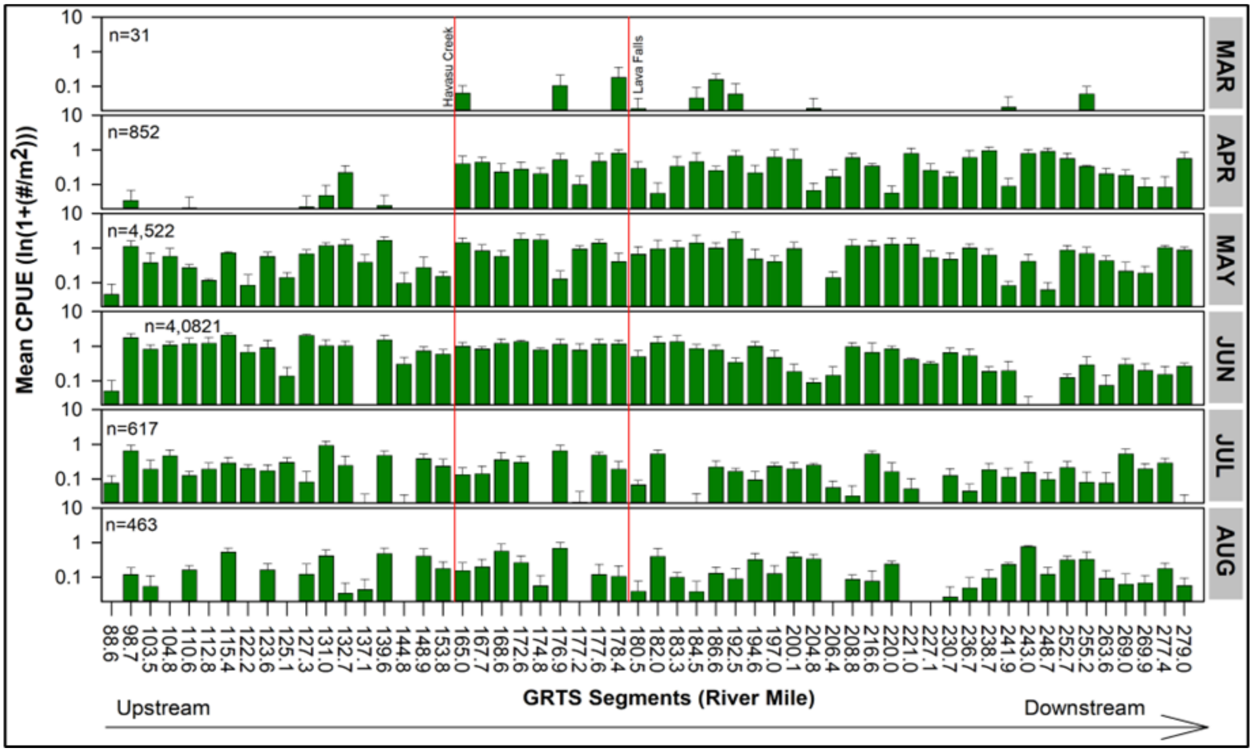

Figure 2.14. Mean CPUE of age-0 Flannelmouth Sucker by 2022 sampling trip (month) and GRTS segment. The *y*-axis scale is $\log_{10}$ and error bars are ± 1 SE.

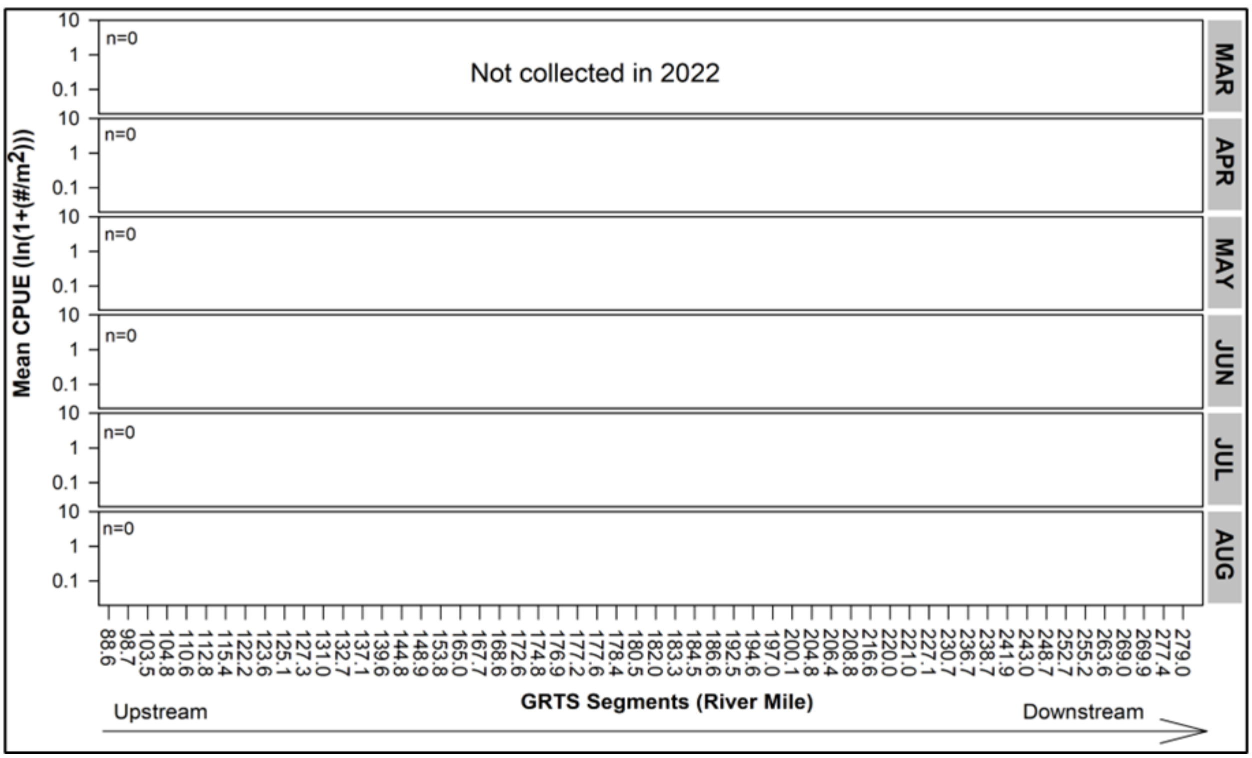

Figure 2.15. Mean CPUE of age-0 Razorback Sucker by 2022 sampling trip (month) and GRTS segment. The *y*-axis scale is $\log_{10}$ and error bars are ± 1 SE. None collected in 2022. Graph is a placeholder for between-year consistency.

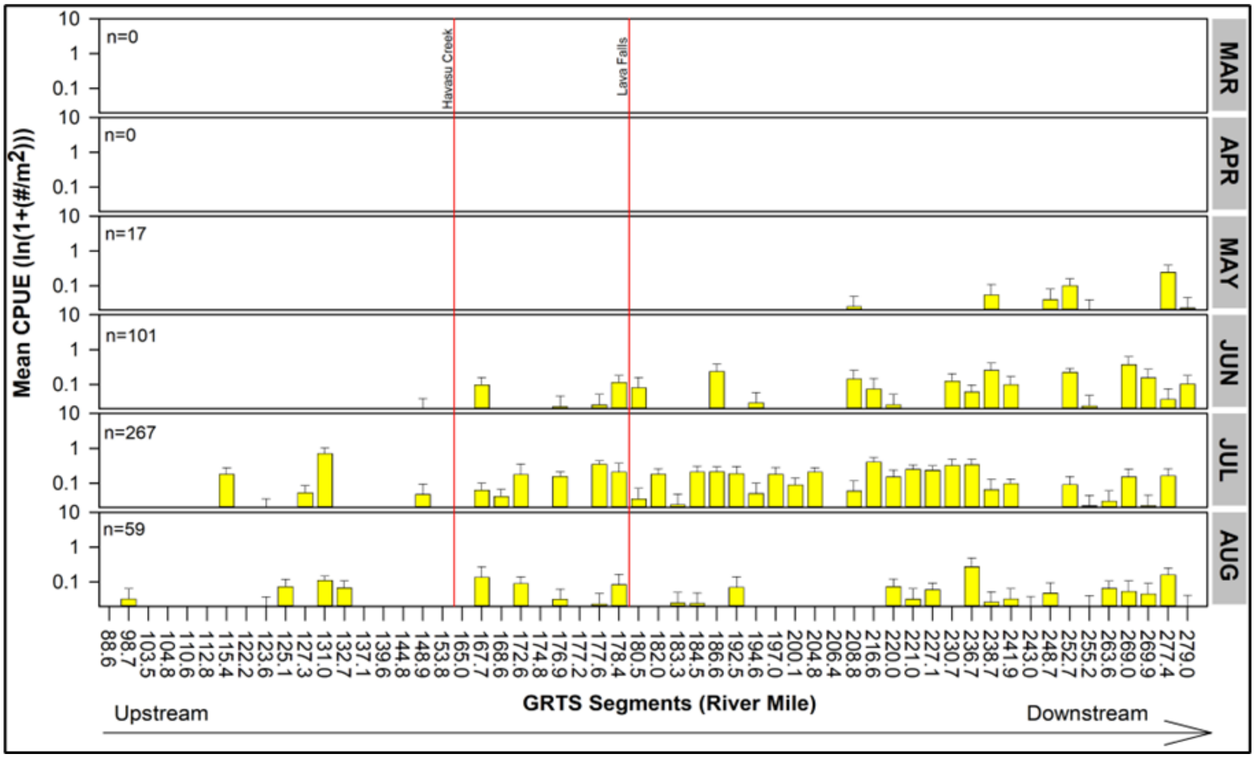

Figure 2.16. Mean CPUE of age-0 Humpback Chub by 2022 sampling trip (month) and GRTS segment. The *y*-axis scale is $\log_{10}$ and error bars are ± 1 SE.

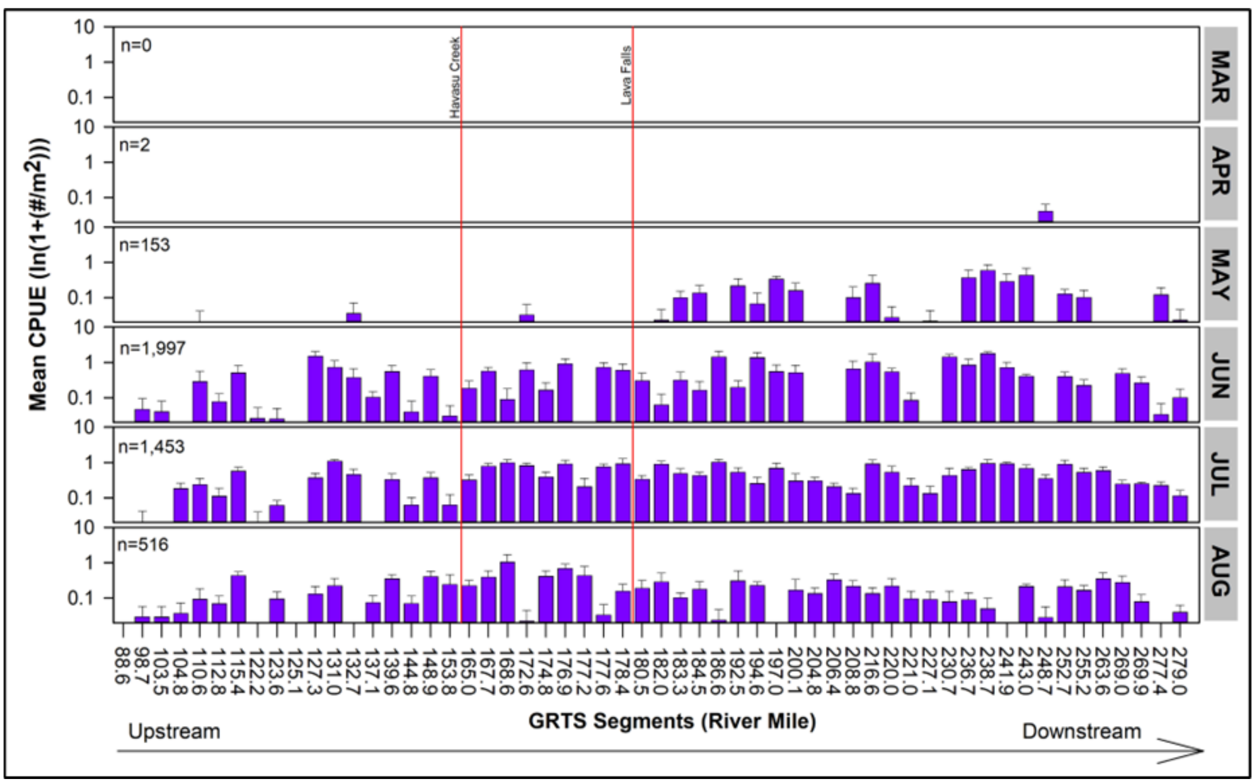

Figure 2.17. Mean CPUE of age-0 Speckled Dace by 2022 sampling trip (month) and GRTS segment. The *y*-axis scale is $\log_{10}$ and error bars are ± 1 SE.

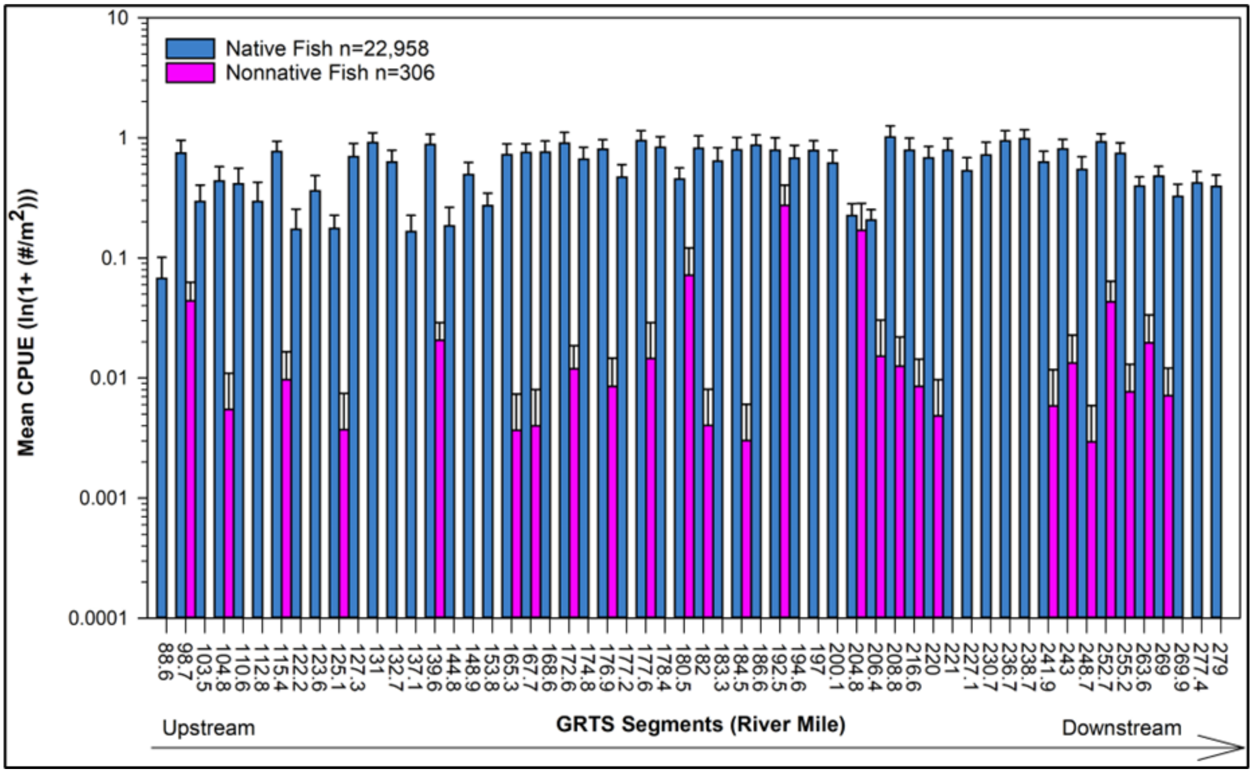

Figure 2.18. Mean CPUE of age-0 native and nonnative fishes by GRTS segment for 2022 survey months (March–August) combined. The *y*-axis scale is $\log_{10}$ and error bars are ± 1 SE.

Individuals in the June sample were more developed (later ontogenetic stages) than in the May sample. The eight flexion mesolarval Humpback Sucker present in the June collection were distributed between RM 167.7 and RM 238.7 (Figure 2.16). The remainder of the specimens were post-flexion mesolarvae (n=37, 36.6%), while the largest portion of the sample was metalarval fish (n=56, 55.5%). Juvenile Humpback Chub were not collected in the June 2022 sample. Speckled Dace numbers, distribution, and catch rate increased greatly from May to June (Figure 2.17). This species was collected from the second GRST location (RM 98.7) downstream to the lowermost site (RM 279.0). June sampling also produced the lowest catch rate of age-0 nonnative fishes among 2022 monthly surveys. Interestingly, only two nonnative species, Fathead Minnow and Western Mosquitofish, were collected during June 2022, and they were represented (collectively) by only three specimens collected at three separate GRTS sites.

Age-1 incidental captures during June 2022 were composed of three native species (Appendix F.5). Speckled Dace was the most abundant (n=28; 80.0%) followed by Flannelmouth Sucker (n=6) and Bluehead Sucker (n=1). Catch rates of age-1+ fishes were low in June and comparable to the April survey.

July: The July 2022 larval fish survey occurred 5–13 July (Table 2.6). Mean hourly discharge in the Colorado River during this survey (as measured from the USGS gage 09402500 near Grand Canyon, Arizona) was 11,411 cfs while mean daily discharge ranged from 9,827 to 12,242 cfs (Figure 2.11). Periods of lower flow corresponded to reduced weekend releases (although travel time ameliorates the decline in flow downstream). Water clarity during the July

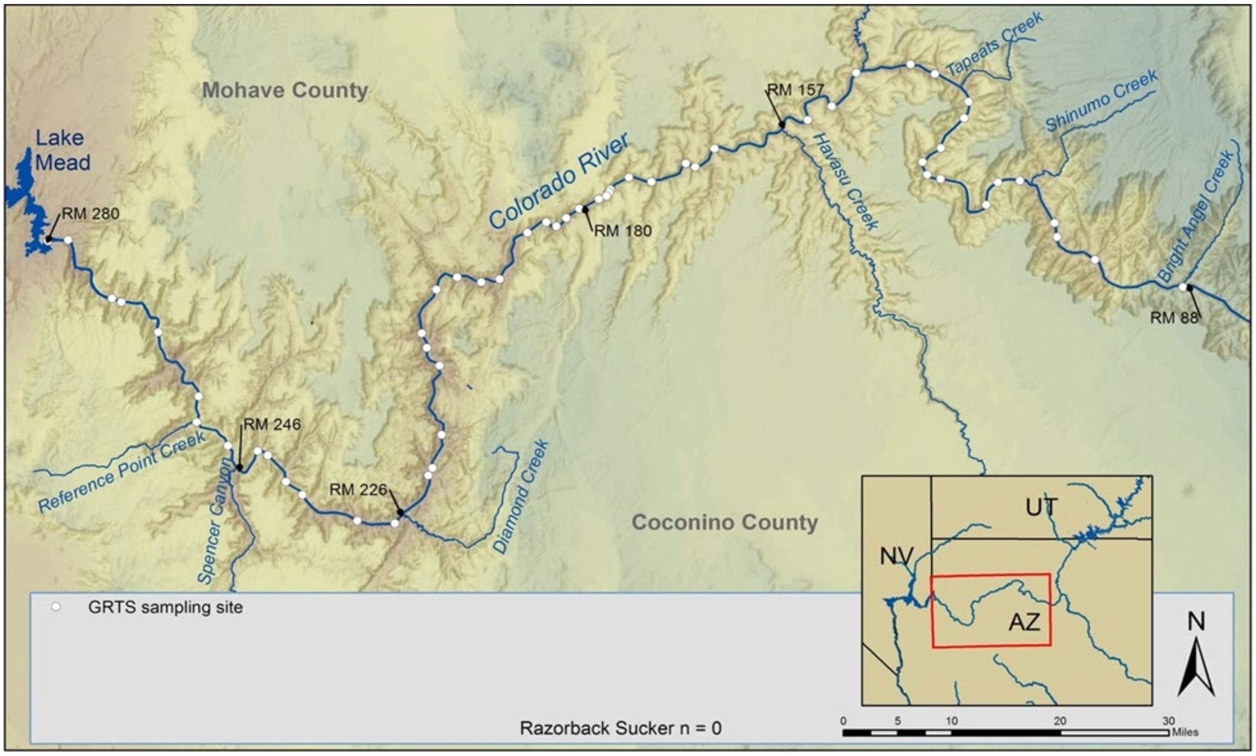

Figure 2.19. Frequency of occurrence of larval Razorback Sucker at GRTS segments during the 2022 larval fish survey. None collected in 2022. Graph is a placeholder for between-year consistency.

2022 trip, as measured with a Secchi disk, was greatly reduced from all previous 2022 trips (where it was generally >1 m). Secchi disk depth during July ranged between only 6 and 12 cm from RM 86.6–RM 279.0 (7–13 July) and was generally <10 cm throughout the study area. Water clarity in the Colorado River was high; Secchi disk depth was greater than 100 cm at 48 of 56 sites (RM 88.6–243.0) and decreased from 64 cm at RM 248.7 to 11 cm at RM 279.0. Mean daily water temperature, recorded near the middle of the study area (RM 190.6), was 18.7°C and ranged from 18.5 to 18.9°C (Figure 2.11). Conversely, mainstem daytime (0800 to 1700) water temperatures recorded at low-velocity sample locations ranged from 20.0 to 29.4°C, increasing slowly downstream.

Capture rate of age-0 fishes during the July survey was moderate but significantly lower than the May and June surveys (ANOVA, $F_{5,\,330}$=68.55, P<0.001; Tukey's HSD, P<0.05) (Figure 2.12). Catostomids continued to be the most numerous and widely distributed age-0 fishes captured (Appendix E.6). Bluehead Sucker (n=327) and Flannelmouth Sucker (n=617) occurred in nearly every segment sampled (n=47 and 50, respectively) and collectively comprised 34.7% of the total age-0 captures (Figures 2.13 and 2.14). Speckled Dace (n=1,453) and Humpback Chub (n=267) were the two most numerous native age-0 cyprinids captured during July 2022 (Appendix E.4). This month produced the greatest number of Humpback Chub, which were present at 36 of 56 (64.3%) GRTS segments and distributed over 148 river miles (RM 115.4–277.4) (Figure 2.16). Humpback Chubs were represented by all developmental phases except protolarvae, with the oldest two stages (metalarvae and juvenile) comprising the majority of the specimens. Nonnative, age-0 fish captures remained low and were less than 3% (n=59) of the total age-0 fish captured (Appendix E.4). Nonnative, age-0 fishes were primarily Plains Killifish (n=43) and Fathead Minnow (n=7). The July 2022 sample yielded six larval Striped Bass (nonnative), which is a species that had not been previously collected in this study. These six specimens were collected at six separate GRTS sites between RM 139.6 and RM 220.0 and measured 27.0 mm SL to 31.5 mm SL (mean=28.9 mm SL). This was the only sampling event in which Striped Bass were collected.

During the July survey, 335 age-1 fishes were incidentally captured. Age-1 fish collected were primarily Speckled Dace (n=316; 94.3%), Humpback Chub (n=12; 3.6%), Fathead Minnow (n=2; 0.6%), Flannelmouth Sucker (n=1, 0.3%) Plains Killifish (n=3, 0.9%) and Western Mosquitofish (n=1, 0.3%) (Appendix F.6).

***August**:* The final larval fish survey of 2022 occurred during 9–16 August (Table 2.6). Mean hourly discharge in the Colorado River during this survey was 13,119 cfs, while mean daily discharge during the August survey ranged from 10,980 to 15,093 cfs. Water clarity during the August 2022 trip, as measured with a Secchi disk, was greatly reduced from all previous 2022 trips (when it was generally >1 m). Secchi disk depth during August ranged between only 2 and 3 cm throughout the study area. Mean hourly water temperature near the middle of the study area (RM 190.6) was 23.5°C and ranged between 22.8 to 24.2°C. These temperatures are markedly higher than any previous 2022 sampling events.

Larval fish capture rate in August was comparable to April and was significantly lower than it was during the May–July surveys (ANOVA, $F_{5,330}$=68.55, P<0.001; Tukey's HSD, P<0.05) (Figure 2.12). Cyprinidae was the most abundant family collected in August (n=587, 54.8%) followed by Catostomidae (n=474, 44.3%). The remaining two species were represented by 10 total specimens which were <1% of the August catch (Appendix E.7). Ontogenetic stage (juvenile) could only be determined for retained Bluehead Sucker (n=5) and Flannelmouth Sucker (n=19), which were a small percent of the total catch. Released specimens were most likely juveniles. While Bluehead Sucker were collected at only nine sites, they were present throughout almost the entire study area (RM 88.6 to RM 269.9). Conversely, Flannelmouth Sucker were taken at 46 of the 56 sample sites but were also distributed throughout almost the entire study area (RM 98.7 to RM 279.0). Humpback Chub (n=59) was also widely distributed, occurring at 27 GRTS segments from RM 98.7 to RM 279.0. All Humpback Chubs retained during the August collection were juveniles. Catch rates of nonnative, age-0 fishes were very low in August, at 2.1% of the total monthly fish captured. Fathead Minnow was the most abundant of the three nonnative, age-0 fish species collected (n=12; 1.1%).

Age-1 incidental captures during August were the second-highest of the months surveyed during 2022 (Appendix F.7). Speckled Dace was the most abundant species collected (n=141; 60.0%), followed by age-1 Humpback Chub (n=26; 28.9%). Age-1 Rainbow Trout (a nonnative) were the third-most abundant species collected in August 2022. The remaining five age-1 species were represented by 13 specimens, including five age-1 catostomids.

***Native and nonnative fishes**:* Ten species of age-0 fish were captured during the 2022 larval fish surveys. Four of the 10 species were native fishes representing two families: Catostomidae (n=2 species) and Cyprinidae (n=2 species). Native fishes numerically dominated the monthly captures in 2022 (98.6%) and were taken at all 56 GRTS segments (RM 88.6–279.0) (Figure 2.18). Native catostomids, Bluehead Sucker (n=7,812) and Flannelmouth Sucker (n=10,566), were the two most commonly captured age-0 species, collectively accounting for 79.0% of age-0 fishes. Native cyprinids—Speckled Dace (n=4,121) and Humpback Chub (n=444)—were the next most abundant age-0 species collected. Nonnative fishes captured were represented by five families (Cyprinidae, Salmonidae, Fundulidae, Poeciliidae, and Moronidae), seven species, and 306 specimens. Age-0 nonnative fishes were found in extremely low densities in 26 of 56 GRTS segments throughout most of the study area (RM 98.7–269.9) (Figure 2.18). Fathead Minnow (n=185), Common Carp (n=54), and Plains Killifish (n=54) were the three most abundant nonnative, age-0 species captured. Overall, nonnative, age-0 fishes (n=306) represented a small proportion (1.3%) of the total age-0 captures (n=23,264) (Appendix E.1). The highest number of nonnative, age-0 fishes were collected in May (n=124, 40.5%) followed by April (n=97, 31.7%), and July (n=59, 19.3%). The majority of nonnative, age-0 fishes were collected at RM 192.5 (n=308; 74.4%) and were represented by three species: Common Carp (n=53), Fathead Minnow (n=39), and Plains Killifish (n=1). Green Sunfish, an invasive and piscivorous species of concern collected during previous years (2019–2020), was not collected in 2021 or 2022. The absence of specimens in 2022 does not preclude this species presence in the Grand Canyon. Unfortunately, a previously undetected (by this study) piscivorous nonnative fish, Striped Bass, was recorded via the capture of larval specimens in July 2022. Between RM 139.6 and RM 220.0, a total of six larval Striped Bass (27.0 mm SL to 31.5 mm SL; mean=28.9 mm SL) were collected at six separate GRTS sample sites.

Unidentified Larval Specimens

Of the approximately 23,000 age-0 fishes collected in the 2022 Grand Canyon study, all except 15 were identified to species. The 15 specimens not yet identified to species were all catostomids of the subfamily Catostomidae (which includes *Catostomus* and *Xyrauchen*). The reason these individuals were not identified to species is because they did not exhibit a sufficient suite of morphological characteristics necessary to assign its species identity with a high level of confidence. Many of the 15 specimens exhibited one characteristic indicative of one species and a second or third characteristic that potentially indicated a different species.

These fish were collected from 15 March 2022, through 10 July 2022, in 10 discrete samples and were distributed from RM 98.7 to RM 255.2. While most samples (n=9) of unidentified Catostomidae contained a single individual, one sample (March, RM 186.6) yielded six specimens. The remainder of the monthly samples contained one, two, or three specimens. Unidentified catostomid specimens ranged from 12.5 to 15.5 mm SL (mean 14.7 mm SL) and were distributed across the three earliest developmental stages (protolarval n=1, flexion mesolarval n=14, post-flexion mesolarval n=1). Laboratory notes associated with the unidentified fish indicate that most of the specimens are likely Flannelmouth Sucker (with unusual pigmentation), Bluehead Sucker (one individual, also with unusual pigmentation), and a potential Flannelmouth Sucker x Razorback Sucker (with intermediate pigmentation). Obviously, these notes are indicative of preliminary observations and do not represent final determination of identifications.

We are working with the Southwestern Native Aquatic Resources and Recovery Center in Dexter, New Mexico, to perform molecular genetic analysis of the 22 unidentified 2021 and the

15 unidentified 2022 specimens. The purpose of the analysis is to provide species-specific identifications of the larval specimens so we can also determine if the parents of the specimens are of the same (i.e., "pure") or different (i.e., "hybrid") species. We hope to have these data for both years before submission of the 2023 report and will include that information in that document.

Razorback Sucker

Larval Razorback Suckers were collected in Grand Canyon for six consecutive years during the study period (2014–2019). The number of larval Razorback Suckers taken per sampling year has declined since the initiation of sampling for this species (2014=462, 2015=81, 2016=46, 2017=27, 2018=10, 2019=8) although sampling effort has remained relatively consistent throughout the study.

Razorback Sucker larvae have not been collected during the past three sampling seasons (2020, 2021, and 2022), although it is important to note that sampling was not conducted in April or May 2020 (because of national park closures during the COVID-19 pandemic). From 2014 through 2019, these 2 months (April and May) collectively yielded over 90% of the larval Razorback Sucker catch from the Grand Canyon (monthly catch of Razorback Sucker 2014–2019: March: 4.8%, April+May: 90.3%, June:4.3%, July: 0.5%, August: 0.2%). Sampling during April and May was conducted in both 2021 and 2022 but has not yet again produced Razorback Suckers (Figures 2.19, 2.20, 2.21, and 2.22).

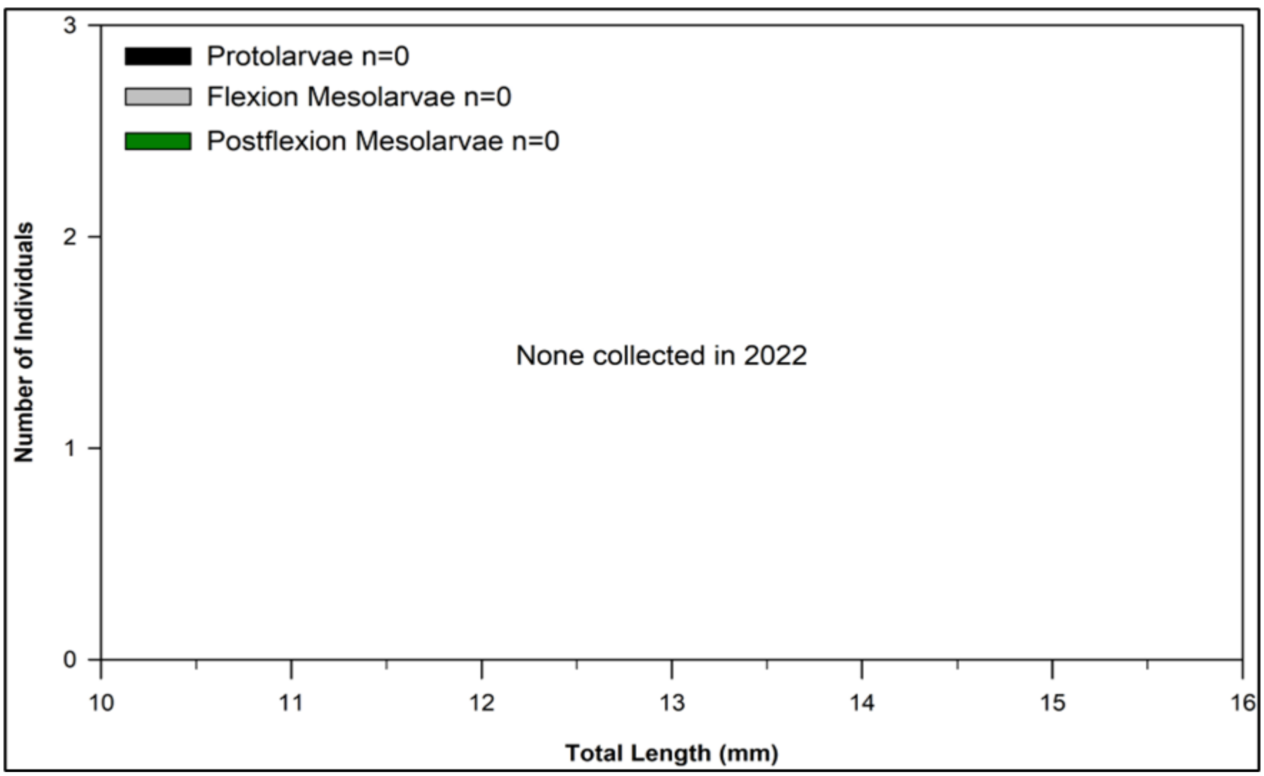

Figure 2.20. Distribution of total lengths (TL) of larval Razorback Sucker captured during the 2022 larval fish survey. None collected in 2022. Graph is a placeholder for between-year consistency.

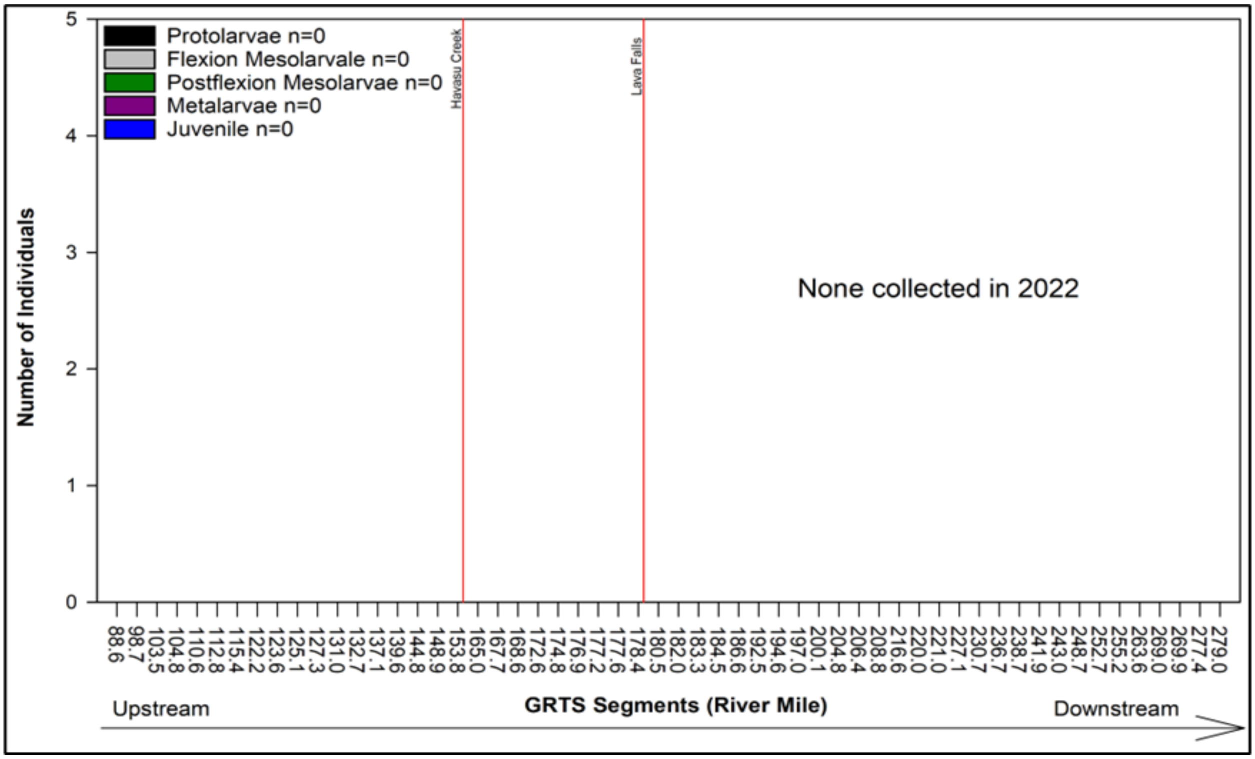

Figure 2.21. Spatial and ontogenetic stage distribution of larval Razorback Sucker captured during the 2022 larval fish survey. None collected in 2022. Graph is a placeholder for between-year consistency.

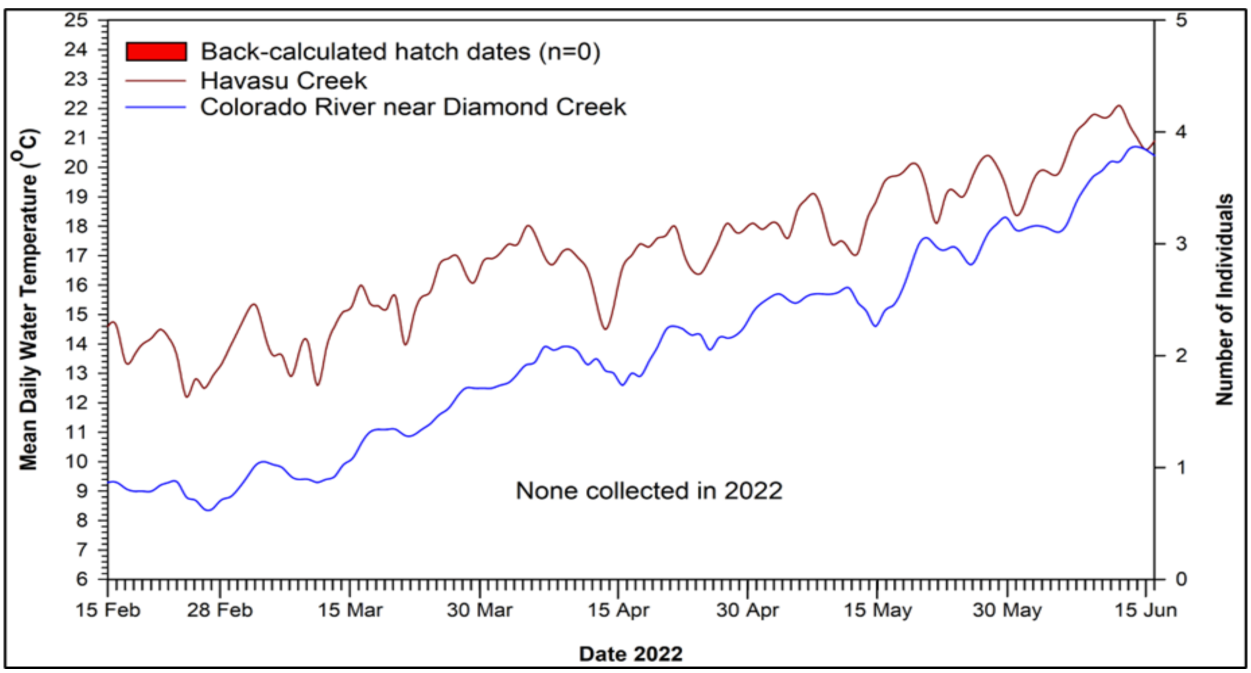

Figure 2.22. Water temperature of Havasu Creek and the Colorado River upstream of Diamond Creek (USGS gage 09404200) displayed with the back-calculated hatching dates of Razorback Sucker based on 2022 larval fish standard length (SL). None collected in 2022. Graph is a placeholder for between-year consistency.

Humpback Chub

Larval fish sampling in 2022 yielded 444 age-0 Humpback Chubs from RM 98.7 to the downstream-most site in the study area (RM 279.0) (Figure 2.23). Age-0 specimens ranged from 9.2 to 38.0 mm TL and were represented by flexion mesolarvae, postflexion mesolarvae, metalarvae, and juvenile ontogenetic stages—no protolarvae were collected in 2022 (Figures 2.24 and 2.25). The first age-0 Humpback Chubs were collected during the May survey (n=17)—the majority of Humpback Chubs collected in May were flexion mesolarvae (n=12; 70.1%) with five specimens in the postflexion mesolarvae stage.

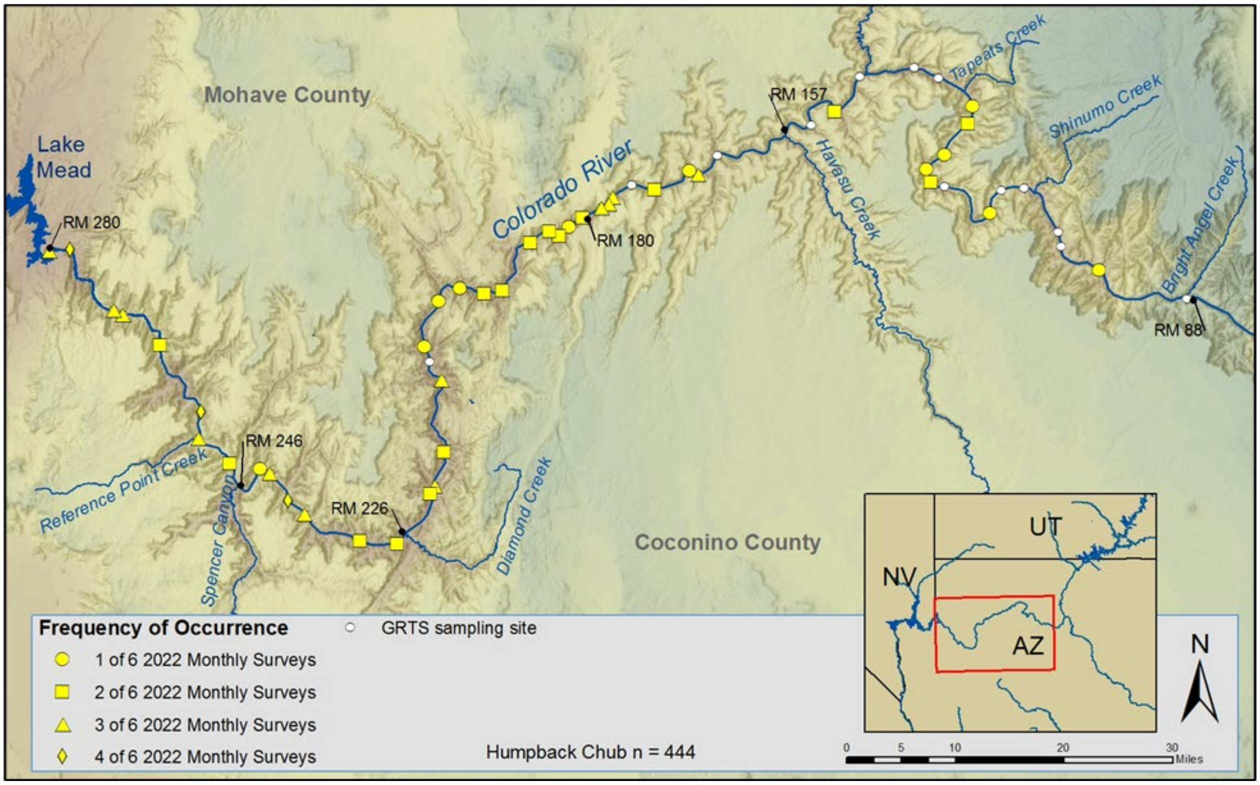

Figure 2.23. Frequency of occurrence of larval Humpback Chub at GRTS segments during the 2022 larval fish survey.

(This space intentionally left blank.)

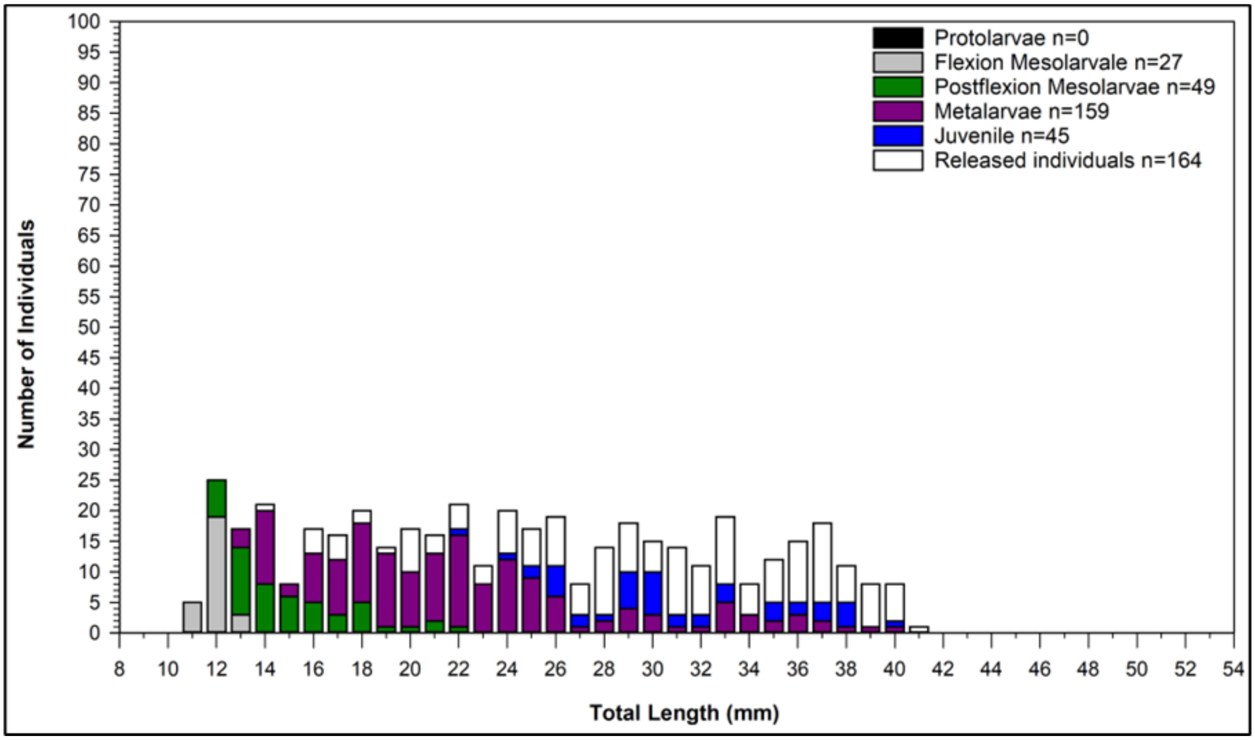

Figure 2.24. Distribution of total lengths (TL) of Humpback Chub captured during the 2022 larval fish survey.

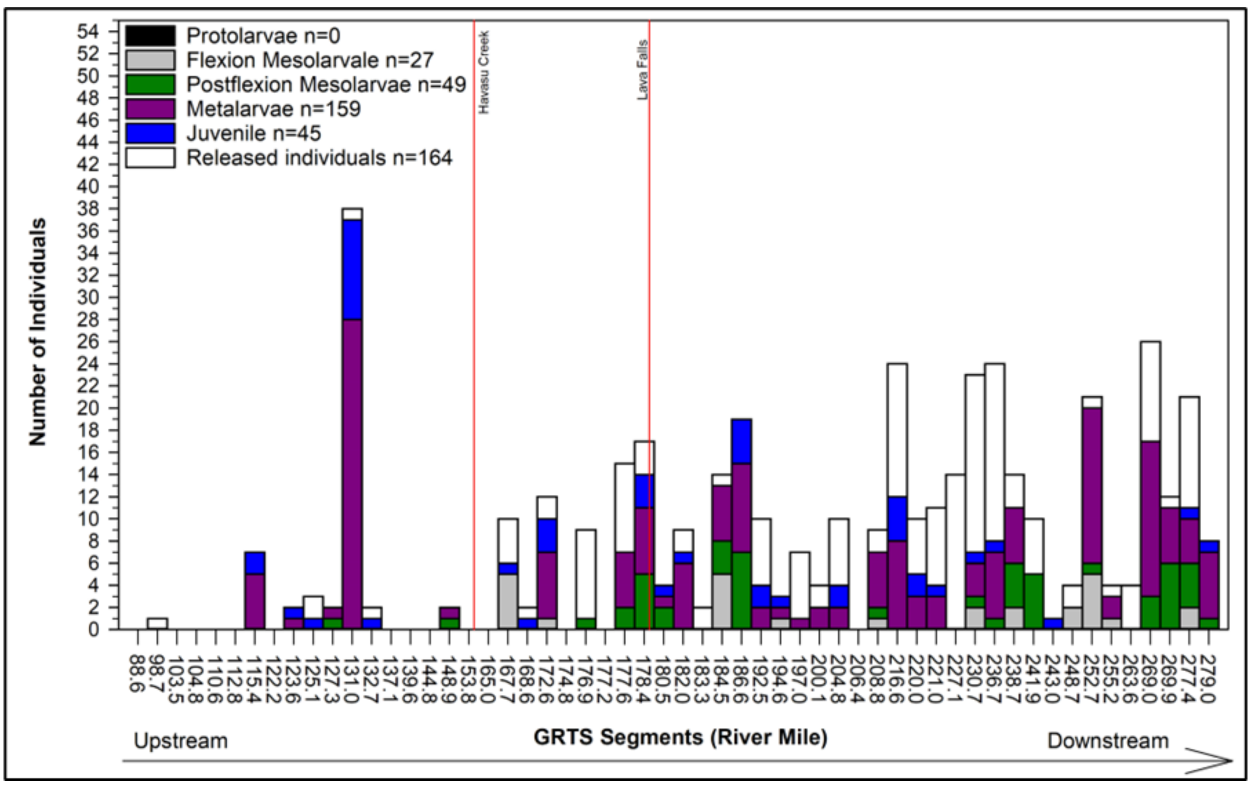

Figure 2.25. Spatial and ontogenetic stage distribution of Humpback Chub captured during the 2022 larval fish survey.

The June and July surveys produced 101 and 267 Humpback Chubs, respectively, which accounted for 82.3% of the age-0 Humpback Chubs collected during 2022. Specimens collected in June and July were primarily flexion mesolarvae and postflexion mesolarvae. The first metalarval Humpback Chubs were collected in June (n=56) and the first juvenile Humpback Chubs were collected in July (n=33). Age-0 Humpback Chubs collected in July were represented by all ontogenetic stages except protolarvae. Humpback Chubs collected during 2022 showed a trend of increasing abundance and ontogenetic phase progression with distance downstream during May–August (Figure 2.25). During 2022, approximately half (57.2%) of age-0 Humpback Chubs were collected downstream of RM 200.1. The upstream-most collection of larval Humpback Chubs (n=1) in 2022 occurred at RM 98.7, during the August survey.

Back-calculated hatch dates for Humpback Chub in 2022 spanned 10 weeks (70 days) from 3 May to 11 July 2022 (Figure 2.26). The distribution of hatch dates suggests that multiple peaks in hatching occurred, beginning in early May with the majority occurring late-May to early June and a final hatch occurring in late-June. Catch rates of Humpback Chub were significantly different across months (ANOVA, $F_{3, 220}$=12.56, P<0.001); catch rates in July were significantly higher than those recorded during the other monthly surveys (Tukey's HSD, P<0.05).

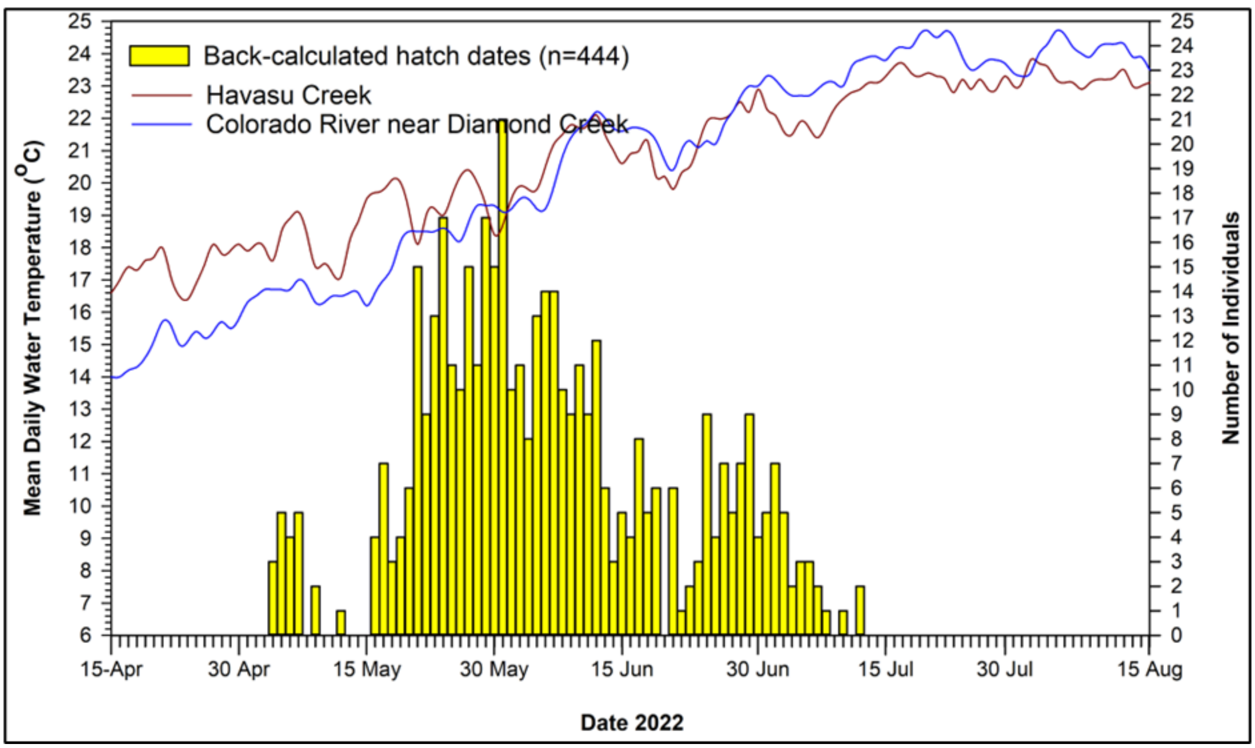

Figure 2.26. Back-calculated hatch dates of Humpback Chub based on 2022 larval fish standard lengths.

Habitat

Ten mesohabitat types were sampled during the 2022 larval fish survey (Figure 2.27). Habitats were sampled in relatively similar proportions during 2022 as in previous years (2016–2021); the largest change in habitats sampled in 2022 was an increase in the percentage of sandshoals and eddies sampled (Table 2.7). Slackwater (40.6%), sandshoal (26.9%), and pool (21.7%) comprised almost 90% (89.2%) of habitats sampled during 2022. Catch rates of larval fishes differed across habitats (ANOVA, $F_{9, 657}$=4.37, P<0.001); catch rates in embayment, pool, and slackwater habitats were significantly higher than in eddy habitats (Tukey's HSD, P<0.05). Bluehead Sucker and Speckled Dace were captured in every habitat type sampled during 2022 except isolated pools, while Flannelmouth Sucker was taken in all 10 aquatic habitats (Figure 2.28).

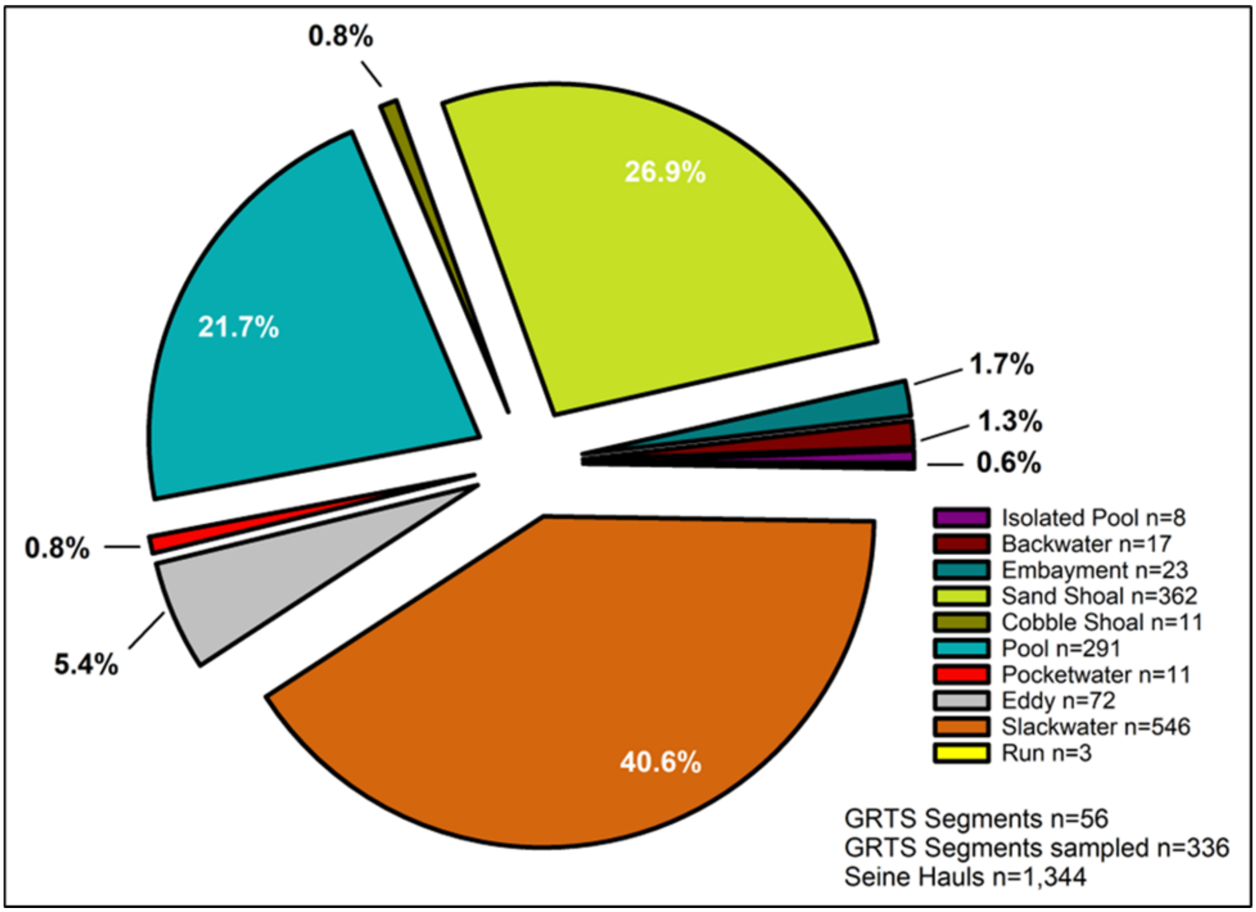

Figure 2.27. Frequency distribution of habitats sampled at GRTS segments during the 2022 larval fish survey.

Table 2.7. Habitats sampled (percent) from monthly 2017–2022 larval fish surveys.

HABITAT	HABITAT SAMPLED 2017	HABITAT SAMPLED 2018	HABITAT SAMPLED 2019	HABITAT SAMPLED 2020	HABITAT SAMPLED 2021	HABITAT SAMPLED 2022	PERCENT CHANGE[a] 2017–2022
Isolated Pool	1.35%	1.49%	0.90%	1.21%	2.25%	0.60%	0.84
Backwater	6.29%	4.99%	5.39%	1.95%	1.65%	1.27%	2.78
Embayment	6.29%	3.65%	7.04%	5.19%	4.27%	1.71%	3.58
Sandshoal	23.28%	22.17%	23.65%	24.58%	19.54%	26.94%	4.30
Cobbleshoal	1.27%	1.56%	1.27%	1.11%	1.42%	0.82%	0.51
Pool	19.24%	20.23%	19.54%	26.81%	32.11%	21.65%	1.94
Pocketwater	2.40%	0.82%	0.45%	0.19%	0.30%	0.82%	0.01
Slackwater	37.28%	40.85%	40.87%	37.76%	36.98%	40.63%	1.88
Eddy	1.70%	4.09%	0.60%	1.02%	1.50%	5.36%	3.85
Run	0.90%	0.15%	0.30%	0.09%	0.00%	0.22%	0.07

[a] Percent change (absolute value): current year percent sampled minus mean of previous years' percent sampled.

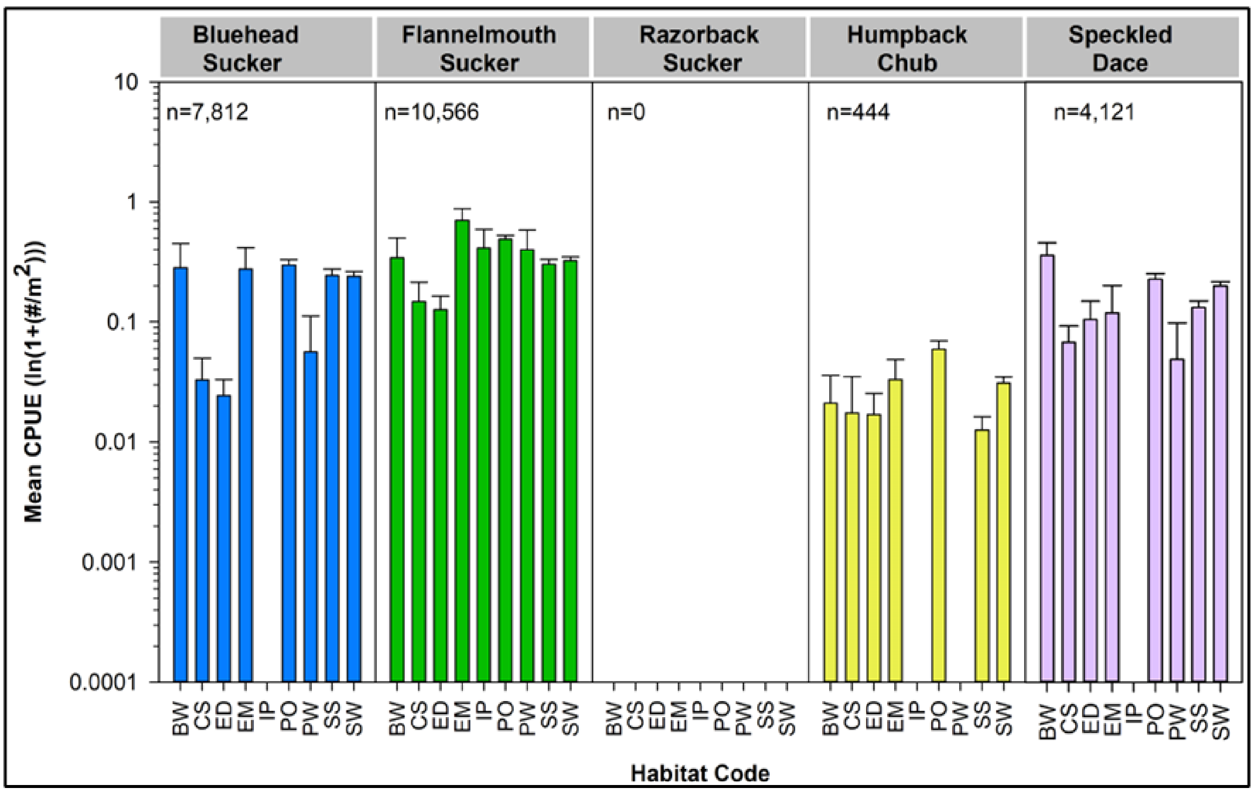

Figure 2.28. Mean CPUE by species and habitat type during the 2022 larval fish survey. The *y*-axis scale is $\log_{10}$ and error bars are ± 1 SE.

Humpback Chub was also collected in most of the habitat types sampled during 2022 except isolated pool and pocketwater habitats. Most Humpback Chub captures (95.2%) occurred in slackwater (43.0%; n=191), pool (39.4%; n=175), or sandshoal (12.8%; n=57) habitats. Eddies, embayments, backwaters, and cobble shoal habitats yielded the remaining specimens of Humpback Chub. Catch rates of Humpback Chub were not significantly different across habitats (ANOVA, $F_{9, 417}$=1.50, P=0.15).

Ontogenetic Phase Distributions

Native fishes in the 2022 larval fish survey were represented by the earliest larval ontogenetic phases through early juvenile. The 2022 catostomid developmental stages showed increasing maturity along a downstream longitudinal gradient. Increasing monthly percentages of late stage larvae and early juveniles at downstream sites is evident for Flannelmouth and Bluehead Suckers, and to a lesser extent, for Humpback Chub (Figures 2.29, 2.30, 2.31). This pattern is apparent in all years when catostomids were ontogenetically staged (2016–2022). Similarly, ontogenetic stages showed a seasonal trend of increasing percentages of late-stage larvae and early juveniles with each progressive monthly survey in 2022.

During larval fish surveys in recent years (2016–2022), the initial captures of catostomid larvae occurred at sites downstream of Havasu Creek (RM 157.3). During March 2022, all larvae Flannelmouth Sucker (n=31) and Bluehead Sucker (n=9) were collected downstream of Havasu Creek. By May 2022, larval catostomids increased in distribution and abundance to encompass the study area (Figures 2.29, 2.30). The first appearance of larval Humpback Chub is typically in May, and again in 2022, the first larval Humpback Chub capture occurred in May, approximately 55 miles downstream of Havasu Creek. In June 2022, Humpback Chubs were collected at RM 148.9, just upstream of Havasu Creek, and downstream to RM 279.0 (Figure 2.30). Catch rates of Humpback Chub upstream of Havasu Creek increased from June through August. In July, Humpback Chub larvae were taken upstream as RM 115.4, while in August a specimen was collected at RM 98.7. During August 2022, larval and juvenile Humpback Chubs were distributed throughout 180.3 river miles (94.7%) of the study area (RM 98.7–RM 279.0).

Distribution of protolarvae, the earliest developmental stage, can be used to infer spatial patterns of spawning over time. The protolarval stage is the shortest of the developmental phases and recently hatched larvae spend much of that stage in the interstitial zones of spawning bars. The hypothesis is that captured protolarvae are likely taken from or relatively close to their natal spawning areas. For the two common sucker species, protolarvae were initially observed in downstream reaches and then documented higher in the system during progressive sampling months, indicating the upstream expansion of spawning (Figures 2.29 and 2.30).

Assessing monthly longitudinal abundance and distribution of discrete ontogenetic phases reveals an interesting pattern. Downstream regions of the study area consistently had higher proportions of more developed ontogenetic stages (i.e., older fish). Conversely, upstream reaches of the study area had higher proportions of less developed larvae (i.e., younger fish). These patterns are likely related to warmer water temperatures in downstream reaches that may stimulate spawning and foster faster development of larval fishes. This pattern, apparent in both Bluehead Sucker and Flannelmouth Sucker (Figures 2.29 and 2.30), might also be indicative of drift (active and passive) of age-0 fish. The pattern of increasing proportions of more-developed fish in downstream reaches is also apparent with larval Humpback Chub. However, due to the rapid growth rate of this species, there is a proportional increase in the catch of older ontogenetic stages of this species later in the year (June–August) (Figure 2.31).

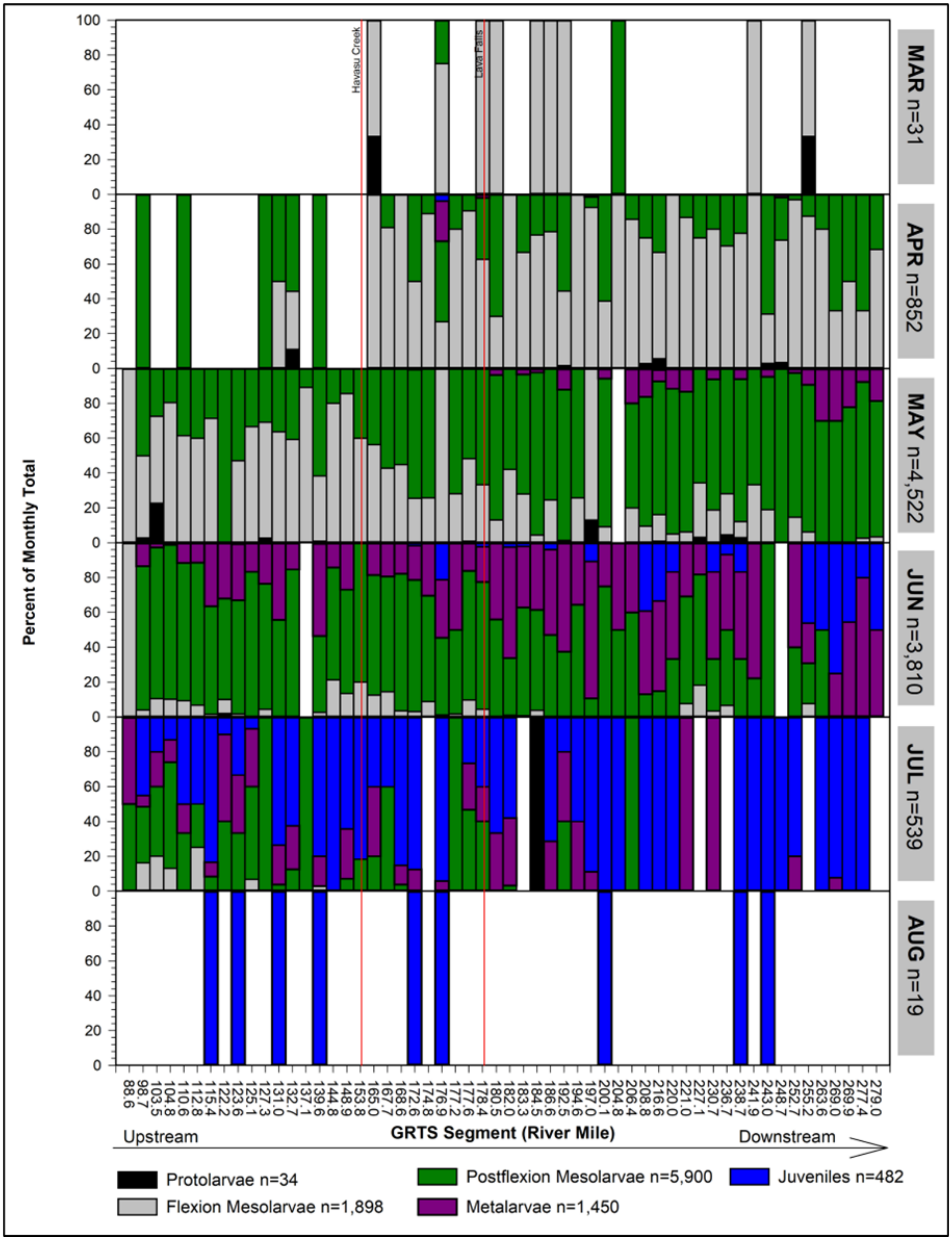

Figure 2.29. Longitudinal distribution of ontogenetic phases of age-0 Flannelmouth Sucker by 2022 sampling trip (month) and GRTS segment.

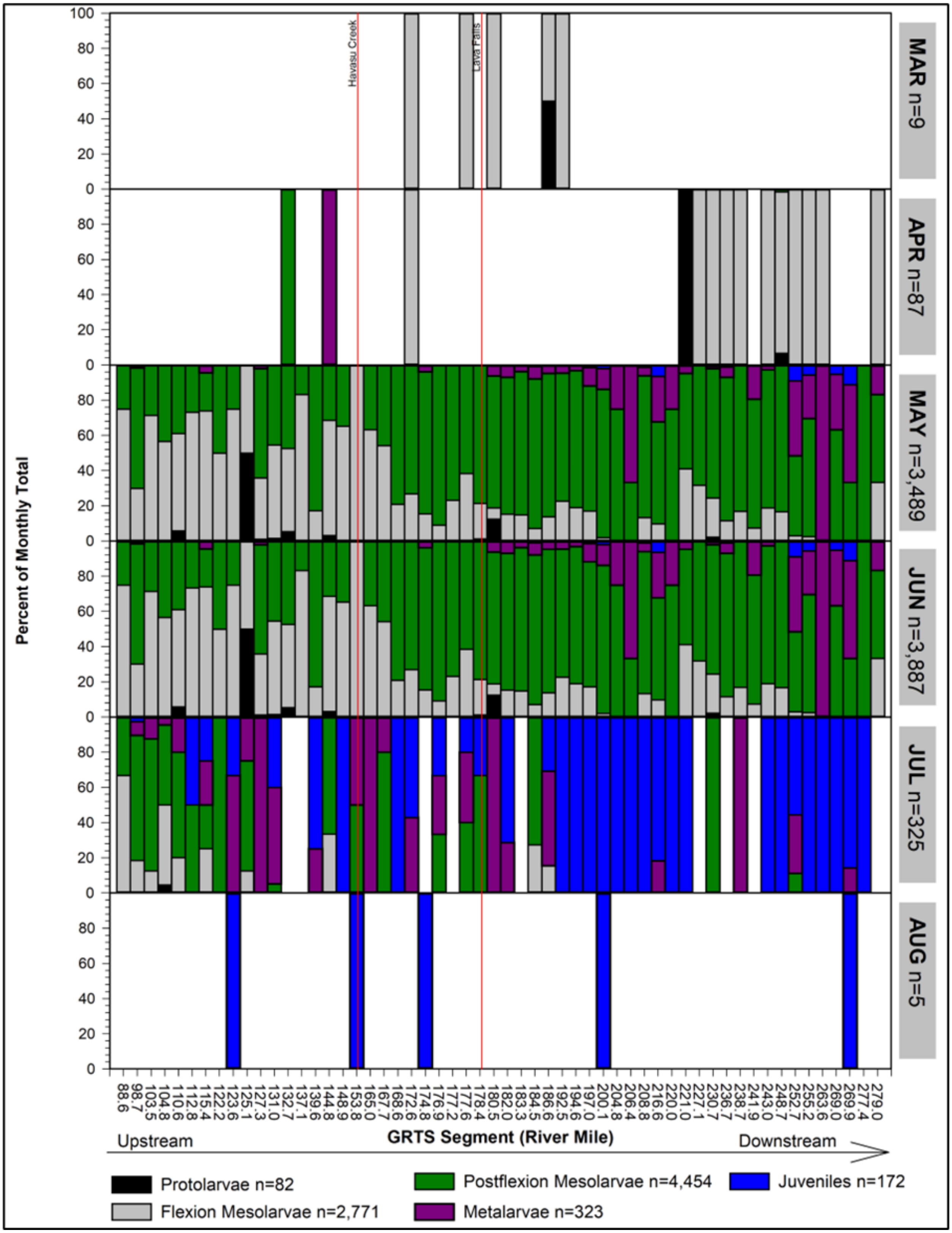

Figure 2.30. Longitudinal distribution of ontogenetic phases of age-0 Bluehead Sucker by 2022 sampling trip (month) and GRTS segment.

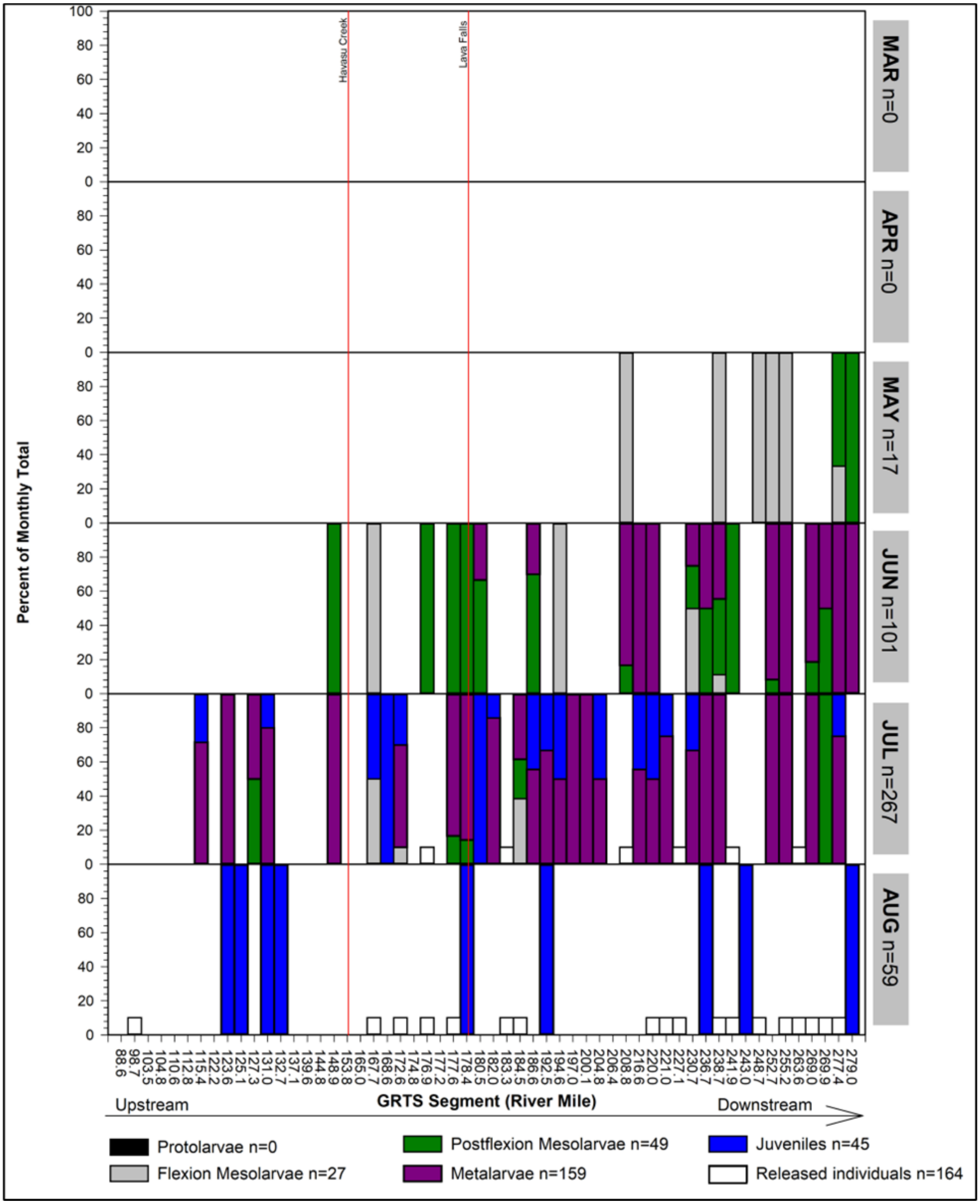

Figure 2.31. Longitudinal distribution of ontogenetic phases of age–0 Humpback Chub by 2022 sampling trip (month) and GRTS segment.

Supplemental Investigations of Larval-Fish Community Sampling (2014–2022)

Project researchers continually evaluate the results of the study and make recommendations for appropriate modifications as needed. The most important project modification was the 2016 upstream expansion of the study area due to the collection of larval Razorback Sucker at the upper end of the study area (Albrecht et al., 2014). At that time, the study area was expanded from 100 to 190 river miles, a 90-river-mile upstream expansion. Conversely, the number of sampling sites remained the same (n=56).

In 2020, comparison of spatial sampling methodologies (random [GRTS] versus opportunistic sampling) was performed using July 2020 collections. Comparison of the two July 2020 larval fish CPUE values (1.83 fish/m^2 GRTS and 1.33 fish/m^2 opportunistic) indicated the GRTS sample catch rate was significantly higher (t-test, t=2.03, P<0.05) than the opportunistic sampling effort. Likewise, CPUE of native fishes during the July GRTS sample was significantly higher (t-test, t=2.02, P<0.05) than the opportunistic effort. Conversely, there was not a statistically significant difference (t-test, t=0.40, P=0.69) between the two July 2020 nonnative larval fish catch rates.

In 2021, the effect of the 2016 upstream expansion of the study area on interannual variation in larval fish catch rates was investigated. Financial and regulatory prerequisites of the upstream expansion of the study area (90 river miles upstream) necessitated maintaining the same number of sampling sites (n=56) despite nearly doubling the length of the study reach. As a result, post-2016 efforts had only 29 sites in the lower 100 river miles (RM 179.0–279.0), whereas there had previously been 56 sites. The potential effects of these changes to site density per river mile and distribution of larval catch rates motivated a supplementary statistical comparison of catch rates in the downstream portion of the study area. Larval fish catch rates from 2016–2021 were determined using only the 29 GRTS sites in the lower 100 river miles of the Grand Canyon (RM 179.0–279.0) and compared for the duration of the study (2014–2021).

A Tukey's Honestly Significant Difference (HSD) post-hoc test (α=0.05) was used to examine all pairwise comparisons of catch rates across years (2014–2021) for: (1) families (Catostomidae, Cyprinidae), and (2) species (Bluehead Sucker, Flannelmouth Sucker, Razorback Sucker, Humpback Chub, and Speckled Dace). Of 196 possible pairwise combinations across years for families and species, 65 combinations were significantly different (P<0.05). Most statistically different combinations included 2014 (n=44; 68.0%). The significantly different combinations that did not include 2014 (n=21) were statistically weaker than comparisons that included 2014—the notable exception was for Humpback Chub, which has been collected at relatively low catch rates throughout the study. As noted in previous annual reports, overall catch rates during 2014 were significantly higher than catch rates during the remainder of the study period (Figure 2.32).

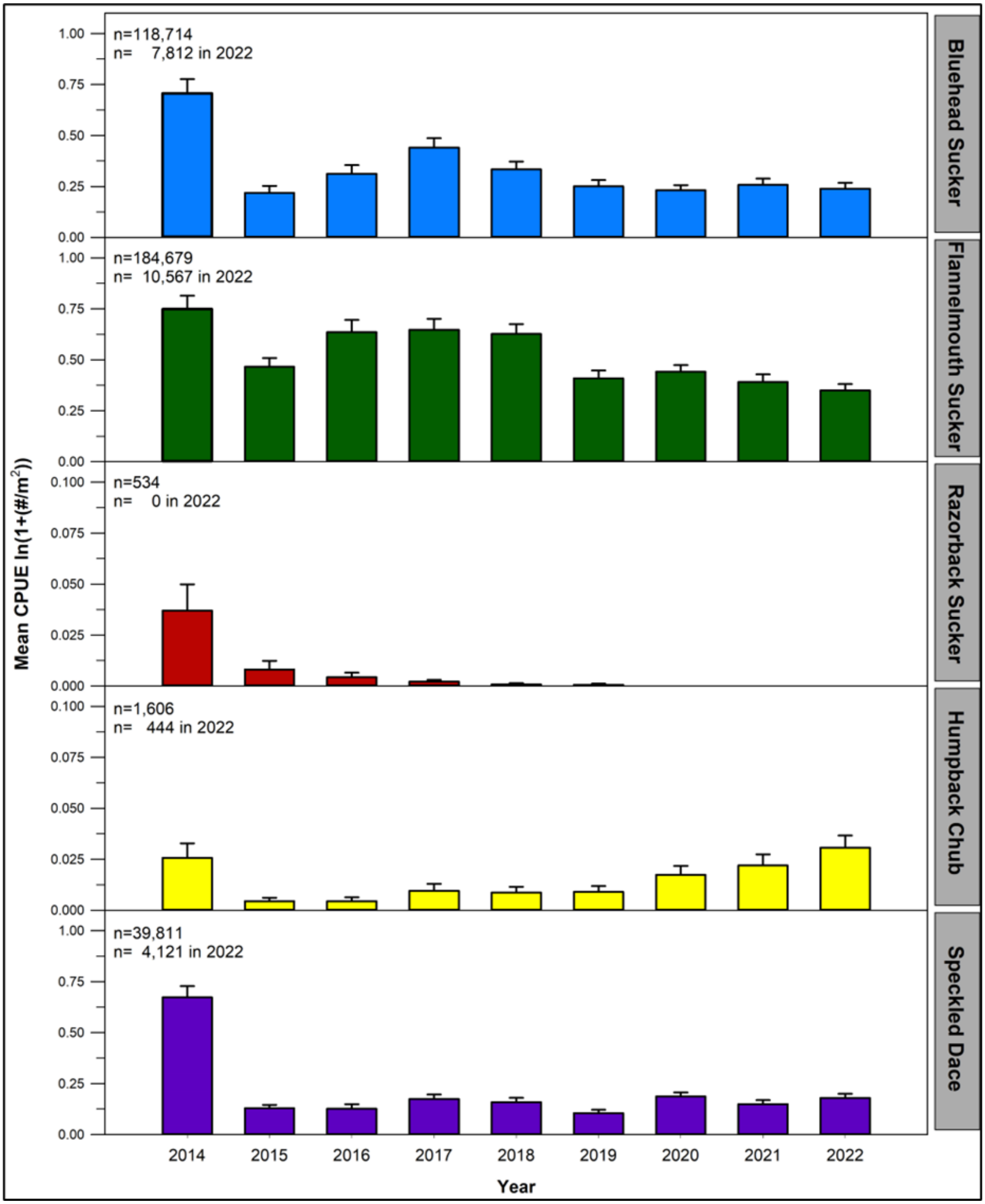

Figure 2.32. Mean CPUE of age-0 native fishes by year. The *y*-axis scales for Razorback Sucker and Humpback Chub are, compared to other species, reduced one order of magnitude. Error bars are 95% confidence intervals.

This analysis indicated that catch rates in the current 190.4 river mile study area (2016–2021) are comparable to 2014–2015 survey years. Differences in the distribution and density of GRTS sample segments per river mile did not explain differences in catch rates across years and the high catch rate in 2014 remains an anomaly. Continued larval fish sampling in Grand Canyon may yet elucidate factors that contributed to the elevated 2014 annual catch rate. In the meantime, this analysis provides statistical validity to continue comparisons of 2014–2021 (and subsequent) catch rates of larval fishes in the Grand Canyon.

Larval-Fish Community Sampling Summary (2014–2022)

During the study period (2014–2022), larval-fish community sampling in Grand Canyon has consistently documented reproduction annually by the four following native species: Bluehead Sucker, Flannelmouth Sucker, Humpback Chub, and Speckled Dace. Until 2020, reproduction by Razorback Sucker was documented annually (2014–2019) (Figure 2.32). The loss of the ability to sample during April and May 2020 (because of national park closures during the COVID-19 pandemic), the 2 months that formerly yielded greater than 90% of larval Razorback Suckers collected 2014–2019, precluded inferences on reproduction of Razorback Sucker that year. In 2021 and 2022, no Razorback Sucker larvae were collected; 22 larval 2021 catostomids and 15 larval 2022 catostomids remain to be identified to species using genetic procedures. The 2022 larval-fish survey continued to document spatial and temporal trends related to the reproduction of native and nonnative fishes in the Grand Canyon. Consistent with previous survey years (2014–2021), native fishes dominated (98.7%) collections of age-0 fishes in Grand Canyon during 2022 (Figure 2.18).

While intraspecific age-0 larval fish densities (CPUE) have varied somewhat across years, 2014 yielded significantly higher densities (Tukey's HSD, $P<0.05$) than subsequent years (2015–2022) for all five native species collected, except Humpback Chub (Figure 2.32). Catch rates of Humpback Chub were significantly higher in 2021 and 2022 than during 2015–2019 ($P<0.05$); however, this species has typically occurred in low abundances relative to the other native species (Figure 2.32). Overall, the finding of significantly higher densities in 2014 held for both Catostomidae and Cyprinidae ($P<0.05$) and appears independent of their distinct spawning periods (Figure 2.33).

(This space intentionally left blank.)

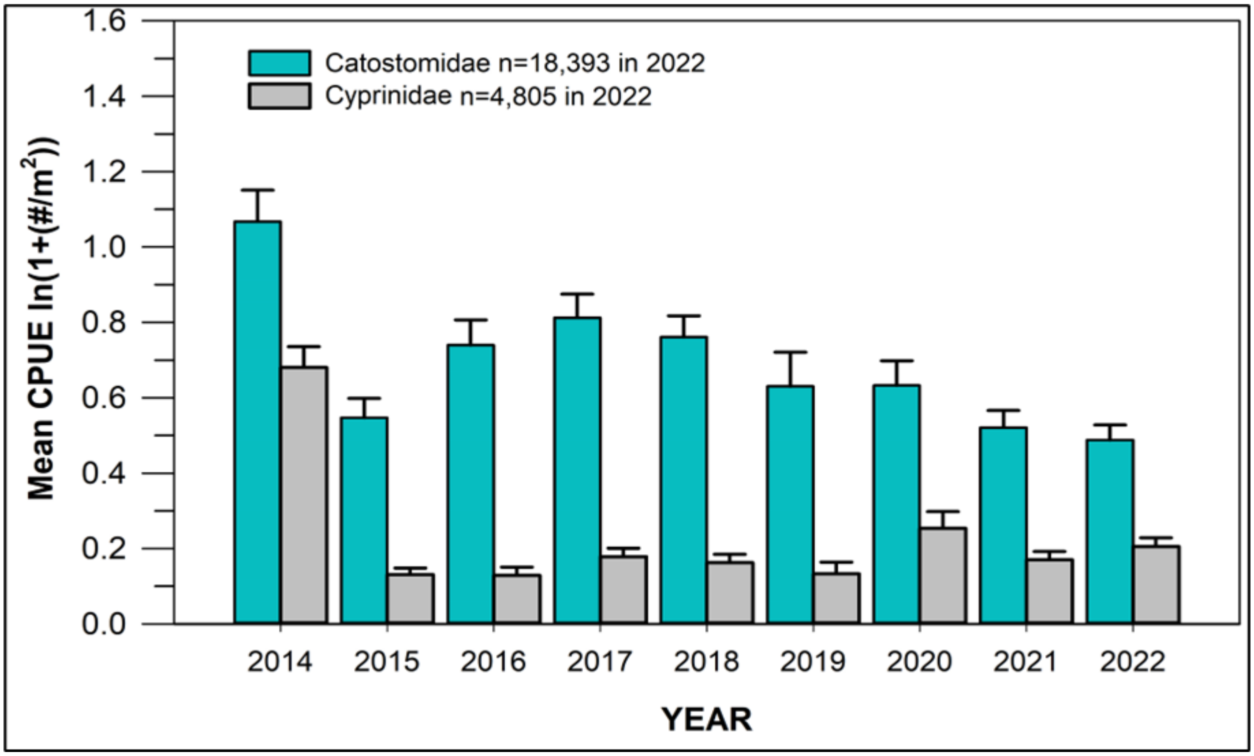

Figure 2.33. Annual mean CPUE of age-0 catostomids and cyprinids. Error bars are 95% confidence intervals.

DISCUSSION

Small-bodied Fish Community Sampling

Whether assessing overall or relative abundance, native fishes continue to dominate the small-bodied fish catch throughout Grand Canyon, regardless of differing spatial and temporal catch rates. The sampling design has allowed us to track monthly recruitment as age-0 suckers begin appearing in early samples and become identifiable as the season progresses. Maintaining consistent effort and sampling all segments during subsequent sampling trips will be important in tracking temporal and spatial trends over time. Perhaps this study's greatest strength is that current methods represent a robust, repeatable, statistically sound, and relevant way to track both the native and nonnative fish communities over time within the study area. Given the importance and demands placed on the Colorado River and the uniqueness of Grand Canyon, this information will undoubtedly be useful for those managing the system in the future.

Although no larval Razorback Suckers were captured in 2022, previous captures of larval Razorback Suckers is promising; it shows that conditions are favorable for spawning within Grand Canyon, and there is potential for in-river recruitment. There is little to suggest that Razorback Suckers are not or cannot recruit within Grand Canyon, or perhaps the CRI, as previous data confirm juvenile fish presence at the CRI and within the overall study area of this project (e.g., Kegerries and Albrecht 2013b).

The capture of Humpback Chub is a fairly regular occurrence during small-bodied fish community sampling within Grand Canyon. Young Humpback Chub have been widely distributed, are relatively common, and appear to be using nursery and rearing habitats throughout the study area and within the full-pool footprint of Lake Mead (Rogowski et al. 2018; Kegerries et al. 2020b; Rogers et al. 2021b). Young Humpback Chub varied in size, both within and between trips, which likely indicates variable hatching times and drift rates, differential growth rates of captured individuals, and some level of mainstem recruitment. The collected data should be useful to those researching, managing, and recovering this species.

Habitat data will become more valuable as juvenile or adult Razorback Suckers are captured in Grand Canyon. The goal is to use these data to identify habitats that may be conducive for Razorback Sucker spawning, nurseries, and recruitment. Currently, the data help identify where other listed and native species are captured and may indicate the types of study area habitats that are conducive to sampling using current methods. Because native fish species are so prevalent and ubiquitous throughout the study area, it is difficult at this juncture to identify which habitats and characteristics are most important. Generally speaking, the data show that slow-moving, complex habitats (e.g., isolated pools, embayment, backwaters) typically yield higher catch rates than fast-moving, main-channel habitat features (e.g., runs, riffles, eddies). However, this could be due to the effectiveness of sampling certain habitat types more so than other fast-moving and/or deep features. Continual, consistent habitat data collection is critical to documenting study area habitat changes and identifying differences that may influence recruitment. First and foremost, it will be critical to identify where these Razorback Suckers are spawning and determine whether this is a relatively new phenomenon, and potentially a mechanism of change, that has allowed spawning to occur.

Comparisons of species' composition through time have provided insight into the community shift of native and nonnative fishes within Grand Canyon over the last three decades (Kegerries et al. 2020b; Rogers et al. 2021b). More-recent fish surveys, which included portions of the upper Grand Canyon, also indicated a community dominated by nonnative species, although there is a notable downstream longitudinal increase in the density of native species (Trammell et al. 2001). It is remarkable how members of the native fish community are currently dominating the catch below Diamond Creek when Red Shiner, Common Carp, and Channel Catfish were the dominant species throughout the mid-2000s. During that time, the Colorado River in the LGC changed from mostly lentic habitats below Bridge Canyon (RM 235.1) in the late 1990s and early 2000s, to mostly lotic habitats well below Pearce Ferry today. Such change has affected the fish community and favored native fishes (Kegerries et al. 2020b). This change lends hope for Razorback Sucker reproduction, recruitment, and ultimately helping to achieve recovery goals.

The increased numbers of captures in the mainstem river below Havasu Creek during the 2022 small-bodied fish survey supports the hypothesis that Havasu Creek is an important tributary for native fish in Grand Canyon. However, identification of the mechanism(s) responsible for changes in the Grand Canyon fish community (whether in the mainstem or the tributary) has been challenging. Differing flow regimes under different water management and runoff conditions, along with changes in water temperature and the receding inflow of Lake Mead, could each impact the fish community. Since the closing of Glen Canyon Dam, the Colorado River downstream has experienced cooler summer flows, which could hinder native fish reproduction, growth, and survival. Flow regulation has reduced annual peak flows, raised minimum flows, and increased the daily flow fluctuation because of hydropower demand (Topping et al. 2003; Voichick and Wright 2007), all of which are potentially detrimental to the Grand Canyon fish community, especially their early life-stages. Dam-released water also reduced turbidity within the river, which likely favored nonnative sight predators (e.g., trout species, Striped Bass, Walleye) over native fishes, which are adapted to turbid river conditions (Valdez and Ryel 1995; Gloss et al. 2005). Although cooler water temperatures can impact native-species reproduction, growth, and survival, these species continue to persist within the Colorado River in Grand Canyon. Recent data suggest that nonnative fish abundance is declining while native fish abundance is increasing (Kegerries et al. 2020b; Rogers et al. 2021b). In fact, the data presented from this study since 2014 have shown that multiple size-classes of Humpback Chub are present throughout the mainstem Colorado River, while Razorback Sucker are now spawning within Grand Canyon. Warming water temperatures within the mainstem is a likely cause for native fish success, but it does not fully explain the more-recent decline in nonnative fish abundance. Most of the nonnative fish species found within Grand Canyon are warm-water species. However, many of these species prefer more lentic habitats. As Lake Mead water elevation continues to recede, one source of nonnative fish species is moved further downstream from Grand Canyon. This change in proximity alone could hinder nonnative fish abundance within Grand Canyon. The Pearce Ferry Rapid and more recently developing Devil’s Cove Rapid (approximately 12 miles downstream of Pearce Ferry Rapid) could also serve as a potential upstream migration barriers, which may help protect the native fish community from additional nonnative competition and predation from Lake Mead. As erosion occurs through the historic Lake Mead sediment, the amount of turbidity created in the LGC could also be a factor limiting utilization by nonnative fish; especially sight-dependent predators (Albrecht et al. 2017; Ward and Vaage 2018). Changes within habitats throughout the mainstem river are less understood, but perhaps they could be favoring native fish species. There could also be native fish emigrating from tributaries into the mainstem, but the possible sources of native fish are not understood at this time. If the elevations of Lake Powell and Lake Mead continue to recede, water temperatures within the Grand Canyon will likely continue to increase (Kegerries et al. 2018) and the distance of nonnative fishes will increase, potentially protecting the native fish community in Grand Canyon. Although warmer water temperatures could benefit native fish species, warm-water nonnative species could also benefit. In 2022, the first Striped Bass were captured during small-bodied seining. This species could be detrimental to the native fish community in the Grand Canyon and highlights the importance of small-bodied sampling to detect rare fishes in the river. The sampling design described in this study provides statistically robust data and a repeatable methodology to facilitate future comparisons and documentation of changes to the Grand Canyon small-bodied and larval fish communities under the adaptive management of abiotic and biotic factors.

Larval-Fish Community Sampling

Since its inception in 2014, there have been several adaptive changes to the timing and spatial extent of the larval Razorback Sucker survey in Grand Canyon. These changes were initiated after detailed review of previous field data. The addition of an earlier monthly sampling trip (March) beginning in 2015 was an effort to better identify the initiation of Catostomidae spawning. That change has been instrumental in understanding spawning periodicity of not just Razorback Sucker, but all three native catostomids.

A second major modification to the project was the 2016 expansion of the study area. In 2015, larval Razorback Suckers were documented at the uppermost site of the former study area (just above Lava Falls Rapid; RM 179.0) thereby confirming spawning by adult Razorback Suckers upstream of the 2015 study area (Kegerries et al. 2017a; Gilbert et al. 2022). To identify the upstream extent of spawning Razorback Suckers, the study area was expanded 91 river miles upstream from Lava Falls Rapid to Phantom Ranch (RM 88.6). Expansion of the study area in 2016 revealed spatial patterns of distribution for the early life history phases of the Razorback Sucker and other native fishes, including the Humpback Chub.

In 2020, the COVID-19 pandemic interrupted sampling activities. While the initial (March) 2020 larval fish sampling effort was conducted as scheduled, the April and May trips were cancelled as Grand Canyon National Park was temporarily closed. Sampling was reinitiated in June 2020 and continued monthly through September 2020. In July 2020, we added a one-time (i.e., 2020 only), second monthly sampling trip that employed opportunistic sampling instead of the standard GRTS sampling protocol to test if there were any significant differences in catch rates between the two sampling methodologies. Comparison of the two July 2020 larval fish CPUE values (1.83 fish/m^2 and 1.33 fish/m^2, respectively) indicated the GRTS sample catch rate was significantly higher than the opportunistic sampling effort. Likewise, CPUE of native fishes during the July GRTS sample was significantly higher than the opportunistic effort. Conversely, there were no statistically significant differences between July 1 and July 2 nonnative catch rates. These findings suggested that spatially randomized sampling (GRTS) produced adequate catch rates and did not warrant any changes to the study design.

From 2016 to 2017, RM 167.7 represented the most upstream site where larval catostomid captures are typically first recorded or where larval catostomid captures begin to increase in frequency and abundance relative to upstream sites (2016–2018). These patterns suggest catostomids are spawning immediately upstream of RM 167.7. The first 2018 larval fish survey in March documented Razorback Sucker larvae at nearly the same location as the previous 2 years (RM 167.7). However, in April 2018, a single protolarval Razorback Sucker was captured about 23 river miles further upstream (RM 144.8) of the former upstream-most collection site for this species. The 2019 capture of a Razorback Sucker (n=1) at RM 127.3 is the furthest upstream Razorback Sucker larva has been taken in the study area (2016–2019; RM 88.6–279.0). This finding increases the distribution of age-0 Razorback Sucker 17.5 river miles further upstream than the previously identified upstream-most capture of Razorback Sucker in 2018 (n=1, RM 144.8). The single 2018 and 2019 data points strongly suggest the presence of limited spawning by Razorback Sucker somewhere between RM 88.6 (Phantom Ranch) and RM 127.3.

Larval Razorback Suckers were collected in Grand Canyon for six consecutive years (2014–2019). The number of larval Razorback Suckers taken per sampling season has continued to decline since the 2014 start of this study (2014: n=462, 2015: n=81, 2016: n=46, 2017: n=27, 2018: n=10, 2019: n=8), even though effort has remained relatively consistent throughout this study. While Razorback Suckers were not collected in 2020, it is important to note that, in 2020, sampling was not conducted in April or May, which precluded inferences of presence/absence of spawning adults that year. From 2014 through 2019, the April and May (combined) collections yielded over 90% of the larval Razorback Sucker catch from the Grand Canyon. In 2021, no Razorback Sucker larvae were positively identified, suggesting a continued decline in spawning by the species.

Larval Razorback Suckers collected in 2019 were represented by two ontogenetic phases (protolarvae and flexion and postflexion mesolarval subphases). The developmental stages of these fish, in combination with their locations of capture, strongly suggest multiple spawning sites. The range of length-based back-calculated hatching dates encompassed only five-weeks from 30 March to 5 May, 2019, a shorter spawning season than estimated in previous years.

The results of the 2016–2022 larval fish surveys support the hypothesis that Havasu Creek plays an important role in initial spawning of catostomids in Grand Canyon. In 2016–2022, captures of larval suckers have tended to occur close to this tributary during March and April surveys. Spatial spawning patterns of catostomids are inferred by the presence of early larval developmental stages (i.e., protolarvae and mesolarvae) downstream of Havasu Creek and the upstream absence (or near absence) of specimens. The overwhelming majority of 2016–2019 Razorback Sucker larvae were captured downstream of Havasu Creek, further supporting the hypothesis that Havasu Creek may be one of the sources of spawning for this species. Havasu Creek has also been shown to support the reproduction of Humpback Chub, following translocations of juveniles 2011–2016 (Healy et al. 2020). Havasu Creek has warmer mean daily water temperatures compared with the Colorado River, particularly during the initial spawning months (February–April). The warm water of Havasu Creek is generally consistent with water temperatures of spawning catostomids (Bozek et al. 1990; Tyus and Karp 1990; Bestgen 2008). Conversely, mean daily water temperatures in the Colorado River during this same period (February–April) were cold enough to significantly reduce hatching success (Marsh 1985; Bozek et al. 1990). The detection of catostomid larvae upstream of Havasu Creek (March 2018, May 2019, and April–May 2021) documents that spawning occurred further upstream, either in the mainstem Colorado River or upstream tributaries.

The suspected importance of tributaries such as Havasu Creek in the spawning of native catostomids in Grand Canyon motivated changes to the methods used to estimate spawning periodicity in this study. In previous years (2014–2016), spawning dates of Razorback Sucker were back-calculated using larval Razorback Sucker TL and mainstem Colorado River water temperatures. Given the hypothesized importance of Havasu Creek to Razorback Sucker spawning, and discordance between temperatures in Havasu Creek and mainstem Colorado River, hatching dates were calculated, instead of spawning dates, for the 2019 analysis. This protocol was first initiated in 2018. Length-based, back-calculated hatching dates do not incorporate water temperature and are a conservative calculation.

Development of age-0 fishes through the larval period and into the juvenile phase is essential for recruitment into the adult population. A multitude of factors affect mortality of larval fishes, including hatching success, starvation, predation, and competition. Transition from larval to juvenile phases has been documented for native cyprinids, Humpback Chub and Speckled Dace, and catostomids, Bluehead Sucker and Flannelmouth Sucker, in Grand Canyon. Juvenile Razorback Suckers have not been collected in either small-bodied monitoring or larval fish monitoring efforts in the Grand Canyon during the study period; however, they have been captured at the CRI and within the Colorado River proper below Pearce Ferry (inflow to Lake Mead; see Chapter 1 and Kegerries et al. 2017b, 2018, 2019).

It is intriguing that, while Humpback Chub and Razorback Sucker had similar catch rates among years 2014–2018, late-phase larvae and juvenile Humpback Chubs were collected while late stage Razorback Suckers were not. Important differences between spawning periodicity of Razorback Sucker and Humpback Chub are timing (earlier spawning for Razorback Sucker) and spatial extent of spawning. Mean daily water temperatures in the Colorado River were cooler during March and April (and May in 2019) when larval Razorback Suckers were present. While only three Razorback Sucker larvae have been documented upstream of RM 167.7, Humpback Chub larvae have been documented near the upstream extent of the study area (RM 88.6), and known reproducing populations exist farther upstream (e.g., Little Colorado River). The broader distribution of Humpback Chub larvae may mean that it's likely they remain in the system long enough to mature beyond the larval period, thereby increasing the likelihood for recruitment to the adult population.

Retention of larval fishes in a river system is dependent not only on their distribution but also on the drifting behavior of early ontogenetic phases and availability of suitable larval fish nursery habitats. A review of 2016–2022 larval ontogenetic stage distributions showed a trend of increasing maturity along a downstream longitudinal gradient. Similarly, ontogenetic stages showed a seasonal trend of increasing percentages of late stage larvae and early juveniles with each progressive monthly survey. These results support the hypothesis that the spatial and temporal gradients of water temperatures support recruitment of native Colorado River basin fishes in Grand Canyon.

For the ninth consecutive year, larval fish monitoring documented extremely low abundances and limited distributions of age-0 nonnative fishes in Grand Canyon. Native fishes accounted for 98.6% of all age-0 fishes collected during 2022. The prevalence of native fishes further suggests that environmental conditions in Grand Canyon are suitable for the reproduction, recruitment, and persistence of Colorado River basin endemics.

Striped Bass are broadcast spawners who disperse semibuoyant eggs (pelagophils) into the current where they develop and hatch. Eggs are relatively large (3.4 mm, 2.4–3.9 mm) and remain a component of the drift after water hardening. Hatching occurs 2 to 3 days after fertilization, depending on water temperature. We do not know if the six larval Striped Bass collected in the Grand Canyon in July 2022 were a product of spawning by adult Striped Bass upstream of RM 139.6 or if the eggs were from Lake Powell and were transported through Glen Canyon Dam. Discovery of this nonnative predacious fish in the Grand Canyon highlights the value of larval fish sampling for early detection of rare fishes (Brandenburg et al. 2019).
Future annual larval fish monitoring will continue to allow inference of causal effects on age-0 fish abundances and inform conservation of native fishes in the Grand Canyon. Those studies will continue systematic sampling of GRTS segments to provide long-term comparative data to further characterize spatial and temporal trends in the reproduction of fishes in Grand Canyon. This study has documented reproduction by native fishes of the Colorado River in Grand Canyon, including the Razorback Sucker, and recruitment of the Humpback Chub.

GRAND CANYON SMALL-BODIED AND LARVAL FISH COMMUNITY STUDY RECOMMENDATIONS

The results of the 2022 and comprehensive 2014–2022 small-bodied and larval-fish community sampling have provided valuable information regarding the early life-stages of the native fish fauna in Grand Canyon. The results were based on a statistically sound, repeatable methodology, which captured a snapshot of the annual variation of distribution and densities of small-bodied and larval fishes. Continuation of these surveys will build a foundation of data that can be used to track community changes over time. Understanding trends in reproductive success and early life-stage abundance is a valuable management tool for species recovery.

1. Given the small-bodied and larval-fish community sampling success described herein, it is recommended that all components of Grand Canyon sampling continue. The presence of larval Razorback Suckers has been confirmed, and additional data have been collected on the native fish community throughout Grand Canyon. This includes information pertaining to timing and distribution of larval fishes within the study area, particularly Razorback Sucker and Humpback Chub spawning and recruitment on a temporal and longitudinal scale. It is important to conduct sampling consistent with methods described in this report, and it is particularly important to follow the GRTS segment sampling protocols that have been used. This will facilitate better comparisons within and between years, allow for direct comparisons, and facilitate learning as the study continues.

   The current survey protocol consists of seven monthly trips (March–August) with 56 GRTS segments sampled between Phantom Ranch (RM 89) and Pearce Ferry (RM 280). It is recommended that this protocol continue in 2023 without adjustments, as was recommended by the science panel (Reclamation 2017), to better assess differences in catch rates, habitat occupancy, and abiotic factors such as discharge and temperature.

2. An assessment of larval nursery habitats, their adequacy to advance developmental phases of Razorback Sucker, and how they are affected by dam operations was of interest to the science panel (Reclamation 2017). With standardization of survey protocols, greater statistical rigor can be applied to larval-fish captures by habitat types and difference in habitat types pertaining to ontogenetic phases.

   Similarly, longitudinal differences in larval and small-bodied catches could be assessed over time and related to dam operations. It would be particularly important to continue assessing the larval and small-bodied fish community in relation to high-flow events in spring and fall, equalization flows, and trout-management flows.

3. The NPS also has shown interest in this study by providing larval and small-bodied fish community information to help serve as an early warning method to consistently and routinely track changes and threats imparted by nonnative fishes, something that this study design can do well, and can be used to place future findings into a more historical context. Previous years have demonstrated that this was a successful method to detect Green Sunfish. This year, small-bodied sampling detected Striped Bass and Walleye, and larval sampling detected Striped Bass.

4. Investigate food limitations for early life-stages of fishes in Grand Canyon. The science panel discussed interest in identifying the primary food source for larval and juvenile fishes in the CRI (Reclamation 2017). Food limitations for early life-stages of fishes in Grand Canyon could be investigated by examining gut contents of the formalin-preserved specimens curated at the MSB. Because larval fish were previously preserved in formalin, their gut contents are well suited for dietary investigations. Conducting stable isotope analysis of larval fishes and their diets could further increase understanding of content, complexity, and origin of food resources for early life-stages of Colorado River fishes within Grand Canyon. A logical first step might be to conduct a literature review of all available information regarding food resources that would focus on Grand Canyon, but the study might also be broadened to include other portions of the Colorado River basin.

5. Conduct additional larval sampling in the CRI to determine whether larvae are being transported out of the river and into the inflow area and what types of nursery habitats are provided by Lake Mead. The investigations that were commenced in 2017 pertaining to small-bodied and larval fish captures in the CRI could be expanded to address the questions of habitat availability and movement of larvae into the inflow areas.

6. Collect additional samples specifically for genetic evaluation (genetic evaluation for hybridization or genetic Ne evaluation for population size). This recommendation was discussed by the science panel (Reclamation 2017), and samples were collected in 2018 for the investigation of hybridization between Flannelmouth Sucker and Razorback Sucker in Grand Canyon. Because few Razorback Sucker larvae were obtained in 2018 and 2019, and none in 2020, 2021, or 2022, additional collections could occur in 2023, if desired. Genetic evaluation requires specimens be preserved in 95% EtOH, which has been used exclusively during recent sampling efforts (2021–2022). The current charge of this project is to identify larval fish based on morphomeristic characteristics, and the use of formalin as a preservative is the standard for that technique. While the quality of the specimens would be reduced by using EtOH, this change allows for genetic analysis of larvae as well as the preservation of otoliths. Ethanol preservation retains the chemical and physical structure of otoliths, thus increasing the potential for a wide range of ecological and physiological questions to be posed and potentially answered from investigation of otolith chemical and/or physical structure.

7. Investigate the source of native fish within the mainstem Colorado River through Grand Canyon. It is apparent that native fish are able to thrive within the mainstem throughout Grand Canyon, but the mechanism(s) allowing for this more-recent success have yet to be identified. Another hypothesis would be that increased tributary reproduction and recruitment may allow for an increase in native fish immigrating to the mainstem. Additional sampling and tributary fish community comparisons may help answer the question of tributary inputs, while genetic analysis could also be investigated as a feasible method to determine natal origin.

CHAPTER 3: TELEMETRY WITHIN THE COLORADO RIVER INFLOW AREA OF LAKE MEAD (CRI) AND GRAND CANYON

INTRODUCTION

This chapter presents telemetry results for 2022 at the CRI and in Grand Canyon, with previous results from both locations included for context when applicable. Following Kegerries and Albrecht (2013b) and Albrecht et al. (2014a), data for the CRI portions of this project are reported from July 2021 through June 2022. Telemetry data collected from Grand Canyon are reported from October 2021 through September 2022.

Sonic-telemetry data collected during Lake Mead Razorback Sucker studies have provided valuable information on spawning, movement patterns, and shifts in spawning-sites over time and under varying habitat conditions. These data have also demonstrated that tracking sonic-tagged Razorback Sucker preceding spawning activity can be a highly effective method for locating new spawning areas and maintaining effective monitoring, particularly when coupled with other methodologies (e.g., Albrecht et al. 2017). Monitoring sonic-tagged fish can increase efficiency of field efforts and provide substantial data related to Razorback Sucker habitat use.

Because movement to and from the Colorado River proper was previously documented (Albrecht et al. 2010a; Kegerries and Albrecht 2011, 2013a, 2013b, 2014a; Kegerries et al. 2015a), this chapter combines sonic- and radio-telemetry data from the CRI and Grand Canyon, presents the data holistically, and shows the relationship between the Colorado River and Lake Mead.

STUDY AREA

The 2022 CRI study activities occurred within Gregg Basin of Lake Mead and the Colorado River upstream to Pearce Ferry Rapid in Grand Canyon (Figure 3.1). Sonic- and radio-telemetry efforts within Grand Canyon encompassed the Colorado River from Pearce Ferry Rapid upstream to Lee’s Ferry (RM 0) (Figures 3.2a, Figure 3.2b, and Figure 3.2c).

METHODS

Sonic Tagging

During the 2022 field season, a single Razorback sucker was captured in the CRI study area. The project team successfully implanted and released this fish at the CRI. The Razorback Sucker was implanted with a Sonotronics model CT-05-48-I (48-month) sonic tag.

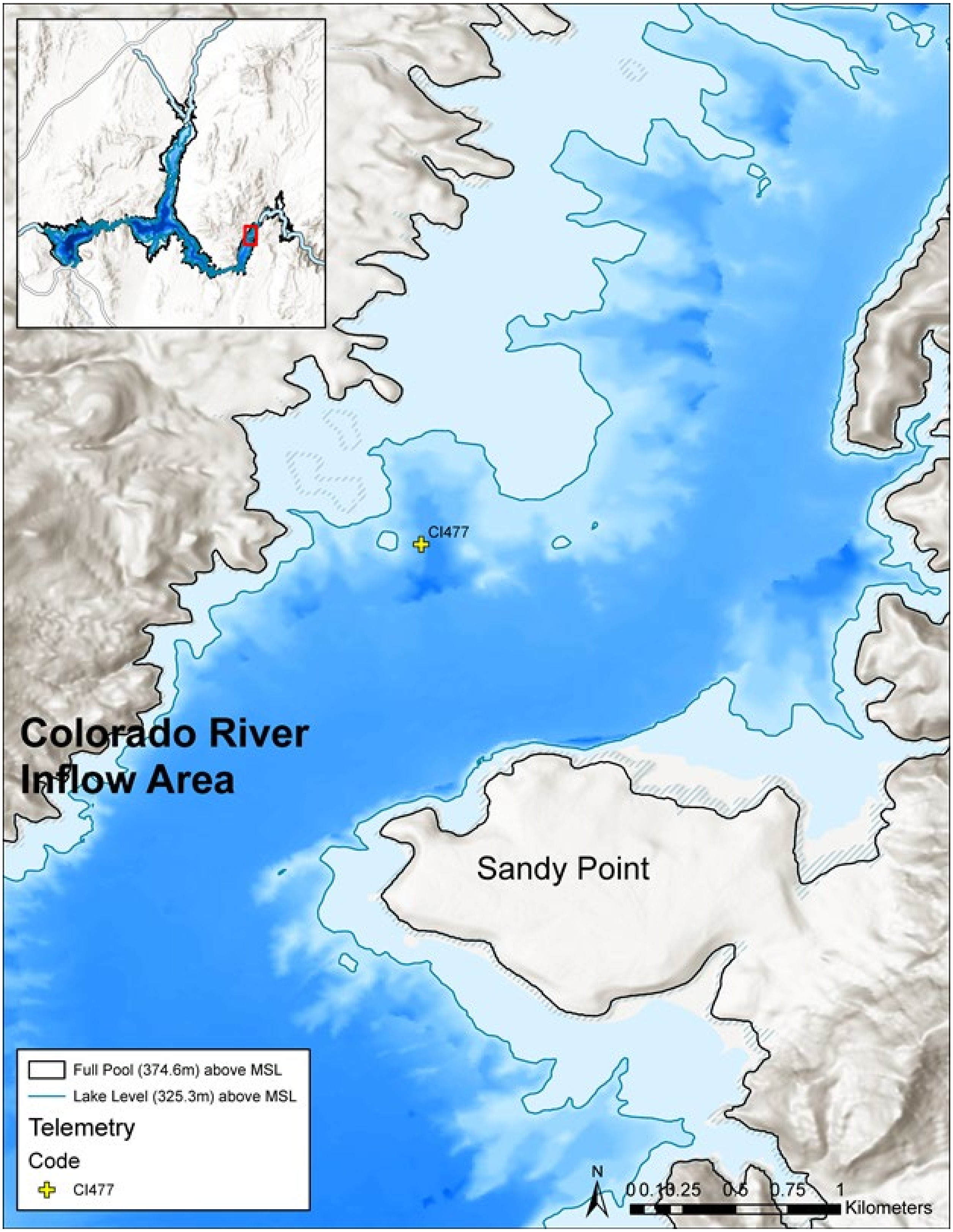

Figure 3.1. **General Colorado River Inflow Area of Lake Mead (CRI) study area with the distribution of sonic-tagged fish contacts and submersible ultrasonic receiver (SUR) location.**

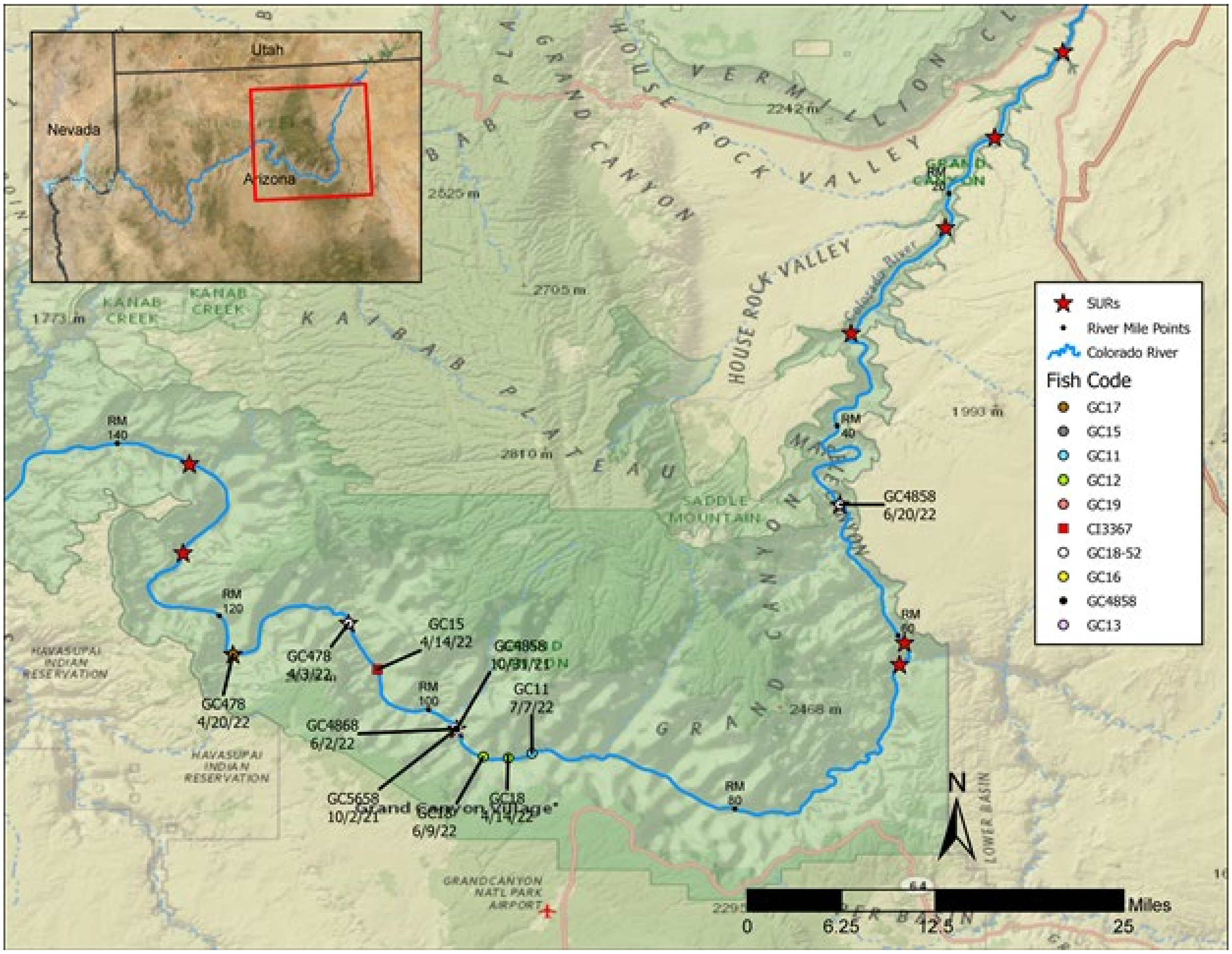

Figure 3.2a. General Grand Canyon study area with the distribution of sonic-tagged fish contacts and submersible ultrasonic receiver (SUR) locations. The top section is approximately river mile (RM) 0–90. Middle Section is approximately RM 80–200 Bottom section is approximately RM 200–280.

(This space intentionally left blank.)

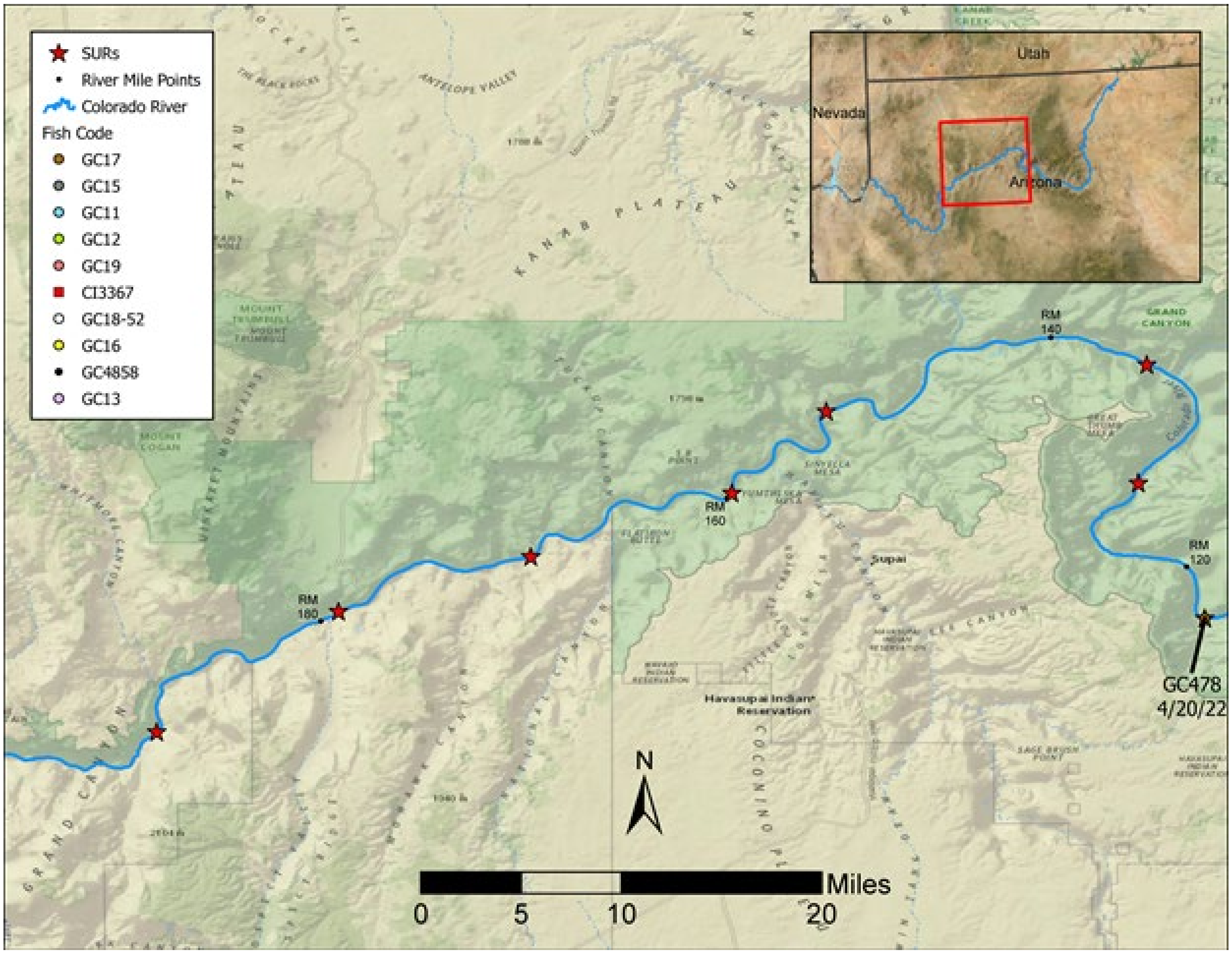

Figure 3.2b. General Grand Canyon study area with the distribution of sonic-tagged fish contacts and submersible ultrasonic receiver (SUR) locations. The top section is approximately river mile (RM) 0–90. Middle Section is approximately RM 80–200 Bottom section is approximately RM 200–280.

(This space intentionally left blank.)

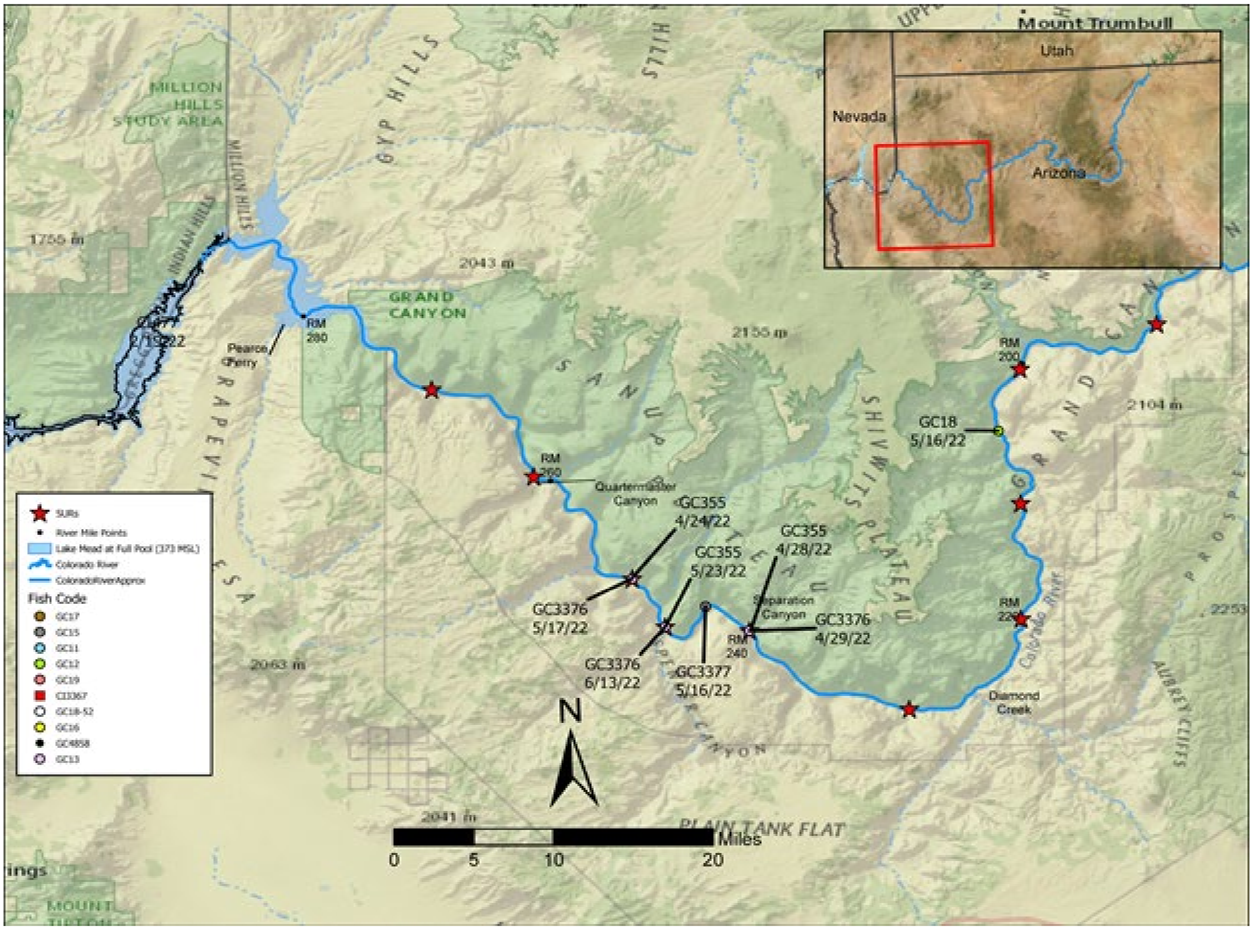

Figure 3.2c. General Grand Canyon study area with the distribution of sonic-tagged fish contacts and submersible ultrasonic receiver (SUR) locations. The top section is approximately river mile (RM) 0–90. Middle Section is approximately RM 80–200 Bottom section is approximately RM 200–280.

Prior to surgery, the fish were placed into a designated tank containing fresh hatchery/reservoir water, and all sonic tags were checked for full function and identification. All surgical instruments were cold sterilized with iodine and 90% isopropyl alcohol and allowed to air dry on a disposable, sterile cloth. Razorback suckers were initially anaesthetized in 10 L of reservoir water following Anderson et al. (1997) and Bunt et al. (1999). After anesthesia was induced, TL in mm, FL in mm, SL in mm, and weight in grams were recorded. The individual was placed dorsal-side down on a padded surgical cradle for support during surgery with head and gills submerged in a maintenance-concentration anesthetic (Bunt et al. 1999). Following introduction to the maintenance anesthetic, the surgeon made a 10–15 mm incision on the left side, posterior to the left pelvic girdle. A PIT tag was inserted into the incision followed by the sonic tag, which was placed between the pelvic girdle and urogenital pore. The incision was closed with two to four 3-0 Monocryl Plus absorbable poliglecaprone 25 sutures using an attached PS-1 reverse-cutting, curved needle. Surgery times typically ranged from 2 to 5 minutes per fish.
Once surgical implantation was complete, the individual was allowed to recover in fresh reservoir/hatchery water until regaining equilibrium. Prior to release, the individual was re-examined for signs of stress, and sonic tags were rechecked for functionality. Wild Razorback Sucker were released at their capture location, and no Razorback Suckers were held for an

extended period of time or harmed during these efforts. Fish sonic tagged in the hatchery were released into Grand Canyon as a cooperative effort between BIO-WEST and state and federal agency personnel.

Active Sonic Telemetry and Tracking

Sonic-tagged fish were tracked monthly and sometimes weekly or daily, depending on the field schedule and project goals at the CRI. Searches for fish were conducted largely along shorelines, and distances between listening points varied based on shoreline configuration and factors that could impact signal reception. Sonic-telemetry signals are line-of-sight, and any obstruction can reduce or block reception. Also, sonic-telemetry signal reception is often hampered by shallow, turbid, and swift water.

Active tracking consisted of listening for underwater acoustic signals from coded sonic tags using a Sonotronics USR-08 ultrasonic receiver and DH4 directional or TH-2 omnidirectional hydrophone. The directional hydrophone was lowered into the water and rotated 360 degrees to detect the presence of sonic-tagged fish. Once a signal was detected, the position of the sonic-tagged fish was pinpointed by adjusting the gain (sensitivity) on the receiver and moving in the fish's direction until the signal was heard in all directions with the same intensity. In all cases, sonic-tag numbers (codes), GPS locations, and habitat characteristics were recorded.

Active telemetry within Grand Canyon was conducted opportunistically and when logistically feasible on each of the trips. When a fish was contacted, the directional hydrophone was employed to try to pinpoint the location of the detected fish, verify the correct tag code, and ensure that the location and habitat characteristics were recorded. Additional efforts using the Sonotronics USR-08 ultrasonic receiver and DH4 directional or TH-2 omnidirectional hydrophone were conducted near areas known to be frequented by Razorback Sucker.

Passive Sonic Telemetry and Data Collection

Submersible ultrasonic receivers were deployed in various locations throughout the CRI and Grand Canyon (Figures 3.1 and 3.2). The advantage of SURs is their ability to autonomously and continuously record sonic-telemetry data. With an approximate 9-month battery life and the ability to detect ultrasonic tags, SURs save valuable field time and collect additional and important sonic-telemetry data; they can be particularly useful in difficult-to-access field locations (Sonotronics 2014).

One SUR remains at the southernmost end of Gregg's Basin to monitor inter-basin travel of sonic-tagged fish. More SURs were also distributed in Grand Canyon from RM 97.5 (below Boucher Rapid downstream to Pearce Ferry) to RM 280.0 (Figure 3.2). These SURs were deployed approximately 10 river miles apart, except between RM 240.0 (near Separation Canyon) and RM 250.6 (below Surprise Canyon), where SURs were approximately 5 river miles apart. This was meant to ensure contact with fish that may be aggregating just below Spencer Creek, as they have in past years. The SURs within Grand Canyon have remained in the same locations since 2015. In cooperation with NPS, and primarily to assess Brown Trout movement, two additional SURs were installed near the confluence of the Little Colorado River in June

2017, one above and one below. In 2018, eight additional SURs were deployed between RM 8 and RM 50 primarily to expand the coverage for assessing Brown Trout movement (Figure 3.2). Additional SUR data were collected opportunistically in Grand Canyon as a result of deploying a SUR from the boat while camping overnight. The deployment and retrieval times, along with location information, were recorded to cross-reference contact data. At the conclusion of the Brown Trout movement study in 2021, four SURs were removed, while four remained in the river to aid in monitoring sonic-tagged fish movements.

All SURs were programmed to detect active sonic-tag frequencies using Sonotronics's SURsoft software. The semibuoyant SURs were then suspended from an anchor attached directly to the unit. A lead of vinyl-coated cable was secured to the unit as the SUR was deployed and allowed to sink to the reservoir/river bottom. The cable was secured on shore and concealed. The SURs were downloaded frequently by pulling the SUR into the boat and downloading the data via Sonotronics's SURsoft software. These data were then processed through Sonotronics's SURsoftDPC software to ascertain the time, date, and frequency of positive sonic-tagged fish detections within 2-millisecond interval units (e.g., a range of 898–902 for a 900-interval tag). To avoid any false-positive contacts due to environmental "noise" in data analysis, at least two records were required within 60 minutes of one another for a SUR record to be considered valid. Once data were validated through the software's confidence-scanning feature, the resulting dataset was further scrutinized against active sonic-telemetry records. This was to establish movement timelines of individual sonic-tagged fish and further solidify all positive SUR contacts.

Radio Telemetry

The primary radio telemetry methodology for tracking the study area in 2022 was to use a Lotek SRX 1200 and a Telonics RA-2AK VHF antenna to track Razorback Suckers implanted with Lotek MCFT2-3FM radio tags within Grand Canyon. The SRX 1200 unit scans for radio frequencies (164.260mHz for this study) while paired with a proprietary Lotek code set. This code set technology allows for unique individual tag codes to exist on a single frequency. The signal is then decoded and recorded. These data are coupled with GPS technology to ascertain fish location, as well as detecting and recording signal strength, which is then used in the data-processing criteria. The unit stores tag and location data, which were obtained on a monthly (per Grand Canyon trip) basis. All data collected from the autonomous scanning from the Lotek SRX 1200 receiver were processed by filtering it through a set of criteria in an attempt to remove false positives. These criteria were established with baseline testing, and are consistent with Beeman and Perry (2012), with the intent of removing false positives without the removal of any true positives. The criteria established included: (1) the removal of any tag IDs that were not part of the study, (2) tag IDs that were recorded below the set Received Signal Strength indicator (RSSI) limit of 130 (Lotek Receivers rank strength 1-250, with 250 being the strongest signal strength) were considered false positives and rejected, and (3) using quality-control techniques to review the locations of fish compared to the locations of their releases, as well as the times and locations of detections.

To verify the data-processing criteria and preliminary settings for the Lotek SRX1200 receiver, baseline testing was conducted near the inflow of the Bear River at Cutler Reservoir, near

Benson, Utah. This test site was selected because it has similar water-quality conditions to that of Grand Canyon. The results from this testing concluded that a set gain of 60, which was the suggested value from Lotek personnel (M. Knoff, Lotek Wireless, Inc. personal communication), along with single-bandwidth scanning of 164.260mHz, would result in the highest number of positive, accepted contacts. These settings can limit the maximum distance of detecting a fish, but they lead to higher RSSI values (and consequently more frequently accepted values) at closer ranges. Positive detection ranges started at 40m with a tag depth of 1m, decreasing to 30m at a tag depth of 2m. Deeper testing was limited due to the depth of the test site. Baseline testing was also conducted in the riverine portions of the CRI, which helped to further verify the unit settings, as described above. Continued baseline testing is encouraged to help understand the positive detection limits of tags at greater depths.

RESULTS

Through collaborative research and monitoring efforts, 99 sonic-tagged and radio-tagged fish have been released into the CRI and Grand Canyon since 2010 (Albrecht et al. 2010c; Kegerries and Albrecht 2011, 2013b, 2014a; Kegerries et al. 2015a, 2016a, 2018, 2019; Rogers et al. 2021b) (Table 3.1). In 2022, one wild Razorback Sucker was sonic-tagged on March 15, 2022 (Table 3.1).

One wild adult male Razorback Sucker captured in trammel nets on March 15, 2022, was sonic-tagged with 48-month battery-life tag and released at the point of capture at the Colorado River inflow (Table 3.1). This fish was not detected at the CRI or in the LGC for the remainder of 2022.

A total of 11, unique, sonic-tagged (n=8) or radio-tagged (n=3) fish were contacted 1,052 times (1 active contact; 555 passive contacts; 496 radio contacts) from July 2021 to June 2022 at the CRI and from October 2021 to September 2022 in Grand Canyon (Figures 3.1 and 3.2; Table 3.1). Of these 11 fish, one was a wild, sonic-implanted fish that had been released at the CRI in 2021; seven (3 radio-tagged; 4 sonic-tagged) were hatchery-reared fish that had been released at Bright Angel Creek (RM 88.3) in 2021; and three of the sonic-tagged fish were hatchery-reared fish that had been released near Separation Canyon (RM 239.8) <<in what year?>> (Table 3.1). Of the 99 fish that have been tagged and released in the CRI, Grand Canyon, or Bonelli Bay since 2010, 11 are confirmed active, and 31 are of unknown status and were not contacted in 2022 or were nearing the end of their battery life. The remaining 57 tags are presumed to be no longer detectable due to expired batteries.

The approximate distances traveled by sonic-tagged Razorback Sucker throughout the reporting period ranged from 0 to 198.4 river miles. The fish that moved the greatest distance was a 2021 hatchery-reared, radio-tagged fish (GC18) that moved from RM 134.5 upstream to RM 94.0, then a month later moved downstream to RM 205.0 before finally returning to RM 95.5, for a total traveled distance of 261 river miles. Three fish moved more than 20 river miles and one moved greater than 200 river miles (Figure 3.3). Both downstream and upstream movement was observed in radio-tagged and sonic-tagged Razorback Sucker.

Table 3.1. Tagging and stocking information, location, last contact date, and current status of sonic-tagged fish released in the Colorado River Inflow Area of Lake Mead (CRI) and Grand Canyon (GC) from 2018 to 2022.

SOURCE LOCATION[a]	DATE TAGGED	TAG CODE	TOTAL LENGTH (mm)	SEX[b]	STOCKING LOCATION[a]	LAST LOCATION[a]	DATE OF LAST CONTACT	CONTACTS MADE: ACTIVE (PASSIVE)[c]	CURRENT TAG STATUS[d]	ESTIMATED TAG EXPIRATION
Fish Tagged in 2022										
CRI	3/15/22	4556	563	M	CRI	CRI	3/15/2022	0 (0)	Active	2025
Fish Tagged in 2021										
NDOW	1/26/2021	11	430	U	BA	GC	9/5/2021	0(8)	Active	2024
NDOW	1/26/2021	12	413	U	BA	GC	9/5/2021	0(1)	Active	2024
NDOW	1/26/2021	15	405	U	BA	GC	9/3/2021	0(17)	Active	2024
NDOW	1/26/2021	18	440	U	BA	GC	9/3/2021	0(22)	Active	2024
NDOW	1/26/2021	19	444	U	BA	GC	9/3/2021	0(3)	Active	2024
NDOW	1/26/2021	13	434	U	SC	GC	9/10/2021	0(2)	Active	2024
NDOW	1/26/2021	14	434	U	SC	GC	1/26/2021	0(0)	Unknown	2024
NDOW	1/26/2021	16	421	U	SC	GC	9/3/2021	0(11)	Active	2024
NDOW	1/26/2021	17	434	U	SC	GC	9/3/2021	0(2)	Active	2024
NDOW	1/26/2021	20	440	U	SC	GC	1/26/2021	0(0)	Unknown	2024
NDOW	1/26/2021	4545	376	U	BA	GC	1/26/2021	0(0)	Unknown	2023
NDOW	1/26/2021	4648	446	U	BA	GC	4/4/2021	0(2)	Active	2023
NDOW	1/26/2021	4655	376	U	BA	GC	7/14/2021	0(2)	Active	2023
NDOW	1/26/2021	4858	370	U	BA	GC	8/12/2021	0(96)	Active	2023
NDOW	1/26/2021	4868	414	U	BA	GC	1/26/2021	0(0)	Unknown	2023
NDOW	1/26/2021	5657	371	U	BA	GC	5/15/2021	0(8)	Active	2023
NDOW	1/26/2021	5658	366	U	BA	GC	4/21/2021	0(22)	Active	2023
NDOW	1/26/2021	5787	414	U	BA	GC	5/2/2021	0(4688)	Active	2023
NDOW	1/26/2021	5788	374	U	BA	GC	1/26/2021	0(0)	Unknown	2023
NDOW	1/26/2021	6868	365	U	BA	GC	1/26/2021	0(0)	Unknown	2023
NDOW	1/26/2021	356	456	U	BA	GC	1/26/2021	0(0)	Unknown	2025
NDOW	1/26/2021	387	446	U	BA	GC	1/26/2021	0(0)	Unknown	2025
NDOW	1/26/2021	478	446	U	BA	GC	1/26/2021	0(0)	Unknown	2025
NDOW	1/26/2021	3344	426	U	BA	GC	1/26/2021	0(0)	Unknown	2025
NDOW	1/26/2021	3345	456	U	BA	GC	1/26/2021	0(0)	Unknown	2025
NDOW	1/26/2021	355	450	U	SC	GC	1/26/2021	0(0)	Unknown	2025
NDOW	1/26/2021	588	452	U	SC	GC	1/26/2021	0(0)	Unknown	2025
NDOW	1/26/2021	3376	451	U	SC	GC	6/15/2021	1(0)	Active	2025
NDOW	1/26/2021	3377	451	U	SC	GC	7/31/2021	2(4)	Active	2025
NDOW	1/26/2021	6887	459	U	SC	GC	1/26/2021	0(0)	Unknown	2025
CRI	3/9/2021	477	506	M	CRI	CRI	3/18/2021	1(0)	Active	2025
CRI	3/9/2021	587	540	M	CRI	CRI	3/9/2021	0(0)	Unknown	2025

[a] Locations: BA=Bright Angle (RM=87.5), CRI=Colorado River Inflow Area of Lake Mead, GC=Grand Canyon above Pearce Ferry, NDOW=Nevada Department of Wildlife Lake Mead fish hatchery, SC=Separation Canyon (RM 240.0)
[b] Sex: F=female, M=male, U=Unknown
[c] Number of contacts are presented using active and passive sonic-telemetry techniques (i.e., submersible ultrasonic receivers [SURs]). Please refer to the active and passive sonic-tracking methodologies in this report for details.
[d] Active=fish considered active and moving, Unknown=fish at-large for the whole tracking season

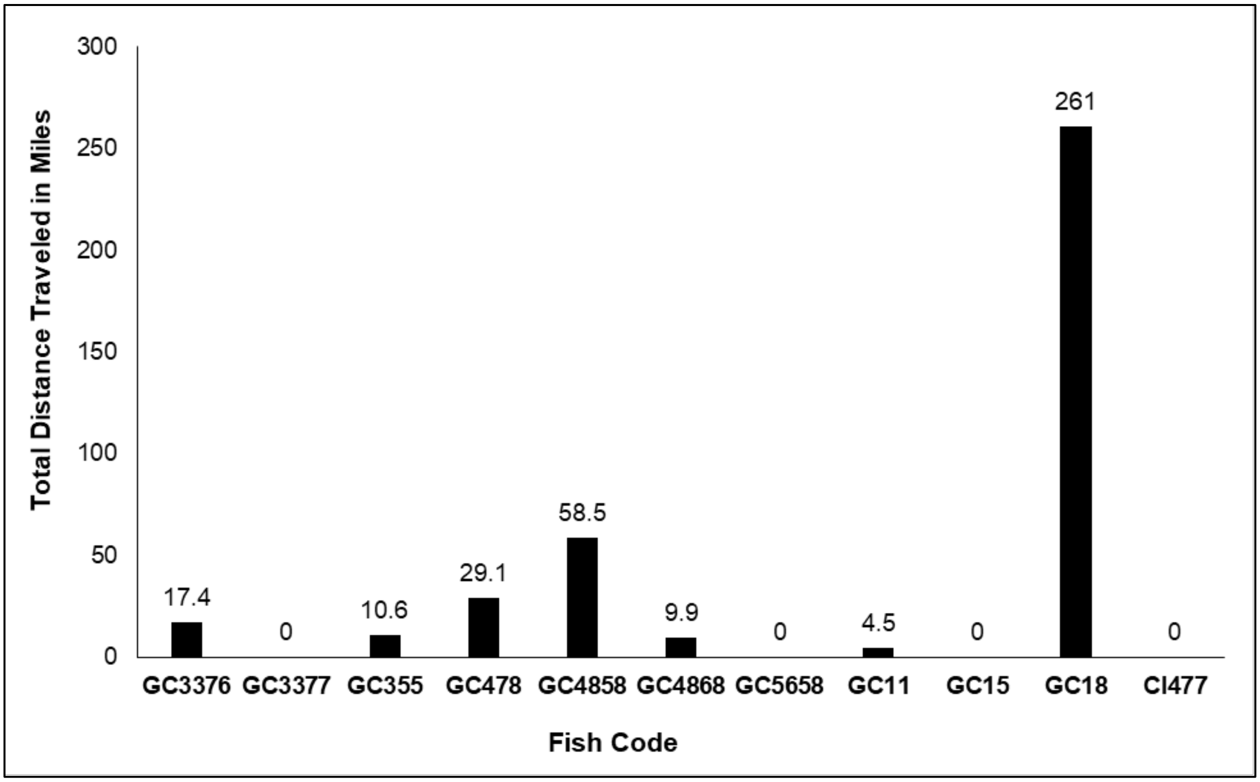

Figure 3.3. Net Distance Traveled in 2022 *Cumulative Telemetry Results.*

Since the project at the CRI began in 2010, data have documented multiple Razorback Sucker movements and overlapping habitat use at Lake Mead and the Colorado River within Grand Canyon (Appendix G). Movement of Razorback Sucker throughout the study area has differed among years and individuals, and has ranged from relatively stationary to largescale movements of more than 200 miles through riverine and lentic systems. For example, a sonic-tagged fish (code 3376) was released at RM 239.8, detected in Echo Bay (in Lake Mead), then returned to the river and detected at RM 246.6, all within an 18-month time period (Table 3.2). Conversely, another sonic-fish (code 3377) remained at RM 243.0 for 11 months (Table 3.2).

In 2010, Razorback Sucker were released in Gregg Basin and near the confluence of the Colorado River and Lake Mead. Four of the five fish released in Gregg Basin were later found at the CRI and within the river below Pearce Ferry Rapid. Lake-wide movements were also noted with a fish from the Overton Arm and another from Las Vegas Bay traveling to the CRI. The only fish observed to move any notable distance in 2011 was the same fish that came from the Overton Arm in 2010, when it returned to the Overton Arm in 2011.

In 2012, we expanded our tracking area to better monitor fish movement upstream of the CRI and into the LGC. The water elevation in Lake Mead during 2012 allowed upstream navigation and effective telemetry efforts. The result was detection of 10 Razorback Suckers using both river and lake habitats, 4 of which were utilizing the LGC above Pearce Ferry Rapid. Fish were contacted as high as Quartermaster Canyon (RM 260.8) and many traveled from the CRI into the river before returning back to the CRI within that year. Additional movement was documented by two fish between the CRI and Las Vegas Bay.

Table 3.2. Movement of sonic-tagged fish released into the Colorado River Inflow Area of Lake Mead (CRI) and Grand Canyon (GC) from last known location.

TAGID	DATE	RIVER MILE (RM)	RM CHANGE FROM PREVIOUS CONTACT	NET MOVEMENT (RM)
3376	6/15/2021	243	89	181
	4/29/2022	240.1	2.9	183.9
	5/3/2022	250.6	10.5	194.4
	5/6/2022	250.6	0	194.4
	5/9/2022	250.6	0	194.4
	5/17/2022	250.6	0	194.4
	5/3/2022	250.6	0	194.4
	6/13/2022	246.6	4	198.4
GC3377	6/15/2021	243	0	0
	5/16/2022	243	0	0
GC355	2/25/2021	240	0	0
	4/28/2022	240.1	0.1	0.1
	5/1/2022	240.1	0	0.1
	5/23/2022	246.6	6.5	6.6
	5/24/2022	250.6	4	10.6
	5/25/2022	250.6	0	10.6
GC478	2/25/2021	88	0	0
	4/3/2022	108.2	20.2	20.2
	4/20/2022	117.1	8.9	29.1
	4/21/2022	117.1	0	29.1
	4/26/2022	117.1	0	29.1
GC4858	8/13/2021	108	0	0
	9/14/2021	108.2	0.2	0.2
	10/31/2021	97.9	10.3	10.5
	6/20/2022	49.9	48	58.5
GC4868	2/25/2021	88	0	0
	6/2/2022	97.9	9.9	9.9
	6/6/2022	97.9	0	9.9
GC5658	4/21/2021	97.9	0	0
	10/2/2021	97.9	0	0
	10/8/2021	97.9	0	0
	10/9/2021	97.9	0	0
	10/12/2021	97.9	0	0
	10/15/2021	97.9	0	0
	10/19/2021	97.9	0	0
	10/23/2021	97.9	0	0
	10/25/2021	97.9	0	0
	10/26/2021	97.9	0	0
	10/31/2021	97.9	0	0
	11/6/2021	97.9	0	0
	11/7/2021	97.9	0	0
CI477	3/18/2021	CRI	0	0
	2/16/2022	CRI	0	0
GC11	9/5/2021	90.5	0	0
	7/7/2022	92.5	2	2
GC15	4/14/2022	104.7	0	0
	5/12/2022	104.7	0	0
	6/9/2022	104.7	0	0
	7/7/2022	104.7	0	0
	8/11/2022	104.7	0	0
GC18	9/3/2021	23	0	0
	4/14/2022	94	71	71
	5/16/2022	205	111	182
	6/9/2022	95.5	109.5	291.5

Use of both lake and riverine habitats continued in 2013–2015. Eight unique Razorback Suckers were documented moving between the CRI and Columbine Falls (RM 274.8), Salt Creek (RM 255.7), Quartermaster Canyon (RM 260.3), Bat Cave (RM 266.5), Spencer Creek (RM 246.3), RM 243.0, and Whitmore Rapid (RM 187.7) in the LGC. One Razorback Sucker released just below Lava Falls (RM 179.7) in 2014 was contacted at the CRI in 2015. Several other fish moved between the CRI and the river below Pearce Ferry Rapid, while movement between other Lake Mead spawning areas was documented by five individuals.

From 2016 through 2020, largescale Razorback Sucker movement had become relatively rare. Most movement and habitat use was limited to between the Pearce Ferry Rapid and the CRI. Notable movements during these years were primarily downstream movements. One Razorback Sucker released near Diamond Creek (RM 225.9) was documented at the CRI later that year, one fish released near Bright Angel Creek (RM 88.3) in 2018 was documented at the CRI later that year, and two fish contacted near RM 243.0 in 2018 were contacted at the CRI in 2019.

However, in 2021, there was increased fish movement throughout the Colorado River, in which there were two notable largescale upstream movements by Razorback Suckers from Lake Mead to above Pearce Ferry Rapid, which has not been documented since 2014. One Razorback Sucker, which was tagged in 2018 at the CRI, where it remained through 2020, was contacted above Pearce Ferry Rapid at RM 127.5 in 2021. Additionally, a fish that was tagged in Las Vegas Bay in 2017 was contacted at RM 107.5 in 2021.

In 2022, the single Razorback Sucker tagged at the CRI on March 15, 2022, (code 4556) was not detected again after its release post-surgery for the remainder of the season. There was no movement detected up or down Pearce Ferry Rapid in 2022.

DISCUSSION

Telemetry observations from the CRI and LGC reinforce the importance of inflow areas to Razorback Sucker. Large inflow areas have been documented to contain greater fish-species diversity and reproduction and to allow recruitment of native fishes in a variety of systems (Kaemingk et al. 2007; Schreck 2010; Albrecht et al. 2010c, 2017). It is important to further investigate Razorback Sucker use of shallow, riverine areas within the Colorado River proper because annual patterns and variations in movement might be dictated by different flows, reservoir levels, and/or changes in habitat. For example, despite receding reservoir levels and perhaps increased flow velocities and turbulence at the Pearce Ferry Rapid, sonic-tagged fish were able to navigate through the rapid and into Grand Canyon during the 2013–2014 field season (Albrecht et al. 2014a). Similarly, in 2021, documentation of two Razorback Sucker navigating upstream through Pearce Ferry Rapid occurred. One of these fish had not been contacted since 2017, thus making the timing of navigation of Pearce Ferry Rapid impossible to know. The other fish had previously been documented at the CRI as recently as February 2020, giving a 15-month window of possible movement upstream, through Pearce Ferry Rapid. Until 2021, the number of contacts with fish above the Pearce Ferry Rapid since 2014 had been declining, despite research-related stocking events within Grand Canyon in 2016 and 2018. This suggests, at minimum, that Pearce Ferry Rapid may be serving as a movement deterrent (Albrecht et al. 2014a; Kegerries et al. 2015a, 2016a, 2017a, Kegerries et al. 2018, 2019, 2020a).

However, data from 2021 suggest that at least some Razorback Suckers are still capable of moving up Pearce Ferry Rapid, despite continually declining lake levels and variable riverine conditions.

It is also important to continue to document movements of sonic-tagged fish to see whether they return to previously utilized spawning areas during similar water years, or shift spawning locations based on water levels. Given the above findings, coupled with observations from the San Juan River near Lake Powell, where Razorback Sucker appear to aggregate at a waterfall (Cathcart et al. 2018), additional research effort at the Pearce Ferry Rapid is likely warranted to investigate the feature as a fish barrier to upstream movement.

In addition to illustrating movement patterns and providing habitat-use data, sonic-tagged fish helped determine the placement of trammel nets for the successful capture of wild Razorback Suckers at the CRI in nearly all years of this study (see Chapter 1). As reservoir levels fluctuate, sonic-tagged fish will continue to provide valuable data on changes in Razorback Sucker movement patterns, habitat use, and spawning-site selection within Lake Mead and Grand Canyon. For example, the 2021 primary spawning location at the CRI is now cut off from the river/lake interface, which underscores the importance that telemetered fish will have for field crews during the 2022 spawning season.

The detection of fish that have been released at other long-term sampling sites across Lake Mead, the CRI, and within Grand Canyon during this study confirm largescale movements of Razorback Sucker within Lake Mead and within Grand Canyon. This in turn underscores the connected nature of the overall Lake Mead and Colorado River within Grand Canyon. Aside from the sonic-tagged fish from Echo Bay found at the CRI in September 2016, wild Razorback Suckers originally captured and PIT-tagged at the Virgin River/Muddy River inflow area in 2009 and 2014 were recaptured at the CRI in 2012 and 2016. In fact, the fish recaptured in 2012 was also recaptured in Echo Bay in 2009, shortly after being captured at the Virgin River/Muddy River inflow area (Kegerries and Albrecht 2013a). Wild sonic-tagged and PIT-tagged Razorback Suckers have been observed using various spawning locations (Kegerries et al. 2020a, Rogers et al. 2020). By sonic-tagging additional wild Razorback Suckers, other questions posed in this report could be addressed, such as whether wild fish also use the flowing portions of the Colorado River proper. The AZGFD captured three wild Razorback Suckers in Grand Canyon, one in 2012, one in 2013, and one in 2018 (Bunch et al. 2012; Rogowski and Wolters 2014, D. Rogowski, AZGFD, personal communication). The wild, adult fish captured in 2013 was near a sonic-tagged fish just below Spencer Creek, which supports the use of sonic-tagged fish to identify new areas where other wild Razorback Suckers may aggregate for a variety of reasons (e.g., feeding, spawning). Additionally, the use of hatchery-reared and wild Razorback Suckers to locate wild conspecifics has been successful in Lake Mead. This technique led to the discovery of the Virgin River/Muddy River and CRI spawning aggregates (Albrecht and Holden 2005; Albrecht et al. 2010a), which suggests that hatchery-reared fish will integrate with established wild populations or perhaps behave similarly to wild fish.

Although sonic-tagged fish have been documented using flowing portions of the Colorado River proper since 2011 (as high as RM 23.0), the scale of documented movement has differed among individual fishes and years (i.e., Kegerries et al. 2016a). So far, most of the fish released in

Grand Canyon have remained in the river proper, and not all of the fish released in the CRI have utilized Grand Canyon. However, in past years, many of the fish released at the CRI appeared to take periodic, longer-term residency in Grand Canyon (e.g., Albrecht et al. 2014a). In 2011, we documented sonic-tagged fish that were released in the CRI moving above the Pearce Ferry Rapid during the spawning season. These fish usually returned to the CRI by July (Kegerries and Albrecht 2011). Conversely, 1 of the 10 sonic-tagged fish released in Grand Canyon in 2013 traveled downstream to the CRI during the spawning season and returned to the river in May 2014 (Albrecht et al. 2014a). Through 2020, six fish that had been released in Grand Canyon have been located at the CRI, and in 2021—one fish tagged in 2018 at the CRI and another fish tagged in 2017 in Las Vegas Bay were documented in the river. Comprehensive movement data suggest there may be a seasonal pattern in sonic-fish activity and movement (Kegerries et al. 2016a). At this time, it appears that wild fish and hatchery-reared fish utilized for telemetry purposes use habitats similarly. Regardless, the amount of time sonic-tagged fish spend in the flowing portion of the Colorado River, and their movements into and out of the area, suggest that the habitats offered by the lake and river combined are likely important to the wild Razorback Sucker in this system. In fact, past movements of fish from the CRI to just below Spencer Creek and Separation Canyon during the spawning season suggest that this area may be important for Razorback Sucker reproduction and therefore warrant future attention. Continuing to monitor these areas for adult, juvenile, larval, and sonic-tagged individuals will be critical for effective habitat-use determination and habitat protection. Fluctuating water levels may change the quality of spawning habitat found within the CRI from year to year; this also applies to Grand Canyon because flows vary and the interaction between the lake and the river changes over time.

Both sonic telemetry and radio telemetry in Grand Canyon has provided useful data regarding the feasibility and effectiveness of tracking Razorback Sucker within the riverine habitats. The adaptability of the individuals released into the river system and their proximity to other sonic-tagged and/or radio-tagged fish indicate that sonic-tagged and/or radio-tagged Razorback Suckers can incorporate with conspecifics and seek out habitat used by other Razorback Suckers. Although some of the sonic-tagged and radio-tagged fish released in Grand Canyon were not contacted this season, it is plausible that these individuals are not making the largescale movements that trigger passive detection.

Since the project's inception, telemetry has been used in Lake Mead and particularly the CRI, and it has proved to be a valuable monitoring tool. With the expansion of telemetry efforts into Grand Canyon, more Razorback Sucker movement data have been collected that illustrate the connectivity between the CRI, Grand Canyon, and LTM sites in terms of Razorback Sucker use. Additionally, movement of sonic-tagged fish from the CRI to other spawning areas in Lake Mead, and vice versa, has been documented. Sonic-tagged fish provided crucial information regarding the general location of the Razorback Sucker population, thus greatly enhancing our ability to capture new, wild Razorback Suckers at the CRI and verify their presence in, and use of, Grand Canyon. Their use in informing sampling should be continued within the greater study area.

In 2021, the introduction of 10 hatchery-reared Razorback Suckers implanted with radio tags (along with the passive, autonomous scanning) allowed for the documentation of 8 Razorback Sucker to be released during the 2021 reporting season. After nearly a year of data gathering, testing, and processing, the data (while provisional) suggest that radio-tagged Razorback Suckers may not by itself be a consistent way to track the fish movement. A test tag placed in the mainstem of the Colorado River at a depth of 2 m was not detected by the receiver, in either autonomous or active listening modes, until the water depth was decreased to 1 m. This test, along with previous testing in a lentic system, suggests that if Razorback Suckers are not located in the top 2 m of the water column, they will not be readily detected. Despite this, the use of radio-tagged fish allowed researchers to observe new movement patterns and unknown, upstream-most locations for Razorback Sucker in Grand Canyon during 2021 and 2022. Continued use of and research using this technique will likely refine the methodology used in future monitoring years and may lead to additional observations (much like what has occurred with sonic-tagged fish in Lake Mead and now Grand Canyon).

The network of SURs within Grand Canyon now in place and maintained by this study has provided important insights into not only Razorback Sucker, but also Humpback Chub (USFWS unpublished data), nonnative Brown Trout (NPS unpublished data), and Rainbow Trout (AZGFD unpublished data). The advantage to this telemetry system is that, when fish are deeper in the water column, SURs are more likely to detect their movement patterns. Continued use and maintenance of this telemetry network could prove highly beneficial for these ongoing studies, as well as any future question for which telemetry could help in assessing movement within Grand Canyon and the greater Lake Mead system.

Finally, it appears that while both telemetry techniques have limitations and advantages, the continued use of both radio telemetry and sonic telemetry can result in the discovery and documentation of new native-fish movement patterns. Sonic telemetry has been the foundation of this research; it has guided researchers from Lake Mead into the river, and from Lava Falls to Phantom Ranch. Now these technologies (radio and sonic telemetry together) have allowed researchers to observe Razorback Sucker movement throughout Lake Mead and throughout most of Grand Canyon. Sonic and radio telemetry, as well as passive and active tracking techniques, have been important to understanding Razorback Sucker movement in this riverine environment, and it may be that the combination of these two tag types, as described herein, will allow for the most-effective monitoring that telemetry can provide within the constraints of current technology.

2022–2023 TELEMETRY STUDY RECOMMENDATIONS

Given (1) the holistic findings from the CRI, (2) locating larval Razorback Suckers in Grand Canyon, and (3) tracking fish movement within both the CRI and Grand Canyon, maintaining telemetry as a tool to guide sampling efforts should be continued. The following recommendations are specific to telemetry efforts.

1. Continue similar monthly efforts to track sonic-tagged fish in the CRI during less-intensive sampling periods while also tracking fish daily and weekly during the spawning season. Because using SURs within the CRI and Grand Canyon is critical to locating fish as they move throughout the study area, the SURs should be downloaded and maintained regularly during sampling events to ensure their efficacy. The continued use of telemetry throughout Grand Canyon from Lee's Ferry to Pearce Ferry is also recommended to help identify adult and juvenile Razorback Sucker spawning sites and habitat use.

2. Continue to implant fish with sonic tags using the methods described herein on an as-needed basis. For the CRI, it is recommended that wild fish be implanted rather than using hatchery-reared individuals to help locate lake spawning aggregations. For Grand Canyon, Lake Mead Razorback Suckers could be supplied by the NDOW Fish Hatchery (supported by the LMWG) and tagged and released. It may be informative to release telemetered Razorback Sucker near Havasu Creek because larvae have been collected just downstream and spawning appears to occur within that region of Grand Canyon.

3. Additionally, smaller juvenile fish, if and when available, could be used for telemetry purposes to determine whether recruitment habitat exists within the CRI and Grand Canyon, and whether juvenile and adult fish display similar movement patterns. Location information gained from this size class could help inform sampling for this life-stage.

4. As mentioned, it is currently unknown to what extent the Pearce Ferry Rapid is a barrier to fish movement, or if it at least serves as a deterrent to upstream fish movement under recent conditions. Given the findings of limited movement above the rapid since 2014, the cooperative effort between Reclamation, USFWS, NPS, AZGFD, and BIO-WEST should continue through 2023, if possible. This effort includes active and passive sampling using electrofishing, seining, hoop netting, angling, and submersible PIT scanning. Telemetry data is also useful for informing that effort.

5. The network of SURs now in place and maintained by this study within Grand Canyon has provided important insight into several species. Continued use and maintenance of this telemetry network could prove highly beneficial for these ongoing studies, as well as any future question where telemetry could help in assessing movement within Grand Canyon and greater Lake Mead system.

6. Finally, the use of radio-tagged fish within Grand Canyon has contributed to the overall understanding of Razorback Sucker movement in the river. Maintaining a cohort of these fish may allow researchers to find other conspecifics in previously unknown or understudied areas in Grand Canyon, Lake Mead, and the holistic lake/river ecosystem.

> However, data collected in 2022 have shown that continued testing may be necessary to refine the use of radio-telemetry in the Grand Canyon. Unknown signals in the Grand Canyon continue to result in what appears to be false positive detections. As the project continues, it may be necessary to refine the criteria the raw data is passed through to improve the removal of false identifications.

CONCLUSIONS AND FUTURE CONSIDERATIONS

An important goal for the CRI and Grand Canyon investigations was to ascertain whether Razorback Sucker recruitment was occurring at these locations. The captures of an age-2 juvenile Razorback Sucker at the CRI in 2013 (Kegerries and Albrecht 2013b), an age-3 immature Razorback Suckers at the CRI in 2014 (Albrecht et al. 2014a), 2017 (Kegerries et al. 2017a), and 2019, and a recently transformed age-0 juvenile Razorback Sucker at Iceberg Canyon in 2014 (Albrecht et al. 2014a) provide some evidence of recruitment. These results highlight the importance of the flowing portions of the Colorado River to Razorback Sucker. They also emphasize the role lentic conditions within the CRI and Grand Canyon have in the species' life history, particularly given the Razorback Sucker attraction to inflow and flowing-water habitats as documented in this report and by others working with the species (Albrecht et al. 2017). Data collected to date show steady numbers of wild, adult Razorback Suckers, spawning areas within the CRI and Grand Canyon, and the presence of all life-stages within the study area. While we think that our study design would allow for detection of juvenile Razorback Suckers during seining efforts in Grand Canyon (e.g., Skorupski et al. 2012; Albrecht et al. 2014a; Gibson and Caldwell 2018), it is plausible that their recruitment habitat is in Lake Mead and perhaps in other riverine, off-channel habitats that are not currently being sampled. We have hypothesized that the combination of river habitats and the diversity of niche space created and maintained within the CRI and the greater, dynamic Lake Mead system, are allowing the continued Razorback Sucker recruitment observed within Lake Mead and perhaps within the Colorado River proper (Albrecht et al. 2017; Kegerries et al. 2017b).

Valdez et al. (2012a) suggest that the distances from spawning locations to floodplains in the middle Green River system range from 6 to 60 miles, and that the distance from a potential spawning area in Grand Canyon could be similar. Should Razorback Sucker larvae be produced in areas below Diamond Creek—for example, near Spencer Creek, as was evinced by telemetry efforts in 2014 (Albrecht et al. 2014a)—drift distances could be substantially less than estimates put forth by Valdez et al. (2012a). Even larval fish produced at the top of the current Grand Canyon study reach, assuming an average river drift speed of 2.5 miles per hour (Valdez et al. 2012a), could reach the Lake Mead within the 8–19-day window before they absorb their yolk sac and risk starvation (Valdez et al. 2012a). Following that same logic, larval fish produced at the very top of Grand Canyon could also reach Lake Mead and its backwater and oxbow-like habitats before starvation is likely (Kegerries et al. 2017b).

Furthermore, during their review and summary of Razorback Sucker habitat in the Colorado River system as it pertains to Grand Canyon, Valdez et al. (2012a) found the following:

> Unimpeded and secure drift corridors are essential to larval survival. Many larvae drift at night or under the cover of turbidity to escape predation. Because the larvae

> lack well-developed fins, they are reliant on river currents to become carried into a productive nursery area. Hence, the location of nursery areas a short distance downstream from spawning sites is vital to the species . . . Although there are no floodplains in the LGC, there are numerous backwaters that are used by other native Colorado River suckers, and are similar to backwaters used by Razorback Sucker larvae in the San Juan River. Speas and Trammell (2009) counted 22 backwaters between RM 181 and RM 265 that could provide potential nursery habitat for larval Razorback Suckers. Additionally, the Colorado River inflow could provide substantial nursery habitat, depending on lake elevation . . .

Lake Mead typically warms more quickly and stays warmer for a longer period (and with more consistency) compared with the hypolimnetic releases typical of the Colorado River in Grand Canyon. As such, important "degree days," which are potentially critical to gonadosomatic growth, could be found by maturing Razorback Sucker. This likely makes Lake Mead critical in the overall continuation of the Razorback Sucker life cycle in this modified system (Kegerries et al. 2017b). Finally, because there are complex habitat and cover types within the overall system, as well as diverse niche space near the changing inflow areas that benefit all native fish species (Albrecht et al. 2017), there is hope for this population. Such reasoning may help us understand the paucity of juvenile Razorback Sucker captures in Grand Canyon through 2021, particularly when coupled with differential use of adult sonic-tagged Razorback Sucker.

Unlike Razorback Sucker, juvenile Humpback Chub have been captured throughout the 2014–2021 Grand Canyon sampling efforts. Although their abundance is lower than that of other native fish species, they appear to occur throughout the study area. The numbers of small, unmarked Humpback Chub should not be surprising, as reproduction has been documented upstream. It also appears, although it has not been verified, that some recruitment is taking place, as varying sizes, if not age-classes, of Humpback Chub are being captured on a fairly routine basis throughout the riverine portions of the study area, including below Pearce Ferry. During investigations at the CRI, few Flannelmouth Sucker larvae and only three documented Bluehead Sucker larvae have been found (Kegerries and Albrecht 2011 and 2013a; Kegerries et al. 2015a). If these species, along with Humpback Chub, are spawning in Grand Canyon, and their larvae drift downstream, it would make sense to find more Humpback Chub, Flannelmouth Sucker, and Bluehead Sucker larvae in the CRI. However, we do know that Humpback Chub, Flannelmouth Sucker, and Bluehead Sucker or more adapted to and prefer riverine habitats as opposed to lentic habitats (Minckley and Marsh 2009). Perhaps most larvae are able to actively swim and seek out shallow, backwater habitats before entering the lake where the CRI larval sampling occurs. We suspect, however, that later ontogenetic stage Grand Canyon-derived Razorback Sucker larvae have been captured at the CRI. It is also apparent that both lotic and lentic habitats seem to be more important for Razorback Sucker than the other native species, and it appears as though our study design is quite good at documenting the small-bodied native fish community through time.

Natural Razorback Sucker recruitment within Lake Mead has been documented for more than two decades (Holden et al. 1997, 1999, 2000a, 2000b, 2001; Abate et al. 2002; Welker and Holden 2003, 2004; Albrecht and Holden 2005; Albrecht et al. 2006a, 2006b, 2007, 2008a, 2008b, 2010a, 2010b, 2013a, 2013b, 2014b, 2017; Kegerries et al. 2009; Shattuck et al. 2011; Shattuck and Albrecht 2014; Mohn et al. 2015, 2016; Rogers et al. 2017, 2018, 2019, 2020, 2021). Through this research, many aspects of the demography and life history of the population of Razorback Sucker in Lake Mead have been found to be somewhat unique throughout the species' current distribution (e.g., high growth rate indicative of a young population [Kegerries and Albrecht 2013a, 2013b; Albrecht et al. 2013a, 2013b, 2014], nearly annual wild recruitment since the 1970s with a relatively high adult survival rate [Shattuck et al. 2011; Albrecht et al. 2013a, 2013b, 2014b; Mohn et al. 2015, 2016; Rogers et al. 2017, 2018, 2019, 2020, 2021], and the continued collection of sexually immature juvenile individuals [Kegerries and Albrecht 2013b; Kegerries et al. 2018, 2019, 2020a]). Furthermore, it has been documented that, in spite of nonnative predatory pressures, natural recruitment appears to have continued in Lake Mead through processes suspected to be related to the amount and availability of inundated cover and turbidity (Welker and Holden 2003, 2004; Albrecht et al. 2010b, 2013a, 2017; Shattuck and Albrecht 2014; Kegerries et al. 2015a, 2016a, 2017b, 2018, 2019, 2020a).

The specific dynamics of potential recruitment through forms of cover, primarily at inflow areas, remain unknown. However, a strong affinity for the inflow areas (Albrecht et al. 2017) of Lake Mead has been documented in the recent habitat associations of sonic-tagged, juvenile Razorback Suckers (Shattuck and Albrecht 2014; Kegerries et al. 2015b, 2016). Clearly, sonic-tagged and radio-tagged Razorback Suckers use the Colorado River throughout Grand Canyon and the CRI, and some Razorback Sucker reproduction is occurring within the river proper (Kegerries et al. 2017b). Moreover, movement of sonic-tagged Razorback Suckers throughout Lake Mead and Grand Canyon during this study has proven that the system is more connected than previously known. Larval Razorback Sucker collections documented individuals in a range of sizes upstream and downstream in Grand Canyon study area. This implies that there may be numerous aggregations of Razorback Sucker spawning in Grand Canyon—as is apparent with Humpback Chub. At a minimum, larval Razorback Sucker collections imply that this is one Razorback Sucker aggregation that is spawning in multiple areas. The level of exchange that occurs between individuals spawned in Grand Canyon and those documented to recruit in Lake Mead is just now becoming better understood. Furthermore, the potential role that the CRI and other Lake Mead inflows may play in the production of juvenile Razorback Suckers, perhaps ultimately leading to recruitment of the species in this system, is an exciting aspect to track during future project efforts. Similarly, inflows appear to be important locations for Razorback Sucker in Lake Powell, which has a habitat scenario analogous to the upper Colorado River basin (Francis et al. 2013, 2015; Albrecht et al. 2017).

The overall shift in community composition of both native and nonnative fish species within Grand Canyon in the past two decades is worth noting (Kegerries et al. 2020b). The increase in abundance of native fish species with the overall decline or lack of nonnative fishes below Diamond Creek is promising. It is apparent that habitat changes have occurred within the LGC, and it is likely that the receding levels of Lake Mead have created more lotic habitats, in which native species thrive. It is interesting that most of the prolific nonnative species that were once present in the LGC—and continue to be prolific in Lake Mead—are not abundant upstream of Lake Mead. This shift in community structure and increase in native fish abundance could be a result of temperature changes through time related to Lake Powell and Lake Mead water levels, or perhaps it is merely a function of distance to the reservoir and the conversion of habitat from lacustrine to riverine. The formation of Pearce Ferry rapid and its potential for deterring or prohibiting upstream fish movement could also play a role in fish community structure within

Grand Canyon. The validity of these hypotheses will likely become clearer as water levels and temperatures continue to change in the future. Certainly, native fishes are thriving in Grand Canyon and it is an opportune time for native fish research.

In summary, the efforts and techniques described in this report have helped define the interactions of Razorback Sucker within Grand Canyon, CRI, and greater Lake Mead study areas. Razorback Sucker movement and habitat utilization within and between all sites have now been documented, and they provide a new, dynamic, and holistic view of this particular population. This also suggests that the Razorback Suckers in the Lake Mead system demonstrate sufficient plasticity in habitat use over a broad range of environmental conditions in Lake Mead and Grand Canyon. Integrated Razorback Sucker monitoring remains important, not only within the Colorado River proper but also at the CRI and LTM sites. Given our understanding of Razorback Sucker within the expanded study area and the particular knowledge that larval Razorback Sucker are being produced within Grand Canyon, or its tributaries (e.g., Havasu Creek), there is a need to better understand the existing wild population, under variable conditions and new management strategies (DOI 2016). Items of particular investigatory interest at this time include but are not limited to (1) establishing the upstream Grand Canyon boundary of tagged Razorback Sucker habitat use, (2) documenting all spawning locations of the species within Grand Canyon, and (3) better characterizing the wild recruitment observed within the expanded study area through the continued use of nonlethal aging techniques.

In conclusion, we highlight the importance of this study, especially when combined with previous research and monitoring efforts for Razorback Sucker on Lake Mead and within Grand Canyon. The following are the result of previous efforts along with the potential benefits of continued, similar studies.

1. Razorback Sucker research and monitoring in Lake Mead helped identify and establish a workable model for understanding and promoting wild recruitment throughout the Razorback Sucker's historic range.

2. Monitoring at the CRI and in Grand Canyon has provided substantial insight into Humpback Chub and the overall small-bodied and larval fish community within the study area.

3. In addition to various annual reports prepared from this project, several peer-reviewed journal publications have stemmed from the combined Lake Mead and Grand Canyon study efforts in recent years (Albrecht et al. 2010c; Albrecht et al. 2017; Kegerries et al. 2017b; Rogowski et al. 2018; Albrecht et al. 2020; Kegerries et al. 2020b).

4. No other study is monitoring native (including Razorback Sucker and Humpback Chub) and nonnative adult, small-bodied, and larval fish in Lake Mead and the Grand Canyon. As much of our sampling focuses on the early life-stages, these data will be important to help inform managers about future nonnative fish concerns and provide an early warning system for potential invasions.

5. This study provides an effective means to monitor future management efforts, including any stockings, reintroductions, and so forth, and place those into context in a comparable and historically valid manner.

6. Due to the breadth of the study area, these efforts currently provide telemetry coverage for ongoing and future studies of Razorback Sucker, Brown Trout, Humpback Chub, and other species of interest.
7. Under ever-changing climate scenarios, this highly repeatable and statistically sound study design will allow for insight into fish community trends.

8. All of the monitoring efforts can provide recommendations for future study and research needs. The recommendations that come out of monitoring efforts can then be used by management agencies to conduct appropriate research under conservation and recovery goals.

9. Because this study overlaps between Lake Mead and the Grand Canyon, we can better track movement of native and nonnative fish between the two systems, allowing for a more holistic understanding of habitat use and the importance of each habitat as they relate to each other.

10. The current study has provided and required and extensive collaboration between government and private entities. This established collaboration can benefit other projects through access to the Grand Canyon, Lake Mead, or the inflow area.

REFERENCES

Abate P.D., T.L. Welker, and P.B. Holden. 2002. Razorback sucker studies on Lake Mead, Nevada. 2001–2002 Annual Report. PR-578-6. Prepared for the Department of Resources, Southern Nevada Water Authority, by BIO-WEST, Inc., Logan, Utah.

Ackerman, M.W. 2007. 2006 Native fish monitoring activities in the Colorado River, Grand Canyon. Annual Report. Prepared for the Grand Canyon Monitoring and Research Center by SWCA Environmental Consultants, Flagstaff, Arizona.

Ackerman, M.W., D.L. Ward, T. Hunt, R.S. Rogers, D.R. Van Haverbeke, and A. Morgan. 2006. 2006 Grand Canyon long-term fish monitoring Colorado River, Diamond Creek to Lake Mead. Annual Report. Prepared for the Grand Canyon Monitoring and Research Center by SWCA Environmental Consultants, Flagstaff, Arizona.

Albrecht, A.B. 1974. Some observations on factors associated with survival of striped bass eggs and larvae. California Fish and Game 59:100-113.

Albrecht, B., and P.B. Holden. 2005. Razorback sucker studies on Lake Mead, Nevada. 2004–2005 Annual Report. PR-960-1. Prepared for the Department of Resources, Southern Nevada Water Authority, by BIO-WEST, Inc., Logan, Utah.

Albrecht, B., P.B. Holden, and M. Golden. 2006a. Razorback sucker studies on Lake Mead, Nevada. 2005–2006 Annual Report. PR-977-1. Prepared for the Department of Resources, Southern Nevada Water Authority, by BIO-WEST, Inc., Logan, Utah.

Albrecht, B., P.B. Holden, and M. Golden. 2006b. Lake Mead Razorback Sucker monitoring recommendations. 2005–2006 Report. PR-977-1. Prepared for the Department of Resources, Southern Nevada Water Authority, by BIO-WEST, Inc., Logan, Utah.

Albrecht, B., P.B. Holden, and R. Kegerries. 2009. Long-term management plan for the conservation of Razorback Sucker in Lake Mead, Nevada and Arizona. PR-1161-03. Prepared for the US Bureau of Reclamation by BIO-WEST, Inc., Logan, Utah.

Albrecht, B., T. Sanderson, and P.B. Holden. 2007. Razorback sucker studies on Lake Mead, Nevada. 2006–2007 Annual Report. PR-1093-1. Prepared for the US Bureau of Reclamation and the Department of Resources, Southern Nevada Water Authority, by BIO-WEST, Inc., Logan, Utah.

Albrecht, B., T. Sanderson, and P.B. Holden. 2008a. Razorback sucker studies on Lake Mead, Nevada and Arizona. 1996–2007 Comprehensive Report. PR-1093-2. Prepared for the US Bureau of Reclamation and the Department of Resources, Southern Nevada Water Authority, by BIO-WEST, Inc., Logan, Utah.

Albrecht, B., R.B. Kegerries, and P.B. Holden. 2008b. Razorback sucker studies on Lake Mead, Nevada and Arizona. 2007–2008 Annual Report. PR-1161-1. Prepared for the US Bureau of Reclamation and the Department of Resources, Southern Nevada Water Authority, by BIO-WEST, Inc., Logan, Utah.

Albrecht, B., R. Kegerries, P.B. Holden, and R. Rogers. 2010a. Razorback sucker investigations at the Colorado River Inflow Area of Lake Mead, Nevada and Arizona. 2010 Final Annual Report. PR-1310-01. Prepared for the US Bureau of Reclamation by BIO-WEST, Inc., Logan, Utah.

Albrecht, B., R. Kegerries, R. Rogers, and P.B. Holden. 2010b. Razorback sucker studies on Lake Mead, Nevada and Arizona. 2009–2010 Annual Report. PR-1303-01. Prepared for the US Bureau of Reclamation and the Department of Resources, Southern Nevada Water Authority, by BIO-WEST, Inc., Logan, Utah.

Albrecht, B., P.B. Holden, R. Kegerries, and M.E. Golden. 2010c. Razorback sucker recruitment in Lake Mead, Nevada–Arizona, why here? Lake and Reservoir Management 26(4):336–344.

Albrecht, B., Z. Shattuck, and R. Rogers. 2013a. Razorback sucker studies on Lake Mead, Nevada and Arizona. 2011–2012 Annual Report. PR-1475-01. Prepared for the US Bureau of Reclamation by BIO-WEST, Inc., Logan, Utah.

Albrecht, B., Z. Shattuck, and R. Rogers. 2013b. Razorback sucker studies on Lake Mead, Nevada and Arizona. 2012–2013 Annual Report. PR-1475-02. Prepared for the US Bureau of Reclamation by BIO-WEST, Inc., Logan, Utah.

Albrecht, B., R. Kegerries, J.M. Barkstedt, W.H. Brandenburg, A.L. Barkalow, S.P. Platania, M. McKinstry, B. Healy, J. Stolberg, and Z. Shattuck. 2014a. Razorback Sucker *Xyrauchen texanus* research and monitoring in the Colorado River inflow area of Lake Mead and the lower Grand Canyon, Arizona and Nevada. Final Report. Prepared by BIO-WEST, Inc., for the US Bureau of Reclamation, Upper Colorado Region, Salt Lake City, Utah.

Albrecht, B., Z. Shattuck, R. Rogers and R. Kegerries. 2014b. Razorback sucker studies on Lake Mead, Nevada and Arizona. 2013–2014 Annual Report. PR-1475-03. Prepared for the US Bureau of Reclamation by BIO-WEST, Inc., Logan, Utah.

Albrecht, B., H. Mohn, R. Kegerries, M.C. McKinstry, R. Rogers, T. Francis, B. Hines, J. Stolberg, D. Ryden, D. Elverud, B. Schliecher, K. Creighton, B. Healy, and B. Senger. 2017. Use of inflow areas in two Colorado River Basin Reservoirs by endangered Razorback Sucker *Xyrauchen texanus*. Western North American Naturalist 77(4):500–514.

Albrecht, B., R. Kegerries, R. Rogers, and P. Holden. 2020. The exotic dilemma: lessons learned from efforts to recover native Colorado River basin fishes. *In* D. Propst, J. Williams, K. Bestgen, and C. Hoagstrom, editors, Standing between life and extinction: Ethics and ecology of conserving aquatic species in the American Southwest. University of Chicago Press Books, Chicago, Illinois.

Anderson, G. W., R. S. McKinley, and M. Colavecchia. 1997. The use of clove oil as an anesthetic for Rainbow Trout and its effects on swimming performance. North American Journal of Fisheries Management. 17 (2):301–307.

Beeman, J.W., and R.W. Perry. 2012. Bias from False-Positive Detections and Strategies for their Removal in Studies Using Telemetry. Pages 505-518 *in* N.S. Adams, J. W. Beeman, and J.H. Eiler, editors. Telemetry techniques: a user guide for fisheries research. American Fisheries Society, Bethesda, Maryland.

Bestgen, K.R. 1990. Status review of the Razorback Sucker, *Xyrauchen texanus*. Submitted to the US Bureau of Reclamation. Contribution 44, Larval Fish Laboratory, Colorado State University.

Bestgen, K.R. 2008. Effects of water temperature on growth of Razorback Sucker larvae. Western North American Naturalist 68 (1):15–20.

Bestgen, K.R., and M.A. Williams. 1994. Effects of fluctuating and constant temperature on early development and survival of Colorado Squawfish. Transactions of the American Fisheries Society 123 (4):574–579.

Bestgen, K.R., G.B. Haines, R. Brunson, T. Chart, M.A. Trammell, R.T. Muth, G. Birchell, K. Christopherson, and J.M. Bundy. 2002. Status of wild Razorback Sucker in the Green River Basin, Utah and Colorado, determined from basin wide monitoring and other sampling programs. Final Report. Colorado River Recovery Implementation Program Project No. 22D.

Bestgen, K.R., G.B. Haines, and A.A. Hill. 2011. Synthesis of flood plain wetland information: Timing of Razorback Sucker reproduction in the Green River, Utah, related to stream flow, water temperature, and flood plain wetland availability. Final Report to the Upper Colorado River Endangered Fish Recovery Program, Denver. Larval Fish Laboratory Contribution 163.

Bestgen, K. R., T. E. Dowling, B. Albrecht, and K. A. Zelasko. 2020. Large-river fish conservation in the Colorado River Basin. Progress and challenges with Razorback Sucker. *In* D. Propst, J. Williams, K. Bestgen, and C. Hoagstrom, editors, Standing between life and extinction: Ethics and ecology of conserving aquatic species in the American Southwest. University of Chicago Press Books, Chicago, Illinois.

Bookstein, F.L., B. Chernoff, R.L. Elder, J.M. Humphries, Jr., G.R. Smith, and R.E. Strauss. 1985. Morphometric in evolutionary biology: the geometry of size and shape change, with examples from fishes. Special Publication 15. The Academy of Natural Sciences of Philadelphia, Pennsylvania.

Bozek, M.A., L.J. Paulson, and G.R. Wilde. 1990. Effects of ambient Lake Mohave temperatures on development, oxygen consumption, and hatching success of the Razorback Sucker. Environmental Biology of Fishes 27:255–263.

Brandenburg, W.H., T.A. Francis, D.E. Snyder, K.R. Bestgen, B.A. Hines, W.D. Wilson, S. Bohn, A. S. Harrison, and S.L. Clark Barkalow. 2019. Discovery of Grass Carp Larvae in the Colorado River Arm of Lake Powell. North American Journal of Fisheries Management 39 (1):166–171.

Bunch, A.J., R.J Osterhoudt, M.C. Anderson, and W.T. Stewart. 2012. Colorado River fish monitoring in Grand Canyon, Arizona. 2012 Annual Report. Submitted to the Grand Canyon Monitoring and Research Center, Flagstaff, Arizona.

Bunt, C.M., S.J. Cooke, C. Katopodis, and R.S. McKinley. 1999. Movement and summer habitat of Brown Trout (*Salmo trutta*) below a pulsed discharge hydroelectric generating station. Regulated Rivers: Research and Management 15 (5):395–403.

Burke, T. 1995. Rearing wild Razorback Sucker larvae in lake-side backwaters, Lake Mohave, Arizona/Nevada. Proceeding of the Desert Fishes Council 26:35 (abstract only).

Carothers, S.W., and C.O. Minckley. 1981. A survey of the fishes, aquatic invertebrates and aquatic plants of the Colorado River and selected tributaries from Lees Ferry to Separation Rapids. Final Report. Submitted to the US Bureau of Reclamation, Museum of Northern Arizona, Flagstaff, Arizona.

Cathcart, C.N., C.A. Pennock, C.A. Cheek, M.C. McKinstry, P.D. MacKinnon, M.M. Conner, and K.B. Gido. 2018. Waterfall formation at a desert river-reservoir delta isolates endangered fishes. River Research and Applications 2018. 34 (8):948–956.

Clarkson, R.W., and M.R. Childs. 2000. Temperature effects of hypolimnial-release dams on early life stages of Colorado River basin big-river fishes. Copeia 2000 (2):402–412.

[DOI] US Department of the Interior. 2016. Glen Canyon Dam long-term experimental and management plan environmental impact statement–Final. Available at: http://ltempeis.anl.gov/documents/final-eis/. Accessed 9/20/2017.

Douglas, M.R., and M.E. Douglas. 2000. Late season reproduction by big-river Catostomidae in Grand Canyon (Arizona). Copeia 2000(1):238–244.

Douglas, M.E., and P.C. Marsh. 1998. Population and survival estimate of Catostomus latipinnis in northern Grand Canyon, with distribution and abundance of hybrids with *Xyrauchen texanus*. Copeia 1998(4): 915–925.

Francis, T.A., D.W. Ryden, B.J. Schleicher, and D.S. Elverud. 2013. San Juan River arm of Lake Powell Razorback Sucker (*Xyrauchen texanus*) survey: 2011. Final Report. Submitted to the US Bureau of Reclamation and the San Juan River Basin Recovery and Implementation Program.

Francis, T.A., D.S. Elverud, B.J. Schleicher, D.W. Ryden, and B. Gerig. 2015. San Juan River arm of Lake Powell Razorback Sucker (*Xyrauchen texanus*) survey: 2012. Final Report. Submitted to the US Bureau of Reclamation and the San Juan River Basin Recovery and Implementation Program.

Gibson, C. and J. Caldwell. 2018. Assessment of stocked Razorback Sucker reproduction in the lower Green and lower Colorado rivers. Annual Project Report. Upper Colorado River Endangered Fish Recovery Program, Denver, Colorado.

Gilbert, E.I., W.H. Brandenburg, A.L. Barkalow, R.B. Kegerries, B.C. Albrecht, B.D. Healy, E.C. Omana Smith, J.R. Stolberg, M.C. McKinstry, and S.P. Platania. 2022. Systematic larval fish surveys and abiotic correlates characterize extant native fish assemblage reproductive success in the Colorado River, western, Arizona. The Southwestern Naturalist. 66: 67–76.

Gloss, S.P., J.E. Lovich, and T.S. Melis (editors). 2005. The state of the Colorado River ecosystem in Grand Canyon. US Geological Survey Circular 1282.

Healy, B.D., E.C. Omana Smith, R.C. Schelly, M.A. Trammell, and C.B. Nelson. 2020. Establishment of a reproducing population of endangered Humpback Chub through translocations to a Colorado River Tributary in Grand Canyon, Arizona. North American Journal of Fisheries Management 40 (1):278–292.

Hedden, C., Rogowski, D., Boyer, J. Mason-Sarantopulos, L., Rogers, R. and Albrecht, B. 2022. Fish monitoring in the Colorado River upstream and downstream of Pearce Ferry Rapid to Lake Mead, 2021. Arizona Game and Fish Department and BIO-WEST, Inc.

Holden, P.B. 1979. Ecology of riverine fishes in regulated stream systems with emphasis on the Colorado River. Pages 57–74 in The ecology of regulated streams. J.V. Ward and J.A. Stanford (editors). Plenum Press, New York, New York.

Holden, P.B. 1994. Razorback sucker investigations in Lake Mead, 1994. Final Report, PR-470-1. Prepared for the Department of Resources, Southern Nevada Water Authority, by BIO-WEST, Inc., Logan, Utah.

Holden, P.B., and C.B. Stalnaker. 1975. Distribution of fishes in the Dolores and Yampa River systems of the upper Colorado basin. Southwestern Naturalist 19 (4):403–412.

Holden, P.B., P.D. Abate, and J.B. Ruppert. 1997. Razorback sucker studies on Lake Mead, Nevada. 1996–1997 Annual Report. PR-578-1. Prepared for the Department of Resources, Southern Nevada Water Authority, by BIO-WEST, Inc., Logan, Utah.

Holden, P.B., P.D. Abate, and J.B. Ruppert. 1999. Razorback sucker studies on Lake Mead, Nevada. 1997–1998 Annual Report. PR-578-2. Prepared for the Department of Resources, Southern Nevada Water Authority, by BIO-WEST, Inc., Logan, Utah.

Holden, P.B., P.D. Abate, and J.B. Ruppert. 2000a. Razorback sucker studies on Lake Mead, Nevada. 1998–1999 Annual Report. PR-578-3. Prepared for the Department of Resources, Southern Nevada Water Authority, by BIO-WEST, Inc., Logan, Utah.

Holden, P.B., P.D. Abate, and J.B. Ruppert. 2000b. Razorback sucker studies on Lake Mead, Nevada. 1999–2000 Annual Report. PR-578-4. Prepared for the Department of Resources, Southern Nevada Water Authority, by BIO-WEST, Inc., Logan, Utah.

Holden, P.B., P.D. Abate, and T.L. Welker. 2001. Razorback sucker studies on Lake Mead, Nevada. 2000–2001 Annual Report. PR-578-5. Prepared for the Department of Resources, Southern Nevada Water Authority, by BIO-WEST, Inc., Logan, Utah.

Hubbs, C.L., and R.R. Miller. 1953. Hybridization in nature between the fish genera *Catostomus* and *Xyrauchen*. Papers of the Michigan Academy of Science, Arts, and Letters 38:207–233.

Hubert, W.A. and M.C. Fabrizio. 2007. Relative abundance and catch per unit effort. Pages 294–306 in C. S. Guy and M. L. Brown, editors. Analysis and interpretation of freshwater fisheries data. American Fisheries Society, Bethesda, Maryland.

JMP. 2021. Version 16.2.0 for Windows. SAS Institute Inc., Cary, North Carolina, USA.

Johnson, J.E., and R.T. Hines. 1999. Effect of suspended sediment on vulnerability of young Razorback Sucker to predation. Transaction of the American Fisheries Society 128:648–655.

Joseph, T.W., J.A. Sinning, R.J. Behnke, and P.B. Holden. 1977. An evaluation of the status, life history, and habitat requirements of endangered and threatened fishes of the upper Colorado River system. FWS/OBS Report 24, part 2. US Fish and Wildlife Service, Office of Biological Services, Fort Collins, Colorado. 183 p.

Kaemingk, M.A., B.D.S. Graeb, C.W. Hoagstrom, and D.W. Willis. 2007. Patterns of fish diversity in a mainstem Missouri River reservoir and associated delta in South Dakota and Nebraska, USA. River Research and Applications 23 (7):786–791.

Kegerries, R., and B. Albrecht. 2011. Razorback sucker investigations at the Colorado River inflow area of Lake Mead, Nevada and Arizona. 2011. Final Annual Report. PR-1310-02. Prepared for the Lower Colorado River Multi-Species Conservation Program, US Bureau of Reclamation, by BIO-WEST, Inc. Logan, Utah.

Kegerries, R., and B. Albrecht. 2013a. Razorback sucker investigations at the Colorado River inflow area of Lake Mead, Nevada and Arizona. 2012 Final Annual Report. PR-1310-03. Prepared for the US Bureau of Reclamation by BIO-WEST, Inc., Logan, Utah.

Kegerries, R., and B. Albrecht. 2013b. Razorback sucker investigations at the Colorado River inflow area of Lake Mead, Nevada and Arizona. 2013 Final Annual Report. PR-1310-04. Prepared for the US Bureau of Reclamation by BIO-WEST, Inc., Logan, Utah.

Kegerries, R., B. Albrecht, and P.B. Holden. 2009. Razorback sucker studies on Lake Mead, Nevada and Arizona. 2008–2009 Annual Report. PR-1161-02. Prepared for the US Bureau of Reclamation and the Department of Resources, Southern Nevada Water Authority, by BIO-WEST, Inc., Logan, Utah.

Kegerries, R., B. Albrecht, H. Mohn, and R. Rogers. 2016b. Sonic telemetry and habitat use of juvenile Razorback Suckers in Lake Mead. 2015–2016 Annual Report. Prepared for the US Bureau of Reclamation by BIO-WEST, Inc., Logan, Utah.

Kegerries, R., B. Albrecht, R. Rogers, E.I. Gilbert, W.H. Brandenburg, A.L. Barkalow, S.P. Platania, M. McKinstry, B. Healy, J. Stolberg, E. Omana Smith, C. Nelson, and H. Mohn. 2015a. Razorback Sucker *Xyrauchen texanus* research and monitoring in the Colorado River inflow area of Lake Mead and the lower Grand Canyon, Arizona and Nevada. Final Report. Prepared by BIO-WEST, Inc., for the US Bureau of Reclamation, Upper Colorado Region, Salt Lake City, Utah.

Kegerries, R., B. Albrecht, E.I. Gilbert, W.H. Brandenburg, A.L. Barkalow, H. Mohn, R. Rogers, M. McKinstry, B. Healy, J. Stolberg, E. Omana Smith, and M. Edwards. 2016a. Razorback Sucker *Xyrauchen texanus* research and monitoring in the Colorado River inflow area of Lake Mead and the lower Grand Canyon, Arizona and Nevada. Final report prepared by BIO-WEST, Inc., for the US Bureau of Reclamation, Upper Colorado Region, Salt Lake City, Utah.

Kegerries, R., Z. Shattuck, B. Albrecht, and R. Rogers. 2015b. Sonic telemetry and habitat use of juvenile Razorback Suckers in Lake Mead. 2014–2015 Annual Report. Prepared for the US Bureau of Reclamation by BIO-WEST, Inc., Logan, Utah.

Kegerries, R.B., B.C. Albrecht, E.I. Gilbert, W.H. Brandenburg, A.L. Barkalow, M.C. McKinstry, H.E. Mohn, B.D. Healy, J.R. Stolberg, E.C. Omana Smith, C.B. Nelson, and R.J. Rogers. 2017b. Occurrence and reproduction by Razorback Sucker *Xyrauchen texanus* in the Grand Canyon, Arizona. The Southwestern Naturalist 62 (3):227–232.

Kegerries, R., B. Albrecht, R.J. Rogers, W.H. Brandenburg, A.L. Barkalow, H. Mohn, M. McKinstry, B. Healy, J. Stolberg, and E. Omana Smith. 2017a. Razorback Sucker *Xyrauchen texanus* research and monitoring in the Colorado River inflow area of Lake Mead and the lower Grand Canyon, Arizona and Nevada. Final report prepared by BIO-WEST, Inc., for the US Bureau of Reclamation, Upper Colorado Region, Salt Lake City, Utah.

Kegerries, R., B. Albrecht, R.J. Rogers, H. Mohn, W.H. Brandenburg, A.L. Barkalow, S.L. Wood, M. McKinstry, B. Healy, J. Stolberg, and E. Omana Smith. 2018. Razorback Sucker *Xyrauchen texanus* research and monitoring in the Colorado River inflow area of Lake Mead and the lower Grand Canyon, Arizona and Nevada. Final report prepared by BIO-WEST, Inc., for the US Bureau of Reclamation, Upper Colorado Region, Salt Lake City, Utah

Kegerries, R.B., B. Albrecht, R.J. Rogers, A.L. Barkalow, S.L. Wood, M.J. Chavez, M. McKinstry, B. Healy, J. Stolberg, and E. Omana Smith. 2019. Razorback Sucker *Xyrauchen texanus* research and monitoring in the Colorado River inflow area of Lake Mead and the lower Grand Canyon, Arizona and Nevada. Report prepared by BIO-WEST, Inc., for the US Bureau of Reclamation, Upper Colorado Region, Salt Lake City, Utah.

Kegerries, R.B., B. Albrecht, R.J. Rogers, A.L. Barkalow, S.L. Wood, M.J. Chavez, M. McKinstry, B. Healy, J. Stolberg, and E. Omana Smith. 2020a. Razorback Sucker *Xyrauchen texanus* research and monitoring in the Colorado River inflow area of Lake Mead and the lower Grand Canyon, Arizona and Nevada. Report prepared by BIO-WEST, Inc., for the US Bureau of Reclamation, Upper Colorado Region, Salt Lake City, Utah.

Kegerries, R.B., B.C. Albrecht, M.C. McKinstry, R.J. Rogers, R.A. Valdez, A.L. Barkalow, E.I. Gilbert, H.E. Mohn, B.D. Healy, E. Omana Smith. 2020b. Small-bodied fish surveys demonstrate native fish dominate over 300 kilometers of the Colorado River through Grand Canyon, Arizona. Western North American Naturalist 80 (2):146–156.

Kesner, B.R., A.P. Karam, C.A. Pacey, K.A. Patterson, and P.C. Marsh. 2012. Demographics and post-stocking survival of repatriated Razorback Suckers in Lake Mohave. Report submitted to the Bureau of Reclamation, Boulder City, Nevada, by Marsh & Associates, L.L.C., Tempe, Arizona.

LaGory, K., T. Chart, K. Bestgen, J. Wilhite, S. Capron, D. Speas, H. Hermansen, K. McAbee, J. Mohrman, M. Trammell, and B. Albrecht. 2012. Study plan to examine the effects of using larval Razorback Sucker occurrence in the Green River as a trigger for Flaming Gorge Dam peak releases. Final Report. Upper Colorado River Endangered Fish Recovery Program, Denver, Colorado.

Lumley, T., P. Diehr, S. Emerson, and L. Chen. 2002. The importance of the normality assumption in large public health data sets. Annual Review of Public Health 23(1):151–169.

Maddux, H.R., D.M. Kubly, J.C. deVos, Jr., W.R. Persons, R. Staedike, and R.L. Wright. 1987. Effects of varied flow regimes on aquatic resources of Glen and Grand canyons. Final Report. US Bureau of Reclamation Contract 4-AG-40-01810. Arizona Game and Fish Department, Phoenix, Arizona.

Marsh, P. C. 1985. Effect of incubation temperature on survival of embryos of native Colorado River fishes. The Southwestern Naturalist 30 (1):129–140.

Marsh, P.C., B.R. Kesner, and C.A. Pacey. 2005. Repatriation as a management strategy to conserve a critically imperiled fish species. North American Journal of Fisheries Management 25 (2):547–556.

Marsh, P.C., C.A. Pacey, and B.R. Kesner. 2003. Decline of Razorback Sucker in Lake Mohave, Colorado River, Arizona and Nevada. Transactions of the American Fisheries Society 132 (1):1251–1256.

Marsh, P.C., T.E. Dowling, B.R. Kesner, T.F. Turner, W.L. Minckley. 2015. Conservation to stem imminent extinction: the fight to save Razorback Sucker *Xyrauchen texanus* in Lake Mohave and its implications for species recovery. Copeia 103 (1):141–156.

McCall, T. 1980. Fishery investigation of Lake Mead, Arizona–Nevada, from Separation Rapids to Boulder Canyon, 1978–79. Final Report. Water and Power Resources Service, Boulder City, Nevada. Contract Number 8-07-30-X0025. 197 p.

Miller, T.J., L.B. Crowder, J.A. Rice, and E.A. Marschall. 1988. Larval size and recruitment mechanisms in fishes: towards a conceptual framework. Canadian Journal of Fisheries Aquatic Science 45 (9):1657–1670.

Minckley, W.L. 1973. Fishes of Arizona. Arizona Game and Fish Department, Phoenix, Arizona.

Minckley, W.L. 1983. Status of the Razorback Sucker, *Xyrauchen texanus* (Abbott), in the lower Colorado River basin. Southwestern Naturalist 28 (2):165–187.

Minckley, C.O., and S.W. Carothers. 1979. Recent collections of the Colorado River Squawfish and Razorback Sucker from the San Juan and Colorado Rivers in New Mexico and Arizona. The Southwestern Naturalist 24 (4):686–687.

Minckley, W.L. and P.C. Marsh. 2009. Inland fishes of the greater Southwest. University of Arizona Press, Tucson, Arizona.

Minckley, W.L., D.A. Hendrickson, and C.E. Bond. 1986. Geography of western North American freshwater fishes: description and relationships to intracontinental tectonism.

Pages 519–613 in Zoogeography of North American freshwater fishes. C.H. Hocutt and E.O. Wiley (editors.) John Wiley and Sons, New York, New York.

Minckley, W.L., P.C. Marsh, J.E. Brooks, J.E. Johnson, and B.L. Jensen. 1991. Management toward recovery of Razorback Sucker. Pages 303–357 in W.L. Minckley and J.E. Deacon, (editors). Battle against extinction: native fish management in the American West. University of Arizona Press, Tucson, Arizona.

Modde, T., K.P. Burnham, and E.J. Wick. 1996. Population status of the Razorback Sucker in the middle Green River (USA). Conservation Biology 10 (1):110–119.

Mohn, H.E, B. Albrecht, and R. Rogers. 2016. Razorback Sucker *Xyrauchen texanus* studies on Lake Mead, Nevada and Arizona. 2015–2016 Final Annual Report. Prepared for the Lower Colorado River Multi-Species Conservation Program, US Bureau of Reclamation, by BIO-WEST, Inc. Logan, Utah.

Mohn, H.E, B. Albrecht, R. Rogers, and R. Kegerries. 2015. Razorback Sucker *Xyrauchen texanus* studies on Lake Mead, Nevada and Arizona. 2014–2015 Final Annual Report. Prepared for the Lower Colorado River Multi-Species Conservation Program, US Bureau of Reclamation, by BIO-WEST, Inc. Logan, Utah.

Mueller, G. A., and P. C. Marsh. 2002. Lost, a desert river and its native fishes: a historical perspective of the lower Colorado River. Information and Technology Report USGS/BRD/ITR-2002-0010: US Government Printing Office, Denver, Colorado, USA.

Muhlfeld, C.C., S. Kalinowksi, T.E. McMahon, M.L. Taper, S. Painter, R.F. Leary, and F.W. Allendorf. 2009. Hybridization rapidly reduces fitness of a native trout in the wild. Biology Letters. 5 (3):328–331.

Muth, R.T. 1990. Ontogeny and taxonomy of Humpback Chub, Bonytail, and Roundtail Chub larvae and early juveniles. Dissertation. Colorado State University, Fort Collins, Colorado.

Muth, R.T., and J.C. Schmulbach. 1984. Downstream transport of fish larvae in a shallow prairie river. Transactions of the American Fisheries Society 113 (2):224–230.

Muth, R.T., L.W. Crist, K.E. LaGory, J.W. Hayse, K.R. Bestgen, T.P. Ryan, J.K. Lyons, and R.A. Valdez. 2000. Flow and temperature recommendations for endangered fishes in the Green River downstream of Flaming Gorge Dam. Final Report. Upper Colorado Endangered Fish Recovery Program, Denver, Colorado.

Muth, R.T., G.B. Haines, S.M. Meismer, E.J. Wick, T.E. Chart, D.E. Snyder, and J.M. Bundy. 1998. Reproduction and early life history of Razorback Sucker in the Green River, Utah and Colorado, 1992–1996. Final Report of Colorado State University Larval Fish Laboratory to Upper Colorado River Endangered Fish Recovery Program, Denver, Colorado.

[NDOW] Nevada Department of Wildlife. 2018. Southern Region Fisheries Division Field Trip Report. Prepared by D. Herndon. Boulder City, Nevada.

Nesler, T.P., R.T. Muth, and A.F. Wasowicz. 1988. Evidence for baseline flow spikes as spawning cues for Colorado Squawfish in the Yampa River, Colorado. American Fisheries Society Symposium 5:68–79.

[NPS] US National Park Service. 2013a. Environmental assessment: Comprehensive fisheries management plan Grand Canyon National Park, Glen Canyon National Recreation Area, Coconino County, Arizona. United States Department of the Interior, National Park Service, Flagstaff, Arizona.

[NPS] US National Park Service. 2013b. Topic 2(b) GRTS spatial sampling (for monitoring). Location: (http://science.nature.nps.gov/im/datamgmt/statistics/r/advanced/grts.cfm).

Osmundson, D.B., R.J. Ryel, V.L. Lamarra, and J. Pitlick. 2002. Flow sediment-biota relations: implications for river regulation effects on native fish abundance. Ecological Applications 12 (6):1719–1739.

Pacey, C.A., and P.C. Marsh. 1998. Growth of wild adult Razorback Sucker in Lake Mohave, Arizona–Nevada. Presented at the 30th Annual Meeting, Desert Fishes Council, Page, Arizona.

Page, L.M., H. Espinosa-Perez, L.T. Findley, C.R. Gilbert, R.N. Lea, N.E. Mandrak, R.L. Mayden, and J.S. Nelson. 2013. Common and scientific names of fishes from the United States, Canada, and Mexico (7th edition). American Fisheries Society special publication 34. Bethesda, Maryland. 384 p.

Pavlov, D.S. 1994. The downstream migration of young fishes in rivers: mechanisms and distribution. Folia Zoologica 43 (3):193–208.

Poff, N.L., J.D. Allan, M.B. Bain, J.R. Karr, K.L. Prestagaard, B.D. Richter, R.E. Sparks, and J.C. Stromberg. 1998. The natural flow regime: a paradigm for river conservation and restoration. Bioscience 47 (11):769–784.

[Reclamation] US Bureau of Reclamation. 2017. Three-year review of Razorback Sucker research in Grand Canyon and Colorado River inflow to Lake Mead. Science Panel Final Report prepared by BIO-WEST, Inc. for US Bureau of Reclamation, Upper Colorado Region, Salt Lake City, Utah.

[Reclamation] US Bureau of Reclamation. 2022. Lower Colorado River Operations. Lower Colorado Region. Location: https://www.usbr.gov/lc/riverops.html. Accessed on July 15, 2022.

Rogers, R.S., M.V. Lauretta, K. Christensen, D.R. Van Haverbeke. 2007. 2005 Grand Canyon long-term fish monitoring Colorado River, Diamond Creek to Lake Mead. 2005 Annual Report. Arizona Game and Fish Department, Phoenix, Arizona.

Rogers, R., B. Albrecht, and H.E Mohn. 2017. Razorback Sucker *Xyrauchen texanus* studies on Lake Mead, Nevada and Arizona. 2016–2017 Final Annual Report. Prepared for the Lower Colorado River Multi-Species Conservation Program, US Bureau of Reclamation, by BIO-WEST, Inc. Logan, Utah.

Rogers, R., B. Albrecht, H.E Mohn, and R. Kegerries. 2018. Razorback Sucker *Xyrauchen texanus* studies on Lake Mead, Nevada and Arizona. 2017–2018 Final Annual Report. Prepared for the Lower Colorado River Multi-Species Conservation Program, US Bureau of Reclamation, by BIO-WEST, Inc. Logan, Utah.

Rogers, R., B. Albrecht, and R. Kegerries. 2019. Razorback Sucker *Xyrauchen texanus* studies on Lake Mead, Nevada and Arizona. 2018–2019 Final Annual Report. Prepared for the Lower Colorado River Multi-Species Conservation Program, US Bureau of Reclamation, by BIO-WEST, Inc. Logan, Utah.

Rogers, R.J., B. Albrecht, and R. Kegerries. 2020. Razorback sucker *Xyrauchen texanus* Studies on Lake Mead, Nevada and Arizona, 2019–2020 Final Annual Report. Submitted to the Lower Colorado River Multi-Species Conservation Program, Bureau of Reclamation, Boulder City, Nevada, by BIO-WEST, Inc., Logan, Utah, under contract No. 140R3020C004.

Rogers, R.J., B. Albrecht, and J. Handtke. 2021a. Razorback sucker *Xyrauchen texanus* Studies on Lake Mead, Nevada and Arizona, 2020–2021 Final Annual Report. Submitted to the Lower Colorado River Multi-Species Conservation Program, Bureau of Reclamation, Boulder City, Nevada, by BIO-WEST, Inc., Logan, Utah, under contract No. 140R3020C004.

Rogers, R.J., B. Albrecht, J. Handtke, J.G. Mortensen, M.K. Akland, S.L. Wood, S.P. Platania, M. McKinstry, K. Pedersen, B. Healy, J. Stolberg, and E. Omana Smith. 2021b. Razorback Sucker *Xyrauchen texanus* research and monitoring in the Colorado River inflow area of Lake Mead and the lower Grand Canyon, Arizona and Nevada. Report prepared by BIO-WEST, Inc., for the US Bureau of Reclamation, Upper Colorado Region, Salt Lake City, Utah.

Rogers, R.J., B. Albrecht, and J. Handtke. 2022. Razorback sucker *Xyrauchen texanus* Studies on Lake Mead, Nevada and Arizona, 2021–2022 Final Annual Report. Submitted to the Lower Colorado River Multi-Species Conservation Program, Bureau of Reclamation, Boulder City, Nevada, by BIO-WEST, Inc., Logan, Utah, under contract No. 140R3020C004.

Rogowski, D.L. and P.N. Wolters. 2014. Colorado River fish monitoring in Grand Canyon, Arizona–2013 Annual Report. Submitted to the Grand Canyon Monitoring and Research Center, Flagstaff, Arizona.

Rogowski, D.L., R.J. Osterhoudt, H.E. Mohn, and J.K. Boyer. 2018. Humpback Chub Gila cypha range expansion in the western Grand Canyon. Western North American Naturalist. 78 (1):26–38.

Ross, R.P. and W.S. Vernieu. 2013. Nearshore temperature findings for the Colorado River in Grand Canyon, Arizona: possible implications for native fish. US Geological Survey Fact Sheet No. 2013–3104.

Ryden, D.W. 2006. Augmentation and monitoring of the San Juan Razorback Sucker population: 2005. Interim Progress Report (Final). US Fish and Wildlife Service, Colorado River Fishery Project, Grand Junction, Colorado.

Schreck, W.J. 2010. Seasonal use of Missouri River reservoir deltas by fishes. Master's thesis. South Dakota State University, Brookings, South Dakota.

Shattuck, Z.R., and B. Albrecht. 2014. Sonic telemetry and habitat use of juvenile Razorback Suckers in Lake Mead. 2013–2014 Annual Report. PR-1588-01. Prepared for the US Bureau of Reclamation by BIO-WEST, Inc., Logan, Utah.

Shattuck, Z.R., B. Albrecht, and R. Rogers. 2011. Razorback sucker studies on Lake Mead, Nevada and Arizona. 2010–2011 Annual Report. PR-1303-01. Prepared for the US Bureau of Reclamation by BIO-WEST, Inc., Logan, Utah.

Sjoberg, J.C. 1995. Historic distribution and current status of the Razorback Sucker in Lake Mead, Nevada–Arizona. Proceedings of the Desert Fishes Council 26:24–27.

Skorupski Jr., J.A., M.J. Breen, B.P. Kiefer, and K. Creighton. 2012. Young-of-the-year Colorado Pikeminnow monitoring. Annual Project Report. . Upper Colorado River Endangered Fish Recovery Program, Denver, Colorado.

Snyder, D.E. 1981. Contributions to a guide to the cypriniform fish larvae of the Upper Colorado River system in Colorado. US Bureau of Land Management, Biological Sciences Series 3, Denver, Colorado.

Snyder, D.E. 2003. Computer-interactive key to eggs, larvae, and early juveniles of catostomid fishes in the upper Colorado River basin (data set for use with DELTA Intkey). Colorado State University Larval Fish Laboratory, Fort Collins, Colorado.

Snyder, D.E., and R.T. Muth. 2004. Catostomid fish larvae and early juveniles of the Upper Colorado River Basin – morphological descriptions, comparisons, and computer-interactive key. Colorado Division of Wildlife. Technical Publication No. 42. Colorado State University, Larval Fish Laboratory, Fort Collins, Colorado.

Snyder, D.E., S.C. Seal, J.A. Charles, and C.L. Bjork. 2016. Guide to the cyprinid fish larvae and early juveniles of the upper Colorado River basin with computer-interactive key. Colorado State University Larval Fish Laboratory contribution to Colorado River Endangered Fish Recovery Program, Denver, Colorado.

Sonotronics, Inc. 2014. SUR submersible ultrasonic receiver. Available at: http://www.sonotronics.com/?page_id=1084. Accessed 08/08/2014.

Speas, D., and M. Trammell. 2009. Aquatic habitat characteristics by river mile in lower Grand Canyon; preliminary results of 2009 field survey. US Bureau of Reclamation and National Park Service, Salt Lake City, Utah.

Stevens, D.L., and A.R. Olsen. 1999. Spatially restricted surveys over time for aquatic resources. Journal of Agricultural, Biological, and Environmental Statistics 4 (6):415–428.

Stevens, D.L., and A.R. Olsen. 2003. Variance estimation for spatially balanced samples of environmental resources. EnvironMetrics 14 (465):593–610.

Stevens, D.L., and A.R. Olsen. 2004. Spatially balanced sampling of natural resources. Journal of the American Statistical Association 99:262–278.

Thode, H. C. 2002. Testing for normality, Volume 16. Marcel Dekker: New York.

Topping, D. J., J. C. Schmidt, and L. E. Vierra. 2003. Computation and analysis of the instantaneous-discharge record for the Colorado River at Lees Ferry, Arizona: May 8, 1921, through September 30, 2000. Professional Paper 1677, 118p.

Trammell, M., R.A. Valdez, S. Carothers, and R. Ryel. 2001. Effects of a low steady summer flow experiment on native fishes of the Colorado River in Grand Canyon, Arizona. Report of SWCA, Inc., Flagstaff, Arizona, to Grand Canyon Monitoring and Research Center, Flagstaff, Arizona.

Tyus, H.M. and C.A. Karp. 1990. Spawning and movements of Razorback Sucker, *Xyrauchen texanus*, in the Green River Basin of Colorado and Utah. The Southwestern Naturalist 35 (4):427–433.

[USFWS] US Fish and Wildlife Service. 1991. Endangered and threatened wildlife and plants: The Razorback Sucker (*Xyrauchen texanus*) determined to be an endangered species. Final Rule, Federal Register 56 (23 October 1991):54957–54967.

[USFWS] US Fish and Wildlife Service. 2002. Razorback sucker (*Xyrauchen texanus*) recovery goals: amendment and supplement to the Razorback Sucker recovery plan. US Fish and Wildlife Service, Mountain-Prairie Region (6), Denver, Colorado.

[USFWS] US Fish and Wildlife Service. 2007. Final biological opinion for the proposed adoption of Colorado River interim guidelines for lower basin shortages and coordinated operations for Lake Powell and Lake Mead. US Fish and Wildlife Service, Phoenix. Available at: https://www.usbr.gov/lc/region/programs/strategies/BOFinal.PDF. Accessed 12/12/ 2007.

[USFWS] US Fish and Wildlife Service. 2011. Final Biological Opinion on the Operation of Glen Canyon Dam Including High-Flow Experiments and Non-Native Fish Control. Arizona Ecological Services Office, Phoenix, Arizona. 150pp.

[USFWS] US Fish and Wildlife Service. 2016. Final Biological Opinion for the Glen Canyon Dam Long-Term Experimental and Management Plan, Coconino County, Arizona. Arizona Ecological Services Office, Phoenix, Arizona. 198pp.

U.S. Office of the Federal Register. 2020. Endangered and threatened wildlife and plants; Reclassification of Humpback Chub from endangered to threatened with a Section 4(d) rule. Proposed rule. Federal Register 85:14 (22 January 2020) 3586–3601.

U.S. Office of the Federal Register. 2021. Endangered and threatened wildlife and plants; Reclassification of Razorback Sucker from endangered to threatened with a Section 4(d) rule. Proposed rule. Federal Register 86:127 (07 July 2021) 35708–35728.

Valdez, R.A. 1994. Effects of interim flows from Glen Canyon Dam on the aquatic resources of the lower Colorado River from Diamond Creek to Lake Mead. Phase I Report to Hualapai Natural Resources Department by Bio/West, Inc., Logan, Utah.

Valdez, R.A. and R.J. Ryel. 1995. Life history and ecology of the Humpback Chub (Gila cypha) in the Colorado River, Grand Canyon, Arizona. Final Report to the Bureau of Reclamation, Salt Lake City, Utah.

Valdez, R.A., and S.W. Carothers. 1998. The aquatic ecosystem of the Colorado River in Grand Canyon: Grand Canyon data integration project synthesis report. Final Report to the US Bureau of Reclamation, Upper Colorado Region, Salt Lake City, by SWCA, Inc., Environmental Consultants, Flagstaff, Arizona.

Valdez, R.A., B.R. Cowdell, and E.E. Prats. 1995. Effects of interim flows from Glen Canyon Dam on the aquatic resources of the lower Colorado River from Diamond Creek to Lake Mead. Phase II Report to the Hualapai Natural Resources Department by BIO-WEST, Inc., Logan, Utah.

Valdez, R.A., D.A. House, M.A. McLeod, and S.W. Carothers. 2012a. Review and summary of Razorback Sucker habitat in the Colorado River system, Report Number 1. Final Report. Prepared by SWCA Environmental Consultants for the US Bureau of Reclamation, Upper Colorado Region, Salt Lake City, Utah.

Valdez, R.A., C. McAda, G. Mueller, D. Ryden, and M. Trammell. 2012b. The potential of habitat for the Razorback Sucker in the lower Grand Canyon and Colorado River inflow to Lake Mead: A Science Panel Report, Report Number 2. Final Report. Prepared by SWCA Environmental Consultants for the US Bureau of Reclamation, Upper Colorado Region, Salt Lake City, Utah.

Valdez, R.A., D.A. House, M.A. McLeod, and S.W. Carothers. 2012c. Strategy for establishing the Razorback Sucker in the lower Grand Canyon and Lake Mead inflow, Report Number 3. Final Report. Prepared by SWCA Environmental Consultants for the US Bureau of Reclamation, Upper Colorado Region, Salt Lake City, Utah.

Voichick, N. and S.A. Wright. 2007. Water-temperature data for the Colorado River and tributaries between Glen Canyon Dam and Spencer Canyon, northern Arizona, 1988–2005. US Geological Survey data series 251. 24 p.

Ward, D.L. and B.M. Vaage. 2019. What environmental conditions reduce predation vulnerability for juvenile Colorado River native fishes? Journal of Fish and Wildlife Management. 10 (1): 196–205.

Welker, T.L. and P.B. Holden. 2004. Razorback sucker studies on Lake Mead, Nevada. 2003–2004 Annual Report. PR-578-8. Prepared for the Department of Resources, Southern Nevada Water Authority, by BIO-WEST, Inc., Logan, Utah.

Welker, T.L. and P.B. Holden. 2003. Razorback sucker studies on Lake Mead, Nevada. 2002–2003 Annual Report. PR-578-7. Prepared for the Department of Resources, Southern Nevada Water Authority, by BIO-WEST, Inc., Logan, Utah.

Wick, E.J., C.W. McAda, and R.V. Bulkley. 1982. Life history and prospects for recovery of the Razorback Sucker. Pages 120–126 in W.H. Miller, H.M. Tyus, and C.A. Carlson (editors). Fishes of the upper Colorado River system: present and future. American Fisheries Society, Western Division, Bethesda, Maryland.

Wolters, P.N., D.L. Rogowski, D.L. Ward, and A.C. Gibb. 2019. Viability of Razorback-Flannelmouth Sucker hybrids. The Southwestern Naturalist 63(4):280–283.

APPENDIX A: DATE, PASSIVE INTEGRATED TRANSPONDER (PIT) TAG NUMBER, AND SIZE INFORMATION FOR FLANNELMOUTH SUCKERS CAPTURED AT THE COLORADO RIVER INFLOW AREA OF LAKE MEAD (CRI), 2022

DATE	SPECIES [a]	PIT-TAG NUMBER	SONIC CODE	DATE [b] (ORIG.)	RECAPTURE (STATUS)	TL [c] (mm)	FL [d] (mm)	SL [e] (mm)	WT [f] (g)	SEX [g]	GEAR
2/10/2022	FM	3dd.003ba20832		3/25/2014	Yes(Wild)	542	519	474	1259	F	Trammel
2/10/2022	FM	3dd.003ba2089a		3/3/2016	Yes(Wild)	525	486	450	1206	M	Trammel
2/10/2022	FM	3dd.003ba208ce		5/12/2015	Yes(Wild)	499	470	425	949	M	Trammel
2/10/2022	FM	3dd.003ba20a3e		4/5/2017	Yes(Wild)	520	495	455	1204	U	Trammel
2/10/2022	FM	3dd.003ba228d5			Yes(Wild)	503	474	438	1063	M	Trammel
2/10/2022	FM	3dd.003bcf3849			Yes(Wild)	482	458	420	961	U	Trammel
2/10/2022	FM	3dd.003be8f1e4		2/2/2017	Yes(Wild)	523	491	461	1142	U	Trammel
2/10/2022	FM	3dd.003d4cc2d1		2/10/2022	No(Wild)	480	450	418	967	U	Trammel
2/10/2022	FM	3dd.003d4cc2da		2/10/2022	No(Wild)	348	323	293	311	I	Trammel
2/10/2022	FM	3dd.003d4cc2df		2/10/2022	No(Wild)	450	421	392	713	U	Trammel
2/10/2022	FM	3dd.003d4cc2e8		2/10/2022	No(Wild)	414	386	354	592	M	Trammel
2/10/2022	FM	3dd.003d4cc2e9		2/10/2022	No(Wild)	484	457	420	1000	M	Trammel
2/10/2022	FM	3dd.003d4cc2eb		2/10/2022	No(Wild)	484	454	418	949	U	Trammel
2/10/2022	FM	3dd.003d4cc2ec		2/10/2022	No(Wild)	490	455	420	880	U	Trammel
2/10/2022	FM	3dd.003d4cc2ef		2/10/2022	No(Wild)	489	460	420	966	M	Trammel
2/10/2022	FM	3dd.003d4cc2f6		2/10/2022	No(Wild)	530	500	464	1232	U	Trammel
2/10/2022	FM	3dd.003d4cc302		2/10/2022	No(Wild)	526	496	458	1090	U	Trammel
2/17/2022	FM	- [h]		- [h]	No(Wild)	449	422	365	726	U	Trammel
2/17/2022	FM	3dd.003d4cc2bf		2/17/2022	No(Wild)	415	390	330	551	U	Trammel
2/17/2022	FM	3dd.003d4cca20			Yes(Wild)	535	495	425	1200	F	Trammel
3/2/2022	FM	3dd.003bbeb594			Yes(Wild)	382	355	329	469	U	Trammel
3/2/2022	FM	3dd.003d4cc2c9		3/2/2022	No(Wild)	410	387	355	448	U	Trammel
3/2/2022	FM	3dd.003d4cc2d7		3/2/2022	No(Wild)	346	322	297	352	I	Trammel
3/9/2022	FM	3dd.003ba769f4		2/1/2017	Yes(Wild)	559	532	475	1340	F	Trammel
3/9/2022	FM	3dd.003d4cc2f8		3/9/2022	No(Wild)	421	401	350	680	U	Trammel
3/9/2022	FM	3dd.003d4cc303		3/9/2022	No(Wild)	426	396	352	577	U	Trammel
3/9/2022	FM	3dd.003d7d2ae7			Yes(Wild)	331	309	272	318	I	Trammel
3/15/2022	FM	3dd.003d4cc2ae		3/15/2022	No(Wild)	490	465	432	1120	M	Trammel
3/15/2022	FM	3dd.003d4cc2fa		3/15/2022	No(Wild)	428	400	368	608	U	Trammel
3/17/2022	FM	3dd.003ba769f4		2/1/2017	Yes(Wild)	557	517	481	1356	F	Trammel
3/24/2022	FM	3dd.003bc89e79		3/24/2022	No(Wild)	475	447	408	958	U	Trammel
3/30/2022	FM	3dd.003d4cc2f3		3/30/2022	No(Wild)	437	410	374	640	U	Trammel
3/30/2022	FM	3dd.003d4cc361		4/28/2021	Yes(Wild)	500	472	435	1044	U	Trammel
4/5/2022	FM	3dd.003ba2fa51		4/24/2013	Yes(Wild)	545	515	470	1329	F	Trammel
4/5/2022	FM	3dd.003d4cc2a5		4/5/2022	No(Wild)	428	408	373	740	U	Trammel
4/5/2022	FM	3dd.003d4cc2a6		4/4/2022	No(Wild)	475	445	410	891	U	Trammel
4/5/2022	FM	3dd.003d4cc2a7		4/5/2022	No(Wild)	422	395	364	701	U	Trammel
4/5/2022	FM	3dd.003d4cc2ab		4/4/2022	No(Wild)	490	460	428	1011	U	Trammel
4/5/2022	FM	3dd.003d4cc2b7		4/4/2022	No(Wild)	415	388	354	638	U	Trammel
4/5/2022	FM	3dd.003d4cc2b9		4/4/2022	No(Wild)	544	515	479	1255	U	Trammel
4/5/2022	FM	3dd.003d4cc2d0		4/5/2022	No(Wild)	333	312	285	293	I	Trammel
4/5/2022	FM	3dd.003d4cc2e3		4/5/2022	No(Wild)	427	399	364	639	U	Trammel
4/5/2022	FM	3dd.003d4cc2e6		4/4/2022	No(Wild)	490	458	421	956	U	Trammel
4/5/2022	FM	3dd.003d4cc2fd		4/5/2022	No(Wild)	497	464	430	1106	U	Trammel
4/5/2022	FM	3dd.003d4cc302		2/10/2022	Yes(Wild)	520	495	460	1101	U	Trammel
4/6/2022	FM	3dd.003d4cc2f7		4/6/2022	No(Wild)	337	316	290	304	I	Trammel
4/14/2022	FM	3dd.003d4cbad3		4/14/2022	No(Wild)	382	355	290	413	U	Trammel
4/14/2022	FM	3dd.003d4cbad6		4/14/2022	No(Wild)	425	400	318	620	U	Trammel
4/14/2022	FM	3dd.003d4cbafa		4/14/2022	No(Wild)	355	330	265	422	U	Trammel
4/14/2022	FM	3dd.003d4cbb05		4/14/2022	No(Wild)	392	345	295	483	U	Trammel
4/14/2022	FM	3dd.003d4cbb07		4/14/2022	No(Wild)	334	308	245	326	I	Trammel
4/14/2022	FM	3dd.003d4cbb2a		4/14/2022	No(Wild)	425	398	325	617	U	Trammel
4/14/2022	FM	3dd.003d4d13d6			Yes(Wild)	382	352	285	482	U	Trammel
4/26/2022	FM	3dd.003d4cc2db		4/26/2022	No(Wild)	371	346	317	354	U	Trammel
5/5/2022	FM	- [h]		- [h]	No(Wild)	234	217	193	100	I	Trammel
5/5/2022	FM	3dd.003d4cc762		5/5/2022	No(Wild)	454	424	392	756	U	Trammel
5/5/2022	FM	3dd.003d4cc78a		5/5/2022	No(Wild)	362	335	304	354	U	Trammel
5/5/2022	FM	3dd.003d4cc78f		5/5/2022	No(Wild)	421	394	361	688	U	Trammel
5/5/2022	FM	3dd.003d4cc7aa		5/5/2022	No(Wild)	480	437	411	837	U	Trammel
5/5/2022	FM	3dd.003d4cc7b4		5/5/2022	No(Wild)	413	383	354	602	U	Trammel

[a] Date originally captured. [b] Total length. [c] Fork length. [d] Standard length. [e] Weight.
[f] F=female, M=male, I=immature, U=unidentified (sex not determined).
[g] Not recorded, typically to avoid excessive handling stress.

APPENDIX B: AGES DETERMINED FROM LAKE MEAD RAZORBACK SUCKER PECTORAL FIN RAY SECTIONS

DATE COLLECTED	TOTAL LENGTH (mm[a])	AGE	PRESUMPTIVE YEAR SPAWNED
LAS VEGAS BAY			
5/10/1998	588	10[b]	1987
12/14/1999	539	13	1986
12/14/1999	606	17+	1979–1982
12/14/1999	705	19+	1977–1980
1/8/2000	650	18+	1978–1981
2/27/2000	628	17+	1979–1982
1/9/2001	378	6	1994
2/7/2001	543	11	1989
2/22/2001	585	13	1987
12/1/2001	576	8–10	1991–1993
12/1/2001	694	22	1979
12/1/2001	553	10	1991
2/2/2002	639	16	1985
3/25/2002	650	22	1979
3/25/2002	578	10–11	1990–1991
3/25/2002	583	22–24	1977–1979
3/25/2002	545	20[b]	1982
3/25/2002	576	20	1982
5/7/2002	641	15	1986
6/7/2002	407	6	1995
6/7/2002	619	20[b]	1982
6/7/2002	642	20[b]	1982
12/3/2002	354	4	1998
12/6/2002	400	4	1998
12/6/2002	376	4	1998
12/19/2002	395	4	1998
1/7/2003	665	16	1986
1/22/2003	394	4	1998
2/5/2003	385	4	1998
2/18/2003	443	5	1997
3/4/2003	635	19	1983
3/20/2003	420	4	1998
4/8/2003	638	21[b]	1982
4/17/2003	618	10	1992
4/22/2003	650	20–22	1980–1982
5/4/2003	415	3+[c]	1999
3/16/2004	370	5	1998
2/22/2005	529	6	1998
2/22/2005	546	6	1998
3/29/2005	656	16	1989
1/26/2006	740	15	1991
2/21/2006	621	23	1983
3/23/2006	461	5	2001
3/23/2006	718	16	1990
3/31/2006	635	7	1999
3/31/2006	605	6	2000
4/4/2006	629	6	2000

DATE COLLECTED	TOTAL LENGTH (mm[a])	AGE	PRESUMPTIVE YEAR SPAWNED
LAS VEGAS BAY			
4/25/2006	452	4	2002
4/25/2006	463	4	2002
1/30/2007	514	5	2002
2/6/2007	519	5	2002
2/6/2007	574	8	1999
2/13/2007	526	5	2002
2/16/2007	530	5	2002
2/20/2007	534	6	2001
2/21/2007	358	3	2004
2/21/2007	511	5	2002
2/27/2007	645	13	1994
2/27/2007	586	15	1992
2/27/2007	603	13	1994
2/27/2007	650	17	1990
3/6/2007	515	4	2003
3/6/2007	611	13	1994
3/6/2007	565	6	2001
3/13/2007	586	7	2000
3/13/2007	636	25	1982
3/13/2007	524	5	2002
4/2/2007	704	9	1998
4/9/2007	644	11	1996
2/12/2008	425	5	2003
2/12/2008	390	3	2005
2/12/2008	490	3	2005
2/12/2008	430	4	2004
2/12/2008	379	4	2004
2/12/2008	399	4	2004
2/12/2008	430	4	2004
2/12/2008	413	4	2004
2/12/2008	554	9	1999
2/12/2008	426	9	1999
2/18/2008	385	3	2005
2/25/2008	605	6	2002
2/25/2008	655	36	1972
4/3/2008	468	4	2004
4/3/2008	619	7	2001
4/3/2008	640	10	1998
4/3/2008	560	11	1997
4/8/2008	423	3	2005
4/8/2008	535	6	2002
4/10/2008	422	3	2005
4/10/2008	375	3	2005
4/10/2008	452	4	2004
4/10/2008	472	4	2004
4/10/2008	467	4	2004
4/10/2008	429	5	2003

DATE COLLECTED	TOTAL LENGTH (mm[a])	AGE	PRESUMPTIVE YEAR SPAWNED
LAS VEGAS BAY			
4/23/2008	430	4	2004
2/13/2009	395	5	2004
2/13/2009	528	11	1998
2/13/2009	630	15	1994
2/17/2009	510	8	2001
2/17/2009	440	5	2004
2/17/2009	420	5	2004
2/18/2009	376	4	2005
2/18/2009	411	4	2005
2/18/2009	427	4	2005
2/24/2009	438	5	2004
2/24/2009	403	6	2003
2/24/2009	446	6	2003
3/3/2009	416	4	2005
3/3/2009	565	8	2001
3/3/2009	431	5	2004
3/3/2009	340	5	2004
3/3/2009	539	8	2001
3/3/2009	521	8	2001
3/3/2009	419	6	2003
3/3/2009	535	6	2003
3/3/2009	748	17	1992
3/17/2009	377	3	2006
3/17/2009	458	4	2005
3/17/2009	421	4	2005
3/17/2009	369	3	2006
3/17/2009	440	5	2004
4/6/2009	546	8	2001
4/13/2009	536	7	2002
4/13/2009	510	7	2002
4/13/2009	451	4	2005
4/13/2009	578	13	1996
2/2/2010	531	5	2005
2/2/2010	391	5	2005
2/2/2010	342	5	2005
2/11/2010	351	3	2007
3/3/2010	485	5	2005
3/3/2010	553	6	2004
3/3/2010	621	9	2001
3/23/2010	395	3	2007
3/23/2010	500	5	2005
3/23/2010	514	6	2004
4/20/2010	560	7	2003
2/8/2011	587	8	2003
2/10/2011	574	12[g]	1999
3/3/2011	364	7	2004
3/3/2011	434	4	2007

DATE COLLECTED	TOTAL LENGTH (mm[a])	AGE	PRESUMPTIVE YEAR SPAWNED
	LAS VEGAS BAY		
3/24/2011	411	4	2007
3/24/2011	390	3	2008
3/29/2011	379	6	2005
3/29/2011	346	4	2007
3/29/2011	376	3	2008
2/5/2013	510	10	2003
2/19/2013	512	7	2006
2/26/2013	500	7	2006
4/16/2013	561	8	2005
3/4/2014	576	7	2007
3/11/2014	649	9	2005
3/27/2014	567	7	2007
3/27/2014	525	5	2009
2/17/2015	468	5	2010
4/28/2015	547	7	2008
2/9/2016	569	11	2005
4/19/2016	599	11	2005
1/10/2017	305	2	2015
1/4/2017	361	2	2015
1/10/2017	586	6	2011
1/11/2017	357	2	2015
2/3/2017	301	2	2015
2/22/2017	586	9	2008
4/4/2017	564	10	2007
2/27/2018	615	9	2009
4/10/2018	600	9	2009
1/29/2019	311	3	2016
1/29/2019	390	3	2016
2/19/2019	402	3	2016
1/28/2020	425	5	2015
1/28/2020	381	4	2016
1/28/2020	356	4	2016
1/28/2020	389	4	2016
1/28/2020	356	4	2016
1/28/2020	343	3	2017
1/28/2020	329	3	2017
2/6/2020	392	4	2016
2/18/2020	376	6	2014
2/18/2020	401	4	2016
2/18/2020	319	3	2017
1/12/2022	691	10	2012
1/19/2022	603	9	2013
1/19/2022	651	8	2014
1/19/2022	536	7	2015
2/8/2022	674	8	2014
2/8/2022	562	6	2016
2/9/2022	645	10	2012
2/9/2022	630	9	2013
2/9/2022	558	7	2015
2/9/2022	493	6	2016

DATE COLLECTED	TOTAL LENGTH (mm[a])	AGE	PRESUMPTIVE YEAR SPAWNED
	ECHO BAY		
1/22/1998	381	5	1993
1/9/2000	527	13	1987
1/9/2000	550	13	1987
1/9/2000	553	13	1987
1/9/2000	599	12–14	1986–1988
1/27/2000	557	13	1986
1/28/2000	558	14	1985
1/27/2000	710	19+	1979–1981
2/9/2001	641	13	1988
2/24/2001	577	18+	1980–1982
2/24/2001	570	8	1992
2/24/2001	576	15	1986
2/24/2001	553	18	1983
12/18/2001	672	13	1988
2/27/2002	610	18–20	1982–1984
3/26/2002	623	16	1986
4/2/2002	617	35+	1966–1968
4/17/2002	583	20[b]	1982
5/2/2002	568	18–19	1983–1984
11/18/2002	551	13	1989
12/4/2002	705	26	1976
1/21/2003	591	16	1986
2/3/2003	655	27–29	1974
2/3/2003	580	13	1989
4/2/2003	639	19–20	1982
4/2/2003	580	23–25	1978
4/23/2003	584	10	1992
5/6/2003	507	9+	1993
5/6/2003	594	20	1982
12/18/2003	522	20	1982
1/14/2004	683	14	1989
2/18/2004	613	10	1993
3/17/2004	616	19	1983
3/17/2004	666	17	1985
3/17/2004	618	9	1994
4/6/2004	755	17	1985
3/2/2005	608	15	1990
3/2/2005	624	8	1996
1/10/2006	630	12	1994
2/1/2006	705	16	1990
2/16/2006	601	22	1984
1/11/2007	535	5	2002
1/11/2007	493	5	2002
2/1/2007	637	7	2000
2/8/2007	609	12	1995
2/14/2007	501	4	2003
3/2/2007	590	11	1996
3/9/2007	660	12	1995

DATE COLLECTED	TOTAL LENGTH (mm[a])	AGE	PRESUMPTIVE YEAR SPAWNED
ECHO BAY			
3/16/2007	691	21	1986
3/28/2007	564	13	1994
2/28/2008	640	25	1983
2/29/2008	635	8	2000
3/5/2008	653	24	1984
3/19/2008	532	6	2002
3/19/2008	510	7	2001
2/20/2009	602	7	2002
2/26/2009	662	16	1993
2/18/2010	520	7	2003
2/25/2010	465	5	2005
3/10/2010	535	7	2003
3/10/2010	530	9[f]	2001
3/24/2010	451	4	2006
3/24/2010	465	5	2005
3/24/2010	466	5	2005
4/8/2010	470	5	2005
4/8/2010	540	8	2002
4/22/2010	538	7	2003
4/22/2010	489	8	2002
4/22/2010	460	9	2001
2/9/2011	529	7	2004
2/9/2011	524	7	2004
2/24/2011	555	7	2004
3/2/2011	513	6	2005
4/7/2011	533	7	2004
4/7/2011	522	7	2004
4/19/2011	537	6	2005
4/19/2011	540	7	2004
4/19/2011	515	6	2005
2/9/2012	619	10	2002
2/9/2012	644	29	1983
2/16/2012	559	9	2003
2/16/2012	565	12	2000
2/22/2012	589	10	2002
2/22/2012	548	12	2000
3/1/2012	585	7	2005
3/7/2012	663	12	2000
3/29/2012	571	12	2000
3/29/2012	595	13	1999
4/12/2012	610	13	1999
4/12/2012	571	14	1998
2/7/2013	670	8	2005
2/7/2013	579	10	2003
2/7/2013	655	7	2006
2/14/2013	692	17	1996
2/27/2014	703	15	1999
3/12/2014	554	8	2006

DATE COLLECTED	TOTAL LENGTH (mm[a])	AGE	PRESUMPTIVE YEAR SPAWNED
	ECHO BAY		
3/13/2014	594	10	2004
3/25/2014	594	8	2006
3/25/2014	630	9	2005
2/16/2016	540	7	2009
2/18/2016	634	9	2007
2/29/2016	631	9	2007
3/8/2016	544	9	2007
3/8/2016	612	10	2006
3/8/2016	650	12	2004
3/22/2016	476	6	2010
3/22/2016	545	8	2008
3/22/2016	545	9	2007
3/22/2016	570	11	2005
3/22/2016	634	12	2004
4/5/2016	591	10	2006
4/5/2016	648	11	2005
4/5/2016	650	11	2005
4/21/2016	463	6	2010
4/21/2016	561	10	2006
2/15/2017	472	6	2011
2/21/2017	521	9	2008
2/21/2017	646	10	2007
2/21/2017	560	9	2008
2/21/2017	628	8	2009
3/2/2017	664	12	2005
3/9/2017	642	9	2008
3/6/2018	472	5	2013
3/22/2018	469	8	2010
3/28/2018	479	5	2013
3/28/2018	489	5	2013
3/28/2018	581	7	2011
4/17/2018	634	9	2009
2/27/2019	552	6	2013
3/5/2019	554	7	2012
4/16/2019	519	5	2014
2/5/2020	641	13	2007
2/11/2020	684	9	2011
2/10/2021	615	10	2011
3/3/2021	681	11	2010
3/3/2021	620	11	2010
4/6/2021	491	5	2016
3/17/2021	504	5	2016
3/3/2021	565	6	2015
3/3/2021	487	6	2015
3/24/2021	566	7	2014
3/24/2021	582	8	2013
3/17/2021	555	8	2013
3/17/2021	611	8	2013

DATE COLLECTED	TOTAL LENGTH (mm[a])	AGE	PRESUMPTIVE YEAR SPAWNED
	ECHO BAY		
3/3/2021	595	8	2013
2/10/2021	565	8	2013
2/10/2021	631	9	2012
2/10/2022	278	3	2019
3/10/2022	668	8	2014
3/10/2022	551	7	2015
3/22/2022	698	11	2011
3/22/2022	671	10	2012
3/22/2022	563	8	2014
3/22/2022	596	8	2014
4/6/2022	551	8	2014
	VIRGIN RIVER/MUDDY RIVER INFLOW AREA		
2/23/2005	608	6	1998
2/22/2006	687	33[d]	1973
2/22/2007	452	4	2003
2/22/2007	542	5	2002
2/22/2007	476	5	2002
2/22/2007	459	4	2003
2/22/2007	494	5	2002
3/1/2007	477	5	2002
3/1/2007	512	4	2003
3/8/2007	463	5	2002
3/8/2007	455	4	2003
3/15/2007	516	4	2003
4/3/2007	508	4	2003
4/11/2007	498	7	2000
2/27/2008	465	4	2004
2/27/2008	670	20	1988
3/25/2008	530	6	2002
3/25/2008	271	2[e]	2006
3/26/2008	345	3	2005
3/26/2008	541	7	2001
3/26/2008	521	7	2001
3/26/2008	665	18	1990
4/1/2008	229	2	2006
4/1/2008	370	3	2005
4/1/2008	360	3	2005
4/1/2008	385	4	2004
4/1/2008	514	5	2003
4/1/2008	536	5	2003
4/1/2008	514	6	2002
4/1/2008	548	6	2002
4/1/2008	518	7	2001
4/1/2008	530	7	2001
4/1/2008	494	8	2000
4/1/2008	535	9	1999
4/1/2008	559	10	1998
4/22/2008	533	6	2002

DATE COLLECTED	TOTAL LENGTH (mm[a])	AGE	PRESUMPTIVE YEAR SPAWNED
VIRGIN RIVER/MUDDY RIVER INFLOW AREA			
4/22/2008	504	6	2002
2/4/2009	496	9	2000
2/12/2009	553	10	1999
2/12/2009	505	8	2001
2/19/2009	464	5	2004
2/25/2009	549	7	2002
3/11/2009	585	8	2001
3/11/2009	552	8	2001
3/24/2009	366	3	2006
3/24/2009	572	9	2000
4/8/2009	348	3	2006
4/8/2009	291	3	2006
4/15/2009	374	3	2006
4/15/2009	372	3	2006
4/15/2009	390	3	2006
4/15/2009	365	3	2006
4/15/2009	375	3	2006
4/15/2009	399	3	2006
4/15/2009	362	3	2006
4/15/2009	386	4	2005
4/15/2009	390	4	2005
2/3/2010	455	3	2007
2/3/2010	475	5	2005
2/3/2010	441	5	2005
2/3/2010	495	7	2003
2/3/2010	532	8	2002
2/9/2010	491	5	2005
2/9/2010	444	5	2005
2/9/2010	500	5	2005
2/9/2010	464	6	2004
2/9/2010	471	6	2004
2/17/2010	494	6	2004
2/17/2010	470	7	2003
2/17/2010	479	7	2003
2/17/2010	425	7	2003
2/17/2010	483	7	2003
2/24/2010	234	4	2006
3/17/2010	477	4	2006
3/17/2010	465	5	2005
3/17/2010	485	5	2005
3/17/2010	499	6	2004
3/17/2010	491	6	2004
3/17/2010	600	9	2001
3/18/2010	452	5	2005
3/18/2010	473	5	2005
3/24/2010	485	5	2005
2/1/2011	601	7	2004
2/1/2011	571	6	2005

DATE COLLECTED	TOTAL LENGTH (mm[a])	AGE	PRESUMPTIVE YEAR SPAWNED
VIRGIN RIVER/MUDDY RIVER INFLOW AREA			
2/1/2011	556	7	2004
2/1/2011	586	6	2005
2/1/2011	506	8	2003
2/1/2011	572	8	2003
2/1/2011	500	6	2005
2/22/2011	501	7	2004
2/22/2011	534	6	2005
2/22/2011	506	6	2005
2/22/2011	508	6	2005
2/22/2011	524	7	2004
2/22/2011	517	8	2003
2/22/2011	580	5	2006
2/22/2011	509	8	2003
2/22/2011	586	6	2005
2/22/2011	512	7	2004
2/22/2011	585	6	2005
2/23/2011	545	6	2005
2/23/2011	500	6	2005
2/23/2011	527	7	2004
2/23/2011	552	5	2006
3/1/2011	510	10	2001
3/1/2011	573	9	2002
3/1/2011	518	8	2003
3/1/2011	538	6	2005
3/1/2011	532	9	2002
3/1/2011	553	6	2005
3/1/2011	595	6	2005
3/1/2011	563	6	2005
3/1/2011	555	6	2005
3/1/2011	483	7	2004
3/1/2011	599	9	2002
3/1/2011	560	5	2006
3/9/2011	556	7	2004
3/9/2011	534	6	2005
3/9/2011	549	7	2004
3/9/2011	494	4	2007
3/9/2011	505	6	2005
3/15/2011	575	8	2003
3/15/2011	551	8	2003
3/15/2011	515	7	2004
3/15/2011	558	8	2003
3/15/2011	576	8	2003
3/15/2011	587	8	2003
3/15/2011	572	7	2004
3/15/2011	575	10	2001
3/15/2011	551	7	2004
3/15/2011	561	7	2004
3/15/2011	566	9	2002

DATE COLLECTED	TOTAL LENGTH (mm[a])	AGE	PRESUMPTIVE YEAR SPAWNED
VIRGIN RIVER/MUDDY RIVER INFLOW AREA			
3/15/2011	542	6	2005
3/15/2011	577	8	2003
4/5/2011	521	7	2004
4/5/2011	495	6	2005
4/12/2011	572	8	2003
1/31/2012	604	7	2005
1/31/2012	570	7	2005
2/1/2012	525	12	2000
2/7/2012	525	9	2003
2/8/2012	536	7	2005
2/8/2012	501	9	2003
2/8/2012	623	12	2000
2/21/2012	566	10	2002
2/21/2012	590	10	2002
3/13/2012	555	9	2003
3/13/2012	521	9	2003
3/13/2012	618	9	2003
3/13/2012	610	12	2000
3/14/2012	539	7	2005
3/14/2012	530	9	2003
3/15/2012	546	7	2005
3/15/2012	576	10	2002
3/15/2012	574	10	2002
3/21/2012	559	7	2005
3/28/2012	575	8	2004
4/4/2012	551	6	2006
4/4/2012	575	7	2005
4/11/2012	535	9	2003
2/6/2013	519	9	2004
2/13/2013	630	10	2003
2/21/2013	546	7	2006
2/21/2013	544	8	2005
2/21/2013	584	8	2005
2/21/2013	606	11	2002
2/21/2013	549	8	2005
3/5/2013	567	10	2003
3/5/2013	537	10	2003
3/5/2013	621	10	2003
3/5/2013	558	8	2005
3/5/2013	601	8	2005
3/14/2013	600	12	2001
3/14/2013	616	9	2004
3/21/2013	551	8	2005
3/21/2013	616	10	2003
3/21/2013	605	10	2003
3/21/2013	629	9	2004
3/21/2013	570	9	2004
3/21/2013	578	9	2004

DATE COLLECTED	TOTAL LENGTH (mm[a])	AGE	PRESUMPTIVE YEAR SPAWNED
VIRGIN RIVER/MUDDY RIVER INFLOW AREA			
3/21/2013	577	10	2003
3/21/2013	621	14	1999
3/21/2013	639	9	2004
3/27/2013	539	8	2005
3/27/2013	580	10	2003
4/3/2013	554	8	2005
4/3/2013	542	7	2006
4/10/2013	560	10	2003
4/10/2013	598	9	2004
2/26/2014	570	12	2002
2/26/2014	626	10	2004
3/6/2014	657	9	2005
3/6/2014	521	9	2005
3/6/2014	591	8	2006
3/6/2014	591	9	2005
3/6/2014	628	12	2002
3/20/2014	569	7	2007
3/20/2014	624	9	2005
3/20/2014	627	11	2003
3/20/2014	549	7	2007
3/20/2014	531	9	2005
3/20/2014	621	9	2005
3/20/2014	593	10	2004
3/20/2014	532	8	2006
3/20/2014	561	9	2005
3/20/2014	592	8	2006
3/20/2014	637	10	2004
3/20/2014	567	9	2005
3/20/2014	574	10	2004
3/20/2014	541	10	2004
3/20/2014	614	9	2005
4/3/2014	572	6	2008
4/3/2014	615	7	2007
4/10/2014	651	7	2007
4/16/2014	504	6	2008
2/4/2015	638	9	2006
2/18/2015	650	9	2006
3/4/2015	558	8	2007
3/4/2015	586	8	2007
3/18/2015	644	9	2006
3/31/2015	560	8	2007
2/9/2016	503	6	2010
2/16/2016	455	5	2011
2/16/2016	555	11	2005
2/16/2016	635	11	2005
2/17/2016	545	8	2008
2/24/2016	471	6	2010
2/24/2016	635	10	2006

DATE COLLECTED	TOTAL LENGTH (mm[a])	AGE	PRESUMPTIVE YEAR SPAWNED
VIRGIN RIVER/MUDDY RIVER INFLOW AREA			
2/24/2016	559	13	2003
2/24/2016	647	14	2002
3/22/2016	541	10	2006
3/23/2016	577	9	2007
3/24/2016	490	6	2010
3/24/2016	582	8	2008
3/24/2016	562	9	2007
3/24/2016	565	11	2005
1/27/2017	592	7	2010
1/27/2017	657	7	2010
2/4/2017	541	6	2011
2/14/2017	624	9	2008
3/3/2017	541	8	2009
3/3/2017	642	7	2010
3/3/2017	586	7	2010
3/22/2017	319	3	2014
2/7/2018	451	4	2014
2/7/2018	535	6	2012
2/15/2018	630	9	2009
2/15/2018	614	8	2010
2/22/2018	655	10	2008
2/22/2018	455	8	2010
3/6/2018	611	13	2005
3/7/2018	468	4	2014
3/8/2018	481	6	2012
4/18/2018	454	5	2013
2/7/2019	579	6	2013
2/7/2019	671	8	2011
2/7/2019	654	10	2009
2/7/2019	498	6	2013
2/7/2019	599	7	2012
2/20/2019	546	7	2012
2/20/2019	545	6	2013
2/20/2019	676	8	2011
2/26/2019	680	9	2010
2/26/2019	643	7	2012
2/26/2019	639	9	2010
3/5/2019	535	6	2013
3/5/2019	582	5	2014
4/3/2019	601	7	2012
1/22/2020	656	10	2010
1/22/2020	541	9	2011
1/22/2020	593	7	2013
2/12/2020	662	11	2009
2/12/2020	616	10	2010
2/12/2020	301	2	2018
2/19/2020	557	7	2013
2/19/2020	605	6	2014

DATE COLLECTED	TOTAL LENGTH (mm[a])	AGE	PRESUMPTIVE YEAR SPAWNED
VIRGIN RIVER/MUDDY RIVER INFLOW AREA			
2/26/2020	635	10	2010
3/4/2020	541	10	2010
3/4/2020	317	3	2017
2/9/2021	582	10	2011
3/31/2021	646	11	2010
3/31/2021	625	11	2010
2/4/2021	724	15	2006
2/9/2021	495	4	2017
1/13/2021	461	4	2017
2/9/2021	525	6	2015
2/4/2021	541	6	2015
3/31/2021	586	7	2014
3/17/2021	554	7	2014
3/17/2021	545	7	2014
2/11/2021	566	7	2014
2/9/2021	576	7	2014
2/4/2021	591	7	2014
1/28/2021	615	7	2014
2/10/2021	572	8	2013
2/9/2021	594	8	2013
2/4/2021	621	8	2013
2/4/2021	605	8	2013
1/28/2021	559	8	2013
1/28/2021	575	8	2013
1/13/2021	606	8	2013
3/17/2021	523	9	2012
2/4/2021	565	9	2012
1/13/2021	601	9	2012
1/20/2022	676	14	2008
2/9/2022	675	11	2011
2/9/2022	597	8	2014
2/16/2022	615	10	2012
2/16/2022	615	9	2013
2/16/2022	592	8	2014
2/16/2022	601	8	2014
4/5/2022	321	2	2020
COLORADO RIVER INFLOW AREA			
4/20/2010	563	6	2004
4/20/2010	508	6	2004
4/20/2010	568	11	1999
2/8/2011	594	8	2003
3/10/2011	659	11	2000
3/24/2011	584	9	2002
3/24/2011	530	7	2004
3/24/2011	545	6	2005
4/19/2011	636	9	2002
4/20/2011	570	10	2001
1/26/2012	602	8	2004

DATE COLLECTED	TOTAL LENGTH (mm[a])	AGE	PRESUMPTIVE YEAR SPAWNED
COLORADO RIVER INFLOW AREA			
2/21/2012	604	10	2002
3/1/2012	546	8	2004
3/1/2012	559	9	2003
3/6/2012	535[g]	11	2001
3/6/2012	573	6	2006
3/6/2012	572	7	2005
3/8/2012	557	8	2004
3/20/2012	630	10	2002
3/20/2012	548	8	2004
3/21/2012	571	9	2003
3/28/2012	572	8	2004
4/3/2012	602	9	2003
4/24/2012	555[e]	9	2003
3/5/2013	215	2	2011
5/14/2014	429	3	2011
2/24/2015	581	10	2005
2/26/2015	634	7	2008
3/3/2015	624	5	2010
3/17/2015	572	6	2009
3/18/2015	595	6	2009
1/21/2016	585	9	2007
3/8/2016	604	10	2006
2/14/2017	268	3	2014
2/15/2017	621	6	2011
3/29/2017	602	10	2007
3/8/2017	556	6	2011
3/7/2017	598	11	2006
4/18/2017	401	6	2011
1/30/2018	521	10	2008
2/1/2018	566	10	2008
2/23/2018	448	6	2012
3/1/2018	606	14	2004
3/7/2018	579	8	2010
3/7/2018	558	9	2009
4/18/2018	454	5	2013
5/2/2018	473	5	2013
2/6/2019	570	8	2011
2/6/2019	526	5	2014
3/27/2019	517	6	2013
4/11/2019	432	4	2015
2/25/2020	532	7	2013
2/26/2020	556	10	2010
3/12/2020	491	5	2015
4/7/2020	648	8	2012
4/9/2020	503	7	2013
4/9/2020	558	7	2013
2/17/2021	624	10	2011
2/17/2021	582	15	2006

DATE COLLECTED	TOTAL LENGTH (mm[a])	AGE	PRESUMPTIVE YEAR SPAWNED
	COLORADO RIVER INFLOW AREA		
2/24/2021	580	7	2014
2/17/2021	467	7	2014
2/18/2021	631	9	2012
	BONELLI BAY		
2/12/2019	700	12	2007
2/12/2019	625	10	2009
2/12/2019	670	10	2009
2/20/2019	656	10	2009
2/20/2019	571	7	2012
3/14/2019	590	6	2013
3/5/2020	710	11	2009
3/5/2020	560	9	2011
3/3/2021	681	11	2010
3/3/2021	641	11	2010
3/3/2021	610	12	2009
3/3/2021	666	8	2013
3/5/2021	602	9	2012
2/24/2022	589	7	2015

[a] mm=millimeters.
[b] Fish stocked from Echo Bay larval fish captured in 1999 and raised at Nevada Department of Wildlife Lake Mead Fish Hatchery.
[c] Fish stocked from Floyd Lamb Park ponds (1982 Dexter National Fish Hatchery cohort placed in Floyd Lamb Park ponds in 1984).
[d] Fish was aged at 33 years of age, +/- 2 years.
[e] Fish was a mortality. Found dead in net.
[f] Fish stocked from Floyd Lamb Park ponds (from an unknown 2001–2003 cohort stocking event).
[g] Fish stocked from Floyd Lamb Park ponds, sonic tagged.

APPENDIX C: GENERALIZED RANDOM TESSELLATION STRATIFIED (GRTS) DESIGN SEGMENTS SELECTED AS MONITORING SITES FOR LARVAL AND SMALL-BODIED FISH COMMUNITY SAMPLING IN THE GRAND CANYON, 2022

SEGMENT	SEGMENT ID	RIVER MILE	UPPER EASTING	UPPER NORTHING	LOWER EASTING	LOWER NORTHING
1	2	88.6	401236	3995420	400511	3995721
2	22	98.7	388380	3999494	387746	3999929
3	31	103.5	382457	4002473	382448	4003271
4	34	104.8	382222	4004849	381871	4005555
5	46	110.6	377056	4011689	376295	4011918
6	50	112.8	373993	4011592	373323	4011163
7	55	115.4	371970	4008526	371871	4007737
8	69	122.2	365560	4011942	364770	4012015
9	72	123.6	363320	4012489	362898	4013141
10	74	125.1	362558	4013855	362634	4014621
11	79	127.3	365038	4016497	365348	4017211
12	86	131.0	368276	4020835	368729	4021479
13	90	132.8	369414	4023642	369342	4024435
14	98	137.1	365162	4027918	364393	4028122
15	103	139.6	361554	4029434	360758	4029476
16	114	144.8	353018	4028380	352375	4027912
17	122	148.9	349661	4023324	348922	4023261
18	132	153.8	345581	4021453	345270	4020756
19	155	165.0	331713	4016623	331204	4016032
20	160	167.7	329165	4013799	328409	4014015
21	162	168.6	327683	4014300	326986	4014018
22	170	172.6	322406	4011609	321631	4011502
23	174	174.8	319412	4012339	318656	4012197
24	178	176.9	316702	4010873	316197	4010257
25	179	177.3	316197	4010257	315815	4009558
26	180	177.7	315815	4009558	315237	4009018
27	181	178.5	315237	4009018	314464	4008849
28	186	180.5	311629	4007474	310979	4007014
29	189	182.0	309681	4006107	309284	4005415
30	191	183.3	308684	4004903	307963	4004566
31	194	184.5	306738	4005396	305959	4005413
32	198	186.6	304150	4003940	303421	4003642
33	210	192.5	299920	3996660	299304	3996239
34	213	194.6	297814	3996633	297109	3996273
35	218	197.0	294276	3997172	293516	3997056
36	225	200.1	290505	3995112	290230	3994364
37	234	205.0	288216	3988826	288329	3988043
38	237	206.4	289061	3986715	288984	3985925
39	242	208.8	290699	3983705	291011	3982987
40	258	216.6	291282	3972808	291242	3972018
41	264	220.1	289841	3968531	289911	3967754

SEGMENT	SEGMENT ID	RIVER MILE	UPPER EASTING	UPPER NORTHING	LOWER EASTING	LOWER NORTHING
42	266	221.0	289509	3967125	289264	3966428
43	278	227.1	284752	3959708	284150	3959229
44	285	230.7	279455	3959383	278736	3959725
45	298	236.7	270655	3963592	270168	3964223
46	302	238.7	268236	3965572	268034	3966335
47	308	241.9	265695	3969415	265137	3969982
48	310	243.0	264489	3970423	263817	3970104
49	322	248.7	259626	3970962	259288	3971678
50	330	252.7	255040	3974650	255186	3975427
51	335	255.2	255116	3978519	255168	3979314
52	353	263.6	249140	3988360	249039	3989146
53	364	269.0	243915	3993196	243131	3993355
54	365	269.9	243131	3993355	242381	3993625
55	382	277.4	235951	4002582	235152	4002626
56	385	279.0	233558	4002699	232850	4002438
43	285	230.65	279455	3959383	278736	3959725
44	298	236.7	270655	3963592	270168	3964223
45	302	238.7	268236	3965572	268034	3966335
46	308	241.9	265695	3969415	265137	3969982
47	310	243	264489	3970423	263817	3970104
48	322	248.7	259626	3970962	259288	3971678
49	330	252.7	255040	3974650	255186	3975427
50	335	255.2	255116	3978519	255168	3979314
51	353	263.6	249140	3988360	249039	3989146
52	364	269	243915	3993196	243131	3993355
53	365	269.9	243131	3993355	242381	3993625
54	369	271.85	240256	3994634	239729	3995230
55	382	277.4	235951	4002582	235152	4002626
56	385	279	233558	4002699	232850	4002438

APPENDIX D: FISH CAPTURED BY TRIP AT EACH GENERALIZED RANDOM TESSELLATION STRATIFIED (GRTS) DESIGN SEGMENT AND OPPORTUNISTIC SAMPLING LOCATION DURING SMALL-BODIED FISH COMMUNITY SAMPLING IN THE GRAND CANYON, 2022

TRIP/GRTS	BLUEHEAD SUCKER	FLANNELMOUTH SUCKER	HUMPBACK CHUB	RAZORBACK SUCKER	SPECKLED DACE	YOY CYRINID	YOY SUCKER	COMMON CARP	FATHEAD MINNOW	PLAINS KILLIFISH	GREEN SUNFISH	WESTERN MOSQUITOFISH	RED SHINER	RAINBOW TROUT	STRIPED BASS	WALLEYE
April	8	47	1	0	53	0	18	0	10	91	0	0	6	34	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	2	0	0	1	0	0	0	0	1	0	0	3	18	0	0
31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
46	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
55	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
69	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
72	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
74	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
79	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
86	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
90	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
98	0	0	0	0	1	0	0	0	0	0	0	0	0	2	0	0
103	0	1	0	0	0	0	0	0	0	0	0	0	0	9	0	0
114	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
122	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
132	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
155	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
160	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
162	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
170	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
174	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
178	0	25	0	0	0	0	1	0	1	0	0	0	0	0	0	0
179	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
180	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
181	0	12	0	0	4	0	0	0	0	4	0	0	0	0	0	0
186	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
189	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
191	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
194	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

TRIP/GRTS	BLUEHEAD SUCKER	FLANNELMOUTH SUCKER	HUMPBACK CHUB	RAZORBACK SUCKER	SPECKLED DACE	YOY CYRINID	YOY SUCKER	COMMON CARP	FATHEAD MINNOW	PLAINS KILLIFISH	GREEN SUNFISH	WESTERN MOSQUITOFISH	RED SHINER	RAINBOW TROUT	STRIPED BASS	WALLEYE
198	0	3	0	0	0	0	1	0	1	0	0	0	0	0	0	0
210	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
213	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
218	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
225	0	1	0	0	0	0	3	0	0	1	0	0	0	0	0	0
234	0	0	1	0	7	0	0	0	3	14	0	0	0	0	0	0
237	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
242	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
258	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
264	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
266	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
278	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
285	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
298	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
302	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
308	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
310	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
322	1	0	0	0	7	0	11	0	2	61	0	0	0	0	0	0
330	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
335	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0
353	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
364	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0
365	0	0	0	0	15	0	0	0	0	0	0	0	0	0	0	0
382	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
385	6	0	0	0	7	0	0	0	2	4	0	0	0	0	0	0
May	0	91	1	0	11	11	302	4	0	2	0	0	0	3	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
46	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

TRIP/GRTS	BLUEHEAD SUCKER	FLANNELMOUTH SUCKER	HUMPBACK CHUB	RAZORBACK SUCKER	SPECKLED DACE	YOY CYRINID	YOY SUCKER	COMMON CARP	FATHEAD MINNOW	PLAINS KILLIFISH	GREEN SUNFISH	WESTERN MOSQUITOFISH	RED SHINER	RAINBOW TROUT	STRIPED BASS	WALLEYE
55	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
69	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
72	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
74	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
79	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
86	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
90	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
98	0	0	0	0	3	0	0	0	0	0	0	0	0	2	0	0
103	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
114	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
122	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
132	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
155	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
160	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
162	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
170	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0
174	0	0	0	0	0	1	6	0	0	0	0	0	0	0	0	0
178	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
179	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0
180	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
181	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0
186	0	3	0	0	0	0	7	0	0	0	0	0	0	0	0	0
189	0	0	0	0	0	0	17	0	0	0	0	0	0	0	0	0
191	0	2	0	0	0	0	3	0	0	0	0	0	0	0	0	0
194	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
198	0	1	0	0	1	0	15	0	0	0	0	0	0	0	0	0
210	0	0	0	0	0	0	9	4	0	0	0	0	0	0	0	0
213	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0
218	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
225	0	6	0	0	0	0	79	0	0	0	0	0	0	0	0	0
234	0	0	0	0	0	2	6	0	0	0	0	0	0	0	0	0
237	0	2	0	0	0	0	1	0	0	0	0	0	0	0	0	0

TRIP/GRTS	BLUEHEAD SUCKER	FLANNELMOUTH SUCKER	HUMPBACK CHUB	RAZORBACK SUCKER	SPECKLED DACE	YOY CYRINID	YOY SUCKER	COMMON CARP	FATHEAD MINNOW	PLAINS KILLIFISH	GREEN SUNFISH	WESTERN MOSQUITOFISH	RED SHINER	RAINBOW TROUT	STRIPED BASS	WALLEYE
242	0	5	0	0	0	4	21	0	0	0	0	0	0	0	0	0
258	0	2	0	0	0	0	35	0	0	0	0	0	0	0	0	0
264	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0
266	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
278	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
285	0	1	0	0	0	0	7	0	0	0	0	0	0	0	0	0
298	0	3	0	0	0	0	19	0	0	0	0	0	0	0	0	0
302	0	9	0	0	0	0	9	0	0	0	0	0	0	0	0	0
308	0	4	0	0	0	0	1	0	0	0	0	0	0	0	0	0
310	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
322	0	4	0	0	0	0	0	0	0	2	0	0	0	0	0	0
330	0	27	0	0	0	1	17	0	0	0	0	0	0	0	0	0
335	0	2	0	0	0	0	9	0	0	0	0	0	0	0	0	0
353	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
364	0	3	0	0	1	0	3	0	0	0	0	0	0	0	0	0
365	0	10	1	0	3	0	6	0	0	0	0	0	0	0	0	0
382	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
385	0	2	0	0	1	0	12	0	0	0	0	0	0	0	0	0
June	4	4568	0	0	433	0	1383	45	56	73	0	4	7	9	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	4	0	0	2	0	11	0	0	2	0	0	0	0	0	0
31	0	1	0	0	0	0	21	0	0	0	0	0	0	0	0	0
34	0	1	0	0	0	0	3	0	0	0	0	0	0	0	0	0
46	0	1	0	0	0	0	6	0	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	54	0	0	0	0	0	0	0	0	0
55	0	65	0	0	0	0	187	0	0	0	0	0	0	0	0	0
69	0	4	0	0	1	0	0	0	0	0	0	0	0	0	0	0
72	0	320	0	0	1	0	10	0	0	0	0	0	0	0	0	0
74	0	2	0	0	0	0	75	0	0	0	0	0	0	0	0	0
79	0	11	0	0	0	0	43	0	0	0	0	0	0	0	0	0
86	0	9	0	0	0	0	50	0	0	0	0	0	0	0	0	0
90	0	21	0	0	0	0	16	0	0	0	0	0	0	0	0	0

TRIP/GRTS	BLUEHEAD SUCKER	FLANNELMOUTH SUCKER	HUMPBACK CHUB	RAZORBACK SUCKER	SPECKLED DACE	YOY CYRINID	YOY SUCKER	COMMON CARP	FATHEAD MINNOW	PLAINS KILLIFISH	GREEN SUNFISH	WESTERN MOSQUITOFISH	RED SHINER	RAINBOW TROUT	STRIPED BASS	WALLEYE
98	1	4	0	0	0	0	2	0	0	0	0	0	0	4	0	0
103	0	92	0	0	1	0	12	0	0	0	0	0	0	3	0	0
114	0	2	0	0	1	0	1	0	0	0	0	0	0	0	0	0
122	0	20	0	0	0	0	27	0	0	0	0	0	0	0	0	0
132	0	12	0	0	8	0	22	0	0	0	0	0	0	0	0	0
155	0	48	0	0	0	0	32	0	1	0	0	0	0	0	0	0
160	0	18	0	0	1	0	10	0	0	0	0	0	0	0	0	0
162	0	35	0	0	2	0	11	0	0	0	0	0	0	0	0	0
170	0	159	0	0	13	0	70	0	2	0	0	0	0	0	0	0
174	0	60	0	0	0	0	45	0	0	0	0	0	0	0	0	0
178	0	34	0	0	1	0	25	0	0	0	0	0	0	0	0	0
179	0	117	0	0	0	0	22	0	0	0	0	0	0	0	0	0
180	0	144	0	0	0	0	27	0	0	0	0	0	0	0	0	0
181	0	72	0	0	6	0	39	0	0	0	0	0	0	0	0	0
186	0	48	0	0	0	0	14	0	0	0	0	0	0	0	0	0
189	0	874	0	0	3	0	29	0	0	1	0	0	0	0	0	0
191	0	110	0	0	3	0	12	0	0	0	0	0	0	0	0	0
194	0	108	0	0	5	0	15	0	0	0	0	0	0	0	0	0
198	0	193	0	0	10	0	71	0	0	1	0	0	0	0	0	0
210	0	49	0	0	1	0	16	45	0	0	0	0	0	0	0	0
213	0	7	0	0	5	0	18	0	0	0	0	0	0	0	0	0
218	0	68	0	0	3	0	36	0	0	0	0	0	0	0	0	0
225	0	120	0	0	24	0	56	0	0	0	0	0	0	0	0	0
234	0	41	0	0	15	0	8	0	45	15	0	0	0	0	0	0
237	0	123	0	0	23	0	2	0	0	9	0	0	0	0	0	0
242	0	21	0	0	0	0	12	0	0	0	0	0	0	0	0	0
258	0	208	0	0	4	0	18	0	0	0	0	0	0	0	0	0
264	0	108	0	0	21	0	15	0	0	0	0	0	0	0	0	0
266	0	97	0	0	8	0	25	0	0	0	0	0	0	0	0	0
278	0	48	0	0	3	0	10	0	0	0	0	0	0	0	0	0
285	0	20	0	0	6	0	13	0	0	0	0	0	0	0	0	0
298	0	58	0	0	18	0	39	0	0	0	0	0	0	0	0	0

TRIP/GRTS	BLUEHEAD SUCKER	FLANNELMOUTH SUCKER	HUMPBACK CHUB	RAZORBACK SUCKER	SPECKLED DACE	YOY CYRINID	YOY SUCKER	COMMON CARP	FATHEAD MINNOW	PLAINS KILLIFISH	GREEN SUNFISH	WESTERN MOSQUITOFISH	RED SHINER	RAINBOW TROUT	STRIPED BASS	WALLEYE
302	0	19	0	0	25	0	14	0	0	0	0	0	0	0	0	0
308	0	53	0	0	51	0	19	0	0	0	0	0	0	0	0	0
310	0	116	0	0	55	0	16	0	7	1	0	0	0	0	0	0
322	0	196	0	0	57	0	2	0	0	39	0	0	0	0	0	0
330	0	88	0	0	17	0	28	0	0	0	0	1	0	0	0	0
335	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0
353	1	10	0	0	5	0	6	0	0	0	0	0	0	0	0	0
364	1	159	0	0	4	0	8	0	0	0	0	3	0	0	0	0
365	0	10	0	0	6	0	2	0	0	0	0	0	0	0	0	0
382	0	18	0	0	0	0	12	0	0	0	0	0	0	0	0	0
385	0	44	0	0	1	0	16	0	1	4	0	0	7	0	0	0
999	1	292	0	0	23	0	30	0	0	1	0	0	0	2	0	0

APPENDIX E: AGE-0 FISH CAPTURED BY TRIP AT GENERALIZED RANDOM TESSELLATION STRATIFIED (GRTS) SEGMENTS DURING LARVAL-FISH COMMUNITY SAMPLING IN THE GRAND CANYON, 2022

Appendix E.1. Age-0 fish captured during 2022.

SPECIES COMMON NAME	RESIDENCE STATUS[a]	NUMBER OF SPECIMENS	PERCENT OF TOTAL	MEAN CPUE[b]	FREQUENCY OF OCCURRENCE[c]	PERCENT FREQUENCY OF OCCURRENCE[c]
Carps and Minnows						
Cyprinella lutrensis Red Shiner	I	1	[d]	[d]	1	0.30
Cyprinus carpio Common Carp	I	54	0.23	[d]	2	0.60
Gila cypha Humpback Chub	N	444	1.91	[d]	91	27.08
Pimephales promelas Fathead Minnow	I	185	0.80	[d]	19	5.65
Rhinichthys osculus Speckled Dace	N	4,121	17.71	0.34	171	50.89
Catostomus discobolus Bluehead Sucker	N	7,812	33.58	0.64	183	54.46
Catostomus latipinnis Flannelmouth Sucker	N	10,566	45.42	0.87	262	77.98
Xyrauchen texanus Razorback Sucker	N	–	–	–	–	–
Catostomidae (Unidentified Sucker)[e]	N	15	0.06	[d]	10	2.98
Trouts and Salmons						
Oncorhynchus mykiss Rainbow Trout	I	2	[d]	[d]	1	0.30
Topminnows						
Fundulus zebrinus Plains Killifish	I	53	0.23	[d]	21	6.25
Livebearers						
Gambusia affinis Western Mosquitofish	I	5	[d]	[d]	3	0.89
Temperate Basses						
Morone saxatilis Striped Bass	I	6	[d]	[d]	6	1.79
TOTAL		**23,264**				

[a] N=native, I=introduced
[b] CPUE=catch-per-unit effort; mean value based on n specimens/total area sampled during 2022 (12,136 m^2)
[c] Frequency and percent frequency of occurrence are based on n=336 GRTS sample segments (2022 total)
[d] Value is <0.05
[e] Species-specific identifications will be acquired in 2023 and included in the 2023 Grand Canyon report

Appendix E.2. Age-0 fish captured during the 08–18 March 2022 survey.

SPECIES COMMON NAME	RESIDENCE STATUS[a]	NUMBER OF SPECIMENS	PERCENT OF TOTAL	MEAN CPUE[b]	FREQUENCY OF OCCURRENCE[c]	PERCENT FREQUENCY OF OCCURRENCE[c]
Carps and Minnows						
Cyprinella lutrensis Red Shiner	I	–	–	–	–	–
Cyprinus carpio Common Carp	I	–	–	–	–	–
Gila cypha Humpback Chub	N	–	–	–	–	–
Pimephales promelas Fathead Minnow	I	–	–	–	–	–
Rhinichthys osculus Speckled Dace	N	–	–	–	–	–
Suckers						
Catostomus discobolus Bluehead Sucker	N	9	19.57	[d]	5	8.93
Catostomus latipinnis Flannelmouth Sucker	N	31	67.39	[d]	10	17.86
Xyrauchen texanus Razorback Sucker	N	–	–	–	–	–
Catostomidae (Unidentified Sucker)[e]	N	6	13.04	[d]	1	1.79
Trouts and Salmons						
Oncorhynchus mykiss Rainbow Trout	I	–	–	–	–	–
Topminnows						
Fundulus zebrinus Plains Killifish	I	–	–	–	–	–
Livebearers						
Gambusia affinis Western Mosquitofish	I	–	–	–	–	–
Temperate Basses						
Morone saxatilis Striped Bass	I	–	–	–	–	–
TOTAL		**46**				

[a] N=native, I=introduced
[b] CPUE=catch-per-unit effort; mean value based on n specimens/total area sampled by month (2,060 m^2)
[c] Frequency and percent frequency of occurrence are based on n=56 GRTS sample segments
[d] Value is <0.05
[e] Species-specific identifications will be acquired in 2022 and included in the 2022 Grand Canyon report

Appendix E.3. Age-0 fish captured during the 12–20 April 2022 survey.

SPECIES COMMON NAME	RESIDENCE STATUS[a]	NUMBER OF SPECIMENS	PERCENT OF TOTAL	MEAN CPUE[b]	FREQUENCY OF OCCURRENCE[c]	PERCENT FREQUENCY OF OCCURRENCE[c]
Carps and Minnows						
Cyprinella lutrensis Red Shiner	I	–	–	–	–	–
Cyprinus carpio Common Carp	I	1	0.10	[d]	1	1.79
Gila cypha Humpback Chub	N	–	–	–	–	–
Pimephales promelas Fathead Minnow	I	95	9.13	[d]	3	5.36
Rhinichthys osculus Speckled Dace	N	2	0.19		1	1.79
Suckers						
Catostomus discobolus Bluehead Sucker	N	87	8.36	[d]	14	25.00
Catostomus latipinnis Flannelmouth Sucker	N	852	81.84	0.40	44	78.57
Xyrauchen texanus Razorback Sucker	N	–	–	–	–	–
Catostomidae (Unidentified Sucker)[e]	N	2	0.19	[d]	2	3.57
Trouts and Salmons						
Oncorhynchus mykiss Rainbow Trout	I	2	0.19	[d]	1	1.79
Topminnows						
Fundulus zebrinus Plains Killifish	I	–	–	–	–	–
Livebearers						
Gambusia affinis Western Mosquitofish	I	–	–	–	–	–
Temperate Basses						
Morone saxatilis Striped Bass	I	–	–	–	–	–
TOTAL		**1,041**				

[a] N=native, I=introduced
[b] CPUE=catch-per-unit effort; mean value based on n specimens/total area sampled by month (2,106 m^2)
[c] Frequency and percent frequency of occurrence are based on n=56 GRTS sample segments
[d] Value is <0.05
[e] Species-specific identifications will be acquired in 2023 and included in the 2023 Grand Canyon report

Appendix E.4. Age-0 fish captured during the 10–17 May 2022 survey.

SPECIES COMMON NAME	RESIDENCE STATUS[a]	NUMBER OF SPECIMENS	PERCENT OF TOTAL	MEAN CPUE[b]	FREQUENCY OF OCCURRENCE[c]	PERCENT FREQUENCY OF OCCURRENCE[c]
Carps and Minnows						
Cyprinella lutrensis Red Shiner	I	–	–	–	–	–
Cyprinus carpio Common Carp	I	53	0.64	[d]	1	1.79
Gila cypha Humpback Chub	N	17	[d]	[d]	7	12.50
Pimephales promelas Fathead Minnow	I	69	0.83	[d]	2	3.57
Rhinichthys osculus Speckled Dace	N	153	1.84	0.08	22	39.29
Suckers						
Catostomus discobolus Bluehead Sucker	N	3,489	42.00	1.85	52	92.86
Catostomus latipinnis Flannelmouth Sucker	N	4,522	54.43	2.40	55	98.21
Xyrauchen texanus Razorback Sucker	N	–	–	–	–	–
Catostomidae (Unidentified Sucker)[e]	N	3	[d]	[d]	3	5.36
Trouts and Salmons						
Oncorhynchus mykiss Rainbow Trout	I	–	–	–	–	–
Topminnows						
Fundulus zebrinus Plains Killifish	I	2	[d]	[d]	2	3.57
Livebearers						
Gambusia affinis Western Mosquitofish	I	–	–	–	–	–
Temperate Basses						
Morone saxatilis Striped Bass	I	–	–	–	–	–
TOTAL		**8,308**				

[a] N=native, I=introduced
[b] CPUE=catch-per-unit effort; mean value based on n specimens/total area sampled by month (1,881 m^2)
[c] Frequency and percent frequency of occurrence are based on n=56 GRTS sample segments
[d] Value is <0.05
[e] Species-specific identifications will be acquired in 2023 and included in the 2023 Grand Canyon report

Appendix E.5. Age-0 fish captured during the 06–14 June 2022 survey.

SPECIES COMMON NAME	RESIDENCE STATUS[a]	NUMBER OF SPECIMENS	PERCENT OF TOTAL	MEAN CPUE[b]	FREQUENCY OF OCCURRENCE[c]	PERCENT FREQUENCY OF OCCURRENCE[c]
Carps and Minnows						
Cyprinella lutrensis Red Shiner	I	–	–	–	–	–
Cyprinus carpio Common Carp	I	–	–	–	–	–
Gila cypha Humpback Chub	N	101	1.00	0.05	21	37.50
Pimephales promelas Fathead Minnow	I	2	[d]	[d]	2	3.57
Rhinichthys osculus Speckled Dace	N	1,997	19.82	0.94	47	83.93
Suckers						
Catostomus discobolus Bluehead Sucker	N	3,889	38.60	1.83	56	100
Catostomus latipinnis Flannelmouth Sucker	N	4,081	40.51	1.92	54	96.43
Xyrauchen texanus Razorback Sucker	N	–	–	–	–	–
Catostomidae (Unidentified Sucker)[e]	N	3	[d]	[d]	3	5.36
Trouts and Salmons						
Oncorhynchus mykiss Rainbow Trout	I	–	–	–	–	–
Topminnows						
Fundulus zebrinus Plains Killifish	I	–	–	–	–	–
Livebearers						
Gambusia affinis Western Mosquitofish	I	1	[d]	[d]	1	1.79
Temperate Basses						
Morone saxatilis Striped Bass	I	–	–	–	–	–
TOTAL		**10,074**				

[a] N=native, I=introduced
[b] CPUE=catch-per-unit effort; mean value based on n specimens/total area sampled by month (2,122 m^2)
[c] Frequency and percent frequency of occurrence are based on n=56 GRTS sample segments
[d] Value is <0.05
[e] Species-specific identifications will be acquired in 2023 and included in the 2023 Grand Canyon report

Appendix E.6. Age-0 fish captured during the 05–13 July 2022 survey.

SPECIES COMMON NAME	RESIDENCE STATUS[a]	NUMBER OF SPECIMENS	PERCENT OF TOTAL	MEAN CPUE[b]	FREQUENCY OF OCCURRENCE[c]	PERCENT FREQUENCY OF OCCURRENCE[c]
Carps and Minnows						
Cyprinella lutrensis Red Shiner	I	1	[d]	[d]	1	1.79
Cyprinus carpio Common Carp	I	–	–	–	–	–
Gila cypha Humpback Chub	N	267	9.80	0.12	36	64.29
Pimephales promelas Fathead Minnow	I	7	[d]	[d]	6	10.71
Rhinichthys osculus Speckled Dace	N	1,453	53.34	0.68	52	92.86
Suckers						
Catostomus discobolus Bluehead Sucker	N	327	12.00	0.15	47	83.93
Catostomus latipinnis Flannelmouth Sucker	N	617	22.65	0.29	53	94.64
Xyrauchen texanus Razorback Sucker	N	–	–	–	–	–
Catostomidae (Unidentified Sucker)[e]	N	1	[d]	[d]	1	1.79
Trouts and Salmons						
Oncorhynchus mykiss Rainbow Trout	I	–	–	–	–	–
Topminnows						
Fundulus zebrinus Plains Killifish	I	43	1.58	[d]	14	25.00
Livebearers						
Gambusia affinis Western Mosquitofish	I	2	0.07	[d]	1	1.79
Temperate Basses						
Morone saxatilis Striped Bass	I	6	0.22	[d]	6	10.71
TOTAL		**2,724**				

[a] N=native, I=introduced
[b] CPUE=catch-per-unit effort; mean value based on n specimens/total area sampled by month (2,136 m^2)
[c] Frequency and percent frequency of occurrence are based on n=56 GRTS sample segments
[d] Value is <0.05
[e] Species-specific identifications will be acquired in 2023 and included in the 2023 Grand Canyon report

Appendix E.7. Age-0 fish captured during the 09–16 August 2022 survey.

SPECIES COMMON NAME	RESIDENCE STATUS[a]	NUMBER OF SPECIMENS	PERCENT OF TOTAL	MEAN CPUE[b]	FREQUENCY OF OCCURRENCE[c]	PERCENT FREQUENCY OF OCCURRENCE[c]
Carps and Minnows						
Cyprinella lutrensis Red Shiner	I	–	–	–	–	–
Cyprinus carpio Common Carp	I	–	–	–	–	–
Gila cypha Humpback Chub	N	59	5.51	[d]	27	48.21
Pimephales promelas Fathead Minnow	I	12	1.12	[d]	6	10.71
Rhinichthys osculus Speckled Dace	N	516	48.18	0.28	49	87.50
Suckers						
Catostomus discobolus Bluehead Sucker	N	11	1.03	[d]	9	16.07
Catostomus latipinnis Flannelmouth Sucker	N	463	43.23	0.25	46	82.14
Xyrauchen texanus Razorback Sucker	N	–	–	–	–	–
Catostomidae (Unidentified Sucker)	N	–	–	–	–	–
Trouts and Salmons						
Oncorhynchus mykiss Rainbow Trout	I	–	–	–	–	–
Topminnows						
Fundulus zebrinus Plains Killifish	I	8	0.75	[d]	5	8.93
Livebearers						
Gambusia affinis Western Mosquitofish	I	2	0.19	[d]	1	1.79
Temperate Basses						
Morone saxatilis Striped Bass	I	–	–	–	–	–
TOTAL		**1,071**				

[a] N=native, I=introduced
[b] CPUE=catch-per-unit effort; mean value based on n specimens/total area sampled by month (1,831 m^2)
[c] Frequency and percent frequency of occurrence are based on n=56 GRTS sample segments
[d] Value is <0.05

APPENDIX F: INCIDENTAL AGE-1+ FISH CAPTURED BY TRIP AT GENERALIZED RANDOM TESSELLATION STRATIFIED (GRTS) SEGMENTS DURING LARVAL-FISH COMMUNITY SAMPLING IN THE GRAND CANYON, 2022

Appendix F.1. Age-1+ fish captured during 2022.

SPECIES COMMON NAME	RESIDENCE STATUS[a]	NUMBER OF SPECIMENS	PERCENT OF TOTAL	MEAN CPUE[b]	FREQUENCY OF OCCURRENCE[c]	PERCENT FREQUENCY OF OCCURRENCE[c]
Carps and Minnows						
Cyprinella lutrensis Red Shiner	I	65	8.62	[d]	5	1.49
Cyprinus carpio Common Carp	I	2	0.27	[d]	1	0.30
Gila cypha Humpback Chub	N	80	10.61	[d]	27	8.04
Pimephales promelas Fathead Minnow	I	19	2.52	[d]	6	1.79
Rhinichthys osculus Speckled Dace	N	496	65.78	[d]	98	29.17
Suckers						
Catostomus discobolus Bluehead Sucker	N	7	0.93	[d]	5	1.49
Catostomus latipinnis Flannelmouth Sucker	N	19	2.52	[d]	13	3.87
Xyrauchen texanus Razorback Sucker	N	–	–	–	–	–
Catostomidae (Unidentified Sucker)[e]	N	–	–	–	–	–
Trouts and Salmons						
Oncorhynchus mykiss Rainbow Trout	I	14	1.86	[d]	7	2.08
Topminnows						
Fundulus zebrinus Plains Killifish	I	51	6.76	[d]	20	5.95
Livebearers						
Gambusia affinis Western Mosquitofish	I	1	0.13	[d]	1	0.30
Temperate Basses						
Morone saxatilis Striped Bass	I	–	–	–	–	–
TOTAL		**754**				

[a] N=native, I=introduced
[b] CPUE=catch-per-unit effort; mean value based on n specimens/total area sampled during 2022 (12,136 m^2)
[c] Frequency and percent frequency of occurrence are based on n=336 GRTS sample segments (2022 total)
[d] Value is <0.05

Appendix F.2. Age-1+ fish captured during the 08–18 March 2022 survey.

SPECIES COMMON NAME	RESIDENCE STATUS[a]	NUMBER OF SPECIMENS	PERCENT OF TOTAL	MEAN CPUE[b]	FREQUENCY OF OCCURRENCE[c]	PERCENT FREQUENCY OF OCCURRENCE[c]
Carps and Minnows						
Cyprinella lutrensis Red Shiner	I	4	10.53	[d]	1	1.79
Cyprinus carpio Common Carp	I	–	–	–	–	–
Gila cypha Humpback Chub	N	–	–	–	–	–
Pimephales promelas Fathead Minnow	I	–	–	–	–	–
Rhinichthys osculus Speckled Dace	N	1	2.63	[d]	1	1.79
Suckers						
Catostomus discobolus Bluehead Sucker	N	1	2.63	[d]	1	1.79
Catostomus latipinnis Flannelmouth Sucker	N	–	–	–	–	–
Xyrauchen texanus Razorback Sucker	N	–	–	–	–	–
Catostomidae (Unidentified Sucker)[e]	N	–	–	–	–	–
Trouts and Salmons						
Oncorhynchus mykiss Rainbow Trout	I	1	2.63	[d]	1	1.79
Topminnows						
Fundulus zebrinus Plains Killifish	I	31	81.58	[d]	8	14.29
Livebearers						
Gambusia affinis Western Mosquitofish	I	–	–	–	–	–
Temperate Basses						
Morone saxatilis Striped Bass	I	–	–	–	–	–
TOTAL		**38**				

[a] N=native, I=introduced
[b] CPUE=catch-per-unit effort; mean value based on n specimens/total area sampled by month (2,060 m^2)
[c] Frequency and percent frequency of occurrence are based on n=56 GRTS sample segments
[d] Value is <0.05

Appendix F.3. Age-1+ fish captured during the 12–20 April 2022 survey.

SPECIES COMMON NAME	RESIDENCE STATUS[a]	NUMBER OF SPECIMENS	PERCENT OF TOTAL	MEAN CPUE[b]	FREQUENCY OF OCCURRENCE[c]	PERCENT FREQUENCY OF OCCURRENCE[c]
Carps and Minnows						
Cyprinella lutrensis Red Shiner	I	58	63.04	[d]	1	1.79
Cyprinus carpio Common Carp	I	–	–	–	–	–
Gila cypha Humpback Chub	N	–	–	–	–	–
Pimephales promelas Fathead Minnow	I	–	–	–	–	–
Rhinichthys osculus Speckled Dace	N	9	9.78	[d]	6	10.71
Suckers						
Catostomus discobolus Bluehead Sucker	N	4	4.35	[d]	2	3.57
Catostomus latipinnis Flannelmouth Sucker	N	8	8.70	[d]	5	8.93
Xyrauchen texanus Razorback Sucker	N	–	–	–	–	–
Catostomidae (Unidentified Sucker)[e]	N	–	–	–	–	–
Trouts and Salmons						
Oncorhynchus mykiss Rainbow Trout	I	–	–	–	–	–
Topminnows						
Fundulus zebrinus Plains Killifish	I	13	14.13	[d]	6	10.71
Livebearers						
Gambusia affinis Western Mosquitofish	I	–	–	–	–	–
Temperate Basses						
Morone saxatilis Striped Bass	I	–	–	–	–	–
TOTAL		**92**				

[a] N=native, I=introduced
[b] CPUE=catch-per-unit effort; mean value based on n specimens/total area sampled by month (2,106 m^2)
[c] Frequency and percent frequency of occurrence are based on n=56 GRTS sample segments
[d] Value is <0.05

Appendix F.4. Age-1+ fish captured during the 10–17 May 2022 survey.

SPECIES COMMON NAME	RESIDENCE STATUS[a]	NUMBER OF SPECIMENS	PERCENT OF TOTAL	MEAN CPUE[b]	FREQUENCY OF OCCURRENCE[c]	PERCENT FREQUENCY OF OCCURRENCE[c]
Carps and Minnows						
Cyprinella lutrensis Red Shiner	I	–	–	–	–	–
Cyprinus carpio Common Carp	I	2	10.53	[d]	1	1.79
Gila cypha Humpback Chub	N	–	–	–	–	–
Pimephales promelas Fathead Minnow	I	15	78.95	[d]	2	3.57
Rhinichthys osculus Speckled Dace	N	1	5.26	[d]	1	1.79
Suckers						
Catostomus discobolus Bluehead Sucker	N	–	–	–	–	–
Catostomus latipinnis Flannelmouth Sucker	N	–	–	–	–	–
Xyrauchen texanus Razorback Sucker	N	–	–	–	–	–
Catostomidae *(Unidentified Sucker)*[e]	N	–	–	–	–	–
Trouts and Salmons						
Oncorhynchus mykiss Rainbow Trout	I	–	–	–	–	–
Topminnows						
Fundulus zebrinus Plains Killifish	I	1	5.26	[d]	1	1.79
Livebearers						
Gambusia affinis Western Mosquitofish	I	–	–	–	–	–
Temperate Basses						
Morone saxatilis Striped Bass	I	–	–	–	–	–
TOTAL		**19**				

[a] N=native, I=introduced
[b] CPUE=catch-per-unit effort; mean value based on n specimens/total area sampled by month (1,881 m^2)
[c] Frequency and percent frequency of occurrence are based on n=56 GRTS sample segments
[d] Value is <0.05

Appendix F.5. Age-1+ fish captured during the 07–14 June 2022 survey.

SPECIES COMMON NAME	RESIDENCE STATUS[a]	NUMBER OF SPECIMENS	PERCENT OF TOTAL	MEAN CPUE[b]	FREQUENCY OF OCCURRENCE[c]	PERCENT FREQUENCY OF OCCURRENCE[c]
Carps and Minnows						
Cyprinella lutrensis Red Shiner	I	–	–	–	–	–
Cyprinus carpio Common Carp	I	–	–	–	–	–
Gila cypha Humpback Chub	N	–	–	–	–	–
Pimephales promelas Fathead Minnow	I	–	–	–	–	–
Rhinichthys osculus Speckled Dace	N	28	80.00	[d]	16	28.57
Suckers						
Catostomus discobolus Bluehead Sucker	N	1	2.86	[d]	1	1.79
Catostomus latipinnis Flannelmouth Sucker	N	6	17.14	[d]	4	7.14
Xyrauchen texanus Razorback Sucker	N	–	–	–	–	–
Catostomidae (Unidentified Sucker)[e]	N	–	–	–	–	–
Trouts and Salmons						
Oncorhynchus mykiss Rainbow Trout	I	–	–	–	–	–
Topminnows						
Fundulus zebrinus Plains Killifish	I	–	–	–	–	–
Livebearers						
Gambusia affinis Western Mosquitofish	I	–	–	–	–	–
Temperate Basses						
Morone saxatilis Striped Bass	I	–	–	–	–	–
TOTAL		**35**				

[a] N=native, I=introduced
[b] CPUE=catch-per-unit effort; mean value based on n specimens/total area sampled by month (2,122 m^2)
[c] Frequency and percent frequency of occurrence are based on n=56 GRTS sample segments
[d] Value is <0.05

Appendix F.6. Age-1+ fish captured during the 05–13 July 2022 survey.

SPECIES COMMON NAME	RESIDENCE STATUS[a]	NUMBER OF SPECIMENS	PERCENT OF TOTAL	MEAN CPUE[b]	FREQUENCY OF OCCURRENCE[c]	PERCENT FREQUENCY OF OCCURRENCE[c]
Carps and Minnows						
Cyprinella lutrensis Red Shiner	I	–	–	–	–	–
Cyprinus carpio Common Carp	I	–	–	–	–	–
Gila cypha Humpback Chub	N	12	3.58	[d]	5	8.93
Pimephales promelas Fathead Minnow	I	2	0.60	[d]	2	3.57
Rhinichthys osculus Speckled Dace	N	316	94.33	0.15	42	75.00
Suckers						
Catostomus discobolus Bluehead Sucker	N	–	–	–	–	–
Catostomus latipinnis Flannelmouth Sucker	N	1	0.30	[d]	1	1.79
Xyrauchen texanus Razorback Sucker	N	–	–	–	–	–
Catostomidae (Unidentified Sucker)[e]	N	–	–	–	–	–
Trouts and Salmons						
Oncorhynchus mykiss Rainbow Trout	I	–	–	–	–	–
Topminnows						
Fundulus zebrinus Plains Killifish	I	3	0.90	[d]	3	5.36
Livebearers						
Gambusia affinis Western Mosquitofish	I	1	0.30	[d]	1	1.79
Temperate Basses						
Morone saxatilis Striped Bass	I	–	–	–	–	–
TOTAL		**335**				

[a] N=native, I=introduced
[b] CPUE=catch-per-unit effort; mean value based on n specimens/total area sampled by month (2,136 m^2)
[c] Frequency and percent frequency of occurrence are based on n=56 GRTS sample segments
[d] Value is <0.05

Appendix F.7. Age-1+ fish captured during the 09–16 August 2022 survey.

SPECIES COMMON NAME	RESIDENCE STATUS[a]	NUMBER OF SPECIMENS	PERCENT OF TOTAL	MEAN CPUE[b]	FREQUENCY OF OCCURRENCE[c]	PERCENT FREQUENCY OF OCCURRENCE[c]
Carps and Minnows						
Cyprinella lutrensis Red Shiner	I	3	1.28	[d]	3	5.36
Cyprinus carpio Common Carp	I	–	–	–	–	–
Gila cypha Humpback Chub	N	68	28.94	[d]	22	39.29
Pimephales promelas Fathead Minnow	I	2	0.85	[d]	2	3.57
Rhinichthys osculus Speckled Dace	N	141	60.00	0.08	32	57.14
Suckers						
Catostomus discobolus Bluehead Sucker	N	1	0.43	[d]	1	1.79
Catostomus latipinnis Flannelmouth Sucker	N	4	1.70	[d]	3	5.36
Xyrauchen texanus Razorback Sucker	N	–	–	–	–	–
Catostomidae (Unidentified Sucker)[e]	N	–	–	–	–	–
Trouts and Salmons						
Oncorhynchus mykiss Rainbow Trout	I	13	5.53	[d]	6	10.71
Topminnows						
Fundulus zebrinus Plains Killifish	I	3	1.28	[d]	2	3.57
Livebearers						
Gambusia affinis Western Mosquitofish	I	–	–	–	–	–
Temperate Basses						
Morone saxatilis Striped Bass	I	–	–	–	–	–
TOTAL		**235**				

[a] N=native, I=introduced
[b] CPUE=catch-per-unit effort; mean value based on n specimens/total area sampled by month (1,831 m^2)
[c] Frequency and percent frequency of occurrence are based on n=56 GRTS sample segments
[d] Value is <0.05

APPENDIX G: RAZORBACK SUCKER MOVEMENTS WITHIN LAKE MEAD AND THE COLORADO RIVER, 2010–2022

STUDY YEAR[a]	FISH CODE	GENERAL LOCATION[b]	DATE[c]	LOCATION DETAILED
2010	227	GB	Feb-10	Released near Scanlon Bay in Gregg Basin
		CRI	Jun-10	Near CRI, and river below PFR[d]
	267	GB	Feb-10	Released near Scanlon Bay in Gregg Basin
		CRI	Feb-10	Near CRI
	348	GB	Feb-10	Released near Scanlon Bay in Gregg Basin
		CRI	May-10	Near CRI, and river below PFR
	357	GB	Feb-10	Released near Scanlon Bay in Gregg Basin
		CRI	May-10	Near CRI, and river below PFR
	3354	MR/VR	Feb-09	Overton Arm
		CRI	Apr-10	Near CRI, and river below PFR
		GB	May-10	Gregg Basin
	465	LVB	Dec-08	Released near Las Vegas Wash
		CRI	May-10	Near CRI
2011	3354	CRI	Oct-10	Near CRI
		EB	Nov-10	Echo Bay
		MR/VR	Apr-11	Overton Arm
2012	3774	CRI	Jan-12	Near CRI
		River	Feb-12	Below PFR
		CRI	May-12	Near CRI
		LGC	May-12	Near Bat Cave and Quartermaster Canyon
		CRI	Dec-12	Near CRI
	5578	CRI	Jan-12	Near CRI
		River	Mar-12	Below PFR
		CRI	Nov-12	Near CRI
	5767	CRI	Jan-12	Near CRI
		River	Feb-12	Below PFR
		CRI	Mar-12	Near CRI
		River	Apr-12	Below PFR
		LGC	May-12	Bat Cave
		CRI	May-12	Near CRI
	6678	CRI	Dec-11	Near CRI
		River	Feb-12	Below PFR
		CRI	Feb-12	Near CRI
	227	CRI	Jul-11	Near CRI
		River	Feb-12	Below PFR
		CRI	Dec-12	Near CRI
	267	CRI	Jul-11	Near CRI
		River	Jan-12	Below PFR
	357	CRI	May-10	Near CRI

STUDY YEAR[a]	FISH CODE	GENERAL LOCATION[b]	DATE[c]	LOCATION DETAILED
	3355	LVB	Apr-12	Near Las Vegas Wash
		LVB	Aug-09	Near Las Vegas Wash
		CRI	Aug-11	Near CRI
	249	River	Jul-11	Below PFR
		LGC	Apr-12	Near Bat Cave
		CRI	Dec-12	Near CRI
	447	CRI	Jul-11	Near CRI
		River	Mar-12	Below PFR
		CRI	May-12	Near CRI
	485	CRI	Jul-11	Near CRI
		River	Feb-12	Below PFR
		LGC	May-12	Near Bat Cave and Quartermaster Canyon
		CRI	Sep-12	Near CRI
		River	Dec-12	Below PFR
		CRI	Aug-11	Near CRI
	3546	GB	Sep-11	Near GB
		CRI	Jan-12	Near CRI
		River	Jan-12	Below PFR
		CRI	Dec-12	Near CRI
2013	227	CRI	Jan-13	Near CRI
		LGC	May-13	Near Spencer Creek
	249	CRI	Feb-13	Near CRI
		LGC	May-13	Near Bat Cave and Spencer Creek
	3774	CRI	Jan-13	Near CRI
		LGC	Apr-13	Near Bat Cave and Spencer Creek
	367	CRI	Mar-13	Near CRI
		River	Mar-13	Below PFR
		GB	May-13	Southern Gregg Basin
	485	River	Feb-13	Below PFR
		CRI	Apr-13	Near CRI
	3546	CRI	Feb-13	Near CRI
		River	Feb-13	Below PFR
		CRI	Feb-13	Near CRI
		LGC	Apr-13	Near Bat Cave
	5578	CRI	Feb-13	Near CRI
		River	Feb-13	Below PFR
		CRI	Apr-13	Near CRI
2014	468	CRI	Feb-14	Near CRI
		MR/VR	Aug-14	Overton Arm

STUDY YEAR[a]	FISH CODE	GENERAL LOCATION[b]	DATE[c]	LOCATION DETAILED
	4455	LGC	Oct-13	Near Columbine Falls and Separation Canyon
		CRI	Jan-14	Near CRI
		LGC	Feb-14	Near Separation Canyon
		CRI	May-14	Near CRI
	3338	LGC	Apr-13	Near river mile 243
		River	May-14	Below PFR
	3774	LGC	Jul-13	Near Quartermaster Canyon
		CRI	Jan-14	Near CRI
		LGC	May-14	Near Spencer and Salt Creek
	227	CRI	Sep-13	Near CRI
		LGC	Apr-14	Near Spencer Creek
	267	River	Jan-12	Below PFR
		LGC	Jul-14	Just above Whitmore
2015	468	MR/VR	Oct-14	Overton Arm
		CRI	Nov-14	Near CRI
		LVB	Feb-15	Near Las Vegas Wash
	3547	CRI	Jun-14	Near CRI
		MR/VR	Nov-14	Overton Arm
	467	LGC	Apr-14	Just below Lava Falls
		CRI	Oct-15	Near CRI
	3028	EB	Aug-14	Echo Bay
		CRI	Apr-15	Near CRI
	3747	LGC	Mar-15	Near Spencer Creek, Salt Creek, and Separation Canyon
		CRI	Apr-15	Near CRI
2016	3375	CRI	Sep-16	Near CRI
		EB	Dec-16	Echo Bay
	3076	LGC	Feb-16	Released near Diamond Creek
		CRI	Aug-16	Near CRI
2017	4455	River	Jan-17	Below PFR
		CRI	Feb-17	Near CRI
	3446	River	Mar-17	Below PFR
		CRI	Jun-17	Near CRI
2018	5777	CRI	Jun-17	Near CRI
		River	Mar-18	Below PFR
	3567	CRI	Mar-18	Near CRI
		River	Mar-18	Below PFR
		CRI	Apr-18	Near CRI
		River	May-18	Below PFR

STUDY YEAR[a]	FISH CODE	GENERAL LOCATION[b]	DATE[c]	LOCATION DETAILED
	3076	CRI	Feb-18	Near CRI
		River	Feb-18	Below PFR
		CRI	Jun-18	Near CRI
	3548	CRI	Apr-18	Near CRI
		River	Apr-18	Below PFR
		CRI	Jun-18	Near CRI
	3466	CRI	Mar-18	Near CRI
		River	Apr-18	Below PFR
		CRI	Jun-18	Near CRI
	3421	LGC	Feb-18	Released at Bright Angel Creek
		CRI	Apr-18	Near CRI
2019	3071	LGC	May-18	Near river mile 243
		CRI	Sep-19	Near CRI
	4555	LGC	Sep-18	Near river mile 243
		GB	May-19	Southern Gregg Basin
2020	No movement documented			
2021	3367	CRI	Feb-20	Near CRI
		LGC	Jul-21	RM 127.5
	3585	LVB	Feb-18	Las Vegas Bay
		LGC	Apr-21	RM 107.5
2022	4556	CRI	15-Mar	No movement documented

[a] Reporting year (Albrecht et al. 2010a, Kegerries and Albrecht 2011, Kegerries and Albrecht 2013a, Kegerries and Albrecht 2013b, Albrecht et al. 2014a, Kegerries et al. 2015a, Kegerries et al. 2016a, Kegerries et al. 2017a, Kegerries et al. 2018, Kegerries et al. 2019)
[b] GB=Gregg Basin, CRI=Colorado River Inflow Area, MR/VR=Muddy River/Virgin River inflow area, LVB=Las Vegas Bay, EB=Echo Bay, River=between CRI and Pearce Ferry Rapid, LGC=Lower Grand Canyon
[c] Date of last contact at general location
[d] PFR=Pearce Ferry Rapid