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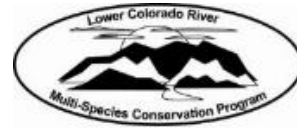
**Razorback Sucker *Xyrauchen texanus*
Research and Monitoring in the Colorado River
Inflow Area of Lake Mead and the Lower Grand
Canyon, Arizona and Nevada
2023 FINAL ANNUAL REPORT**



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



— BUREAU OF —
RECLAMATION



**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**

2023 FINAL ANNUAL REPORT

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COVER PHOTO DESCRIPTIONS

Colorado River Inflow area of Lake Mead, at sunset, March 2023 (credit: B. Albrecht, BIO-WEST, Inc.).

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RECOMMENDED CITATION

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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 (river mile 179) 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 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, particularly early in the study. 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 2023 field season. Data stemming from the CRI are presented in Chapter 1. Results from small-bodied and larval-fish community sampling conducted within Grand Canyon in 2023 are presented in Chapter 2. Lastly, Chapter 3 presents holistic findings from sonic-telemetry efforts which demonstrates the interconnectedness between the lake and the river. These three chapters provide evidence of Razorback Sucker interaction between and among the study areas. While this report presents new information pertaining to the status of Razorback Sucker in Grand Canyon and the CRI, the value of this multiyear study investigates the relationship between the river and Lake Mead, which was recommended by an independent science panel that reviewed project findings to date (Reclamation 2017; Pennock et al. 2022).

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 nearly 500 trammel net-hours at the CRI in 2023, 5 Razorback Suckers, 109 Flannelmouth Suckers, and 12 hybrid suckers (Razorback Sucker x Flannelmouth Suckers) were captured.

Using sonic-tagged fish locations and previous knowledge of potential spawning areas to guide sampling for catostomid larvae during the 2023 spawning period (February–May), 27 larval Razorback Suckers from the CRI were captured.

Since 2010, 199 Razorback Suckers, 1,552 Flannelmouth Suckers, and 137 Razorback Sucker × Flannelmouth Sucker hybrids have been captured via trammel netting. Additionally, 849 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 2023. Additionally, in the Grand Canyon, 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. In 2023, one wild male Razorback Sucker was implanted with a sonic tag. No sonic fish were released in 2023. 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 2023 and continued through September 2023. Larval-fish collection began in March and concluded in August; while small-bodied fish community sampling began in April and concluded in September. Sampling in Grand Canyon in 2023 resulted in the capture of 4 native and 12 nonnative fish species, as well as documentation of young-of-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 2023.

Juvenile and adult Humpback Chub were captured during small-bodied fish sampling throughout Grand Canyon. The first individuals were captured in April 2023, and the species' relative abundance appeared highest in September, 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.

For the ninth consecutive year, systematic larval fish sampling has documented magnitude and duration of reproduction for the fish community throughout the lower Colorado River within the Grand Canyon. In addition to monitoring shifts in fish assemblages, larval fish surveys provide insight into the spatial and temporal occurrence of native and nonnative fish species, as well as the relative success of reproductive output and subsequent recruitment. Larval sampling effort in 2023 encompassed 11,282.3 m² of habitat and produced a total of 10,163 age-0 fishes, representing five families and 13 species. This survey documented the continued dominance of native species in the study area, as 95% of age-0 fishes collected in 2023 were native species endemic to the Colorado River.

Larval fish sampling verified Razorback Sucker spawning and larval production in the Colorado River within Grand Canyon National Park for the first 6 years of the project (2014–2019). In 2019, eight larval Razorback Sucker were captured during April and May and distributed from RM 127.3 to RM 279.0. The May 2019 capture of one Razorback Sucker at RM 127.3 was the farthest upstream that Razorback Sucker larvae had 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 RM farther 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 Sucker were collected in May (n=7). The number of larval Razorback Sucker taken per sampling year has declined since 2014 (2014=462, 2015=81, 2016=46, 2017=27, 2018=10, 2019=8) despite relatively consistent sampling effort since then. 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 the National Park closure during the SARS-CoV-2 pandemic), which are the two most productive months for collection of these larval fish. From 2014 through 2019, the April and May monthly surveys collectively yielded over 90% of the larval Razorback Sucker collected from Grand Canyon. From 2021 to 2023, six annual larval fish surveys occurred (March–August); however, no Razorback Sucker larvae were positively identified from these collections.

The larval Razorback Sucker collected during 2014–2019 were represented by two ontogenetic phases (protolarvae and mesolarvae subphases). The developmental stages of these fish combined with their location of capture strongly suggest multiple spawning locations. The range of length-based back-calculated hatch dates in 2019 encompassed a 5-week period from 30 March to 5 May, a shorter spawning season than observed in previous years. These data highlight the importance of April and May sampling to the collection of larval Razorback Sucker in Grand Canyon.

During 2023, age-0 Humpback Chub (n=529) were distributed over 180.3 RM (RM 98.7–279.0). Later than previous Grand Canyon larval fish surveys (2014–2022), age-0 Humpback Chub were first captured during June in 2023. Larval Humpback Chub were captured during three of the six monthly larval fish surveys during 2023 and were represented by multiple ontogenetic phases (flexion mesolarvae, postflexion mesolarvae, and metalarvae). The protolarval phase in Humpback Chub, the earliest ontogenetic phase, is relatively short, and specimens in this developmental stage are rarely collected. Protolarval Humpback Chub were not collected during 2023, and have been collected only between 2018 and 2020. We documented a trend of increasing abundance and ontogenetic-phase progression with distance downstream in this species. More than half of age-0 Humpback Chub (56.3%) were collected downstream of RM 186.6 during 2023. Back-calculated hatch dates indicate Humpback Chub hatching began in early May and continued through early August. Spanning 10 weeks, the distribution of hatch dates suggests two primary peaks occurred, with the majority hatching in late May and a final peak in occurring in late June.

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 high abundance; (4) sonic-tagged Razorback Sucker (stocked and wild) utilize both the CRI and Grand Canyon; and (5) native fish dominate the fish community in Grand Canyon and are under constant threat from nonnative fishes.

Within the study period (2014–2023), 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.

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CONTENTS

| | |
|--|----|
| GENERAL INTRODUCTION AND BACKGROUND | 1 |
| CHAPTER 1: RAZORBACK SUCKER MONITORING AT THE COLORADO RIVER INFLOW AREA OF LAKE MEAD (CRI)..... | 7 |
| INTRODUCTION | 7 |
| STUDY AREA..... | 7 |
| METHODS..... | 9 |
| Reservoir Elevation | 9 |
| Adult Studies | 9 |
| Trammel Netting | 9 |
| Length and Growth | 9 |
| Larval Sampling..... | 10 |
| Spawning-Site Identification | 11 |
| Age Determination..... | 11 |
| Population and Annual Apparent Survival Estimation | 12 |
| Supplemental Efforts | 12 |
| Colorado River Proper | 12 |
| Bonelli Bay Investigations | 13 |
| RESULTS | 13 |
| Reservoir Elevation | 13 |
| Adult Studies | 14 |
| Trammel Netting | 14 |
| Length and Growth Information..... | 17 |
| Larval Sampling..... | 18 |
| Spawning-Site Identification and Observations..... | 19 |
| Razorback Sucker Aging | 20 |
| Supplemental Efforts | 20 |
| Colorado River Proper (below Pearce Ferry Rapid to Colorado River Inflow Area of Lake Mead [CRI]) | 20 |
| Bonelli Bay Investigations | 20 |
| DISCUSSION AND CONCLUSIONS | 24 |
| Adult Studies and Spawning-Related Observations..... | 24 |
| Larval Sampling..... | 25 |
| Growth and Aging..... | 26 |
| Future Considerations | 27 |
| 2023–2024 COLORADO RIVER INFLOW AREA OF LAKE MEAD (CRI) STUDY RECOMMENDATIONS..... | 28 |

| | |
|---|-----------|
| CHAPTER 2: SMALL-BODIED AND LARVAL FISH COMMUNITY SAMPLING WITHIN GRAND CANYON | 31 |
| INTRODUCTION | 31 |
| STUDY AREA | 31 |
| METHODS | 32 |
| Discharge | 32 |
| Small-bodied Fish Community Sampling | 33 |
| Larval-Fish Community Sampling | 36 |
| RESULTS | 39 |
| 2023 Discharge | 39 |
| Small-Bodied Fish Community Sampling | 40 |
| Catch Rates | 41 |
| Habitat | 45 |
| Habitat and Catch Rates per Habitat Sampled 2023 | 48 |
| Fish Community Composition 2014–2023 | 49 |
| Larval-Fish Community Sampling | 50 |
| 2023 Sampling | 50 |
| Ontogenetic Phase Distributions | 66 |
| Supplemental Investigations of Larval Fish Community Sampling (2014–2023) | 70 |
| Larval Fish Community Sampling Summary (2014–2023) | 72 |
| DISCUSSION | 74 |
| Small-bodied Fish Community Sampling | 74 |
| Larval-Fish Community Sampling | 77 |
| GRAND CANYON SMALL-BODIED AND LARVAL FISH COMMUNITY STUDY RECOMMENDATIONS | 81 |
| CHAPTER 3: TELEMETRY WITHIN THE COLORADO RIVER INFLOW AREA OF LAKE MEAD (CRI) AND GRAND CANYON | 84 |
| INTRODUCTION | 84 |
| STUDY AREA | 84 |
| METHODS | 84 |
| Active Sonic Telemetry and Tracking | 84 |
| Passive Sonic Telemetry and Data Collection | 89 |
| Radio Telemetry | 89 |
| RESULTS | 90 |
| 2022–2023 Telemetry | 90 |
| HISTORICAL MOVEMENTS, 2014–2023 | 92 |

DISCUSSION.....95
 2022–2023 Telemetry.....95

HISTORICAL MOVEMENT, 2014–202296

CONCLUSION98

2023–2024 TELEMETRY STUDY RECOMMENDATIONS98

CONCLUSIONS AND FUTURE CONSIDERATIONS99

REFERENCES104

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), 2023

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

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, 2023

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, 2023

APPENDIX E: AGE-0 FISH CAPTURED BY TRIP AT GENERALIZED RANDOM
 TESSELLATION STRATIFIED (GRTS) SEGMENTS DURING LARVAL-
 FISH COMMUNITY SAMPLING IN THE GRAND CANYON, 2023

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, 2023

APPENDIX G: RAZORBACK SUCKER MOVEMENTS WITHIN LAKE MEAD
 AND THE COLORADO RIVER, 2010–2023

Figures

| | | |
|-------------|---|----|
| 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. | 8 |
| Figure 1.2. | Lake Mead month-end elevations (Reclamation 2023) in meters above mean sea level from February 1935 to June 2023 with projected elevations in red. | 13 |
| Figure 1.3. | Trammel-netting locations and numbers of fishes captured in the Colorado River Inflow Area of Lake Mead (CRI), February–May 2023. | 15 |
| Figure 1.4. | Trammel-netting catch-per-unit effort (CPUE) expressed as the mean $\ln(1+(\#Razorback\ Sucker/net-hour)) (\pm SE)$ values from the Colorado River Inflow Area of Lake Mead (CRI) and long-term monitoring (LTM) sites throughout Lake Mead, 2005–2023. | 16 |
| Figure 1.5. | Length-frequency (mm total length) distributions for Razorback Suckers captured at the Colorado River Inflow Area of Lake Mead (CRI) in 2023 (red bars) and combined from 2010 to 2023 (gray bars). | 17 |
| Figure 1.6. | Larval Razorback Sucker sample and capture locations in the Colorado River Inflow Area of Lake Mead (CRI), 2023. | 18 |
| Figure 1.7. | Larval Razorback Sucker mean catch-per-unit effort (CPUE) ($\ln(1+(\text{number larvae/light-minute sampled})) (\pm SE)$) comparisons by primary sampling location on Lake Mead for 2007–2023. | 19 |
| Figure 1.8. | Lake Mead hydrograph from January 1935 to June 2023, with the number of aged Razorback Suckers spawned each year through 2020. | 22 |
| Figure 1.9. | Trammel-netting, larval fish sampling, and telemetry contact locations for Razorback Sucker in Bonelli Bay in Lake Mead, January–May 2023. | 23 |
| 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 2023 (some GRTS segments are adjoining). | 32 |
| 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, 2022, through September 30, 2023, recorded at the USGS gage above Diamond Creek (#09404200). | 39 |
| Figure 2.3. | Mean native and nonnative fish catch-per-unit effort (CPUE) ($\ln(1+(\#/m^2))$) by sampling trip for 2014–2023. | 42 |
| Figure 2.4. | Mean native and nonnative fish catch-per-unit effort (CPUE) ($\ln(1+(\#/m^2))$) by sampling year for 2014–2023. | 43 |

| | | |
|--------------|---|----|
| 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)..... | 44 |
| Figure 2.6. | Mean native fish catch-per-unit effort (CPUE) ($\ln(1+(\#/m^2))$) by sampling trip separated according to species in 2023. | 45 |
| 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, 2016–2023..... | 46 |
| Figure 2.8. | Frequency distribution of habitat, substrate, and cover present for samples at generalized random tessellation stratified (GRTS) segments during the 2023 small-bodied fish survey. | 47 |
| Figure 2.9. | Catch-per-unit effort (CPUE) in the habitats sampled in the generalized random tessellation stratified (GRTS) Grand Canyon (RM 89.5–279.9) segments in 2023..... | 48 |
| 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 2014–2023..... | 49 |
| Figure 2.11. | Colorado River discharge upstream of Diamond Creek (USGS gage 09404200), water temperatures during 2023 from Lee’s Ferry (USGS gage 09380000, RM 0), Havasu Creek above confluence (USGS gage 09404115, near RM 157.3), and three mainstem Colorado River water temperature loggers (RM 108.2, RM 200.4, and RM 260.9)..... | 51 |
| Figure 2.12. | Mean catch-per-unit effort (CPUE) of age-0 native fishes by sampling trip (month) during the 2023 larval fish survey..... | 52 |
| Figure 2.13. | Mean catch-per-unit effort (CPUE) of age-0 Bluehead Sucker by 2023 sampling trip (month) and generalized random tessellation stratified (GRTS) segment..... | 54 |
| Figure 2.14. | Mean catch-per-unit effort (CPUE) of age-0 Flannelmouth Sucker by 2023 sampling trip (month) and generalized random tessellation stratified (GRTS) segment..... | 55 |
| Figure 2.15. | Mean catch-per-unit effort (CPUE) of age-0 Razorback Sucker by 2023 sampling trip (month) and generalized random tessellation stratified (GRTS) segment..... | 55 |
| Figure 2.16. | Mean catch-per-unit effort (CPUE) of age-0 Humpback Chub by 2023 sampling trip (month) and generalized random tessellation stratified (GRTS) segment..... | 56 |
| Figure 2.17. | Mean catch-per-unit effort (CPUE) of age-0 Speckled Dace by 2023 sampling trip (month) and generalized random tessellation stratified (GRTS) segment..... | 56 |

| | | |
|--------------|--|----|
| Figure 2.18. | Mean catch-per-unit effort (CPUE) of age-0 native and nonnative fishes by generalized random tessellation stratified (GRTS) segment for 2023 survey months (March–August) combined. | 58 |
| Figure 2.19. | Frequency of occurrence of larval Razorback Sucker at generalized random tessellation stratified (GRTS) segments during the 2023 larval fish survey. | 60 |
| Figure 2.20. | Distribution of total lengths (TL) of larval Razorback Sucker during the 2023 larval fish survey. | 60 |
| Figure 2.21. | Spatial and ontogenetic stage distribution of larval Razorback Sucker during the 2023 larval fish survey..... | 61 |
| Figure 2.22. | Water temperature of Havasu Creek (USGS gauge 0940115) and the Colorado River near Diamond Creek (RM 229.6) displayed with the back-calculated hatch dates of Razorback Sucker based on 2023 larval fish standard length (SL)..... | 61 |
| Figure 2.23. | Frequency of occurrence of larval Humpback Chub at generalized random tessellation stratified (GRTS) segments during the 2023 larval fish survey. | 62 |
| Figure 2.24. | Distribution of total lengths (TL) of age-0 Humpback Chub captured during the 2023 larval fish survey..... | 63 |
| Figure 2.25. | Spatial and ontogenetic stage distribution of Humpback Chub captured during the 2023 larval fish survey..... | 63 |
| Figure 2.26. | Back-calculated hatch dates of 2023 larval Humpback Chub based on standard lengths (mm). | 64 |
| Figure 2.27. | Distribution of habitats sampled at generalized random tessellation stratified (GRTS) segments during the 2023 larval fish survey. | 65 |
| Figure 2.28. | Mean catch-per-unit effort (CPUE) by species and habitat type during the 2023 larval fish survey. | 67 |
| Figure 2.29. | Longitudinal distribution of ontogenetic phases for age-0 Flannelmouth Sucker by 2023 sampling trip (month) and generalized random tessellation stratified (GRTS) segment. | 68 |
| Figure 2.30. | Longitudinal distribution of ontogenetic phases for age-0 Bluehead Sucker by 2023 sampling trip (month) and generalized random tessellation stratified (GRTS) segment..... | 69 |
| Figure 2.31. | Longitudinal distribution of ontogenetic phases for age-0 Humpback Chub by 2023 sampling trip (month) and generalized random tessellation stratified (GRTS) segment..... | 71 |
| Figure 2.32. | Mean catch-per-unit effort (CPUE) of age-0 native fishes by year (2014–2023). | 73 |
| Figure 2.33. | Annual mean catch-per-unit effort (CPUE) of age-0 catostomids and cyprinids between 2014 and 2023..... | 74 |

| | | |
|--------------|---|----|
| Figure 3.1. | Lake Mead with the distribution of sonic-tagged fish contacts and submersible ultrasonic receiver (SUR) locations. | 85 |
| Figure 3.2a. | General Grand Canyon study area with the distribution of sonic-tagged fish contacts and submersible ultrasonic receiver (SUR) locations. | 86 |
| Figure 3.2b. | General Grand Canyon study area with the distribution of sonic-tagged fish contacts and submersible ultrasonic receiver (SUR) locations. | 87 |
| Figure 3.2c. | General Grand Canyon study area with the distribution of sonic-tagged fish contacts and submersible ultrasonic receiver (SUR) locations. | 88 |
| Figure 3.3. | Upstream and downstream passages through Pearce Ferry Rapid by year, 2014–2023. | 93 |
| Figure 3.4. | Number of directional movements detected by Razorback Sucker in the Colorado River (Grand Canyon) by year, 2014–2023. | 94 |
| Figure 3.5. | Total directional movements (river miles) moved by Razorback Sucker across each year, 2014–2023. | 94 |

Tables

| | | |
|------------|--|----|
| Table 1.1. | Trammel netting effort in the Colorado River Inflow Area of Lake Mead (CRI) during 2023, showing total nets set and net-hours by month. | 14 |
| 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 2023 via trammel nets and electrofishing. | 14 |
| Table 1.3. | Number and catch rate of Razorback Suckers, Flannelmouth Suckers, and hybrid suckers captured from 2010 to 2023. | 16 |
| Table 1.4. | Growth histories of applicable Razorback Sucker recaptured at the Colorado River Inflow Area of Lake Mead (CRI) in 2023. | 17 |
| Table 1.5. | Supplemental sampling between Pearce Ferry Rapid and the Colorado River Inflow Area of Lake Mead (CRI) from March to May 2023. | 21 |
| Table 1.6. | Date, passive integrated transponder (PIT) tag number, size, and status information for Razorback Suckers captured in Bonelli Bay during 2023. | 21 |
| Table 2.1. | Grand Canyon sampling dates and trip purpose, 2023. | 31 |
| Table 2.2. | Mesohabitat definitions for larval and small-bodied fish collections. | 35 |
| Table 2.3. | Substrate (A) and cover (B) codes determined for each seine haul. | 35 |
| Table 2.4. | Additional mesohabitat descriptors determined for each sample (seine haul) in the larval fish surveys. | 37 |

| | | |
|------------|--|----|
| Table 2.5. | Sampling effort from 2023 small-bodied fish surveys. | 40 |
| Table 2.6 | Nonnative fish captures, mean total length, standard error, total length range, and river mile range of capture during the 2023 sampling year. | 41 |
| Table 2.7. | Monthly sampling effort during 2023 larval fish surveys. | 50 |
| Table 2.8. | Habitats sampled (percent) from monthly 2017–2023 larval fish surveys. | 66 |
| 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 2023. | 91 |

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 one 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, 2023a, 2023).

Larval Razorback Suckers were found in the Colorado River Inflow Area of Lake Mead (CRI) during 2000 and 2001, but 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 monitoring efforts in Lake Mead.

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), the *Operation of Glen Canyon Dam Including High-Flow Experiments and Non-Native Fish Control* (USFWS 2011), and most recently the *Biological Opinion for the Glen Canyon Dam Long-Term Experimental and management Plan, Coconino County, Arizona* (USFWS 2016), identified conservation measures to examine the potential for, and suitability of, habitat in the lower Grand Canyon for Razorback Sucker. 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). The most recent Biological Opinion for the *Glen Canyon Dam Long-term Experimental and Management Plan* (USFWS 2016) calls for Reclamation to assist the 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 321.4 m above mean sea level (amsl) by 2023. 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 reservoir and impacts to Razorback Sucker.

Since 2021, the lentic portion of Lake Mead begins just south of 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 and meet water delivery obligations. The historical hydrologic cycle has been replaced with a daily fluctuation of water, which may impact on the survival of the early life-stages of the Colorado River's native fish 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 typically occurs from January through May, 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). Juvenile 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. From 1944 through 1990, 10 adult Razorback Suckers were documented in Grand Canyon from Lee's 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 2023, 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 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, sampling efforts were confined to January–May, and these efforts were similar to the intensive field efforts conducted since 2010. As such, field work in 2014–2023

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 Grand Canyon, 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. (2021b, 2023b). 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; Pennock et al. 2022), and in 2023 the study was continued in both Lake Mead and Grand Canyon.

This report contains information from 2023, the 10th 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 2023, the 14th year of study within the Colorado River Inflow Area (CRI), and the 10th year under the current study objectives. The results presented are based on trammel-netting and larval-fish sampling within Lake Mead and opportunistic sampling within the Colorado River proper (i.e., electrofishing, seines, etc.). Following Kegerries and Albrecht (2013b) and subsequent reports, data for the CRI portions of this project are reported from July 1, 2023, through June 30, 2023. The period of reporting is referred to as the 2023 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. 2023). 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, our hope is that these efforts may also be insightful for all managers of this species basin-wide.

STUDY AREA

The 2023 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.

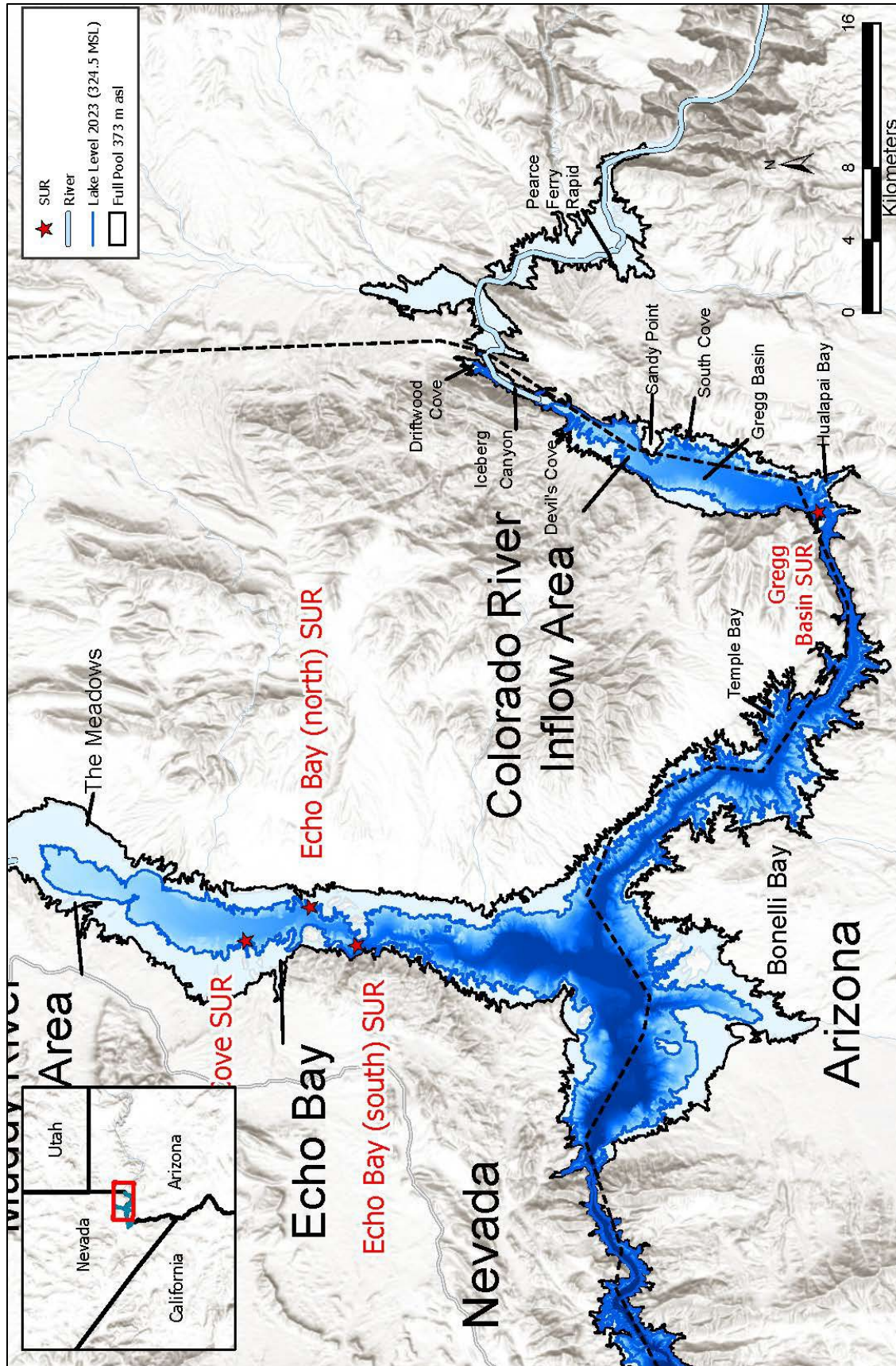


Figure 1.1. General study area and submersible ultrasonic receiver (SUR) location at the Colorado River Inflow Area (CRI) and Bonelli Bay of Lake Mead.

METHODS

Reservoir Elevation

Month-end and projected reservoir elevations (February 1, 1935–June 30, 2023) were reported in meters above mean sea level (amsl) and obtained from Reclamation’s Lower Colorado Regional Office website (Reclamation 2023).

Adult Studies

Trammel Netting

Trammel nets of two sizes were used to sample for adult fish; 91.4 m long by 1.8 m deep and 45.7 m long by 1.8 m deep. Both nets had internal panels of 2.54 centimeters (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. As in previous years, 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 in 2023.

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 to determine annual growth analysis only 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, because they were likely the 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 2023. The lengths of all wild Razorback Sucker captured via trammel netting to date and growth rates for recaptured fish are reported.

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 3–6 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 at the CRI. The larval light-traps were deployed by tying a lead line to vegetation, or the near shore end of a trammel net, 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). A subset of larvae was collected for verification and genetic analysis by 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 [$\ln(\text{CPUE} + 1)$]. 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 2023 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 procedure for identifying spawning sites 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 2023 CRI spawning season efforts involved an emphasis on collecting fin-ray sections from unaged Razorback Suckers and suspected hybrids for aging purposes using this technique.

During the 2023 spawning period, new Razorback Suckers 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, 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 and annual apparent survival was assessed at the reservoir-wide scale and provided in Rogers et al. (2023).

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 Separation Canyon (RM 240) to above Pearce Ferry Rapid and below Pearce Ferry Rapid downstream to the CRI. These efforts were conducted opportunistically, depending on the weekly project goals, weather, 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 collected as a cooperative effort with AZGFD in 2023. 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. 2023) 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. (2023).

RESULTS

Reservoir Elevation

The elevation of Lake Mead has generally declined since 2000 (Figure 1.2). However, during the 2022–2023 sampling season, the reservoir elevation increased approximately 5 m from July 2022 through February 2023, with a peak elevation of 321.9 m above mean sea level by June 2023 (Figure 1.2). During the spawning season (January through April), the reservoir elevation was fairly stable, with a slight increase in elevation (Figure 1.2) (Reclamation 2023).

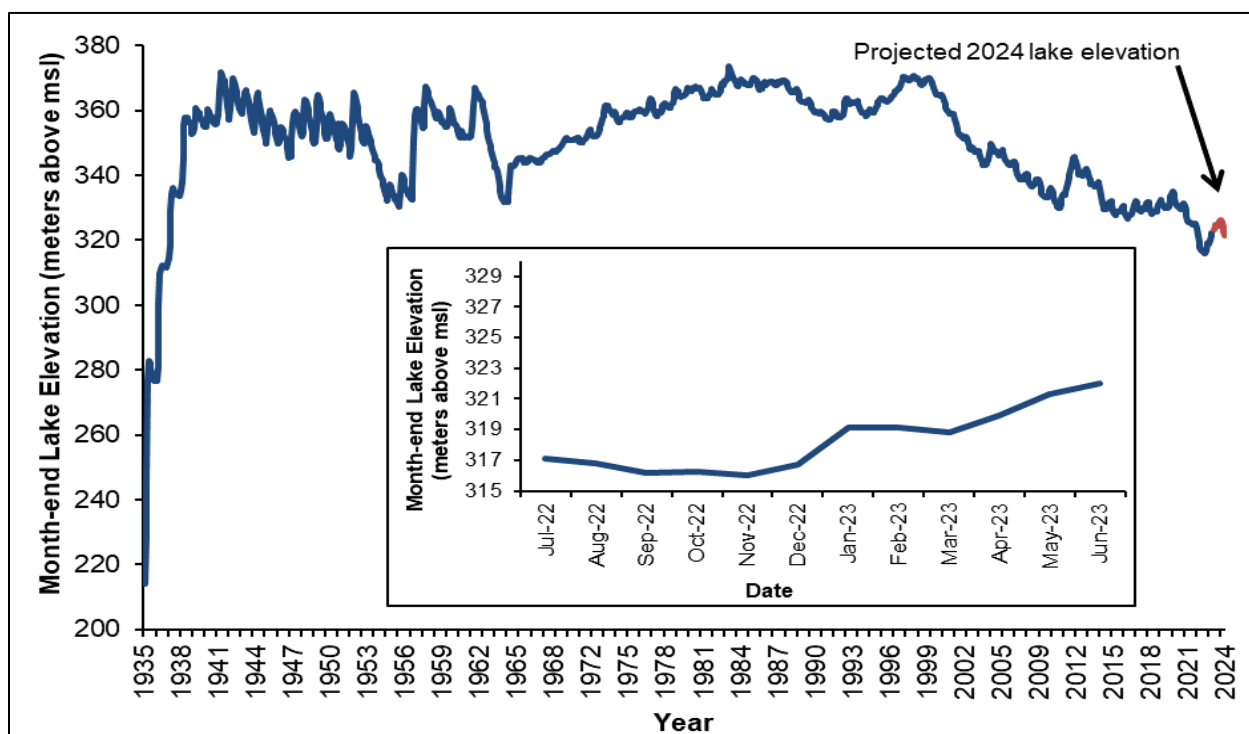


Figure 1.2. Lake Mead month-end elevations (Reclamation 2023) in meters above mean sea level from February 1935 to June 2023 with projected elevations in red. The inset graph depicts reservoir elevations during the study period, (July 2022 to June 2023).

Adult Studies

Trammel Netting

During 2023, 32 nets were set for a total of 498.7 net-hours, which resulted in the capture of five Razorback Suckers (Table 1.1). Netting was generally concentrated near the CRI, and more specifically, off the western shore south of Sandy Point because of the detection of sonic-tagged Razorback Suckers in that area (Figure 1.3 and Table 1.2). All five of the Razorback Suckers were captured off the western shoreline approximately 2 km south of South Point, where the river came into the reservoir (Figure 1.3).

Table 1.1. Trammel netting effort in the Colorado River Inflow Area of Lake Mead (CRI) during 2023, showing total nets set and net-hours by month.

| MONTH | TOTAL NET SETS | TOTAL NET-HOURS |
|--------------|----------------|-----------------|
| February | 8 | 137.2 |
| March | 12 | 194.9 |
| April | 10 | 140.9 |
| May | 2 | 25.7 |
| TOTAL | 32 | 498.7 |

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 2023 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 | Origin |
|-----------|----------------------|----------------|------------|---------------------------|--------------------|----------------------|----------------------|----------------------|---------------------|------------------|--------|
| 2/11/2023 | RZ | 3DD.003BE66285 | NO | 2/11/2023 | No | 631 | 570 | 513 | 2778 | F | Wild |
| 3/7/2023 | RZ | 3DD.003D4CBEA9 | NO | 2/17/2021 | Yes | 592 | 544 | 500 | 2490 | M | Wild |
| 3/7/2023 | RZ | 3DD.003D4CC76D | NO | 3/7/2023 | No | 590 | 550 | 512 | 2368 | M | Wild |
| 3/7/2023 | RZ | 3DD.003D4CC777 | NO | 3/7/2023 | No | 681 | 636 | 592 | 3488 | F | Wild |
| 4/20/2023 | RZ | 3DD.003C06F100 | NO | 4/9/2020 | Yes | 560 | 528 | 490 | 1912 | M | Wild |
| 3/7/2023 | HYB | 3DD.003BA20A1B | NO | 2/15/2017 | Yes | 581 | 539 | 500 | 1918 | F | Wild |
| 3/7/2023 | HYB | 3DD.003BA20A60 | NO | 2/13/2019 | Yes | 506 | 468 | 430 | 1250 | M | Wild |
| 3/7/2023 | HYB | 3DD.003BA2FAB4 | NO | 3/17/2016 | Yes | 518 | 483 | 452 | 1474 | M | Wild |
| 3/7/2023 | HYB | 3DD.003D4CC794 | NO | 3/7/2023 | No | 504 | 488 | 453 | 1268 | U | Wild |
| 3/23/2023 | HYB | 3DD.003BA20A60 | NO | 2/13/2019 | Yes | 510 | 462 | 431 | 1213 | U | Wild |
| 4/6/2023 | HYB | 3DD.003BE66276 | NO | 4/6/2023 | No | 297 | 270 | 244 | 258 | I | Wild |
| 4/11/2023 | HYB | 3DD.003BA20A79 | NO | 3/21/2017 | Yes | 549 | 511 | 476 | 1834 | F | Wild |
| 4/20/2023 | HYB | 3DD.003BA05282 | NO | 4/20/2023 | No | 541 | 509 | 465 | 1469 | U | Wild |

^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.

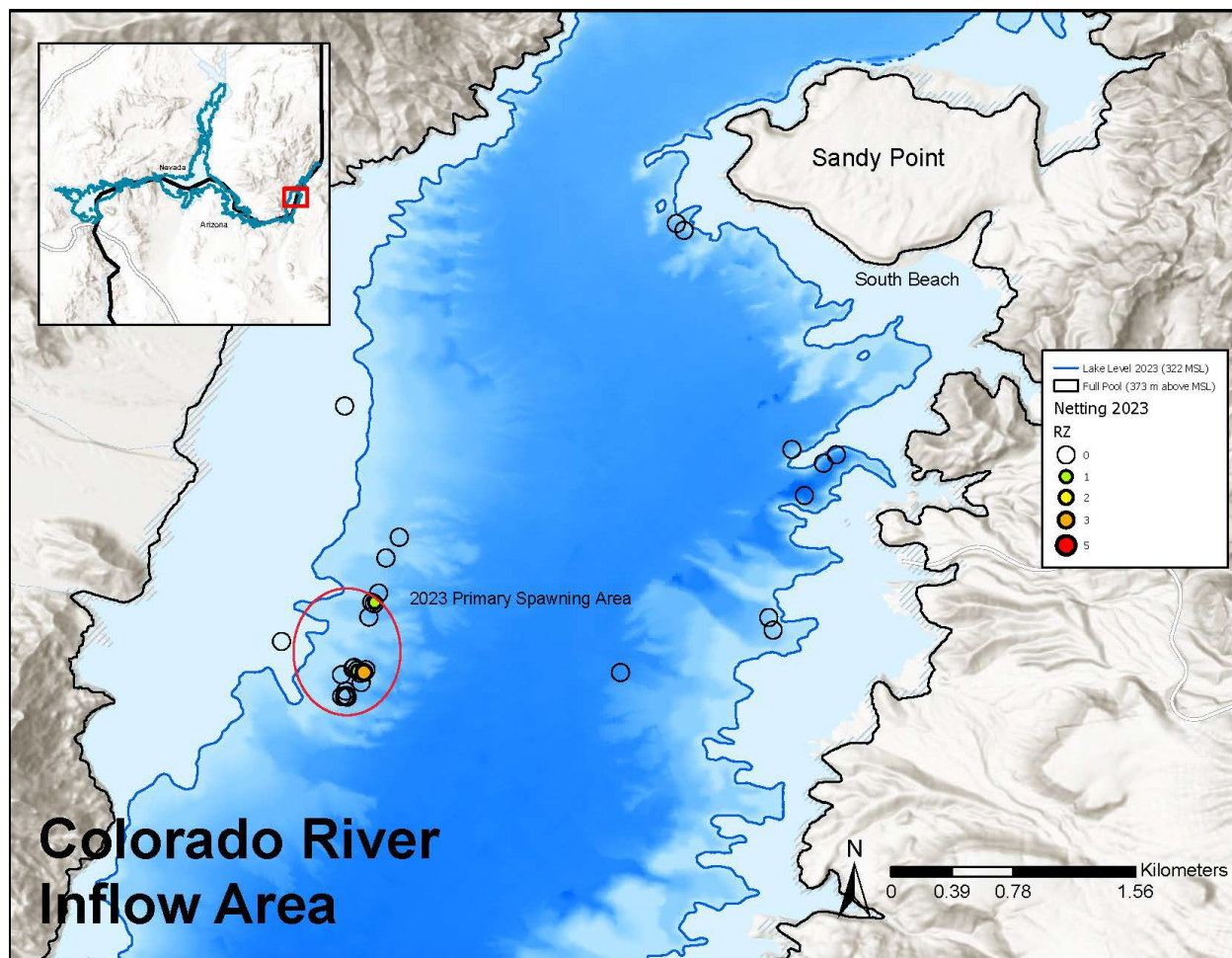


Figure 1.3. Trammel-netting locations and numbers of fishes captured in the Colorado River Inflow Area of Lake Mead (CRI), February–May 2023. Please note that the reservoir elevation increased rapidly during the sampling year. Consequently, the maps were created using the peak elevation for the sampling season, which may result in the appearance of sampling locations slightly off the shoreline.

The Razorback Sucker catch rate at the CRI in 2023 was 0.010 (SE±0.006) fish per net-hour (Table 1.3 and Figure 1.4), falling within the historical catch rate of the project. A significant difference in mean annual catch rates was detected (ANOVA, $F_{13,1259}=5.35$, $P<0.0001$), and Tukey's HSD determined that catch rates in 2023 were statistically lower compared to that of 2021 (Figure 1.4).

To date, a total of 1,552 Flannemouth Suckers have been captured in trammel nets at the CRI. In 2023, 109 Flannemouth Suckers were captured with trammel nets (Appendix A), resulting in a mean catch rate of 0.183 (SE±0.033) (Table 1.3). One Flannemouth Sucker was not measured due to handling stress (Appendix A). Five Flannemouth Suckers were captured via electrofishing in 2023 (Appendix A). While no Bluehead Suckers *Catostomus discobolus* were captured at the CRI in 2023, four Bluehead Suckers have been captured at the CRI since 2010. Lastly, 12 hybrid suckers were captured in 2023, resulting in a mean catch rate of 0.024 (SE±0.010) (Table 1.3).

Table 1.3. Number and catch rate of Razorback Suckers, Flannelmouth Suckers, and hybrid suckers captured from 2010 to 2023.

| 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) |
| 2023 | 1 | 0.001 (0.001) | 69 | 0.145 (0.051) | 0 | 0 |
| 2023 | 5 | 0.010 (0.006) | 109 | 0.183 (0.033) | 12 | 0.024 (0.010) |

^a Catch-per-unit effort (CPUE) expressed as mean $\ln(1+(\text{number}/\text{net-hour}))$.

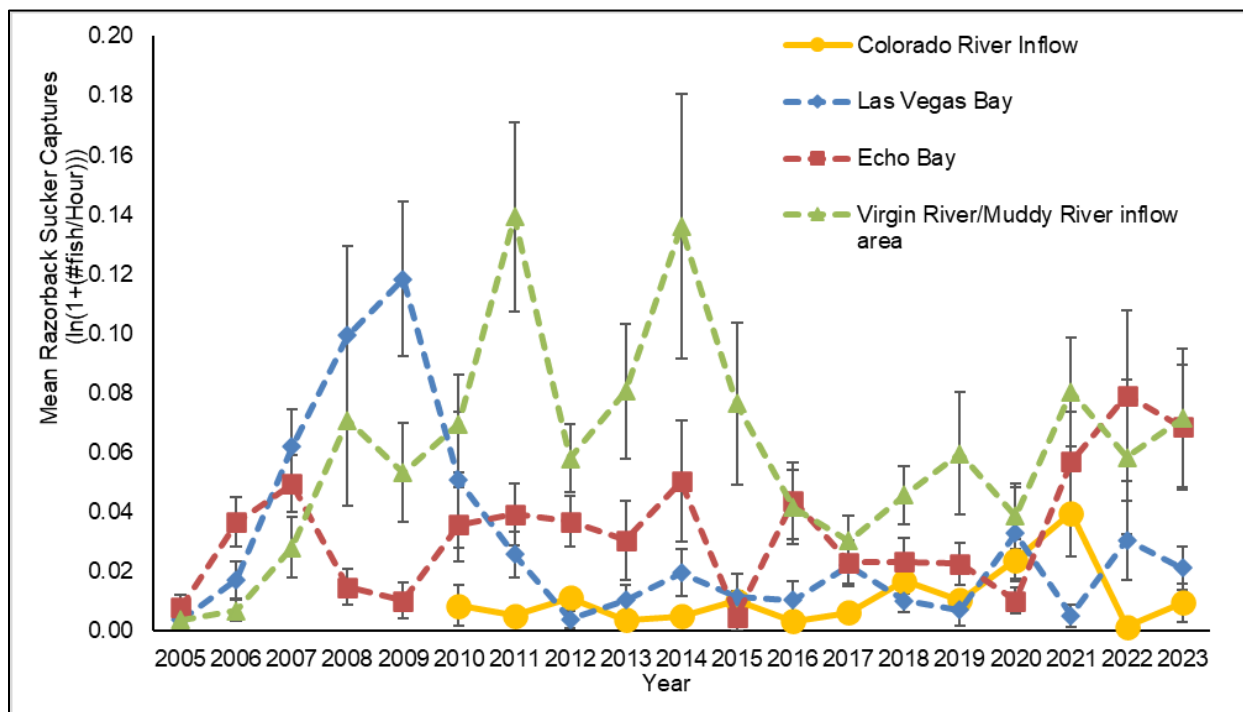


Figure 1.4. Trammel-netting catch-per-unit effort (CPUE) expressed as the mean $\ln(1+(\text{#Razorback Sucker}/\text{net-hour})) (\pm\text{SE})$ values from the Colorado River Inflow Area of Lake Mead (CRI) and long-term monitoring (LTM) sites throughout Lake Mead, 2005–2023.

Length and Growth Information

The Razorback Suckers captured in trammel nets in 2023 ranged in size from 560 to 681 mm (TL) with a mean TL of 610.8 (SE±20.9) (Figure 1.5). The annual growth rate, which was calculated using two recaptured Razorback Suckers, was 11.6 mm per year (SE±6.7) (Table 1.4). Flannelmouth Suckers captured in 2023 at the CRI ranged in size from 236 to 543 mm (TL) with a mean TL of 422.2 mm (SE±5.7) (Appendix A).

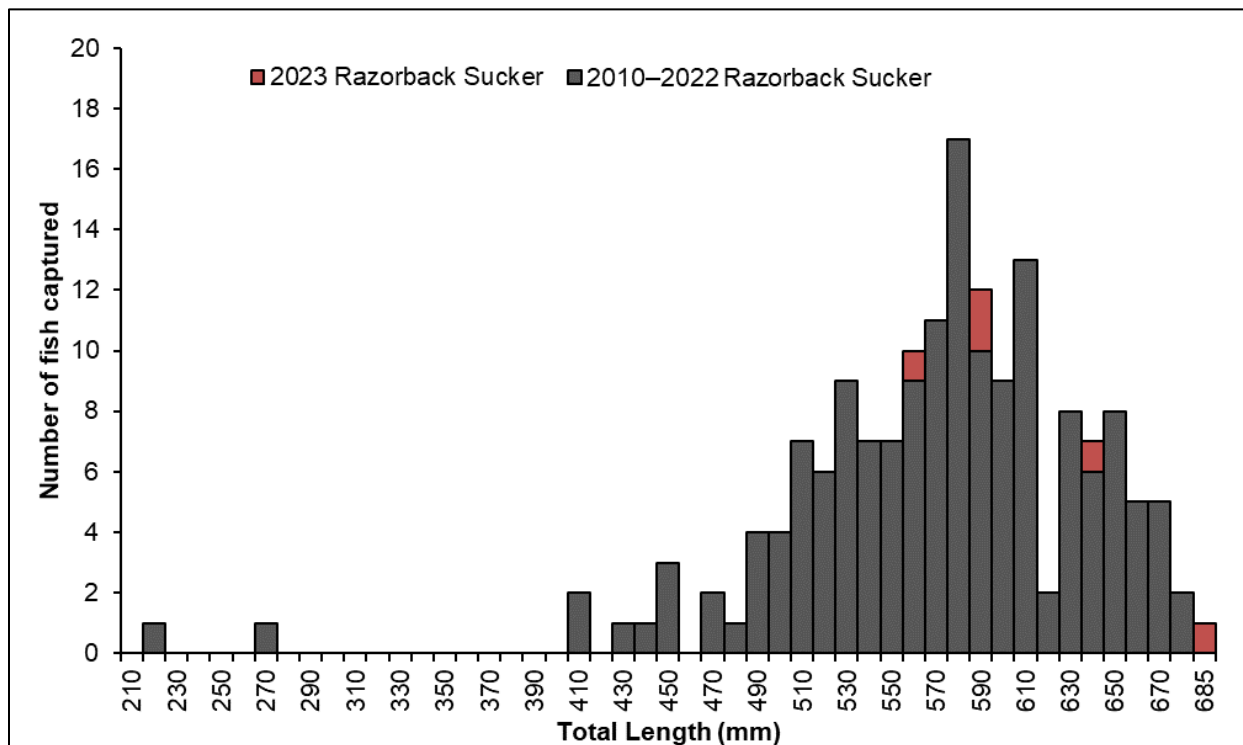


Figure 1.5. Length-frequency (mm total length) distributions for Razorback Suckers captured at the Colorado River Inflow Area of Lake Mead (CRI) in 2023 (red bars) and combined from 2010 to 2023 (gray bars). Data from trammel netting efforts only.

Table 1.4. Growth histories of applicable Razorback Sucker recaptured at the Colorado River Inflow Area of Lake Mead (CRI) in 2023.

| PIT TAG NUMBER | ORIGINAL CAPTURE OR STOCK DATE ^a | TL ^b (mm) | LAST DATE RE-CAPTURED | TL (mm) | TOTAL GROWTH (mm) | DAYS BETWEEN MEASUREMENTS | GROWTH/YEAR (mm/365 days) |
|------------------|---|----------------------|-----------------------|---------|-------------------|---------------------------|---------------------------|
| Wild Fish | | | | | | | |
| 3DD.003C06F100 | 4/9/2020 | 503 | 4/20/2023 | 560 | 57 | 1,106 | 18.8 |
| 3DD.003D4CBEA9 | 2/17/2021 | 582 | 3/7/2023 | 592 | 10 | 748 | 4.9 |

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

^b TL=total length.

Larval Sampling

Sampling for Razorback Sucker larvae began on March 6, 2023, and continued through May 2, 2023. Larval fish were captured off the western shore approximately 2 km south of Sandy Point (Figure 1.6).

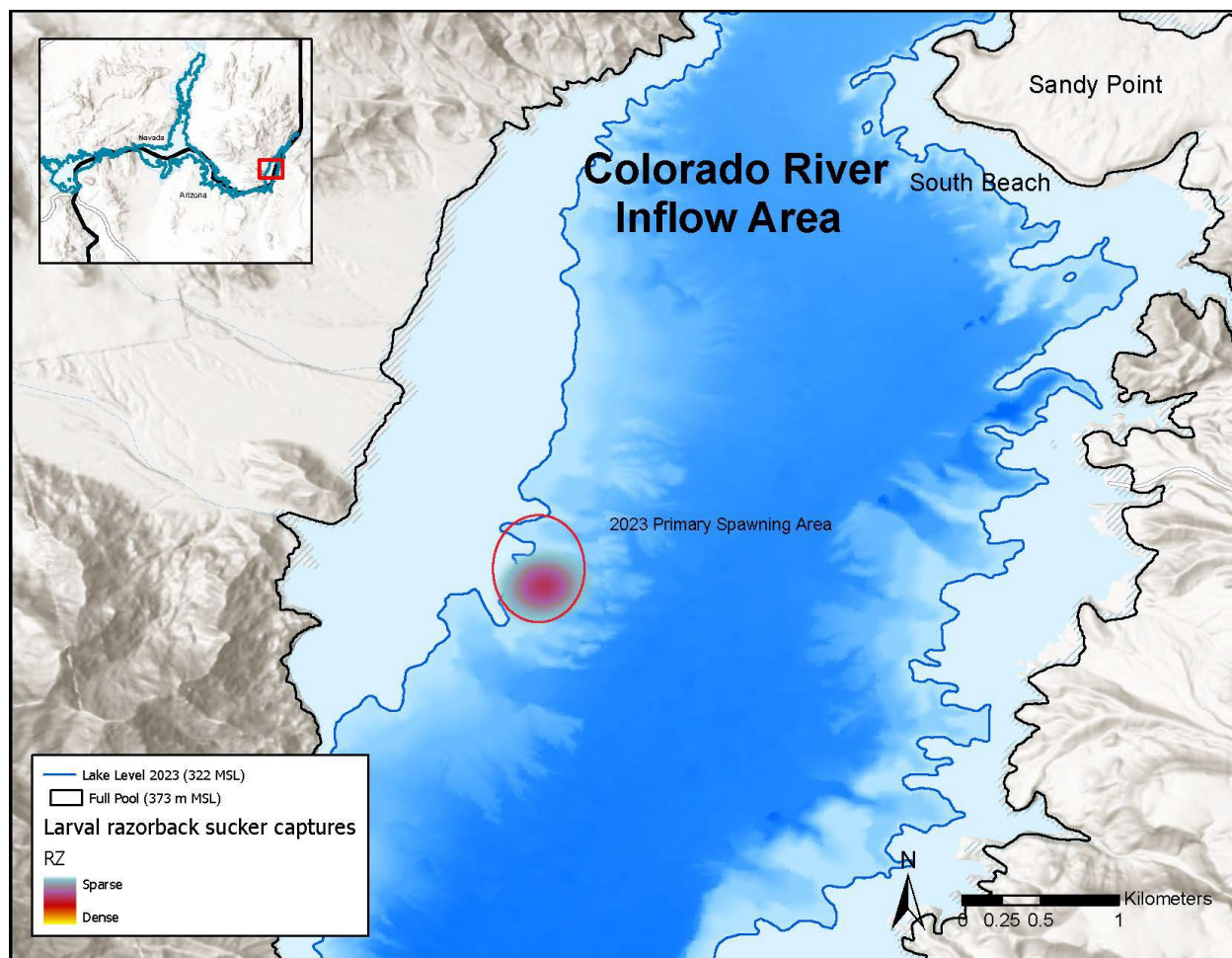


Figure 1.6. Larval Razorback Sucker sample and capture locations in the Colorado River Inflow Area of Lake Mead (CRI), 2023. Please note that the reservoir elevation increased rapidly during the sampling year. Consequently, the maps were created using the peak elevation for the sampling season, which may result in the appearance of sampling locations slightly off the shoreline.

Active larval sampling in 2023 resulted in the capture of 27 Razorback Sucker larvae. Larvae were captured along a western shoreline 2 km south of Sandy Point (Figure 1.6). The first larvae were captured on April 10, 2023, (n=4) at a water temperature of 17.4°C. Larvae were captured through the remainder of the field season, at water temperatures ranging from 14.3 to 19.3°C (Figure 1.6).

In 2023, the mean larval Razorback Sucker catch rate was 0.0360 (SE±0.0197), which falls within the historical context of the area (Figure 1.7). Significant differences in catch rates were found between sample years (ANOVA, $F_{13,1101}=16.7$, $P<0.0001$). Post-hoc pairwise comparisons confirmed that the mean larval CPUE in 2023 was lower than it was in 2021 (Figure 1.7).

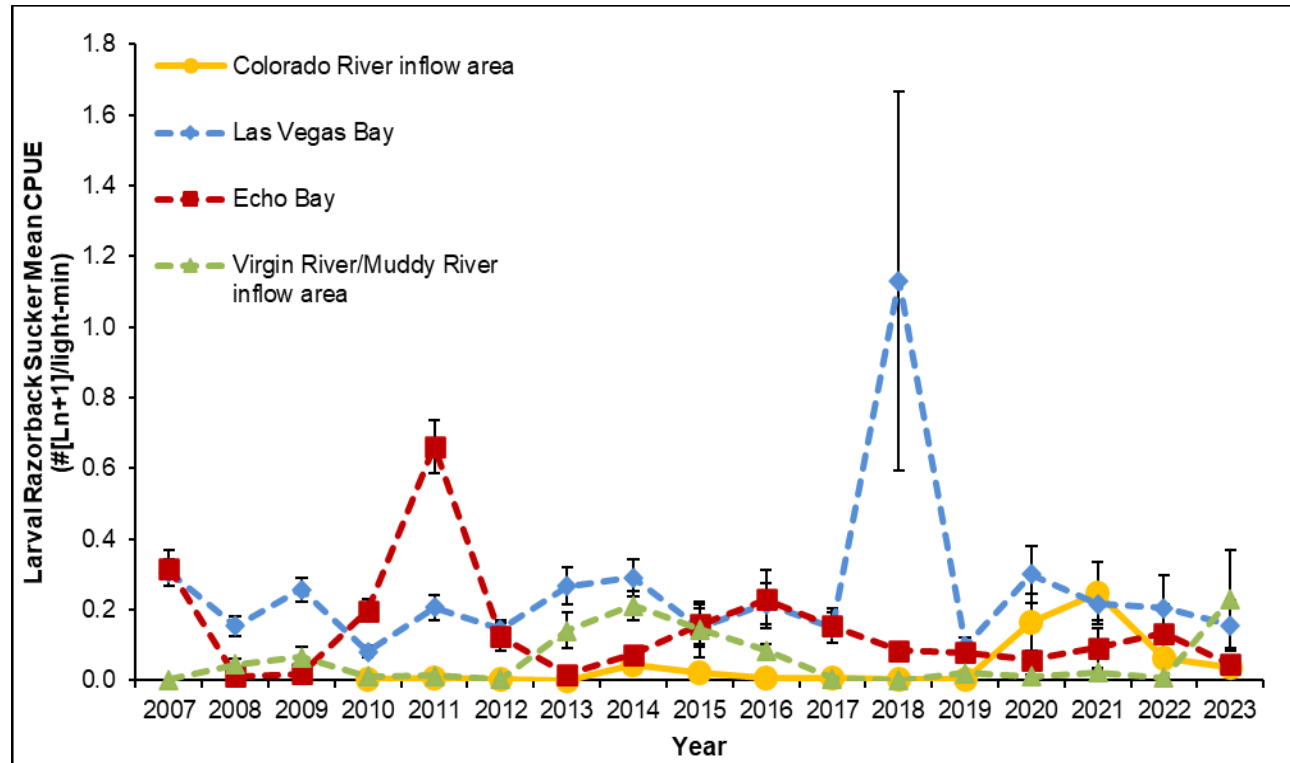


Figure 1.7. Larval Razorback Sucker mean catch-per-unit effort (CPUE) ($\ln(1+(\text{number larvae}/\text{light-minute sampled}))$) (\pm SE) comparisons by primary sampling location on Lake Mead for 2007–2023.

Lastly, to increase larval sampling efforts and cover more area for longer periods of time, six passive light traps were deployed in 2023 at the CRI. No larvae were captured during those efforts.

Spawning-Site Identification and Observations

At the CRI in 2023, sonic-tagged, adult, and larval Razorback Suckers were all observed off the western shoreline 2 km south of Sandy Point (Figure 1.6). This area of the CRI is adjacent to the reservoir/river interface. It is an area with relatively high turbidity and the shoreline is a mix of bedrock shelf, cobbles, and finer sediment. Successful spawning occurred in this area, indicating that this area was the spawning location in 2023.

Razorback Sucker Aging

Fin-ray sections from three Razorback Suckers were obtained for aging in 2023, bringing the total number of aged Razorback Suckers from the CRI to 64. The Razorback Suckers were determined to be age-9 (n=1; 2014 year-class) and age-11 (n=2; 2012 year-class) (Figure 1.8) (Appendix B).

Razorback Suckers have been observed moving between spawning locations in Lake Mead and between the reservoir and the Colorado River. Figure 1.8 presents cumulative Lake Mead Razorback Sucker aging data from all sampling locations (see Rogers et al. 2023). 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 sampling efforts were conducted with electrofishing in the Colorado River below Pearce Ferry Rapid downstream to the CRI from February to March 2023 and resulted in the capture of nine Flannelmouth Suckers (Table 1.5). Supplemental electrofishing efforts above Pearce Ferry Rapid also occurred in February and March; however, no fish were captured during these efforts, likely due to high flows and turbidity.

Bonelli Bay Investigations

Collaborative sampling between NDOW and BIO-WEST (198.3 total net hours) was conducted within Bonelli Bay, resulting in the capture of five Razorback Suckers ranging in TL from 604 to 685 mm, with a mean TL of 652.8 (SE±13.3) (Table 1.6 and Figure 1.9). The resulting Razorback Sucker CPUE was 0.026 (SE±0.016). Additional movement information was observed when a recaptured Razorback Sucker originally tagged at the Virgin River/Muddy River inflow area in 2009 was recaptured in Bonelli Bay (Table 1.6). Additionally, four Flannelmouth Suckers (CPUE=0.025 [SE±0.016]) ranging in TL from 430 to 510 mm, with a mean TL of 461.8 (SE±17.4), were captured in Bonelli Bay (Table 1.6).

One Razorback Sucker captured in Bonelli Bay was aged in 2023 and determined to be 13 years old (year-class 2010), further adding to the body of knowledge in this area (Figure 1.8) (Appendix B). No larvae were captured in Bonelli Bay in 2023.

Table 1.5. Supplemental sampling between Pearce Ferry Rapid and the Colorado River Inflow Area of Lake Mead (CRI) from March to May 2023.

| DATE | GEAR TYPE | NUMBER OF SAMPLES | RAZORBACK SUCKER | FLANNELMOUTH SUCKER | HYBRID SUCKER | BLUEHEAD SUCKER | HUMPBACK CHUB | SPECKLED DACE | AGGREGATE NONNATIVE CATCH |
|-----------------------------------|----------------|-------------------|------------------|---------------------|---------------|-----------------|---------------|---------------|---------------------------|
| SMALL-BODIED FISH SAMPLING | | | | | | | | | |
| 2/28/2023 | Electrofishing | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 3/1/2023 | Electrofishing | 1 | 0 | 2 | 0 | 0 | 0 | 0 | 0 |
| 3/21/2023 | Electrofishing | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 2 |
| 3/21/2023 | Electrofishing | 1 | 0 | 5 | 0 | 0 | 0 | 0 | 1 |
| TOTAL FISH | | 4 | 0 | 9 | 0 | 0 | 0 | 0 | 3 |

Table 1.6. Date, passive integrated transponder (PIT) tag number, size, and status information for Razorback Suckers captured in Bonelli Bay during 2023.

| 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 | Origin |
|-----------|----------------------|----------------|------------|---------------------------|--------------------|----------------------|----------------------|----------------------|---------------------|------------------|--------|
| 1/12/2023 | RZ | 3DD.003BC89C8F | No | 1/12/2023 | No | 604 | 575 | — ^h | 3060 | M | Wild |
| 1/25/2023 | RZ | 3D9.1C2C856E36 | No | 2/12/2009 | Yes | 655 | 615 | — ^h | 3200 | M | Wild |
| 1/25/2023 | RZ | 3DD.003BC89C79 | No | 1/25/2023 | No | 660 | 626 | — ^h | 3580 | F | Wild |
| 1/25/2023 | RZ | 3DD.003BC89E61 | No | 3/3/2021 | Yes | 685 | 645 | — ^h | 3600 | F | Wild |
| 1/25/2023 | RZ | 3DD.003BC89C5E | No | 1/25/2023 | No | 660 | 620 | — ^h | 3400 | U | Wild |
| 1/12/2023 | FM | 3DD.003BC89C5D | No | 1/12/2023 | No | 462 | 441 | — ^h | 860 | U | Wild |
| 1/25/2023 | FM | 384.36F2B2436D | No | 1/25/2023 | No | 430 | 395 | — ^h | 770 | U | Wild |
| 1/12/2023 | FM | — ^h | No | — ^h | — ^h | 510 | 482 | — ^h | 1090 | U | Wild |
| 1/25/2023 | FM | — ^h | No | — ^h | — ^h | 445 | 425 | — ^h | 820 | U | Wild |

^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.

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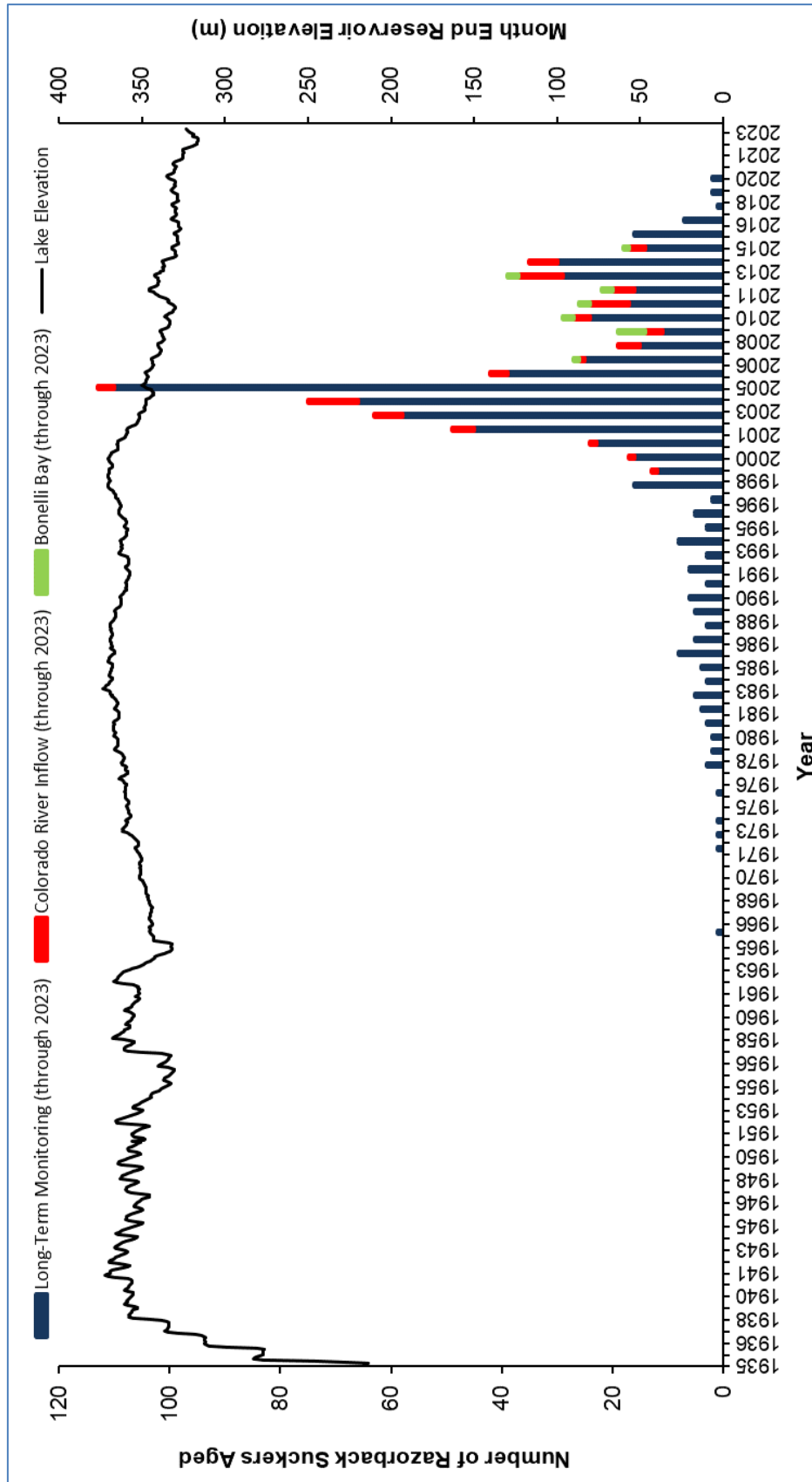


Figure 1.8. Lake Mead hydrograph from January 1935 to June 2023, with the number of aged Razorback Suckers spawned each year through 2020. Red bars denote the Razorback Suckers aged from the Colorado River Inflow Area of Lake Mead (CRI), green bars denote the Razorback Suckers aged from Bonelli Bay, while blue bars denote Razorback Suckers aged from the long-term monitoring (LTM) study.

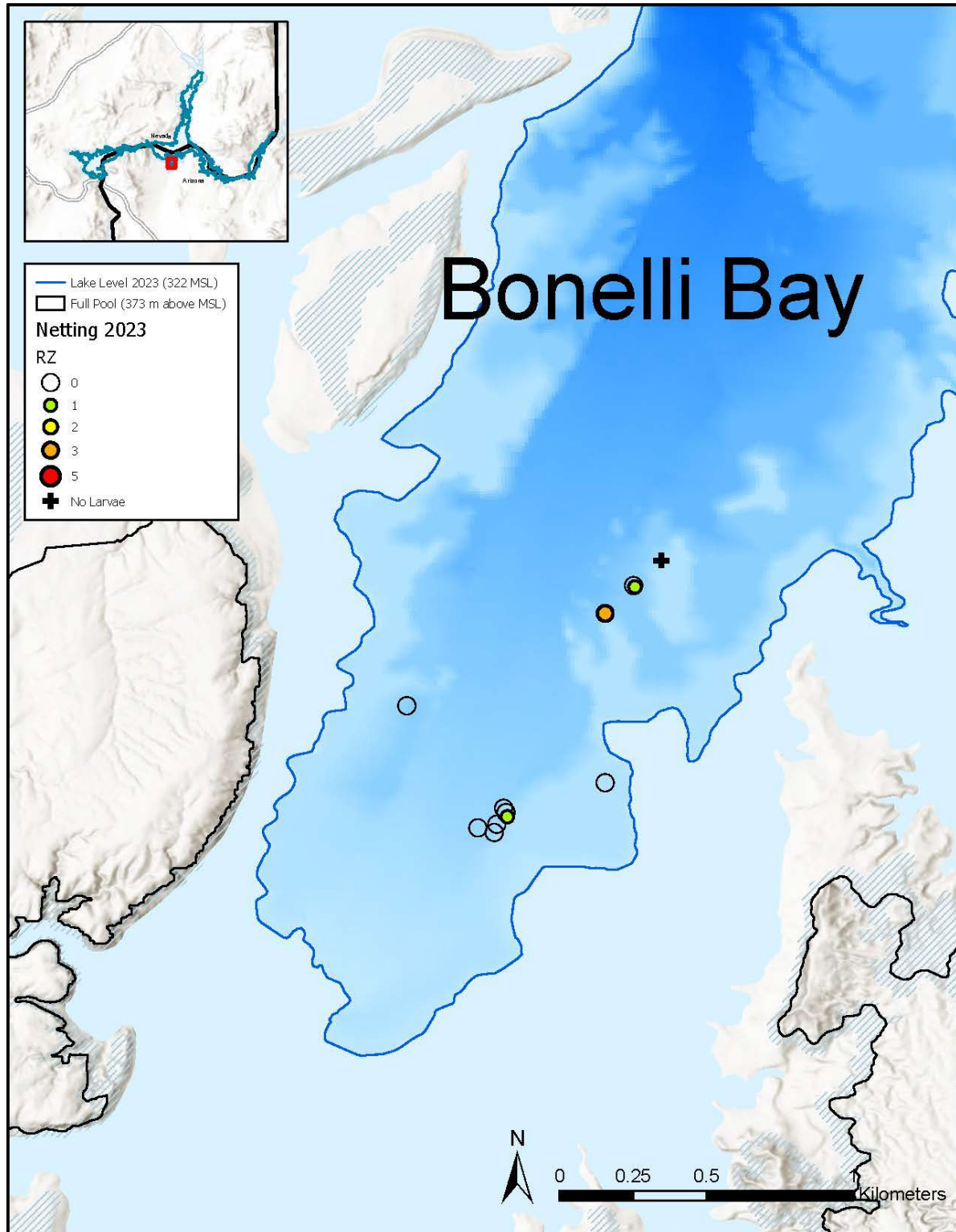


Figure 1.9. Trammel-netting, larval fish sampling, and telemetry contact locations for Razorback Sucker in Bonelli Bay in Lake Mead, January–May 2023. Please note that the reservoir elevation increased rapidly during the sampling year. Consequently, the maps were created using the peak elevation for the sampling season, which may result in the appearance of sampling locations slightly off the shoreline.

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 the 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 during the 14-year study period.

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 the river corridor to some degree. 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). Conversely in 2023, we observed the lowest catch rates of adult Razorback Sucker, yet captured larvae in eddies adjacent to the CRI, suggesting spawning occurred in the riverine habitat (Rogers et al. 2023b). Similar observations have been made in Las Vegas Bay (Rogers et al. 2023a). Although it is intuitive to assume that more adults would result in more larvae captured, that has not been the case based on the 2010–2023 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 adult, larval, and sonic-tagged Razorback Sucker concentrated on the western shore south of Sandy Point, suggesting that it was the spawning area in 2023. Additionally, in 2023, Flannelmouth Sucker and hybrid sucker were observed in this area as well, and Flannelmouth Sucker were captured in the flowing portion of the river.

The number of juvenile Razorback Suckers captured each year has varied since the project began in 2010. 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). Conversely, 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. 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. Hybridization between these two species has also been documented on the San Juan River (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 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. Lastly, in May 2023, the NPS released 866 juvenile (150–200 mm TL) Razorback Sucker at Havasu Creek (E. Omana-Smith, NPS, personal communication). Management actions by other agencies, such as this, as well as, nonnative eradication efforts and native fish repatriation efforts may affect the native fish community within the study area, which may be detected with continued monitoring efforts.

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 in past years throughout the lake (e.g., Rogers et al. 2019b, 2023b). 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.

The newly formed 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. (2023) observed that while fish passage at Pearce Ferry Rapid is possible, the species composition above the rapid is dominated by native species, which may suggest it is a partial barrier to upstream passage. The new rapid at the mouth of Iceberg Canyon may serve as a similar deterrent, 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 fluctuates from year to year. The 2023 larval CPUE falls within the historical context of the project; however, it appears to be lower than it was during the previous 3 years. This may be due to the fluctuation of reservoir elevations during the 2022 and 2023 spawning periods. In 2022, the reservoir elevation declined dramatically (decreased 7.6 m), and in 2023 it slowly increased throughout the spawning season. Spawning in the area may have been reduced for one of the following reasons: (1) Razorback Suckers could not find suitable/stable habitats, (2) larvae

edded out of the river/delta into areas not accessible to researchers, or (3) adults moved upstream and larvae did not drift into the delta/lake. 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. Continued monitoring of larvae will help determine spawning variability or trend analysis.

Growth and Aging

Overall, Lake Mead growth rates continue to surpass the growth rates (<2.0 mm/year) reported for Razorback Suckers in Lake Mohave (Pacey and Marsh 1998) and the Green River (McAda and Wydoski 1980; Tyus 1987). Growth rates at the CRI in 2023 appear to be similar to those of other long-term monitoring sites in Lake Mead (Rogers et al. 2023). These 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, 2023a, 2023b, 2023). 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.

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 while the reservoir was relatively stable around the 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, 2023a, 2023), 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, 2023a, 2023). Based on previous observations, as well as the year-class strength analysis from Rogers et al. (2023), 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, 2023b, 2023). 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. Wild produced 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.
3. Wild Razorback Suckers have been captured at different locations in the CRI for 14 consecutive field seasons. It is possible 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). Ongoing studies at the LTM, CRI and LGC show the interconnectedness of the reservoir and river. Continued efforts at the CRI and LGC are imperative for data continuity and understanding the community dynamics throughout the whole system.
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. Recaptured Razorback Suckers from previous years at other sites on the lake demonstrates the interconnectedness of Lake Mead and the necessity to explore and monitor unknown and known areas with the reservoir.

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 2010–2023 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 Razorback Sucker 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, or the newly formed Devils Cove 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? Are there other potential barriers between the newly formed Devils Cove Rapid and Pearce Ferry Rapid? 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 14 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 long-term monitoring 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 of wild Razorback Sucker 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 relative 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).

2023–2024 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 as a whole. Data collected in all study sites within Lake Mead and LGC are fundamental to understanding population dynamics of Razorback

Sucker and, ultimately, recovery. 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.

2. 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 native fish repatriation and nonnative fish eradication efforts. 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; Pennock et al. 2022; Burgad et al. 2023). 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”), Post 2026 Colorado River Operations, and the drought currently affecting Lake Powell and Lake Mead.
3. 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 suckers) 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 in previous years (see Chapter 2), larval and small-bodied fish sampling (utilizing methods described in Chapter 2) are warranted and should be continued upstream of the CRI.
4. 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 Pearce Ferry Rapid may be beneficial by possibly providing insights into the fish community above and below the rapid, but also support management decisions. 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.
5. Identify new potential spawning sites that appear similar to known spawning areas within Lake Mead as described by Albrecht et al. (2009). For example, additionally sonic-tagged Razorback Sucker could be stocked and tracked, 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 in the bay (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, 2023b). Sonic-tagged Razorback Sucker could be used to identify additionally Razorback Sucker aggregates in Lake Mead.

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 2023. This chapter also presents results from previous study years (October 2013 through September 2023) 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 2023 (Table 2.1). More specifically, the intent of this study is to (1) help describe the overall fish community within Grand Canyon, (2) allow for the capture of young Razorback Sucker, if present, and (3) better understand the reproductive success, habitat use, and movement of (and areas of importance to) Razorback Sucker and the overall Grand Canyon fish community.

Table 2.1. Grand Canyon sampling dates and trip purpose, 2023.

| MONTH | SAMPLING DATES | TRIP PURPOSE |
|-----------|-----------------------------|--|
| March | 3/6/2023 through 3/16/2023 | Larval-fish community sampling (GRTS ^a) |
| April | 4/11/2023 through 4/18/2023 | Telemetry, small-bodied, and larval-fish community sampling (GRTS) |
| May | 5/9/2023 through 5/18/2023 | Telemetry, small-bodied, and larval-fish community sampling (GRTS) |
| June | 6/6/2023 through 6/13/2023 | Telemetry, small-bodied, and larval-fish community sampling (GRTS) |
| July | 7/4/2023 through 7/11/2023 | Telemetry, small-bodied, and larval-fish community sampling (GRTS) |
| August | 8/8/2023 through 8/15/2023 | Telemetry, small-bodied, and larval-fish community sampling (GRTS) |
| September | 9/2/2023 through 9/9/2023 | 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 2023, 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 (river mile [RM] 88.5) to Pearce Ferry (RM 280.0) (Figure 2.1).

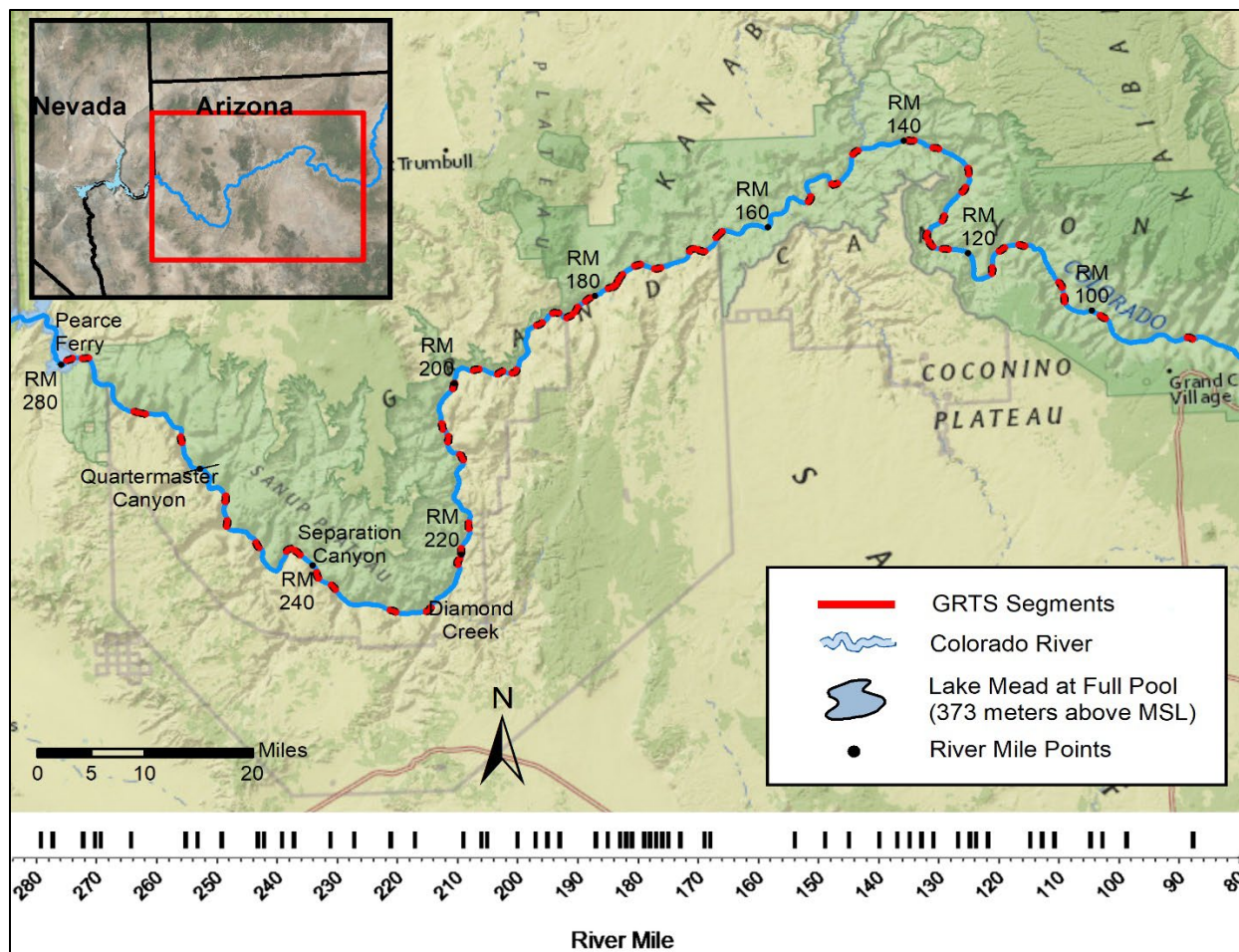


Figure 2.1. The general study area within Grand Canyon and the 56 generalized random tessellation stratified (GRTS) design segments (red) located in the 191.5-river-mile study area from below Phantom Ranch to just above Pearce Ferry in 2023 (some GRTS segments are adjoining). Tick marks denote linear 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, 2023, through September 30, 2023. 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 study area. Data include both approved and provisional information from USGS, and measurements are presented in cubic feet per second (ft³/s).

Small-bodied Fish Community Sampling

Sampling sites in Grand Canyon in 2023 for the larval and small-bodied fish surveys were the same as those from 2016–2022. 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.

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 one of the primary objectives of these surveys, so at times complex and diverse habitats were targeted.

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 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.

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.

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.

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 indentation, 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 found in 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 margins 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 found 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 | | | | |

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

Finally, comparisons were made between historic data and data collected in this study. Results from 2014–2023 and comparisons to historic data are published in Rogers et al. (2022b). In this report, small-bodied fish catch data from 2014–2023 were examined for holistic trends where appropriate. However, most statistical comparisons were limited to data from 2016–2023, when the study area and effort remained relatively consistent.

Larval-Fish Community Sampling

The larval-fish sampling effort encompassed 190.4 river miles—from immediately downstream of the Bright Angel Creek-Colorado River confluence (RM 88.6) 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 2017, two GRTS segments were removed due to unsafe sampling conditions and replaced with the next sequential GRTS segments. Since 2018, all GRTS sampling locations have remained consistent throughout Grand Canyon larval- and small-bodied fish sampling efforts.

Larval-fish sampling was conducted using a short, 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 length), were made at each GRTS segment. Standard length (SL mm) was measured for fishes that could be accurately identified in the field, they were then enumerated, held in a live well, and released at their capture location. In addition to standard length, total length (TL mm) was recorded for federally threatened Humpback Chub (USFWS 2020). 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 because of 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), primary substrate, secondary substrate, instream cover, and maximum depth (cm). Sampling effort (m^2) was determined by multiplying seine width (1 m) by seine haul length.

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. |

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 miles). 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 August of the previous year are typically downloaded and replaced during the August or September survey of the following year.

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 to await 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, which enhance the delineation of larval-fish characters used to 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 in 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 the following 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-, and 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. (2023).

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 stages. Length measurements and ontogenetic phase were recorded for all retained federally listed fish species. Additionally, ontogenetic phase was determined for both native suckers (Bluehead Sucker and Flannelmouth Sucker).

Hatch-date estimates were limited to larval Humpback Chub with a body length below 30 mm (SL), as growth rates are extremely variable past the early larval stage in this species. A species-specific polynomial equation was used to back-calculate hatch dates, where D is the number of days from hatch and SL is the standard length of the specimen (Muth 1990):

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

Catch-per-unit effort 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 stabilize variance and better approximate normality. Analysis of variance 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 HSD post-hoc test ($\alpha = 0.05$) was used to further examine all possible pairwise comparisons. All statistical analyses were performed using R version 4.1.2 (R Core Team 2022).

Log scales for Figures 2.13 through 2.17 (which are found later in this chapter) in 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

2023 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 7,010 and 45,700 cubic feet per second (cfs) during sampling events (Figure 2.2). Mean monthly discharge values for April, May, June, and July were significantly higher than the other months' samples (ANOVA, $F_{11,353}=80.0$, $P<0.0001$). Mean monthly hydropeaking (the difference between maximum and minimum discharge) also differed with the lowest daily fluctuations in March and May; while the highest hydropeaking occurred in April. April hydropeaking values were significantly higher than those of any of the other month sampled (ANOVA, $F_{11,353}=7.80$, $P<0.0001$). It is noted that a high-flow event occurred in April 2023 (Figure 2.2). This high-flow experiment event led to a significant increase in the mean daily discharge and a higher mean hydropeaking in April.

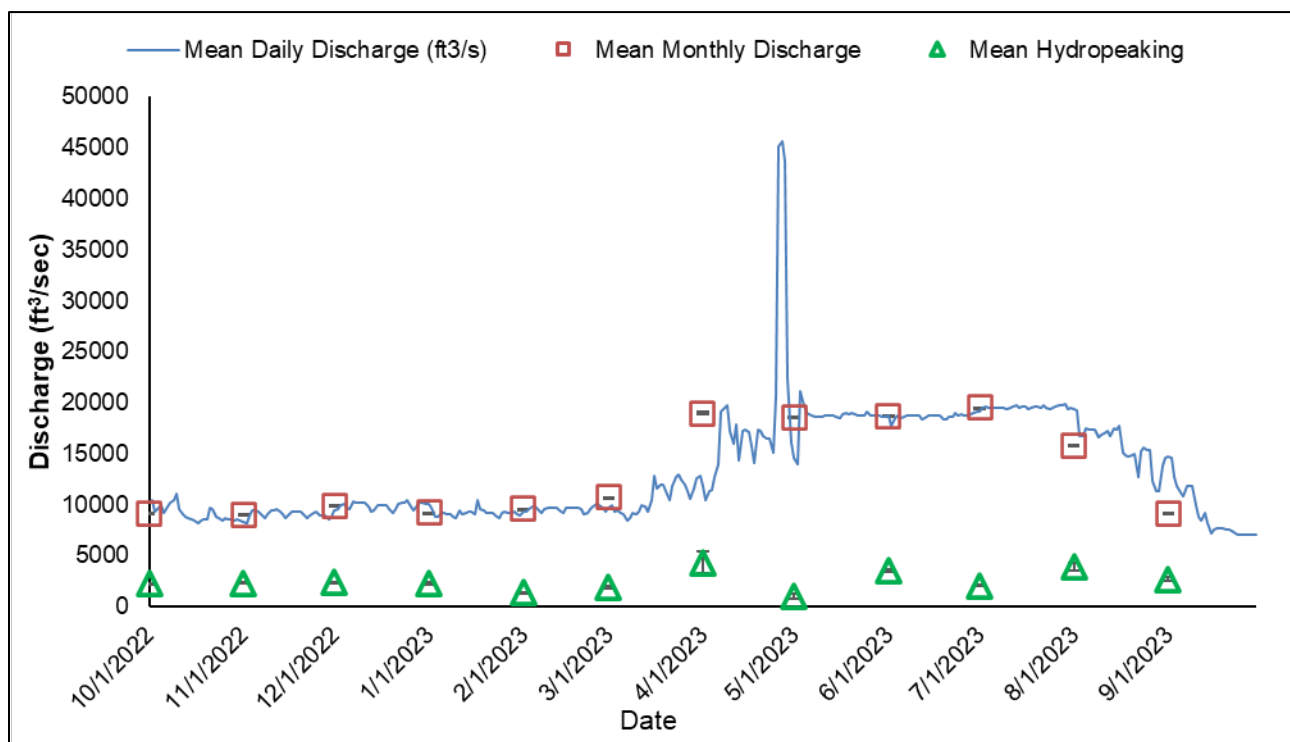


Figure 2.2. Mean daily discharge, mean monthly discharge, and mean monthly hydropeaking in cubic feet per second (cfs) of the Colorado River for the period of October 1, 2022, through September 30, 2023, recorded at the USGS gage above Diamond Creek (#09404200). Error bars are ± 1 SE.

Small-Bodied Fish Community Sampling

The GRTS segments were sampled from March to September 2023 (Table 2.5). No small-bodied sampling was conducted in March. Monthly effort under the GRTS sampling design ranged from 5,819.4 to 9,630.0 m² (241–355 seine hauls) of habitat sampled.

Table 2.5. Sampling effort from 2023 small-bodied fish surveys.

| SAMPLING MONTH | DATES OF SAMPLING | NUMBER OF HAULS | EFFORT (m ²) AT GRTS ^a SEGMENTS | GRTS SEGMENTS SAMPLED |
|----------------|-------------------|--|--|-----------------------|
| March | 6–16 | Small-bodied sampling was not conducted. | | |
| April | 11–18 | 284 | 7,896.4 | 54 |
| May | 9–18 | 277 | 6,618.0 | 53 |
| June | 6-13 | 305 | 6,911.8 | 54 |
| July | 4–11 | 300 | 7,743.0 | 55 |
| August | 8–15 | 241 | 5,819.4 | 56 |
| September | 2–9 | 355 | 9,630.0 | 55 |

^a GRTS=generalized random tessellation stratified.

During small-bodied fish community sampling efforts in 2023, 7,084 native fishes of four species (Bluehead Sucker [n=165], Flannelmouth Sucker [n=2,328], Humpback Chub [n=1,284], and Speckled Dace [n=3,307] [Appendix D]) were captured in GRTS segments. Native fish dominated Grand Canyon, representing approximately 83.3% 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 2023.

The following 12 nonnative fish species were captured during small-bodied fish community sampling in 2023: Bluegill *Lepomis macrochirus* (n=1), Channel Catfish *Ictalurus punctatus* (n=5), Common Carp (n=3), Fathead Minnow (n=902), Plains Killifish *Fundulus zebrinus* (n=51), Green Sunfish *L. cyanellus* (n=10), Gizzard Shad *Dorosoma cepedianum* (n=2), Western Mosquitofish *Gambusia affinis* (n=329), Red Shiner *Cyprinella lutrensis* (n=99), Rainbow Trout *Oncorhynchus mykiss* (n=13), Striped Bass *Morone saxatilis* (n=1), and Walleye *Sander vitreus* (n=3), totaling 1,419 individuals (Table 2.6). The Bluegill was captured at RM 123.6 with TL of 52mm (Table 2.6). The Green Sunfish were captured between RM 98.7 and 252.7 with a mean TL of 95.3 (SE=13.5) and ranging in size from 41–46 mm TL (Table 2.6). The Striped Bass ranged in size from 104 to 108 mm TL (mean TL=106.0 [SE=2.0] mm) and were captured from RM 172.6 to 255.2. The Walleye had a mean TL of 115.0 (SE=40) mm and ranged in size from 74 to 195 mm TL; they were captured from RM 197 to 269.9 (Table 2.6). 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 or catch rates, as reported below (Appendix D).

In addition to the fish readily identifiable in the field and not included in the total counts, 1,208 YOY (i.e., age-0) fishes (n=1,205 suckers and n=5 cyprinids) were captured.

Table 2.6 Nonnative fish captures, mean total length, standard error, total length range, and river mile range of capture during the 2023 sampling year.

| SPECIES | TOTAL NUMBER CAPTURED | MEAN TL ^a | STANDARD ERROR | MINIMUM TL | MAXIMUM TL | UPSTREAM RANGE (RM ^b) | DOWNSTREAM RANGE (RM) |
|----------------------|-----------------------|----------------------|----------------|------------|------------|-----------------------------------|-----------------------|
| Bluegill | 1 | 52.0 | NA | 52 | 52 | 123.6 | 123.6 |
| Channel Catfish | 5 | 69.2 | 8.0 | 50 | 89 | 115.4 | 279 |
| Common Carp | 3 | 208.0 | 137.6 | 61 | 483 | 98.7 | 248.7 |
| Fathead Minnow | 902 | 39.1 | 0.6 | 17 | 85 | 88.6 | 279 |
| Plains Killifish | 51 | NA | NA | NA | NA | 123.6 | 269.6 |
| Green Sunfish | 10 | 95.3 | 13.5 | 42 | 164 | 98.7 | 252.7 |
| Gizzard Shad | 2 | 43.5 | 2.5 | 41 | 46 | 255.2 | 277.4 |
| Western Mosquitofish | 329 | 33.5 | 1.3 | 17 | 60 | 248.7 | 279 |
| Red Shiner | 99 | 37.2 | 1.3 | 20 | 88 | 88.6 | 279 |
| Rainbow Trout | 13 | 179.8 | 25.5 | 68 | 360 | 88.6 | 274.4 |
| Striped Bass | 1 | 106.0 | 2.0 | 104 | 108 | 172.6 | 255.2 |
| Walleye | 3 | 115.0 | 40.0 | 74 | 195 | 197 | 269.9 |

^a TL=total length. ^b RM=river mile.

Catch Rates

A comparison of mean CPUE ($\ln(1+(\#/m^2))$) of native and nonnative fishes captured at GRTS segments in 2023 demonstrates dominance and significantly higher catch rates of native, small-bodied fish species in Grand Canyon (ANOVA, $F_{1,3522}=251$, $P<0.0001$) (Figures 2.3 and 2.4). When evaluated by trip, significant differences were found in native fish catch rates (ANOVA, $F_{5,1756}=36.1$, $P<0.0001$) (Figure 2.3). Post-hoc analysis revealed that catch rates for native fish in August and September 2023 had the highest mean catch rates, while June 2023 had the lowest mean catch rate (Figure 2.3).

In comparison with previous data, native catch rates in 2023 were significantly lower compared to 2014, 2017, 2018 and 2022 (ANOVA, $F_{9,16223}=81.5$, $P<0.0001$; Tukey's HSD). Nonnative fish catch rates in 2023 were also significantly lower than those of 2014 and similar to all other years (ANOVA, $F_{9,16223}=8.71$, $P<0.0001$) (Figure 2.4).

Native fish catch rates differed among sampling segments in 2023 (ANOVA, $F_{56,1705}=3.05$, $P<0.0001$) (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 2016–2023 with differences among segments, but it is difficult to determine where those differences occurred (ANOVA, $F_{100,16132}=12.1$, $P<0.0001$).

To better assess mean catch rates longitudinally for segments, catch rates in the upper half and lower half of the study area for 2016–2023 were compared. Catch rates above Lava Falls were compared with mean catch rates for segments below Lava Falls (RM 179.0).

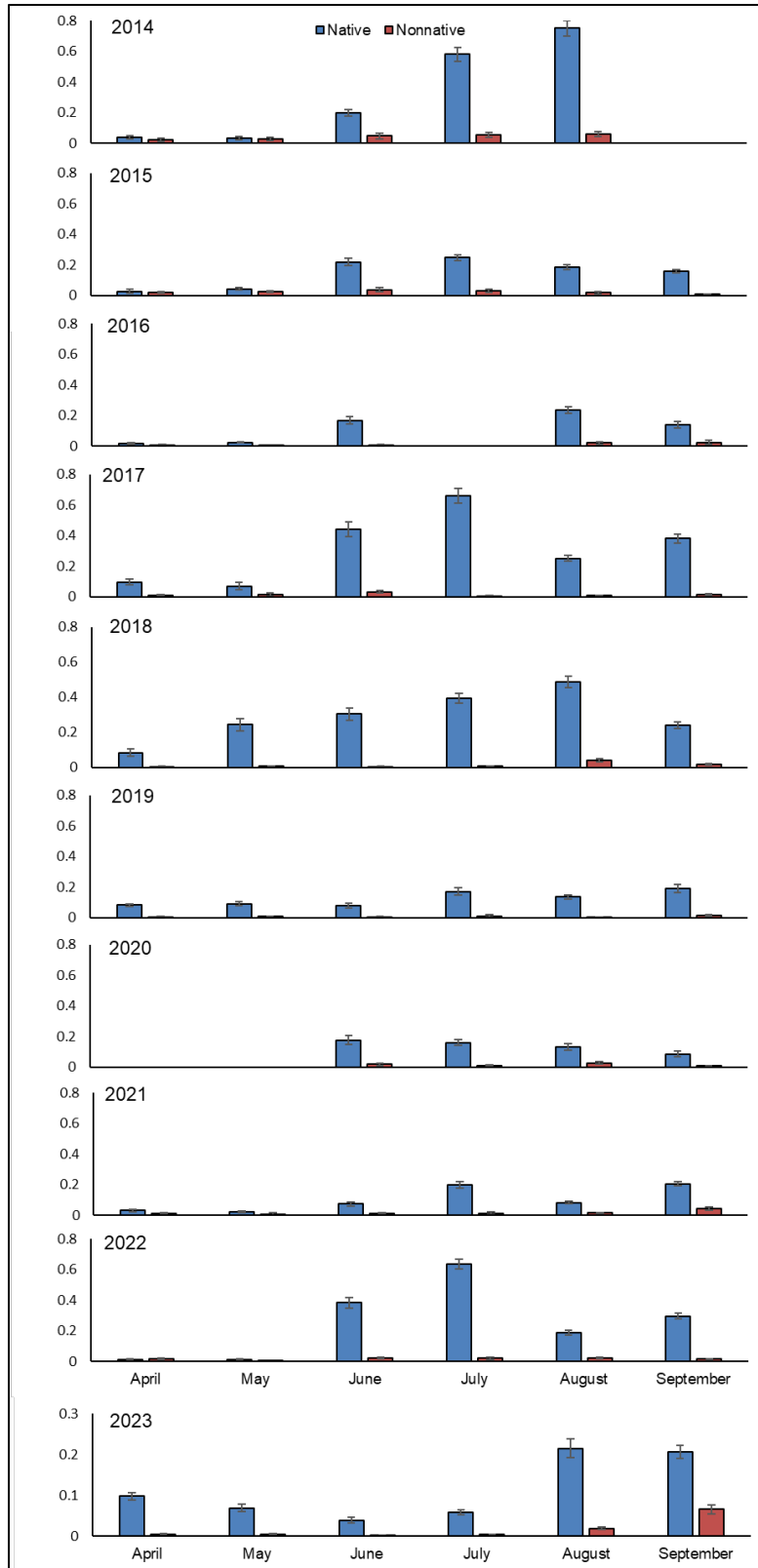


Figure 2.3. Mean native and nonnative fish catch-per-unit effort (CPUE) ($\ln(1+(\#/m^2))$) by sampling trip for 2014–2023. Error bars are ± 1 SE.

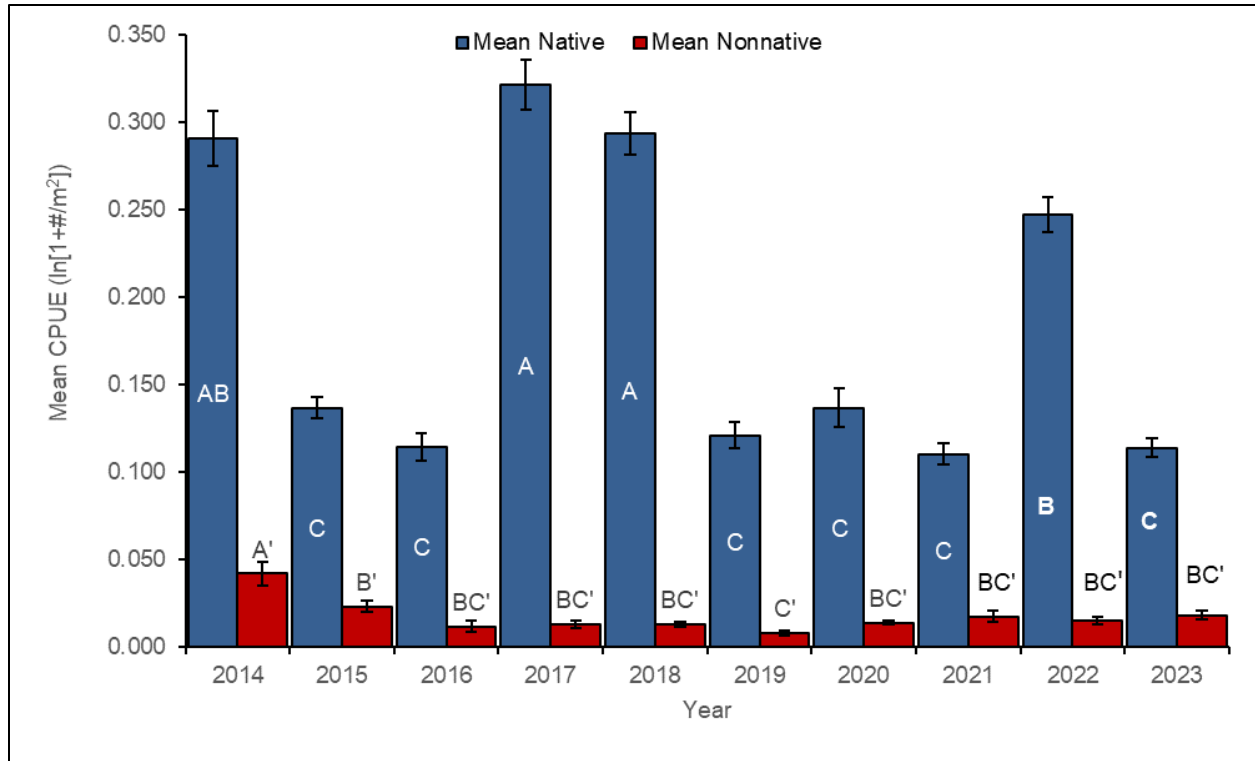


Figure 2.4. Mean native and nonnative fish catch-per-unit effort (CPUE) ($\ln(1+(\#/m^2))$) by sampling year for 2014–2023. Error bars are ± 1 SE. Letters denote statistically significant groups.

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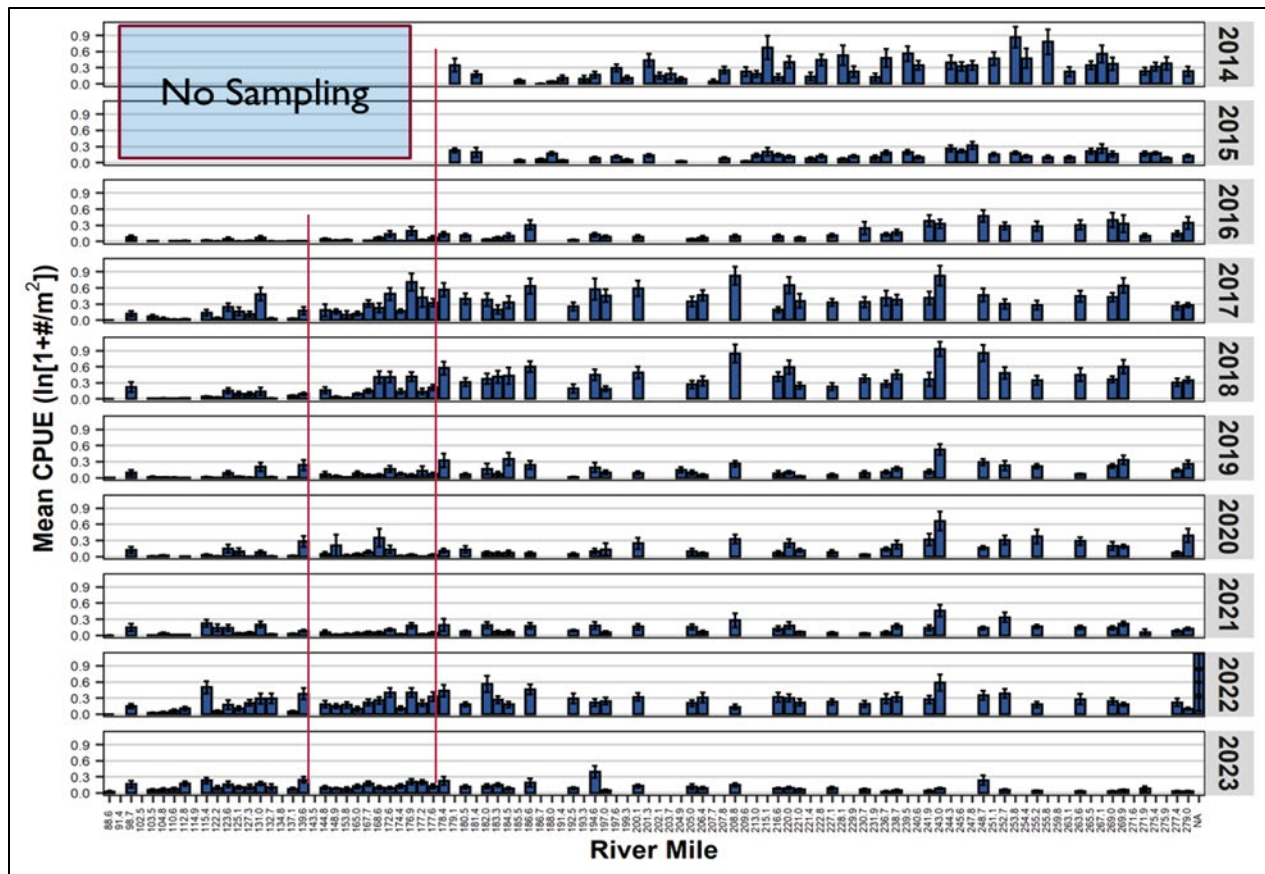


Figure 2.5. Mean native fish catch-per-unit effort (CPUE) ($\ln(1+(\#/m^2))$) by river mile (generalized random tessellation stratified [GRTS] design segment) upstream to downstream separated by sampling year (Red lines designate Havasu Creek and Lava Falls). Error bars are ± 1 SE.

This analysis confirmed that mean catch rates for native fish were significantly higher below Lava Falls than above it (ANOVA, $F_{1,13297}=305$, $P<0.0001$) (Figure 2.5). Additionally, mean catch rates for native fish were significantly higher below Havasu Creek than above it (ANOVA, $F_{1,13297}=388$, $P<0.0001$), suggesting the tributary is important for native fishes (Figure 2.5).

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 2023 (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 July before becoming more easily identifiable during August–September (Figure 2.6). Humpback Chub catch rates increased steadily from July to September (Figure 2.6).

Since 2014, a total of 4,812 Humpback Chub have been captured during small-bodied sampling. In 2023 alone, 1,284 Humpback Chub were captured, which represents 27% of the total catch. Humpback Chub catch rates were relatively low from April to June and peaked in September (Figure 2.6). Humpback Chub catch rates differed each year from 2014 to 2023, with 2022 having the highest catch rate and 2016 the lowest (ANOVA, $F_{9,16235}=23.2$, $P<0.0001$).

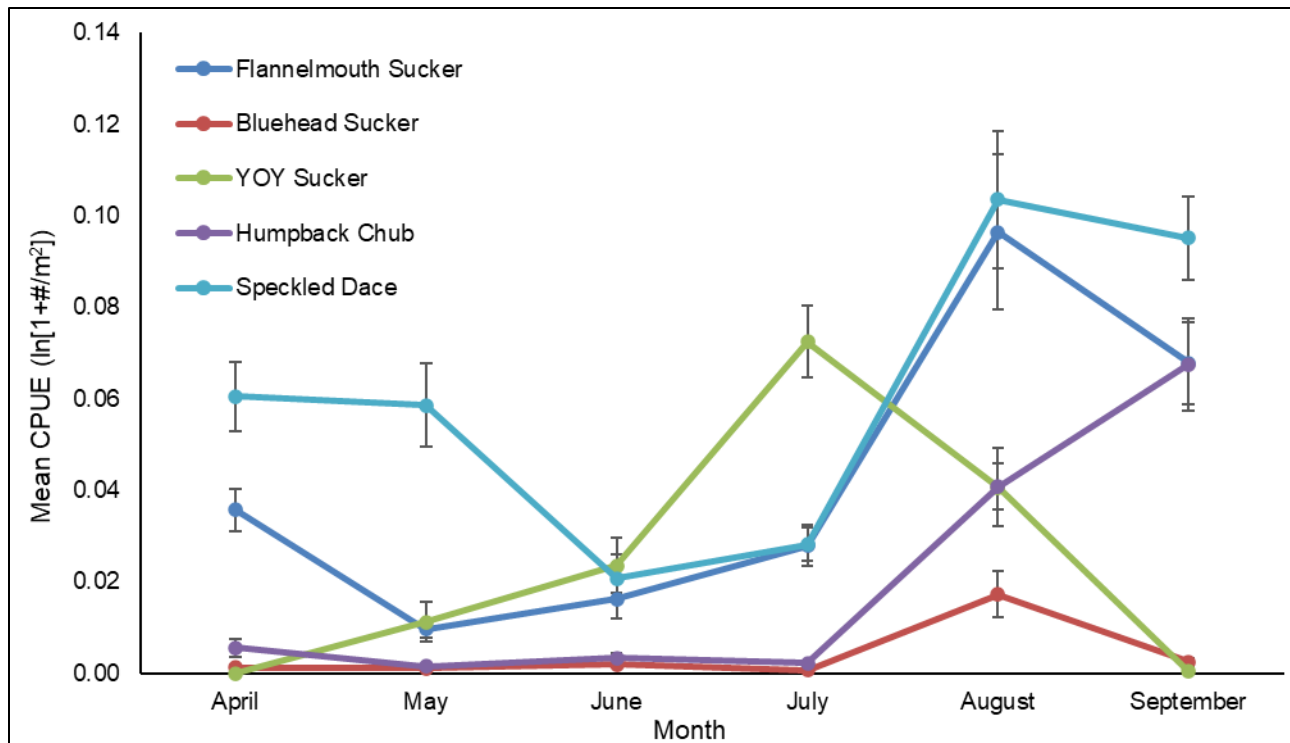


Figure 2.6. Mean native fish catch-per-unit effort (CPUE) ($\ln(1+(\#/m^2))$) by sampling trip separated according to species in 2023. Error bars are ± 1 SE.

In 2023, native fish numbers and their TL varied by sampling trip. Humpback Chub lengths ranged from 19–325 mm TL (mean TL=50.9 mm; SE=1.1) and were captured throughout the GRTS segments (Figure 2.7). Flannelmouth Sucker total length ranged from 21 to 482 mm (mean=71.0 mm; SE=0.1). Bluehead Sucker total length ranged from 31 to 395 mm (mean=90.0 mm; SE=6.7). Lastly, Speckled Dace total length ranged from 17 to 125 mm (mean=44.9 mm; SE=0.4).

Habitat

In 2023, most seine hauls (52.3%) were conducted in slackwater habitat, followed by runs, pools and shoals (21.7, 7.7, and 6.4%, respectively). These habitats also provide low-velocity conditions conducive to seining. Fine substrates, such as sand and silt, covered 87.9% of the habitat sampled during all seine hauls. While forms of cover varied, inundated vegetation and boulders were the most prevalent cover types (36.0% and 21.1%, respectively), although 25.3% of the sampling occurred where no cover was present (Figure 2.8).

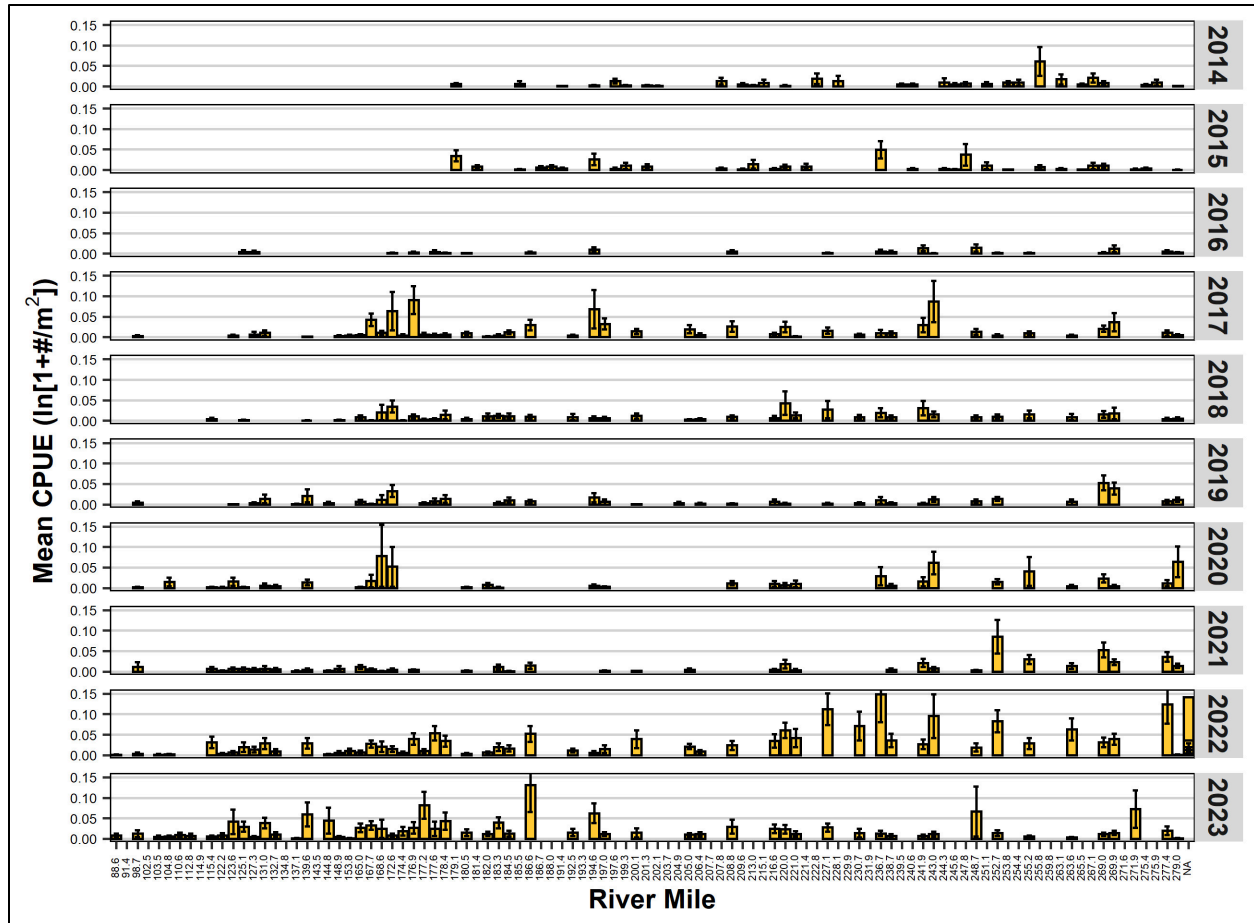


Figure 2.7. Mean Humpback Chub catch-per-unit effort (CPUE) ($\ln(1+(\#/m^2))$) by river mile (generalized random tessellation stratified [GRTS] design segment) upstream to downstream, 2016–2023. Error bars are ± 1 SE.

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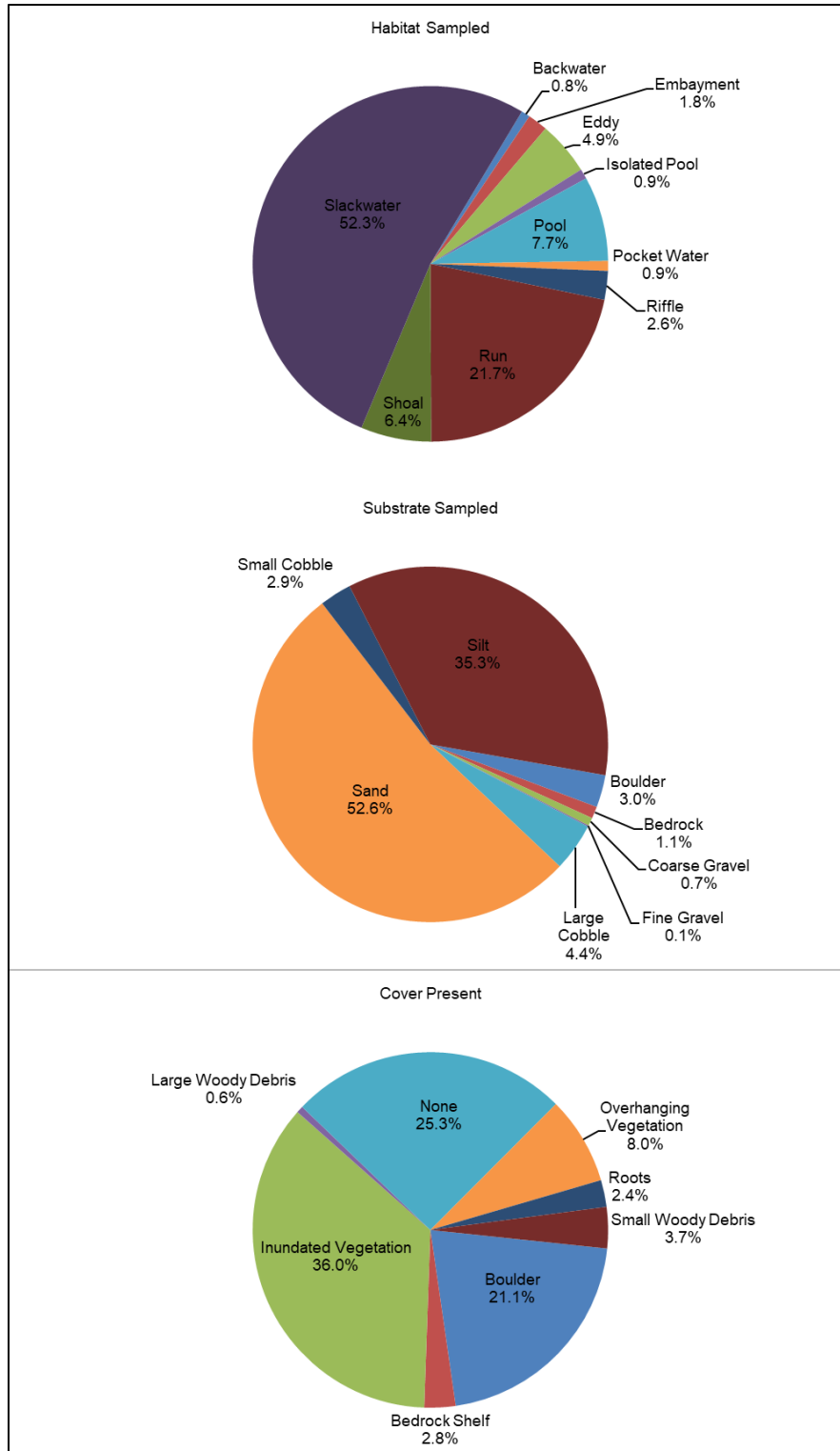


Figure 2.8. Frequency distribution of habitat, substrate, and cover present for samples at generalized random tessellation stratified (GRTS) segments during the 2023 small-bodied fish survey.

Habitat and Catch Rates per Habitat Sampled 2023

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 2023.

During the combined sampling events in 2023, a significant difference in mean catch rates among native fishes in different habitat types was detected (ANOVA: $F_{9,1752}=15.2$, $P<0.0001$); however, post-hoc analysis showed higher catch rates in backwater, embayment, and isolated pool habitats (Figure 2.9). In testing for differences of mean catch rates of nonnative fishes, isolated pool, embayment and backwater habitats were also shown to have higher catch rates compared to all other habitat types sampled in 2023 (ANOVA: $F_{9,1752}=9.10$, $P<0.0001$) (Figure 2.9).

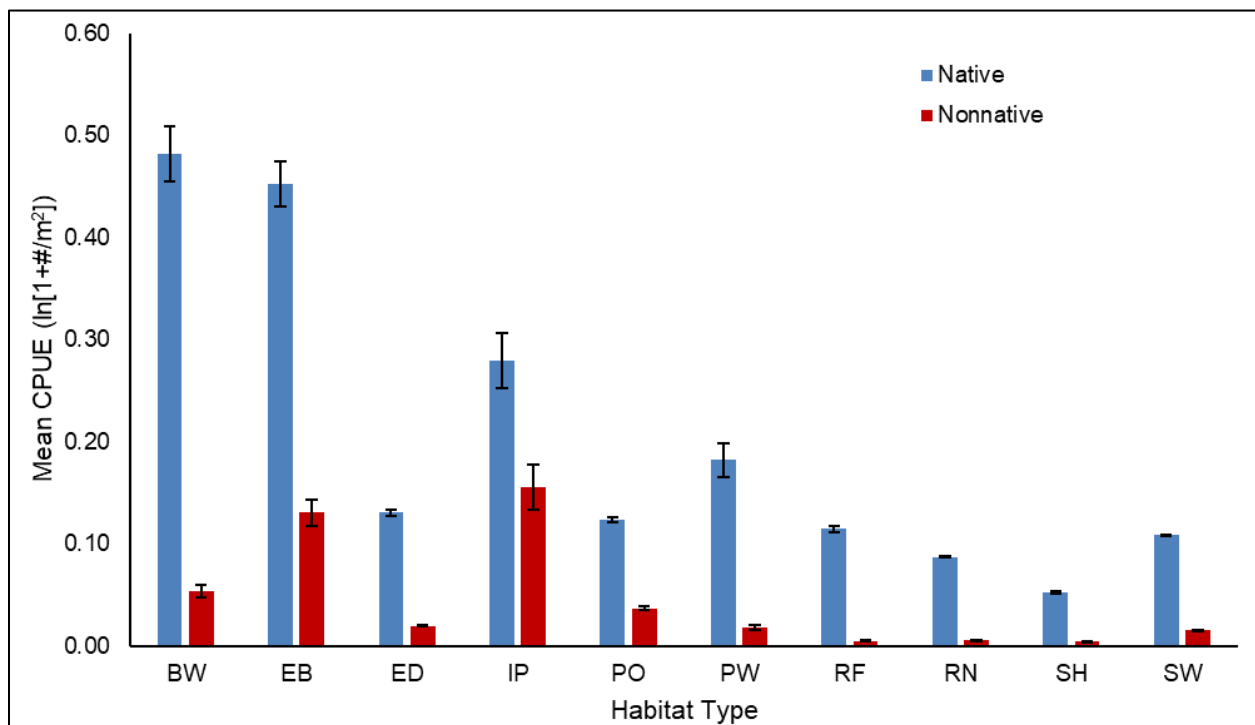


Figure 2.9. Catch-per-unit effort (CPUE) in the habitats sampled in the generalized random tessellation stratified (GRTS) Grand Canyon (RM 89.5–279.9) segments in 2023.

Fish Community Composition 2014–2023

The fish community at the GRTS segments sampled during 2014–2023 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, 2021, and 2023 (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 15.1% of the catch in 2023 (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 2023, Bluegill (0.012%), Channel Catfish (0.059%), Green Sunfish (0.118%), Striped Bass (0.012%), and Walleye (0.035%) were captured during GRTS sampling in Grand Canyon. While they represent a small percentage of the catch, these predatory species may pose a risk to the native fish community. In 2023, Gizzard Shad were captured for the first time since the projects inception and represented 0.024% of the catch. Small-bodied sampling has shown to be valuable in detecting rare and elusive fish species in the mainstem river.

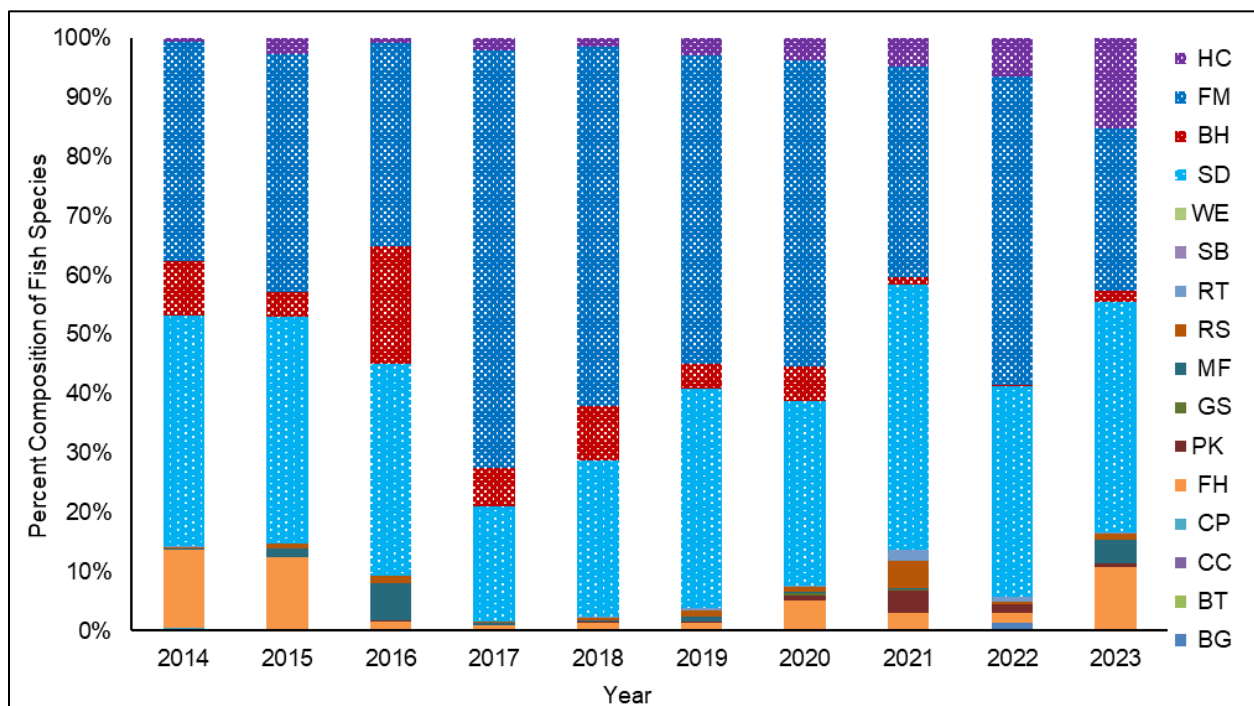


Figure 2.10. Percent composition of the fish community in the generalized random tessellation stratified (GRTS) Grand Canyon (RM 89.5–279.9) segments from 2014–2023.

Larval-Fish Community Sampling

2023 Sampling

Six larval fish surveys were conducted (06 March through 16 August) in the Colorado River in the Grand Canyon during 2023 (Table 2.7). Sampling design remained consistent with previous larval fish community sampling efforts—GRTS segments that were systematically sampled 2016–2022 (n=56) were surveyed again during 2023. High flows throughout the 2023 sampling period limited accessibility at sampling sights; however, efforts were made to maintain sampling consistency when feasible. A total of four seine hauls (i.e., samples) were taken at each GRTS segment (when possible) per monthly survey, resulting in 1,768–2,076 m² of larval fish habitat sampled per month in 2023. A total of 10,163 larval fishes (i.e., age-0, YOY), represented by 13 species, were collected in 2023 (Appendix E.1). Larval-fish sampling during 2023 incidentally captured 939 age-1+ fishes, which were represented by nine species (Appendix F.1).

Table 2.7. Monthly sampling effort during 2023 larval fish surveys.

| SAMPLING MONTH | SAMPLE DATES | NUMBER OF HAULS | EFFORT (m ²) AT GRTS ^a SITES | GRTS SEGMENTS SAMPLED |
|----------------|--------------|-----------------|---|-----------------------|
| March | 6–16 March | 212 | 2,075 | 53 |
| April | 12–20 April | 216 | 1,802 | 54 |
| May | 10–17 May | 212 | 1,768 | 53 |
| June | 6–14 June | 218 | 1,924 | 55 |
| July | 5–13 July | 220 | 1,927 | 55 |
| August | 9–16 August | 224 | 1,786 | 56 |

^a GRTS=generalized random tessellation stratified.

2023 Monthly Capture Summary

March: The first 2023 larval fish survey (Phantom Ranch [RM 89] to Pearce Ferry [RM 280]) occurred 7–20 March. During this period, mean daily discharge measured in the Colorado River just upstream of Diamond Creek (USGS gage 09404200) ranged from 7,110 to 12,000 cfs. Water clarity was low throughout the study area and remained between 13 and 21 cm from Phantom Ranch to RM 200.1. Water clarity decreased below RM 200.1 and remained <10 cm downstream through 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 9.6 to 12.8°C (Figure 2.11).

Of the 28 specimens retained in March, two of the species were native and the other 26 were nonnative individuals collected at RM 168.6. The March collection of age-0 fish consisted of three specimens and represented only two taxa (Appendix E.2). March had the lowest catch rate among monthly surveys in 2023 and was significantly lower than catch rates during the June–August surveys (ANOVA, $F_{5, 658}=41.84$, $P<0.001$; Tukey’s HSD, $P<0.05$) (Figure 2.12). The age-0 specimens collected consisted of native Flannelmouth Sucker (n=1), nonnative Brown Trout (n=1), and nonnative Rainbow Trout (n=1).

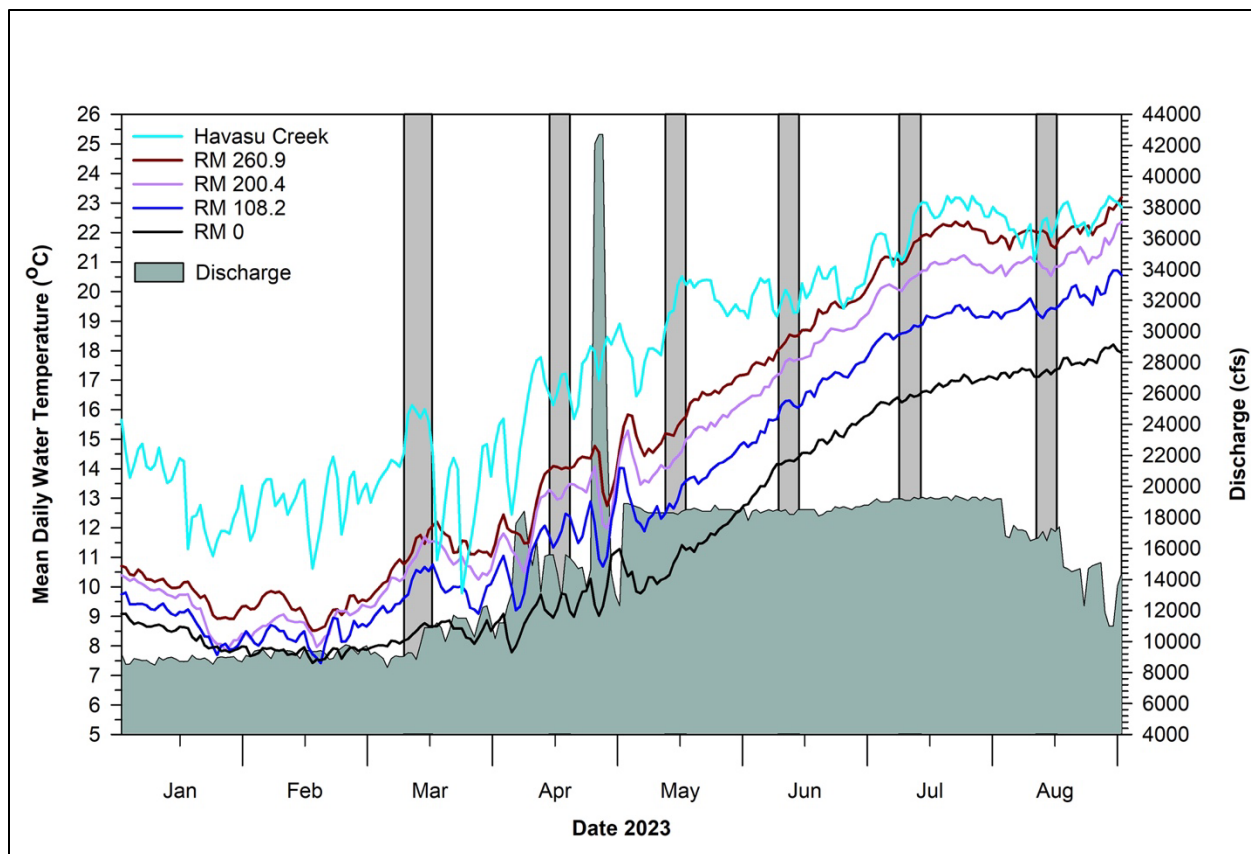


Figure 2.11. Colorado River discharge upstream of Diamond Creek (USGS gage 09404200), water temperatures during 2023 from Lee’s Ferry (USGS gage 09380000, RM 0), Havasu Creek above confluence (USGS gage 09404115, near RM 157.3), and three mainstem Colorado River water temperature loggers (RM 108.2, RM 200.4, and RM 260.9). Vertical, gray-filled bars denote timing of larval survey trips. The peak in discharge shows the magnitude of the April HFE (24–27 April).

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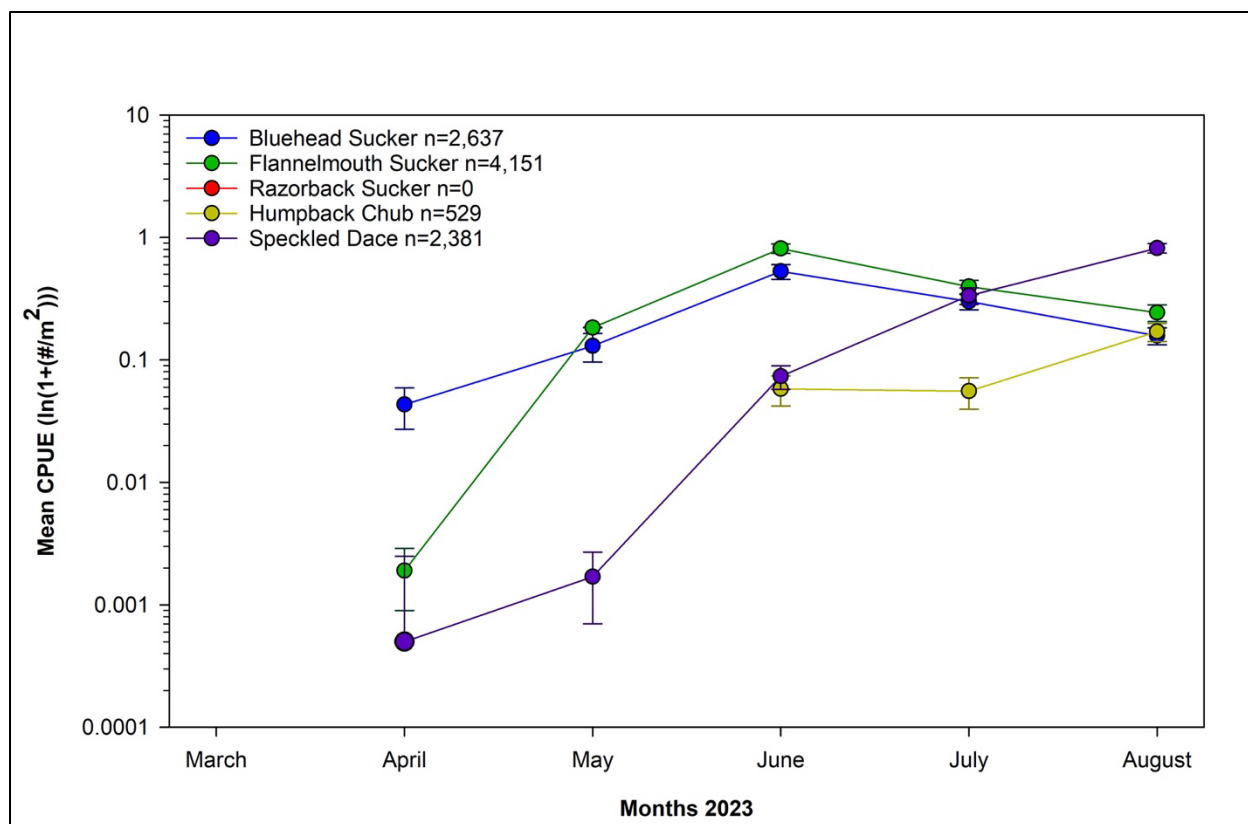


Figure 2.12. Mean catch-per-unit effort (CPUE) of age-0 native fishes by sampling trip (month) during the 2023 larval fish survey. The y-axis scale is \log_{10} and error bars represent ± 1 SE.

Age-1 incidental captures during the March larval fish survey ($n=142$) were composed of 80% native species and 20% nonnative species. Native age-1 species collected were Humpback Chub ($n=4$), Flannemouth Sucker ($n=17$), and Speckled Dace ($n=92$). Nonnative age-1 species included Fathead Minnow, Green Sunfish, Plains Killifish, Red Shiner, and Western Mosquitofish. (Appendix F.2).

April: The April 2023 survey occurred 11–18 April (Table 2.7) with sampling beginning on 13 April. Hourly discharge in the Colorado River during the April survey, as measured from the USGS gage 09402500 near Grand Canyon, Arizona, ranged from 11,600 to 17,800 cfs, with mean daily discharge ranging from 15,550 to 16,304 cfs (14,635 cfs mean discharge). Water clarity ranged from 5 to 7 cm throughout the study area. Mainstem water temperatures recorded at sampling locations ranged from 12.1 to 16.0°C.

The abundance of age-0 fishes increased in April relative to March (Appendix E.3); however, distribution decreased. Larval fishes were collected only at 8 of 56 sampling sites. The catch rate in April was significantly lower than catch rates during the June–August surveys (ANOVA, $F_{5,658}=41.84$, $P<0.001$; Tukey's HSD, $P<0.05$) (Figure 2.12). The upstream-most April capture of larval fish (Bluehead Sucker) occurred at RM 236.7.

The entire age-0 composition collected in April 2023 consisted of native fishes. Catostomidae were the most abundant family collected during April, comprising >84% of larval fishes collected that month. Bluehead Sucker were the most abundant age-0 species collected in April (n=93, 93.9%), followed by Flannelmouth Sucker (n=4, 4.0%) and Speckled Dace (n=1, 1.0%).

The species composition of age-1 fishes captured during April 2023 was eight species (Appendix F.3). The majority of these age-1 fishes were Speckled Dace (n=240, 67.9%). The second most abundant age-1 species collected was Flannelmouth Sucker (n=50, 14.1%). The most abundant nonnative age-1 was Fathead Minnow (n=16, 4.5%), followed by Western Mosquitofish (n=11, 3.1%).

May: The May 2023 survey occurred 10–17 May and was the first larval fish survey following the April 2023 High Flow Experiment-HFE (24 April to 27 April 2023) (Figure 2.11). Mean daily discharge in the Colorado River during the May survey ranged from 18,708 to 18,741 cfs (18,712 mean cfs). Mainstem water temperatures recorded at sampling locations ranged from 12.1 to 18.0°C. Water clarity, as measured with a Secchi disk, ranged from 16 to 59 cm. Turbidity increased downstream of the confluence with the Little Colorado River and continued to increase steadily until Pearce Ferry.

The May survey age-0 catch remained relatively low compared to previous years but increased in abundance relative to the April catch (Appendix E.4). The catch rate in May was significantly higher than catch rates during the June–August surveys (ANOVA, $F_{5, 658}=41.84$, $P<0.001$; Tukey's HSD, $P<0.05$) (Figure 2.12). Native fishes (n=608) comprised 100% of the age-0 fishes collected during May.

The first nonnative age-1 species in 2023 were captured during the May survey (Appendix F.4). Nine species comprised the May age-1 fish catch (n=172). The catch was primarily Speckled Dace (n=144, 83.7%), followed by Flannelmouth Sucker (n=9, 5.2%). Nonnative age-1 species included Fathead Minnow (n=5), Plains Killifish (n=3), Western Mosquitofish (n=2), Red Shiner (n=1), and Green Sunfish (n=1). Both the Green Sunfish and Red Shiner were collected at RM 263.6.

June: The June 2023 survey occurred 5–14 June (Table 2.7). Discharge, as measured from the USGS gage 09402500 near Grand Canyon, Arizona, ranged from 15,300 to 20,200 cfs, with mean daily discharge ranging from 18,319 to 18,622 cfs (18,523 mean cfs). Mainstem water temperatures recorded at sampling locations ranged from 15.7 to 20.2°C. Water clarity, as measured with a Secchi disk, ranged from 11 to 70 cm. Turbidity increased downstream of Diamond Creek and continued to increase steadily until Pearce Ferry.

June had the highest catch rate of age-0 fishes (n=4,027) among the 2023 monthly surveys and was significantly higher than all other months surveyed (ANOVA, $F_{5, 658}=41.84$, $P<0.001$; Tukey's HSD, $P<0.05$) (Figure 2.12) (Appendix E.5).

Catostomids were distributed throughout the study area and numerically dominated the June collection, comprising greater than 93% (n=3,733) of the total age-0 catch. Flannelmouth Sucker was the most abundant age-0 species collected (n=2,390; 59.7%) followed by Bluehead Sucker

(n=1,341; 33.5%) (Figures 2.13 and 2.14). As with previous monthly trips, Razorback Sucker larvae were not present in June samples (Figure 2.15). Native cyprinids represented a smaller proportion of the age-0 catch in June (6.5%). Speckled Dace was the most abundant native cyprinid (n=146) and was distributed over most of the study area (RM 98.7–279.0).

June was the first monthly survey that yielded age-0 Humpback Chub in 2023. These fish (n=115) were distributed between RM 98.7 (the second downstream GRTS site) and RM 279.0 (Figure 2.16). All Humpback Chub specimens collected in June were mesolarvae, with n=57 flexion mesolarvae and n=59 post-flexion mesolarvae. Juvenile Humpback Chub were not collected in the June 2023 sample. Nonnative age-0 fish captures in June comprised less than 1% of the total age-0 fish captured (Appendix E.4). Fathead Minnow (n=7) was the only nonnative age-0 species collected in June 2023.

Six species comprised the June age-1 fish collected (n=40). The composition was primarily Speckled Dace (n=32, 80.0%), followed by Humpback Chub (n=3, 7.5%). Nonnative age-1 species included Fathead Minnow (n=2), Plains Killifish (n=1), and Western Mosquitofish (n=1).

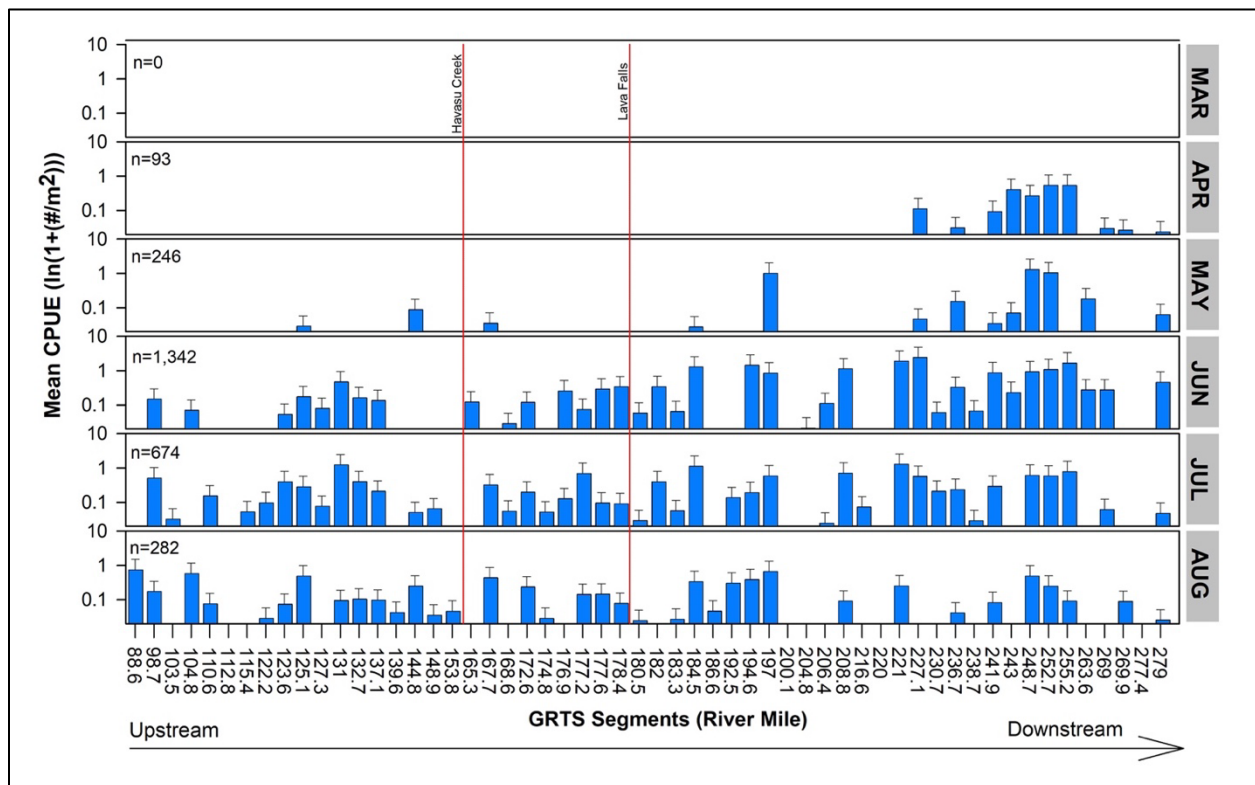


Figure 2.13. Mean catch-per-unit effort (CPUE) of age-0 Bluehead Sucker by 2023 sampling trip (month) and generalized random tessellation stratified (GRTS) segment. The y-axis scale is log₁₀ and error bars are ±1 SE.

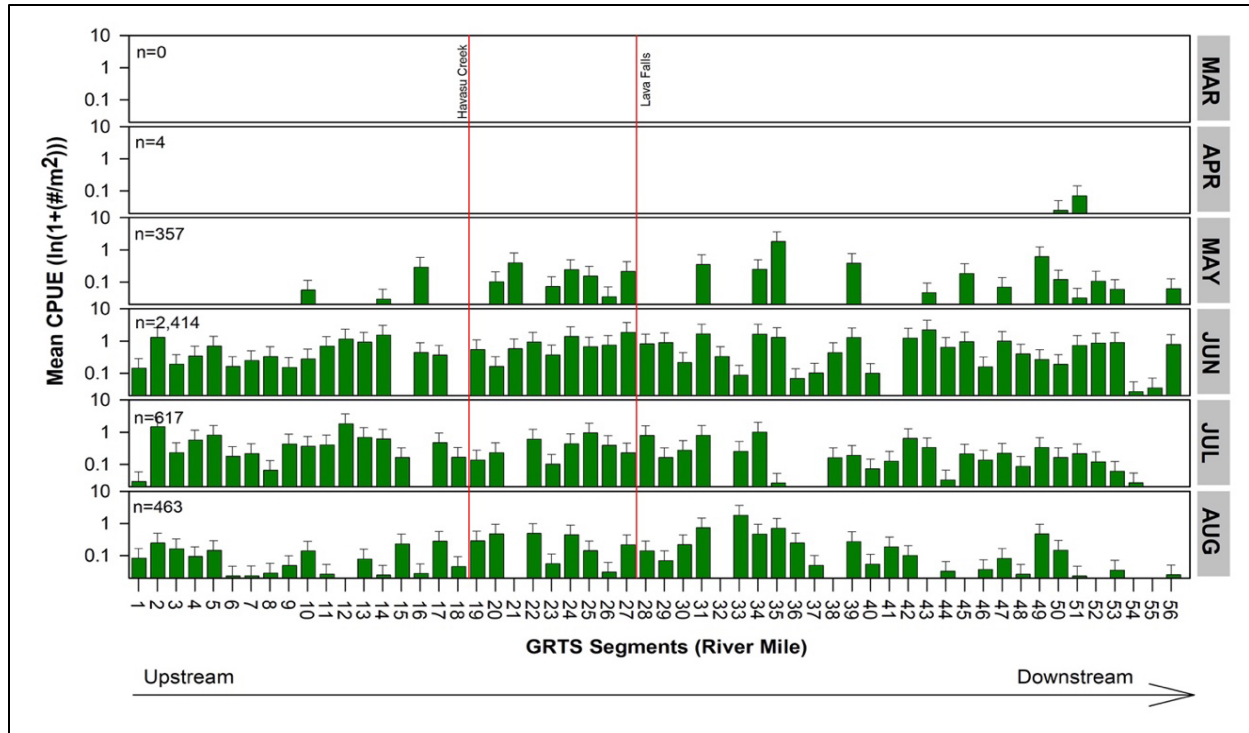


Figure 2.14. Mean catch-per-unit effort (CPUE) of age-0 Flannelmouth Sucker by 2023 sampling trip (month) and generalized random tessellation stratified (GRTS) segment. The y-axis scale is \log_{10} and error bars are ± 1 SE.

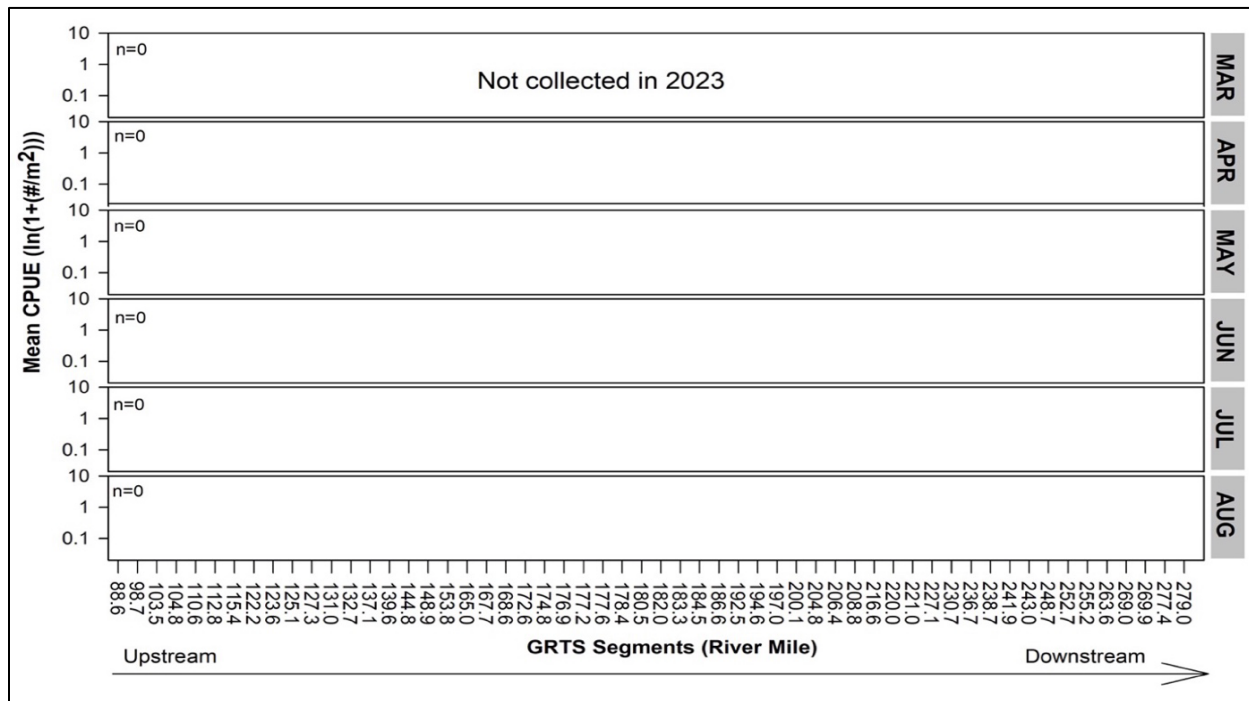


Figure 2.15. Mean catch-per-unit effort (CPUE) of age-0 Razorback Sucker by 2023 sampling trip (month) and generalized random tessellation stratified (GRTS) segment. The y-axis scale is \log_{10} and error bars are ± 1 SE. None collected in 2023. Graph is a placeholder for between-year consistency.

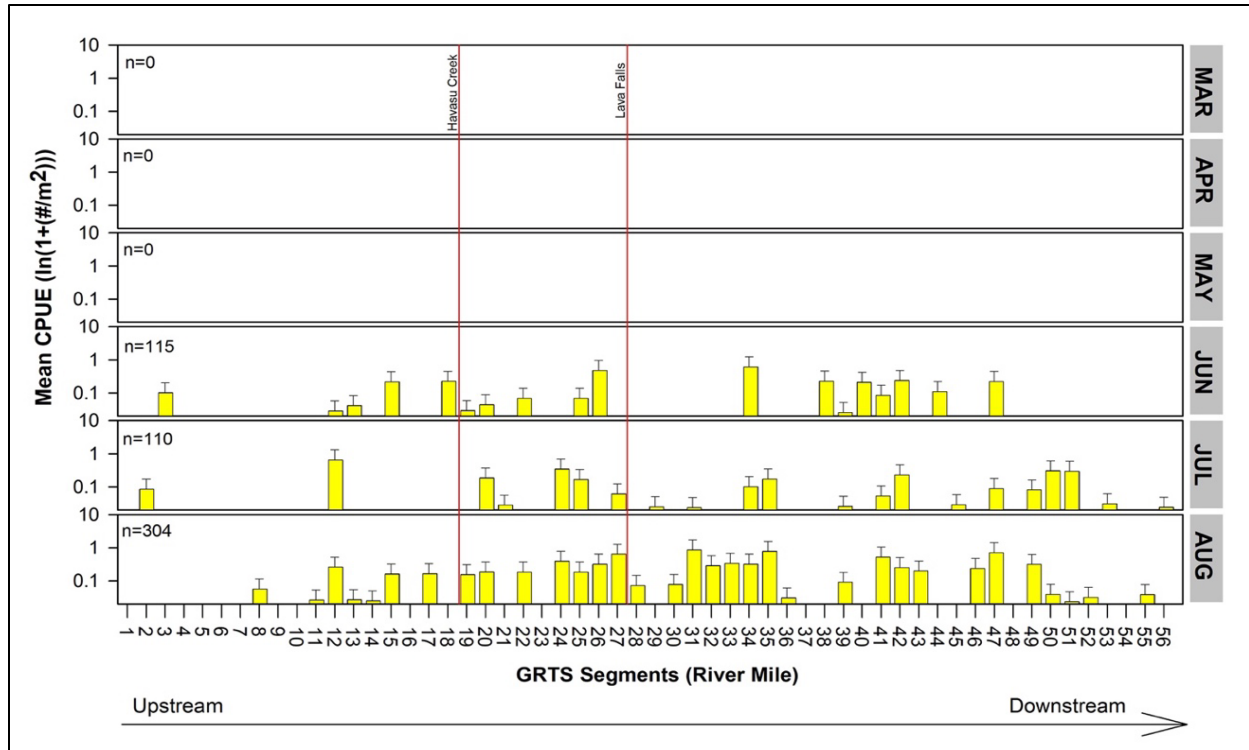


Figure 2.16. Mean catch-per-unit effort (CPUE) of age-0 Humpback Chub by 2023 sampling trip (month) and generalized random tessellation stratified (GRTS) segment. The y-axis scale is \log_{10} and error bars are ± 1 SE.

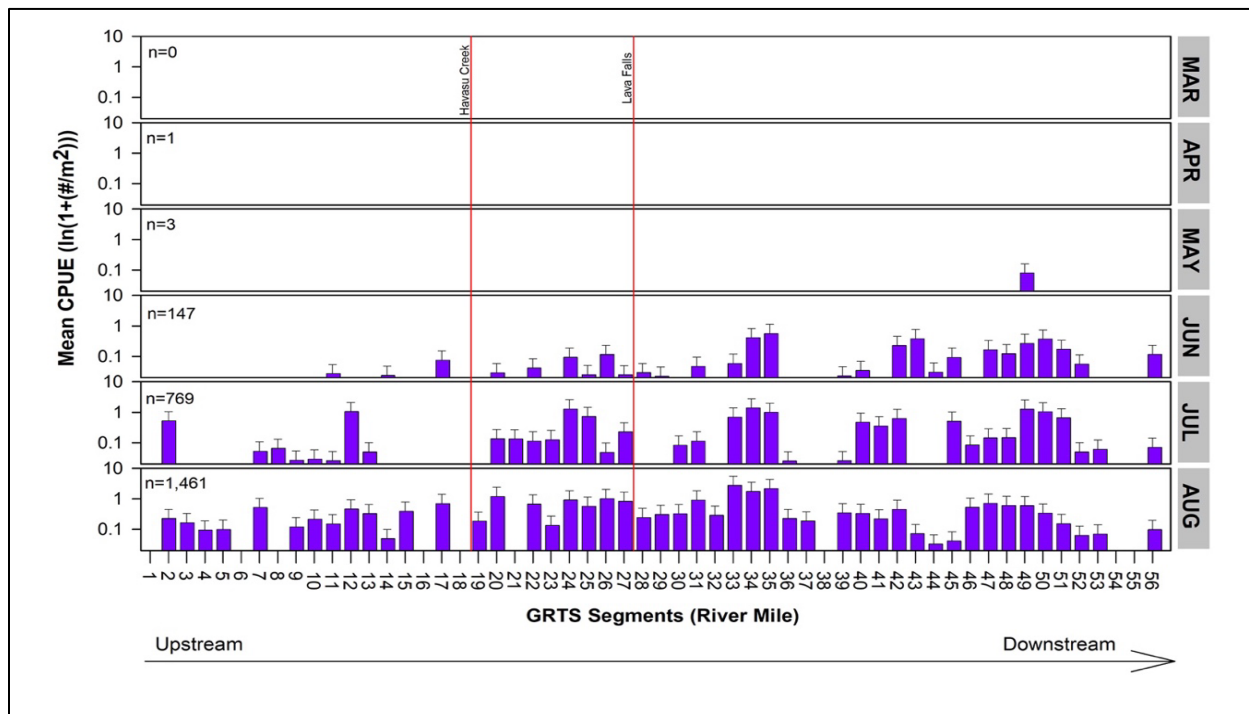


Figure 2.17. Mean catch-per-unit effort (CPUE) of age-0 Speckled Dace by 2023 sampling trip (month) and generalized random tessellation stratified (GRTS) segment. The y-axis scale is \log_{10} and error bars are ± 1 SE.

July: The July 2023 larval fish survey occurred 4–12 July (Table 2.7). Mean daily discharge over the duration of the July survey was high; however, sampling sites remained largely unchanged from June. Discharge, as measured from the USGS gage 09402500 near Grand Canyon, Arizona, ranged from 17,525 to 20,100 cfs, with mean daily discharge ranging from 19,006 to 19,270 cfs (19,152 mean cfs). Temperatures were much higher in July than they were in June, with air temperatures recorded at sampling locations reaching 43°C. Mainstem water temperatures recorded at sampling locations ranged from 18.8 to 23.6°C. Water clarity ranged from 7 to 82 cm, with turbidity increasing drastically downstream of Separation Canyon (RM 239.8).

Capture rate of age-0 fishes during the July survey was moderate but significantly higher than March–May surveys (ANOVA, $F_{5, 658}=41.84$, $P<0.001$; Tukey's HSD, $P<0.05$) (Figure 2.12). Catostomidae continued to be the most numerous and widely distributed age-0 fishes captured (Appendix E.6). Bluehead Sucker ($n=674$) and Flannelmouth Sucker ($n=941$) occurred in nearly every segment sampled and collectively comprised 60.3% of the total age-0 captures in July (Figures 2.13 and 2.14). Speckled Dace ($n=769$) and Humpback Chub ($n=110$) were the two most numerous native age-0 cyprinids captured during July 2023 (Appendix E.4). In July, Humpback Chub specimens were represented by all larval developmental phases except protolarvae.

Nonnative age-0 specimens were Fathead Minnow ($n=175$) and Western Mosquitofish ($n=12$). Captures of nonnative age-0 fish remained low and were less than 3% ($n=59$) of the total age-0 fish captured (Appendix E.4). During the July survey, 24 age-1 fishes were incidentally captured. The age-1 fish collected were primarily Speckled Dace ($n=14$; 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 2023 occurred 9–16 August (Table 2.7). Mean daily discharge over the duration of the August survey was high, with larger fluctuations than previous months. Discharge, as measured from the USGS gage 09402500 near Grand Canyon, Arizona, ranged from 11,575 to 19,525 cfs, with mean daily discharge ranging from 15,033 to 17,548 cfs (16,780 mean cfs). Mainstem water temperatures recorded at sampling locations ranged from 19.5 to 23.5°C. Water clarity ranged from 5 to 90 cm, with turbidity increasing rapidly downstream of Racetrack Camp at RM 134.2.

The larval fish capture rate in August was comparable to that of April and was significantly lower than it was during the May–July surveys (ANOVA, $F_{5, 658}=41.84$, $P<0.001$; Tukey's HSD, $P<0.05$) (Figure 2.12). Native species comprised 90% of the total age-0 fishes collected ($n=2,482$) in August 2023 (Appendix E.7). The most abundant native age-0 species collected in August 2023 was Speckled Dace ($n=1,461$), followed by Flannelmouth Sucker ($n=435$) (Figure 2.17). Cyprinidae was the most abundant family collected in August ($n=1,883$; 68.6%). The August survey produced 57.5% of the age-0 Humpback Chub collected in 2023. Retained age-0 Humpback Chub were represented by flexion mesolarvae ($n=2$), postflexion mesolarvae ($n=18$), metalarvae ($n=131$), and juveniles ($n=23$). Catch rates of nonnative age-0 fishes were very low in August (0.95% of total monthly fish catch). Plains Killifish was the most abundant of the five nonnative age-0 fish species collected ($n=109$; 3.97%), followed by Fathead Minnow ($n=107$;

3.90%). August produced the only age-0 Common Carp collected in 2023. Age-1 incidental captures during August were the second highest of months surveyed during 2023 (Appendix F.7). Speckled Dace was the most abundant age-1 species collected (n=139; 66.8%), followed by Flannemouth Sucker (n=15; 7.21%) and Plains Killifish (n=15; 7.21%).

Native and nonnative fishes: Both native and nonnative age-0 fishes were collected during the 2023 larval fish surveys, representing 13 species. Four of the 13 age-0 species were native fishes representing two families: Catostomidae (n=2 species) and Cyprinidae (n=2 species). Native fishes numerically dominated the monthly captures in 2023 (95.4%) and were taken at all 56 GRTS segments (RM 88.6–279.0) (Figure 2.18). Native catostomids, Bluehead Sucker (n=2,637) and Flannemouth Sucker (n=4,151), were the two most commonly captured age-0 species, collectively accounting for 66.8% of age-0 fishes.

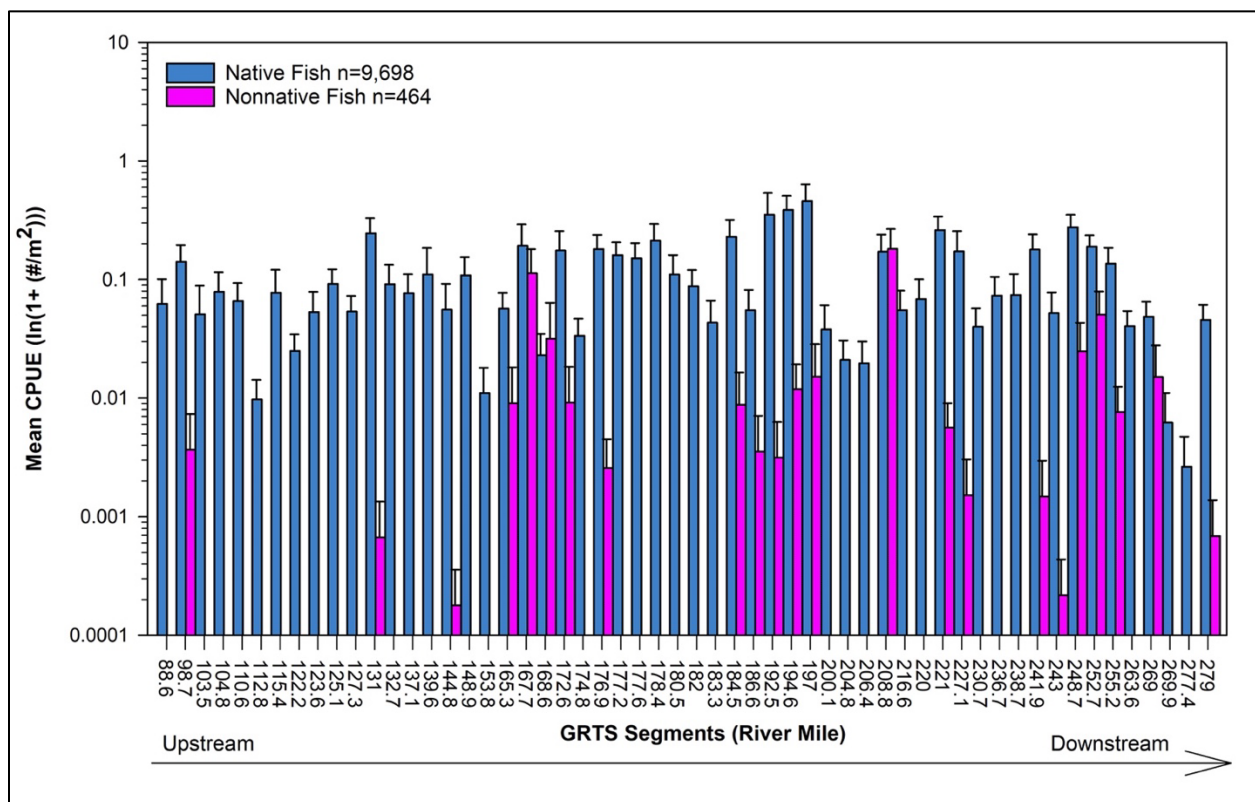


Figure 2.18. Mean catch-per-unit effort (CPUE) of age-0 native and nonnative fishes by generalized random tessellation stratified (GRTS) segment for 2023 survey months (March–August) combined. The y-axis scale is log₁₀.

Native cyprinids, Speckled Dace (n=2,381) and Humpback Chub (n=529), were the next most abundant age-0 species collected. Notably, early-staged larval Humpback Chub were collected in higher abundances in 2023 than in previous study years. Nonnative age-0 fishes were found in low densities throughout the study area and were represented by seven species and 457 specimens. The most abundant nonnative age-0 species captured were Fathead Minnow (n=289), Plains Killifish (n=109), and Western Mosquitofish (n=46). Overall, nonnative age-0 fishes (n=457) represented a small proportion (0.04%) of the total age-0 captures (n=10,163) (Appendix E.1). April and May surveys did not produce a single nonnative age-0 capture. The

August survey produced the most nonnative age-0 species (n=261), followed by July (n=187). A single age-0 Common Carp was collected during the August survey in 2023. Green Sunfish, an invasive and piscivorous species of concern collected during previous years (2019–2020), was not collected in 2021 or 2022. However, two age-1 Green Sunfish were collected in 2023 (March: n=1; May: n=1). The March survey produced the only captures of age-0 Salmonidae in 2023 (Brown Trout [n=1] and Rainbow Trout [n=1]).

Unidentified Larval Specimens

Of the 10,163 age-0 fishes collected in the 2023 Grand Canyon study, only 7 specimens were not identified to species; all were all Catostomidae (*Catostomus* and *Xyrauchen*). These individuals were not identified to species because they did not exhibit a sufficient suite of morphological characters necessary to assign species identity with a high level of confidence. Many of the specimens exhibited one character indicative of one species and an additional character indicative of a different species.

These seven fish were collected during March, May, June, and July surveys in seven discrete samples between RM 168.6 and RM 241.9. Unidentified larval catostomid specimens were distributed across the two developmental stages (flexion mesolarvae n=6, post-flexion mesolarvae n=1). Laboratory notes associated with the unidentified fish indicate that many of the specimens are likely Bluehead Sucker (with unusual pigmentation) and potential Flannelmouth Sucker x Razorback Sucker hybrids. However, these notes are 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 27 unidentified specimens from 2021 to 2022 and the 7 unidentified specimens from 2023. The purpose of the analysis is to provide species-specific identifications of the larval specimens and can also determine if the parents of the specimens are of the same (i.e., “pure”) or different (i.e., “hybrid”) species.

Razorback Sucker

Larval Razorback Sucker were collected in Grand Canyon for six consecutive years during the study period (2014–2019). The number of larval Razorback Sucker 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 (Figures 2.19, 2.20, 2.21, and 2.22).

Razorback Sucker larvae have not been collected during the past four surveys (2020, 2021, 2022, or 2023); however, it is important to note that sampling was not conducted in April or May 2020 due to National Park closure. From 2014 through 2019, April and May surveys 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%).

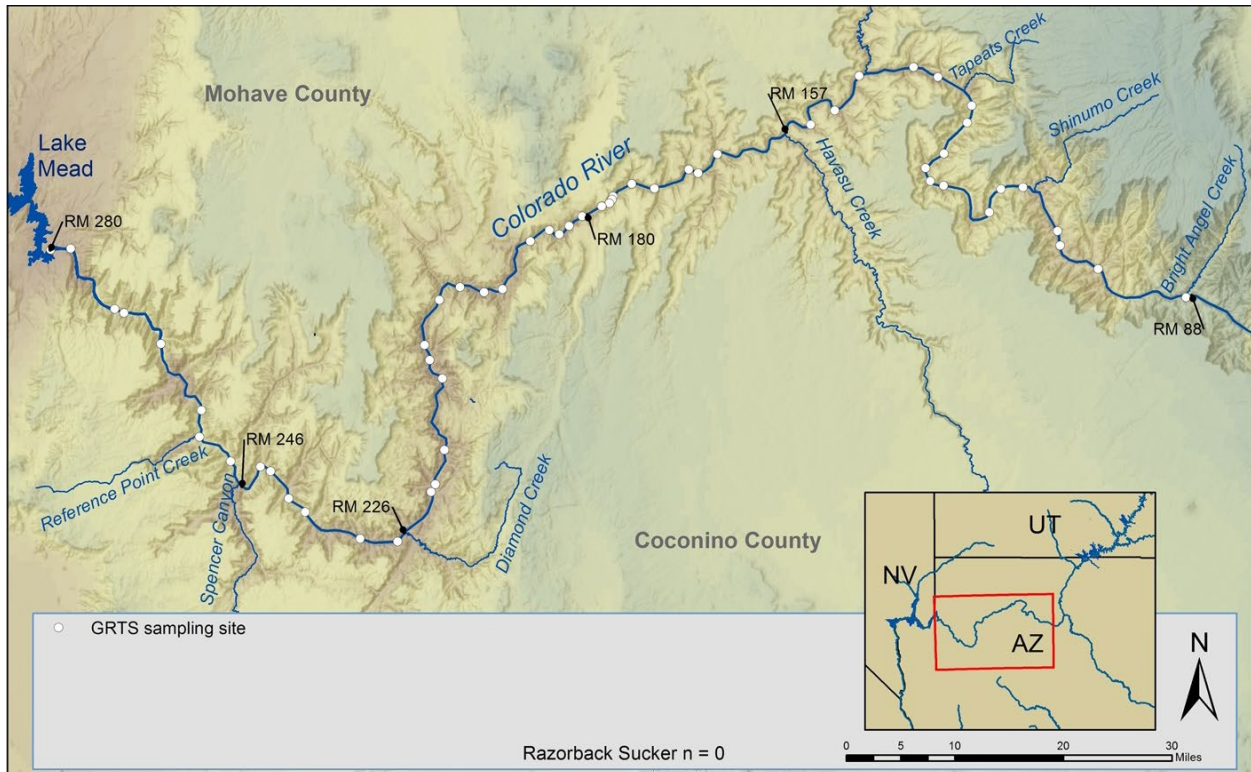


Figure 2.19. Frequency of occurrence of larval Razorback Sucker at generalized random tessellation stratified (GRTS) segments during the 2023 larval fish survey. None collected in 2023. Graph is a placeholder for between-year consistency.

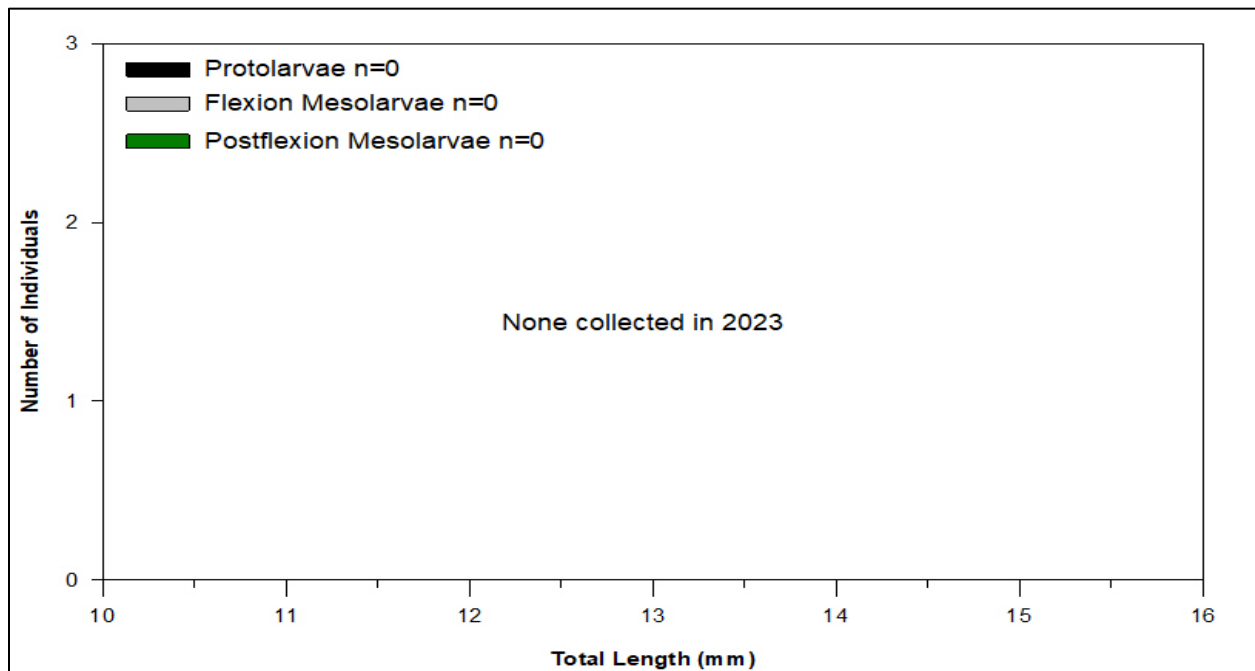


Figure 2.20. Distribution of total lengths (TL) of larval Razorback Sucker during the 2023 larval fish survey. None collected in 2023. Graph is a placeholder for between-year consistency.

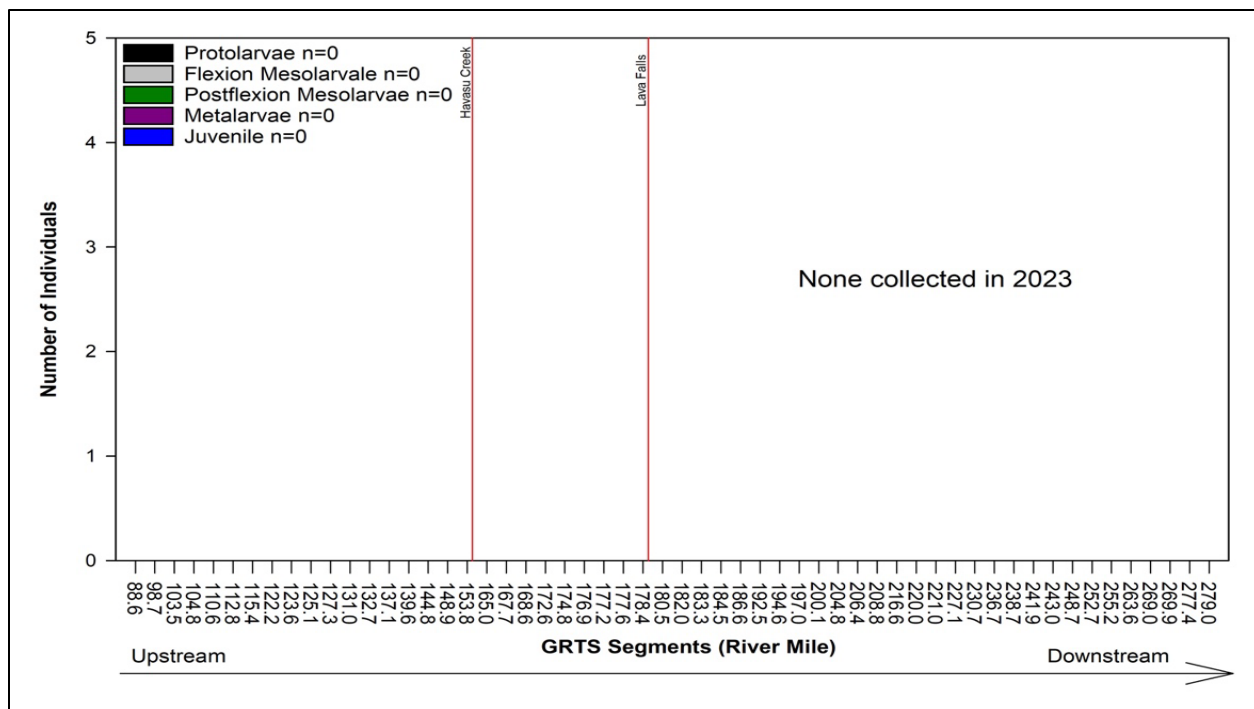


Figure 2.21. Spatial and ontogenetic stage distribution of larval Razorback Sucker during the 2023 larval fish survey. None collected in 2023. Graph is a placeholder for between-year consistency.

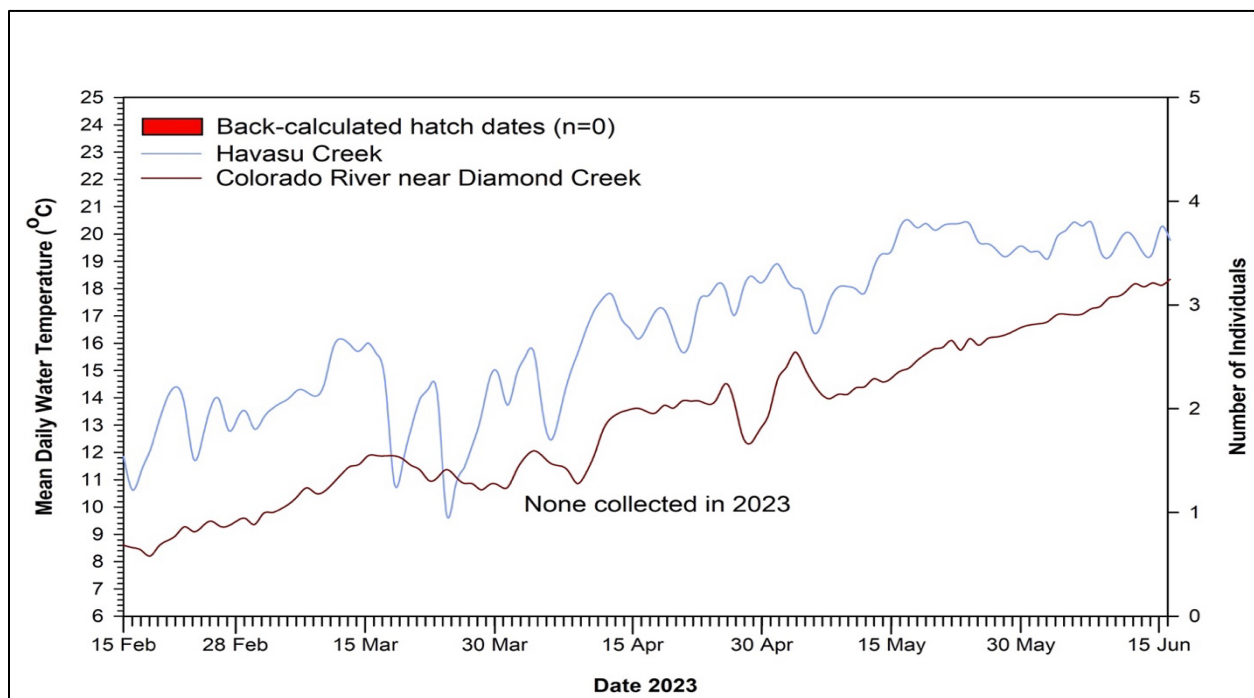


Figure 2.22. Water temperature of Havasu Creek (USGS gauge 0940115) and the Colorado River near Diamond Creek (RM 229.6) displayed with the back-calculated hatch dates of Razorback Sucker based on 2023 larval fish standard length (SL). None were collected in 2023. The graph is a placeholder for between-year consistency.

Humpback Chub

Larval fish sampling in 2023 yielded 529 age-0 Humpback Chub from RM 98.7 to the downstream-most site in the study area (RM 279.0) (Figure 2.23). Retained age-0 specimens ranged from 9.5 to 34.8 mm TL and were represented by flexion mesolarvae, postflexion mesolarvae, and metalarvae ontogenetic stages—no protolarvae were collected in 2023 (Figures 2.24 and 2.25). The first age-0 Humpback Chub were collected during the June survey, a month later than in previous years.

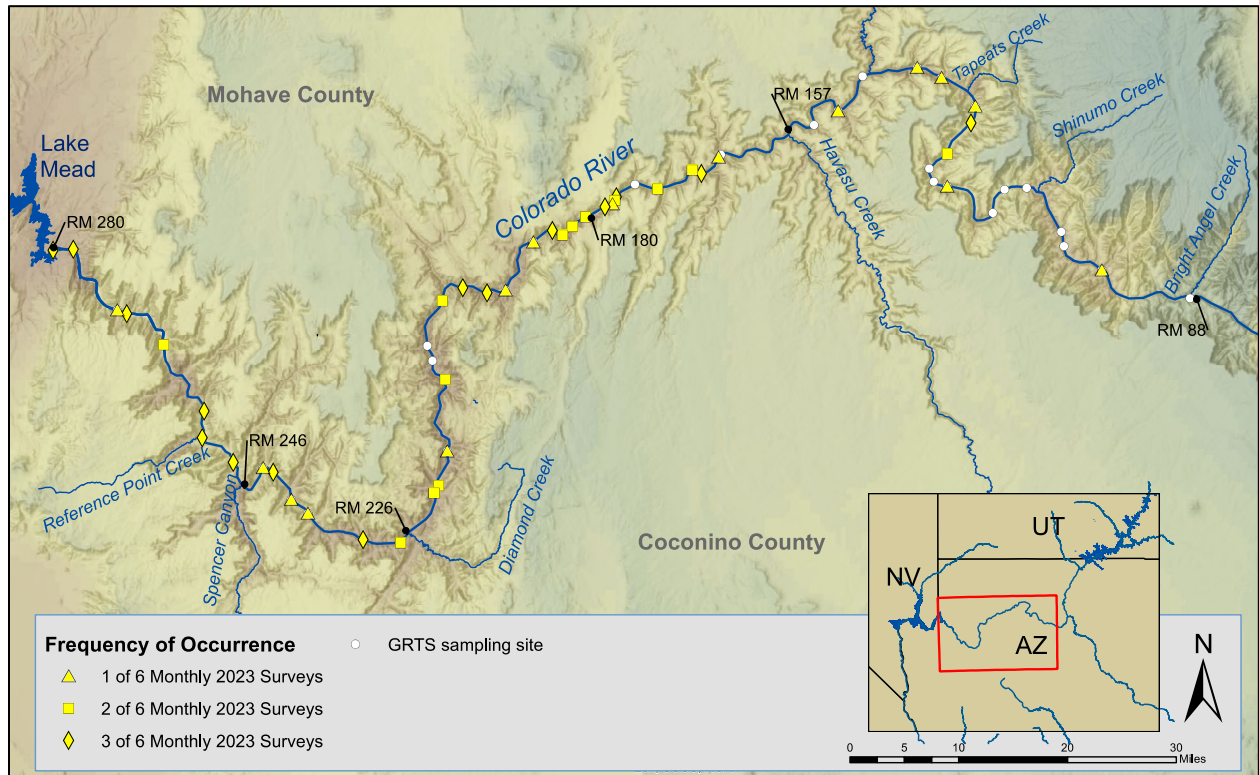


Figure 2.23. Frequency of occurrence of larval Humpback Chub at generalized random tessellation stratified (GRTS) segments during the 2023 larval fish survey.

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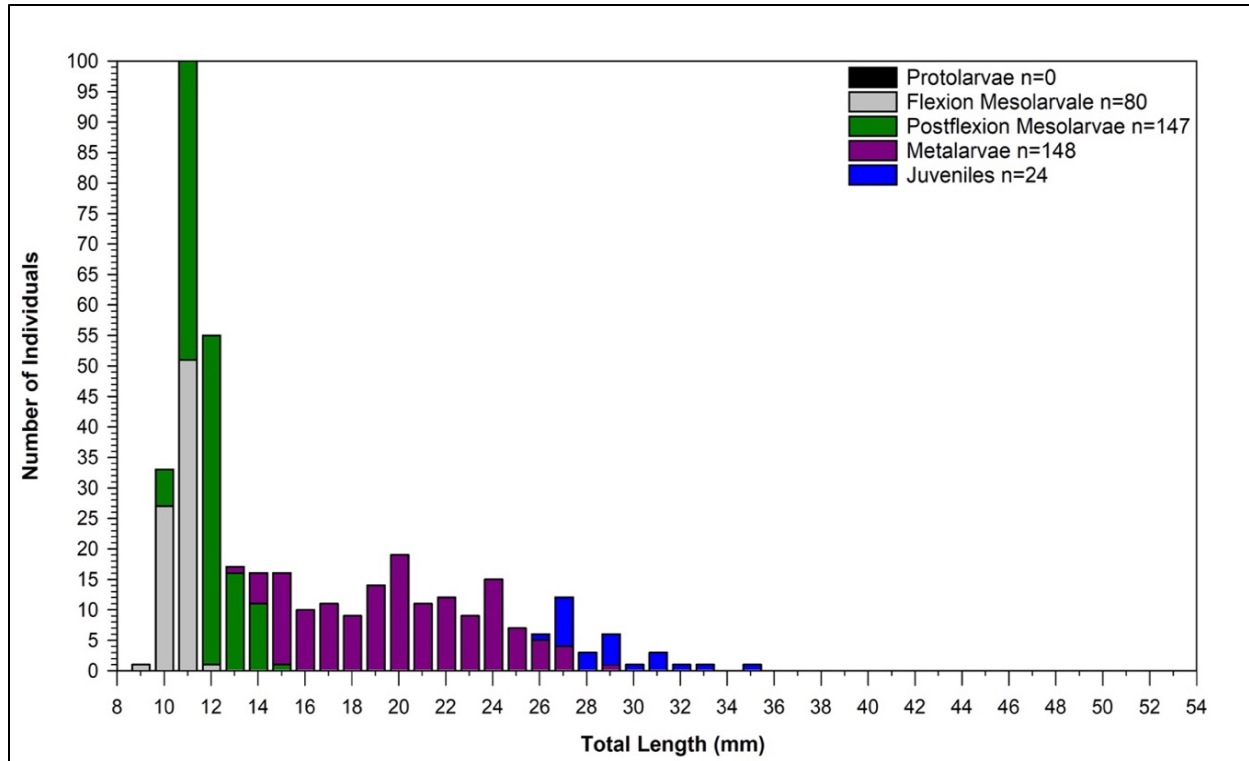


Figure 2.24. Distribution of total lengths (TL) of age-0 Humpback Chub captured during the 2023 larval fish survey.

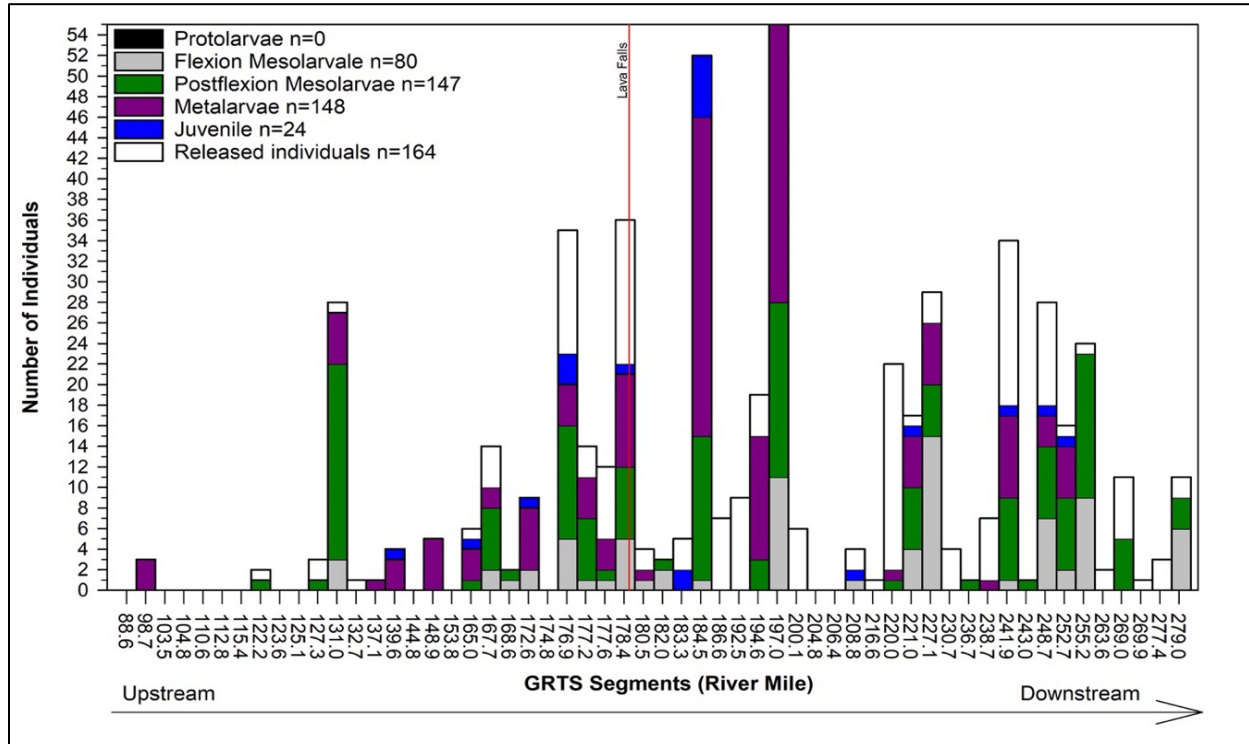


Figure 2.25. Spatial and ontogenetic stage distribution of Humpback Chub captured during the 2023 larval fish survey.

The August survey produced 304 Humpback Chub, which accounted for 57.5% of the age-0 Humpback Chub collected during 2023. The first metalarval ($n=17$) and juvenile Humpback Chub ($n=1$) were collected in July. Age-0 Humpback Chub collected in July and August were represented by all ontogenetic stages except protolarvae. Humpback Chub collected during 2023 showed a trend of increasing abundance and ontogenetic phase progression with distance downstream during June–August (Figure 2.25). The upstream-most collection of larval Humpback Chub ($n=3$) in 2023 occurred at RM 98.7 during the July survey.

Back-calculated hatch dates for larval Humpback Chub ($SL < 30$ mm) in 2023 spanned approximately 4 months, from 25 May to 3 August 2023 (Figure 2.26). The distribution of hatch dates suggests multiple hatch peaks occurred, beginning in late May through early June, with an additional peak occurring in late June through early August. The largest peak occurred in late May, followed by a decline in early through mid-June. Catch rates of Humpback Chub were significantly different across months (ANOVA, $F_{5, 658}=17.56$, $P < 0.001$); catch rates in August were significantly higher than those observed during the other monthly surveys (Tukey's HSD, $P < 0.05$).

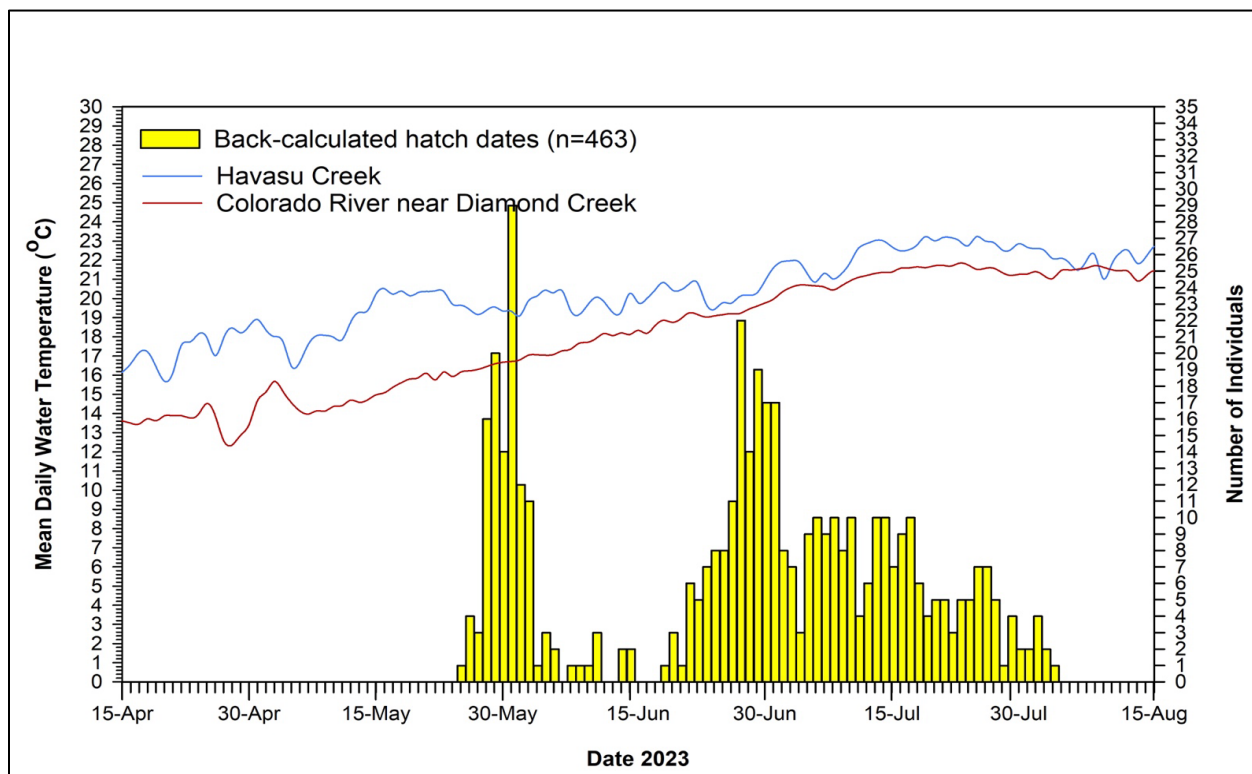


Figure 2.26. Back-calculated hatch dates of 2023 larval Humpback Chub based on standard lengths (mm).

Habitat

Eleven distinct mesohabitat types were sampled during the 2023 larval fish survey (Figure 2.27). Habitats were sampled in relatively similar proportions during 2023 as in previous years (2016–2022); the largest change in habitats sampled in 2023 was a decrease in the percentage of sandshoals sampled (Table 2.8). This decrease is likely due to elevated magnitudes of discharge throughout the majority of the study period. Additionally, sediment was rapidly redistributed downstream following the April HFE, potentially resulting in a decrease in shoal habitats throughout the study area between the May and August surveys.

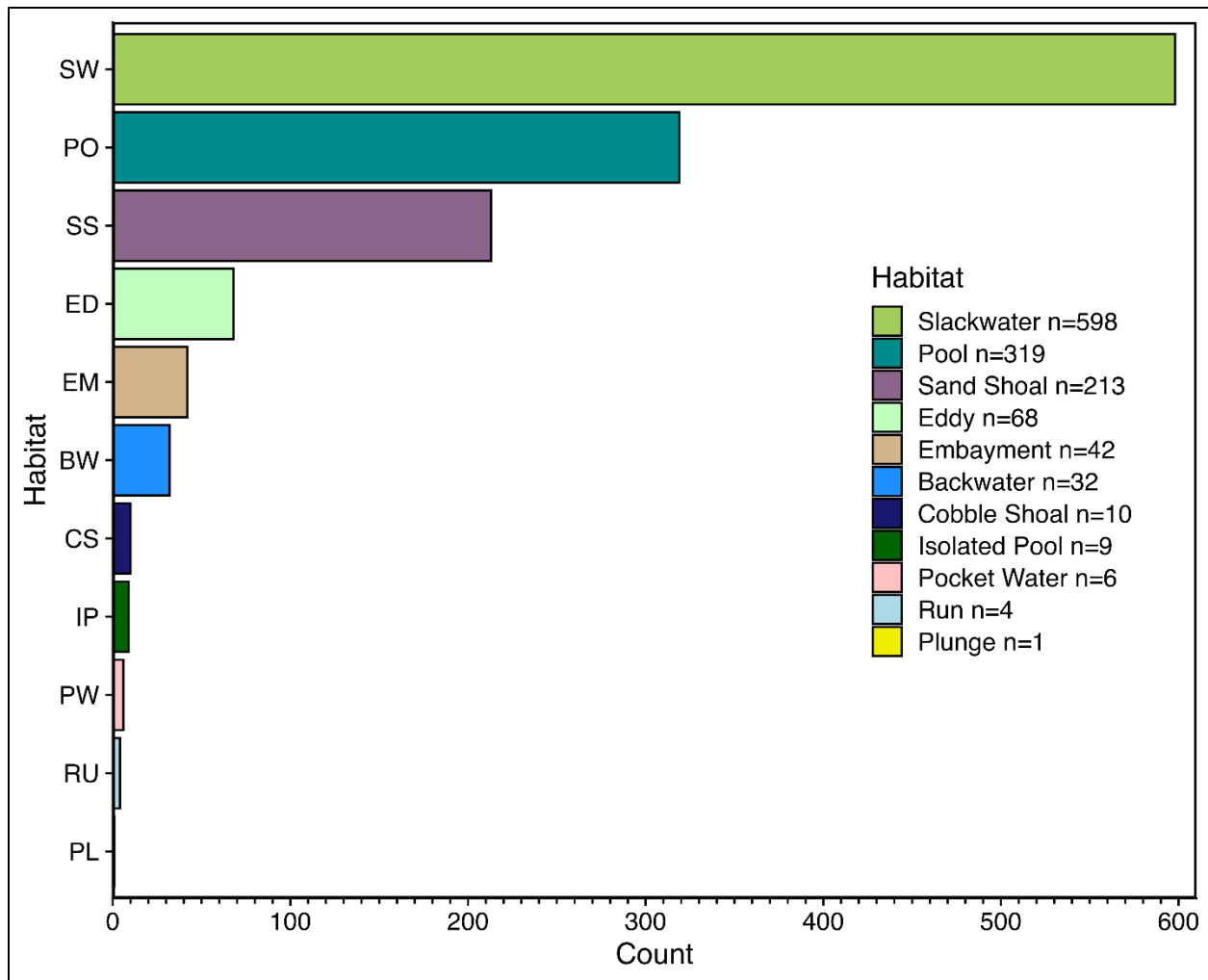


Figure 2.27. Distribution of habitats sampled at generalized random tessellation stratified (GRTS) segments during the 2023 larval fish survey.

Table 2.8. Habitats sampled (percent) from monthly 2017–2023 larval fish surveys.

| HABITAT | HABITAT SAMPLED 2017 | HABITAT SAMPLED 2018 | HABITAT SAMPLED 2019 | HABITAT SAMPLED 2020 | HABITAT SAMPLED 2021 | HABITAT SAMPLED 2022 | HABITAT SAMPLED 2023 | PERCENT CHANGE ^a 2017–2023 |
|---------------|----------------------------|----------------------------|----------------------------|----------------------------|----------------------------|----------------------------|----------------------------|---|
| Isolated Pool | 1.35% | 1.49% | 0.90% | 1.21% | 2.25% | 0.60% | 0.70% | 0.60 |
| Backwater | 6.29% | 4.99% | 5.39% | 1.95% | 1.65% | 1.27% | 2.50% | 1.09 |
| Embayment | 6.29% | 3.65% | 7.04% | 5.19% | 4.27% | 1.71% | 3.20% | 1.49 |
| Sandshoal | 23.28% | 22.17% | 23.65% | 24.58% | 19.54% | 26.94% | 16.40% | 6.96 |
| Cobbleshoal | 1.27% | 1.56% | 1.27% | 1.11% | 1.42% | 0.82% | 0.80% | 0.44 |
| Pool | 19.24% | 20.23% | 19.54% | 26.81% | 32.11% | 21.65% | 24.50% | 1.24 |
| Pocketwater | 2.40% | 0.82% | 0.45% | 0.19% | 0.30% | 0.82% | 0.50% | 0.33 |
| Slackwater | 37.28% | 40.85% | 40.87% | 37.76% | 36.98% | 40.63% | 45.90% | 6.84 |
| Eddy | 1.70% | 4.09% | 0.60% | 1.02% | 1.50% | 5.36% | 5.20% | 2.82 |
| Run | 0.90% | 0.15% | 0.30% | 0.09% | 0.00% | 0.22% | 0.30% | 0.02 |

^aPercent change (absolute value): current year percent sampled minus mean of previous years percent sampled.

Catch rates of age-0 fishes differed across habitats (ANOVA, $F_{10, 653}=5.947$, $P<0.001$); catch rates in pool 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 2023 except isolated pools, while Flannelmouth Sucker was taken in all 10 habitat types (Figure 2.28). Humpback Chub was also collected in most habitat types sampled during 2023 (except runs, plunges, and pocket water habitats). Humpback Chub captures predominantly occurred in pool (57.7%; $n=305$), slackwater (23.6%; $n=125$), or embayment (11.0%; $n=58$) habitats. Habitats yielding the remaining specimens of Humpback Chub included cobbleshoals, sandshoals, backwaters, eddies and isolated pools. Catch rates of Humpback Chub were significantly different across habitat types (ANOVA, $F_{10, 653}=4.071$, $P=0.15$); catch rates were significantly higher in pool habitats than any other habitat type sampled (Tukey's HSD, $P<0.05$).

Ontogenetic Phase Distributions

Native fishes collected were represented by flexion mesolarval ontogenetic phase through early juvenile; no protolarvae were collected in 2023. The developmental stages of catostomids in 2023 showed increasing maturity along a downstream longitudinal gradient. Increasing monthly percentages of late-stage larvae and early juveniles at downstream sites was evident for Flannelmouth and Bluehead Sucker (Figures 2.29 and 2.30). Similarly, the percentage of late-stage larvae and early juveniles increased with each progressive monthly survey. This spatiotemporal pattern in ontogenetic phase distribution is apparent in all years when catostomids were ontogenetically staged (2016–2023). The initial 2023 captures of catostomid larvae occurred at sites downstream of Havasu Creek (RM 157.3), similar to results from larval fish surveys in previous years (2016–2022). By June 2023, larval catostomids increased in distribution and abundance, encompassing the entire study area (Figures 2.29 and 2.30). Flexion mesolarval and post-flexion mesolarval catostomids were captured in greater densities than any other ontogenetic stage. The June and July surveys produced the greatest number of mesolarval catostomids ($n=5,827$).

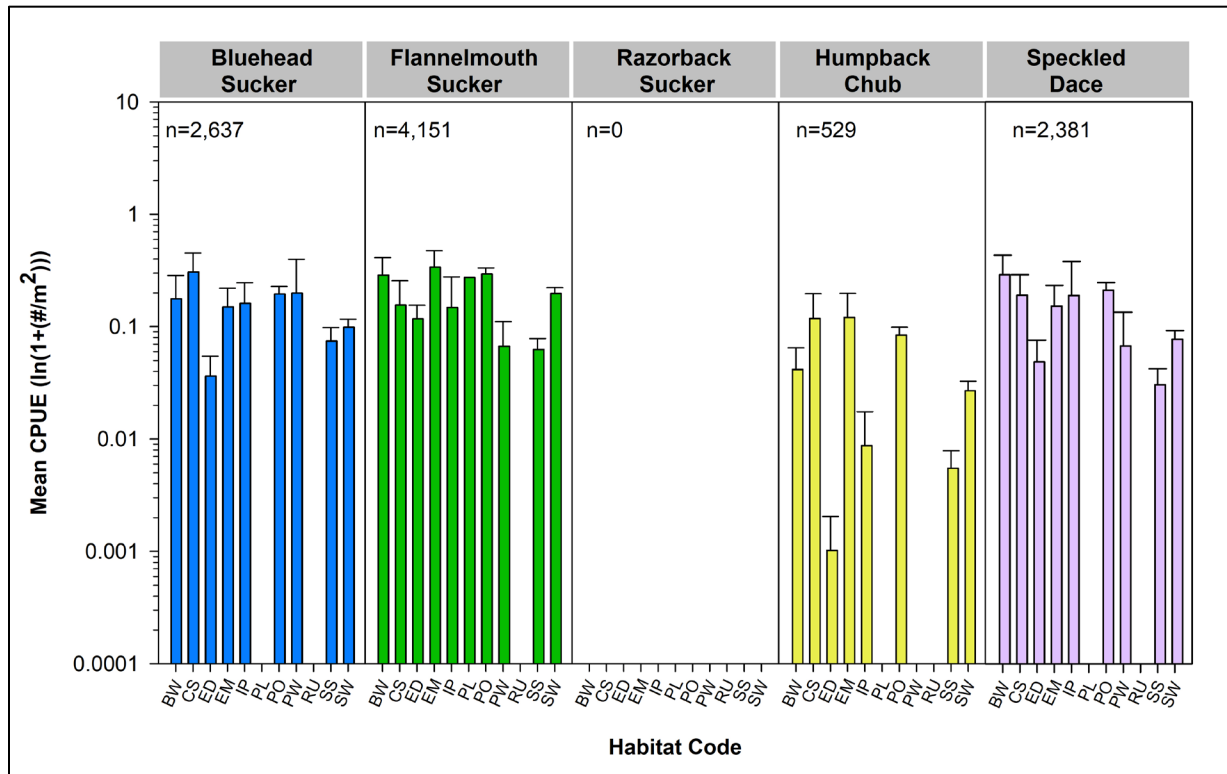


Figure 2.28. Mean catch-per-unit effort (CPUE) by species and habitat type during the 2023 larval fish survey. The y-axis scale is log₁₀ and error bars are ±1 SE.

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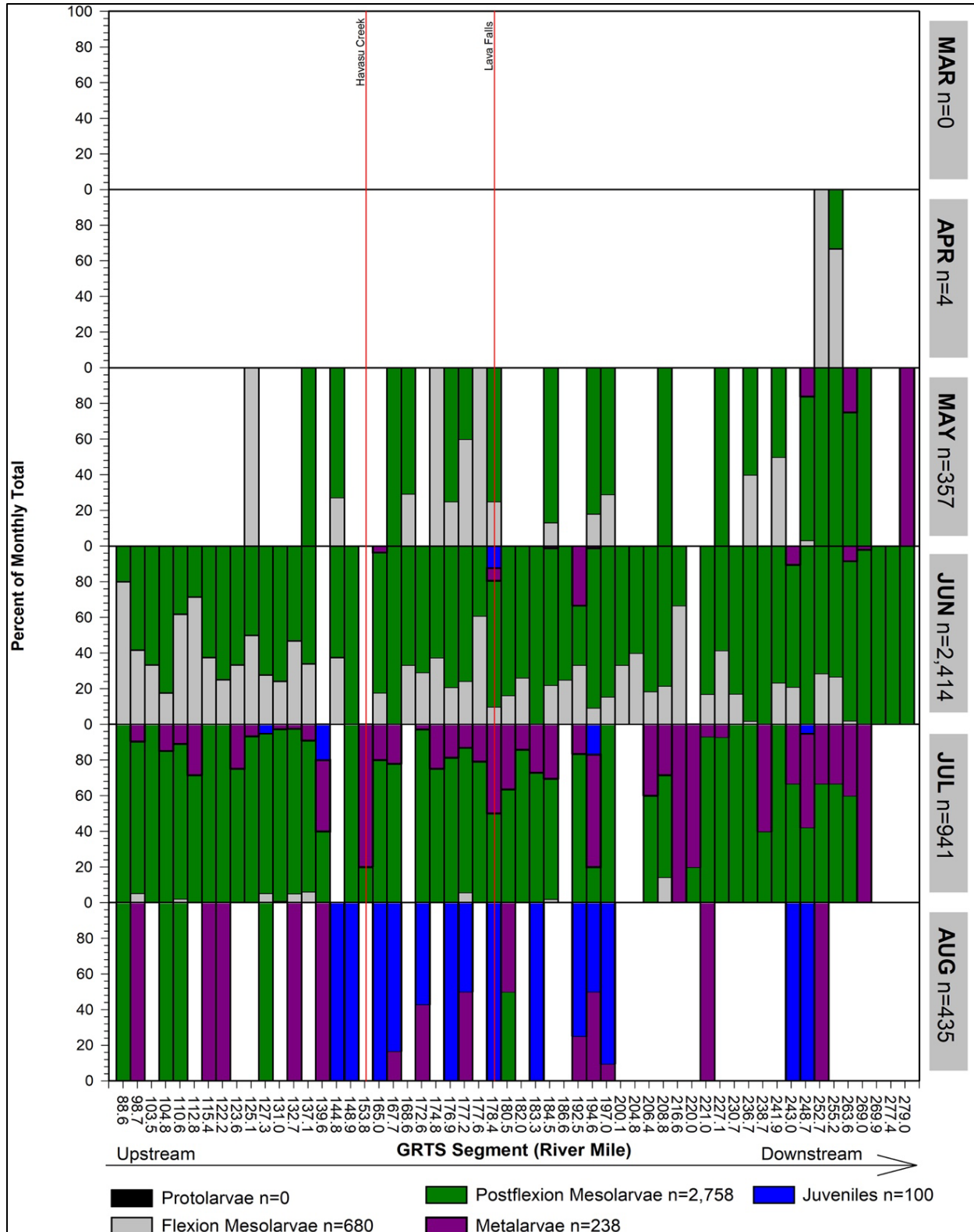


Figure 2.29. Longitudinal distribution of ontogenetic phases for age-0 Flannelmouth Sucker by 2023 sampling trip (month) and generalized random tessellation stratified (GRTS) segment.

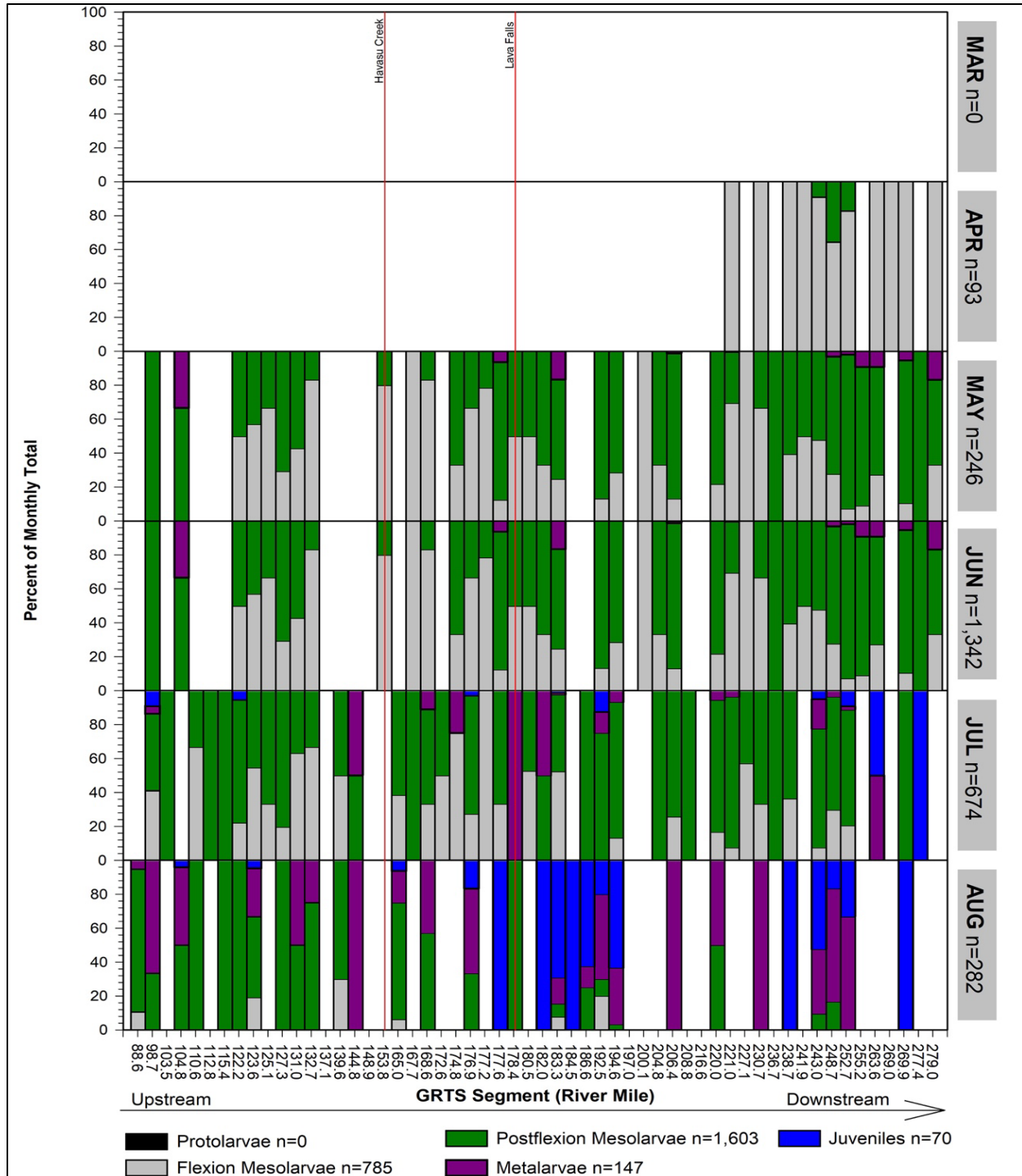


Figure 2.30. Longitudinal distribution of ontogenetic phases for age-0 Bluehead Sucker by 2023 sampling trip (month) and generalized random tessellation stratified (GRTS) segment.

The first appearance of larval Humpback Chub is typically in May; however, the first larval Humpback Chub captures in 2023 occurred in June ($n=3$) at RM 131, approximately 26 river miles above Havasu Creek (Figure 2.31). In July, the upstream most collection of Humpback Chub larvae occurred at RM 98.7, while the upstream most specimen in August was collected at RM 122.2. During 2023, larval and juvenile Humpback Chub were distributed across 180.3 river miles (RM 98.7–RM 279.0), encompassing 94.7% of the study area. Over 35% of Humpback Chub captured (including both retained and released) had recruited to the early juvenile stage.

Distribution of the earliest developmental stages can be used to infer spatial patterns of spawning over time. The protolarval stage is the earliest and shortest of the larval developmental phases, and recently hatched larvae spend much of that stage in the interstitial zones of spawning areas. As such, captures of this ontogenetic stage are often difficult to achieve. Additionally, many larval fishes experience a period of drift after hatch. The hypothesis is that captured protolarvae are likely taken in relatively close proximity to the parental spawning area. Protolarvae were not captured for any species throughout the 2023 sample period (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, which may stimulate spawning and more rapid 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 Humpback Chub later in the year (July–August) (Figure 2.31).

Supplemental Investigations of Larval Fish Community Sampling (2014–2023)

Project researchers continually evaluate the results of the study and make recommendations for appropriate modifications, as needed. The most important project modification to date was the 2016 upstream expansion of the study area, which was made in response 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/m² GRTS and 1.33 fish/m² 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.

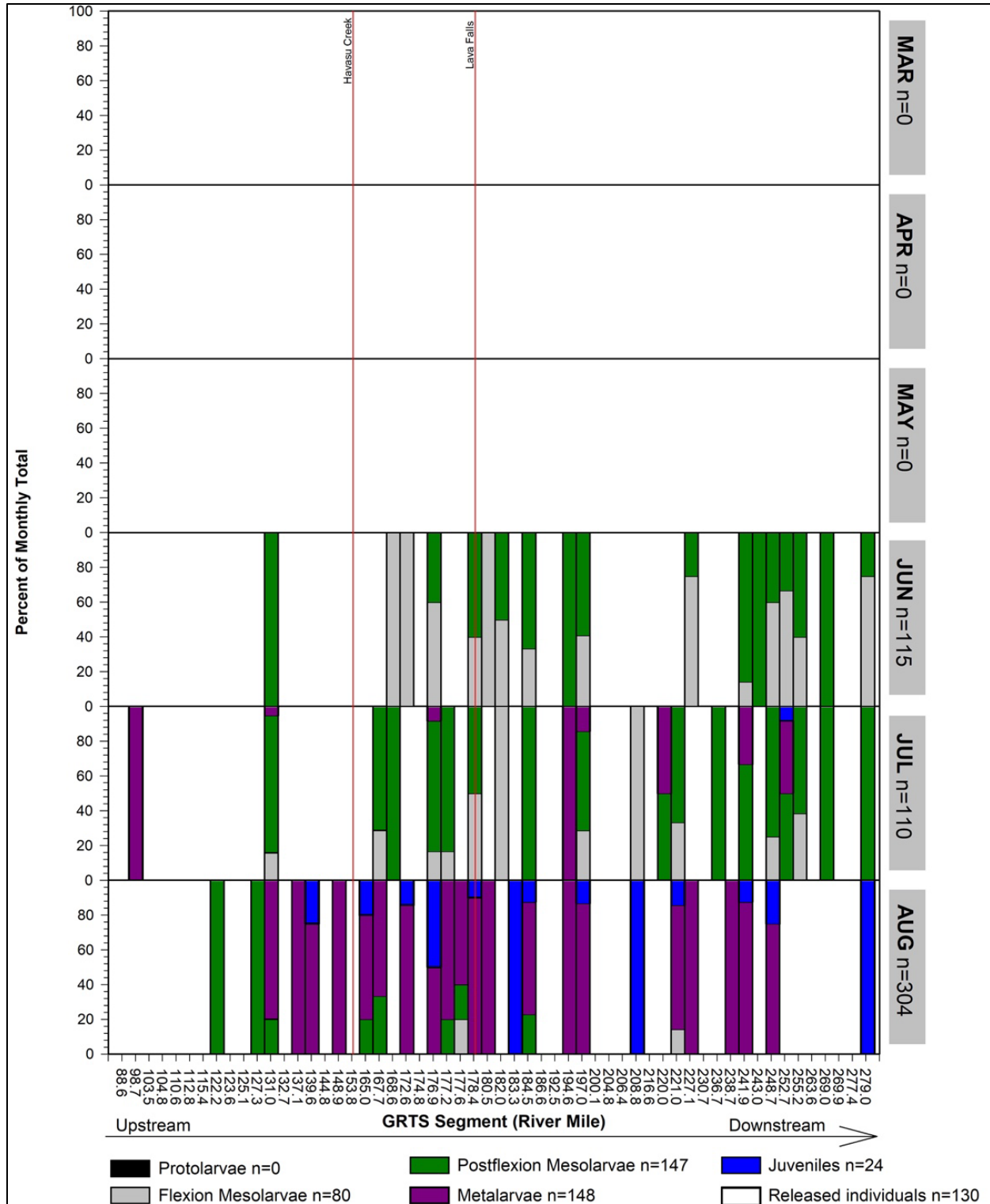


Figure 2.31. Longitudinal distribution of ontogenetic phases for age-0 Humpback Chub by 2023 sampling trip (month) and generalized random tessellation stratified (GRTS) segment.

In 2021, the effect of the upstream expansion of the study area (in 2016) 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 only had 29 sites in the lower 100 river miles (RM 179.0–279.0), whereas previously, there had 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 to 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 period (2014–2021).

A Tukey's HSD post-hoc test ($\alpha=0.05$) 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%). 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).

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 unexplained anomaly. Continued larval fish sampling in Grand Canyon may elucidate factors that contributed to the elevated 2014 annual catch rate. In the meantime, this analysis provides statistical validity to continue comparisons of catch rates of larval fishes in the Grand Canyon across years.

Larval Fish Community Sampling Summary (2014–2023)

During the entirety of the study period (2014–2023), larval fish community sampling in Grand Canyon has consistently documented annual reproduction by four 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 inability to sample during April and May 2020 (because of the National Park closures during the SARS-CoV-2 pandemic), which are the two months of the year that formerly yielded greater than 90% of larval Razorback Sucker collected 2014–2019, precluded inferences on reproduction of Razorback Sucker that year. Razorback Sucker larvae were not collected during the 2020–2023 surveys. Consistent with previous survey years (2014–2022), native fishes comprised the majority (95%) of age-0 fishes collected in Grand Canyon during 2023 (Figure 2.18). Catch rates of age-0 Catostomidae have been consistently higher than age-0 Cyprinidae across all years of the study period (Figure 2.33).

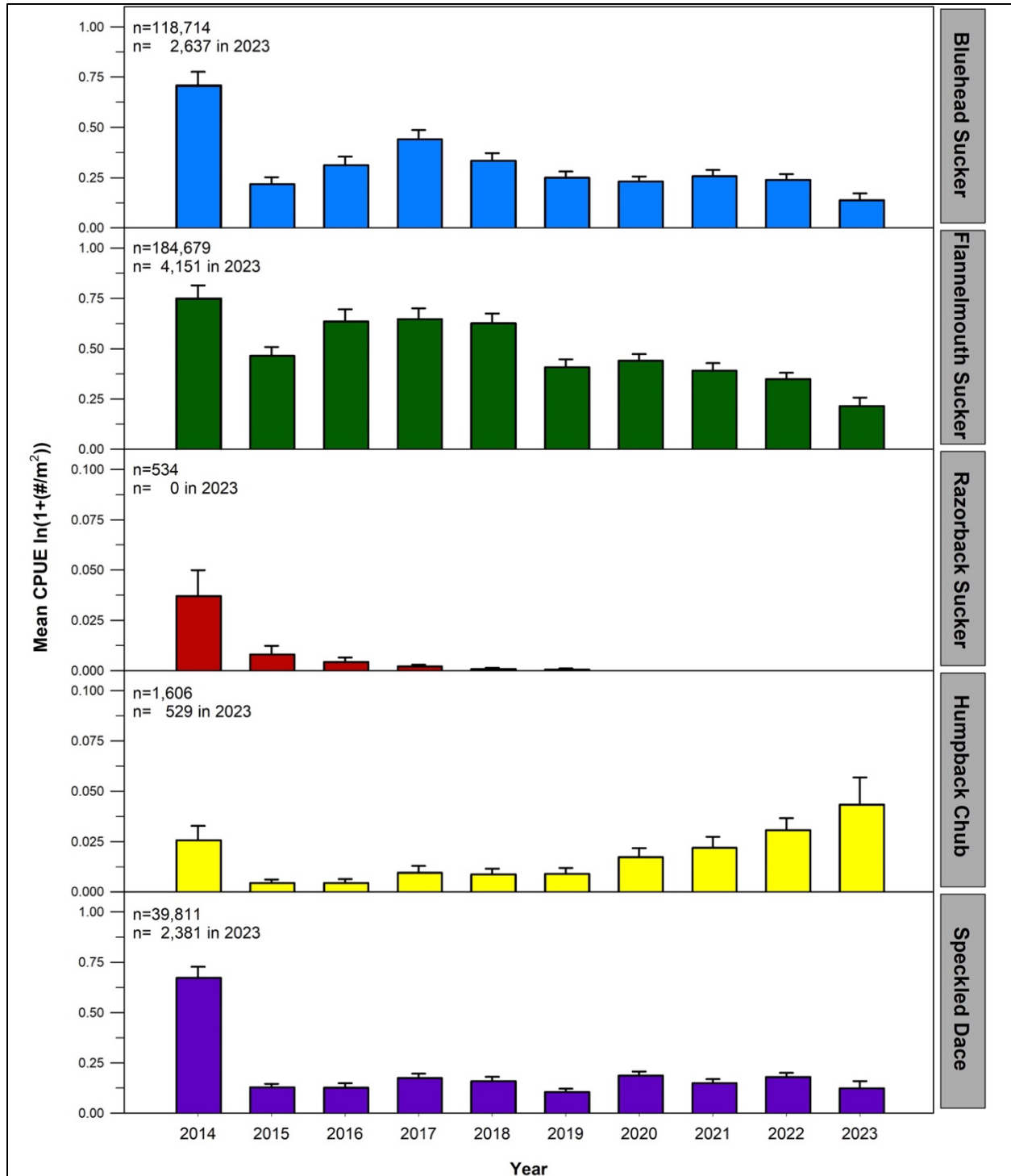


Figure 2.32. Mean catch-per-unit effort (CPUE) of age-0 native fishes by year (2014–2023). The y-axis scales for Razorback Sucker and Humpback Chub are, compared to other species, reduced by one order of magnitude. Error bars are 95% confidence intervals.

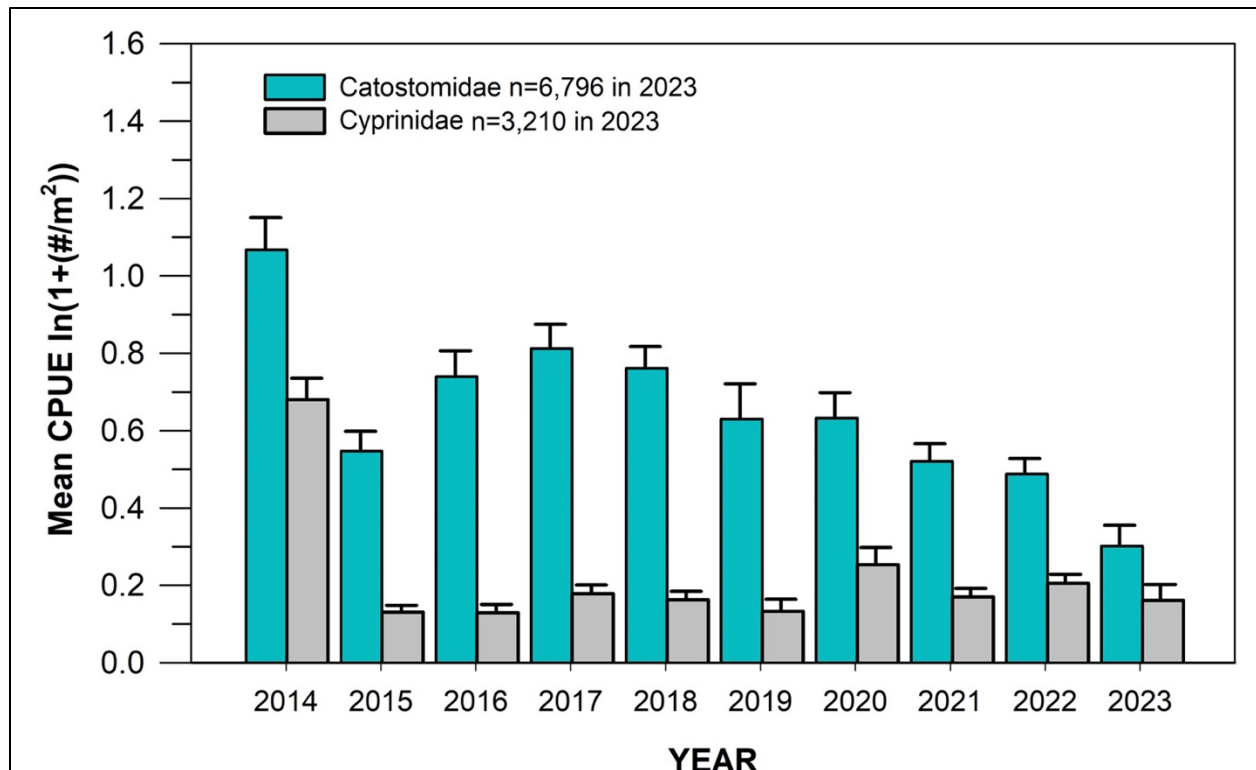


Figure 2.33. Annual mean catch-per-unit effort (CPUE) of age-0 catostomids and cyprinids between 2014 and 2023. Error bars are 95% confidence intervals.

While intraspecific age-0 larval fish densities (as expressed using 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 2023 and 2022 than during 2015–2020 ($P < 0.05$); however, this species has typically occurred in low abundances relative to the other native species (Figure 2.32).

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 2023, 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 recruiting or cannot recruit within Grand Canyon or perhaps the CRI, because 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 has been a fairly regular occurrence during small-bodied fish community sampling within Grand Canyon. Young Humpback Chub have been observed to be 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. Additionally, since 1978, no Colorado Pikeminnow *Ptychocheilus lucius* have been captured in Grand Canyon (Dibble et al. 2023). Recently, Dibble et al. (2023) has recommended that Colorado Pikeminnow be repatriated to the Grand Canyon in an experimental capacity. The current methods of this project are ideal to aid in tracking the success of this effort via telemetry infrastructure that is currently deployed, as well as small-bodied and larval seining efforts to document spawning and recruitment of all native and nonnative fishes.

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 2023 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 during 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 barrier, 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 its distance from the nonnative fishes of Lake Mead 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 and Walleye were captured during small-bodied seining. These species were observed again in 2023, which may be a concern in the near future if they were to become

established in the river. Early detection and continued monitoring may aid in a quick response to eradicate any threatening species before they become detrimental to the native fishes. These 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. Burgad (et al. 2023) suggests that despite vast data collection, understanding the holistic interactions of species within the Colorado River basin is complex and the dynamic nature of the system requires constant attention. 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

Long-term larval fish surveys provide valuable empirical data on abundance and distribution of native and nonnative fishes across time. The 2023 larval fish survey continued to document spatial and temporal trends related to the timing and magnitude of reproduction for native and nonnative fishes in Grand Canyon. Additionally, the results of the 2023 sampling effort indicate the age-0 fish community consists predominantly of native species. The systematic design of this study provides crucial insights into the composition of Grand Canyon native and nonnative fish communities over time. Larval fishes serve as valuable indicators of the ecological integrity of the river; as such, the long-term robust dataset produced by this sampling effort can inform future management strategies.

This study also documents fish community responses to environmental variation over time. In 2023, discharge of the Colorado River during the sampling period (March–August) reached the highest magnitude since the inception of the project in 2014. In addition to the immediate habitat changes following the HFE, discharge remained high and relatively stable with little diel fluctuation for the remainder of the 2023 study period. As a result, sampling conditions during the May–August trips were deep and swift relative to previous surveys. Capture rates of age-0 fishes remained relatively low from March through May.

Since its inception in 2014, there have been several adaptive changes to the timing and spatial extent of the larval fish surveys in Grand Canyon to document the presence of federally endangered Razorback Sucker (USFWS 2021). These changes were initiated after detailed review of previous field data. The addition of an earlier monthly sampling trip (March) beginning in 2015—an effort to better identify the initiation of Catostomidae spawning—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 Sucker 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 Sucker upstream of the 2015 study area (Kegerries et al. 2017a; Gilbert et al. 2022). To identify the upstream extent of spawning Razorback Sucker, the study area was subsequently expanded 91 river miles upstream from Lava Falls Rapid to Phantom Ranch (RM 88.6). Expansion of the study area in 2016 informed spatial patterns of distribution for early life-history phases of Razorback Sucker and other native fishes, including federally threatened Humpback Chub (USFWS 2020).

In 2020, the SARS-CoV-2 pandemic interrupted sampling activities. While the initial 2020 larval fish sampling effort was conducted as scheduled (March), 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/m² and 1.33 fish/m², 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 the first and second July 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. These patterns suggest catostomids are spawning in close proximity (i.e., 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 two previous years (RM 167.7). However, in April 2018, a single protolarval Razorback Sucker was captured about 23 RM 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 farthest 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 2018 and 2019 data points strongly suggest the presence of limited spawning by Razorback Sucker somewhere between Phantom Ranch (RM 88.6) and RM 127.3.

Larval Razorback Sucker were collected in Grand Canyon for six consecutive years (2014–2019). The number of larval Razorback Sucker 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 Sucker were not collected in 2020, it is important to note that sampling was not conducted in April or May of that year, which precluded inferences of presence/absence of spawning adults. From 2014 through 2019, the April and May (combined) collections yielded over 90% of the larval Razorback Sucker catch from the Grand Canyon. From 2021 to present, no Razorback Sucker larvae were positively identified, suggesting a continued decline in spawning by the species. Larval Razorback Sucker collected in 2019 were represented by two ontogenetic phases (protolarval and flexion and postflexion mesolarval subphases). The developmental stages of these few fish in combination with their locations of capture strongly suggest multiple spawning sites. The range of length-based back-calculated hatch dates encompassed only 5 weeks, from 30 March to 5 May 2019, a shorter spawning season than estimated in previous years.

The results of the 2016–2023 larval fish surveys support the hypothesis that Havasu Creek plays an important role in initial spawning of catostomids in Grand Canyon. In 2016–2023, captures of

larval catostomids tended to occur in close proximity 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 larval 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 in 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) suggests that spawning occurred farther upstream, either in the mainstem Colorado River or upstream tributaries.

The demonstrated importance of tributaries to the spawning of native catostomids in the Colorado River Basin motivated changes to the methods used to estimate spawning periodicity in this study (Cathcart et al. 2015; Hooley-Underwood et al. 2021). In previous years, spawning dates of Razorback Sucker were back-calculated using larval Razorback Sucker lengths (TL mm) and water temperatures from the mainstem Colorado River. Given the hypothesized importance of tributaries to the spawning of catostomids and the discordance between temperatures in the mainstem and tributaries, hatch dates were calculated instead of spawning dates. As length-based back-calculated hatch dates do not incorporate water temperature, they provide a more-accurate and conservative estimate. In 2024, we will produce a species-specific growth model using otoliths of age-0 Humpback Chub collected between 2019 and 2021 in the main stem of the Colorado River in the Grand Canyon. The development of this model may provide more-accurate estimates of spawning periodicity of Humpback Chub in Grand Canyon.

In this study, 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 Sucker 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, 2020).

Recruitment into older life phases is largely dependent on development during the larval and juvenile phases. A multitude of factors affect the naturally high mortality of larval fishes including hatching success, starvation, predation, and competition (Clark Barkalow et al. 2021). Opercular deformities are associated with increased mortality of age-0 fishes and affect recruitment to older life stages (Barkstedt et al. 2018). Opercular deformities were observed in both Bluehead Sucker and Flannelmouth Sucker collected during this survey in 2023. Specifically, we documented 112 opercular deformities (49.5%) in the 226 age-0 Bluehead Sucker and Flannelmouth Sucker collected during the August survey. Because of the likely increase in mortality among individuals with such deformities and the disproportionate

occurrences in early life stages, it is often difficult to quantify the prevalence of opercular deformities in a population. In the San Juan River, opercular deformities were documented in all three age-0 native catostomids (Razorback Sucker, Bluehead Sucker, and Flannelmouth Sucker) collected from 1998 to 2018 (Barkstedt et al. 2018). Given the importance of recruitment to older life stages in the recovery of Razorback Sucker, and continued stability of native catostomids in the Colorado River Basin, a greater understanding of potential limiting factors can be a valuable conservation tool.

While catch rates of Humpback Chub and Razorback Sucker were similar during 2014–2018, late-phase larvae and juvenile Humpback Chub were collected while late-stage Razorback Sucker were not. Important differences between spawning periodicity of Razorback Sucker and Humpback Chub are timing (the Razorback Sucker spawns earlier) 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 Sucker were present. Although 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 reproducing populations are known to exist further upstream (i.e., Little Colorado River). The broader distribution of Humpback Chub larvae may increase the likelihood that 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 2016–2023 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 low abundances and limited distributions of age-0 nonnative fishes in Grand Canyon. The abundance of nonnative fishes was higher in 2023 than in previous years; however, the relative abundance of natives fishes remains high. 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. Six larval Striped Bass (nonnative) were collected in July 2022, a species that had not been previously collected in this study. Because Striped Bass are broadcast spawners whose eggs experience a degree of drift, we are unable to determine whether the larvae collected are a product of spawning by adult Striped Bass upstream of RM 139.6 or if they originated from Lake Powell and were transported through Glen Canyon Dam. However, discovery of this nonnative predacious fish in the Grand Canyon underscores the value of larval fish sampling for early detection of rare and nonnative fish species (Brandenburg et al. 2019).

Recently, there has been increased interest in augmenting populations of federally endangered fishes in Grand Canyon (Dibble et al. 2023; Pennock et al. 2022). Given the low prevalence of nonnative species and the demonstrated resilience of native fish populations, as well as the

warming thermal regime, Grand Canyon has the potential to support successful reproduction and recruitment of these fragile species. However, the suitability of habitat in the lower Colorado River to support early life stages is uncertain (Pennock et al. 2022). Should this management action occur, the continuance of small-bodied and larval fish surveys will be crucial in assessing the status and overall success of released individuals over time. Further, this monitoring effort has the potential to fill knowledge gaps regarding factors inhibiting or facilitating the successful recruitment of endangered fish species in Grand Canyon.

This study has documented reproduction by native fishes of the Colorado River in Grand Canyon, including Razorback Sucker, and recruitment of Humpback Chub. Given the unique suite of stressors placed on native fishes in modified desert rivers, the results of this long-term effort can provide insight into the mechanisms promoting reproduction and successful recruitment of native fishes in Grand Canyon. Future annual larval fish monitoring will continue to infer causal effects on age-0 fish abundances and inform conservation strategies for native fishes in Grand Canyon. Continued systematic larval fish surveys will provide long-term comparative data to further characterize spatial and temporal trends in the reproduction of fishes in Grand Canyon.

GRAND CANYON SMALL-BODIED AND LARVAL FISH COMMUNITY STUDY RECOMMENDATIONS

The results of the 2023 and comprehensive 2014–2023 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—particularly after the NPS release of nearly 1,000 juvenile Razorback Suckers in Grand Canyon. Additionally, if experimental repatriation of Colorado Pikeminnow occurs, the methodology described in this report can help detect and monitor spawning, recruitment, and movement patterns. 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 2024 without adjustments, as was recommended by the science panel (Reclamation 2017), to better assess differences in catch rates, habitat occupancy, nonnative fish community, 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. In 2022, 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 2020–2023, additional collections could occur in 2024. Genetic evaluation requires specimens be preserved in 95% EtOH, which has been used exclusively during recent sampling efforts (2021–2023). 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 2023 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 2022 through June 2023. Telemetry data collected from lower Grand Canyon (LGC) are reported from October 2022 through September 2023.

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 prior to 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 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 2023 CRI study activities occurred within Gregg Basin and Bonelli Bay 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

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 (Rogers et al. 2022b).

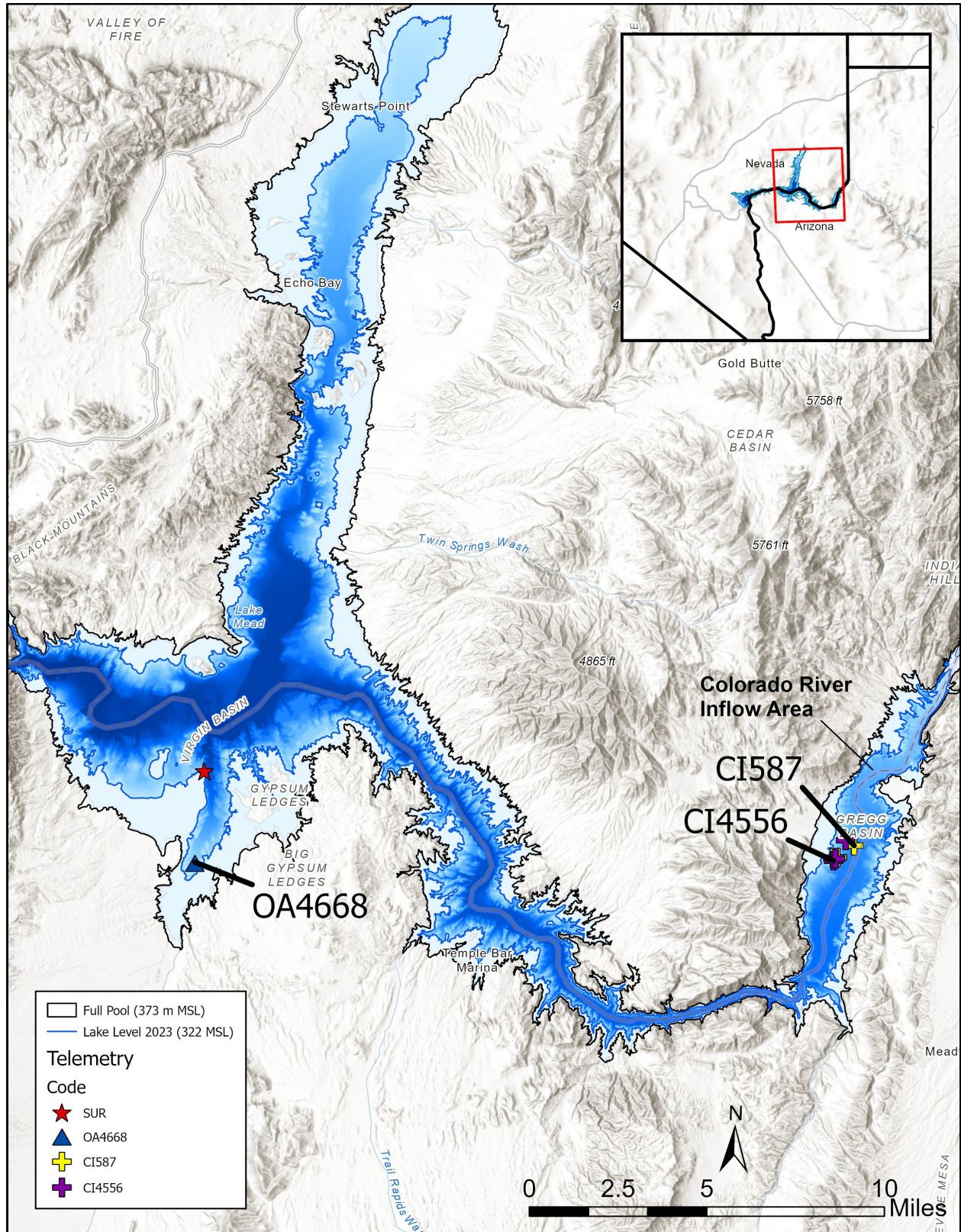


Figure 3.1. Lake Mead with the distribution of sonic-tagged fish contacts and submersible ultrasonic receiver (SUR) locations.

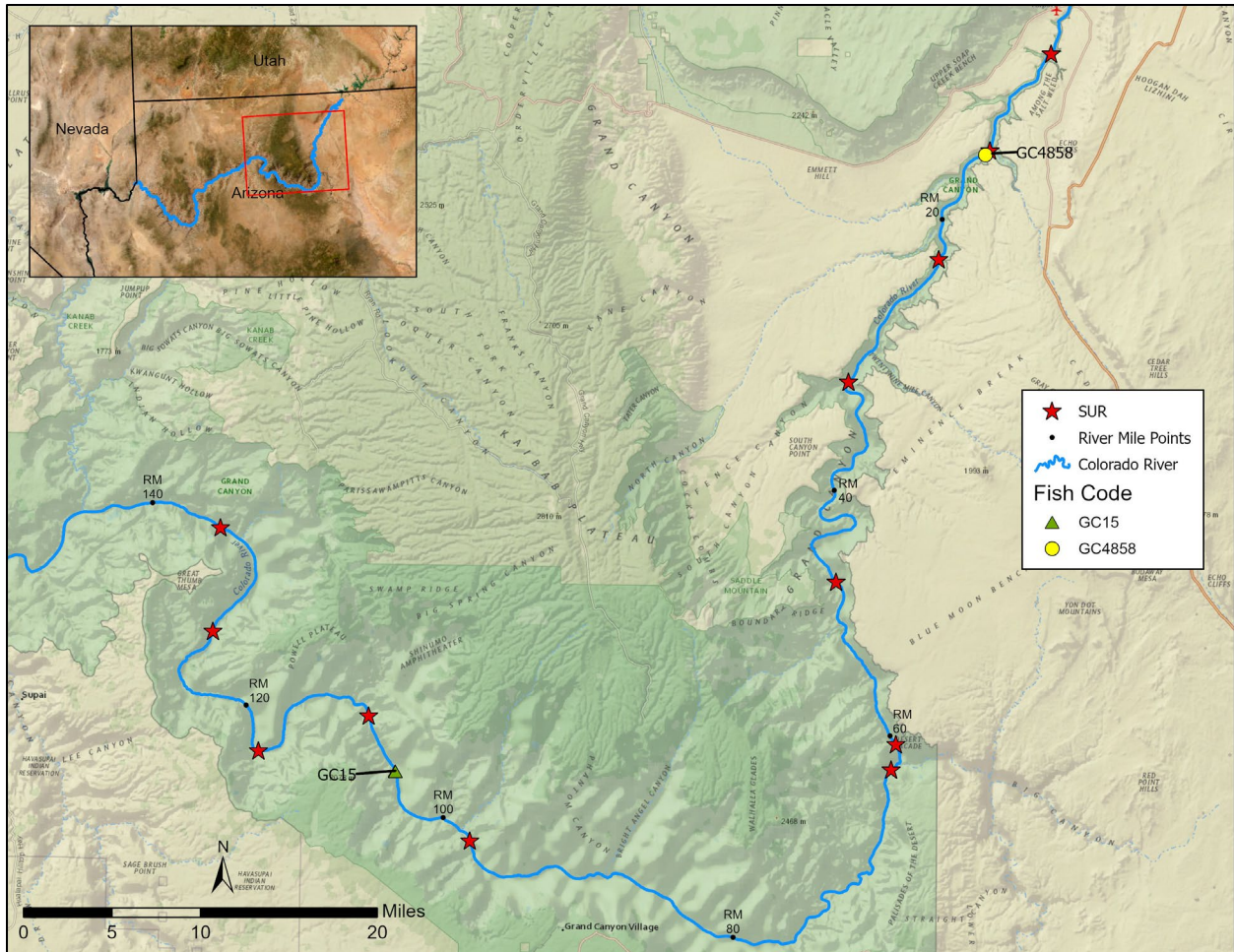


Figure 3.2a. General Grand Canyon study area with the distribution of sonic-tagged fish contacts and submersible ultrasonic receiver (SUR) locations. The top section is approximately river mile (RM) 0–90. Middle Section is approximately RM 80–200 Bottom section is approximately RM 200–280.

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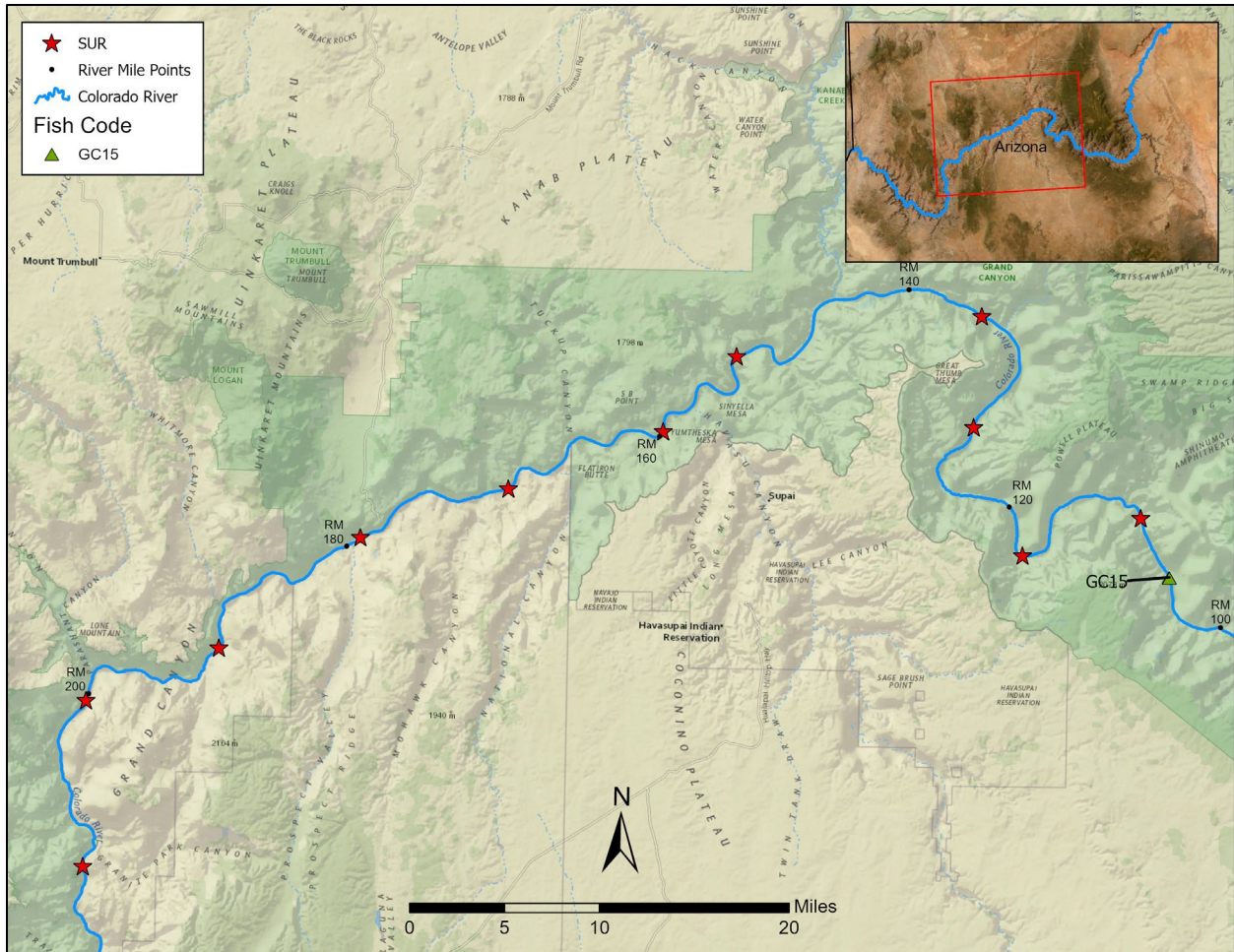


Figure 3.2b. General Grand Canyon study area with the distribution of sonic-tagged fish contacts and submersible ultrasonic receiver (SUR) locations. The top section is approximately river mile (RM) 0–90. Middle Section is approximately RM 80–200 Bottom section is approximately RM 200–280.

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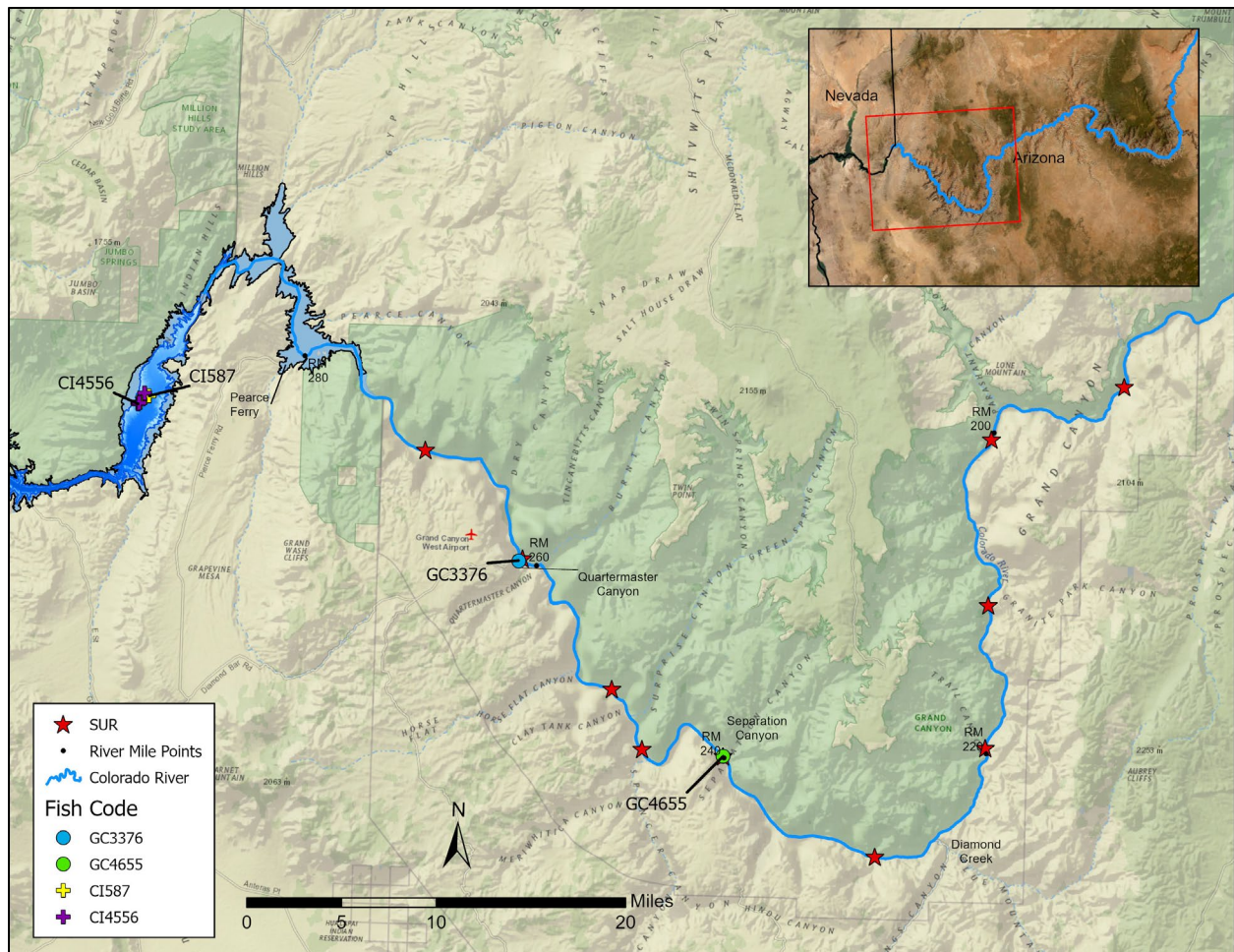


Figure 3.2c. General Grand Canyon study area with the distribution of sonic-tagged fish contacts and submersible ultrasonic receiver (SUR) locations. The top section is approximately river mile (RM) 0–90. Middle Section is approximately RM 80–200. Bottom section is approximately RM 200–280.

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 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).

Several SURs were distributed in Grand Canyon from RM 97.5 to RM 270.0 (below Boucher Rapid downstream to Pearce Ferry) (Figure 3.2). These SURs were deployed approximately 10 river miles apart. The SURs within Grand Canyon have remained in the same locations since 2015, to the extent possible. Additional SUR data were collected opportunistically in Grand Canyon as a result of deploying a SUR from the boat while camping overnight.

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

Radio telemetry methodology utilized 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 ID and location data, which were obtained on a monthly (per Grand Canyon trip; April–September) basis. All data collected from the autonomous scanning from the Lotek SRX 1200 receiver were processed by filtering them through a set of criteria 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 in 2021. This test site was selected because it has water-quality conditions similar to those 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, 2022b) (Table 3.1).

2022–2023 Telemetry

A total of 7 unique, sonic- (n=6) or radio-tagged (n=1) fish were contacted 282 times (8 active contacts, 161 SUR contacts, 113 radio contacts) from July 2022 to June 2023 at the CRI and from October 2022 to September 2023 in Grand Canyon (Figures 3.1 and 3.2) (Table 3.1). Of these seven fish, two were wild, sonic-implanted fish that had been released at the CRI in 2021 and 2022; one was a wild, sonic-implanted fish released at the Virgin River/Muddy River Inflow Area in 2021, three telemetry-tagged fish (one radio-tagged; two sonic-tagged) were hatchery-reared fish that had been released at Bright Angel Creek (RM 88.3) in 2021. Lastly, one was a sonic-tagged hatchery-reared fish that had been released near Separation Canyon (RM 239.8) in 2021 (Table 3.1). Of the 99 fish that have been tagged and released in the CRI, Grand Canyon, or Bonelli Bay since 2010, 6 are confirmed active, and 27 are of unknown status and were not contacted in 2023. The remaining 66 tags are presumed to be no longer detectable due to expired batteries. One fish (code 4668, originally tagged at the Virgin River/Muddy River Inflow Area) was detected in Bonelli Bay and then detected in the Virgin River/Muddy River Inflow Area where it remained for the season. Fish 4858 was detected at RM 49.9 by a SUR in June 2022 and then detected again at RM15 in November 2022. Since that detection, it has remained at large.

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 2023.

| 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 | 3/15/2022 | 4556 | 563 | M | CRI | CRI | 3/15/2022 | 3(0) | Active | 2025 |
| Fish Tagged in 2021 | | | | | | | | | | |
| NDOW | 1/26/2021 | 11 | 430 | U | BA | GC | 9/5/2021 | 0(0) | Unknown | 2024 |
| NDOW | 1/26/2021 | 12 | 413 | U | BA | GC | 9/5/2021 | 0(0) | Unknown | 2024 |
| NDOW | 1/26/2021 | 15 | 405 | U | BA | GC | 9/4/2023 | 0(113) | Active | 2024 |
| NDOW | 1/26/2021 | 18 | 440 | U | BA | GC | 9/3/2021 | 0(0) | Unknown | 2024 |
| NDOW | 1/26/2021 | 19 | 444 | U | BA | GC | 9/3/2021 | 0(0) | Unknown | 2024 |
| NDOW | 1/26/2021 | 13 | 434 | U | SC | GC | 9/10/2021 | 0(0) | Unknown | 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(0) | Unknown | 2024 |
| NDOW | 1/26/2021 | 17 | 434 | U | SC | GC | 9/3/2021 | 0(0) | Unknown | 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(0) | Unknown | 2023 |
| NDOW | 1/26/2021 | 4655 | 376 | U | BA | GC | 4/1/2023 | 0(20) | Active | 2023 |
| NDOW | 1/26/2021 | 4858 | 370 | U | BA | GC | 11/3/2022 | 0(8) | 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(0) | Unknown | 2023 |
| NDOW | 1/26/2021 | 5658 | 366 | U | BA | GC | 4/21/2021 | 0(0) | Unknown | 2023 |
| NDOW | 1/26/2021 | 5787 | 414 | U | BA | GC | 5/2/2021 | 0(0) | Unknown | 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 | 9/4/2023 | 0(133) | Active | 2025 |
| NDOW | 1/26/2021 | 3377 | 451 | U | SC | GC | 7/31/2021 | 0(0) | Unknown | 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 | 0(0) | Unknown | 2025 |
| CRI | 3/9/2021 | 587 | 540 | M | CRI | CRI | 6/7/2023 | 4(0) | Active | 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

HISTORICAL MOVEMENTS, 2014–2023

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, in 2021, 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. Conversely, another sonic-fish (code 3377) remained at RM 243.0 for 11 months.

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 upstream 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 when two fish were observed moving between the CRI and Las Vegas Bay.

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 in 2014 just below Lava Falls (RM 179.7) 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 in 2016 near Diamond Creek (RM 225.9) was documented at the CRI later that year. Another fish released in 2018 near Bright Angel Creek (RM 88.3) was documented at the CRI later that year. Finally, two fish contacted near RM 243.0 in 2018 were contacted again 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 from Pearce Ferry Rapid in 2022.

Since 2014, there have been 26 sonic-tagged Razorback Sucker passages upstream and/or downstream of Pearce Ferry Rapid (Figure 3.3). Of these, 10 upstream passages and 16 downstream passages by 18 unique individuals were observed (Figure 3.3). Six sonic-tagged Razorback Sucker made both downstream and upstream movements between 2014 and 2021. Most recently, in 2021, four passages (two upstream and two downstream) of Pearce Ferry Rapid were observed.

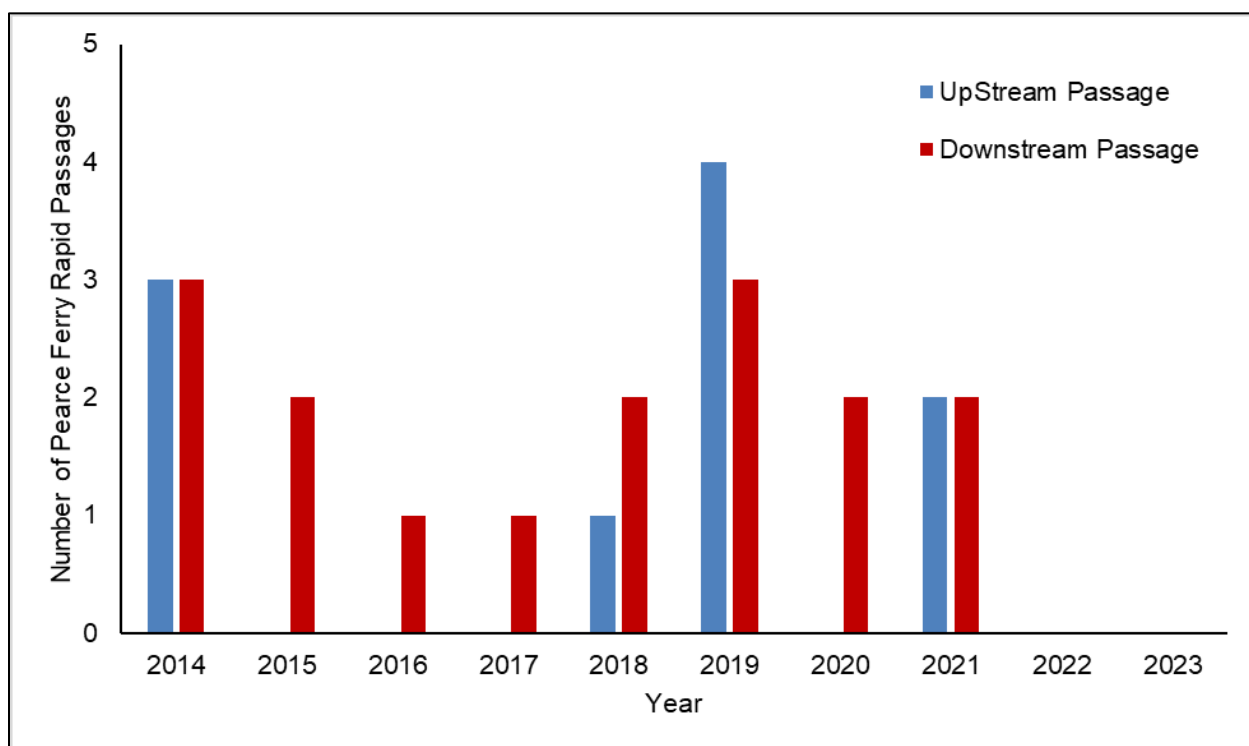


Figure 3.3. Upstream and downstream passages through Pearce Ferry Rapid by year, 2014–2023.

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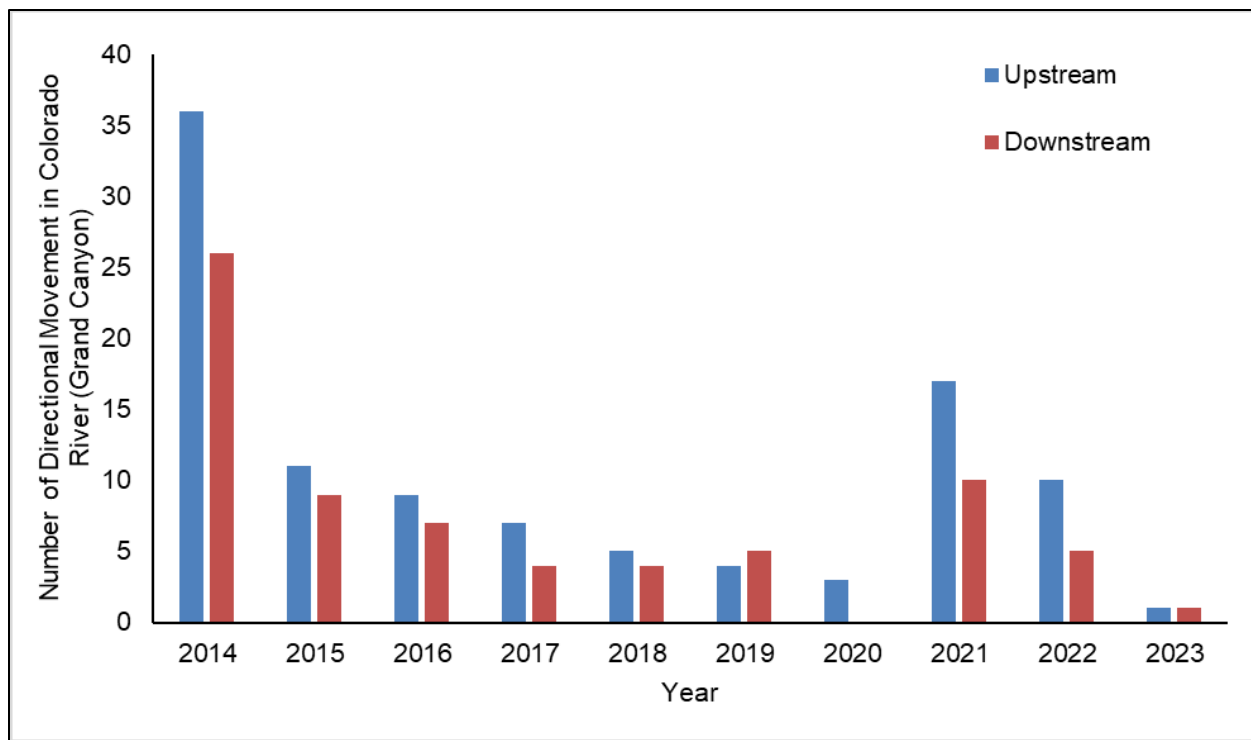


Figure 3.4. Number of directional movements detected by Razorback Sucker in the Colorado River (Grand Canyon) by year, 2014–2023.

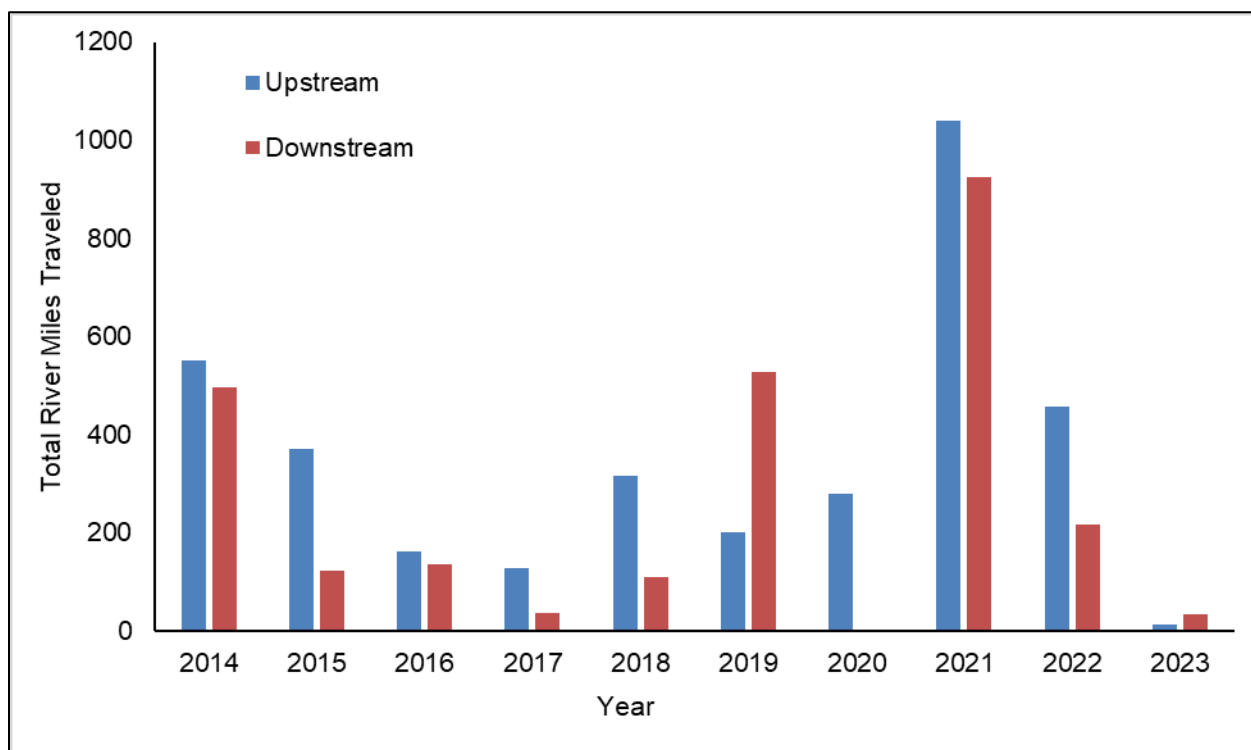


Figure 3.5. Total directional movements (river miles) moved by Razorback Sucker across each year, 2014–2023.

Throughout the study period, telemetry-tagged Razorback Sucker have been documented moving, relatively undeterred by rapids, throughout the Grand Canyon. All sonic- and radio-tagged fish from this study have collectively documented 103 upstream movements and 71 downstream movements (Figure 3.4). From 2014 to 2020, an apparent decline in the number of movements within the river was observed, followed by an apparent increase of the number movements in 2021 (Figure 3.4). These movements totaled 3,525 river miles upstream and 2,610 river miles downstream (Figure 3.5). From 2014 to 2017, an apparent decrease in the distances of movements was observed, followed by an apparent increase in those distances from 2018 to 2021 (Figure 3.5).

DISCUSSION

2022–2023 Telemetry

Data from sonic-tagged Razorback Sucker 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). These efforts also helped to illustrate movement patterns by providing habitat-use data and informing the selection of spawning-sites as reservoir levels have fluctuated. For example, the 2021 primary spawning location at the CRI is now cut off from the river/lake interface. This underscores how important telemetered fish were to field crews during the 2022–2023 spawning season as the fish moved through the system to find suitable spawning habitat.

Both sonic- 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. Another plausible explanation is that the batteries in the tags may have expired.

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. 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 populations, 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.

Razorback Suckers implanted with radio tags allowed for the documentation of movement patterns within Grand Canyon. Since 2021, these tags have allowed for the detection of upstream movements that had not been previously documented by SUR detections alone. These tags also allowed for autonomous data collection spanning from RM 0 to 280 throughout the entire river

corridor during monthly sampling trips. However, Eiler (2012) suggests that detections can be limited by multiple factors; including, tracking via boat decreases the detection range of radio-tags due to the decreased height of receiving antenna, high frequency tags are more easily reflected by physical barriers that are present in side channel or gravel/sand bars that are present in main channels. Additionally, motor noise and boat speed also factor into decreased detection ranges due to increased noise or even causing fish to increase their depth to avoid the boat (Eiler 2012). 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 from 2021 to 2023. 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 that which 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) movement patterns. The advantage to maintaining this telemetry system is that, when fish are deeper in the water column, SURs are likely to detect their movement patterns. Continued use and maintenance of this now established 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.

It is worth noting that the existing SUR network in Grand Canyon underwent a significant change during the September 2023 trip as this project looked to the future and the USFWS began additional telemetry efforts targeting Humpback Chub. The responsibility for maintenance of the SUR network was transferred to the USFWS, leading to the relocation of SURs to support the goals of that movement study. All SURs located above RM 60.6 were either unrecovered or relocated after the 2023 High Flow Experiment (and its associated habitat change), leaving this portion of the river, currently unmonitored. Specifically, six SURs (RM 8.0, 15.0, 97.9, 117.1, 135.8, and 151.9) were relocated, while the remaining four SURs (RM 49.9, 159.6, 170.1, and 240.1) became unretrievable or lost. Replacement of these SURs, as well as additional tagged fish may aid in further understanding of the movement patterns of Razorback Sucker during future efforts within Grand Canyon and Lake Mead, particularly the extent, range, frequency, use of tributaries, and so forth, all as defined by project goals.

HISTORICAL MOVEMENT, 2014–2022

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. Although sonic-tagged fish have been documented using flowing portions of the Colorado River proper since 2011 (as high as RM 15), the scale of documented movement has differed among individual fishes and years. 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). The number of contacts with fish above the Pearce Ferry Rapid has declined since 2014 despite research-related augmentation events within Grand Canyon in 2016, 2018, and 2021. At a minimum, this suggests that Pearce Ferry Rapid, as well as other newly formed rapids between Pearce Ferry Rapid and Lake Mead, may be serving as movement deterrents (Albrecht et al. 2014a; Kegerries et al. 2015a, 2016a, 2017a, Kegerries et al. 2018, 2019, 2020a, Rogers et al. 2022b). Through 2020, six fish that had been released in Grand Canyon have been located at the CRI—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 spends 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. Movements across years may be influenced by factors such as the number of active tags in the system, the level of active telemetry efforts, and the number of SURs that are deployed and retrievable. Most years show Razorback Sucker having a higher number of upstream movements as well as lengthier movements. Continuing to monitor these areas for adult, juvenile, larval, and sonic-tagged individuals will be critical for effective habitat-use determination and habitat protection. The detection of telemetry-tagged 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 (Kegerries and Albrecht 2013a, 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 continue to use the flowing portions of the Colorado River proper, how far they continue to travel, the extent to which they may utilize tributaries, and so forth. 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, Bonelli Bay, and CRI spawning aggregates (Albrecht and Holden 2005; Albrecht et al. 2010a; Shattuck et al. 2011), which suggests that hatchery-reared fish will integrate with established wild populations or perhaps behave similarly to wild fish.

CONCLUSION

Finally, it appears that while both telemetry techniques have limitations and advantages, the continued use of both radio telemetry and sonic telemetry as described herein 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 (RM 15). Sonic and radio telemetry, as well as passive and active tracking techniques, have been important in understanding Razorback Sucker movement within this riverine environment. As we move forward, the combination of the two tag types discussed here will allow for the most-effective monitoring that telemetry can provide within the constraints of current technology.

2023–2024 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 habitat use and any specific spawning site locations that may warrant protection.
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 better 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 2024, 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 those efforts.

5. The network of SURs previously 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 questions where telemetry could help in assessing movement within Grand Canyon and greater Lake Mead system, be those questions about native or nonnative fishes.
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 2023 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 further 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 evidenced by telemetry efforts in 2014 (Albrecht et al. 2014a)—drift distances could be substantially shorter 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 2023 particularly when coupled with differential use of adult sonic-tagged Razorback Sucker.

Unlike Razorback Sucker, juvenile Humpback Chub have been captured throughout the 2014–2023 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 are 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, 2021a, 2022a, 2023). 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. These unique aspects include (1) a high growth rate indicative of a young population (Kegerries and Albrecht 2013a, 2013b; Albrecht et al. 2013a, 2013b, 2014); (2) 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, 2021a, 2022a, 2023); and (3) 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 the 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 items have resulted from 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 result from 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. This study design will facilitate early warning of concerns for native and nonnative fishes within the Grand Canyon at early life stages.
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, and the inflow area.

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**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),
2023**

| DATE ^a | SPECIES | PIT-TAG NUMBER | RECAP -TURE | TL ^c (mm) | FL ^d (mm) | SL ^e (mm) | WT ^f (g) | SEX ^g | STATUS | GEAR |
|-------------------|---------|----------------|-------------|----------------------|----------------------|----------------------|---------------------|------------------|--------|----------------|
| 2/8/2023 | FM | 3DD.003D4CBCDA | No | 351 | 332 | 265 | 307 | U | Wild | Trammel |
| 2/8/2023 | FM | 3DD.003D4CC2EB | Yes | 484 | 460 | 385 | 968 | F | Wild | Trammel |
| 2/8/2023 | FM | 3DD.003D4CBCD8 | No | 360 | 340 | 272 | 347 | U | Wild | Trammel |
| 2/11/2023 | FM | 3DD.003BE6626A | No | 405 | 384 | 342 | 564 | U | Wild | Trammel |
| 2/11/2023 | FM | 3DD.003BE66282 | No | 384 | 355 | 311 | 428 | U | Wild | Trammel |
| 2/28/2023 | FM | 3DD.003D4CBEF5 | No | 200 | 181 | —h | 55 | I | Wild | Electrofishing |
| 3/1/2023 | FM | —h | No | 183 | —h | —h | —h | —h | Wild | Electrofishing |
| 3/1/2023 | FM | —h | No | 171 | —h | —h | —h | —h | Wild | Electrofishing |
| 3/2/2023 | FM | 3DD.003D4BEDD | No | 445 | 421 | 382 | 693 | U | Wild | Trammel |
| 3/2/2023 | FM | 3DD.003D4CBEDD | No | 335 | 317 | 288 | 300 | I | Wild | Trammel |
| 3/2/2023 | FM | 3DD.003D4CBEE6 | No | 505 | 483 | 477 | 951 | U | Wild | Trammel |
| 3/2/2023 | FM | 3DD.003D4CBEE9 | No | 472 | 444 | 409 | 944 | U | Wild | Trammel |
| 3/2/2023 | FM | 3DD.003D4CBefd | No | 430 | 402 | 369 | 674 | M | Wild | Trammel |
| 3/2/2023 | FM | 3DD.003BE6626A | Yes | 411 | 390 | 351 | 544 | M | Wild | Trammel |
| 3/7/2023 | FM | 3DD.003BEFB9CD | No | 516 | 484 | 450 | 1205 | F | Wild | Trammel |
| 3/7/2023 | FM | 3DD.003BFB4A46 | Yes | 489 | 455 | 421 | 999 | U | Wild | Trammel |
| 3/7/2023 | FM | 3DD.003C06F114 | Yes | 486 | 466 | 422 | 918 | U | Wild | Trammel |
| 3/7/2023 | FM | 3DD.003D4CBEDD | Yes | 336 | 321 | 338 | 288 | I | Wild | Trammel |
| 3/7/2023 | FM | 3DD.003D4CC757 | No | 406 | 400 | 366 | 605 | M | Wild | Trammel |
| 3/7/2023 | FM | 3DD.003D4CC79C | No | 428 | 410 | 377 | 705 | U | Wild | Trammel |
| 3/7/2023 | FM | 3DD.003D4CC789 | No | 301 | 277 | 257 | 226 | I | Wild | Trammel |
| 3/7/2023 | FM | 3DD.003D4CC790 | No | 404 | 382 | 350 | 558 | U | Wild | Trammel |
| 3/7/2023 | FM | 3DD.003D4CC79C | Yes | 428 | 410 | 382 | 702 | F | Wild | Trammel |
| 3/7/2023 | FM | 3DD.003D4CC7A8 | No | 361 | 336 | 304 | 311 | U | Wild | Trammel |
| 3/16/2023 | FM | 3DD.003D4CC765 | No | 341 | 320 | 295 | 338 | I | Wild | Trammel |
| 3/16/2023 | FM | 3DD.003D4CC769 | No | 482 | 455 | 387 | 1025 | M | Wild | Trammel |
| 3/16/2023 | FM | 3DD.003D4CC779 | No | 392 | 374 | 396 | 540 | U | Wild | Trammel |
| 3/16/2023 | FM | 3DD.003D4CC77D | No | 421 | 403 | 330 | 540 | U | Wild | Trammel |
| 3/16/2023 | FM | 3DD.003D4CC784 | No | 440 | 435 | 425 | 770 | U | Wild | Trammel |
| 3/16/2023 | FM | 3DD.003D4CC789 | Yes | 301 | 283 | 225 | 215 | I | Wild | Trammel |
| 3/16/2023 | FM | 3DD.003D4CC753 | No | 464 | 435 | 363 | 775 | F | Wild | Trammel |
| 3/16/2023 | FM | 3DD.003D4CC75C | No | 410 | 385 | 325 | 520 | U | Wild | Trammel |
| 3/22/2023 | FM | 3DD.003D4CBEE8 | No | 426 | 400 | 362 | 701 | U | Wild | Trammel |
| 3/22/2023 | FM | 3DD.003BFB1A29 | Yes | 468 | 438 | 405 | 951 | U | Wild | Trammel |
| 3/22/2023 | FM | 3DD.003D4CBECF | No | 389 | 360 | 330 | 475 | I | Wild | Trammel |
| 3/22/2023 | FM | 3DD.003D4CBED8 | No | 475 | 450 | 411 | 915 | U | Wild | Trammel |
| 3/22/2023 | FM | 3DD.003D4CBEE3 | No | 424 | 362 | 345 | 655 | U | Wild | Trammel |
| 3/22/2023 | FM | 3DD.003D4CBEE7 | No | 488 | 456 | 424 | 992 | U | Wild | Trammel |
| 3/22/2023 | FM | 3DD.003D4CBefC | No | 515 | 485 | 443 | 1128 | U | Wild | Trammel |
| 3/22/2023 | FM | 3DD.003D4CBefd | Yes | 425 | 403 | 362 | 703 | U | Wild | Trammel |
| 3/22/2023 | FM | 3DD.003D4D4916 | Yes | 398 | 375 | 344 | 503 | U | Wild | Trammel |
| 3/23/2023 | FM | 3DD.003D4CC785 | No | 495 | 460 | 428 | 1029 | U | Wild | Trammel |
| 3/23/2023 | FM | 3DD.003D4CC787 | No | 408 | 385 | 340 | 500 | U | Wild | Trammel |
| 3/29/2023 | FM | 3DD.003BC89E4D | No | 426 | 402 | 369 | 658 | U | Wild | Trammel |
| 3/29/2023 | FM | 3DD.003BC89E75 | No | 425 | 395 | 361 | 658 | U | Wild | Trammel |
| 3/29/2023 | FM | 3DD.003D7D2EC3 | Yes | 406 | 381 | 345 | 610 | M | Wild | Trammel |
| 3/29/2023 | FM | 3DD.003BC89E4A | No | 485 | 463 | 427 | 866 | U | Wild | Trammel |
| 3/29/2023 | FM | 3DD.003BC89E4E | No | 317 | 296 | 271 | 280 | I | Wild | Trammel |
| 3/29/2023 | FM | 3DD.003BC89E85 | No | 451 | 430 | 393 | 798 | U | Wild | Trammel |
| 3/29/2023 | FM | 3DD.003D4CC79C | Yes | 425 | 405 | 375 | 680 | U | Wild | Trammel |
| 4/6/2023 | FM | 3DD.003BE66264 | No | 447 | 418 | 383 | 838 | U | Wild | Trammel |
| 4/6/2023 | FM | 3DD.003BE6627F | No | 430 | 403 | 372 | 712 | U | Wild | Trammel |
| 4/6/2023 | FM | 3DD.003BE662A2 | No | 297 | 280 | 258 | 246 | I | Wild | Trammel |
| 4/6/2023 | FM | —h | No | 365 | 345 | 317 | 408 | M | Wild | Trammel |

| DATE ^a | SPECIES | PIT-TAG NUMBER | RECAP -TURE | TL ^c (mm) | FL ^d (mm) | SL ^e (mm) | WT ^f (g) | SEX ^g | STATUS | GEAR |
|-------------------|---------|-----------------|-------------|----------------------|----------------------|----------------------|---------------------|------------------|--------|----------------|
| 4/6/2023 | FM | 3DD.003BC89E8F | No | 543 | 504 | 467 | 1288 | U | Wild | Trammel |
| 4/6/2023 | FM | 3DD.003BE662A1 | No | 491 | 461 | 421 | 858 | U | Wild | Trammel |
| 4/6/2023 | FM | 3DD.003BE662A7 | No | 395 | 366 | 340 | 488 | I | Wild | Trammel |
| 4/6/2023 | FM | 3DD.003BE662BD | No | 391 | 374 | 339 | 488 | U | Wild | Trammel |
| 4/6/2023 | FM | 3DD.003C06F106 | Yes | 506 | 472 | 441 | 1068 | U | Wild | Trammel |
| 4/11/2023 | FM | 3DD.003BFB4A46 | No | 487 | 452 | 425 | 798 | M | Wild | Trammel |
| 4/11/2023 | FM | 3DD.003D4CC75F | No | 318 | 299 | 267 | 256 | I | Wild | Trammel |
| 4/11/2023 | FM | 3DD.003D4CC765 | No | 483 | 452 | 418 | 904 | F | Wild | Trammel |
| 4/11/2023 | FM | 3DD.003D4CC767 | No | 418 | 392 | 364 | 606 | U | Wild | Trammel |
| 4/11/2023 | FM | 3DD.003D4CC76B | No | 402 | 379 | 351 | 552 | U | Wild | Trammel |
| 4/11/2023 | FM | 3DD.003D4CC77A | No | 416 | 400 | 364 | 663 | F | Wild | Trammel |
| 4/11/2023 | FM | 3DD.003D4CC781 | No | 306 | 293 | 264 | 249 | I | Wild | Trammel |
| 4/11/2023 | FM | 3DD.003D4CC790 | Yes | 401 | 375 | 346 | 536 | U | Wild | Trammel |
| 4/11/2023 | FM | 3DD.003D4CC7A1 | No | 478 | 450 | 412 | 997 | M | Wild | Trammel |
| 4/11/2023 | FM | 3DD.003D4CC7AD | No | 417 | 394 | 364 | 629 | U | Wild | Trammel |
| 4/11/2023 | FM | 384.3B2399FE86 | Yes | 460 | 435 | 399 | 673 | F | Wild | Trammel |
| 4/11/2023 | FM | 3DD.003BC89E85 | Yes | 446 | 442 | 388 | 761 | F | Wild | Trammel |
| 4/11/2023 | FM | 3DD.003D4CC756 | No | 446 | 422 | 387 | 687 | F | Wild | Trammel |
| 4/19/2023 | FM | 3DD.003D4CC770 | No | 470 | 444 | 405 | 857 | U | Wild | Electrofishing |
| 4/19/2023 | FM | 3DD.003D4CC768 | No | 240 | 227 | 195 | 202 | I | Wild | Electrofishing |
| 4/20/2023 | FM | 3DD.003D4CBAA3 | No | 435 | 410 | 378 | 777 | U | Wild | Trammel |
| 4/20/2023 | FM | 3DD.003D4CBAA4 | No | 471 | 448 | 407 | 883 | U | Wild | Trammel |
| 4/20/2023 | FM | 3DD.003D4CBABF | No | 236 | 216 | 190 | 104 | I | Wild | Trammel |
| 4/20/2023 | FM | 3DD.003D4CBAC7 | No | 445 | 406 | 382 | 709 | U | Wild | Trammel |
| 4/20/2023 | FM | 3DD.003BA20A38 | Yes | 520 | 500 | 445 | 1176 | U | Wild | Trammel |
| 4/20/2023 | FM | 3DD.003BC89E85 | Yes | 450 | 426 | 390 | 728 | U | Wild | Trammel |
| 4/20/2023 | FM | 3DD.003BFB17A7 | Yes | 435 | 409 | 372 | 801 | U | Wild | Trammel |
| 4/20/2023 | FM | 3DD.003BFB4121 | Yes | 456 | 438 | 394 | 824 | U | Wild | Trammel |
| 4/20/2023 | FM | 3DD.003C06F106 | Yes | 502 | 475 | 445 | 1088 | U | Wild | Trammel |
| 4/20/2023 | FM | 3DD.003D4CBA6F | No | 430 | 409 | 378 | 689 | U | Wild | Trammel |
| 4/20/2023 | FM | 3DD.003D4CBA87 | No | 432 | 413 | 375 | 717 | U | Wild | Trammel |
| 4/20/2023 | FM | 3DD.003D4CBA89 | No | 485 | 460 | 420 | 1107 | M | Wild | Trammel |
| 4/20/2023 | FM | 3DD.003D4CBA91 | No | 396 | 378 | 340 | 509 | U | Wild | Trammel |
| 4/20/2023 | FM | 3DD.003D4CBA98 | No | 420 | 387 | 355 | 615 | U | Wild | Trammel |
| 4/20/2023 | FM | 3DD.003D4CBA9D | No | 474 | 439 | 409 | 955 | U | Wild | Trammel |
| 4/20/2023 | FM | 3DD.003D4CBAA2 | No | 399 | 380 | 338 | 528 | U | Wild | Trammel |
| 4/20/2023 | FM | 3DD.003D4CBAA5 | No | 415 | 390 | 360 | 641 | M | Wild | Trammel |
| 4/20/2023 | FM | 3DD.003D4CBAAE | No | 435 | 415 | 380 | 687 | U | Wild | Trammel |
| 4/20/2023 | FM | 3DD.003D4CBAB9 | No | 364 | 340 | 318 | 450 | M | Wild | Trammel |
| 4/20/2023 | FM | 3DD.003D4CBAC0 | No | 432 | 405 | 377 | 724 | U | Wild | Trammel |
| 4/20/2023 | FM | 3DD.003D4CBAC8 | No | 431 | 415 | 380 | 710 | M | Wild | Trammel |
| 4/20/2023 | FM | 3DD.003D4CBACB | No | 450 | 419 | 390 | 807 | U | Wild | Trammel |
| 4/20/2023 | FM | 3DD.003D4CBAD0 | No | 416 | 395 | 360 | 517 | U | Wild | Trammel |
| 4/20/2023 | FM | 3DD.003D4CC2DF | Yes | 460 | 435 | 400 | 818 | U | Wild | Trammel |
| 4/27/2023 | FM | 3DD.003D4CC755 | No | 362 | 340 | 278 | 373 | I | Wild | Trammel |
| 4/27/2023 | FM | 3DD.003D4CC76C | No | 447 | 428 | 350 | 708 | M | Wild | Trammel |
| 4/27/2023 | FM | 3DD.003D4CBEB A | No | 480 | 455 | 365 | 916 | F | Wild | Trammel |
| 4/27/2023 | FM | 3DD.003D4CBEDC | No | 452 | 420 | 345 | 740 | F | Wild | Trammel |
| 4/27/2023 | FM | 3DD.003D4CBEE2 | No | 308 | 285 | 225 | 195 | I | Wild | Trammel |
| 4/27/2023 | FM | 3DD.003D4CC780 | No | 455 | 430 | 335 | 723 | M | Wild | Trammel |
| 4/27/2023 | FM | 3DD.003D4CC7A5 | No | 498 | 472 | 390 | 1024 | F | Wild | Trammel |
| 5/3/2023 | FM | 3DD.003D4CBA79 | No | 252 | 230 | 209 | 129 | I | Wild | Trammel |
| 5/3/2023 | FM | 3DD.003D4CBA8C | No | 421 | 394 | 365 | 664 | U | Wild | Trammel |
| 5/3/2023 | FM | 3DD.003D4CBA8F | No | 380 | 350 | 325 | 408 | U | Wild | Trammel |

| DATE ^a | SPECIES | PIT-TAG NUMBER | RECAP -TURE | TL ^c (mm) | FL ^d (mm) | SL ^e (mm) | WT ^f (g) | SEX ^g | STATUS | GEAR |
|-------------------|---------|----------------|-------------|----------------------|----------------------|----------------------|---------------------|------------------|--------|---------|
| 5/3/2023 | FM | 3DD.003D4CBA9F | No | 345 | 317 | 290 | 335 | I | Wild | Trammel |
| 5/3/2023 | FM | 3DD.003D4CBAAA | No | 421 | 400 | 370 | 567 | U | Wild | Trammel |
| 5/3/2023 | FM | 3DD.003D4CBABC | No | 353 | 330 | 305 | 350 | M | Wild | Trammel |
| 5/3/2023 | FM | 3DD.003D4CBACC | No | 422 | 400 | 370 | 632 | M | Wild | Trammel |
| 5/3/2023 | FM | 3DD.003D4CBAD1 | No | 434 | 416 | 380 | 700 | U | Wild | Trammel |

^a Date originally captured.

^b FM=flannelmouth sucker.

^c Total length. ^d Fork length. ^e Standard length. ^f Weight.

^g F=female, M=male, I=immature, U=unidentified (sex not determined).

^h 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 |
| 4/25/2006 | 452 | 4 | 2002 |
| 4/25/2006 | 463 | 4 | 2002 |

| DATE COLLECTED | TOTAL LENGTH (mm ^a) | AGE | PRESUMPTIVE YEAR SPAWNED |
|------------------------------|---------------------------------|-----|--------------------------|
| LAS VEGAS BAY (Cont.) | | | |
| 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 |
| 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 |

| DATE COLLECTED | TOTAL LENGTH (mm ^a) | AGE | PRESUMPTIVE YEAR SPAWNED |
|------------------------------|---------------------------------|-----------------|--------------------------|
| LAS VEGAS BAY (Cont.) | | | |
| 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 |
| 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 |

| DATE COLLECTED | TOTAL LENGTH (mm^a) | AGE | PRESUMPTIVE YEAR SPAWNED |
|------------------------------|--------------------------------------|------------|---------------------------------|
| LAS VEGAS BAY (Cont.) | | | |
| 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 |
| 1/12/2023 | 691 | 10 | 2012 |
| 1/19/2023 | 603 | 9 | 2013 |
| 1/19/2023 | 651 | 8 | 2014 |
| 1/19/2023 | 536 | 7 | 2015 |
| 2/8/2023 | 674 | 8 | 2014 |
| 2/8/2023 | 562 | 6 | 2016 |
| 2/9/2023 | 645 | 10 | 2012 |
| 2/9/2023 | 630 | 9 | 2013 |
| 2/9/2023 | 558 | 7 | 2015 |
| 2/9/2023 | 493 | 6 | 2016 |
| 01/18/23 | 545 | 7 | 2016 |
| 01/24/23 | 521 | 7 | 2016 |
| 01/26/23 | 666 | 13 | 2010 |
| 02/07/23 | 522 | 6 | 2017 |
| 02/07/23 | 639 | 13 | 2010 |
| 02/16/23 | 597 | 10 | 2013 |
| 02/28/23 | 556 | 9 | 2014 |
| ECHO BAY | | | |
| 1/22/1998 | 381 | 5 | 1993 |
| 1/9/2000 | 527 | 13 | 1987 |
| 1/9/2000 | 550 | 13 | 1987 |

| DATE COLLECTED | TOTAL LENGTH (mm ^a) | AGE | PRESUMPTIVE YEAR SPAWNED |
|-------------------------|---------------------------------|-----------------|--------------------------|
| ECHO BAY (Cont.) | | | |
| 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 |
| 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 |

| DATE COLLECTED | TOTAL LENGTH (mm ^a) | AGE | PRESUMPTIVE YEAR SPAWNED |
|-------------------------|---------------------------------|----------------|--------------------------|
| ECHO BAY (Cont.) | | | |
| 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 |
| 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 |

| DATE COLLECTED | TOTAL LENGTH (mm ^a) | AGE | PRESUMPTIVE YEAR SPAWNED |
|-------------------------|---------------------------------|-----|--------------------------|
| ECHO BAY (Cont.) | | | |
| 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 |
| 3/3/2021 | 595 | 8 | 2013 |
| 2/10/2021 | 565 | 8 | 2013 |
| 2/10/2021 | 631 | 9 | 2012 |
| 2/10/2023 | 278 | 3 | 2019 |
| 3/10/2023 | 668 | 8 | 2014 |
| 3/10/2023 | 551 | 7 | 2015 |
| 3/22/2023 | 698 | 11 | 2011 |
| 3/22/2023 | 671 | 10 | 2012 |
| 3/22/2023 | 563 | 8 | 2014 |
| 3/22/2023 | 596 | 8 | 2014 |
| 4/6/2023 | 551 | 8 | 2014 |
| 3/09/23 | 577 | 10 | 2013 |

| DATE COLLECTED | TOTAL LENGTH (mm^a) | AGE | PRESUMPTIVE YEAR SPAWNED |
|---|--------------------------------------|-----------------|---------------------------------|
| ECHO BAY (Cont.) | | | |
| 3/22/23 | 563 | 8 | 2015 |
| 3/22/23 | 590 | 10 | 2013 |
| 3/22/23 | 666 | 10 | 2013 |
| 3/22/23 | 578 | 10 | 2013 |
| 3/22/23 | 566 | 11 | 2012 |
| 3/22/23 | 641 | 12 | 2011 |
| 3/30/23 | 566 | 8 | 2015 |
| 3/30/23 | 611 | 11 | 2012 |
| 3/30/23 | 690 | 13 | 2010 |
| 4/04/23 | 577 | 9 | 2014 |
| 4/04/23 | 566 | 10 | 2013 |
| 4/04/23 | 631 | 13 | 2010 |
| 4/04/23 | 607 | 15 | 2008 |
| 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 |

| DATE COLLECTED | TOTAL LENGTH (mm^a) | AGE | PRESUMPTIVE YEAR SPAWNED |
|---|--------------------------------------|------------|---------------------------------|
| VIRGIN RIVER/MUDDY RIVER INFLOW AREA (Cont.) | | | |
| 4/22/2008 | 533 | 6 | 2002 |
| 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 |
| 2/1/2011 | 556 | 7 | 2004 |
| 2/1/2011 | 586 | 6 | 2005 |

| DATE COLLECTED | TOTAL LENGTH (mm^a) | AGE | PRESUMPTIVE YEAR SPAWNED |
|---|--------------------------------------|------------|---------------------------------|
| VIRGIN RIVER/MUDDY RIVER INFLOW AREA (Cont.) | | | |
| 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 |
| 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 |

| DATE COLLECTED | TOTAL LENGTH (mm^a) | AGE | PRESUMPTIVE YEAR SPAWNED |
|---|--------------------------------------|------------|---------------------------------|
| VIRGIN RIVER/MUDDY RIVER INFLOW AREA (Cont.) | | | |
| 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 |
| 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 |

| DATE COLLECTED | TOTAL LENGTH (mm^a) | AGE | PRESUMPTIVE YEAR SPAWNED |
|---|--------------------------------------|------------|---------------------------------|
| VIRGIN RIVER/MUDDY RIVER INFLOW AREA (Cont.) | | | |
| 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 |
| 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 |

| DATE COLLECTED | TOTAL LENGTH (mm^a) | AGE | PRESUMPTIVE YEAR SPAWNED |
|---|--------------------------------------|------------|---------------------------------|
| VIRGIN RIVER/MUDDY RIVER INFLOW AREA (Cont.) | | | |
| 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 |
| 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 |

| DATE COLLECTED | TOTAL LENGTH (mm^a) | AGE | PRESUMPTIVE YEAR SPAWNED |
|---|--------------------------------------|------------|---------------------------------|
| VIRGIN RIVER/MUDDY RIVER INFLOW AREA (Cont.) | | | |
| 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 |
| 1/20/2023 | 676 | 14 | 2008 |
| 2/9/2023 | 675 | 11 | 2011 |
| 2/9/2023 | 597 | 8 | 2014 |
| 2/16/2023 | 615 | 10 | 2012 |
| 2/16/2023 | 615 | 9 | 2013 |
| 2/16/2023 | 592 | 8 | 2014 |
| 2/16/2023 | 601 | 8 | 2014 |
| 4/5/2023 | 321 | 2 | 2020 |
| 02/02/23 | 552 | 8 | 2015 |
| 02/02/23 | 566 | 12 | 2011 |
| 02/02/23 | 706 | 14 | 2009 |
| 02/02/23 | 578 | 15 | 2008 |
| 02/07/23 | 651 | 11 | 2012 |
| 03/02/23 | 577 | 7 | 2016 |
| 03/08/23 | 629 | 12 | 2011 |
| 04/05/23 | 365 | 3 | 2020 |
| 04/05/23 | 336 | 4 | 2019 |
| 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 |
| 2/21/2012 | 604 | 10 | 2002 |
| 3/1/2012 | 546 | 8 | 2004 |
| 3/1/2012 | 559 | 9 | 2003 |
| 3/6/2012 | 535 ⁹ | 11 | 2001 |
| 3/6/2012 | 573 | 6 | 2006 |
| 3/6/2012 | 572 | 7 | 2005 |
| 3/8/2012 | 557 | 8 | 2004 |

| DATE COLLECTED | TOTAL LENGTH (mm^a) | AGE | PRESUMPTIVE YEAR SPAWNED |
|---|--------------------------------------|------------|---------------------------------|
| COLORADO RIVER INFLOW AREA (Cont.) | | | |
| 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 |
| 2/24/2021 | 580 | 7 | 2014 |
| 2/17/2021 | 467 | 7 | 2014 |
| 2/18/2021 | 631 | 9 | 2012 |
| 2/11/2023 | 631 | 11 | 2012 |
| 3/7/2023 | 590 | 9 | 2014 |
| 3/7/2023 | 681 | 11 | 2012 |
| BONELLI BAY | | | |
| 2/12/2019 | 700 | 12 | 2007 |
| 2/12/2019 | 625 | 10 | 2009 |
| 2/12/2019 | 670 | 10 | 2009 |

| DATE COLLECTED | TOTAL LENGTH (mm ^a) | AGE | PRESUMPTIVE YEAR SPAWNED |
|----------------------------|---------------------------------|-----|--------------------------|
| BONELLI BAY (Cont.) | | | |
| 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 |
| 2/24/2023 | 589 | 7 | 2015 |
| 1/12/2023 | 604 | 13 | 2010 |

^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, 2023**

| 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 |
| 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 |

**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, 2023**

| 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 |
|-------------|-----------------|---------------------|---------------|------------------|---------------|-------------|------------|-------------|----------------|------------------|---------------|----------------------|------------|---------------|--------------|----------|
| 160 | 0 | 4 | 0 | 0 | 16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 162 | 1 | 5 | 0 | 0 | 6 | 0 | 2 | 0 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 170 | 0 | 0 | 1 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 174 | 0 | 3 | 0 | 0 | 48 | 0 | 0 | 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 | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 180 | 0 | 7 | 0 | 0 | 15 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 181 | 0 | 3 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 186 | 0 | 1 | 0 | 0 | 27 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 189 | 0 | 1 | 1 | 0 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 191 | 0 | 1 | 3 | 0 | 23 | 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 |
| 198 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 213 | 0 | 1 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 218 | 0 | 0 | 0 | 0 | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 225 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 234 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 237 | 0 | 2 | 0 | 0 | 20 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 242 | 0 | 2 | 1 | 0 | 13 | 0 | 1 | 0 | 3 | 7 | 0 | 0 | 0 | 0 | 0 | 0 |
| 258 | 0 | 0 | 0 | 0 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 266 | 1 | 5 | 0 | 0 | 14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 278 | 0 | 0 | 0 | 0 | 9 | 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 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 308 | 0 | 1 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 310 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 322 | 0 | 3 | 0 | 0 | 0 | 0 | 54 | 0 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| 330 | 0 | 0 | 0 | 0 | 0 | 0 | 20 | 0 | 1 | 0 | 0 | 3 | 0 | 0 | 0 | 0 |
| 335 | 0 | 1 | 1 | 0 | 3 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 353 | 0 | 4 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 364 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 365 | 0 | 0 | 1 | 0 | 2 | 0 | 0 | 0 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 382 | 0 | 0 | 1 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 385 | 0 | 2 | 0 | 0 | 2 | 0 | 17 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| June | 13 | 157 | 23 | 0 | 212 | 0 | 212 | 0 | 6 | 0 | 0 | 3 | 2 | 1 | 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 | 3 | 0 | 1 | 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 |
|-------------|-----------------|---------------------|---------------|------------------|---------------|-------------|------------|-------------|----------------|------------------|---------------|----------------------|------------|---------------|--------------|----------|
| 266 | 0 | 0 | 2 | 0 | 6 | 0 | 35 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 278 | 3 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 285 | 0 | 2 | 1 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 298 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 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 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 310 | 0 | 2 | 1 | 0 | 3 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 322 | 3 | 73 | 0 | 0 | 74 | 0 | 80 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 330 | 0 | 2 | 2 | 0 | 0 | 0 | 28 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 335 | 0 | 5 | 0 | 0 | 0 | 0 | 12 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 |
| 353 | 0 | 3 | 0 | 0 | 2 | 0 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 364 | 0 | 1 | 3 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 365 | 0 | 2 | 2 | 0 | 5 | 0 | 1 | 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 | 0 | 0 | 0 | 1 | 0 | 2 | 0 | 0 | 0 | 0 | 1 | 2 | 0 | 0 | 0 |
| July | 6 | 261 | 18 | 0 | 238 | 0 | 660 | 0 | 22 | 5 | 3 | 4 | 0 | 0 | 0 | 1 |
| 2 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 22 | 0 | 4 | 0 | 0 | 0 | 0 | 17 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 31 | 0 | 2 | 0 | 0 | 1 | 0 | 3 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 34 | 0 | 1 | 1 | 0 | 7 | 0 | 19 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 46 | 0 | 4 | 0 | 0 | 1 | 0 | 13 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 50 | 0 | 3 | 1 | 0 | 11 | 0 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 55 | 0 | 0 | 0 | 0 | 4 | 0 | 6 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 69 | 0 | 1 | 0 | 0 | 2 | 0 | 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 72 | 0 | 4 | 0 | 0 | 2 | 0 | 25 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 74 | 0 | 25 | 0 | 0 | 13 | 0 | 23 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 79 | 0 | 0 | 0 | 0 | 2 | 0 | 14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 86 | 0 | 2 | 0 | 0 | 13 | 0 | 37 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 90 | 0 | 1 | 0 | 0 | 2 | 0 | 14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 98 | 0 | 2 | 0 | 0 | 6 | 0 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 103 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 114 | 0 | 1 | 0 | 0 | 10 | 0 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 122 | 0 | 1 | 0 | 0 | 4 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 132 | 0 | 0 | 0 | 0 | 1 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 155 | 0 | 4 | 0 | 0 | 2 | 0 | 20 | 0 | 0 | 1 | 2 | 0 | 0 | 0 | 0 | 0 |
| 160 | 0 | 7 | 0 | 0 | 6 | 0 | 27 | 0 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 162 | 0 | 6 | 0 | 0 | 3 | 0 | 6 | 0 | 1 | 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 |
|-----------|-----------------|---------------------|---------------|------------------|---------------|-------------|------------|-------------|----------------|------------------|---------------|----------------------|------------|---------------|--------------|---------|
| 31 | 1 | 1 | 2 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 34 | 0 | 6 | 1 | 0 | 11 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 46 | 0 | 5 | 1 | 0 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 50 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 55 | 0 | 8 | 1 | 0 | 21 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 69 | 0 | 0 | 2 | 0 | 3 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 72 | 3 | 13 | 3 | 0 | 21 | 0 | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 74 | 1 | 2 | 0 | 0 | 2 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 79 | 0 | 2 | 1 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 86 | 0 | 3 | 3 | 0 | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 90 | 0 | 3 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 98 | 0 | 3 | 0 | 0 | 1 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 103 | 2 | 11 | 3 | 0 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 114 | 0 | 0 | 3 | 0 | 7 | 0 | 1 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 122 | 2 | 3 | 3 | 0 | 14 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 132 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 155 | 0 | 21 | 6 | 0 | 1 | 0 | 1 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 160 | 0 | 3 | 2 | 0 | 30 | 0 | 1 | 0 | 3 | 8 | 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 | 8 | 1 | 0 | 6 | 0 | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 174 | 2 | 5 | 1 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 178 | 0 | 35 | 5 | 0 | 41 | 0 | 9 | 0 | 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 179 | 4 | 8 | 2 | 0 | 10 | 0 | 4 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 180 | 2 | 9 | 8 | 0 | 28 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 181 | 29 | 33 | 20 | 0 | 58 | 0 | 5 | 0 | 17 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 186 | 3 | 10 | 5 | 0 | 11 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 189 | 1 | 7 | 5 | 0 | 49 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 191 | 2 | 4 | 4 | 0 | 4 | 0 | 3 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 194 | 2 | 3 | 3 | 0 | 6 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 198 | 0 | 8 | 12 | 0 | 4 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 210 | 2 | 16 | 10 | 0 | 11 | 0 | 3 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 213 | 22 | 230 | 5 | 0 | 147 | 0 | 51 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 218 | 3 | 15 | 13 | 0 | 20 | 0 | 7 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| 225 | 1 | 2 | 1 | 0 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 234 | 0 | 125 | 1 | 0 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 237 | 4 | 6 | 7 | 0 | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 242 | 1 | 9 | 2 | 0 | 11 | 0 | 7 | 0 | 7 | 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 |
|-----------------|-----------------|---------------------|---------------|------------------|---------------|-------------|------------|-------------|----------------|------------------|---------------|----------------------|------------|---------------|--------------|---------|
| 258 | 0 | 3 | 8 | 0 | 3 | 0 | 2 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 264 | 0 | 5 | 11 | 0 | 5 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 266 | 1 | 7 | 3 | 0 | 0 | 0 | 12 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 278 | 1 | 2 | 11 | 0 | 0 | 0 | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 285 | 1 | 0 | 4 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 298 | 0 | 2 | 3 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 302 | 0 | 3 | 2 | 0 | 5 | 0 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 308 | 1 | 1 | 3 | 0 | 1 | 0 | 3 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 310 | 1 | 9 | 5 | 0 | 17 | 0 | 5 | 0 | 11 | 0 | 0 | 0 | 2 | 0 | 0 | 0 |
| 322 | 7 | 29 | 1 | 0 | 38 | 0 | 39 | 0 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 330 | 2 | 6 | 4 | 0 | 8 | 0 | 0 | 0 | 3 | 0 | 0 | 9 | 0 | 0 | 0 | 0 |
| 335 | 0 | 6 | 2 | 0 | 2 | 0 | 2 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| 353 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 364 | 0 | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 |
| 365 | 0 | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 382 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 385 | 0 | 3 | 1 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Sept. 27 | 852 | 999 | 0 | 1177 | 3 | 4 | 3 | 759 | 21 | 3 | 309 | 84 | 9 | 1 | 1 | |
| 2 | 0 | 4 | 4 | 0 | 6 | 0 | 3 | 0 | 5 | 0 | 0 | 0 | 4 | 1 | 0 | 0 |
| 22 | 1 | 144 | 8 | 0 | 24 | 0 | 0 | 1 | 24 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 31 | 0 | 4 | 0 | 0 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| 34 | 0 | 9 | 1 | 0 | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 46 | 0 | 0 | 4 | 0 | 8 | 0 | 0 | 0 | 5 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 50 | 0 | 8 | 4 | 0 | 67 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 55 | 0 | 39 | 3 | 0 | 43 | 0 | 0 | 0 | 10 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| 69 | 0 | 2 | 6 | 0 | 8 | 0 | 0 | 0 | 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 72 | 1 | 59 | 62 | 0 | 23 | 0 | 0 | 0 | 53 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 74 | 0 | 19 | 31 | 0 | 4 | 0 | 1 | 0 | 15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 79 | 0 | 7 | 1 | 0 | 139 | 0 | 0 | 0 | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 86 | 1 | 30 | 21 | 0 | 15 | 0 | 0 | 0 | 26 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 90 | 0 | 2 | 9 | 0 | 3 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 98 | 5 | 8 | 1 | 0 | 22 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 4 | 0 | 0 |
| 103 | 0 | 24 | 30 | 0 | 39 | 0 | 0 | 0 | 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 114 | 0 | 0 | 52 | 0 | 8 | 0 | 0 | 0 | 30 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 122 | 1 | 6 | 0 | 0 | 9 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 132 | 0 | 6 | 1 | 0 | 56 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| 155 | 0 | 17 | 11 | 0 | 15 | 1 | 0 | 0 | 4 | 1 | 0 | 0 | 14 | 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 |
|--------------------|-----------------|---------------------|---------------|------------------|---------------|-------------|-------------|-------------|----------------|------------------|---------------|----------------------|------------|---------------|--------------|----------|
| 160 | 0 | 11 | 22 | 0 | 18 | 0 | 0 | 0 | 19 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 162 | 0 | 20 | 36 | 0 | 6 | 0 | 0 | 0 | 31 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 170 | 0 | 17 | 6 | 0 | 29 | 0 | 0 | 0 | 10 | 1 | 0 | 0 | 0 | 0 | 1 | 0 |
| 174 | 0 | 7 | 15 | 0 | 41 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| 178 | 0 | 41 | 10 | 0 | 16 | 0 | 0 | 0 | 11 | 0 | 0 | 0 | 3 | 0 | 0 | 0 |
| 179 | 0 | 5 | 84 | 0 | 44 | 0 | 0 | 0 | 17 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 181 | 1 | 10 | 4 | 0 | 15 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 186 | 0 | 16 | 2 | 0 | 6 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 3 | 0 | 0 | 0 |
| 189 | 0 | 31 | 2 | 0 | 23 | 0 | 0 | 0 | 11 | 2 | 0 | 0 | 3 | 0 | 0 | 0 |
| 191 | 0 | 5 | 17 | 0 | 31 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 194 | 1 | 9 | 5 | 0 | 26 | 0 | 0 | 0 | 11 | 0 | 1 | 0 | 2 | 0 | 0 | 0 |
| 198 | 0 | 2 | 35 | 0 | 6 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 4 | 0 | 0 | 0 |
| 210 | 0 | 10 | 7 | 0 | 12 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 213 | 0 | 30 | 66 | 0 | 56 | 1 | 0 | 0 | 4 | 0 | 0 | 0 | 19 | 0 | 0 | 0 |
| 218 | 0 | 3 | 3 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 225 | 1 | 34 | 21 | 0 | 41 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 234 | 0 | 4 | 8 | 0 | 30 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 |
| 237 | 0 | 5 | 4 | 0 | 11 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 3 | 0 | 0 | 0 |
| 242 | 0 | 8 | 22 | 0 | 25 | 0 | 0 | 0 | 7 | 0 | 0 | 0 | 11 | 0 | 0 | 0 |
| 258 | 2 | 8 | 7 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 264 | 0 | 2 | 1 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 266 | 1 | 2 | 6 | 0 | 3 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 278 | 0 | 0 | 9 | 0 | 26 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 |
| 285 | 0 | 1 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 298 | 0 | 2 | 3 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 302 | 0 | 2 | 2 | 0 | 23 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 308 | 0 | 2 | 3 | 0 | 21 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 1 | 0 | 0 | 0 |
| 310 | 0 | 3 | 5 | 0 | 14 | 0 | 0 | 0 | 2 | 2 | 0 | 0 | 1 | 0 | 0 | 0 |
| 322 | 10 | 159 | 318 | 0 | 101 | 0 | 0 | 2 | 394 | 7 | 0 | 0 | 0 | 0 | 0 | 0 |
| 330 | 0 | 5 | 3 | 0 | 13 | 0 | 0 | 0 | 5 | 4 | 1 | 275 | 1 | 0 | 0 | 0 |
| 335 | 0 | 2 | 1 | 0 | 4 | 0 | 0 | 0 | 2 | 0 | 0 | 2 | 1 | 0 | 0 | 0 |
| 353 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 364 | 0 | 2 | 3 | 0 | 5 | 0 | 0 | 0 | 1 | 0 | 0 | 24 | 4 | 0 | 0 | 1 |
| 365 | 2 | 2 | 10 | 0 | 13 | 0 | 0 | 0 | 7 | 0 | 0 | 1 | 1 | 0 | 0 | 0 |
| 382 | 0 | 0 | 10 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 385 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 0 | 0 | 0 | 0 |
| Grand Total | 165 | 2328 | 1284 | 0 | 3307 | 3 | 1205 | 3 | 902 | 51 | 10 | 329 | 99 | 13 | 1 | 3 |

**APPENDIX E: AGE-0 FISH CAPTURED BY TRIP AT
GENERALIZED RANDOM TESSELLATION
STRATIFIED (GRTS) SEGMENTS DURING
LARVAL-FISH COMMUNITY SAMPLING IN
THE GRAND CANYON, 2023**

Appendix E.1. Age-0 fish captured during 2023.

| SPECIES COMMON NAME | RESIDENCE STATUS^a | NUMBER OF SPECIMENS | PERCENT OF TOTAL | MEAN CPUE^b | FREQUENCY OF OCCURRENCE^c | PERCENT FREQUENCY OF OCCURRENCE^c |
|---|---|--------------------------------|-----------------------------|----------------------------------|--|--|
| Carp and Minnows | | | | | | |
| <i>Cyprinella lutrensis</i> Red Shiner | I | 10 | 0.10 | d | 2 | 0.61 |
| <i>Cyprinus carpio</i> Common Carp | I | 1 | d | d | 2 | 0.60 |
| <i>Gila cypha</i> Humpback Chub | N | 529 | 5.21 | 0.05 | 72 | 27.08 |
| <i>Pimephales promelas</i> Fathead Minnow | I | 289 | 2.84 | d | 30 | 5.65 |
| <i>Rhinichthys osculus</i> Speckled Dace | N | 2,381 | 23.43 | 0.21 | 113 | 50.89 |
| Suckers | | | | | | |
| <i>Catostomus discobolus</i> Bluehead Sucker | N | 2,6374 | 25.95 | 0.23 | 138 | 54.46 |
| <i>Catostomus latipinnis</i> Flannelmouth Sucker | N | 4,151 | 40.84 | 0.87 | 174 | 77.98 |
| <i>Xyrauchen texanus</i> Razorback Sucker | N | – | – | – | – | – |
| Catostomidae (Unidentified Sucker) ^e | N | 8 | 0.08 | d | 8 | 2.15 |
| Trout and Salmons | | | | | | |
| <i>Oncorhynchus mykiss</i> Rainbow Trout | I | 1 | d | d | 1 | 0.31 |
| <i>Salmo trutta</i> Brown Trout | I | 1 | d | d | 1 | 0.31 |
| Topminnows | | | | | | |
| <i>Fundulus zebrinus</i> Plains Killifish | I | 109 | 1.07 | d | 4 | 1.23 |
| Livebearers | | | | | | |
| <i>Gambusia affinis</i> Western Mosquitofish | I | 46 | d | d | 5 | 1.53 |
| TOTAL | | 10,163 | | | | |

^a N= native, I= introduced

^b CPUE= catch-per-unit effort; mean value based on n specimens/total area sampled during 2023 (11,282 m²)

^c Frequency and percent frequency of occurrence are based on n=336 GRTS sample segments (2023 total)

^d Value is <0.05

^e Species-specific identifications will be acquired in 2024 and included in the 2024 Grand Canyon report

Appendix E.2. Age-0 fish captured during the 06–16 March 2023 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 |
|---|---|--------------------------------|-----------------------------|----------------------------------|--|--|
| Carp and Minnows | | | | | | |
| <i>Cyprinella lutrensis</i> Red Shiner | I | – | – | – | – | – |
| <i>Cyprinus carpio</i> Common Carp | I | – | – | – | – | – |
| <i>Gila cypha</i> Humpback Chub | N | – | – | – | – | – |
| <i>Pimephales promelas</i> Fathead Minnow | I | – | – | – | – | – |
| <i>Rhinichthys osculus</i> Speckled Dace | N | – | – | – | – | – |
| Suckers | | | | | | |
| <i>Catostomus discobolus</i> Bluehead Sucker | N | – | – | d | – | – |
| <i>Catostomus latipinnis</i> Flannelmouth Sucker | N | – | – | d | – | – |
| <i>Xyrauchen texanus</i> Razorback Sucker | N | – | – | – | – | – |
| Catostomidae (Unidentified Sucker) ^e | N | 1 | 33.33 | d | 1 | 1.89 |
| Trout and Salmons | | | | | | |
| <i>Oncorhynchus mykiss</i> Rainbow Trout | I | – | – | d | 1 | 1.89 |
| <i>Salmo trutta</i> Brown Trout | I | – | – | d | 1 | 1.89 |
| Topminnows | | | | | | |
| <i>Fundulus zebrinus</i> Plains Killifish | I | – | – | – | – | – |
| Livebearers | | | | | | |
| <i>Gambusia affinis</i> Western Mosquitofish | I | – | – | – | – | – |
| Sunfishes | | | | | | |
| <i>Lepomis cyanellus</i> Green Sunfish | I | – | – | – | – | – |
| TOTAL | | 3 | | | | |

^a N=native, I=introduced

^b CPUE=catch-per-unit effort; mean value based on n specimens/total area sampled by month (2,075 m²)

^c Frequency and percent frequency of occurrence are based on n=53 GRTS sample segments

^d Value is <0.05

^e Species-specific identifications will be acquired in 2024 and included in the 2024 Grand Canyon report

Appendix E.3. Age-0 fish captured during the 11–18 April 2023 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 |
|---|---|--------------------------------|-----------------------------|----------------------------------|--|--|
| Carp and Minnows | | | | | | |
| <i>Cyprinella lutrensis</i> Red Shiner | I | – | – | – | – | – |
| <i>Cyprinus carpio</i> Common Carp | I | – | – | – | – | – |
| <i>Gila cypha</i> Humpback Chub | N | – | – | – | – | – |
| <i>Pimephales promelas</i> Fathead Minnow | I | – | – | – | – | – |
| <i>Rhinichthys osculus</i> Speckled Dace | N | 1 | 1.01 | | 1 | 1.85 |
| Suckers | | | | | | |
| <i>Catostomus discobolus</i> Bluehead Sucker | N | 93 | 93.84 | 0.40 | 10 | 18.52 |
| <i>Catostomus latipinnis</i> Flannelmouth Sucker | N | 4 | 4.04 | 0.05 | 2 | 3.70 |
| <i>Xyrauchen texanus</i> Razorback Sucker | N | – | – | – | – | – |
| Catostomidae (Unidentified Sucker) ^e | N | 1 | 1.01 | ^d | 1 | 1.85 |
| Trout and Salmons | | | | | | |
| <i>Oncorhynchus mykiss</i> Rainbow Trout | I | 2 | 0.19 | ^d | 1 | 1.79 |
| <i>Salmo trutta</i> Brown Trout | | | | | | |
| Topminnows | | | | | | |
| <i>Fundulus zebrinus</i> Plains Killifish | I | – | – | – | – | – |
| Livebearers | | | | | | |
| <i>Gambusia affinis</i> Western Mosquitofish | I | – | – | – | – | – |
| Sunfishes | | | | | | |
| <i>Lepomis cyanellus</i> Green Sunfish | I | – | – | – | – | – |
| TOTAL | | 99 | | | | |

^a N= native, I= introduced

^b CPUE= catch-per-unit effort; mean value based on n specimens/total area sampled by month (1,802 m²)

^c Frequency and percent frequency of occurrence are based on n=54 GRTS sample segments

^d Value is <0.05

^e Species-specific identifications will be acquired in 2024 and included in the 2024 Grand Canyon report

Appendix E.4. Age-0 fish captured during the 10–18 May 2023 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 |
|---|---|--------------------------------|-----------------------------|----------------------------------|--|--|
| Carp and Minnows | | | | | | |
| <i>Cyprinella lutrensis</i> Red Shiner | I | – | – | – | – | – |
| <i>Cyprinus carpio</i> Common Carp | I | – | – | – | – | – |
| <i>Gila cypha</i> Humpback Chub | N | – | – | – | – | – |
| <i>Pimephales promelas</i> Fathead Minnow | I | – | – | – | – | – |
| <i>Rhinichthys osculus</i> Speckled Dace | N | 3 | 0.49 | ^d | 1 | 1.89 |
| Suckers | | | | | | |
| <i>Catostomus discobolus</i> Bluehead Sucker | N | 246 | 40.46 | 0.14 | 13 | 24.53 |
| <i>Catostomus latipinnis</i> Flannelmouth Sucker | N | 357 | 58.72 | 0.20 | 23 | 43.40 |
| <i>Xyrauchen texanus</i> Razorback Sucker | N | – | – | – | – | – |
| <i>Catostomidae</i> (Unidentified Sucker) ^e | N | 2 | 0.33 | ^d | 2 | 3.77 |
| Trout and Salmons | | | | | | |
| <i>Oncorhynchus mykiss</i> Rainbow Trout | I | – | – | – | – | – |
| <i>Salmo trutta</i> Brown Trout | I | – | – | – | – | – |
| Topminnows | | | | | | |
| <i>Fundulus zebrinus</i> Plains Killifish | I | – | – | – | – | – |
| Livebearers | | | | | | |
| <i>Gambusia affinis</i> Western Mosquitofish | I | – | – | – | – | – |
| Sunfishes | | | | | | |
| <i>Lepomis cyanellus</i> Green Sunfish | I | – | – | – | – | – |
| TOTAL | | 608 | | | | |

^a N=native, I=introduced

^b CPUE=catch-per-unit effort; mean value based on n specimens/total area sampled by month (1,768 m²)

^c Frequency and percent frequency of occurrence are based on n=53 GRTS sample segments

^d Value is <0.05

^e Species-specific identifications will be acquired in 2024 and included in the 2024 Grand Canyon report

Appendix E.5. Age-0 fish captured during the 06–14 June 2023 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 |
|---|---|--------------------------------|-----------------------------|----------------------------------|--|--|
| Carp and Minnows | | | | | | |
| <i>Cyprinella lutrensis</i> Red Shiner | I | – | – | – | – | – |
| <i>Cyprinus carpio</i> Common Carp | I | – | – | – | – | – |
| <i>Gila cypha</i> Humpback Chub | N | 115 | 2.86 | 0.06 | 18 | 32.73 |
| <i>Pimephales promelas</i> Fathead Minnow | I | 7 | 0.17 | ^d | 5 | 9.09 |
| <i>Rhinichthys osculus</i> Speckled Dace | N | 147 | 3.65 | 0.08 | 28 | 50.91 |
| Suckers | | | | | | |
| <i>Catostomus discobolus</i> Bluehead Sucker | N | 1,342 | 33.33 | 0.70 | 37 | 67.27 |
| <i>Catostomus latipinnis</i> Flannelmouth Sucker | N | 2,414 | 59.95 | 1.25 | 53 | 96.36 |
| <i>Xyrauchen texanus</i> Razorback Sucker | N | – | – | – | – | – |
| Catostomidae (Unidentified Sucker) ^e | N | 2 | 0.05 | ^d | 2 | 3.64 |
| Trout and Salmons | | | | | | |
| <i>Oncorhynchus mykiss</i> Rainbow Trout | I | – | – | – | – | – |
| <i>Salmo trutta</i> Brown Trout | | | | | | |
| Topminnows | | | | | | |
| <i>Fundulus zebrinus</i> Plains Killifish | I | – | – | – | – | – |
| Livebearers | | | | | | |
| <i>Gambusia affinis</i> Western Mosquitofish | I | – | – | – | – | – |
| Sunfishes | | | | | | |
| <i>Lepomis cyanellus</i> Green Sunfish | I | – | – | – | – | – |
| TOTAL | | 4,027 | | | | |

^a N=native, I=introduced

^b CPUE=catch-per-unit effort; mean value based on n specimens/total area sampled by month (1,924 m²)

^c Frequency and percent frequency of occurrence are based on n=55 GRTS sample segments

^d Value is <0.05

^e Species-specific identifications will be acquired in 2024 and included in the 2024 Grand Canyon report

Appendix E.6. Age-0 fish captured during the 04–12 July 2023 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 |
|---|---|--------------------------------|-----------------------------|----------------------------------|--|--|
| Carp and Minnows | | | | | | |
| <i>Cyprinella lutrensis</i> Red Shiner | I | – | – | – | – | – |
| <i>Cyprinus carpio</i> Common Carp | I | – | – | – | – | – |
| <i>Gila cypha</i> Humpback Chub | N | 110 | 4.10 | 0.06 | 21 | 38.18 |
| <i>Pimephales promelas</i> Fathead Minnow | I | 175 | 6.52 | 0.09 | 11 | 20.00 |
| <i>Rhinichthys osculus</i> Speckled Dace | N | 769 | 28.66 | 0.40 | 36 | 65.45 |
| Suckers | | | | | | |
| <i>Catostomus discobolus</i> Bluehead Sucker | N | 327 | 12.00 | 0.15 | 47 | 83.93 |
| <i>Catostomus latipinnis</i> Flannelmouth Sucker | N | 617 | 22.65 | 0.29 | 53 | 94.64 |
| <i>Xyrauchen texanus</i> Razorback Sucker | N | – | – | – | – | – |
| Catostomidae (Unidentified Sucker) ^e | N | 1 | d | d | 1 | 1.79 |
| Trout and Salmons | | | | | | |
| <i>Oncorhynchus mykiss</i> Rainbow Trout | I | – | – | – | – | – |
| <i>Salmo trutta</i> Brown Trout | I | – | – | – | – | – |
| Topminnows | | | | | | |
| <i>Fundulus zebrinus</i> Plains Killifish | I | – | – | – | – | – |
| Livebearers | | | | | | |
| <i>Gambusia affinis</i> Western Mosquitofish | I | 12 | 0.45 | d | 2 | 3.64 |
| Sunfishes | | | | | | |
| <i>Lepomis cyanellus</i> Green Sunfish | I | – | – | – | – | – |
| TOTAL | | 2,683 | | | | |

^a N=native, I=introduced

^b CPUE=catch-per-unit effort; mean value based on n specimens/total area sampled by month (1,927 m²)

^c Frequency and percent frequency of occurrence are based on n=55 GRTS sample segments

^d Value is <0.05

^e Species-specific identifications will be acquired in 2024 and included in the 2024 Grand Canyon report

Appendix E.7. Age-0 fish captured during the 08–16 August 2023 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 | | | | | | |
| <i>Cyprinella lutrensis</i> Red Shiner | I | 10 | 0.36 | ^d | 2 | 3.57 |
| <i>Cyprinus carpio</i> Common Carp | I | 1 | ^d | ^d | 1 | 1.79 |
| <i>Gila cypha</i> Humpback Chub | N | 304 | 11.08 | 0.17 | 33 | 58.93 |
| <i>Pimephales promelas</i> Fathead Minnow | I | 107 | 3.90 | 0.06 | 14 | 25.00 |
| <i>Rhinichthys osculus</i> Speckled Dace | N | 1,461 | 53.26 | 0.82 | 47 | 83.93 |
| Suckers | | | | | | |
| <i>Catostomus discobolus</i> Bluehead Sucker | N | 282 | 10.28 | 0.16 | 36 | 64.29 |
| <i>Catostomus latipinnis</i> Flannelmouth Sucker | N | 435 | 15.86 | 0.24 | 47 | 83.93 |
| <i>Xyrauchen texanus</i> Razorback Sucker | N | – | – | – | – | – |
| Catostomidae (Unidentified Sucker) | N | – | – | – | – | – |
| Trout and Salmons | | | | | | |
| <i>Oncorhynchus mykiss</i> Rainbow Trout | I | – | – | – | – | – |
| <i>Salmo trutta</i> Brown Trout | I | – | – | – | – | – |
| Topminnows | | | | | | |
| <i>Fundulus zebrinus</i> Plains Killifish | I | 109 | 3.97 | 0.06 | 4 | 7.14 |
| Livebearers | | | | | | |
| <i>Gambusia affinis</i> Western Mosquitofish | I | 34 | 1.24 | ^d | 3 | 5.36 |
| Sunfishes | | | | | | |
| <i>Lepomis cyanellus</i> Green Sunfish | I | – | – | – | – | – |
| TOTAL | | 2,743 | | | | |

^a N=native, I=introduced

^b CPUE=catch-per-unit effort; mean value based on n specimens/total area sampled by month (1,786 m²)

^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, 2023**

Appendix F.1. Age-1+ fish captured during 2023.

| SPECIES COMMON NAME | RESIDENCE STATUS^a | NUMBER OF SPECIMENS | PERCENT OF TOTAL | MEAN CPUE^b | FREQUENCY OF OCCURRENCE^c | PERCENT FREQUENCY OF OCCURRENCE^c |
|---|---|--------------------------------|-----------------------------|----------------------------------|--|--|
| Carp and Minnows | | | | | | |
| <i>Cyprinella lutrensis</i> Red Shiner | I | 12 | 1.28 | ^d | 6 | 1.84 |
| <i>Cyprinus carpio</i> Common Carp | I | – | – | – | – | – |
| <i>Gila cypha</i> Humpback Chub | N | 34 | 3.62 | ^d | 20 | 6.13 |
| <i>Pimephales promelas</i> Fathead Minnow | I | 47 | 5.01 | ^d | 23 | 7.06 |
| <i>Rhinichthys osculus</i> Speckled Dace | N | 661 | 70.39 | 0.06 | 150 | 46.01 |
| Suckers | | | | | | |
| <i>Catostomus discobolus</i> Bluehead Sucker | N | 21 | 2.24 | ^d | 11 | 3.37 |
| <i>Catostomus latipinnis</i> Flannelmouth Sucker | N | 97 | 10.33 | ^d | 48 | 14.72 |
| <i>Xyrauchen texanus</i> Razorback Sucker | N | – | – | – | – | – |
| Trout and Salmons | | | | | | |
| <i>Oncorhynchus mykiss</i> Rainbow Trout | I | – | – | – | – | – |
| <i>Salmo trutta</i> Brown Trout | I | – | – | – | – | – |
| Topminnows | | | | | | |
| <i>Fundulus zebrinus</i> Plains Killifish | I | 41 | 4.37 | ^d | 17 | 5.21 |
| Livebearers | | | | | | |
| <i>Gambusia affinis</i> Western Mosquitofish | I | 24 | 2.56 | ^d | 7 | 2.15 |
| Sunfishes | | | | | | |
| <i>Lepomis cyanellus</i> Green Sunfish | I | 2 | 0.21 | ^d | 2 | 0.61 |
| TOTAL | | 939 | | | | |

^a N=native, I=introduced

^b CPUE=catch-per-unit effort; mean value based on n specimens/total area sampled during 2023 (11,282 m²)

^c Frequency and percent frequency of occurrence are based on n=326 GRTS sample segments (2023 total)

^d Value is <0.05

Appendix F.2. Age-1+ fish captured during the 06–16 March 2023 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 |
|---|---|--------------------------------|-----------------------------|----------------------------------|--|--|
| Carp and Minnows | | | | | | |
| <i>Cyprinella lutrensis</i> Red Shiner | I | 2 | 1.41 | ^d | 1 | 1.89 |
| <i>Cyprinus carpio</i> Common Carp | I | – | – | – | – | – |
| <i>Gila cypha</i> Humpback Chub | N | 4 | 2.82 | ^d | 4 | 7.55 |
| <i>Pimephales promelas</i> Fathead Minnow | I | 11 | 7.75 | ^d | 5 | 9.43 |
| <i>Rhinichthys osculus</i> Speckled Dace | N | 92 | 64.79 | ^d | 27 | 50.94 |
| Suckers | | | | | | |
| <i>Catostomus discobolus</i> Bluehead Sucker | N | – | – | – | – | – |
| <i>Catostomus latipinnis</i> Flannelmouth Sucker | N | 17 | 11.97 | ^d | 9 | 16.98 |
| <i>Xyrauchen texanus</i> Razorback Sucker | N | – | – | – | – | – |
| Trout and Salmons | | | | | | |
| <i>Oncorhynchus mykiss</i> Rainbow Trout | I | – | – | – | – | – |
| <i>Salmo trutta</i> Brown Trout | I | – | – | – | – | – |
| Topminnows | | | | | | |
| <i>Fundulus zebrinus</i> Plains Killifish | I | 14 | 9.86 | ^d | 3 | 5.66 |
| Livebearers | | | | | | |
| <i>Gambusia affinis</i> Western Mosquitofish | I | 1 | 0.70 | ^d | 1 | 1.89 |
| Sunfishes | | | | | | |
| <i>Lepomis cyanellus</i> Green Sunfish | I | 1 | 0.70 | ^d | 1 | 1.89 |
| TOTAL | | 142 | | | | |

^a N= native, I= introduced

^b CPUE= catch-per-unit effort; mean value based on n specimens/total area sampled by month (2,075 m²)

^c Frequency and percent frequency of occurrence are based on n=53 GRTS sample segments

^d Value is <0.05

Appendix F.3. Age-1+ fish captured during the 11–18 April 2023 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 |
|---|---|--------------------------------|-----------------------------|----------------------------------|--|--|
| Carp and Minnows | | | | | | |
| <i>Cyprinella lutrensis</i> Red Shiner | I | 2 | 0.57 | ^d | 1 | 1.85 |
| <i>Cyprinus carpio</i> Common Carp | I | – | – | – | – | – |
| <i>Gila cypha</i> Humpback Chub | N | 12 | 3.40 | ^d | 5 | 9.26 |
| <i>Pimephales promelas</i> Fathead Minnow | I | 16 | 4.53 | ^d | 10 | 18.52 |
| <i>Rhinichthys osculus</i> Speckled Dace | N | 240 | 67.99 | 0.13 | 41 | 75.93 |
| Suckers | | | | | | |
| <i>Catostomus discobolus</i> Bluehead Sucker | N | 15 | 4.25 | ^d | 6 | 11.11 |
| <i>Catostomus latipinnis</i> Flannelmouth Sucker | N | 50 | 14.16 | ^d | 19 | 35.19 |
| <i>Xyrauchen texanus</i> Razorback Sucker | N | – | – | – | – | – |
| Trout and Salmons | | | | | | |
| <i>Oncorhynchus mykiss</i> Rainbow Trout | I | – | – | – | – | – |
| <i>Salmo trutta</i> Brown Trout | I | – | – | – | – | – |
| Topminnows | | | | | | |
| <i>Fundulus zebrinus</i> Plains Killifish | I | 7 | 1.98 | ^d | 5 | 9.26 |
| Livebearers | | | | | | |
| <i>Gambusia affinis</i> Western Mosquitofish | I | 11 | 3.12 | ^d | 1 | 1.85 |
| Sunfishes | | | | | | |
| <i>Lepomis cyanellus</i> Green Sunfish | I | 1 | 0.70 | ^d | 1 | 1.89 |
| TOTAL | | 353 | | | | |

^a N=native, I=introduced

^b CPUE=catch-per-unit effort; mean value based on n specimens/total area sampled by month (1,802 m²)

^c Frequency and percent frequency of occurrence are based on n=54 GRTS sample segments

^d Value is <0.05

Appendix F.4. Age-1+ fish captured during the 10–18 May 2023 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 |
|---|---|--------------------------------|-----------------------------|----------------------------------|--|--|
| Carp and Minnows | | | | | | |
| <i>Cyprinella lutrensis</i> Red Shiner | I | 1 | 0.58 | ^d | 1 | 1.89 |
| <i>Cyprinus carpio</i> Common Carp | I | – | – | – | – | – |
| <i>Gila cypha</i> Humpback Chub | N | 5 | 2.91 | ^d | 2 | 3.77 |
| <i>Pimephales promelas</i> Fathead Minnow | I | 5 | 2.91 | ^d | 2 | 3.77 |
| <i>Rhinichthys osculus</i> Speckled Dace | N | 144 | 83.72 | 0.08 | 27 | 50.94 |
| Suckers | | | | | | |
| <i>Catostomus discobolus</i> Bluehead Sucker | N | 2 | 1.16 | ^d | 2 | 3.77 |
| <i>Catostomus latipinnis</i> Flannelmouth Sucker | N | 9 | 5.23 | ^d | 7 | 13.21 |
| <i>Xyrauchen texanus</i> Razorback Sucker | N | – | – | – | – | – |
| Trout and Salmons | | | | | | |
| <i>Oncorhynchus mykiss</i> Rainbow Trout | I | – | – | – | – | – |
| <i>Salmo trutta</i> Brown Trout | I | – | – | – | – | – |
| Topminnows | | | | | | |
| <i>Fundulus zebrinus</i> Plains Killifish | I | 3 | 1.74 | ^d | 3 | 5.66 |
| Livebearers | | | | | | |
| <i>Gambusia affinis</i> Western Mosquitofish | I | 2 | 1.16 | ^d | 1 | 1.89 |
| Sunfishes | | | | | | |
| <i>Lepomis cyanellus</i> Green Sunfish | I | 1 | 0.58 | ^d | 1 | 1.89 |
| TOTAL | | 172 | | | | |

^a N=native, I=introduced

^b CPUE=catch-per-unit effort; mean value based on n specimens/total area sampled by month (1,768 m²)

^c Frequency and percent frequency of occurrence are based on n=53 GRTS sample segments

^d Value is <0.05

Appendix F.5. Age-1+ fish captured during the 06–14 June 2023 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 |
|---|---|--------------------------------|-----------------------------|----------------------------------|--|--|
| Carp and Minnows | | | | | | |
| <i>Cyprinella lutrensis</i> Red Shiner | I | – | – | – | – | – |
| <i>Cyprinus carpio</i> Common Carp | I | – | – | – | – | – |
| <i>Gila cypha</i> Humpback Chub | N | 3 | 7.50 | ^d | 3 | 5.45 |
| <i>Pimephales promelas</i> Fathead Minnow | I | 2 | 5.00 | ^d | 1 | 1.82 |
| <i>Rhinichthys osculus</i> Speckled Dace | N | 32 | 80.00 | ^d | 15 | 27.27 |
| Suckers | | | | | | |
| <i>Catostomus discobolus</i> Bluehead Sucker | N | – | – | – | – | – |
| <i>Catostomus latipinnis</i> Flannelmouth Sucker | N | 1 | 2.50 | ^d | 1 | 1.82 |
| <i>Xyrauchen texanus</i> Razorback Sucker | N | – | – | – | – | – |
| Trout and Salmons | | | | | | |
| <i>Oncorhynchus mykiss</i> Rainbow Trout | I | – | – | – | – | – |
| <i>Salmo trutta</i> Brown Trout | I | – | – | – | – | – |
| Topminnows | | | | | | |
| <i>Fundulus zebrinus</i> Plains Killifish | I | 1 | 2.50 | ^d | 1 | 1.82 |
| Livebearers | | | | | | |
| <i>Gambusia affinis</i> Western Mosquitofish | I | 1 | 2.50 | ^d | 1 | 1.82 |
| Sunfishes | | | | | | |
| <i>Lepomis cyanellus</i> Green Sunfish | I | – | – | – | – | – |
| TOTAL | | 40 | | | | |

^a N=native, I=introduced

^b CPUE=catch-per-unit effort; mean value based on n specimens/total area sampled by month (1,924 m²)

^c Frequency and percent frequency of occurrence are based on n=55 GRTS sample segments

^d Value is <0.05

Appendix F.6. Age-1+ fish captured during the 04–12 July 2023 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 |
|---|---|--------------------------------|-----------------------------|----------------------------------|--|--|
| Carp and Minnows | | | | | | |
| <i>Cyprinella lutrensis</i> Red Shiner | I | – | – | – | – | – |
| <i>Cyprinus carpio</i> Common Carp | I | – | – | – | – | – |
| <i>Gila cypha</i> Humpback Chub | N | 1 | 4.17 | ^d | 1 | 1.82 |
| <i>Pimephales promelas</i> Fathead Minnow | I | – | – | – | – | – |
| <i>Rhinichthys osculus</i> Speckled Dace | N | 14 | 58.33 | ^d | 9 | 16.36 |
| Suckers | | | | | | |
| <i>Catostomus discobolus</i> Bluehead Sucker | N | – | – | – | – | – |
| <i>Catostomus latipinnis</i> Flannelmouth Sucker | N | 5 | 20.83 | ^d | 3 | 5.45 |
| <i>Xyrauchen texanus</i> Razorback Sucker | N | – | – | – | – | – |
| Trout and Salmons | | | | | | |
| <i>Oncorhynchus mykiss</i> Rainbow Trout | I | – | – | – | – | – |
| <i>Salmo trutta</i> Brown Trout | I | – | – | – | – | – |
| Topminnows | | | | | | |
| <i>Fundulus zebrinus</i> Plains Killifish | I | 1 | 4.17 | ^d | 1 | 1.82 |
| Livebearers | | | | | | |
| <i>Gambusia affinis</i> Western Mosquitofish | I | 3 | 12.50 | ^d | 1 | 1.82 |
| Sunfishes | | | | | | |
| <i>Lepomis cyanellus</i> Green Sunfish | I | – | – | – | – | – |
| TOTAL | | 24 | | | | |

^a N=native, I=introduced

^b CPUE=catch-per-unit effort; mean value based on n specimens/total area sampled by month (1,927 m²)

^c Frequency and percent frequency of occurrence are based on n=55 GRTS sample segments

^d Value is <0.05

Appendix F.7. Age-1+ fish captured during the 08–16 August 2023 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 |
|---|---|--------------------------------|-----------------------------|----------------------------------|--|--|
| Carp and Minnows | | | | | | |
| <i>Cyprinella lutrensis</i> Red Shiner | I | 7 | 3.37 | ^d | 3 | 5.36 |
| <i>Cyprinus carpio</i> Common Carp | I | – | – | – | – | – |
| <i>Gila cypha</i> Humpback Chub | N | 9 | 4.33 | ^d | 5 | 8.93 |
| <i>Pimephales promelas</i> Fathead Minnow | I | 13 | 6.25 | ^d | 5 | 8.93 |
| <i>Rhinichthys osculus</i> Speckled Dace | N | 139 | 66.83 | 0.08 | 31 | 55.36 |
| Suckers | | | | | | |
| <i>Catostomus discobolus</i> Bluehead Sucker | N | 4 | 1.92 | ^d | 3 | 5.36 |
| <i>Catostomus latipinnis</i> Flannelmouth Sucker | N | 15 | 7.21 | ^d | 9 | 16.07 |
| <i>Xyrauchen texanus</i> Razorback Sucker | N | – | – | – | – | – |
| Trout and Salmons | | | | | | |
| <i>Oncorhynchus mykiss</i> Rainbow Trout | I | – | – | – | – | – |
| <i>Salmo trutta</i> Brown Trout | I | – | – | – | – | – |
| Topminnows | | | | | | |
| <i>Fundulus zebrinus</i> Plains Killifish | I | 15 | 7.21 | ^d | 4 | 7.14 |
| Livebearers | | | | | | |
| <i>Gambusia affinis</i> Western Mosquitofish | I | 6 | 2.88 | ^d | 2 | 3.57 |
| Sunfishes | | | | | | |
| <i>Lepomis cyanellus</i> Green Sunfish | I | – | – | – | – | – |
| TOTAL | | 208 | | | | |

^a N= native, I= introduced

^b CPUE= catch-per-unit effort; mean value based on n specimens/total area sampled by month (1,786 m²)

^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, 2010–2023**

| 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 |
| | | CRI | Dec-11 | Near CRI |
| | 6678 | River | Feb-12 | Below PFR |
| | | CRI | Feb-12 | Near CRI |
| | | CRI | Jul-11 | Near CRI |
| | 227 | River | Feb-12 | Below PFR |
| | | CRI | Dec-12 | Near CRI |
| CRI | | Jul-11 | Near CRI | |
| 267 | River | Jan-12 | Below PFR | |
| | CRI | May-10 | Near CRI | |

| STUDY YEAR ^a | FISH CODE | GENERAL LOCATION ^b | DATE ^c | LOCATION DETAILED | |
|-------------------------|-----------|-------------------------------|-------------------|--|--------------------|
| 2013 | 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 | |
| | 3546 | CRI | Aug-11 | Near CRI | |
| | | GB | Sep-11 | Near GB | |
| | | CRI | Jan-12 | Near CRI | |
| | | River | Jan-12 | Below PFR | |
| | 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 | |
| 3076 | CRI | Feb-18 | Near CRI | | |

| STUDY YEAR ^a | FISH CODE | GENERAL LOCATION ^b | DATE ^c | LOCATION DETAILED |
|-------------------------|------------------------|-------------------------------|-------------------|--------------------------------|
| | | 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 | Mar-15 | No movement documented |
| 2023 | 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