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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

2017 ANNUAL REPORT

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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

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Prepared by:

Ron Kegerries[1]*, Brandon Albrecht*[1]*, Ron Rogers*[1]*, W. Howard Brandenburg*[2]*, Adam L. Barkalow*[2]*, Harrison Mohn*[1]*, Mark McKinstry*[3]*, Brian Healy*[4]*, James Stolberg*[5]*, Emily Omana Smith*[4]

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

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COVER PHOTO DESCRIPTIONS

Upper: The Grand Canyon below Diamond Creek. *Bottom left*: Razorback Sucker captured from the Colorado River inflow area. *Bottom center left*: Larval Razorback Sucker from the Grand Canyon. *Bottom center right:* Seining in the Grand Canyon. *Bottom right*: Downloading a submersible ultrasonic receiver.

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RECOMMENDED CITATION

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EXECUTIVE SUMMARY

In 2010 the U.S. 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 a Biological Opinion from the U.S. Fish and Wildlife Service (USFWS) recommending that Reclamation begin a project to ". . . examine the potential habitat in the lower Grand Canyon for the species, and institute an augmentation program in collaboration with USFWS, if appropriate" (USFWS 2007). The "lower Grand Canyon" was subsequently defined as the Grand Canyon from Lava Falls Rapid downstream, including the inflow portion in Lake Mead and several miles of lake habitat (Leslie Fitzpatrick, USFWS, personal communication). The project was also recommended in a comprehensive report that reviewed 10 years of Razorback Sucker monitoring on Lake Mead (Albrecht et al. 2008a). Several of the recommendations from that report were highlighted by the Lake Mead Work Group (LMWG) for inclusion in its long-term management plan (Albrecht et al. 2009), and investigating the CRI and other unsampled locations for Razorback Sucker presence are some of the first items of that plan to be implemented.

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

BIO-WEST, Inc. (BIO-WEST) was selected to lead this study and teamed with American Southwestern Ichthyological Researchers, LLC (ASIR), as well as personnel from Reclamation and the U.S. National Park Service (NPS). Larval sampling expertise within the Grand Canyon was provided by ASIR. In addition, Dr. Rich Valdez and Dr. Paul Holden were added as team members to provide historical context, species expertise, and peer review. Other collaborators include personnel from the LCR MSCP, Arizona Game and Fish Department, U.S. Fish and Wildlife Service, and Nevada Department of Wildlife (NDOW). These groups are represented on, participate in, and comprise the LMWG, a multiagency group that is 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 the 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 fourth year of a current 5-year study. Data stemming from the 2016–2017 CRI study are presented as Chapter 1. Chapter 2 covers small-bodied and larval fish community sampling conducted within the Grand Canyon in 2017. Because of the interconnectedness observed between the lake and river, Chapter 3 presents holistic findings from sonic-telemetry efforts. These three chapters provide evidence of Razorback Sucker interaction between and among the study areas. While this report presents interesting and new information pertaining to the status of Razorback Sucker in the Grand Canyon and CRI, the value of this multiyear study will be found in investigating the relationship between the river and

Lake Mead, which was recommended by an independent science panel that reviewed project findings to date (Reclamation 2017).

Colorado River Inflow Area of Lake Mead (CRI)

At the CRI, sonic-telemetry and trammel-netting techniques were used to capture adult and juvenile fish where concentrations of Razorback Suckers were suspected, and fin ray specimens were obtained from previously unaged Razorback Suckers for aging purposes. In nearly 1,525 trammel net-hours at the CRI in 2017, 12 Razorback Suckers, 18 Razorback Sucker × Flannelmouth Sucker *Catostomus latipinnis* hybrids, and 68 Flannelmouth Suckers were captured.

Using sonic-tagged fish locations, adult and juvenile capture locations, and previous knowledge of potential spawning areas to guide efforts, sampling for catostomid larvae during the 2016 spawning period (February–May) resulted in the capture of five larval Razorback Sucker from the CRI.

Since 2010, 97 Razorback Suckers and 51 Razorback Sucker × Flannelmouth Sucker hybrids have been captured via trammel netting, including three juvenile Razorback Suckers (age-2 and age-3). Additionally, 316 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 tracking these fish using sonic-telemetry techniques. In 2013, efforts were initiated to implant wild fish with sonic tags, which resulted in the surgical implantation of one wild fish at the CRI. Seven additional wild Razorback Suckers were implanted with sonic tags at the CRI, two in 2014, three in 2015, and two in 2016. Additionally, 10 hatchery-reared fish were successfully implanted with sonic tags in 2013 and released below Separation Canyon. Nine hatchery-reared fish were implanted with sonic tags and released just below Lava Falls in 2014, and 10 hatchery-reared fish were implanted with dual radio/sonic tags and released at Diamond Creek in 2016. These fish were all from NDOW’s Lake Mead Fish Hatchery. Sonic-tagged Razorback Suckers are regularly monitored via manual tracking as well as passive tracking, which uses submersible ultrasonic receiver (SUR) technology.

Grand Canyon

Grand Canyon small-bodied fish community sampling in 2017 resulted in the capture of four native and eight nonnative fish species, as well as documentation of young-of-the-year (age-0) catostomid and cyprinid fishes. The native species captured included Bluehead Sucker *Catostomus discobolus*, Flannelmouth Sucker, Humpback Chub *Gila cypha*, and Speckled Dace *Rhinichthys osculus*. Seining results indicated that native species (particularly native suckers) dominate the Grand Canyon fish community, especially below Havasu Creek. No Razorback Suckers were captured during small-bodied fish seining efforts within the Grand Canyon study area. However, larval fish community sampling resulted in the capture of early life stage Razorback Suckers in the Grand Canyon. This, along with capturing other native fish species in the Grand Canyon during small-bodied fish community sampling and tracking sonic-tagged fish movement within Lake Mead and the Grand Canyon, suggests that we can use sampling to identify the larvae and juveniles of species that have life histories and ecological traits similar to Razorback Sucker.

Juvenile Humpback Chub were captured during small-bodied fish sampling throughout the Grand Canyon. The first individuals were captured in April, and the species' relative abundance increased through June when juvenile Humpback Chub were captured throughout the entire sampling reach (just below Phantom Ranch to near Pearce Ferry). The collection of additional data throughout the Grand Canyon regarding this endangered 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 the Grand Canyon and the full-pool footprint of Lake Mead.

Larval fish sampling in 2017 verified, for the fourth consecutive year, Razorback Sucker spawning and larval production in the Colorado River within the Grand Canyon. In addition to detection of this rare species, larval fish sampling documented the duration and magnitude of reproduction by Humpback Chub and other members (native and nonnative) of the ichthyofaunal community in the Grand Canyon. In 2017, larval Razorback Suckers (n=27) were captured during four of six monthly samples (March–June) and were distributed from RM 168.6 to the downstream most sampling segment (RM 279.0; Pearce Ferry). As in previous years, the highest numerical capture of larval Razorback Suckers was in April (n=11). Larval Razorback Suckers consisted of three ontogenetic phases (protolarvae–metalarvae). The vast majority of captured were mesolarvae (88.8%; n=24) with the earlier subphase (flexion mesolarvae, n=21) being more common in samples than the later subphase (post-flexion mesolarvae, n=3). Single protolarva were taken in both March and May surveys while a single metalarva was documented in June. This is only the second time this later ontogenetic phase (metalarva) has been encountered in Razorback Sucker; the first was in 2014. Back-calculated hatching dates of larval Razorback Sucker encompassed a 12-week period from February 23 to May 18, 2017.

Age-0 Humpback Chub were captured during four of the six monthly 2017 surveys (May–August) yielding a total of 129 age-0 individuals. Age-0 Humpback Chub were captured between RM 98.7 and 277.4. During the May survey, Humpback Chub larvae were distributed throughout the downstream 107 river miles. Subsequent sampling surveys documented an upstream increase in captures of this species. Larval ontogenetic phases of Humpback Chub were represented by both subphases of mesolarvae (flexion and post-flexion), metalarvae, and numerous early juveniles. Back-calculated hatching dates of Humpback Chub encompassed an 11-week hatch period (May 4–July 28, 2017).

During each 2017 monthly survey, the larval fish catch was numerically dominated by native catostomids. Flannelmouth Sucker was the most abundant species captured in 2017, followed by Bluehead Sucker. Distribution and first occurrence of the larvae of these two relatively common suckers followed patterns observed during 2016 sampling with the initial capture of age-0 specimens occurring at the first GRTS segment downstream of Havasu Creek. Larval fish collections documented recruitment of both species to the age-0 juvenile stage. Like the pattern observed in 2016, older (more developed) larval fish became progressively more prevalent in the more downstream monthly samples than the earlier developmental phases. Larval Speckled Dace were first taken in April with subsequent months producing higher catches of this taxon along an upstream gradient. Collectively, native age-0 fishes comprised 99.99% of the total 2017 larval fish catch.

With the expansion of sonic-telemetry efforts into the Grand Canyon in 2012 and continuation of sonic-telemetry through 2017, more data have been collected on Razorback Sucker movement and CRI-Grand Canyon connectivity. Additionally, sonic-tagged Razorback Sucker movement between the CRI, other areas of Lake Mead, and the Colorado River has been documented. Sonic-tagged fish provided crucial information about Razorback Sucker general habitat use within the Grand Canyon.

Overall Findings

Major findings for this study to date include: (1) Multiple year classes of Razorback Sucker, including juvenile fish, occupy the Colorado River delta to Lake Mead (CRI) and adults spawn there; (2) Razorback Sucker spawn within the Grand Canyon or its associated tributaries; (3) young Humpback Chub *Gila cypha* occur throughout the Grand Canyon in relatively higher abundance than perhaps previously suspected; and (4) sonic-tagged Razorback Sucker (stocked and wild) utilize both the CRI and the Grand Canyon.

The efforts expended and techniques described in this report have allowed us to document the interaction of Razorback Sucker within the Grand Canyon and the CRI. This research will hopefully provide better definition as to where and by what mechanism current conditions allow Razorback Sucker to reproduce and display continued 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 the Grand Canyon. Based on research efforts and results to date, it appears that large efforts to stock Razorback Sucker in the Grand Canyon are likely not necessary at this time. 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 basinwide.

CONTENTS

Figures

Tables

GENERAL INTRODUCTION AND BACKGROUND

The Razorback Sucker *Xyrauchen texanus* is one of four endemic, big-river fish species of the Colorado River basin presently listed as endangered by the U.S. Department of the Interior (USFWS 1991). The other three species are the Colorado Pikeminnow *Ptychocheilus lucius*, Bonytail *Gila elegans*, and Humpback Chub *Gila cypha*. 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 that 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 apparently 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 also have 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, it is thought that predation by bass *Micropterus* spp., Common Carp *Cyprinus carpio,* Channel Catfish *Ictalurus punctatus*, sunfish *Lepomis* spp., and other nonnative species is the primary reason for the lack of Razorback Sucker recruitment throughout its original distribution (Minckley et al. 1991; Marsh et al. 2003).

It was widely believed that the trends of Razorback Sucker decline observed in the Colorado River were also occurring 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 U.S. Bureau of Reclamation (Reclamation), U.S. National Park Service (NPS), Colorado River Commission of Nevada, and the U.S. Fish and Wildlife Service (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; Kegerries et al. 2009, 2015a; Shattuck et al. 2011; Shattuck and Albrecht 2014; Mohn et al. 2015).

Larval Razorback Suckers were found in the Colorado River Inflow Area of Lake Mead (CRI) during 2000 and 2001 but, despite opportunistic netting efforts, no adult Razorback Suckers were captured at that time (Holden et al. 2001; Abate et al. 2002; Albrecht et al. 2008a). In 2008 the

Arizona Game and Fish Department (AZGFD) captured a large adult Razorback Sucker during annual gill-netting efforts in Gregg Basin, and NDOW captured two adult fish in the Virgin Basin. These captures emphasized the possibility that other Razorback Sucker populations may occur in areas of Lake Mead that were not being sampled under existing Lake Mead Razorback Sucker monitoring efforts.

A comprehensive review evaluating the entire Lake Mead Razorback Sucker dataset obtained from 1996 to 2007 summarized the methods used and cumulative findings from Lake Mead Razorback Sucker research and provided recommendations for future monitoring and research on Lake Mead (Albrecht et al. 2008a). These recommendations were incorporated into a long-term management plan that is used and updated by the Lake Mead Work Group (LMWG) and serves as a guide for future Razorback Sucker studies on Lake Mead (Albrecht et al. 2009).

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, a Biological Opinion 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) recommended that Reclamation begin a project to ". . . examine the potential habitat in the lower Grand Canyon for the species, and institute an augmentation program in collaboration with USFWS, if appropriate." Thus, the LMWG decided to begin investigative efforts in the CRI with the goal of identifying whether an unknown 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 from the USFWS in its 2007 Biological Opinion (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. (2012a, 2012b, 2012c) produced three reports to provide background information pertaining to the 2007 Biological Opinion (USFWS 2007). These three reports include (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).

As recently as 2009 there was an apparent expansion in Razorback Sucker recruitment, and the overall numbers of juvenile fish increased at known spawning areas in Lake Mead (Albrecht et al. 2008a; Kegerries et al. 2009). It was hypothesized that there was a high potential to successfully document Razorback Sucker in the CRI at that time. Given the recent success of monitoring fish implanted with improved sonic tags, it was concluded that renewed efforts in the CRI would help clarify whether an additional spawning population existed within Lake Mead (Albrecht et al. 2008a; Kegerries et al. 2009). Thus, initiating telemetry and limited sampling efforts in the CRI was proposed in 2010. Combining stocking and tracking of sonic-tagged Razorback Suckers with trammel netting and larval sampling increased the potential of finding a new spawning population of Razorback Sucker in the CRI. This multimethod approach confirmed a newly identified Lake Mead spawning aggregation (Albrecht et al. 2010a). In addition to providing greater understanding of habitat use and movement patterns within Lake Mead, sampling this population provided even more information regarding the overall recruitment patterns of Lake Mead Razorback Sucker, which will undoubtedly help identify the conditions that are conducive to these unique recruitment events as the study progresses.

Furthermore, investigating the CRI provided information regarding the impact, scale, and magnitude of lake-level and habitat changes in relation to Razorback Sucker spawning. As a result of fluctuating lake 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 lake (e.g., Las Vegas Bay, Echo Bay, Virgin River/Muddy River inflow area). For example, lake elevation dropped from approximately 365 m in 2001 to below 330 m above sea level (ASL) in 2016. With that decline in elevation, the lake receded from the confined canyon reach of the LGC to the more open area of the CRI basin, thereby exposing shallow cobble/gravel shoals.

Currently, the lentic portion of Lake Mead extends to Sandy Point, over 3 km south of the mouth of Iceberg Canyon. Above that interface, several kilometers of once-lentic habitats are now riverine and essentially part of the Colorado River proper. Thus, compared with the remainder of Lake Mead, the scale of change at the CRI has been fairly large (kilometers of habitat change compared with meters of change at some of the known spawning locations in Lake Mead). This disparity 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 lake—if lake levels continue to decline.

There is little information available regarding the spawning activities of Razorback Sucker in the Grand Canyon reach of the Colorado River, Arizona. From 1944 through 1990, 10 adult Razorback Suckers were documented in the Grand Canyon from Lees Ferry (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 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 in October 1998 (Douglas and Douglas 2000) was later determined to be a Razorback Sucker. Razorback Suckers were detected in 1990 at the confluence of the Little Colorado River, but the species was thought to be functionally extirpated in the Grand Canyon since there was no evidence of reproduction there (Clarkson and Childs 2000). More recently, two additional adult Razorback Suckers were captured by AZGFD in 2012 and 2013 below Spencer Creek (Bunch et al. 2012; Rogowski and Wolters 2014).

The life history of the Razorback Sucker is closely linked to the highly variable conditions of the Colorado River system, especially streamflow and channel geomorphology that 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). The larvae emerge and are transported downstream. 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. In reservoirs of the lower Colorado River basin spawning occurs in March and April, and adults congregate to spawn on shallow gravel shorelines where emerging young find food and shelter from predators in complex, rocky shorelines and vegetation (Albrecht et al. 2008a; Kegerries et al. 2009). The numbers 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 at a larger size (Marsh et al. 2005). Postlarval Razorback Sucker feed on small invertebrates, so the timing and chronology of zooplankton development in nursery habitats may be vital to the survival of 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).

Instream dams along the Colorado River corridor are recognized as one of the reasons for 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 where 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. In many systems, there is an attempt to mimic the historical hydrologic cycle by managing the dam accordingly. Management of instream 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). Largely, these natural river system attributes are absent in the Grand Canyon section of the Colorado River. Glen Canyon Dam is operated to produce hydropower, where releases are made in direct proportion to energy demands. The historical hydrologic cycle has been replaced with a daily fluctuation of water that may play a significant role in the survival of the early life stages of the Colorado River’s native fish fauna in the Grand Canyon.

Research concerning early life history of Razorback Sucker within Lake Mead and the LCG was conducted from 2013 through 2017, and continuing research into the early life history of native fishes in the Grand Canyon will help determine the current extent and future feasibility of upstream expansion of Razorback Sucker into the Grand Canyon by movement of Lake Mead populations. 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 the Grand Canyon (D. Speas, Reclamation, personal communication).

Future decreases in lake elevations and a warming climate may also contribute to more suitable habitats for endangered and native fishes in the Grand Canyon.

The overall 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 in 2010 through 2013:

- using sonic-tagged Razorback Suckers to locate and capture wild Razorback Suckers in 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, overall study objectives remained the same for 2011 and 2012 but with twice the field effort compared to 2010. This increased effort was meant to capitalize on the sampling opportunity presented by recent Razorback Sucker recruitment, cover more area, and 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 2013 at the CRI, all sampling efforts were strictly confined to January–May, and these efforts were similar to the intensive field efforts conducted during the original 2010 study year. As such, field work in 2013 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 (Albrecht et al. 2014a; Kegerries et al. 2015a). The overall goal of this effort was to quantify the fish community and reproductive success, with a focus on documenting the presence or absence of wild Razorback Sucker within the understudied Grand Canyon area, while continuing to monitor the Lake Mead CRI population by completing the following general tasks:

- conducting larval and small-bodied fish studies to quantitatively assess annual fish reproduction, spawning, and nursery areas in the 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, L.L.C. (ASIR), as well as personnel from Reclamation and NPS. ASIR provided expertise specific to the larval sampling conducted within the Grand Canyon. In addition, Drs. Rich Valdez and Paul Holden were added as team members to provide historical context, species expertise, and peer review. Other collaborators included personnel from USFWS, AZGFD, and NDOW. All of these groups are represented on, participate with, and comprise the LMWG, a multiagency group that is 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 the LCG 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, 2017).

Following the goals of the initial study, this report contains information from the fourth year of this 5-year study. More specifically, information stemming from 2016 to 2017 in the CRI is presented as Chapter 1 (keeping in line with dates of effort provided in Kegerries and Albrecht [2013b], Albrecht et al. [2014a], and Kegerries et al. [2015a]), while Chapter 2 covers sampling conducted in the Grand Canyon. Because of the interconnectedness between the lake and river, Chapter 3 provides sonic-telemetry findings in a holistic and seamless manner. While this report presents interesting and new information pertaining to the status of Razorback Sucker in the Grand Canyon and CRI, the true value of this multiyear study will be obtained as the study progresses. This was recently confirmed by an independent science panel that evaluated and recommended that the study efforts contained herein continue into the foreseeable future (Reclamation 2017).

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

INTRODUCTION

This chapter presents findings from the eighth year of study within the lentic and lotic areas of the CRI. Following Kegerries and Albrecht (2013b), data for the CRI portions of this project are reported from July 1, 2016, through June 30, 2017.

In addition to this study of 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 additional, critical insight into this wild, recruiting population of Razorback Sucker (Rogers et al. 2017). Research on the juvenile life stage of Razorback Sucker was also conducted (2013–2016) within Lake Mead in the same general areas as the LTM efforts, with the hopes of better understanding this early life stage and the near-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 the Grand Canyon, it may also be insightful for all managers of this species basinwide.

STUDY AREA

The 2016–2017 CRI study activities occurred within Gregg Basin of Lake Mead and the Colorado River upstream to Pearce Ferry Rapid in the lower Grand Canyon (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 boat.

- The interface is the area where the river proper meets the lake proper. This area may or may not have flow, is typically turbid, and is transitory and highly dynamic.

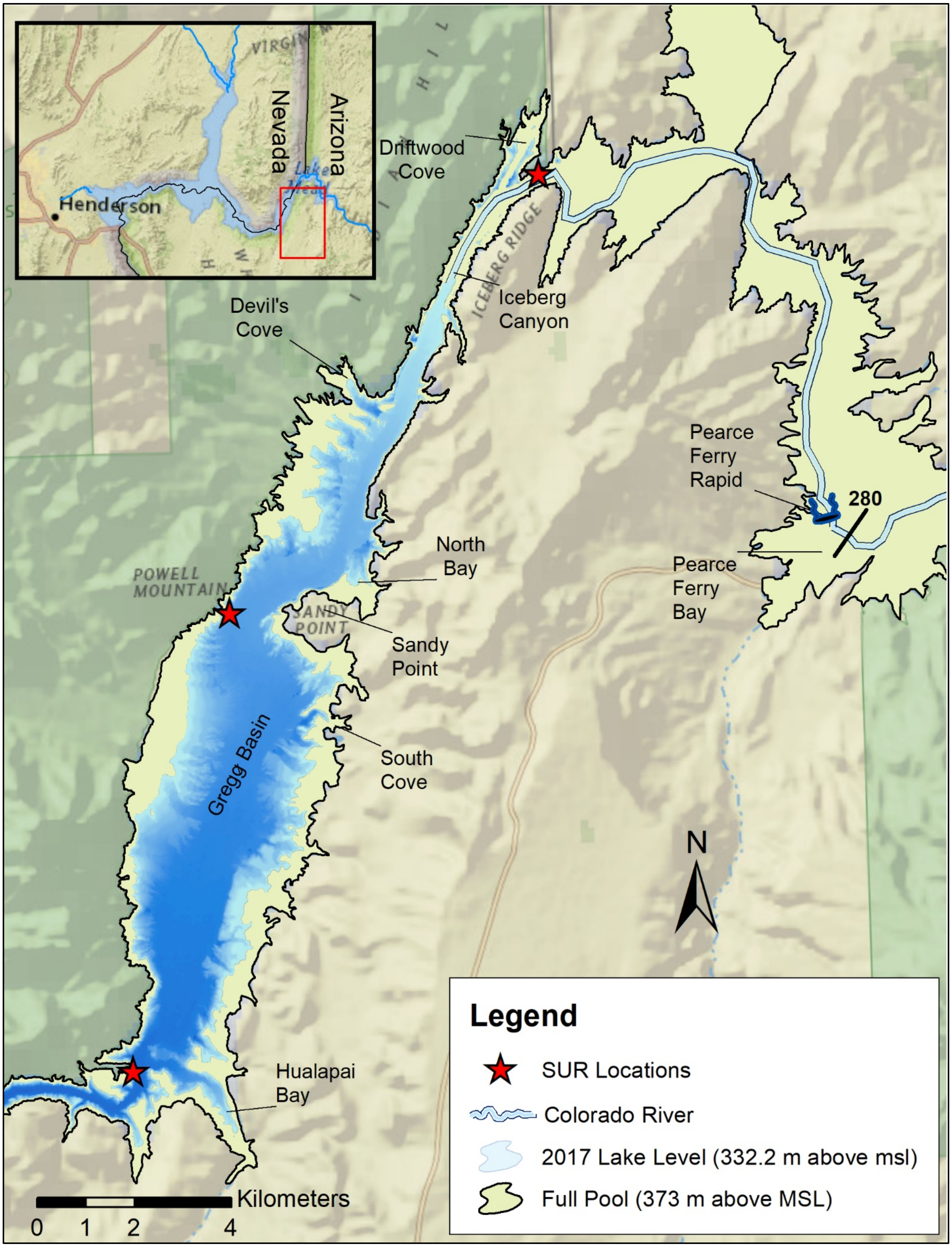


Figure 1.1. General study area and submersible ultrasonic receiver (SUR) location at the Colorado River Inflow Area (CRI) of Lake Mead.

METHODS

Lake Elevation

Month-end and projected lake elevations (February 1, 1935–June 30, 2017) were reported in meters above mean sea level (msl) and obtained from Reclamation's Lower Colorado Regional Office website (Reclamation 2017).

Sonic Telemetry

No Razorback Suckers were surgically implanted with sonic tags during the 2016–2017 field season at the CRI. Please refer to Chapter 3 of this report for detailed telemetry methods and results.

Adult Studies

Trammel Netting

Adult fish were captured using trammel nets either 91.4 m long by 1.8 m deep (300 ft), 45.7 m long by 1.2 m deep (150 ft), 22.9 m long by 1.2 m deep (75 ft) or 15.2 m long by 1.2 m deep (50 ft) with internal panels of 2.54 cm (1 in) mesh and external panels of 30.48 cm (12 in) mesh. Nets were generally set with one end near shore and the net stretched out into deeper areas usually exceeding 2.0 m. Most trammel nets were set in the late afternoon just before sundown and pulled the next morning shortly after sunrise. Netting locations were selected based on the locations of sonic-tagged Razorback Sucker individuals, the presence of concentrated larval fish, and previous knowledge of Razorback Sucker capture locations.

Fish were taken from nets and held in large, 94.6-L coolers filled with lake water. Razorback Suckers, Flannelmouth Suckers *Catostomus latipinnis*, and/or Razorback Sucker × Flannelmouth Sucker hybrids (hybrid suckers) were held in aerated live wells. All but the first five nonnative species were enumerated and returned to the lake, while five of each nonnative species were identified, measured for total length (TL) and fork length (FL), weighed, and released at their capture location. 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 suspected hybrid suckers were scanned for passive integrated transponder (PIT) tags. If the individuals were not recaptured fish, they were 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. 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 caudle fin, preserving it in 95% ethanol, and providing samples to Reclamation for further laboratory analysis.

Catch per unit effort for Razorback Suckers captured via trammel netting (91.4 m, 45.7 m, and 22.9 m nets combined) was calculated as the mean number of fish captured per net-hour fished. The program Statistix 8.1 was used for all statistical analysis. As 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 not be normally distributed ($P \leq 0.05$), the data were transformed [Ln(CPUE+1)]. An ANOVA was used to test for yearly differences in mean CPUE for each sampling site following recommendations of Hubert and Fabrizio (2007). When 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 pair-wise comparisons.

Growth

Razorback Sucker annual growth was calculated from recaptured individuals in trammel-netting collections. Recaptured individuals were only measured once during the spawning season to avoid handling stress, and they were only used for annual growth analysis if approximately one sampling year had passed between capture occasions. Recently stocked individuals, as applicable, were excluded from the dataset and analyses to account for discrepancies in environmental conditions (e.g., a hatchery- 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 and 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.

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 "crappie" 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, identified and enumerated, and placed into a holding bucket. Larvae were released at the point of capture when sampling at a site was complete. The procedure was repeated for 15 minutes at 2–5 sampling sites on each night attempted.

Because of the vast sampling area, turbidity, flowing water, and the potential for larval drift at the CRI, larval light traps were also deployed as a method to capitalize on efforts to collect catostomid larvae. The larval light traps were deployed by tying a lead rope to vegetation near shore in suspected spawning areas or in habitats with little-to-no current velocity. A light stick was inserted into the trap and allowed to float freely. The light traps were set out overnight and collected the next morning or after the desired deployment time. The catch bowls were checked for larval fish. All larval fish were identified, enumerated, returned to the lake, or retained in 10% formalin for species verification as described below.

Because other native sucker species are present at the CRI, some larval suckers were preserved in 10% formalin for microscopic verification using a key to catostomid fish larvae developed by Snyder and Muth (2004). It should be noted that not all larvae were preserved for identification. Only a subset of those collected for verification of field identification and those that were questionable or otherwise difficult to identify in the field were preserved. Some preserved specimens for were also sent to ASIR for identification.

Catch per unit effort for larval Razorback Sucker captures via active light sampling was calculated as the mean number of fish captured per light-minute for analyzing the relative abundance by year. The data set was tested for normality, transformed as necessary, and compared statistically following the methods described for analyzing trammel netting CPUE.

Spawning-Site Identification

Multiple methods are needed to identify primary annual Razorback Sucker spawning sites. The basic, most effective spawning-site identification procedure has been to track sonic-tagged fish and identify their most frequented areas (see Chapter 3). Typically, once a location is identified as frequently used by sonic-tagged fish, particularly during crepuscular hours, trammel nets are set in an effort to capture adult 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 sonic-tagged Razorback Sucker habitat use and other, untagged juvenile or adult 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.

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, an emphasis of the 2017 CRI spawning season efforts involved collecting fin ray sections from Razorback Suckers, suspected hybrids, and occasionally Flannelmouth Suckers for aging purposes using this technique.

During the 2017 spawning period, new fish captured via trammel nets were anesthetized and a single, approximately 0.5-cm-long segment 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 blade, and the section was placed in a labeled envelope for drying. All surgical equipment was cold sterilized 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 lake 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. Each sectioned fin ray was aged independently by at least two readers. Sections were then reviewed by all readers in instances in which the assigned age was not agreed upon. If age discrepancies remained after the second reading, a third reader viewed the structure and all three readers collectively assigned an age to the individual.

Population and Apparent Survival Rate Estimation

Because stocked and wild Razorback Suckers have been observed moving between all study locations within Lake Mead (i.e., the CRI, Las Vegas Bay, Echo Bay, the Virgin River/Muddy River inflow area) (Kegerries and Albrecht 2011, 2013a, b; Shattuck et al. 2011; Albrecht et al. 2013a, b, 2014a, b; Kegerries et al. 2015a; Mohn et al. 2015, 2016), the population was assessed at the lakewide scale. As such, a population and annual apparent survival rate estimate specific to the CRI is not included due to the connectivity throughout the lake and between spawning aggregations. Razorback Sucker capture and recapture data stemming from the CRI were included as part of the lakewide population and survival rate estimates provided in Rogers et al. (2017).

Supplemental Efforts

In addition to weekly research at the CRI, efforts in the lotic section of the Colorado River were conducted from below Pearce Ferry Rapid downstream to the CRI. These efforts were conducted opportunistically, depending on the weekly project goals and field schedule. Sonic telemetry was conducted following the methods described in Chapter 3. Trammel nets (45.7-m long by 1.2-m deep and 22.9-m long by 1.2-m deep with internal mesh of 2.54 cm and external panel mess of 30.48 cm), hoop nets (0.61-m in diameter and 1.28-m long with 0.10-m throats and 6.40-mm mesh), fyke nets (two 1.2-m long by 0.6-m wide rectangular steel frames and two 0.6-m circular hoops with a lead net 0.6-m tall with a 4.5-m long all with 3-mm mesh), and seines (1.2-m tall by 4.6-m wide with 3-mm mesh) were utilized to sample the small-bodied fish community. The gear types used depended on habitat availability and varied during each sampling event due to the dynamic nature of this section of river. Native fishes were identified and measured (TL, FL, SL [mm]) and weighed (grams), implanted with a PIT tag if they were untagged fish, then released at the point of capture. Nonnative species were measured (TL, FL [mm]) and weighted (grams) then released at the point of capture.

Sampling for the larval fish community was conducted using a fine mesh seine (1-m x 1-m x 0.8-mm mesh) and primarily occurred in low-velocity habitats. Individual seine hauls were sorted, and larval fish were retained in a 10% formalin solution. For each seine haul, a discrete suite of data was recorded on a data sheet including fish count and length (mm), length of seine haul (m), habitat type, and habitat attributes such as substrate, cover, and depth (cm). Larvae were identified following Snyder and Muth (2004) or by ASIR, as previously mentioned. Lastly, larval lights were deployed in the river in low- to zero-velocity habitats with the goal of catching larvae that had escaped the drift.

RESULTS

Lake Elevation

The highest Lake Mead elevation during the study period was in February 2017 at approximately 332.2 m above msl. Declining by about 2.5 m from February to the end of May, the lake elevation receded steadily to approximately 329.7 m above msl (Figure 1.2). During the first sampling event in February 2017, the lake elevation was 1.7 m higher than in February 2016 (Figure 1.2). In general, a declining trend has been observed on Lake Mead for more than a decade (Figure 1.2). The effects of littoral desiccation were evident; however, based on our visual observations, habitats changed relatively slowly and remained fairly consistent compared with previous years at the CRI.

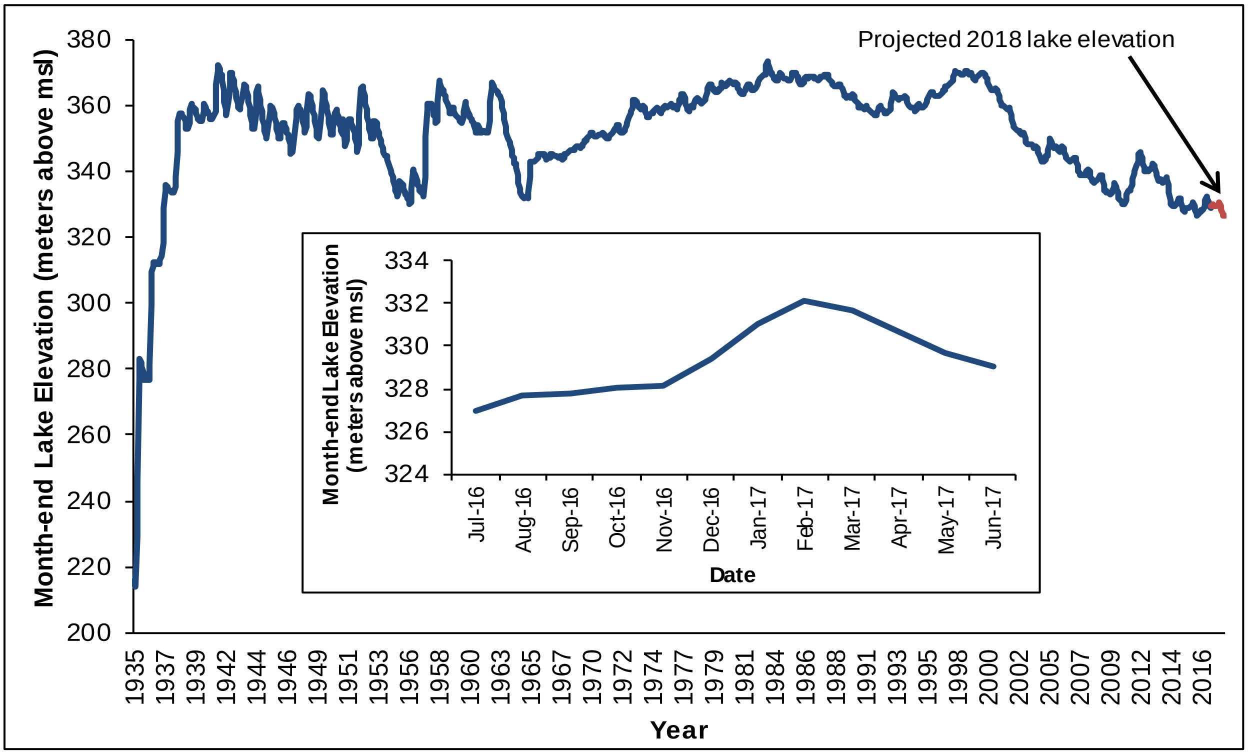


Figure 1.2. **Lake Mead month-end elevations in meters above mean sea level (msl) from February 1935 to June 2017 with projected elevation in red. The inset graph depicts lake elevations from July 2016 to June 2017, or the 2017 study period.**

Adult Sampling

Trammel Netting

During the 2017 field season, 104 nets were set for a total 1,524.9 net-hours (Table 1.1). Netting was generally concentrated near the CRI, more specifically within "Lunch Cove," (1) because this area was frequented by sonic-tagged fish and (2) because of previous successes capturing Razorback Suckers at this location during past field seasons. Netting was also conducted farther south along the western shoreline, as well as in a calm-water "side channel" just north of Sandy Point. Additional nets were set in the southern part of Gregg Basin on the eastern shoreline near the location of a sonic-tagged fish (Figure 1.3).

Table 1.1. Trammel netting effort in the Colorado River Inflow Area of Lake Mead (CRI) during 2017 showing total nets set and net-hours by month.

MONTH	TOTAL NET SETS	TOTAL NET-HOURS
February	37	551.3
March	43	639.2
April	24	334.4
TOTAL	**104**	**1,524.9**

Ten wild and two stocked Razorback Suckers were captured during the 2017 spawning season at the CRI (Table 1.2). Eleven of these fish were unique individuals and one Razorback Sucker was captured twice in 2017. Five unique individuals were new, wild Razorback Suckers that included one juvenile fish (Table 1.2). Two wild Razorback Suckers were originally captured and tagged near the Virgin River/Muddy River inflow area. One individual that was stocked for telemetry purposes in the Grand Canyon in 2016 was recaptured at CRI. Of the 11 unique fish, eight were female, two were male, and one was a juvenile (sexually immature with a TL of 268 mm) (Table 1.2). The first Razorback Sucker captured from the CRI on February 3, 2017, was a 578 mm (TL) wild, sonic-tagged male (Table 1.2). The first female Razorback Sucker was captured on February 14, 2017, and expressing eggs (Table 1.2). She was a recaptured fish originally tagged in 2009 at the Virgin River/Muddy River inflow area (Table 1.2). Razorback Suckers were captured throughout the spawning season from February through April.

The mean catch rate for Razorback Sucker at the CRI in 2017 was 0.007 (SE±0.002) fish per net-hour (Table 1.3 and Figure 1.4). For comparison, catch rates for Razorback Suckers captured at the CRI in 2013, 2014, 2015, and 2016 were 0.004 (SE ± 0.002), 0.005 (SE ± 0.002), 0.010 (SE±0.003), and 0.003 (SE ± 0.001), respectively (Table 1.3 and Figure 1.4). While mean catch rates have varied over the past eight study years, no significant difference was detected among years (ANOVA, $F_{7,910}$=1.96, P=0.058). Mean catch rates at the CRI appear to be lower than at other spawning locations throughout Lake Mead. However, they are within the range historically experienced throughout the LTM studies since 2005 (Figure 1.4).

Additionally, in 2017, 68 Flannelmouth Suckers were captured, of which 18 were recaptured fish (Appendix A), resulting in a mean catch rate of 0.041 (SE ± 0.007) (Table 1.3). Since 2010, 1,187 Flannelmouth Suckers have been captured at the CRI. Flannelmouth Sucker mean catch rates have varied by year but appear to remain higher than mean catch rates of Razorback Sucker

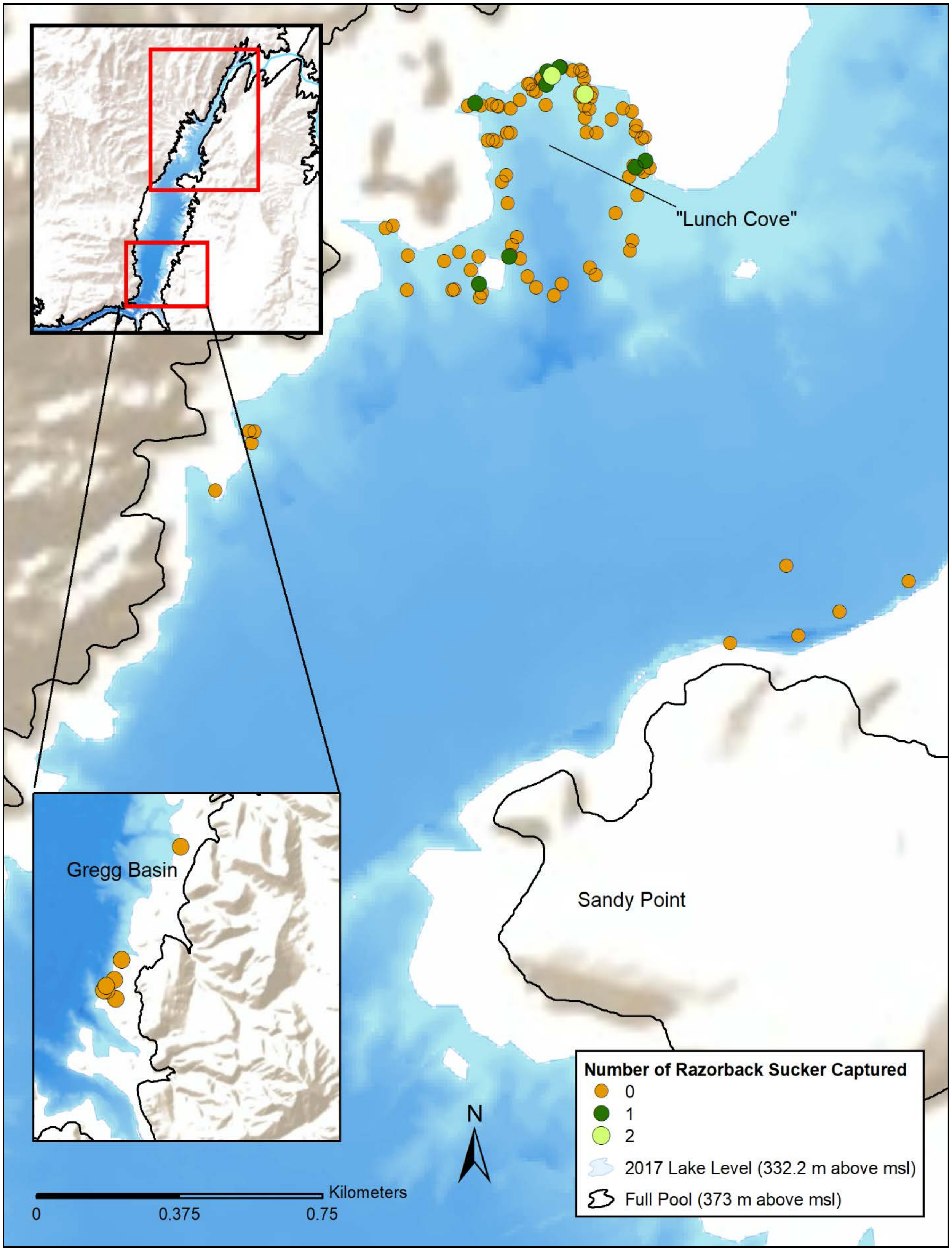


Figure 1.3. Trammel-netting locations and numbers of fishes captured in the Colorado River Inflow Area of Lake Mead (CRI), February–April 2017.

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 2017.

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]
2/3/2017	RBS	3DD.003BA208F2	3465	2/24/2015	YES (WILD)	578	521	485	2,395	M
2/14/2017	RBS	3D9.1C2C8572E3		2/4/2009	YES (WILD)	642	591	556	3,080	F
2/14/2017	RBS	3DD.003BA208D4		2/14/2017	NO (WILD)	268	241	219	175	I
2/15/2017	RBS	3D9.1C2D697167		2/6/2015	YES (STOCKED)	598	565	522	2,688	F
2/15/2017	RBS	3DD.003BA208D4		2/14/2017	YES (WILD)	-- [h]	-- [h]	-- [h]	-- [h]	I
2/15/2017	RBS	3DD.003BE8F1D7		1/19/2017	YES (WILD)	621	581	544	2,450	F
3/1/2017	RBS	3DD.003BCBF7FA	3076	2/22/2016	YES (STOCKED)	517	477	454	1,620	M
3/7/2017	RBS	3DD.003BA2FA83		3/7/2017	NO (WILD)	598	550	514	2,030	F
3/7/2017	RBS	3DD.003BA2FAA5	5777	3/17/2015	YES (WILD)	591	557	528	2,153	F
3/8/2017	RBS	3DD.003BA20A6F		3/8/2017	NO (WILD)	556	515	473	1,855	F
3/29/2017	RBS	3DD.003BA20A55		3/29/2017	NO (WILD)	602	571	528	2,405	F
4/18/2017	RBS	3DD.003BA20A23		4/18/2017	NO (WILD)	401	373	340	895	F
2/2/2017	H	3DD.003BE8F551		2/10/2016	YES (WILD)	565	-- [h]	-- [h]	1,780	U
2/3/2017	H	3DD.003BE8F391		2/3/2017	NO (WILD)	520	-- [h]	-- [h]	1,440	U
2/4/2017	H	3D9.1C2D266590		1/12/2012	YES (WILD)	-- [h]	-- [h]	-- [h]	-- [h]	M
2/14/2017	H	3DD.003BA2FAB4		3/17/2016	YES (WILD)	490	464	427	1,185	M
2/15/2017	H	3DD.003BA2091D		2/17/2015	YES (WILD)	491	457	426	1,178	F
2/15/2017	H	3DD.003BA20A1B		2/15/2017	NO (WILD)	547	511	474	1,688	F
3/1/2017	H	3DD.003BA2091D		2/17/2015	YES (WILD)	-- [h]	-- [h]	-- [h]	-- [h]	F
3/7/2017	H	3D9.1C2D2608F0		4/13/2011	YES (WILD)	596	555	519	1,995	F
3/7/2017	H	3DD.003BA2FA70		3/7/2017	NO (WILD)	476	443	408	915	U
3/7/2017	H	3DD.003BE8F551		2/10/2016	YES (WILD)	566	531	490	1,868	F
3/8/2017	H	3DD.003BE8F551		2/10/2016	YES (WILD)	-- [h]	-- [h]	-- [h]	-- [h]	F
3/8/2017	H	3DD.003BA2FA70		3/7/2017	YES (WILD)	-- [h]	-- [h]	-- [h]	-- [h]	M
3/21/2017	H	3DD.003BA20A4D		3/21/2017	NO (WILD)	482	446	420	1,040	U
3/21/2017	H	3DD.003BA20A79		3/21/2017	NO (WILD)	476	-- [h]	-- [h]	-- [h]	U
3/28/2017	H	384.1B796BBF87		3/28/2017	YES (WILD)	-- [h]	-- [h]	-- [h]	-- [h]	F
4/4/2017	H	384.1B796EE49B		3/23/2011	YES (WILD)	604	571	530	2,340	F
4/5/2017	H	3DD.003BA2FA70		4/26/2016	YES (WILD)	-- [h]	-- [h]	-- [h]	-- [h]	M
4/19/2017	H	3DD.003BA20A7D		3/24/2016	YES (WILD)	431	400	371	825	U

[a] Species: RS=Razorback Sucker, H=hybrid. [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. [h]=Not recorded, typically to avoid excessive handling stress.

Table 1.3. Razorback Suckers, Flannelmouth Suckers, and hybrid suckers captured from 2010 to 2017.

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)

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

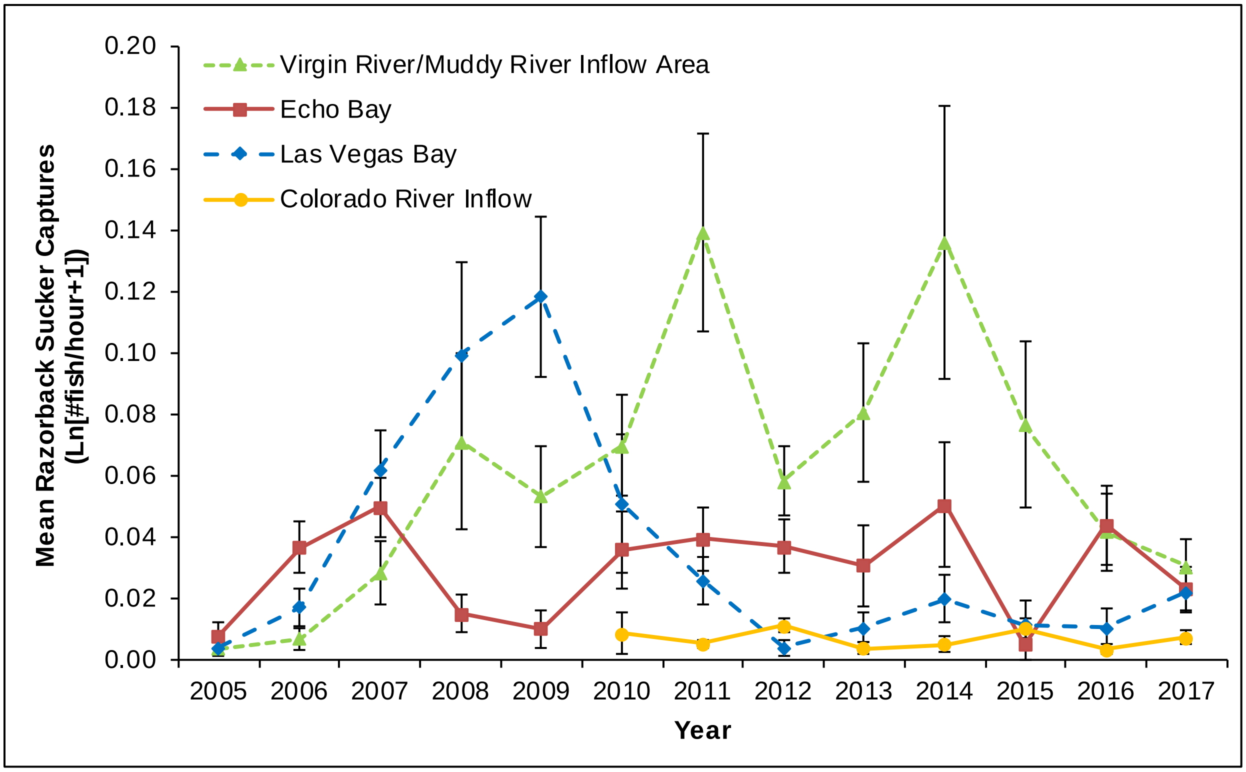


Figure 1.4. Trammel-netting catch per unit effort (CPUE expressed as the mean Ln[#Razorback Sucker/hour +1] [±SE]) values from the Colorado River Inflow Area of Lake Mead (CRI) and long-term monitoring (LTM) sites throughout Lake Mead, 2005–2017.

or hybrid suckers (Table 1.3). Many of these fish were either immature or sex was not readily identifiable at the time of capture; thus, sex ratios are not included (Appendix A).

Eighteen wild hybrid suckers were captured at the CRI in 2017, resulting in a mean catch rate of 0.014 (SE ± 0.005) (Table 1.2). Since 2010, 50 hybrid suckers have been captured at the CRI with a sex ratio of approximately 1:2 (male:female), and adults of both sexes typically exhibited signs of sexual maturity at time of capture. No Bluehead Suckers *Catostomus discobolus* were captured during CRI trammel netting efforts in 2017, although this species was documented during past collections (Kegerries and Albrecht 2013b).

Length and Growth Information

Razorback Suckers captured in 2017 ranged in size from 268 to 642 mm (TL) (Figure 1.5) with a mean TL of 542.9 mm (SE± 33.8). The hybrid suckers captured at the CRI in 2017 ranged from 431 to 604 mm (TL) (Figure 1.5) with a mean TL of 520.3 mm (SE± 15.7). Finally, the more numerous Flannelmouth Suckers captured in 2017 at the CRI ranged in size from 234 to 540 mm (TL) (Figure 1.5) with a mean TL of 441.5 mm (SE± 9.7).

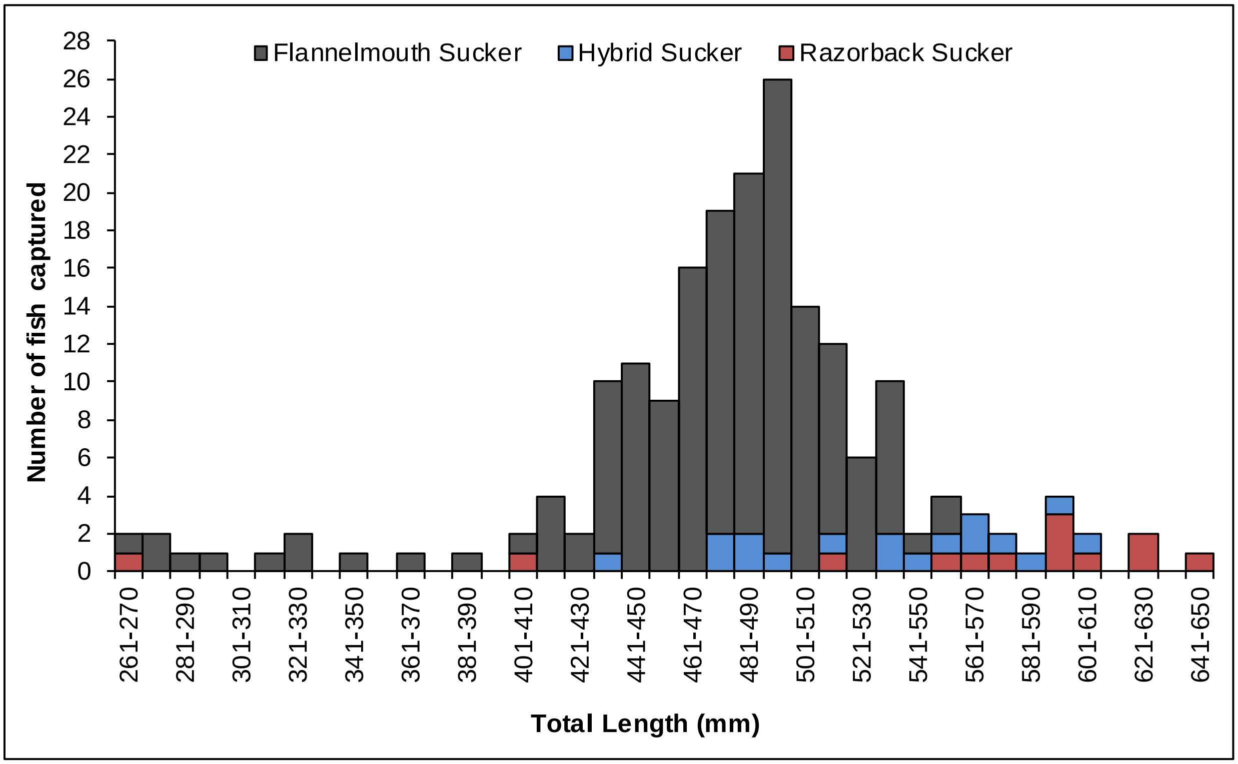


Figure 1.5. **Length-frequency (total length) distributions for native suckers captured at the Colorado River Inflow Area of Lake Mead (CRI) in 2017.**

Although 11 Razorback Suckers were captured at the CRI in 2017, annual growth rate analyses were performed using data from six recaptured Razorback Sucker (three wild and three stocked) (Tables 1.3 and 1.4). As such, these data should not be used to assume typical average growth; rather they should be used in conjunction with growth reported in 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 rate for 2017 were calculated by combining wild and stocked fish. The estimated mean annual growth at the CRI was 24.3 mm TL (SE ± 12.8 mm) per year (Table 1.4). For comparison, mean annual growth of all Razorback Suckers captured from LTM locations in Lake Mead during 2017 was 10.6 mm TL (SE ± 1.7 mm) per year (Rogers et al. 2017).

Table 1.4. Growth histories of applicable Razorback Sucker recaptured at the Colorado River Inflow Area of Lake Mead (CRI) in 2017.

PIT TAG NUMBER	ORIGINAL CAPTURE OR STOCK DATE [a]	TL (mm) [b]	LAST DATE RECAPTURED	TL (mm)	TOTAL GROWTH (mm)	DAYS BETWEEN MEASUREMENTS	GROWTH/ YEAR (mm/365 days)
Wild Fish							
3D9.1C2C8572E3	2/4/2009	602	2/14/2017	642	40	2,932	5.0
3DD.003BA20912	5/14/2014	429	1/31/2017	473	44	993	16.2
3DD.003BA2FAA5	3/17/2015	572	3/7/2017	591	19	721	9.6
Stocked Fish							
384.1B7969CCA6	5/8/2013	237	2/2/2017	565	328	1,366	87.6
3D9.1C2D697167	2/6/2015	566	2/15/2017	598	32	740	15.8
3DD.003BCBF7FA	2/22/2016	505	3/1/2017	517	12	373	11.7
Mean annual growth- All Fish							**24.3 (SE ± 12.8)**

[a] The date a fish was stocked into Lake Mead, or the date a wild fish was originally captured.
[b] Total length in millimeters.

Larval Sampling

Sampling for Razorback Sucker larvae began on February 28, 2017, and it continued through April 24, 2017. Larval sampling was conducted near areas where sonic-tagged fish were contacted, where adult Razorback Suckers were captured, and in coves near to the river outflow. (Figure 1.6). Much of the effort was focused in and around “Lunch Cove” and at the river/lake interface. Additional sampling took place around a sonic-tagged fish in the southern end of Gregg’s Basin; however, no larvae were found in this southern location.

Active larval sampling in 2017 consisted of 1,350 minutes and resulted in the capture of five Razorback Sucker larvae. Additionally, two Flannelmouth Sucker larvae were captured during active sampling. The first larval Razorback Sucker capture during active sampling occurred on April 11, 2017, when surface water temperatures averaged 17.2°C. All Razorback Sucker larvae were captured within a 2-week period when water surface temperatures ranged from 16.1 to 18.7°C at sampling sites within and around “Lunch Cove” along the west shoreline (Figure 1.6).

The mean larval Razorback Sucker catch rate was 0.004 (SE ±0.002) in 2017, with significant differences found in catch rates between years from 2010 through 2017 (ANOVA, $F_{7,929} = 13.6$, $P<0.0001$) (Figure 1.7). Based on post hoc analysis, 2014 mean catch rates were higher than in all other years while 2015 was higher than 2010 and 2012.

Lastly, to increase larval sampling efforts and cover more area for longer periods of time, 39 passive light traps were deployed in 2017. During the 34,147 larval light trap minutes, one Razorback Sucker and one Flannelmouth Sucker larvae were captured. Both larvae were captured off the western shore across from Sandy Point.

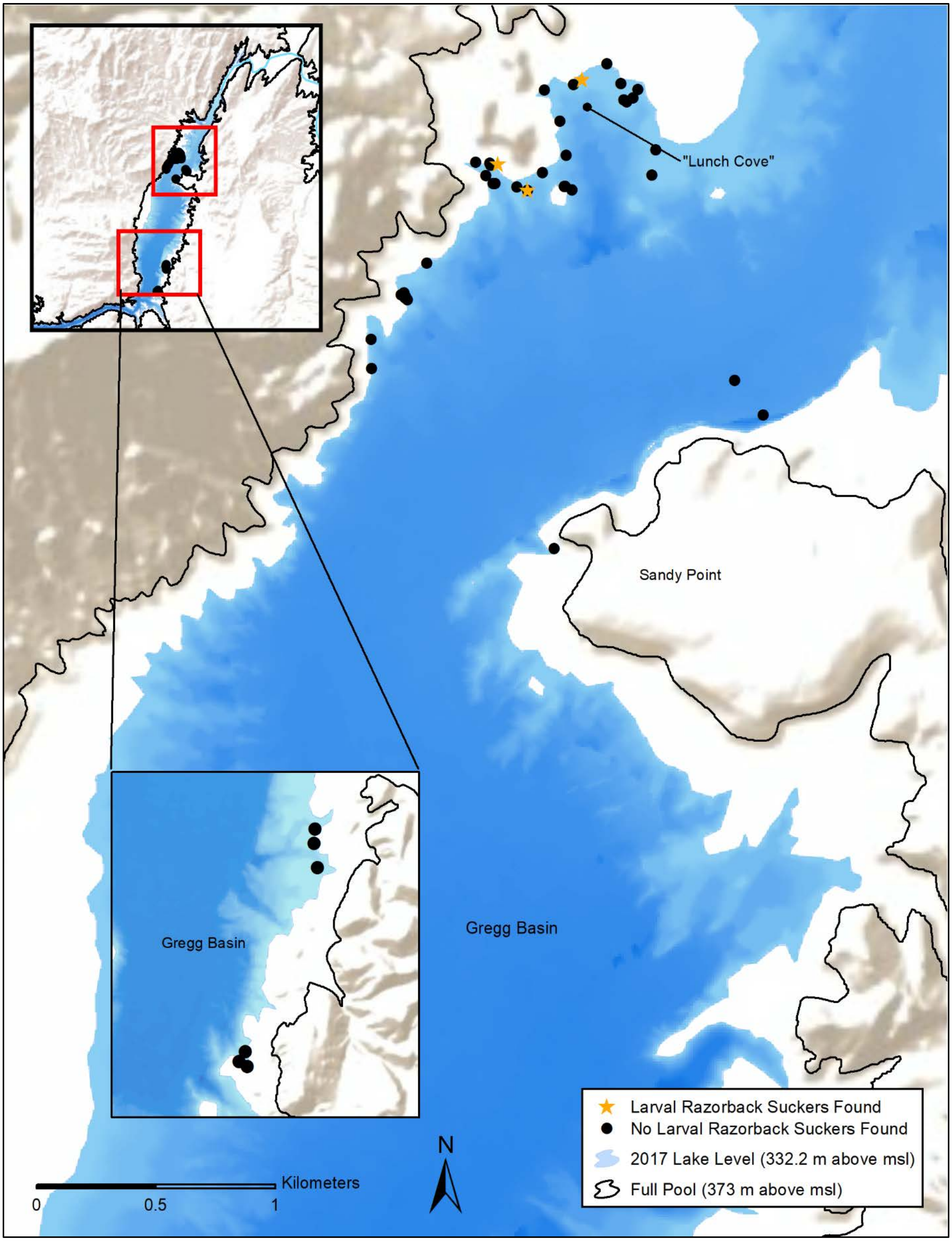


Figure 1.6. **Larval Razorback Sucker sample and capture locations in the Colorado River Inflow Area of Lake Mead (CRI), 2017.**

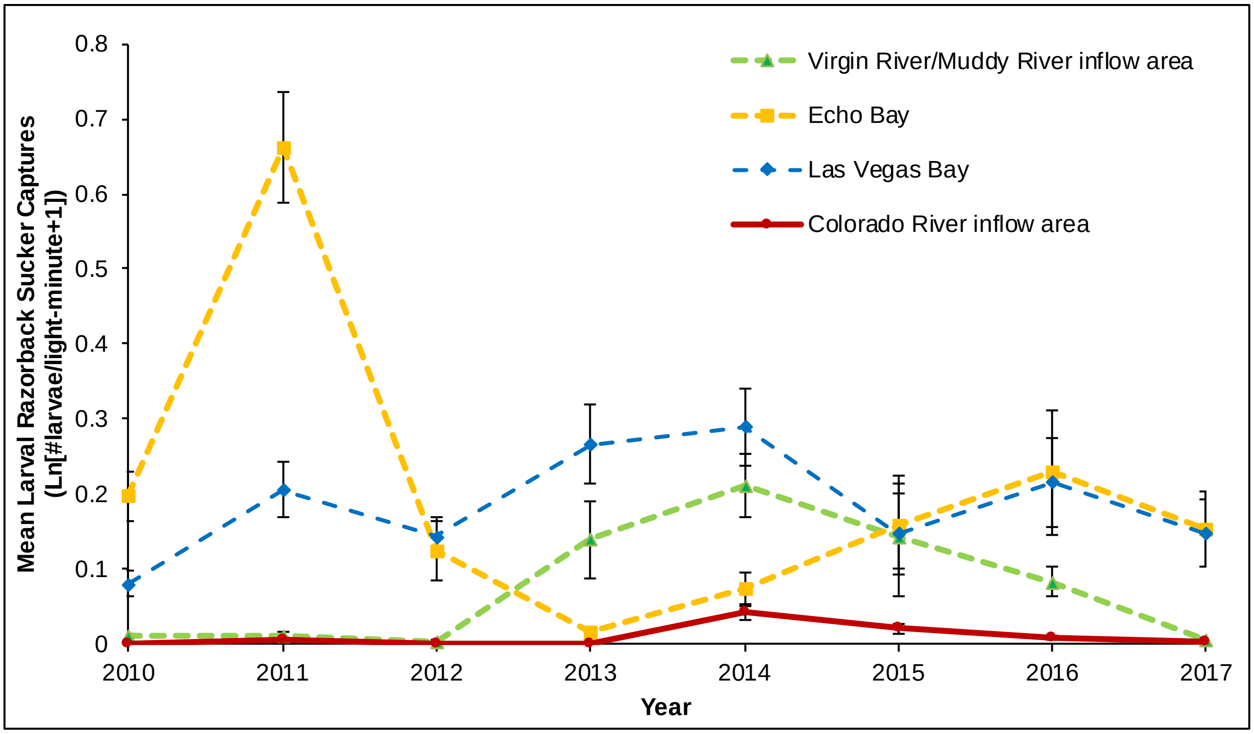


Figure 1.7. **Larval Razorback Sucker mean CPUE (Ln[number larvae/light-minute sampled+1] ±SE) comparisons by primary sampling location on Lake Mead for 2010–2017.**

Spawning-Site Identification and Observations

Larval Razorback Suckers collected at the CRI in 2017 were found along the western shoreline and within “Lunch Cove” (Figure 1.6). The additional presence of sonic-tagged fish (see Chapter 3) and ripe adults suggests that spawning could have occurred at the CRI in 2017. However, a definitive spawning location within the greater CRI was not assigned for 2017 due to the low captures of larvae and what appeared to be inconsistent use of habitat throughout the CRI by adult fish. Although spawning in 2017 was likely, based on previous years of study at the CRI, the exact location becomes difficult to discern while the river is flowing into areas where larvae are captured. Larval drift from the river could be contributing to some, or all, of the larvae captured during sampling.

Razorback Sucker Aging

Fin ray sections were obtained for aging of six Razorback Suckers, six hybrid suckers, and one Flannelmouth Sucker in 2017. This brings the total number of aged Razorback Suckers from the CRI to 39. The six Razorback Suckers were age-3 (*n*=1; 2014 year-class), age-6 (*n*=3; 2011 year-class), age-10 (*n*=1; 2007 year-class) and age-11 (*n*=1; 2006 year-class) (Figure 1.8 and Appendix B).

In addition to presenting information on the Razorback Sucker captured and aged at the CRI in 2017, Figure 1.8 presents cumulative Lake Mead Razorback Sucker lakewide recruitment data. The rationale for presenting the larger aging and recruitment dataset from Lake Mead with the CRI aging data is to continue putting Razorback Sucker recruitment events into a more holistic dataset.

To date, all aged fish were spawned from 1972 to 2015, with the exception of one fish that was spawned around 1966 (Appendix B). Until recently, the majority of fish aged were spawned during high lake elevations between 1978 and 1989 and between 1997 and 1999 (Figure 1.8). However, more current data, including CRI data, show Lake Mead Razorback Sucker recruitment occurring after 1999, which coincides with the steady decline in lake levels through 2010. With the inclusion of this year's data, 2001–2007 appears to be one of the better periods for Lake Mead Razorback Sucker recruitment, despite dropping lake levels (Figure 1.8). When combined with the LTM data, aged fish captured in the CRI coincide with the strong cohorts observed from other areas of the lake (Figure 1.8).

Fin ray specimens were obtained from six hybrid suckers captured in 2017. Those individuals represented four year-classes; one fish was age-4 (year-class 2013), one fish was age-5 (year-class 2012), one fish was age-7 (2010 year-class) and three fish were age-8 (year-class 2009). One Flannelmouth Sucker was determined to be age-6 (2011 year-class).

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

Efforts conducted in the Colorado River below Pearce Ferry Rapid downstream to the CRI from March to May 2017 resulted in the capture of both native and nonnative fish species (Table 1.5). During supplemental sampling efforts between Pearce Ferry and the river outflow, 191 native fishes were captured and made up 46.2% of the catch (Table 1.5). Flannelmouth Suckers were the most commonly captured native species, much like within Lake Mead at the CRI. Flannelmouth Suckers ranged in size from 27 to 514 mm TL with a mean TL of 168.1 mm (SE ± 16.0). Two hybrid suckers were captured (476 and 514 mm TL) with a mean TL of 495.0 (SE ±19.0). Fifty-seven Speckled Dace *Rhinichthys osculus* were captured, and they ranged in size from 40 to 86 mm TL with a mean TL of 49.6 mm (SE ± 1.0). Ten Bluehead Suckers (49–75 mm TL; 63.9 mm mean TL [SE ± 3.3]) and 10 Humpback Chub (71–340 mm TL; 214.3 mm mean TL [SE ± 32.9]) were also captured during these efforts (Table 1.5). One Humpback Chub was captured three times, all in the same general location close to the SUR in Iceberg Canyon (Figure 1.1). We observed similar site fidelity by a Flannelmouth Sucker that was captured 2 weeks apart in the same location using two different gear types.

Native fish larvae composed 49.2% of the total larval catch during supplemental efforts (Table 1.5). One Razorback Sucker larva, 61 Flannelmouth Sucker larvae, and two Bluehead Sucker larvae were captured between Pearce Ferry Rapid and the CRI using seining techniques (Table 1.5). The larval Razorback Sucker was captured within Iceberg Canyon, approximately half way between Devil's Cove and Driftwood Cove (Figure 1.1).

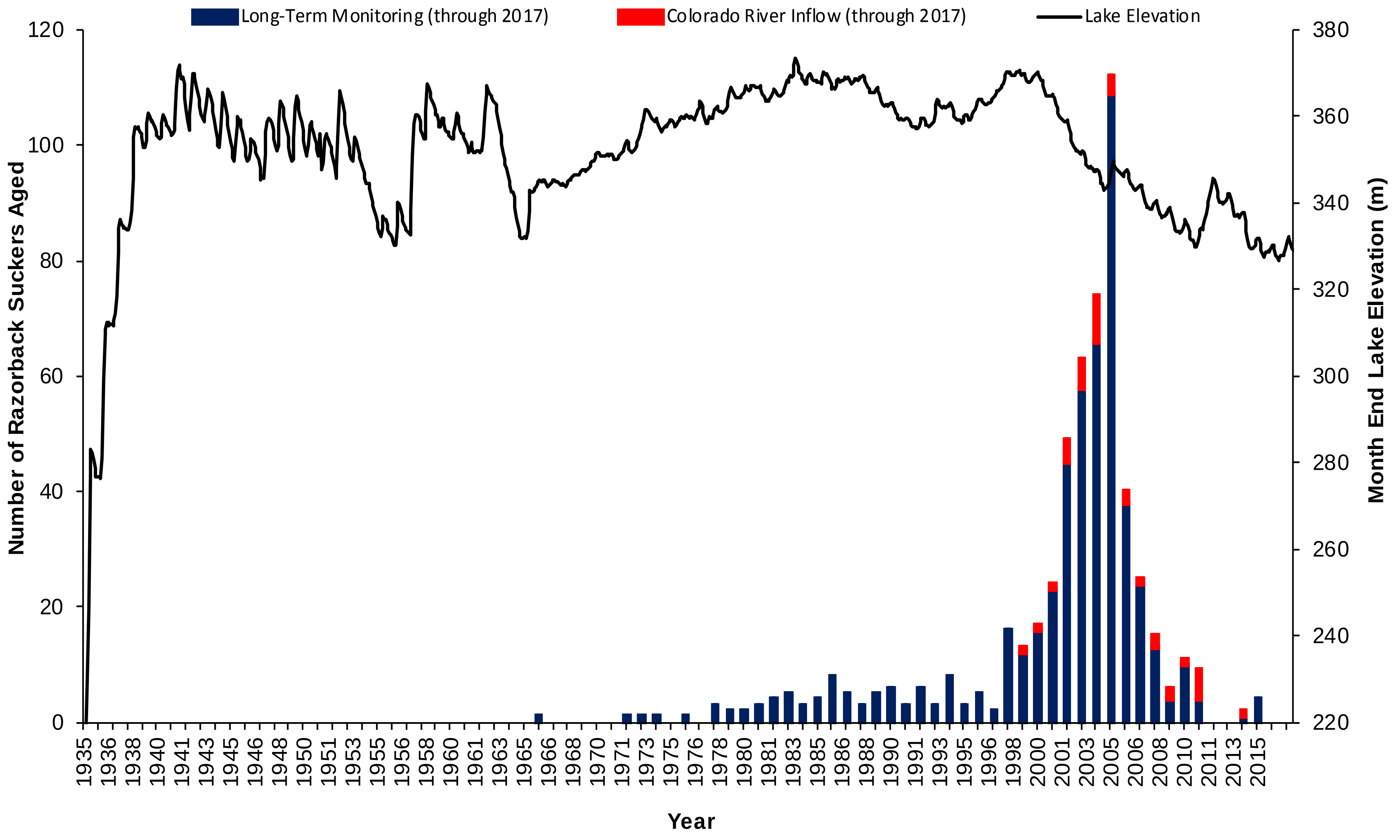


Figure 1.8. Lake Mead hydrograph from January 1935 to June 2017, with the number of aged Razorback Suckers spawned each year through 2017. Red bars denote the Razorback Suckers aged from the Colorado River Inflow Area of Lake Mead (CRI), while blue bars denote Razorback Suckers aged from the long-term monitoring (LTM) study.

Table 1.5. Small-bodied and larval fish supplemental sampling between Pearce Ferry Rapid and the Colorado River inflow of Lake Mead (CRI) from March to May 2017.

DATE	GEAR TYPE	NUMBER OF SAMPLES	RAZORBACK SUCKER	FLANNELMOUTH SUCKER	HYBRID SUCKER	BLUEHEAD SUCKER	HUMPBACK CHUB	SPECKLED DACE	AGGREGATE NONNATIVE CATCH	PERCENT NATIVE
Small-Bodied Fish Sampling										
3/23/2017	trammel net	2	0	0	0	0	0	0	0	- -
	hoop net	5	0	0	0	0	0	0	5	0.0
	1.2x4.6 m seine	9	0	22	0	1	0	16	20	66.1
4/6/2017	trammel net	3	0	6	0	0	0	0	33	15.4
	fyke net	3	0	10	0	0	0	1	1	91.7
	hoop net	6	0	1	0	0	0	0	0	100.0
	1.2x4.6 m seine	2	0	0	0	0	0	2	0	100.0
4/11/2017	trammel net	2	0	5	1	0	0	0	53	10.2
	fyke net	3	0	0	0	0	0	0	1	0.0
	hoop net	5	0	0	0	0	0	0	0	- -
4/13/2017	trammel net	3	0	5	1	0	0	0	30	16.7
	1.2x4.6 m seine	17	0	52	0	7	0	37	48	66.7
4/20/2017	trammel net	3	0	3	0	0	0	0	30	9.1
	fyke net	3	0	2	0	0	0	0	1	66.7
	hoop net	6	0	5	0	0	3	1	0	100.0
4/27/2017	hoop net	6	0	1	0	0	3	0	0	100.0
5/3/2017	hoop net	7	0	2	0	0	4	0	0	100.0
Total Small-Bodied Fish			0	114	2	8	10	57	222	46.2
Larval Fish Sampling										
3/23/2017	larval seine	8	0	1	0	0	0	0	0	100.0
4/6/2017	larval seine	14	1	24	0	2	0	0	20	57.4
4/13/2017	larval seine	20	0	19	0	0	0	0	28	40.4
4/20/2017	larval seine	10	0	17	0	0	0	0	18	48.6
Total Larvae			1	61	0	2	0	0	66	49.2

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, and age. Combined data from sonic-telemetry, trammel-netting, and larval-collection efforts confirm that Razorback Sucker occupy CRI habitats and successfully spawn there. It remains somewhat unclear to what degree Razorback Sucker recruitment occurs within the lacustrine versus riverine portions of the area; however, an age-3 juvenile Razorback Sucker, as well as several younger hybrid suckers aged between 4 and 8 years, was found occupying CRI habitat this year. An age-2, juvenile Razorback Sucker was also captured in the CRI in 2013 (Kegerries and Albrecht 2013b). Recent findings, as contained in this report, continue to link Lake Mead and the Grand Canyon and indicate that continued—and perhaps additional—studies are needed to fully understand Razorback Sucker use of these areas.

Adult Sampling- and Spawning-Related Observations

At this stage of our research and monitoring it seems logical that fluctuations in the number of Razorback Suckers spawning, number of larval fish collected, and the amount of sonic-tagged fish activity are tied, at least in part, to the relationship that the species has with the Grand Canyon. In 2014 spawning was confirmed in the Grand Canyon (below Lava Falls), but limited evidence was found for spawning within the CRI (Albrecht et al. 2014a). In 2015, spawning evidence was discovered in riverine and lake locations (Kegerries et al. 2015a), while in 2016 spawning only was confirmed within the river (Kegerries et al. 2016b). In 2017 we saw very few Razorback Sucker larvae but did document ripe adults at the CRI and spawning success within the river (see Chapter 2). Our knowledge of the relationship between the river proper and the CRI, as it relates to Razorback Sucker and spawning, would benefit from evaluations of multiple, future, spawning seasons.

The youngest Razorback Sucker was a 3-year-old captured at the CRI in 2017. The number of juvenile Razorback Suckers has varied since the project began in 2010. In some years, such as 2015, the habitat in Iceberg Canyon was dominated by a channelized river and consisted of run and instream slackwater habitats; few backwater habitats were available in this section of river. Contrastingly, in 2014 and similar years, several backwater and slackwater habitats occurred in Iceberg Canyon, which is where several of the recently transformed age-0 juvenile Razorback Suckers were captured (Albrecht et al. 2014a). It is possible that changes in the river allow for better-targeted sampling of prime recruitment habitat. Furthermore, oxbow-like areas within the river may allow for better recruitment. These somewhat sporadic findings highlight the cryptic nature of juvenile Razorback Suckers and the difficult-to-sample habitats they occupy.

Captures of Flannelmouth Suckers and hybrid suckers have been common at the CRI since 2010 (Albrecht et al. 2010a, 2014a; Kegerries and Albrecht 2011, 2013a, 2013b; Kegerries et al. 2015a, 2016). Although hybridization between Flannelmouth Sucker and Razorback Sucker has been extensively documented and was summarized by Bestgen (1990), the reasons for hybridization between these species at the CRI and Grand Canyon are not clearly understood. Habitat alterations could also potentially reduce reproductive isolation, thereby increasing the likelihood of hybridization (Muhlfeld et al. 2009), which may be more likely the case at the CRI.

Hybridization between these two species has also been documented on the San Juan River, where Razorback Suckers are stocked into areas with large Flannelmouth Sucker populations (Ryden 2006). It is unclear whether hybridization will negatively impact the wild Razorback Sucker population at the CRI. It appears the hybrids do produce viable gametes, which allows for backcrossing to either species (Douglas and Marsh 1998; T. Dowling, Wayne State University, personal communication). Flannelmouth Sucker and Razorback Sucker are both Lower Colorado River Multi-Species Conservation Program (LCR MSCP) species of concern, which highlights the importance of the CRI to the sustainability and conservation of both species. With the presence of Flannelmouth Suckers, Razorback Suckers, hybrids, and Bluehead Suckers, the CRI appears to be providing key habitats for native catostomids within the lower Colorado River system.

Compared with Echo Bay, Las Vegas Bay, and the Virgin River/Muddy River inflow area, less is known regarding spawning Razorback Sucker habitat use in the CRI and the river. Similar to the original documentation of the Virgin River/Muddy River inflow area as a spawning site for Razorback Sucker in 2006, sonic-tagged fish movement patterns within specific CRI habitats that appeared to be spawning areas led to the collection of ripe, wild, adult Razorback Suckers. An important goal for investigation of the CRI was to ascertain whether recruitment was occurring. Some evidence for recruitment was provided by the capture of an age-2 juvenile in 2013 (Kegerries and Albrecht 2013b), recently transformed age-0 juvenile fish captured in Iceberg Canyon in 2014 (Albrecht et al. 2014a), and age-3 immature Razorback Suckers captured at the CRI during the 2014 (Albrecht et al. 2014a) and 2017 seasons. Perhaps more importantly, these results highlight the significance of the flowing portions of the Colorado River, as well as the role of the lentic conditions within the CRI. Questions—such as how is recruitment occurring and to what degree does recruitment impact Lake Mead Razorback Sucker population dynamics as a whole—still remain. The documentation of successful recruitment at the CRI will likely be reinforced by future studies as young individuals are captured during subsequent sampling efforts and through data obtained from aging fish captured in Lake Mead proper and the Grand Canyon.

Lake Mead water levels will fluctuate over the next several years. As this occurs, Razorback Suckers in the CRI are likely to change spawning site locations to adapt to the highly variable conditions imposed by these fluctuations and Colorado River dynamics, as they have done in preceding years. 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 will likely be observed during future field seasons. These changes necessitate continued and careful monitoring of this relatively understudied Razorback Sucker spawning aggregation, both within the lake and the river.

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

1. Juvenile Razorback Suckers (along with juvenile Flannelmouth Suckers and hybrid suckers) occur in the CRI and can be captured by the standard methods used to capture adult Razorback Sucker. The capture of recently transformed (age-0) juvenile Razorback Sucker and age-2 and age-3 immature fish near habitat frequented by other Razorback

Sucker since 2010 suggests that the CRI may provide important recruitment habitat and function like the historic oxbow and floodplain habitats this species used to thrive (Minckley 1973; Minckley et al. 1991; Minckley and Marsh 2009; Albrecht et al. 2014a; Kegerries et al. 2015a, 2017).

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 nebulous than at other known spawning areas in Lake Mead (Albrecht et al. 2010b, 2010c; Kegerries and Albrecht 2011; Shattuck et al. 2011). This disparity may comprise factors like annual changes in river and lake conditions, including interannual and intra-annual river and lake water-level fluctuations resulting in gains or losses of littoral habitat types at the CRI, temperature differences and variability, overall flow of the Colorado River within the Grand Canyon, the addition of river-derived sediment during crucial spawning times, and the interactions of these factors. A more holistic understanding of the importance of this location to Razorback Sucker may be attained through continued efforts at the CRI and within the Colorado River proper, as presented in Chapters 2 and 3.

3. Wild Razorback Suckers, including juveniles of various ages, have been captured at different locations in the CRI for eight consecutive field seasons. The exploration of this area demonstrates that unknown aggregates of Razorback Suckers could exist at other locations in Lake Mead or the Colorado River. As juvenile Razorback Suckers are highly cryptic (Kegerries et al. 2016a), their presence should be considered a strong, positive indication of the importance of this area and this type of inflow habitat to Razorback Sucker in general.

4. Razorback Sucker, Flannelmouth Sucker, and potentially Bluehead Sucker habitat use overlaps at the CRI, as it does throughout the upper Colorado River basin. Hybridization of Razorback Sucker and Flannelmouth Sucker has been documented by capture of hybrid fish. Trammel-netting, telemetry, and larval-sampling data from the CRI suggest that both sucker species and hybrids are using the lentic portions of the CRI for spawning.

Larval Sampling

Larval Razorback Sucker captures at the CRI in 2017 could likely be the result of downstream drift from the Grand Canyon. The adult Razorback Sucker captures in 2017 were dispersed within “Lunch Cove” and throughout the western shoreline, where it is likely larvae could have escaped the swift flow of the river.

Numbers and catch rates of larval Razorback Suckers in the CRI from 2010 to 2017 are similar to those observed during the first three field seasons of larval sampling in the Virgin River/Muddy River inflow area and Echo Bay in 2013 (Albrecht et al. 2014a). Catch rates of larvae, juveniles, and adults in the Virgin River/Muddy River inflow area increased over time (Albrecht et al. 2010b, 2013a, 2013b, 2014; Shattuck et al. 2011; Mohn et al. 2015, 2016; Rogers et al. 2017). We have not observed this same pattern at the CRI, but continued monitoring of larvae will help determine whether reproduction is increasing or decreasing there.

Growth and Aging

Based on data collected from Razorback Suckers captured in the CRI from 2010 to 2017, it appears that growth rates in this area are somewhat lower than those observed in the Las Vegas Bay, Echo Bay, and the Virgin River/ Muddy River inflow study areas (Rogers et al. 2016); however, growth at the CRI is still relatively higher than in other areas of the Colorado River basin (Modde et al. 1996; Pacey and Marsh 1998; Bestgen et al. 2002; Kesner et al. 2012). These higher growth rates are logical, considering the fairly young ages of Razorback Suckers (less than 10 years) recently captured in Lake Mead (Albrecht 2010b, 2013a, 2013b; Shattuck et al. 2011; Mohn et al. 2015, 2016; Rogers et al. 2017). The capture of age-0, age-2, and age-3 juvenile Razorback Suckers at the CRI suggests that the population is relatively young and exists in one of the very few documented locations where natural Razorback Sucker recruitment likely occurs. These findings should be considered significant to managers, and as future study efforts unfold it will be interesting to see whether evidence of continued recruitment is obtained from the CRI.

Determining the ages of six wild CRI Razorback Suckers during the 2017 field season and incorporating the ages of all wild fish from previous studies helped verify that Razorback Sucker recruitment has occurred regularly in Lake Mead from 1973 to 2015, with the exception of one fish that was spawned around 1966 (Albrecht et al. 2013a, 2013b, 2014a, 2014b; Shattuck et al. 2011; Mohn et al. 2015, 2016; Rogers et al. 2017) (Appendix B). At the CRI to date, fish from 10 year classes (1999–2014) have been collected and identified. Interestingly, many of the year classes found at the CRI correspond with relatively strong year classes across Lake Mead. Based on lakewide data collected to date, some of the most pronounced recruitment occurred from 2001 to 2007; from those spawning events alone, 387 Razorback Suckers have been captured. These data suggest a strong, recent recruitment trend. This pulse of young fish indicates that successful spawning and recruitment are occurring even under declining and fluctuating lake elevations. Finally, as more specimens are obtained from all areas of Lake Mead, including the CRI, conditions that promote recruitment pulses can be investigated. Collection of additional data from the CRI should help clarify results from study efforts throughout Lake Mead.

Future Considerations

After 8 years of sampling, many questions associated with the study goals have been answered, including whether Razorback Suckers spawn and recruit at the CRI. Additionally, we determined that the level of spawning activity varies from year to year and that spawning locations may shift as a result of habitat changes. Juvenile Razorback Suckers have been documented at the CRI as recently as 2014, which supports the hypothesis of natural recruitment in this area of Lake Mead—similar to what occurs at other spawning areas throughout Lake Mead. Although much has been answered, many new questions have resulted from this sampling effort. For example: Are there unexplored areas of the lake 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, if any, is the long-term use of the lower portions of the Colorado River proper during both the spawning and nonspawning periods of the year? Does Razorback Sucker use of upstream habitat (above Pearce Ferry Rapid) vary consistently depending on overall water released or specific lake levels? These questions may have never been asked had Razorback Sucker not been tracked into the flowing portions of the Colorado River. These questions, and the results from expanding the study into the CRI, led to the investigation of Razorback Sucker presence in the Grand Canyon.

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

There are also several questions within the scope of our initial study efforts that continued research and monitoring could help answer. For example: Will the CRI be a consistent spawning area for Razorback Sucker beyond 2017? How common are juvenile Razorback Suckers at the CRI compared with other locations in Lake Mead? With more sampling and a longer-term dataset, comparisons regarding recruitment patterns could be made with other Lake Mead locations used by Razorback Suckers.

Study results from the last 8 years demonstrate similarities in characteristics of habitat used by Razorback Sucker 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 Sucker and apply that information to areas throughout the Colorado River basin that are presently, or were historically, occupied by the species. This study at the CRI, combined with the LTM study on Lake Mead, has brought us much closer to understanding and identifying wild recruitment while placing these processes in context within and throughout the historic range of the Razorback Sucker. At a minimum, these efforts have spurred research in other, similar areas (e.g., Lake Powell, Grand Canyon). At this time, it is important to consider where the Razorback Sucker population at the CRI (and Lake Mead in general) fits into conservation and recovery planning for both the lower Colorado River basin and the Grand Canyon. Decisions will need to be made by the LMWG (and others) to determine the importance of, and potential strategies for, monitoring this population, which will be needed for long-term understanding and tracking of this Razorback Sucker population. Determinations of the level and scope of continued research for Razorback Sucker, Flannelmouth Sucker, Humpback Chub, and perhaps other native species, will also need to be made.

2017–2018 COLORADO RIVER INFLOW AREA OF LAKE MEAD (CRI) STUDY RECOMMENDATIONS

1. Maintain sampling efforts at the CRI and within the Grand Canyon. The telemetry (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 in Lake Mead. These techniques, especially telemetry, were also important for determining the extent of Razorback Sucker interactions within the CRI and Grand Canyon. Therefore, these techniques should be continued and improved though future efforts, as suggested within this report.

Data stemming from the sampling efforts listed above can be used to assist with understanding the population size and habitat use of Razorback Suckers at the CRI and in the 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 lakewide recruitment patterns, and help characterize the Lake Mead Razorback Sucker habitat use of the Colorado River proper. All of these items were supported by a recent science panel, who also suggested that monitoring in its current form should continue and that the CRI and the LGC should be studied jointly into the future (Reclamation 2017).

2. Continue and increase sampling efforts in the riverine habitat located below Pearce Ferry to Lake Mead proper. Given the findings of young-of-the-year and three sucker species (Razorback, Flannelmouth, and Bluehead), as well as recent documentation of Humpback Chub below Pearce Ferry and within the broader study area during the past 3 years (see Chapter 2), larval and small-bodied fish sampling (utilizing methods described in Chapter 2) are certainly warranted and should be continued upstream to the extent practical. If potential reproductive movement patterns of sonic-tagged fish are noted within the river proper, netting and use of submersible PIT antennas may also be warranted within the Pearce Ferry to CRI reach. This same recommendation applies to the riverine reach from Separation Canyon to Pearce Ferry.

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

4. Finally, we recommend taking a comprehensive approach to synthesizing the data collected on Lake Mead Razorback Sucker over the past 20+ years. It is apparent that the CRI population should not be viewed or managed independently from other Razorback Sucker populations in Lake Mead. This may also be true for any Razorback Sucker population that may be present in the Grand Canyon, as a substantial link apparently exists between Razorback Suckers that inhabit the lake and river. A holistic assessment of wild Razorback Sucker recruitment in the Lake Mead and Grand Canyon continuum may help better characterize the conditions needed to establish and maintain a recruiting population, not only in Lake Mead but also in other locations historically occupied by this species. Continued efforts may also help address questions and objectives outlined in future recovery goals and plans.

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

INTRODUCTION

This chapter presents findings from small-bodied and larval fish community sampling conducted during the fourth study year (March through September, 2017). This chapter also presents results from subsequent study years (October 2013 through September 2016) within the Grand Canyon to provide context, as applicable. Small-bodied fish sampling, larval fish community sampling, and sonic telemetry were the major efforts conducted within the Grand Canyon during six field trips in 2017 (Table 2.1). More specifically, the intent of this early life stage sampling was to help describe the overall fish community within the Grand Canyon, allow for a mechanism to capture young Razorback Sucker and Humpback Chub, if present, and better understand the reproductive success, habitat use, and movement of, as well as areas of importance to, Razorback Sucker, Humpback Chub, and the overall Grand Canyon fish community.

Table 2.1. Grand Canyon sampling dates and trip purpose, 2017.

MONTH	SAMPLING DATES	TRIP PURPOSE
March	3/09/2017 through 3/17/2017	Larval fish community sampling (GRTS[a]).
April	4/06/2017 through 4/13/2017	Telemetry, small-bodied, and larval fish community sampling (GRTS)
May	5/17/2017 through 5/24/2017	Telemetry, small-bodied, and larval fish community sampling (GRTS)
June	6/12/2017 through 6/19/2017	Telemetry, small-bodied, and larval fish community sampling (GRTS)
July	7/10/2017 through 7/17/2017	Telemetry, small-bodied, and larval fish community sampling (GRTS)
August	8/14/2017 through 8/21/2017	Telemetry, small-bodied, and larval fish community sampling (GRTS)
September	9/11/2017 through 9/19/2017	Telemetry and small-bodied community sampling (GRTS)

[a] Sampling following full generalized random tessellation stratified (GRTS) design (see Methods section).

In 2016 the number of 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 as 2014–2016 efforts documented a marked reduction in the catch rate of larval catostomids and cyprinids; in general, there was a low abundance of larval fish in the system. As with the larval fish sampling effort, the least informative of the seven monthly trips to sample small-bodied fish (March) was eliminated.

STUDY AREA

The study area encompassed 191.4 river miles, from immediately downstream of the Bright Angel Creek confluence near Phantom Ranch (RM 88.5) to Pearce Ferry (RM 280.0) (Figure 2.1). Sampling locations and other river features are presented in river miles, are unique to the Grand Canyon, and are most familiar to Grand Canyon researchers.

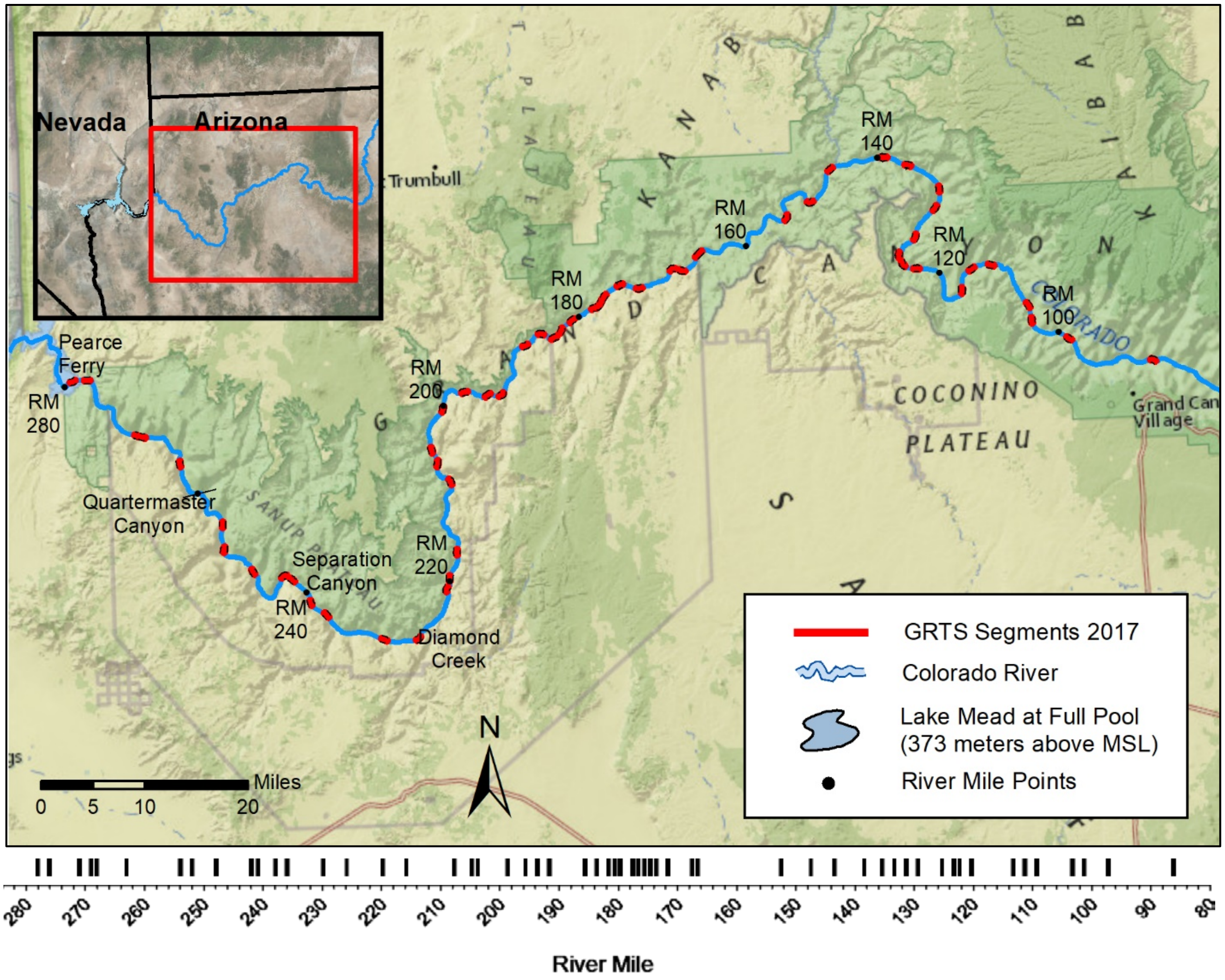


Figure 2.1. **The general study area within the Grand Canyon and the 56 generalized random tessellation stratified (GRTS) design segments (red) located in the 191.4 river mile study area from below Phantom Ranch to just above Pearce Ferry in 2017 (some GRTS segments are adjoining). Tick marks denote linear distribution of GRTS segments.**

METHODS

Discharge

Colorado River discharge measurements were collected from the United States Geological Survey (USGS) gage station above Diamond Creek (#09404200) for the period of October 1, 2016–September 30, 2017. Discharge information from this gage was chosen to add context to the early life stage fish capture data, and the gage was selected due to its centralized location within the Lava Falls to Pearce Ferry reach. Data include both approved and provisional information from USGS, and measurements are presented in ft^3/s.

Small-bodied Fish Community Sampling

The 2016 sampling sites in the Grand Canyon for the larval and small-bodied fish surveys were replicated in 2017 with the exception of two sites that were dropped and replaced. In March, of the generalized random tessellation stratified (GRTS) segments (n=56) determined in 2016, one (segment 369 at RM 271.8) did not have habitat that could be safely sampled. It was replaced with the subsequently ordered GRTS segment (segment 264 at RM 220.1). Similarly, in segment 94 at RM 134.8, which was sampled in March and April, it was determined to be unsafe to maneuver the motorized S-rig. This segment was replaced with segment 155 at RM 165.0. The replacement sites were sampled throughout the remainder of the year. All sites were selected using a 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. This method is well established in the scientific community and used by the NPS for monitoring (NPS 2013).

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 had to be long enough to encompass the suite of mesohabitats present for small-bodied and larval fish community sampling, contain enough area for both sampling methodologies to be used, and 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 the 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 providing the opportunity for an adequate location in 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 (e.g., as with two segments in 2017).

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, 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 conducive to holding young endangered fishes, such as backwaters formed in off-channel lateral canyons, tributary mouths, or other locations offering habitat complexity and diversity, as well as in the presence of sonic-tagged Razorback Suckers. For the purposes of analysis, these sites are treated separately from the GRTS sampling segments because there is potential for field crew selection bias. However, documentation of rare fishes is paramount and was one of the primary objectives of these surveys, so at times complex and diverse habitats were targeted to perhaps bolster documentation of the rarest species.

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

Information collected at each seining location included river mile, segment number, sample number, habitat type, seine type, water temperature, turbidity, area sampled (length and width), maximum depth, and primary and secondary substrate and cover types (Tables 2.2 and 2.3). All fish collected were identified to the species level and counted. At least five randomly selected individuals of each species captured per seine haul were measured, with the exception of Razorback Sucker and Humpback Chub (of which all were measured). This provided information on the general size of the fishes that were collected by seine haul during each sampling trip in various habitat and cover types. All fishes were returned to the habitat alive when conducting small-bodied fish seining (with the exception of a few rare instances when select individuals were preserved for laboratory identification). A PIT-tag reader was taken on all monitoring trips and individual fish larger than 80 mm TL were typically scanned for PIT tags as per Grand Canyon standard protocol (S. Vanderkooi, USGS/Grand Canyon Monitoring and Research Center, personal communication; D. Rogowski, AZGFD, personal communication). In addition, all young Humpback Chub were examined for visual implant elastomer tags. In 2017 all captured Razorback Suckers and Humpback Chub over approximately 80 mm TL were PIT tagged if no mark was present.

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

CODE	HABITAT	DEFINITION
BW	Backwater	Typically, a body of water off-channel in an abandoned secondary mouth, behind a bar, or in a bank indention, with water depth from <10 cm to >1.5 m, 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/sec) over any substrate.
RN	Run	Typically, moderate- or rapid-velocity water 10–30 cm/sec 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/m), water velocity is usually moderate to rapid (10–31 cm/sec), and water surface is disturbed. Substrate is usually cobbles and rubble, and portions of rocks may be exposed. Depths vary from <5–50 cm, rarely greater.
SW	Slackwater	Low-velocity habitat usually along inside margin of river bends or shoreline invaginations, or immediately downstream of debris piles, bars, or other in-stream features but deeper than shoals (>25 cm).
IP	Isolated pool	Small body of water in a depression, old backwater, or side channel that is not connected to the channel as a result of receding flows.
EB	Embayment	Open shoreline depression similar to a backwater but that faces upstream. Typically 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				

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. As 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 transformed [Ln(CPUE+1)]. An ANOVA was then used to test for yearly differences in mean Ln(CPUE+1) 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 using Tukey's honest significant difference all-pairwise comparisons in Statistix was performed to differentiate homogeneous groups. For all tests, α was set at 0.05. Additionally, a least-squares linear regression was used to compare CPUE longitudinally by river mile throughout the study area.

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

Finally, comparisons have been made between catch since 2014 for a holistic data examination and trend analysis. Additionally, proportional abundance data collected during sampling efforts from 1992 to 1995 by Valdez et al. (1995) from National Canyon (RM 167.0) to Pearce Ferry (RM 280.0) and Ackerman et al. (2006) in 2004–2006 from Diamond Creek (RM 226.0) to Pearce Ferry were compared with 2014–2017 data collected during this study. It should be noted that the previous studies consisted of multiple sampling methods; therefore, catch rate comparisons were not conducted. Rather, proportional abundances of native and nonnative fish species were analyzed as a means to compare the fish communities through time.

Larval Fish Community Sampling

Larval fish surveys (n=6) were conducted once a month from March through August. Most of the 2017 sampling locations were the same as the 2016 Grand Canyon larval and small-bodied sampling locations. Sampling for larval fish was conducted using a fine mesh seine (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, were made at each GRTS segment. Fishes that could be accurately identified in the field were enumerated, measured (total length [TL] mm), and held in a live well. In addition to TL, fork length (FL mm) was recorded for Humpback Chub. Identifiable fishes collected at each site remained in a live well until sampling at the site had been completed. They were subsequently released (unharmed) into a low-velocity habitat at the site of their capture. Larval fish too small to be accurately identified were retained (individually for each seine haul) in 10% formalin and stored in a Whirl-pack® with a field tag containing an alphanumeric code (field number), sample number (1–4), and habitat code. For each seine haul, a discrete suite of data was recorded on a data sheet including presence/absence of fish, length of seine haul (to the nearest 0.1 m), mesohabitat type, secondary habitat descriptor (Table 2.4), substrate, instream cover, maximum depth (cm), and water temperature.

At each site, at least one digital photograph of the habitat sampled was recorded. Additional data acquired at each site were 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 sample site were verified using NPS low-elevation aerial photomaps (marked with river mile). Geographic coordinates (UTM Easting and UTM Northing) of sample sites were obtained with a Garmin *etrex 20* handheld GPS unit using the NAD 83 geodetic reference system. Additional notes regarding river conditions and other observations were also recorded on field data sheets.

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.

Hobo® Tidbit water temperature data loggers, set to record once every hour, were placed with each SUR (Chapter 3) to document the longitudinal temperature gradient from near Phantom Ranch (RM 89) downstream to Pearce Ferry (RM 280). Data loggers that were in place from the previous year (fall 2016) were downloaded and replaced during the April and August surveys.

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-packs®, larval fish were separated from debris, the field fixative was replaced with buffered 5% formalin, and specimens were stored in museum-quality glass jars awaiting identification. After samples were cleaned, ASIR staff with Colorado River Basin larval fish identification expertise identified specimens to species. Stereomicroscopes equipped with transmitted light bases (light and dark fields) and polarized filters that enhance the delineation of larval fish 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 with identification:

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

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

Only young-of-the-year (i.e., age-0) specimens were included in analysis of the larval fish portion of this study. The terms young-of-the-year 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) who recognizes three distinct, sequential larval developmental phases: protolarvae, mesolarvae, and metalarvae. Mesolarvae are further divided into two sequential subphases: flexion mesolarva and postflexion mesolarva. Fishes in any of the aforementioned developmental phases are “larval fish”. Juvenile fish have progressed beyond the metalarval phase and no longer retain traits characteristic of fish larvae. Scientific and common names of fishes used in this report follow Page et al. (2013).

Larval fish were enumerated and measured (mm) for each species within each sample. Standard length (SL) was recorded using an electronic caliper or ocular micrometer (minimum and maximum SL recorded for each species in a sample). A stage micrometer was used to calibrate the ocular micrometer. Standard length 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, Synder et al. 2016). Length measurements (TL, SL and, where appropriate, FL), and ontogenetic phase were recorded for all retained endangered fishes. In addition to endangered fishes, ontogenetic phase was determined for both common suckers (Flannelmouth Sucker and Bluehead Sucker).

Hatch dates of larval Razorback Suckers were determined by subtracting 8.0 mm (mean length [TL] of larvae at hatching) from its TL at capture and dividing by a daily growth rate (Bestgen et al. 2002). This model is based on mean daily growth rate (0.3 mm/day) of wild Razorback Sucker larvae from the Green River, Utah (Muth et al. 1998).

For larval Humpback Chub, hatching dates were calculated using the species-specific polynomic equation $D=(\log_e SL-\log_e 7.2843)/0.0280$, where D is the days from hatching and SL is the standard length of the specimen (Muth 1990).

As described for small-bodied sampling, catch rates of larval fish were described using CPUE. These data (CPUE) were transformed [Ln(CPUE+1)] prior to statistical analysis to stabilize variance and better approximate normality. In 2017, CPUE was calculated as the number of fish captured in each seine haul/surface area (m^2) sampled. The CPUE, mean discharge, and diel fluctuation in discharge were analyzed using ANOVA from the statistical software JMP®, Version 11.

RESULTS

Discharge

Discharge of the Colorado River within the Grand Canyon, as recorded at USGS gaging station #09404200 above Diamond Creek for the period of October 1, 2016–September 30, 2017, was variable both within and between sampling events (Figure 2.2). Regulated increases in mean daily discharge were experienced during the June, July, and August trips, along with varied turbidity throughout the study area. Other than the high-flow releases in November 2016, discharges remained below 20,000 ft^3/sec.

Small-bodied Fish Community Sampling

Generalized random tessellated stratified sites were sampled each month from April to September 2017 (Table 2.5). Monthly effort during the study ranged from 9,797.4 to 4,992.0 m^2 (268–381 seine hauls). Seventeen opportunistic sites were also sampled throughout the May, June, August, and September surveys in addition to the 56 standard GRTS segments.

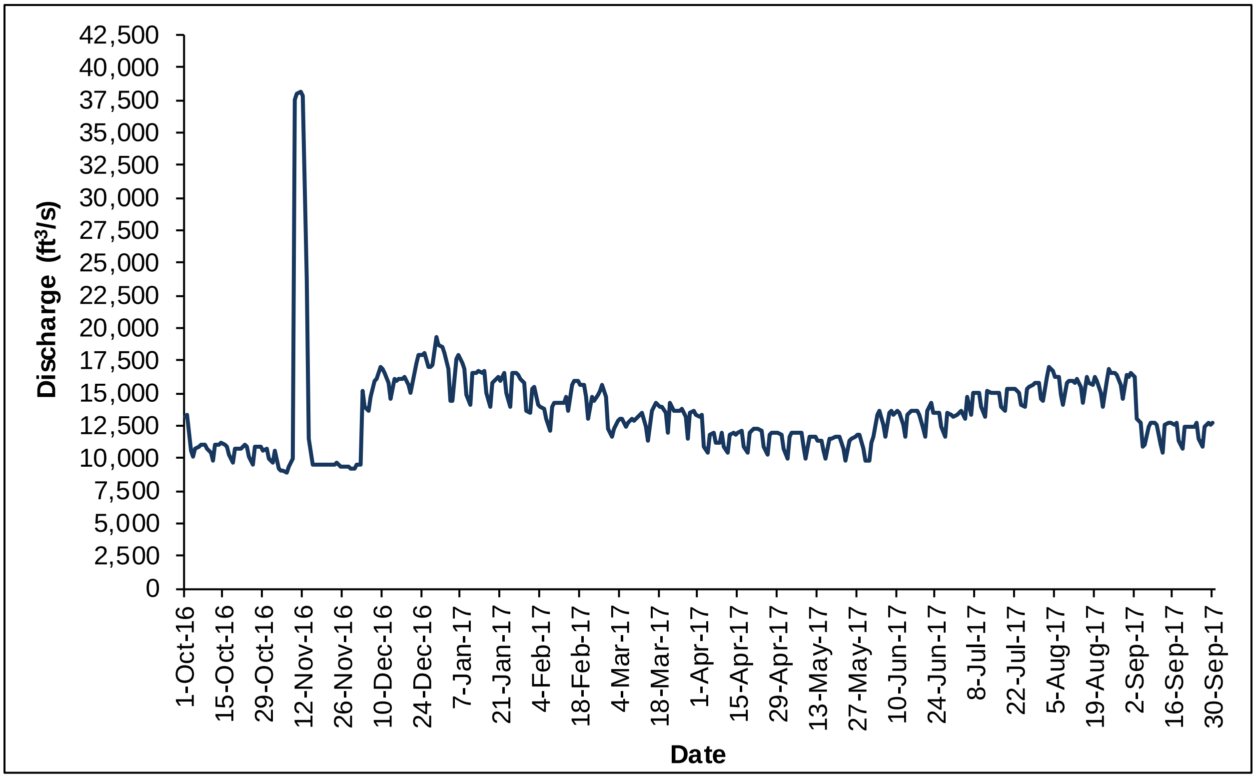


Figure 2.2. Mean daily discharge in ft^3/s typical of the Colorado River for the period of October 1, 2016–September 30, 2017, recorded at the United States Geological Survey (USGS) gage above Diamond Creek (#09404200).

Table 2.5. Sampling effort from small-bodied fish surveys, 2017.

SAMPLING MONTH	DATES OF SAMPLING	NUMBER OF HAULS	EFFORT (m^2) AT GRTS[a] SEGMENTS	GRTS SEGMENTS SAMPLED
March	9–17	Small-bodied sampling was not conducted		
April	8–13	290	8,539.6	56
May	19–24	292	6,817.3	56
June	14–19	268	8,762.0	56
July	11–17	334	8,876.5	56
August	16–21	381	9,797.4	56
September	13–19	332	4,992.0	55

[a] GRTS=generalized random tessellation stratified.

Opportunistic captures were not included in the 2017 analysis of small-bodied fish captures; rather, they were conducted to bolster the likelihood of documenting rare fishes. Small-bodied fish captures at the opportunistic sites represented similar species' relative abundance and composition to the GRTS segments (Appendix D). Flannelmouth Sucker, Bluehead Sucker, Humpback Chub, and Speckled Dace *Rhinichthys osculus* composed nearly 85% of the small-bodied fish captured at opportunistic sites.

During small-bodied fish community sampling efforts in 2017, 46,340 native fishes of four species (Bluehead Sucker, Flannelmouth Sucker, Humpback Chub, and Speckled Dace

[Appendix D]) were captured in GRTS segments. Native fish dominated the Grand Canyon, representing approximately 83% of the total catch. Although other catostomid fishes were captured, no Razorback Suckers were captured during small-bodied seining efforts within the study area.

Eight nonnative fish species were captured during small-bodied fish community sampling in 2017; Rainbow Trout *Oncorhynchus mykiss*, Fathead Minnow *Pimephales promelas*, Plains Killifish *Fundulus zebrinus*, Western Mosquitofish *Gambusia affinis*, Red Shiner *Cyprinella lutrensis*, Brown Trout *Salmo trutta*, Channel Catfish *Ictalurus punctatus*, and Common Carp *Cyprinus carpio* (Appendix D). Although more nonnative species are present in the Grand Canyon, native fishes dominated catch for the small-bodied fish community, whether evaluated by total numbers (Appendix D) or through catch rates, as reported below.

Catch Rates

A comparison of mean CPUE [ln((#/m^2)+1)] of native and nonnative fishes captured in 2017 demonstrates dominance and significantly higher catch rates (ANOVA, $F_{1,3691}$=558, P<0.0001) of native, small-bodied fish species in the Grand Canyon. When evaluated by trip, the highest catch rates of native fish were in July, followed by June and September (Figure 2.3). Significant differences were found in native catch rates by sampling trip (ANOVA, $F_{5,1845}$=44.6, P<0.0001). Post hoc analysis revealed that July catch rates for native fish were higher than in all other months while catch rates in June and September were similar.

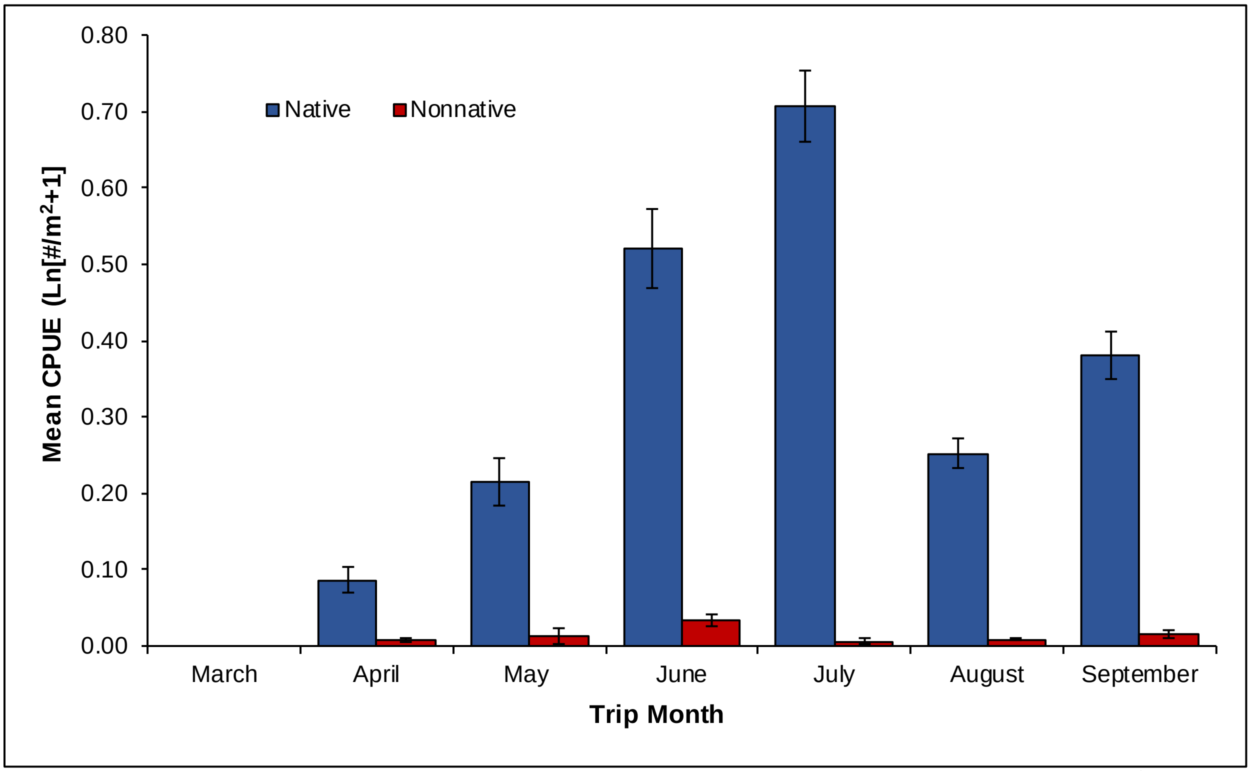


Figure 2.3. **Mean native and nonnative fish catch per unit effort (CPUE) [ln((#/m^2)+1)] by 2017 sampling trip. Error bars are ± 1 SE.**

Similarly, when evaluating catch rates of native and nonnative fishes spatially by sampling segment, the overall dominance of the native fish community throughout the Grand Canyon was notable. Native fishes were caught at higher rates and were present in more locations compared with nonnative fish species (Figure 2.4). Collectively, native fish catch rates differed among sampling segments in 2017 (ANOVA, $F_{56,1845}=4.83$, P<0.0001) (Figure 2.4). 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. To better assess mean catch rates longitudinally for segments, catch in the upper half and lower half of the study area were compared. Catch rates above Lava Falls were compared with mean catch rates for segments below Lava Falls. This analysis confirmed that mean catch rates for native fish were significantly higher below Lava Falls than above it in 2017 (ANOVA, $F_{1,1845}=75.7$, P<0.0001). It appeared that catch rates increased below Havasu Creek (Figure 2.4); thus, catch rates in segments above Havasu Creek versus below were compared. Mean catch rates for native fish were significantly higher below Havasu Creek than above it in 2017 (ANOVA, $F_{1,1845}=123$, P<0.0001). Additionally, a linear least-squares regression showed an increase in native fish catch rates moving downstream throughout the sampling reach ($R^2=0.043$, $F_{1,1845}=82.68$, P<0.0001), although very little of the variation was explained in the model.

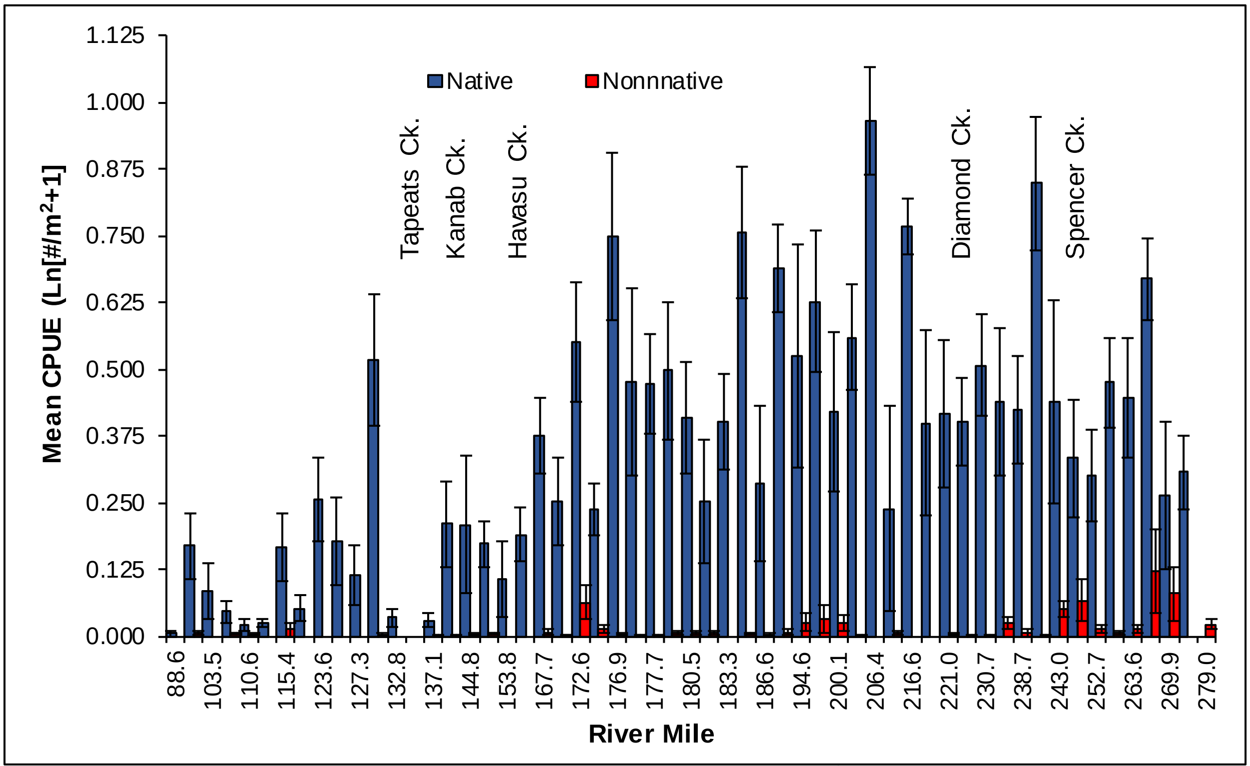


Figure 2.4. Mean native and nonnative fish CPUE [ln((#/m^2)+1)] by river mile (generalized random tessellation stratified [GRTS] design segment) upstream to downstream in 2017 noting approximate location of major tributaries. Error bars are ± 1 SE.

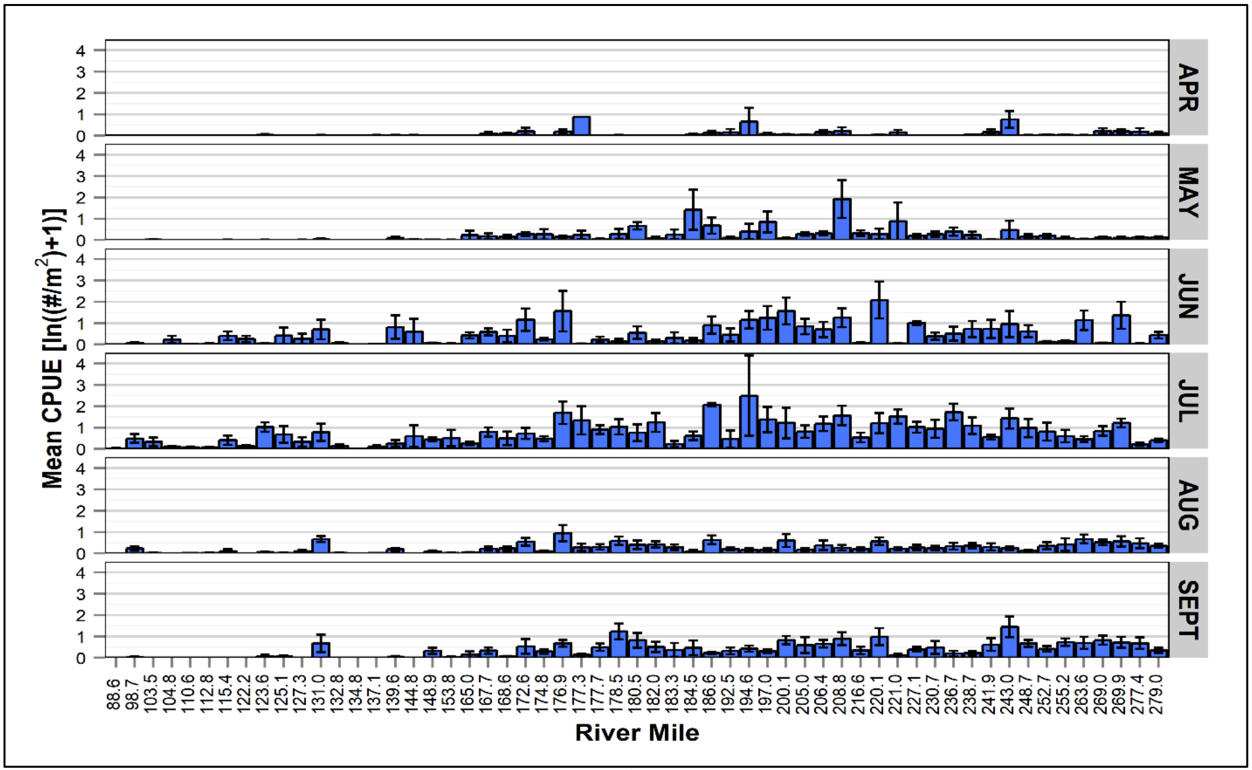


Figure 2.5. Mean native fish CPUE [ln((#/m^2)+1)] by river mile (generalized random tessellation stratified [GRTS] design segment) upstream to downstream separated by 2017 sampling trip. Error bars are ± 1 SE.

When assessing native fish mean CPUE by sampling trip, catch rates increased from April through July before decreasing in August (Figures 2.3 and 2.5). An analysis of catch rates for individual native species by sampling trip was also performed to identify temporal differences in the native fish captured (Figure 2.6). By May, age-0 suckers, too small to be identified to species, dominated the catch, followed by Flannelmouth Suckers and Speckled Dace. Throughout subsequent sampling trips, the age-0 suckers became more easily identifiable, and thus declined in relative abundance. With relatively high Flannelmouth Sucker abundance in July, it is likely that most unidentifiable age-0 suckers were Flannelmouth Suckers. In August and September, Flannelmouth Sucker, Speckled Dace, and Bluehead Sucker dominated the catch (Figure 2.6).

During small-bodied sampling in 2017, 930 total Humpback Chub (19–282 mm TL) were captured at GRTS segments; the first was captured during the April sampling trip (Appendix D). Catch rate analysis by river kilometer for each trip shows an increase in the relative abundance of Humpback Chub from April to June, as well as a wider distribution throughout the study area by August (Figure 2.7). Five Humpback Chub (131–282 mm TL) that were captured in August were PIT tagged before release, and none of the Humpback Chub had been captured during previous tagging or stocking efforts.

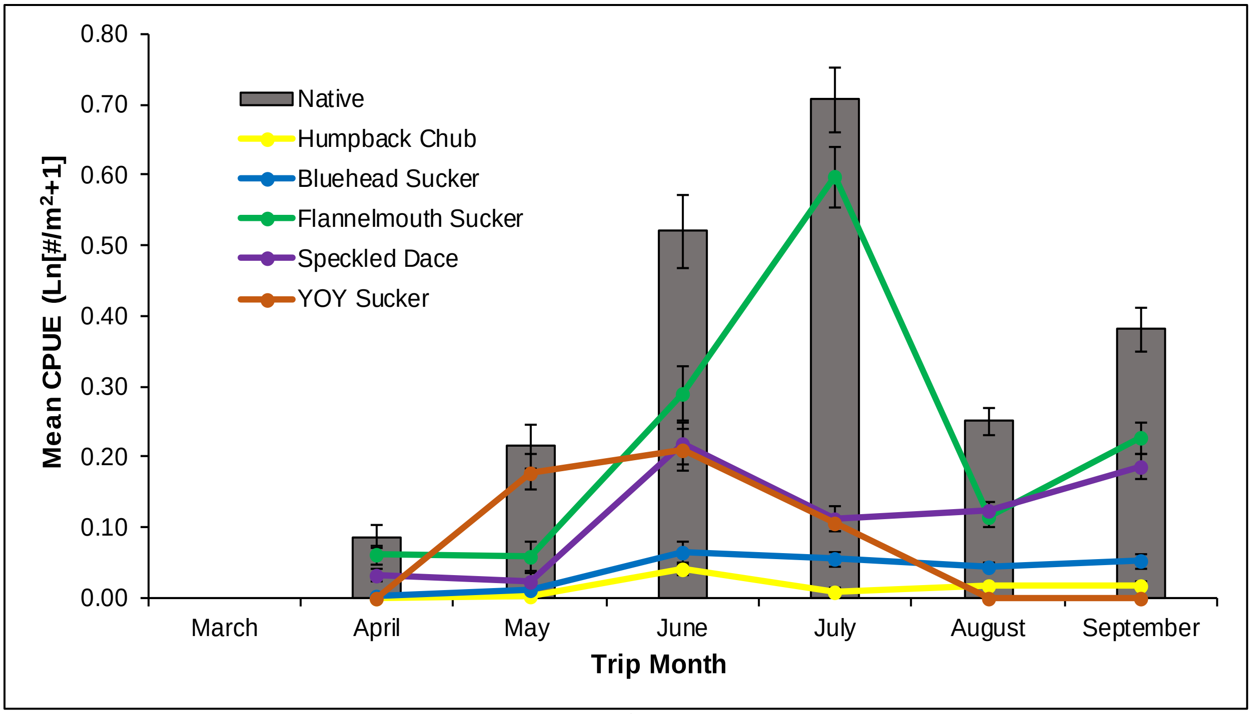


Figure 2.6. **Mean native fish CPUE [ln((#/m^2)+1)] by 2017 sampling trip separated according to species. Error bars are ± 1 SE**

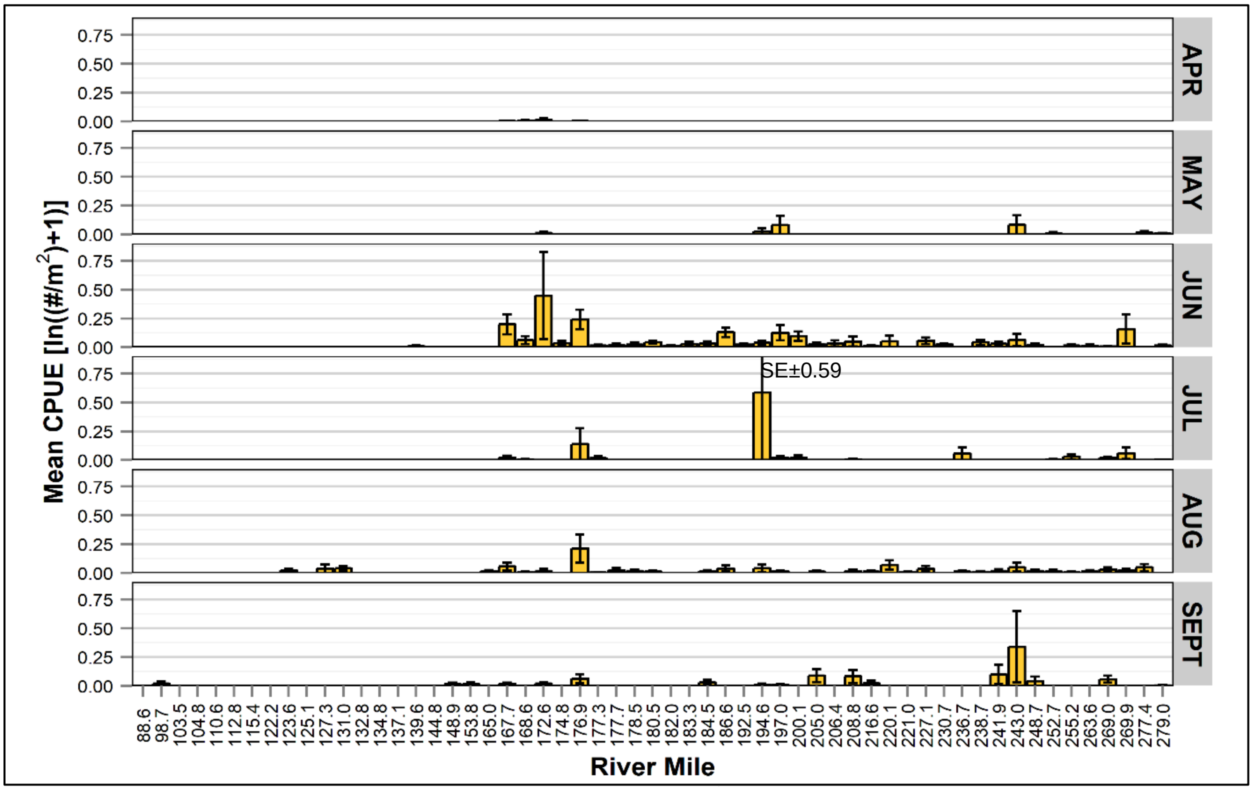


Figure 2.7. **Mean Humpback Chub CPUE [ln((#/m^2)+1)] by river mile (generalized random tessellation stratified [GRTS] design segment) upstream to downstream in 2017 for each sampling trip. Error bars are ± 1 SE.**

Length Frequency

Humpback Chub numbers and their total length varied by sampling trip. The most were captured in June (n=495), and most fish were between 19 and 60 mm (Figure 2.8). Larger fish were captured more frequently in June, July, and August, while smaller fish were continually captured each month (Figure 2.8). Length data provide evidence for reproduction and some level of recruitment, as multiple year classes were present in the Grand Canyon.

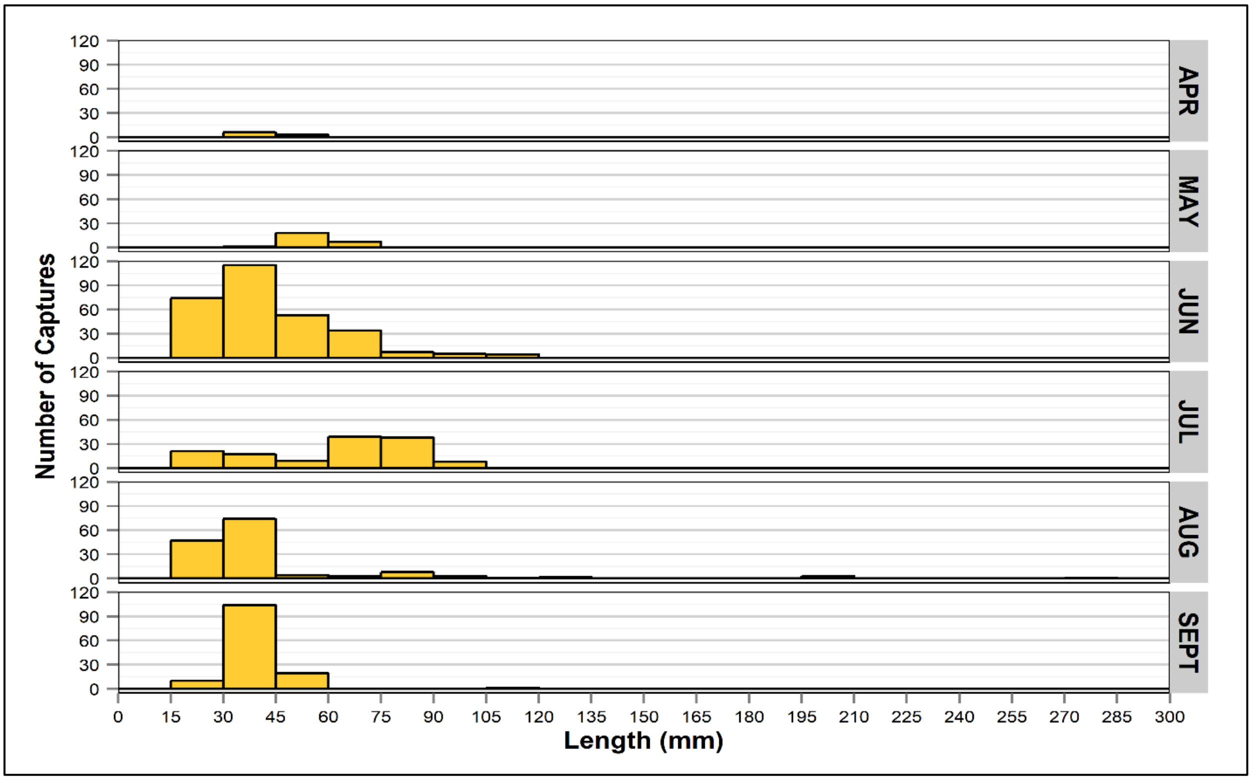


Figure 2.8. **Length frequency (total length in mm) histogram for all Humpback Chub measured in 2017 during small-bodied sampling according to sampling trip.**

Habitat

Because Razorback Suckers were not captured during small-bodied fish community sampling, habitat data collected in 2017 were only analyzed in relation to the collected native fish species. Of the habitats sampled, the most (55%) were slackwaters, followed by runs and pools at 12% each. These habitats also provide low-velocity conditions conducive to seining. Fine substrates, such as sand and silt, covered 90% of the habitat sampled during all seine hauls. While forms of cover varied boulders were the most prevalent cover type, although 39% of the sampling occurred where no cover was present (Figure 2.9).

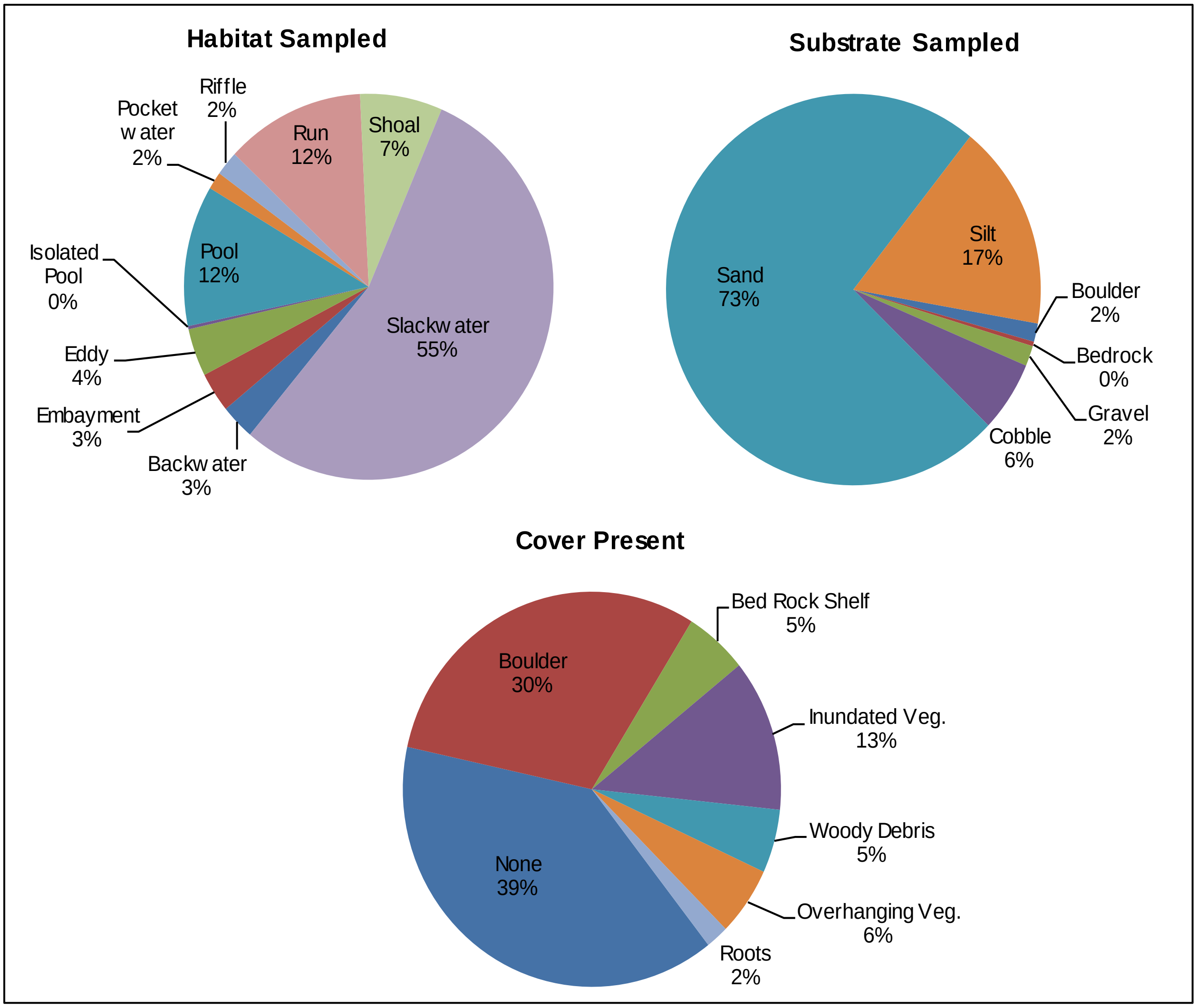


Figure 2.9. Proportion of seine hauls by target habitat, substrate, and cover present for all sampling in 2017.

Native fish catch rates differed significantly among target habitats (ANOVA, $F_{9,1845}=11.9$, $P<0.0001$, Tukey HSD), although post hoc analysis could not differentiate between homogeneous groups (Figure 2.10). Native fish catch rates were highest in habitats with silt, sand, and small cobble. The only significant difference was between silt and boulder, coarse gravel, large cobble, and sand (ANOVA, $F_{7,1845}=7.95$, $P<0.0001$, Tukey HSD), which was likely a function of where sampling took place (i.e., in slower depositional areas). An assessment of cover revealed that catch rates were generally higher when cover was present, and catch rates were highest when overhanging and inundated vegetation were present (ANOVA, $F_{7,1845}=11.4$, $P<0.0001$, Tukey HSD).

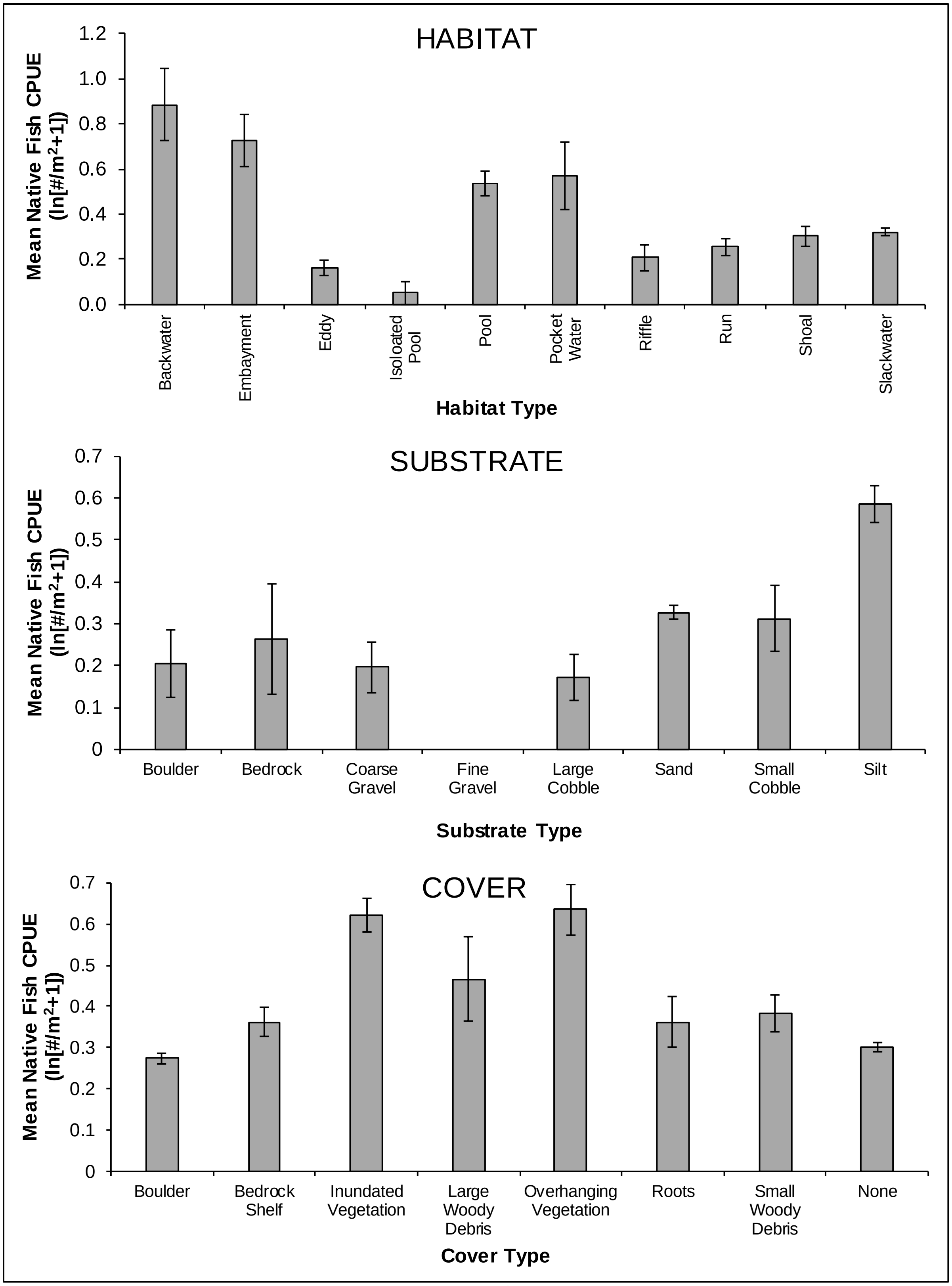


Figure 2.10. **Mean native fish CPUE [Ln((#/m^2)+1)] for all sampling within each target habitat, substrate, and cover type in 2017. Error bars are ± 1 SE.**

Annual and Historical Comparisons

When assessing native fish mean CPUE by sampling trip with data combined from 2014 to 2017, catch rates increased from March through July before decreasing in August and September (Figure 2.11). It should be noted that March sampling only occurred in 2014 and 2015, and there was no sampling event in July 2016. Although 2014 sampling yielded slightly higher catch rates, the relative abundance of native, small-bodied fish in 2017 was similar to 2014 and significantly higher than in 2015 and 2016 (ANOVA, $F_{3,6311}$=104, P<0.0001, Tukey HSD). Although comparisons can be made between sampling years and months, it should be noted that sampling in 2016 and 2017 encompassed a longer river reach (sampling above Lava Falls), and different segments were sampled compared with 2014 and 2015. The comparison of catch rates likely accounts for differing effort among years, but it cannot account for the difference in habitats sampled in reaches above Lava Falls. Thus, a comparison of native fish catch rates from Lava Falls downstream to Pearce Ferry may be more applicable. Native fish catch rates below Lava Falls varied by year, and each year demonstrated significantly different catch rates (ANOVA, $F_{3,4583}$=102, P<0.0001, Tukey HSD). The catch rates in 2017 were highest, followed by 2014, 2016, and 2015, respectively.

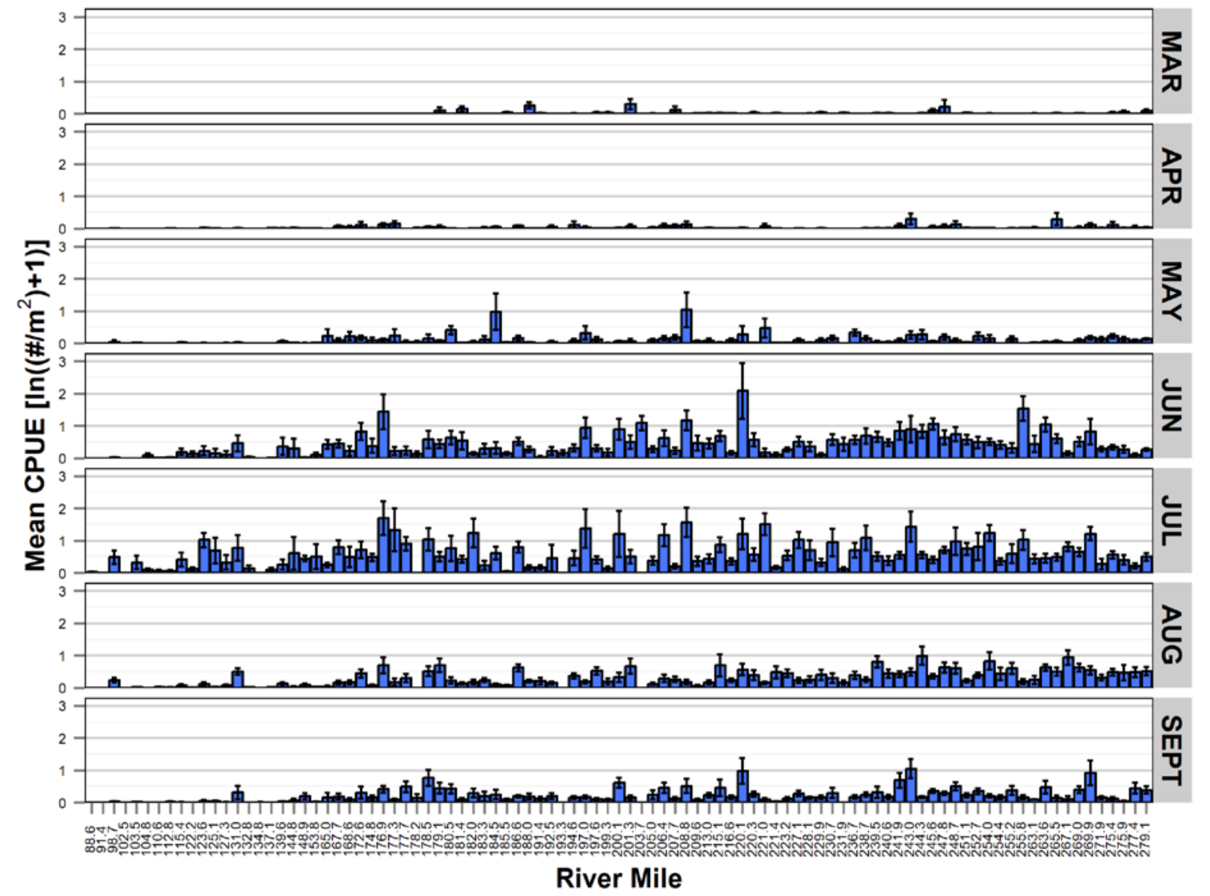


Figure 2.11. **Mean native fish CPUE [ln((#/m^2)+1)] by river mile (generalized random tessellation stratified [GRTS] design segment) upstream to downstream separated by sampling trip for 2014–2016. Error bars are ± 1 SE.**

Similar to the combined native fish data, catch rates for Humpback Chub from 2014 through 2016 increased in June, and Humpback Chub were continually captured throughout the study area through September (Figure 2.12). Humpback Chub catch rates were highest in 2017 and lowest in 2016 (ANOVA, F3,6311=16.1, P<0.0001). Post hoc analysis revealed 2014 Humpback Chub catch rates to be similar to both 2015 and 2016, while 2017 rates were significantly higher than all other years.

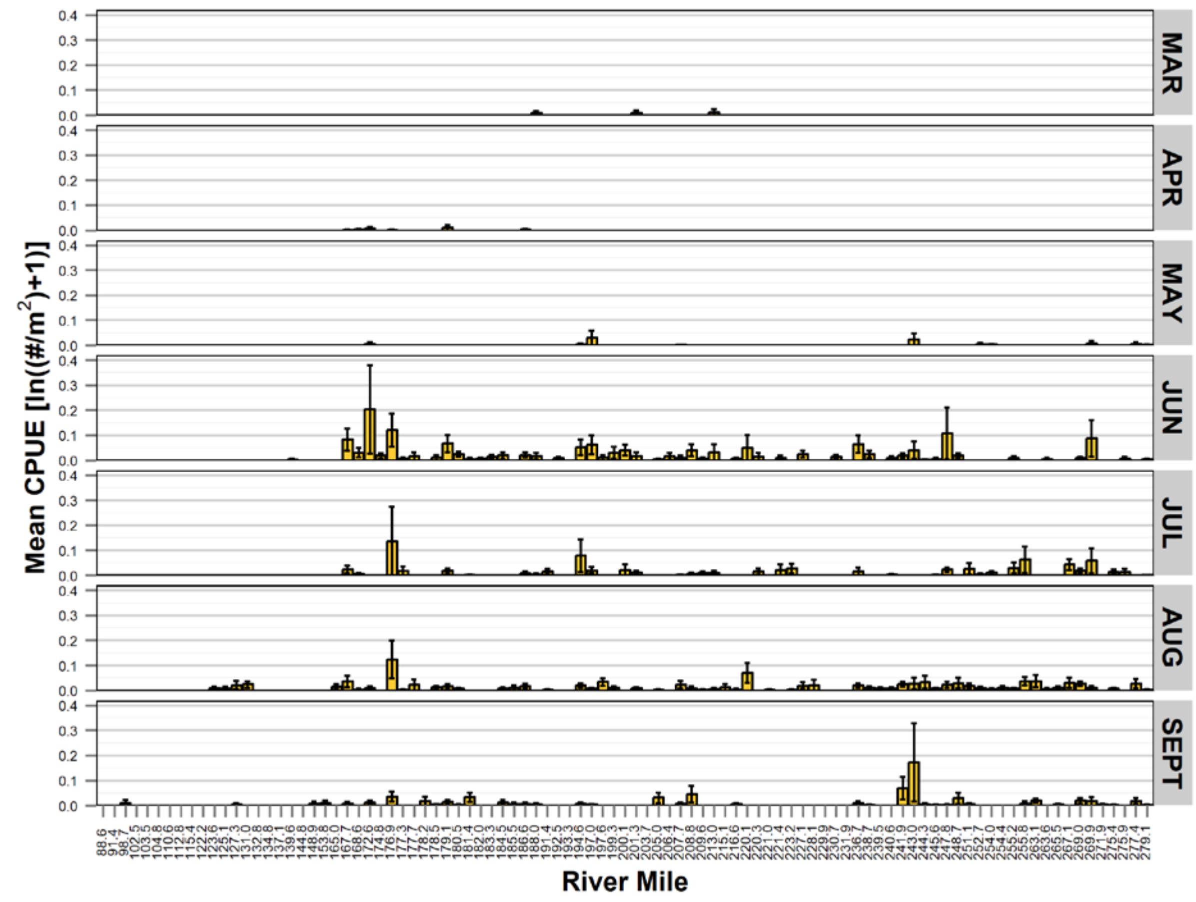


Figure 2.12. Mean Humpback Chub CPUE [ln((#/m2)+1)] by river mile (generalized random tessellation stratified [GRTS] design segment), upstream to downstream, separated by sampling trips from 2014 to 2016. Error bars are ± 1 SE.

Comparisons with Valdez et al. (1995) and Ackerman et al. (2006) reveal that native fish have become more abundant than nonnative fish below Diamond Creek since 1992 (Figure 2.13). It should be noted that Valdez et al. (1995) and Ackerman et al. (2006) calculated relative abundance using catch from various sampling methods including seining. Once less than 5% of the overall catch, native species below Diamond Creek increased to over 90% of the catch in 2014 through 2017. Although data for native fish composition in 2004–2006 above Diamond Creek were unavailable, it appears that native fish abundance has remained relatively stable for over 20 years within that reach.

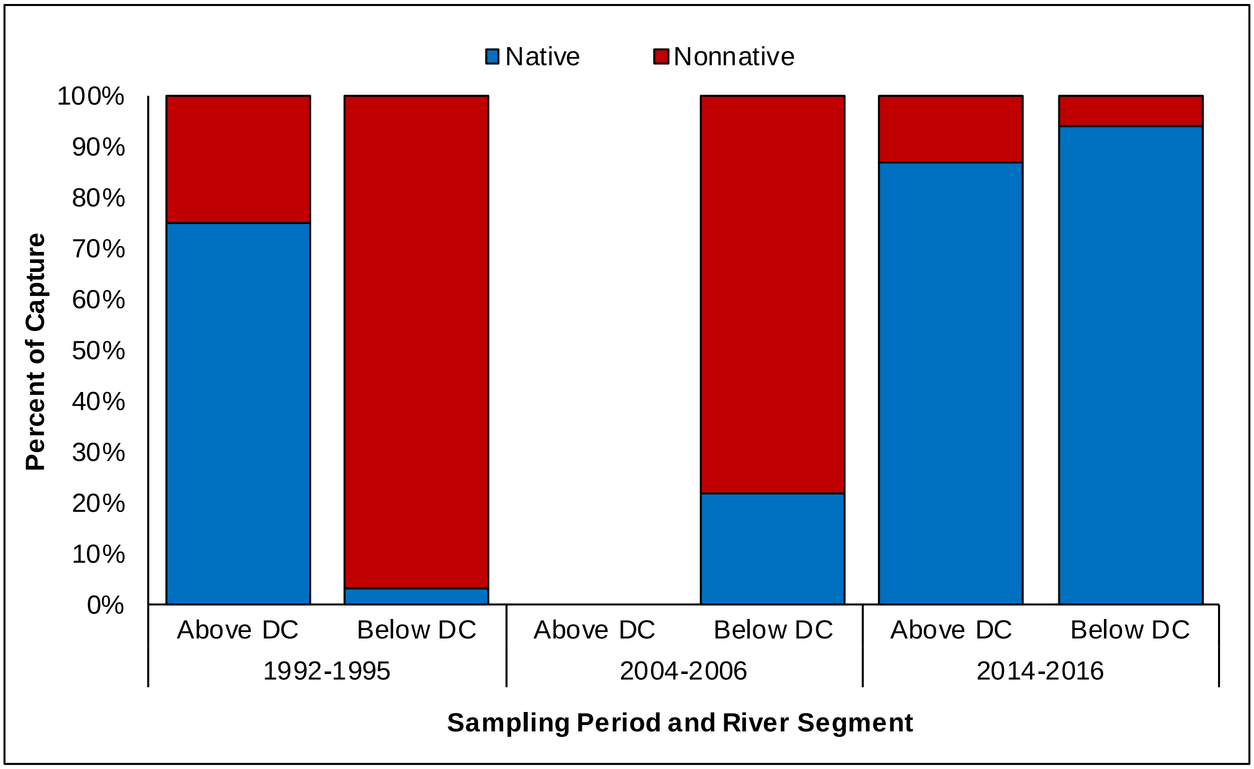


Figure 2.13. Percent composition of native and nonnative fish species captured above and below Diamond Creek (RM 225.9) in the Grand Canyon in 1992–1995 (Valdez et al. 1995), 2004–2006 (Ackerman et al. 2005), and 2014–2017.

Although the proportion of native fish captured above Diamond Creek in the 1990s appears similar to the 2014–2017 proportion, species composition has changed (Figure 2.14). For example, the percent composition of Speckled Dace and Bluehead Sucker has slightly decreased while the Flannelmouth Sucker and Humpback Chub percent composition has increased (Figure 2.14). According to recent sampling efforts above Diamond Creek, Common Carp and Channel Catfish essentially disappeared and Fathead Minnow *Pimephales promelas* is currently the most abundant nonnative fish species.

The more dramatic changes in the Grand Canyon fish community were noted below Diamond Creek. Where Red Shiner were once dominant (>60% of catch in 1992–1996), now Speckled Dace, Flannelmouth Sucker, and Bluehead Sucker are most numerous (>80% of catch in 2014–2017) (Figure 2.14). Humpback Chub are also more prevalent below Diamond Creek than in the past. The overall shift in the community composition from primarily nonnative species to native fishes is encouraging.

In 1990–1991 Speckled Dace were the most abundant native species captured during sampling efforts (Figure 2.15). Flannelmouth Suckers were also found in relatively higher abundances near Kanab and Havasu creeks. Relatively few Humpback Chub and Bluehead Sucker were captured and in relatively few locations. Additionally, no Razorback Suckers were captured within the 200-mile reach. Seventeen nonnative fish species were documented from RM 80 to 280 in 1990–1991 (Figure2.15). Nonnative fish species were more abundant below Diamond Creek with Common Carp, Channel Catfish, and Red Shiner among the most abundant. Nonnative species'

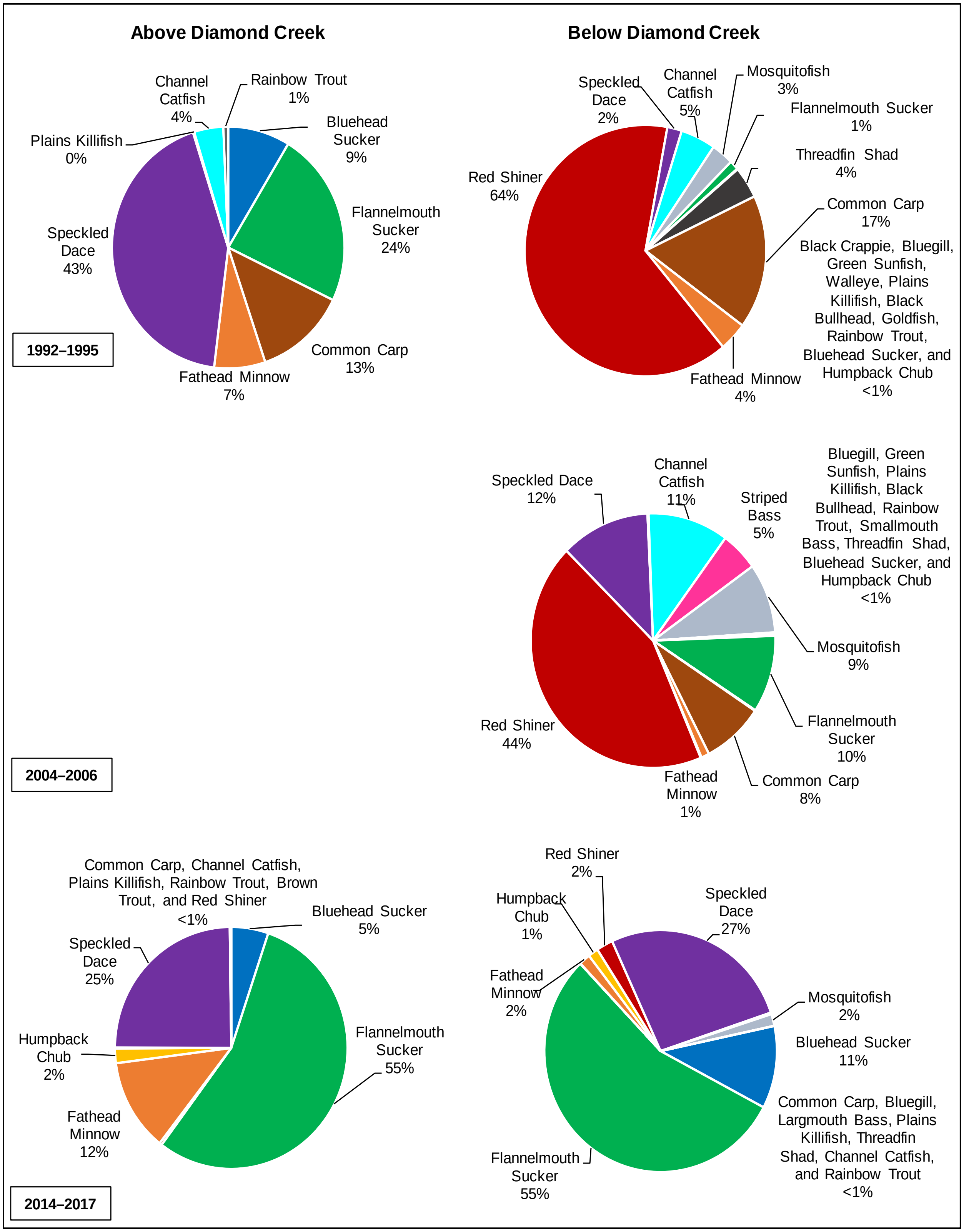
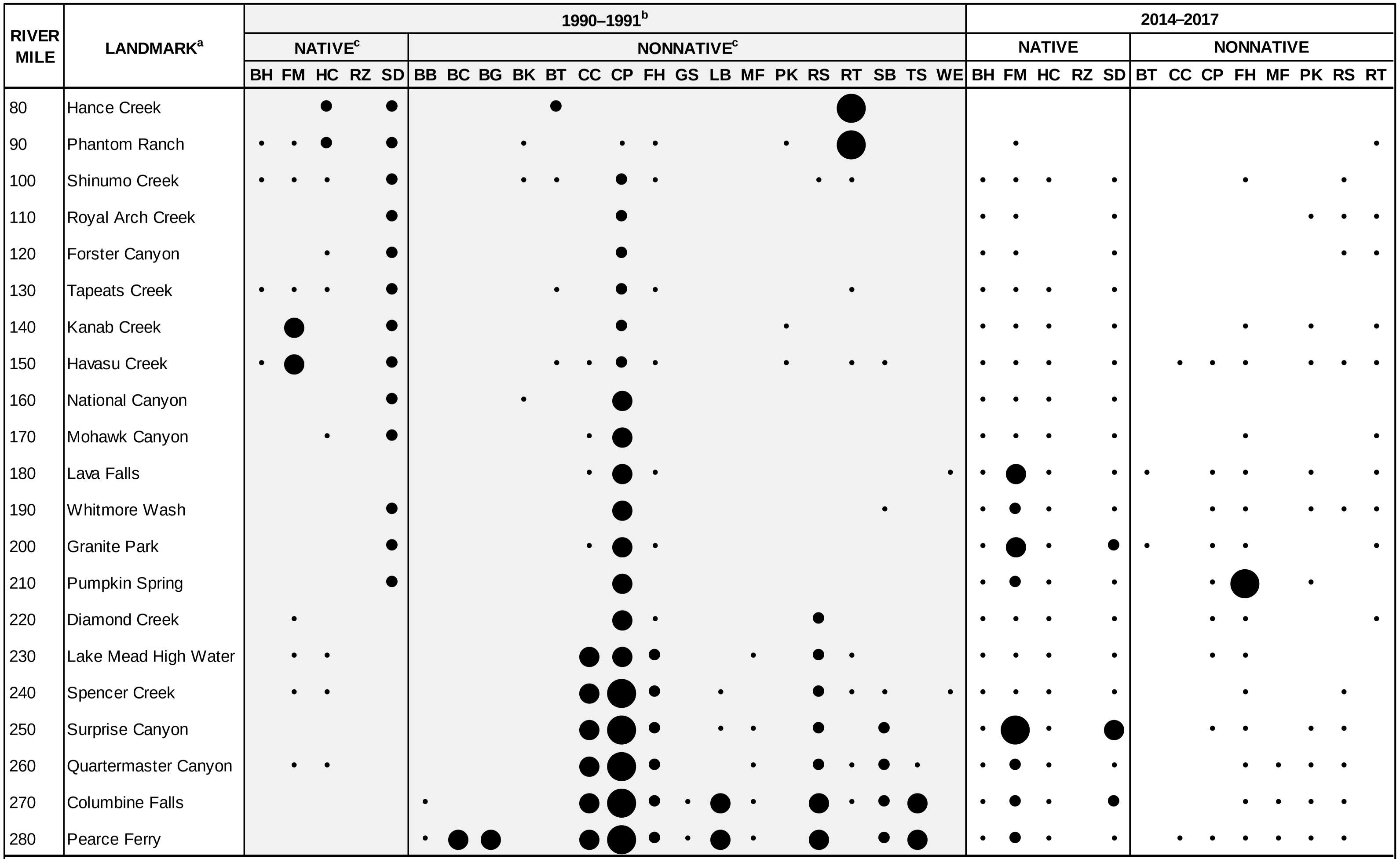


Figure 2.14. Percent composition of all fish species captured above and below Diamond Creek in the Grand Canyon in 1992–1995 (Valdez et al. 1995), 2004–2006 (Ackerman et al. 2006), and 2014–2017.



[a] Known landmark near noted Grand Canyon river mile.

[b] Data modified from Valdez (1996).

[c] Fish species abbreviations: BH=Bluehead Sucker, FM=Flannelmouth Sucker, HC=Humpback Chub, RZ=Razorback Sucker, SD=Speckled Dace, BB=Black Bullhead, BC=Black Crappie, BG=Bluegill, BK=Brook Trout, BT=Brown Trout, CC=Channel Catfish, CP=Common Carp, FH=Fathead Minnow, GS=Green Sunfish, LB=Largemouth Bass, MF=Western Mosquitofish, PK=Plains Killifish, RS=Red Shiner, RT=Rainbow Trout, SB=Striped Bass, TS=Threadfin Shad, WE=Walleye

Figure 2.15 Grand Canyon fish community composition from 1990 to 1991 compared with composition from 2014 to 2017. Dots represent presence and the size of the dot represents relative abundance within native and nonnative species categories.

relative abundance appeared to increase below the high-water mark of Lake Mead, which at the time would have been a lacustrine environment with elevated lake levels.

A comparison of data from 2014 to 2017 shows four native fish species present throughout the study area from approximately RM 100 downstream to 280 (Figure 2.15). Razorback Suckers were not captured, but the other four native species were captured in similar abundance throughout the study area. Flannelmouth Sucker dominated the native catch with increased relative abundance below Lava Falls. Only eight nonnative fish species were captured from 2014–2017, compared with 17 in 1990–1991 (Figure 2.15). Not only was there a reduction in nonnative species, but relative abundances decreased, especially Common Carp, Channel Catfish, Red Shiner, and Rainbow Trout.

Under different runoff conditions and dam operations, releases have varied in water quantity and diel fluctuation. In recent years the Colorado River within the Grand Canyon has experienced slightly reduced mean daily peak flows and increased mean daily water temperatures. Since 1991 minimum mean daily discharge has rarely been below 6,500 ft^3/sec at Lee's Ferry, and it has remained relatively consistent in recent years. However, maximum mean daily discharge was reduced from 2003 to 2017 (Figure 2.16A). Median mean daily discharge from 1991 through 2002 was 13,000 ft^3/sec compared with 12,100 ft^3/sec from 2003 to 2017. Under slightly lower mean daily peak flows, maximum mean daily water temperatures were also higher from 2003 to 2017 compared with 1991–2002 (Figure 2.16B). The median mean daily stream temperature at Lee's Ferry from 1991 to 2002 was 9.3°C compared with 10.2°C from 2003 to 2017. Lake Powell experienced a decline in lake elevation in 2001 through 2005, and lake elevations have remained relatively lower since that time (Figure 2.16C). Median Lake Powell mean daily elevations from 1991 through 2002 was 3,665.4 m ASL compared with 3,605.7 m ASL from 2003 to 2017.

Larval Fish Community Sampling

2017 Sampling

Six larval fish surveys were conducted in 2017, one survey during each month from March through August. During the monthly surveys in 2017, 54–56 GRTS segments were sampled. Total monthly effort (area sampled) at GRTS segments during 2017 ranged from 1,976.5 to 2,017.7 m^2 (Table 2.6).

2017 Capture Summary

March: The first larval fish survey in 2017 (Phantom Ranch [RM 89] to Pearce Ferry [RM 280]) occurred March 9–17 (Table 2.6). During the sampling period, mean daily discharge from Glen Canyon Dam, as measured upstream of Diamond Creek (USGS gage 09404200), fluctuated between 11,355 and 14,201 ft^3/sec and exhibited diel fluctuation of 2,040 ± 382 ft^3/sec (mean ± SD). Turbidity was fairly consistent (mean=9.7 cm; range 7–15 cm) throughout the study area. Mean formazin nephelometric units (FNU) at USGS gage 09404200 were 237.3. Mean daily water temperature near the middle of the study area (RM 190) was 11.7°C and ranged from 10.5 to 12.6°C (Figure 2.17).

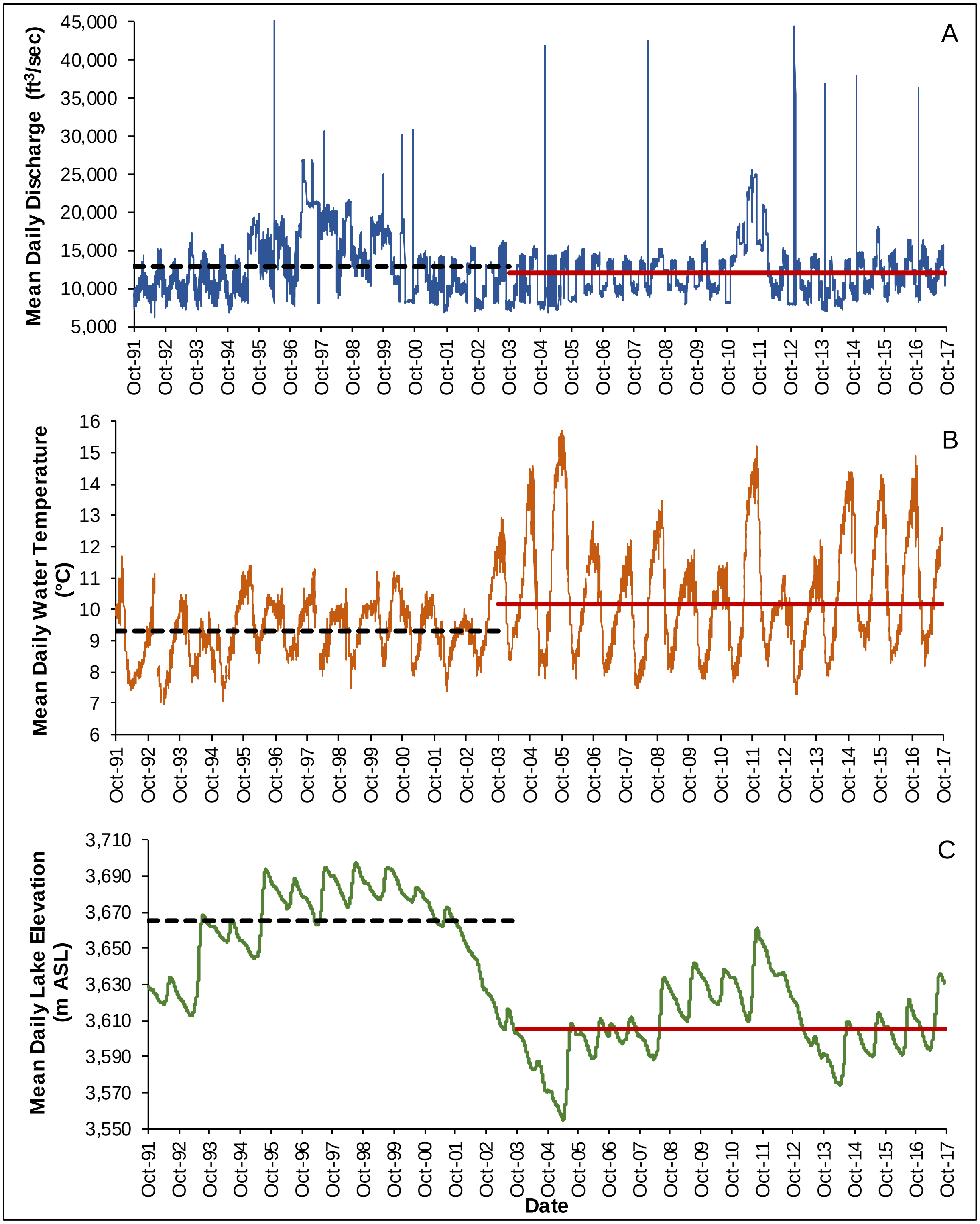


Figure 2.16. Mean daily discharge at Lee's Ferry (USGS gage 09380000) from 1991 to 2017 (A), mean daily water temperature at Lee's Ferry (USGS gage 09380000) from 1991 to 2017 (B), and mean daily Lake Powell water elevation (Reclamation 2017) (C). Median value from 1991 to 2002 shown as dashed black lines and median value from 2003 to 2017 shown as solid red lines.

Table 2.6. Sampling effort from monthly 2017 larval fish surveys.

SAMPLING MONTH	SAMPLE DATES	NUMBER OF HAULS	EFFORT (m^2) AT GRTS[a] SITES	GRTS SEGMENTS SAMPLED
March	9–17	216	1,993	54
April	8–13	225	2,012	56
May	19–24	224	2,218	56
June	14–19	223	1,977	56
July	11–17	224	1,978	56
August	16–23	224	1,991	56

[a] generalized random tessellation stratified

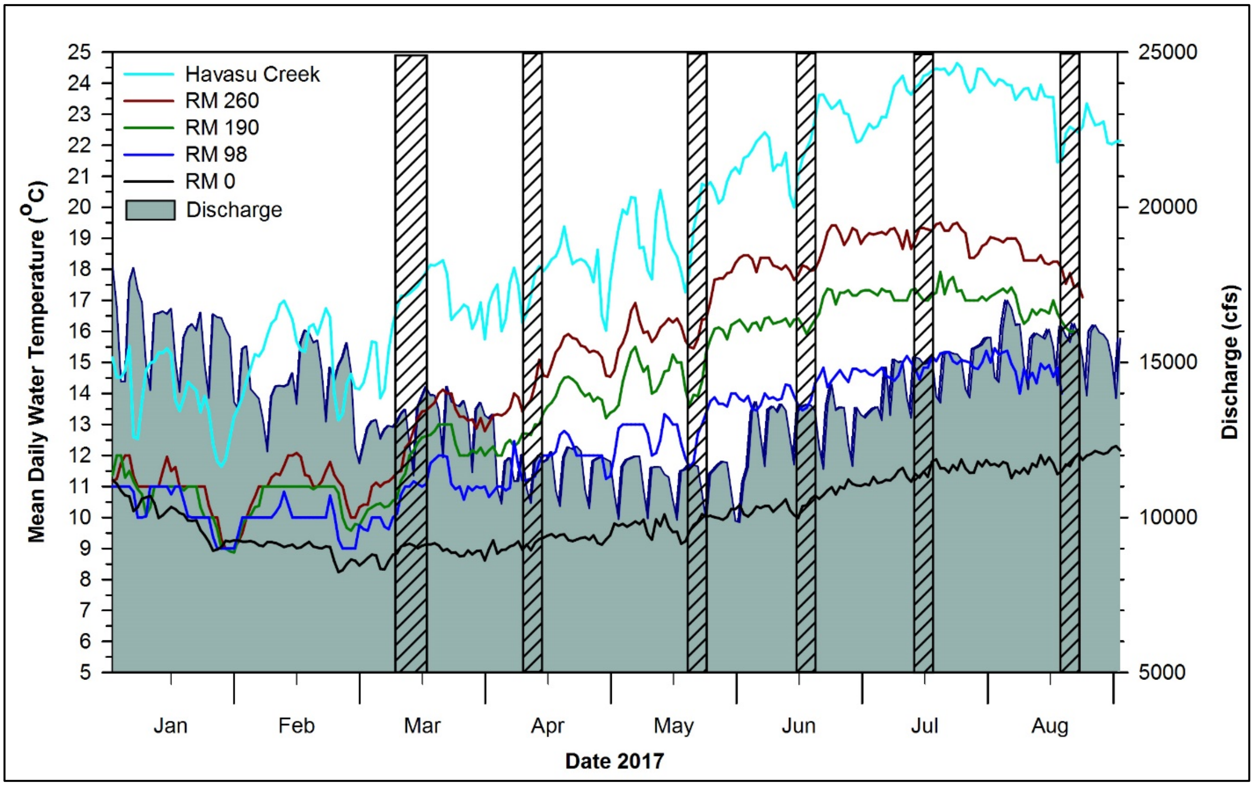


Figure 2.17. Discharge and water temperature during the 2017 sampling period recorded upstream of Diamond Creek (USGS gage 09404200). Vertical bars denote survey trip dates.

Larval fish were not captured in the upstream most 78.8 river miles (40%) of the study area during the March survey (19 GRTS segments, RM 88.6–153.8). The first March collection of larval fish was at GRTS segment 160 (RM 167.7), approximately 10 river miles downstream of Havasu Creek. Larval fish collected in March were Flannelmouth Sucker and Razorback Sucker (Figures 2.18, 2.19, 2.20, and Appendix E.1), with Flannelmouth Sucker comprising 94.7% of the total catch (n=133). This species was documented in most collections downstream of Havasu Creek and recorded at 33.3% (n=18, RM 167.7–279.0) of the 54 GRTS segments sampled in March (Figure 2.19).

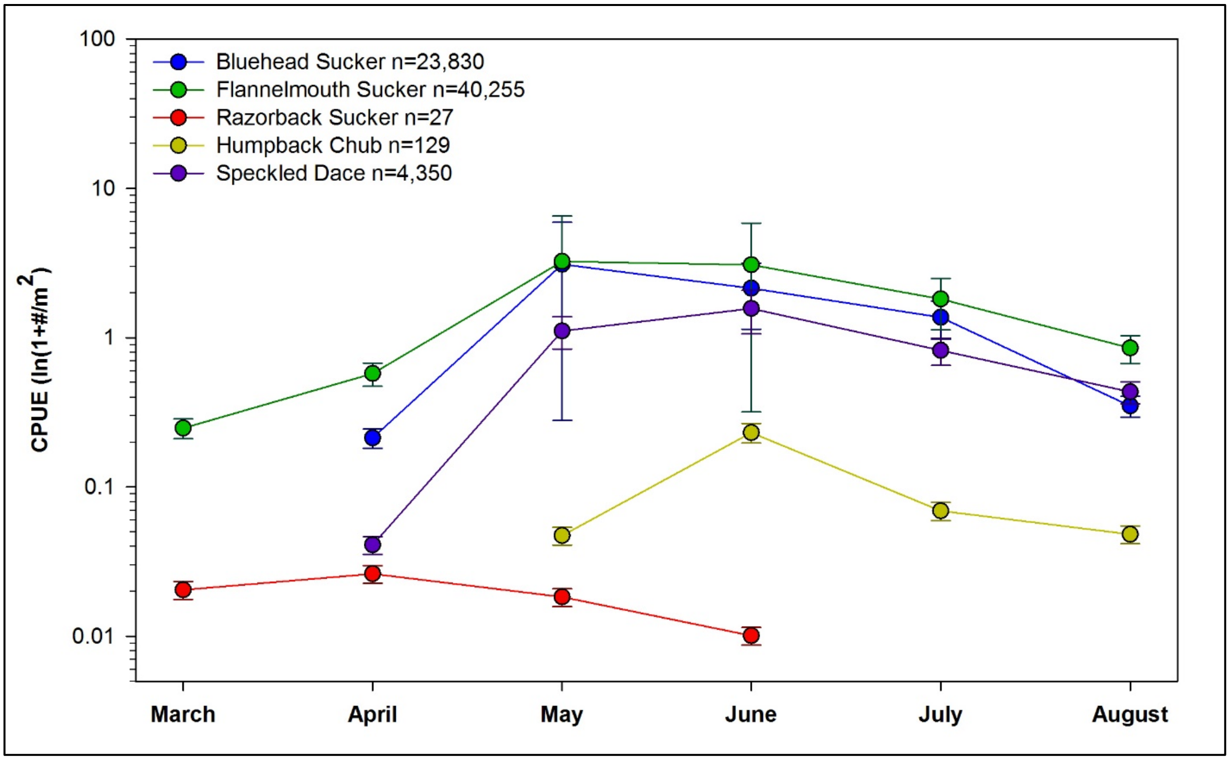


Figure 2.18. **Mean CPUE of age-0 fishes by sampling trip (month) during the 2017 larval fish survey. The y-axis scale is $\log_{10}$ and error bars are ± 1 SE.**

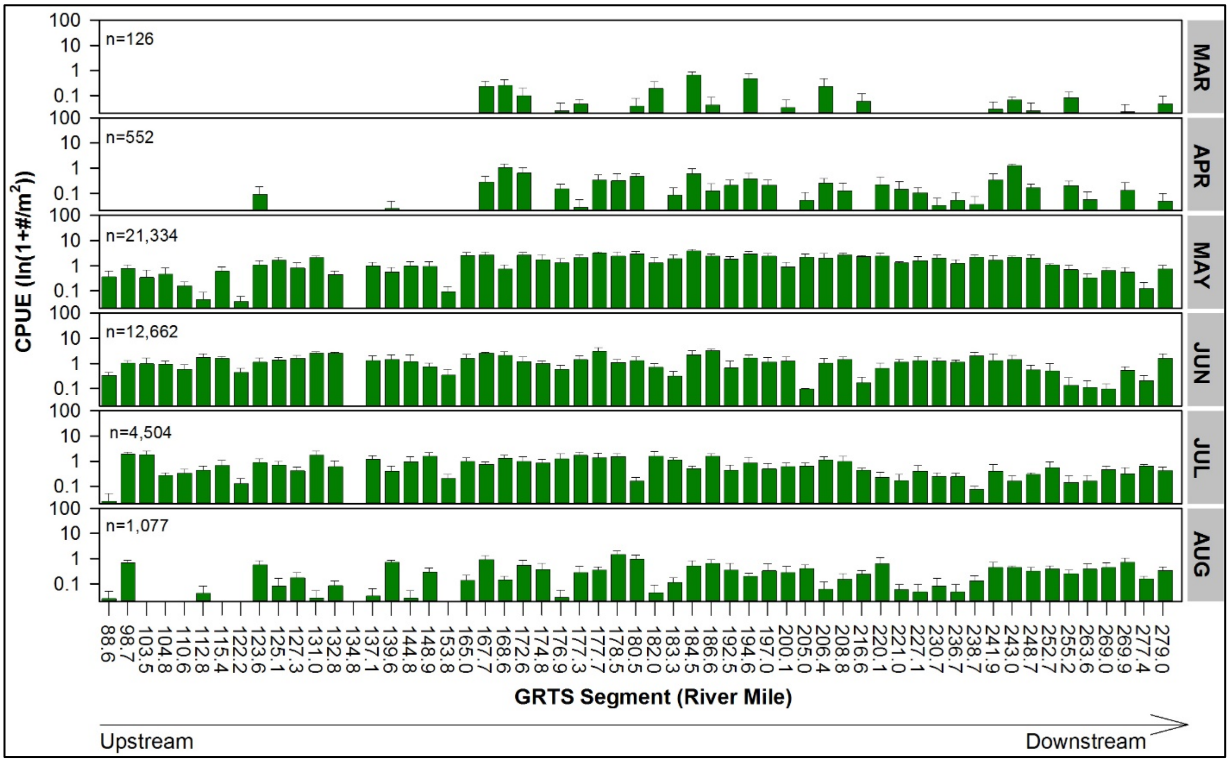


Figure 2.19. **Mean CPUE of age-0 Flannelmouth Sucker by 2017 sampling trip (month) and generalized random tessellation stratified (GRTS) segment. The y-axis scale is $\log_{10}$ and error bars are ± 1 SE.**

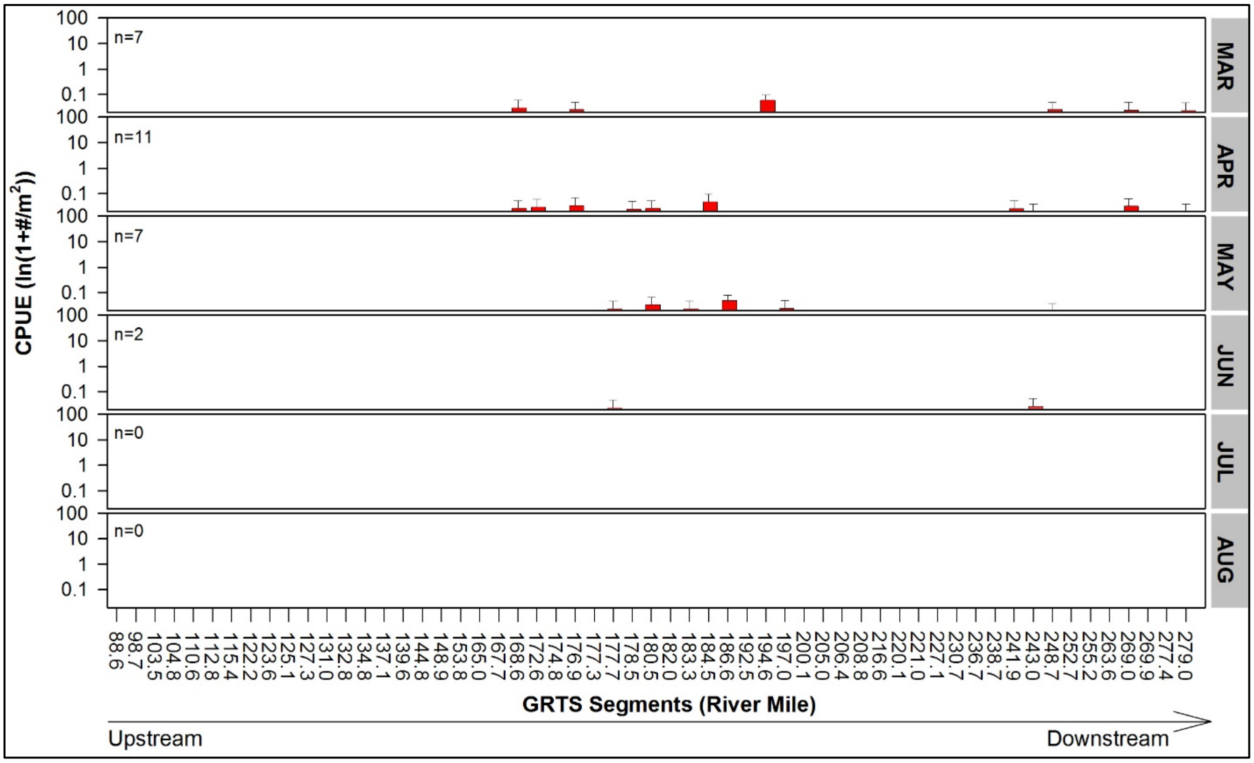


Figure 2.20. Mean CPUE of age-0 Razorback Sucker by 2017 sampling trip (month) and generalized random tessellation stratified (GRTS) segment. The y-axis scale is $\log_{10}$ and error bars are ± 1 SE.

The first March capture of Razorback Sucker was at RM 168.6, 0.9 mile downstream of the first captures of larval Flannelmouth Sucker. Razorback Suckers (n=7) were captured at six GRTS segments in March between RM 168.6 and 279.0 (Figure 2.20). The majority of Razorback Sucker captures (6 of 7) at GRTS segments consisted of single individuals. Ontogenetic phases of Razorback Sucker larvae captured in March ranged from protolarvae (n=1) to flexion mesolarvae (n=6).

Age-1 incidental captures during the March survey were native Humpback Chub, Speckled Dace, Flannelmouth Sucker, and Bluehead Sucker. Age-1 nonnative fish captured were Fathead Minnow, Rainbow Trout, Plains Killifish, Western Mosquitofish, and a single Green Sunfish *Lepomis cyanellus* (31 mm TL). The Green Sunfish was taken at river mile 186.6 (Appendix F.1). Age-1 Humpback Chub (n=18) ranged from 29 to 55 mm TL and were taken at eight GRTS segments. The longitudinal distribution of age-1 Humpback Chub captured in March was from river mile 139.6 to 241.9.

April: This survey occurred April 8–13, 2017 (Table 2.6). Mean daily discharge during the April survey ranged from 10,465 to 12,031 ft^3/sec with diel fluctuations of 2,546 ± 161.2 ft^3/sec (mean ± SD). Turbidity decreased compared with the March survey (mean=42 cm; range 14–57 cm). Mean turbidity recorded at the USGS gage upstream of Diamond Creek (09404200) was 52.3 FNU. Mean daily water temperature recorded near the middle of the study area (RM 190) was 12.8°C, which was a 1.1°C increase from the March survey (Figure 2.17).

An increase in the upstream distribution and abundance of age-0 fishes was documented in April (Figures 2.18–2.21 and Appendix E.2). The upstream most capture of larval catostomids expanded 44.1 river miles to RM 123.6 compared with the March survey. Catostomidae was the most abundant family documented during the April survey, comprising 99.6% of age-0 fishes captured. The remaining 0.4% of age-0 fishes were Speckled Dace (n=3) taken at RM 248.7 (Figure 2.22). Flannelmouth Sucker composed 81.5% (n=552) of the April larval catostomid capture while Bluehead Suckers were 16.5% (n=111) of the catostomid catch. This later species was first documented at RM 167.7, the first GRTS segment downstream of Havasu Creek (Figure 2.21). Razorback Suckers were 1.6% (n=11) of the total catostomid catch. The upstream most sample of larval Razorback Sucker was at RM 168.6, which is the same location recorded during March (Figure 2.20). All larval Razorback Suckers were mesolarvae with the majority (91%) developed to the earlier subphase flexion mesolarvae (n=10). Larval Razorback Suckers were collected in similar proportions and distributions as during the March survey (RM 168.6–279.0).

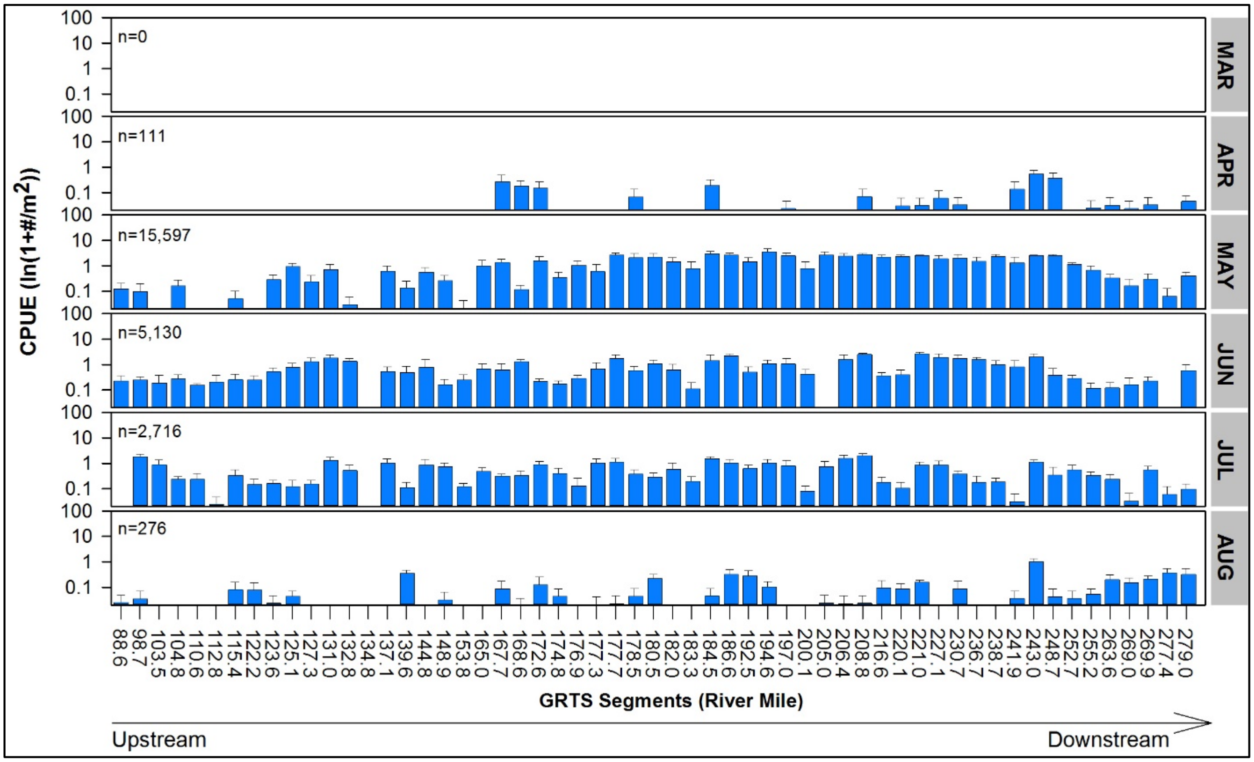


Figure 2.21. Mean CPUE of age-0 Bluehead Sucker by 2017 sampling trip (month) and generalized random tessellation stratified (GRTS) segment. The y-axis scale is $\log_{10}$ and error bars are ± 1 SE.

The species composition of age-1 fishes incidentally captured during April was similar to the March survey but included Red Shiner (Appendix F.2). Green Sunfish was not captured during the April survey. Fewer Humpback Chub (n=2) were taken in April compared with March, and both individuals were collected at RM 172.6. These two individuals were 32 and 45 mm TL.

May: The third larval survey occurred May 19–24, 2017 (Table 2.6). Mean daily discharge during the May survey ranged from 9,895 to 11,705 ft^3/sec with diel fluctuations of 2,372 ±

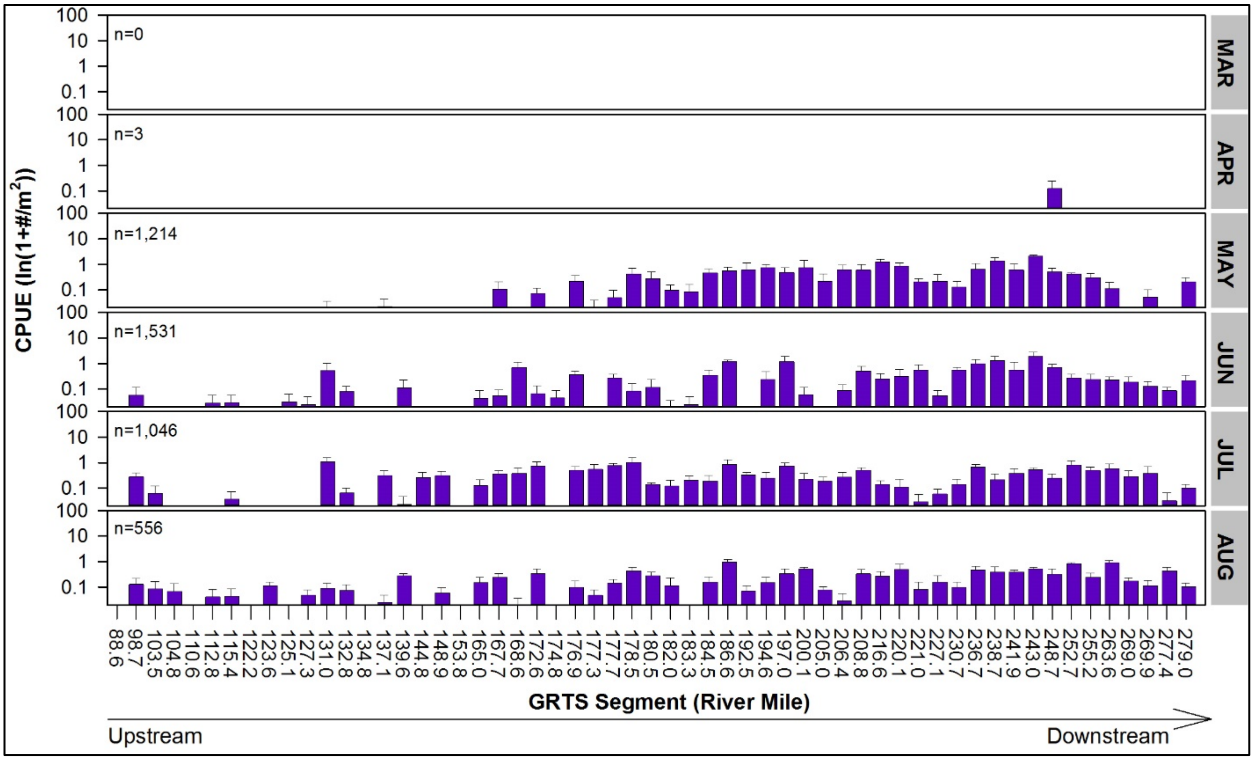


Figure 2.22. Mean CPUE of age-0 Speckled Dace by 2017 sampling trip (month) and generalized random tessellation stratified (GRTS) segment. The y-axis scale is $\log_{10}$ and error bars are ± 1 SE.

409.1 ft^3/sec (mean ± SD). Water clarity rose from March and April surveys (mean=85cm; range 32 to >100 cm). Mean water turbidity recorded at the USGS gage upstream of Diamond Creek (09404200) was 11.5 FNU. During the May survey mean daily water temperature (14.5°C) near the middle of the study area (RM 190) was approximately 2–3°C warmer than during the prior two months (Figure 2.17).

The May larval fish survey documented a marked increase in the longitudinal distribution and abundance of age-0 fishes in the study area and had the highest mean CPUE of all monthly surveys in 2017 (ANOVA, $F_{5,4,670}$=27.1659, P<0.0001) (Figure 2.18 and Appendix E.3). Age-0 fishes were captured at every GRTS segment (RM 88.6–279), which increased the upstream distribution of age-0 fishes 35 river miles upstream from the April survey's most upstream capture (RM 123.6). Catostomidae was the numerically dominant family captured during May, comprising 96.9% of age-0 fishes (Appendix E.3). Age-0 Speckled Dace (n=1,214) and Humpback Chub (n=22) comprised the remaining 3.1% of the May age-0 fish capture. Mean monthly catch rates were highest in May for both Flannelmouth Sucker (ANOVA, $F_{5,1,330}$=106.2324, P<0.0001) and Bluehead Sucker (ANOVA, $F_{5,1,330}$=92.6276, P<0.001). The catostomid capture was composed of primarily Flannelmouth Sucker 57.7% (n=21,334) and Bluehead Sucker 42.2% (n=15,597); the remainder (0.1 %) consisted of Razorback Sucker (n=7) and three unidentifiable catostomid larvae. (These individuals could not be accurately identified further than the family level and are reported herein as Catostomidae). Razorback Sucker was captured at 10.7% (n=6) of the 56 GRTS segments and was distributed from RM 177.65 to 248.7. A protolarval Razorback Sucker was collected at RM 177.6. The remaining Razorback

Suckers were flexion mesolarvae (n=5) and post-flexion mesolarva (n=1). The cyprinid capture was mainly composed of Speckled Dace (99.8%; n=1,214), while Humpback Chub (n=22) comprised the remaining cyprinid captures. May was the first month during which larval Humpback Chub were collected. The first Humpback Chub was taken approximately 15 river miles downstream of Havasu Creek at RM 172.6 (Figure 2.23). All age-0 Humpback Chub collected were mesolarvae; 82% (n=18) were flexion mesolarvae and the remaining individuals (n=4) were post-flexion mesolarvae. Humpback Chub was captured in 23% (n=13) of the GRTS segments and distributed between RM 172.6 and 255.2.

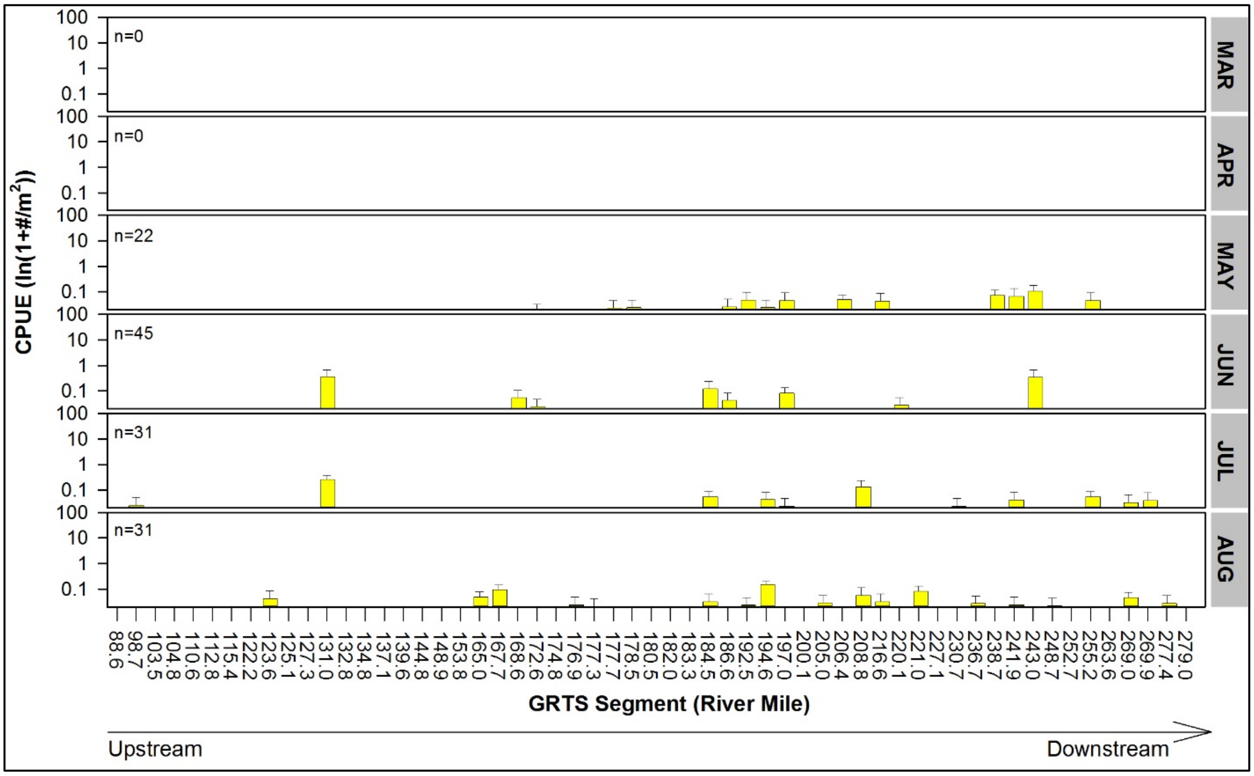


Figure 2.23. Mean CPUE of age-0 Humpback Chub by 2017 sampling trip (month) and generalized random tessellation stratified (GRTS) segment. The y-axis scale is $\log_{10}$ and error bars are ± 1 SE.

Age-1 fishes incidentally captured in May included common native fishes taken during the previous survey months. A single Age-1 Humpback Chub (TL=43 mm) was captured at river mile 172.6. Captures of both native and nonnative age-1 fishes were fewer than either the March and April Surveys (Appendix F.3)

June: The fourth larval fish survey occurred June 14–19, 2017 (Table 2.6). Mean daily discharge during this time increased, compared with the previous three surveys, and ranged from 12,279 to 13,629 ft^3/sec with diel fluctuation of 3,483 ± 116.9 ft^3/sec (mean ± SD). Water clarity at the GRTS segments ranged from 32 to >100 cm (mean=89 cm). Mean turbidity was 10.4 FNU. Mean daily water temperature near the middle of the study area (RM 190) was 1.3°C warmer compared with the May survey and averaged 15.8°C (Figure 17).

Capture rates of age-0 fishes remained high during the June survey and were significantly greater than all months except May (ANOVA, $F_{5,4,670}$=27.1659, P<0.0001) (Figure 2.18, Appendix E.4). Catostomids were distributed throughout the study area and continued to numerically dominant the collections, composing 92% (n=17,792) of the total age-0 catch. Similar to the May survey, Flannelmouth Sucker (n=12,662) was captured at all GRTS segments and was the majority (71%) of the catostomid capture, while Bluehead Sucker (28.8%, n=5,130) and Razorback Sucker (0.02%, n=2) composed the remainder. Razorback Sucker was captured at two GRTS segments (RM 178.2 and 243.0). A Razorback Sucker at RM 243.0 was the largest (20 mm TL) and most developed (metalarva) individual captured during the 2017 survey. The other Razorback Sucker captured in June was a post-flexion mesolarvae. The June survey was the last in 2017 to yield Razorback Sucker. There was not a detectable difference in capture rate between months (March–June; ANOVA, $F_{3,884}$=1.9453, P=0.1207). While June produced the highest catch rate for Humpback Chub, monthly catch rates were not significantly different (ANOVA, $F_{3,891}$ = 0.4613, P=0.7094) (Figure 2.18). Humpback Chub (n=45) were taken at eight GRTS segments across 112 river miles (RM 131.0–243.0). June was the first survey month in 2017 to yield age-0 nonnative fishes. Western Mosquitofish (n=16) and Fathead Minnow (n=2) were each collected at a single GRTS segment, but together they represent <0.01% of the total June age-0 capture.

Native fishes composed more than 90% of the incidental age-1 captures (Appendix F.4). Age-1 Humpback Chub (n=9) were captured in three GRTS segments (RM 168.6, 184.5, 279.0) and were 42–82 mm TL. Speckled Dace (57.5%, n=162) and Flannelmouth Sucker (29.8%, n=84) were the most frequently captured age-1 fishes.

July: The fifth larval fish survey occurred July 11–17, 2017 (Table 2.6). Mean daily discharge increased from previous surveys and ranged from 13,219 to 15,174 ft^3/sec, with diel fluctuation of 5,214 ± 409.9 ft^3/sec (mean ± SD). Water clarity at sampling locations was similar to clarity during previous months (mean=79, range 11–>100 cm). Mean turbidity was 27.0 FNU. Water temperature at RM 190 increased (1.4°C) from the June survey and averaged 17.2°C (Figure 2.17).

Capture rates of age-0 fishes decreased compared with the June survey (Figure 2.18). Catostomids continued to be the most numerous and widely distributed age-0 fishes captured (Appendix E.5). Flannelmouth Sucker (n=4,504) and Bluehead Sucker (n=2,716) occurred in nearly every segment sampled (n=55 and 56, respectively) and composed nearly 87% of the total age-0 captures (Figures 2.19 and 2.21). Razorback Sucker was not captured during the July survey (Figure 2.20). Speckled Dace (n=1,046) and Humpback Chub (n=31) were the two most numerous age-0 cyprinids captured (Figure 2.18). Humpback Chub was captured in 11 of 56 (19.6%) GRTS segments and distributed over 171 river miles (RM 98.6–269.9) (Figure 2.23). Mesolarvae to juvenile developmental phases of Humpback Chub were taken, with juveniles comprising 9.8% of the Humpback Chub captures. Nonnative fishes were 0.3% of the total age-0 fish captured.

In July, 304 total age-1 fishes were incidentally captured. Age-1 fish captured were mainly Speckled Dace (80.6%) and Western Mosquitofish (13.5%) (Appendix F.5). Humpback Chub (58 and 69 mm TL) were captured at RM 167.7 and 168.6.

August: The last larval fish survey occurred August 16–23, 2017. Mean daily discharge during the August survey ranged from 13,930 to 16,251 ft^3/sec and averaged 15,609 ft^3/sec. Diel fluctuation was 5,000 ± 272.5 ft^3/sec (mean ± SD). Water clarity in August was relatively lower than during previous sample months, as was indicated by decreased secchi disk depths (mean = 8.9 cm) and increased mean daily turbidity (mean = 601 FNU). Water temperature near the middle of the study area (RM 190) decreased slightly (0.8°C) from the July survey and averaged 16.3°C (Figure 2.17).

August larval fish capture rates were statistically similar to all prior sampling month rates with the exception of May and June (ANOVA, $F_{5,4,670}$=27.1659, P<0.0001). Flannelmouth Sucker (n=1,077) remained the most abundant species documented, composing slightly more than half (55.4%) of the total fish capture (Appendix E.6). Speckled Dace (n=556) was the second most abundant (28.6%) species, followed by Bluehead Sucker (n=276; 14.2%). Razorback Sucker was not collected in August. Humpback Chub (n=31) were distributed from RM 123.6–277.4, were captured in 17 of 56 (30.4%) GRTS segments, and were 1.6% of the catch. The majority (80.6%) of Humpback Chub taken in August were juveniles; the remainder (n=6) were metalarvae. Nonnative age-0 fishes were <0.3% of the total fish captured.

Age-1 fish incidentally taken were Speckled Dace (79.5%) and Humpback Chub (n=5). Age-1 Humpback Chub were captured at 5 of 56 GRTS segments between RM 167.7 and 236.7.

Native and nonnative fishes: Seven species of age-0 fish were captured during the 2017 larval fish surveys. Five of the seven species were native fishes represented by two families: Catostomidae (n=3 species) and Cyprinidae (n=2 species). Nonnative species captured also were represented by two families: Cyprinidae and Poeciliidae. Fathead Minnow (n=26) and Western Mosquitofish (n=21) were the only age-0 nonnative species captured and when combined they represented an exceedingly small portion (0.07%) of the total age-0 capture (n=68,581) (Appendix E1–6). Nonnative fishes were in very low abundance at 13 of 57 GRTS segments. Native fishes numerically dominated the monthly captures and were taken at all except one GRTS segment (RM 134.8), which was only sampled in March and April (Figure 2.24). Flannelmouth Sucker (n=40,255) and Bluehead Sucker (n=28,830) were the two most commonly captured age-0 species.

Razorback Sucker

Larval Razorback Suckers have been collected in Grand Canyon for four consecutive years (2014–2017). The most upstream capture of Razorback Sucker larvae in the expanded study area (2016 and 2017) has been at GRTS segment 162 (RM 168.6) (Figure 2.20 and 2.25). This locality is close to the most upstream capture of larval catostomids during the March survey (2016 and 2017; RM 167.7) and indicates the upstream proximity of catostomid spawning.

In 2017, 27 total larval Razorback Suckers were captured from March to June. Larval Razorback Suckers were dispersed across the lower 110.4 river miles of the study area (RM 168.6–279.0). Seven larvae were documented in March from RM 168.6 to 279.0, while 11 larval Razorback Suckers were captured during April in the same reach of river. The May survey documented seven larvae in a slightly truncated distribution (RM 177.7–248.7) at six GRTS segments. June

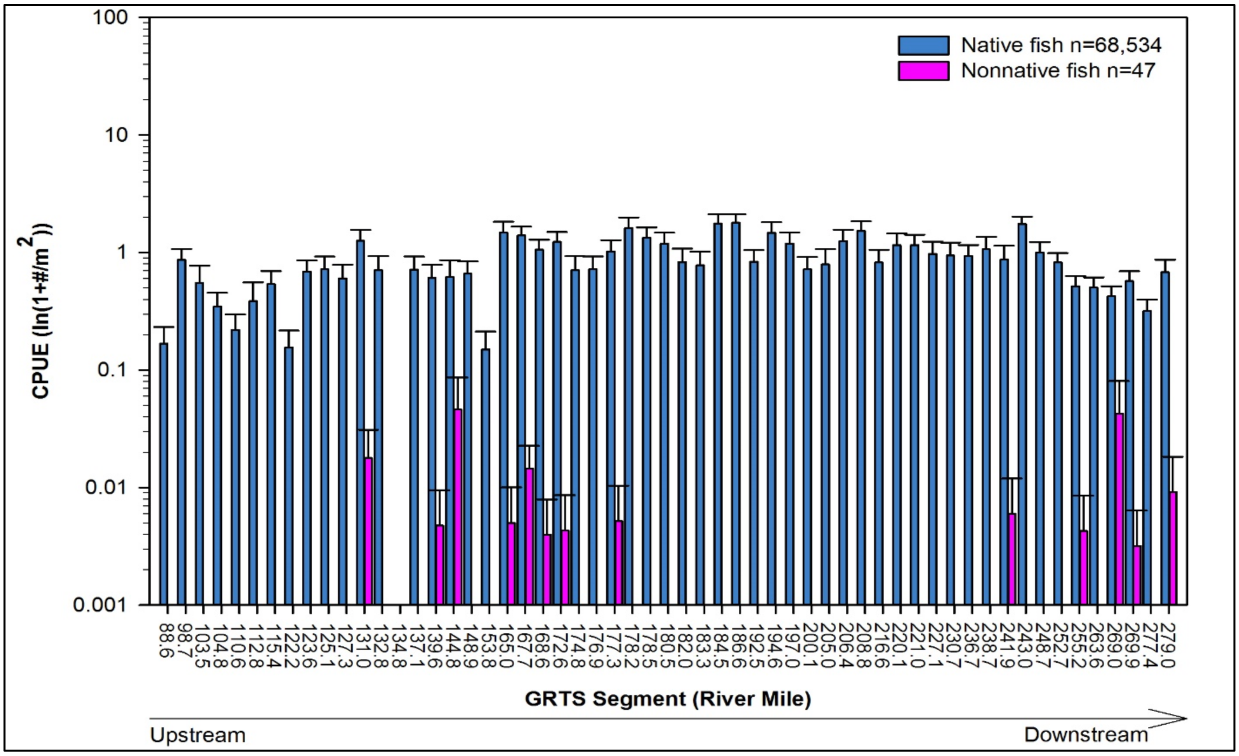


Figure 2.24. Mean CPUE of age-0 native and nonnative fishes by generalized random tessellation stratified (GRTS) segment for all survey months (March–August) combined. The y-axis scale is log10 and error bars are ± 1 SE.

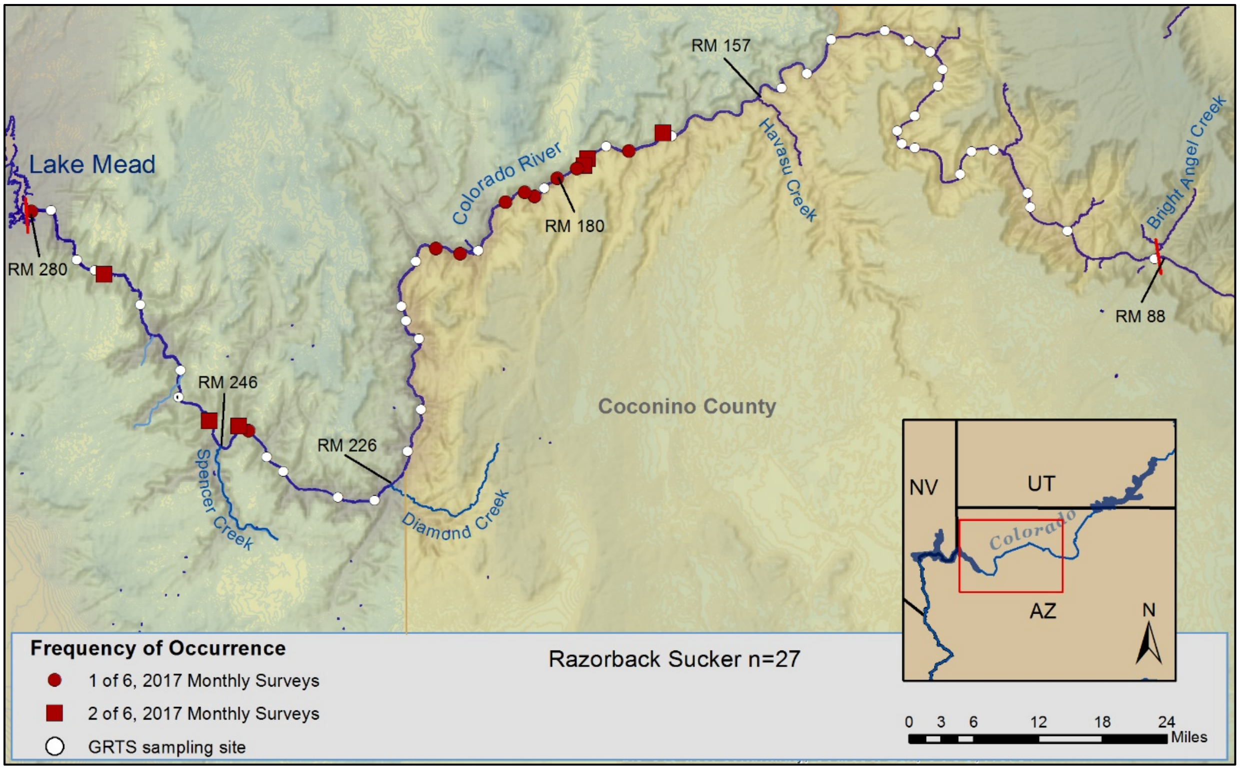


Figure 2.25. Frequency of occurrence of larval Razorback Sucker at generalized random tessellation stratified (GRTS) segments during the 2017 larval fish survey.

was the last month in which larvae of the species were documented. Two fish were captured during the June survey at two localities (RM 177.7 and 243.0). There was no significant difference in CPUE (ANOVA, $F_{3,884}$=1.9453, P=0.1207) among the four months during which this species was captured. Six GRTS segments produced larval Razorback Suckers on two survey trips (Figure 2.25).

Larval Razorback Sucker captured ranged from 11.8 to 20.9 mm TL (Figure 2.26), with most specimens (88.9%) <15 mm TL. Razorback Sucker represented all three larval ontogenetic phases during 2017 (protolarvae, mesolarva, and metalarvae). Protolarva, the earliest life phase, was represented by two specimens captured in March (RM 176.9) and May (RM 197.0). Both subphases of mesolarva (flexion mesolarva and postflexion mesolarva) were taken throughout when this species was captured (March–June). Flexion mesolarvae comprised 91.3% of all mesolarvae captured. One metalarva was captured in the lower portion of the study area (RM 243.0) during June (Figure 2.27). Metalarval Razorback Sucker has not been taken since the 2014 survey and juvenile specimens were not encountered during the 2017 survey.

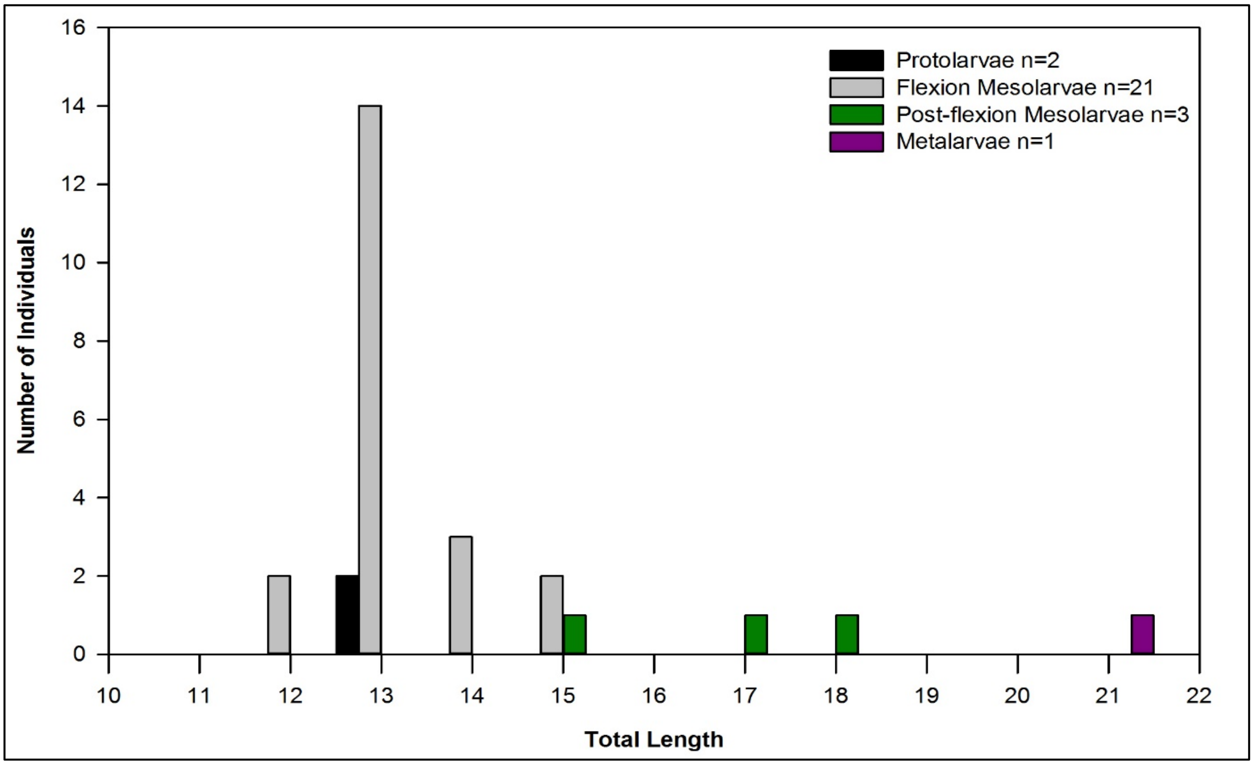


Figure 2.26. **Distribution of total lengths (TL) of larval Razorback Sucker captured during the 2017 larval fish survey.**

Length-based (TL) back-calculated hatching dates encompassed 12-weeks from February 23 to May 18, 2017. Three clusters of hatch dates are evident from the back-calculations; late February, late March, and early to mid-May (Figure 2.28). The upstream most captures of larval Razorback Sucker in 2017 were downstream of Havasu Creek. While mean daily water temperatures in the Colorado River (just upstream of Diamond Creek) during the hatching period do not exceed 16°C, mean daily water temperatures in Havasu Creek are >16ºC at the initiation

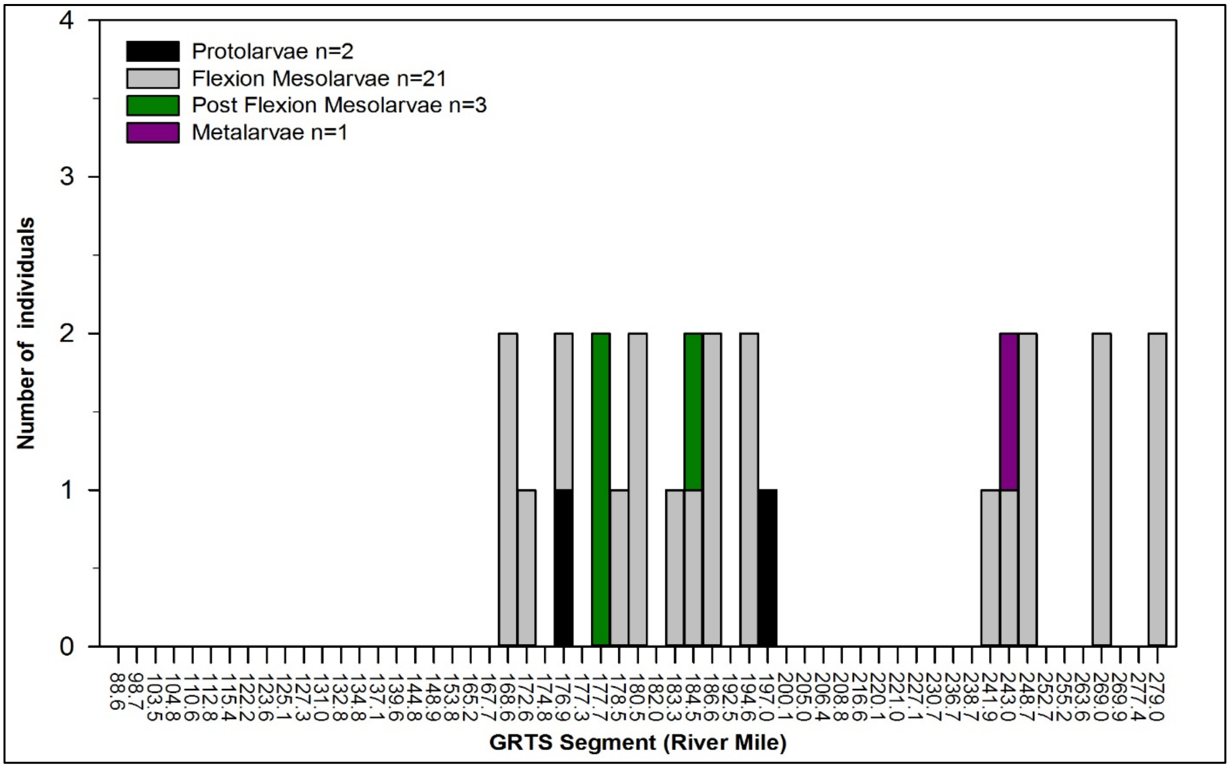


Figure 2.27. **Spatial and ontogenetic stage distribution of larval Razorback Sucker captured during the 2017 larval fish survey.**

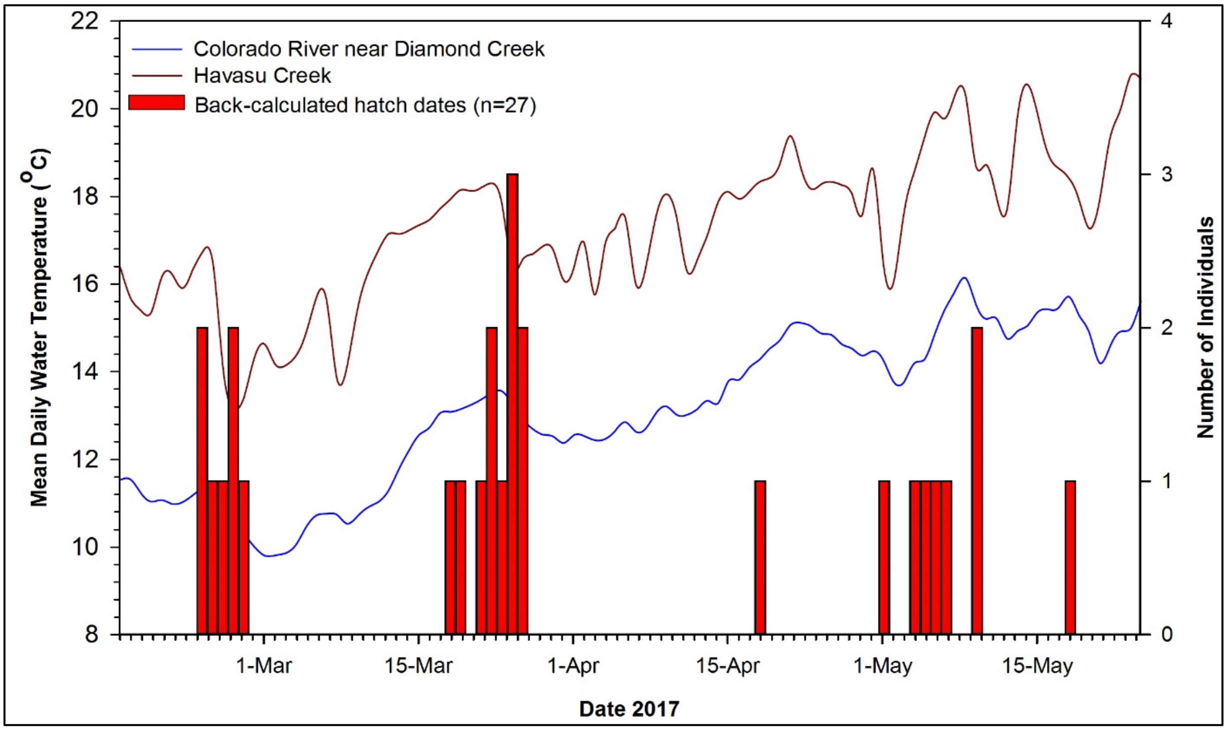


Figure 2.28. **Water temperature of Havasu Creek and the Colorado River upstream of Diamond Creek (USGS gage 09404200) displayed with the back-calculated hatching dates of Razorback Sucker based on 2017 larval fish standard lengths (SL).**

of the hatching period. During the putative hatching of Razorback Sucker, mean daily water temperatures in Havasu Creek were 3.4°C warmer than the Colorado River (Figure 2.28).

Humpback Chub

Age-0 Humpback Chub (n=129) were captured in four of the six monthly 2017 surveys (May–August) and in 57.1% of the GRTS segments in 2017 (Appendix E.3–6). Four GRTS segments produced Humpback Chub during three monthly surveys (Figure 2.29) while nine GRTS segments produced Humpback Chub larvae during two monthly surveys. There was not a significant difference among monthly catch rate of age-0 Humpback Chub (ANOVA, $F_{3,891}$=0.4613, P=0.7094).

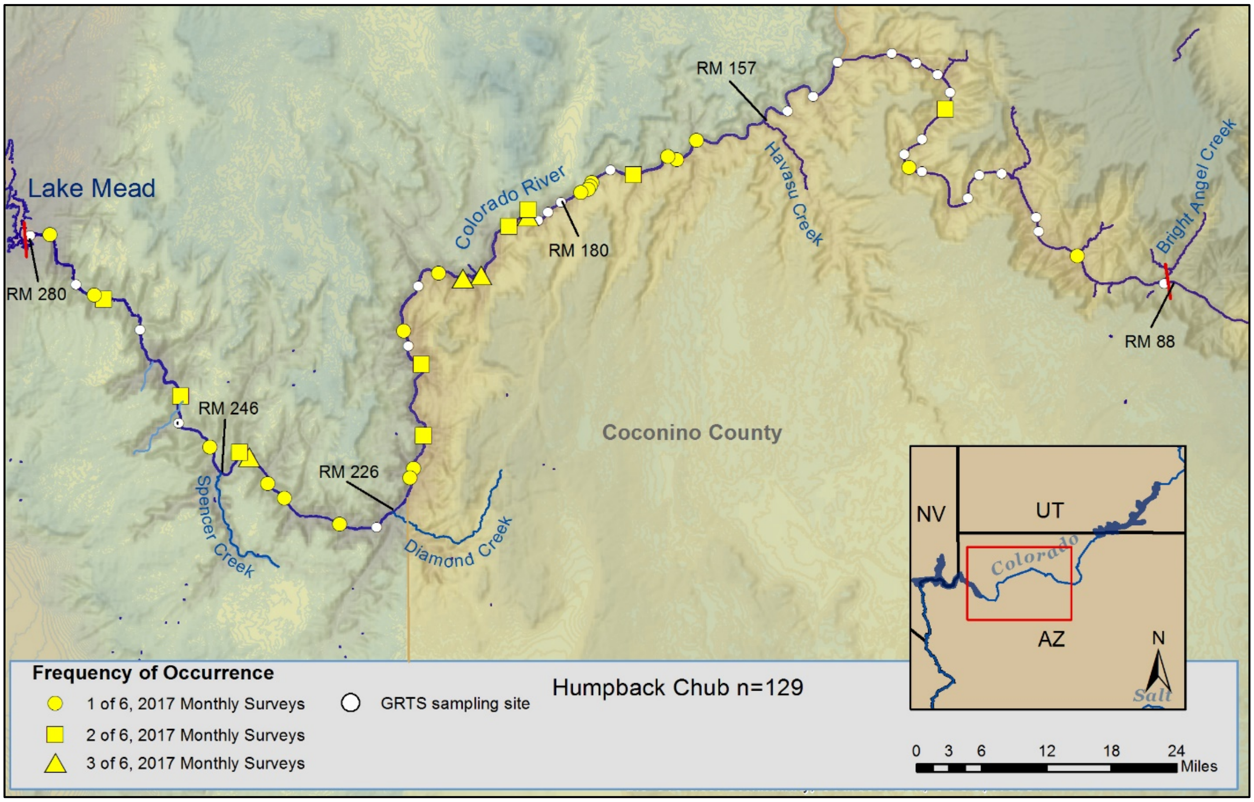


Figure 2.29. Frequency of occurrence of larval Humpback Chub at generalized random tessellation stratified (GRTS) segments during the 2017 larval fish survey.

Larval Humpback Chub were first documented during the May survey and were distributed from RM 172.6–255.2. All May specimens were mesolarvae, the majority of which (81.8%) were flexion mesolarvae. The June survey produced 45 age-0 Humpback Chub between RM 131.0 and 243.0. The upstream most capture of this species was almost 40 river miles further than during the May survey. Sampling efforts in a large backwater at RM 243.0 produced 53.3% of the total June larval Humpback Chub catch (Figure 2.30). Humpback Chub exhibited a broader range of development in June than during previous months, ranging from mesolarvae to juveniles.

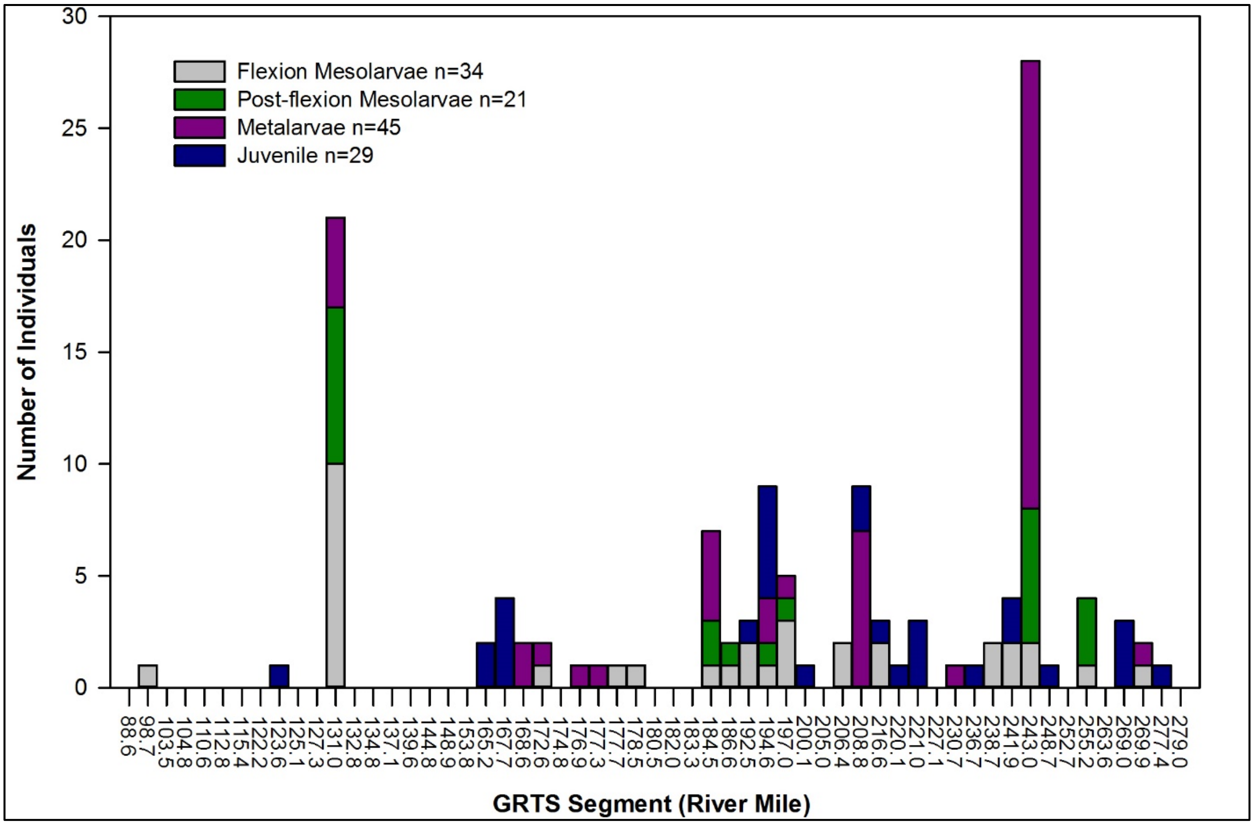


Figure 2.30. Spatial and ontogenetic stage distribution of larval Humpback Chub captured during the 2017 larval fish survey.

Humpback Chub (n=31) were distributed over a larger river reach (RM 98.7–269.9) during July than previous 2017 survey months. Flexion mesolarval to juvenile specimens were taken during July, and juveniles (n=3) were collected in three GRTS segments (RM 208.0–269.0). There were nearly equal proportions of mesolarvae (48.3%; n=15) to metalarvae (41.9%; n=13) in the July survey captures. Metalarval (n=6; 19.3%) and juvenile (n=25; 80.6%) were the only Humpback Chub developmental stages taken in August. Humpback Chub were distributed from RM 123.6 to RM 277.4. Age-0 Humpback Chub captured in 2017 ranged in size from 9.7 to 41 mm TL (Figure 2.31). As in 2016, protolarval Humpback Chub were not collected. Back-calculated hatch dates for Humpback Chub in 2017 ranged from May 4 to July 28, 2017. The distribution of hatch dates suggests that two or three peaks in hatching occurred, most from early May to June (Figure 2.32). This pattern is also supported by the spatiotemporal distributions of larval developmental phases (Figure 2.30).

Habitat

Ten mesohabitat types were sampled during the 2017 larval fish survey (Figure 2.33). Habitats sampled in 2017 were present in relatively similar proportions as in 2016 (Table 2.7). Slackwaters (37.0%), sandshoals (23.2%), and pools (19.2%) comprised the majority (79.4%) of 2017 habitats. Razorback Suckers were captured in six low-velocity habitat types. Most Razorback Sucker captures (77.7%) occurred in embayments (29.6%; n=8), pools (25.9%; n=7), and backwaters (22.2%, n=6). Mean CPUE for Razorback Sucker varied significantly among

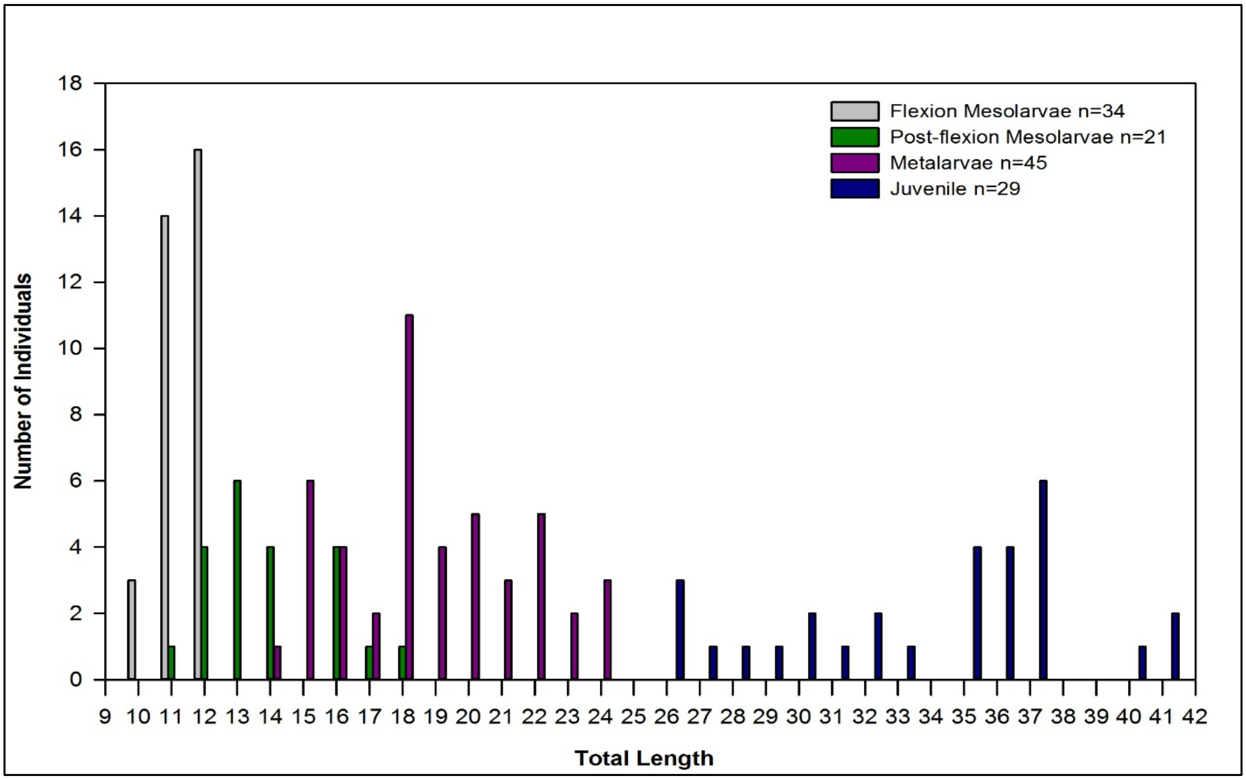


Figure 2.31. Distribution of total lengths (TL) of larval Humpback Chub captured during the 2017 larval fish survey.

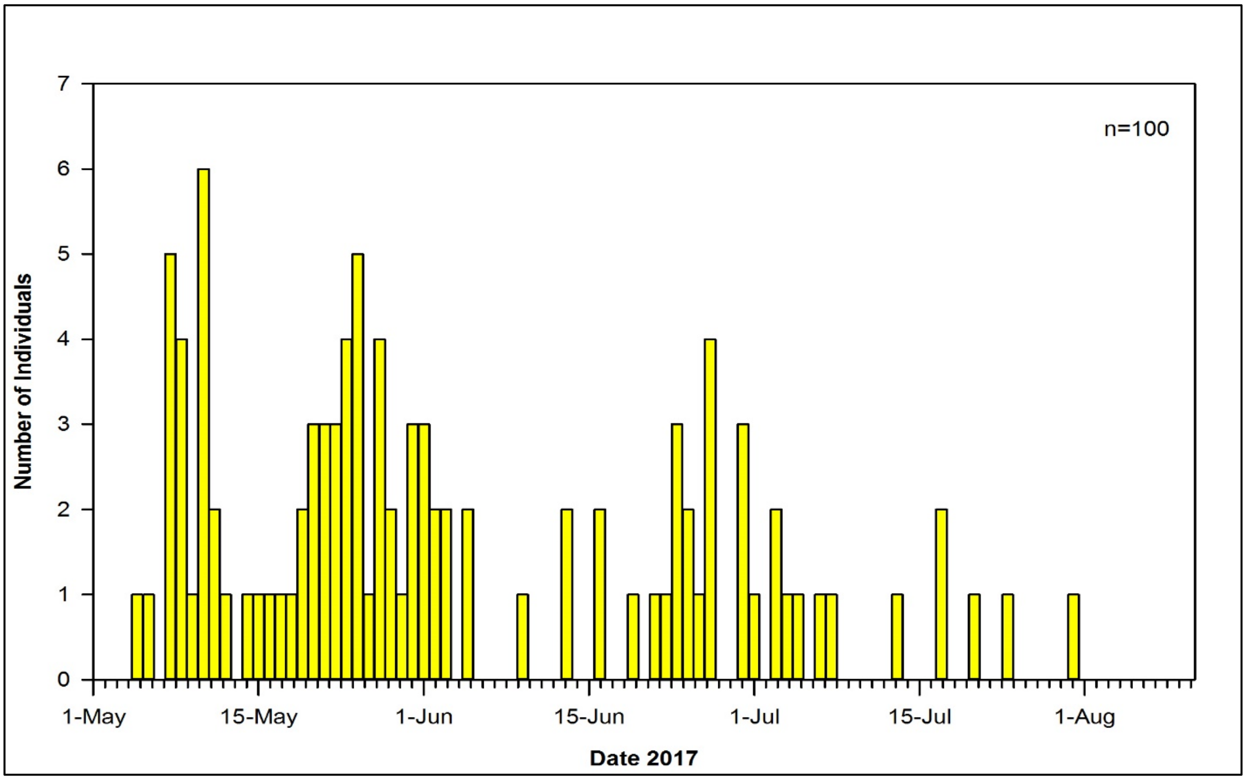


Figure 2.32. Back-calculated hatch dates of Humpback Chub based on 2017 larval fish standard lengths (SL).

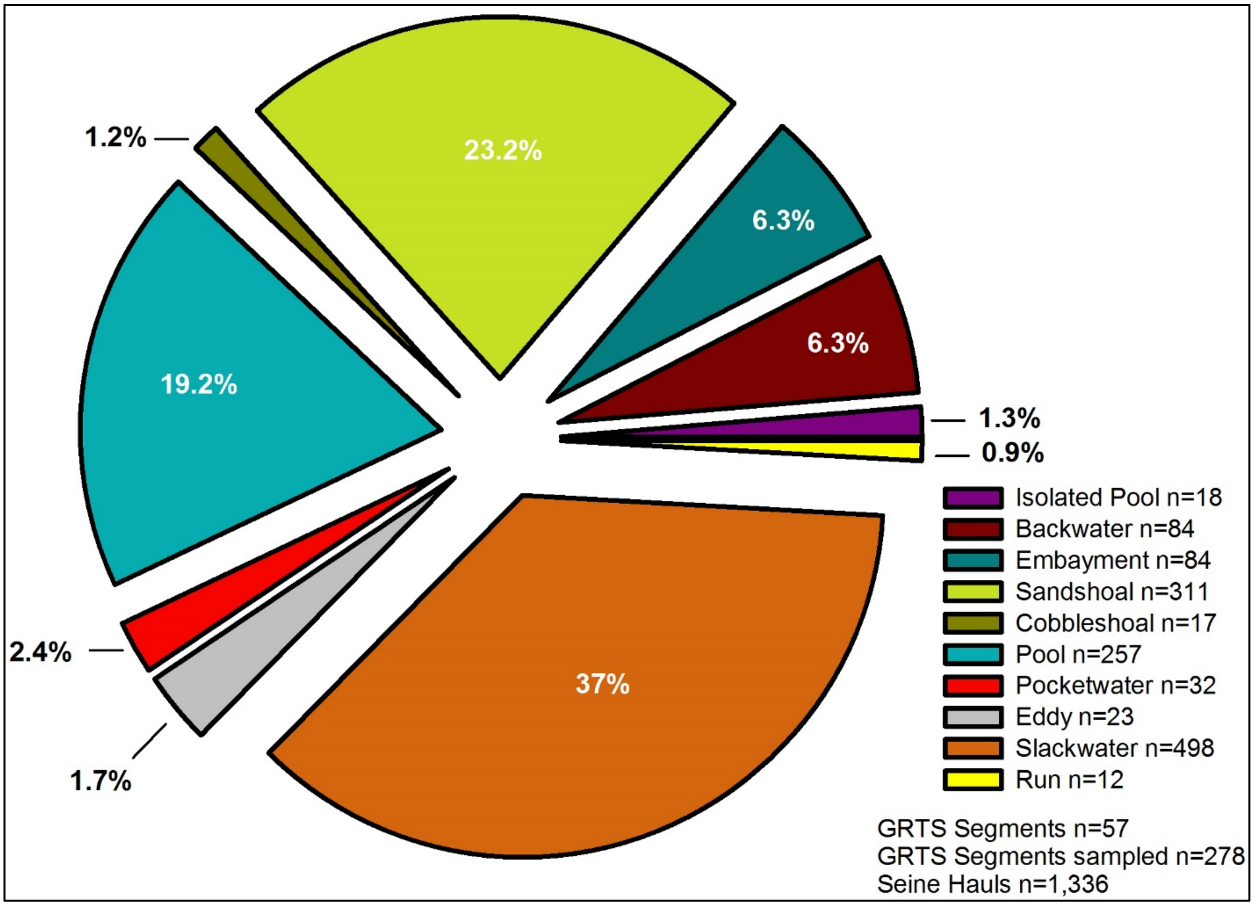


Figure 2.33. Frequency distribution of habitats sampled at generalized random tessellation stratified (GRTS) segments during the 2017 larval fish survey.

Table 2.7. Habitats sampled (percent) from monthly 2016 and 2017 larval fish surveys.

HABITAT	HABITAT SAMPLED 2016	HABITAT SAMPLED 2017	PERCENT CHANGE 2016–2017
Isolated Pool	1.46 %	1.35 %	0.11
Backwater	6.11 %	6.29 %	0.17
Embayment	4.01 %	6.29 %	2.27
Sandshoal	20.99 %	23.28 %	2.29
Cobbleshoal	1.09 %	1.27 %	0.18
Pool	16.88 %	19.24 %	2.36
Pocketwater	4.29 %	2.40 %	1.89
Slackwater	40.33 %	37.28 %	3.05
Eddy	3.65 %	1.70 %	1.93
Run	1.19 %	0.90 %	0.29

habitats (ANOVA, $F_{9,878}$=4.9863, P=0.0001) with the highest catch rates occurring in isolated pools, embayments, and backwaters. While catch rate of Razorback Sucker in these habitats was significantly different (higher) than all other habitat types, catch rates in these habitats were not different from each other (ANOVA, $F_{9,878}$=4.9863, P=0.0001). Flannelmouth Sucker, Bluehead Sucker, and Speckled Dace were captured in every habitat type sampled (Figure 2.34).

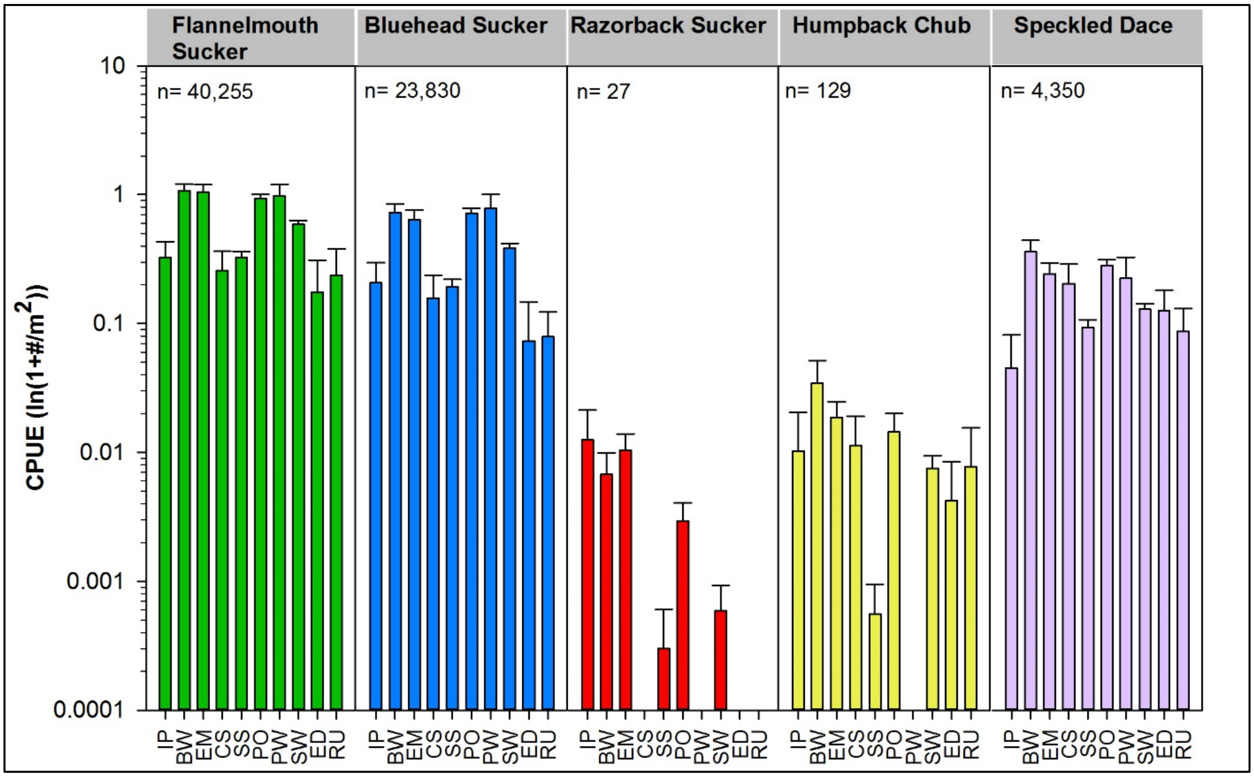


Figure 2.34. **Mean CPUE by species and habitat type during the 2017 larval fish survey. The y-axis scale is $\log_{10}$ and error bars are ± 1 SE. See Table 2.2 for habitat abbreviation definitions.**

Humpback Chub were collected in nearly every (90%) habitat type sampled. Most Humpback Chub captures (81.4%) occurred in slackwaters (30.2%), backwaters (29.5%), and pools (21.7%). Mean catch rates for Humpback Chub were highest in backwater and embayment habitats, but backwater catch rates were only significantly different from slackwater and sandshoal catch rates (ANOVA, $F_{9,885}$=3.1718, P=0.0009).

Ontogenetic Phase Distributions

Native fishes documented in the 2017 larval fish survey, with the exception of Razorback Sucker, were represented by specimens from the earliest larval ontogenetic phases through transition to early juvenile. In assessing the temporal distribution of larval catostomids, it is evident that initial capture of larvae progresses from down-to-upstream. Catostomid larvae were only taken in the lower 111 river miles (RM 168.8–280.0) during the March survey. In April, captures of Flannelmouth Sucker and Bluehead Sucker larvae expanded an additional 42 river miles upstream. By May, larval catostomids increased an additional 38 river miles upstream and encompassed the entire study area (Figures 2.35 and 2.36). A similar temporal pattern of initial larval fish distribution was observed in native cyprinids with spawning occurring in late April and/or May in the lowermost 111 river miles (RM 168.8–280.0). The following month, captures expanded upstream to include approximately 150 river miles for Humpback Chub and nearly the entire 191-river mile study area for Speckled Dace. By July, Humpback Chub were captured throughout the 191-river mile study area (Figure 2.23).

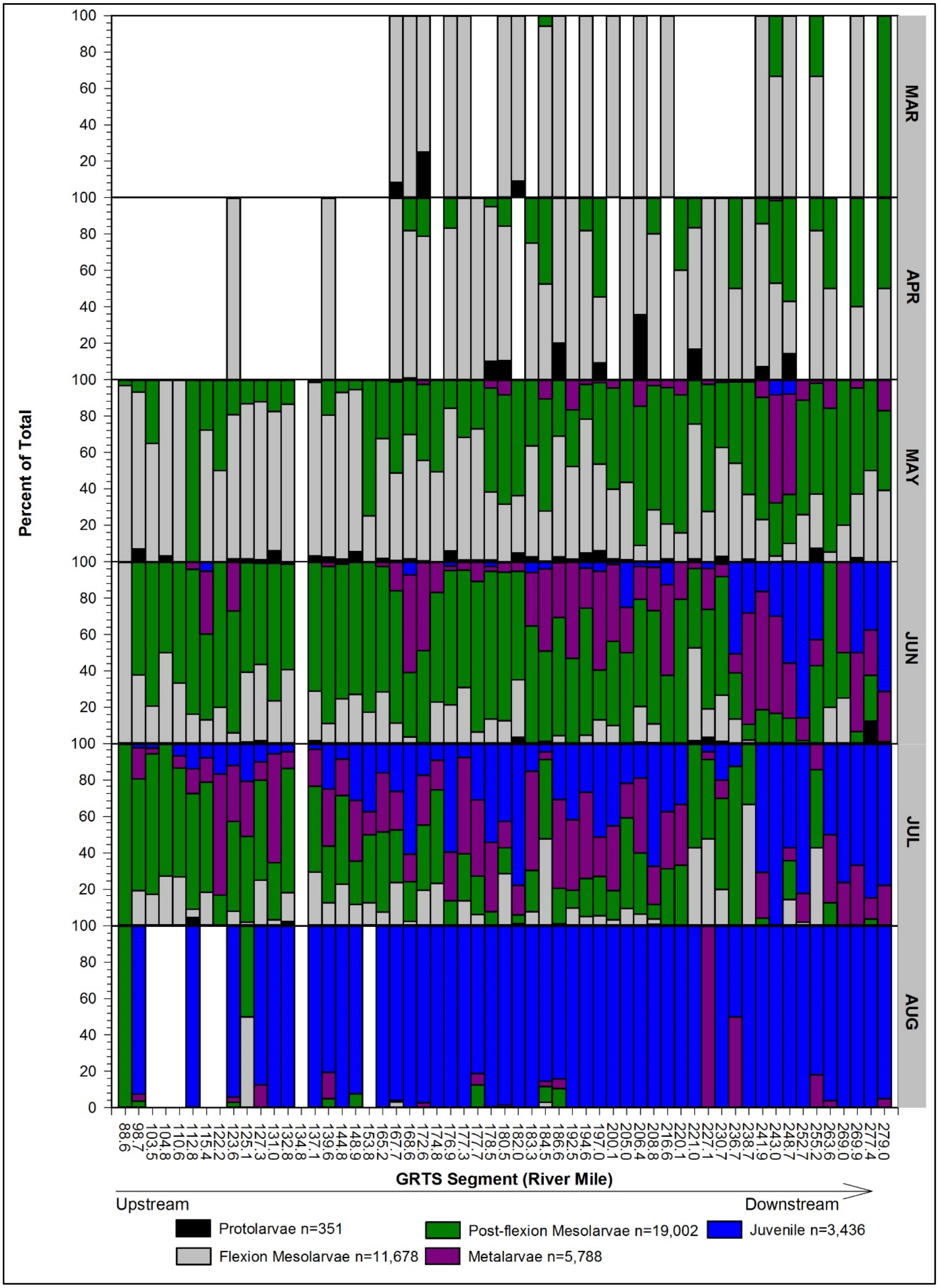


Figure 2.35. **Longitudinal distribution of ontogenetic phases of age-0 Flannelmouth Sucker by 2017 sampling trip (month) and generalized random tessellation stratified (GRTS) segment.**

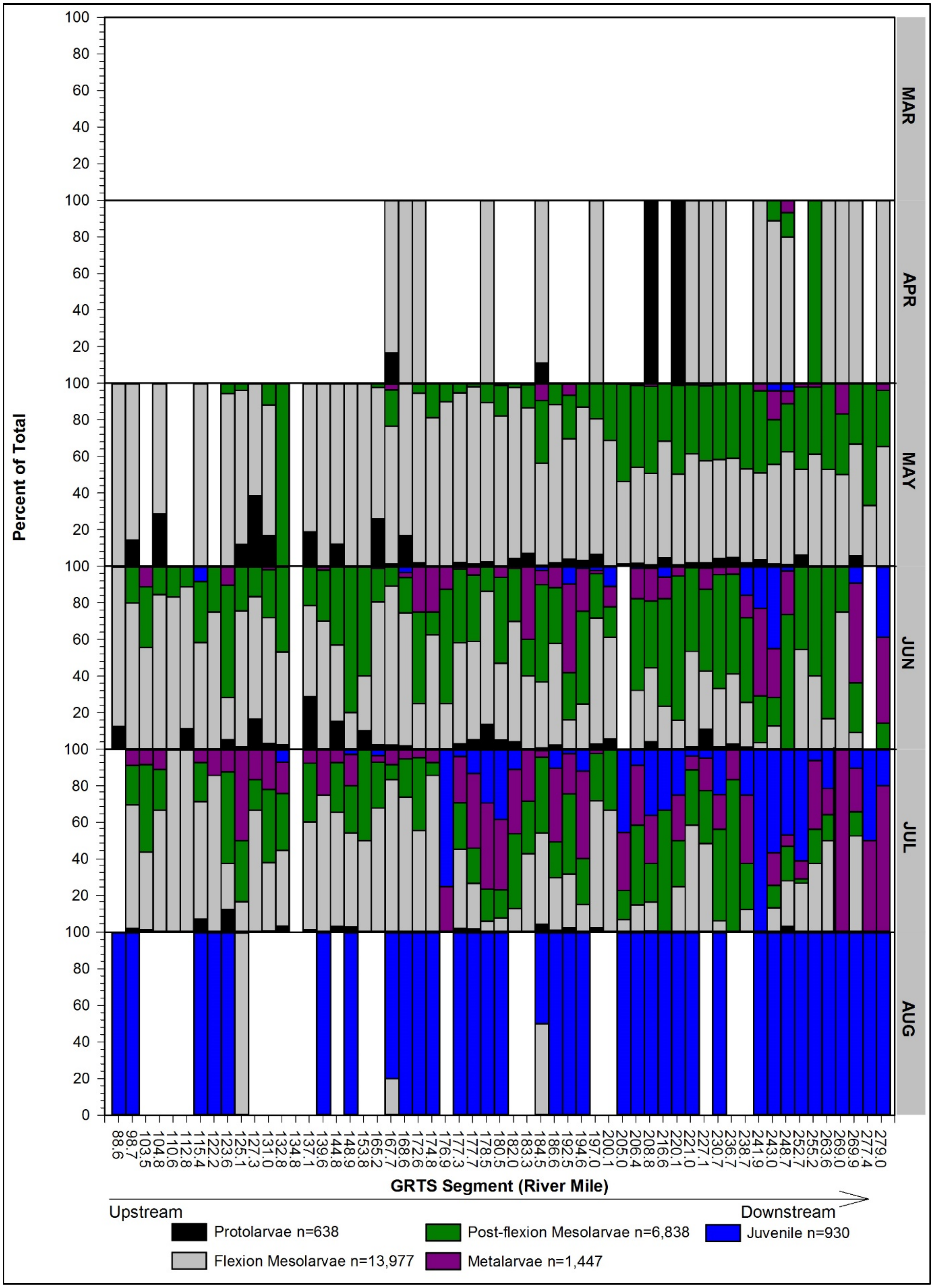


Figure 2.36. Longitudinal distribution of ontogenetic phases of age-0 Bluehead Sucker by 2017 sampling trip (month) and generalized random tessellation stratified (GRTS) segment.

Distribution of protolarvae, the earliest developmental stage, infers spatial patterns of spawning over time. Larvae spend a short time as protolarvae, and much of that time is spent in the interstitial zones of the spawning bars. Captured protolarvae are likely in near spawning areas. For the two common sucker species, protolarvae were initially observed in downstream reaches and then documented higher in the system during progressive sampling months, indicating the upstream expansion of spawning (Figures 2.35 and 2.36). The duration that protolarvae were captured throughout the study period also relates to the spawning period of the adults.

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 (older fish). Conversely, upstream reaches of the study area had higher proportions of less developed larvae (younger fish). These patterns likely relate to warmer water temperatures in downstream reaches that foster faster development of larval fishes. This pattern, apparent in both Flannelmouth Sucker and Bluehead Sucker (Figures 2.35 and 2.36), might be indicative of drift (active or passive) of age-0 fish. The larval catostomid pattern of increased proportion of more developed fish in downstream reaches is not as apparent with larval Humpback Chub. However, there is a proportional increase in the catch of older ontogenetic stages temporally (May–August).

The dearth of late phase larval and absence of recently transformed juvenile Razorback Suckers are noteworthy (Figure 2.37). Four metalarval Razorback Suckers have been collected during the tenure of this project (2014 n=3, 2017 n=1). Humpback Chub, which has comparable abundance to Razorback Sucker, displayed the full range of larval ontogenetic phases, including early juvenile, during all survey years (Figure 2.38). The lack of more developed larvae and early juvenile Razorback Suckers may relate to their truncated larval distribution, compared with the other native species.

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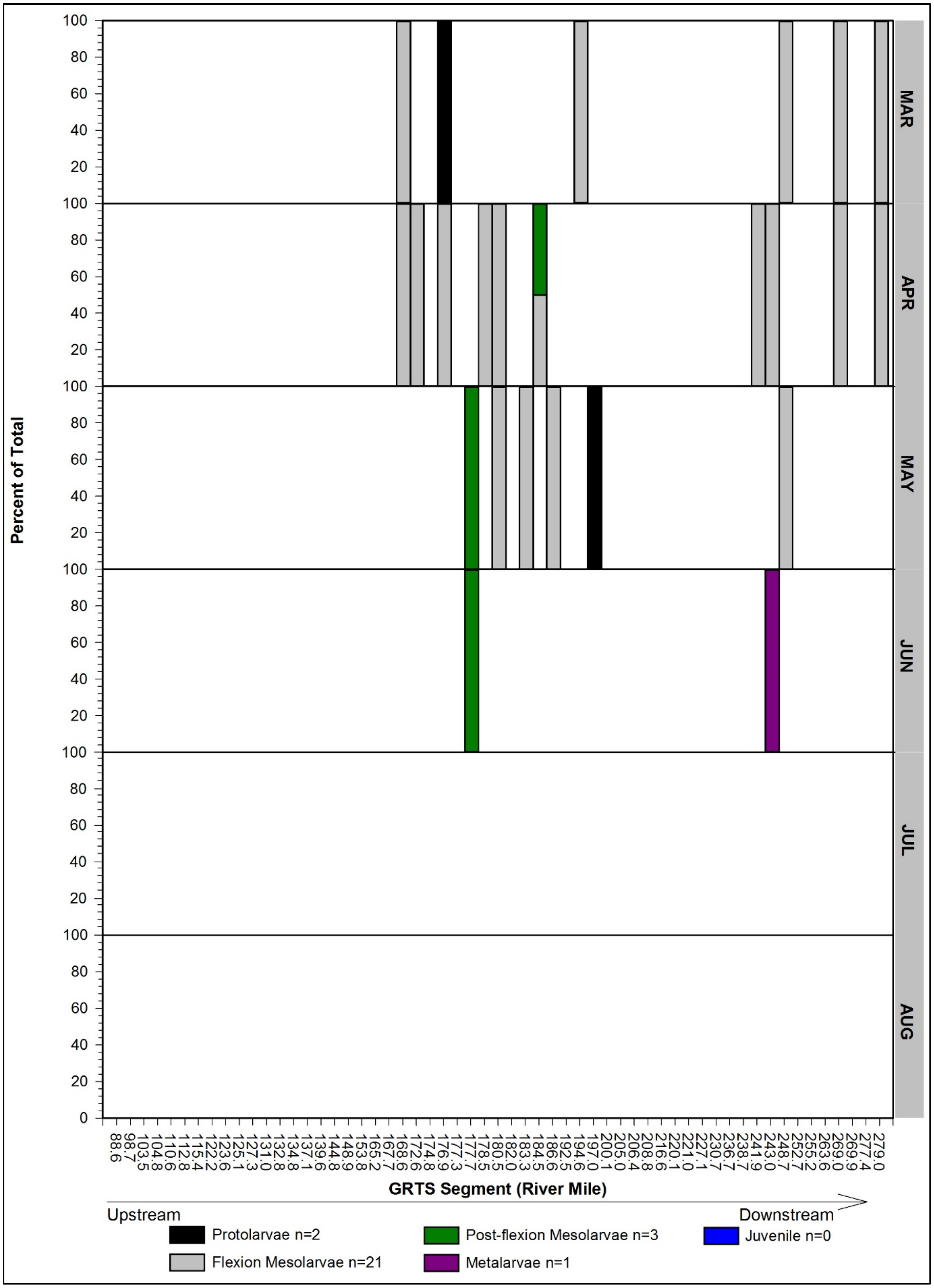

Figure 2.37. Longitudinal distribution of ontogenetic phases of age-0 Razorback Sucker by 2017 sampling trip (month) and generalized random tessellation stratified (GRTS) segment.

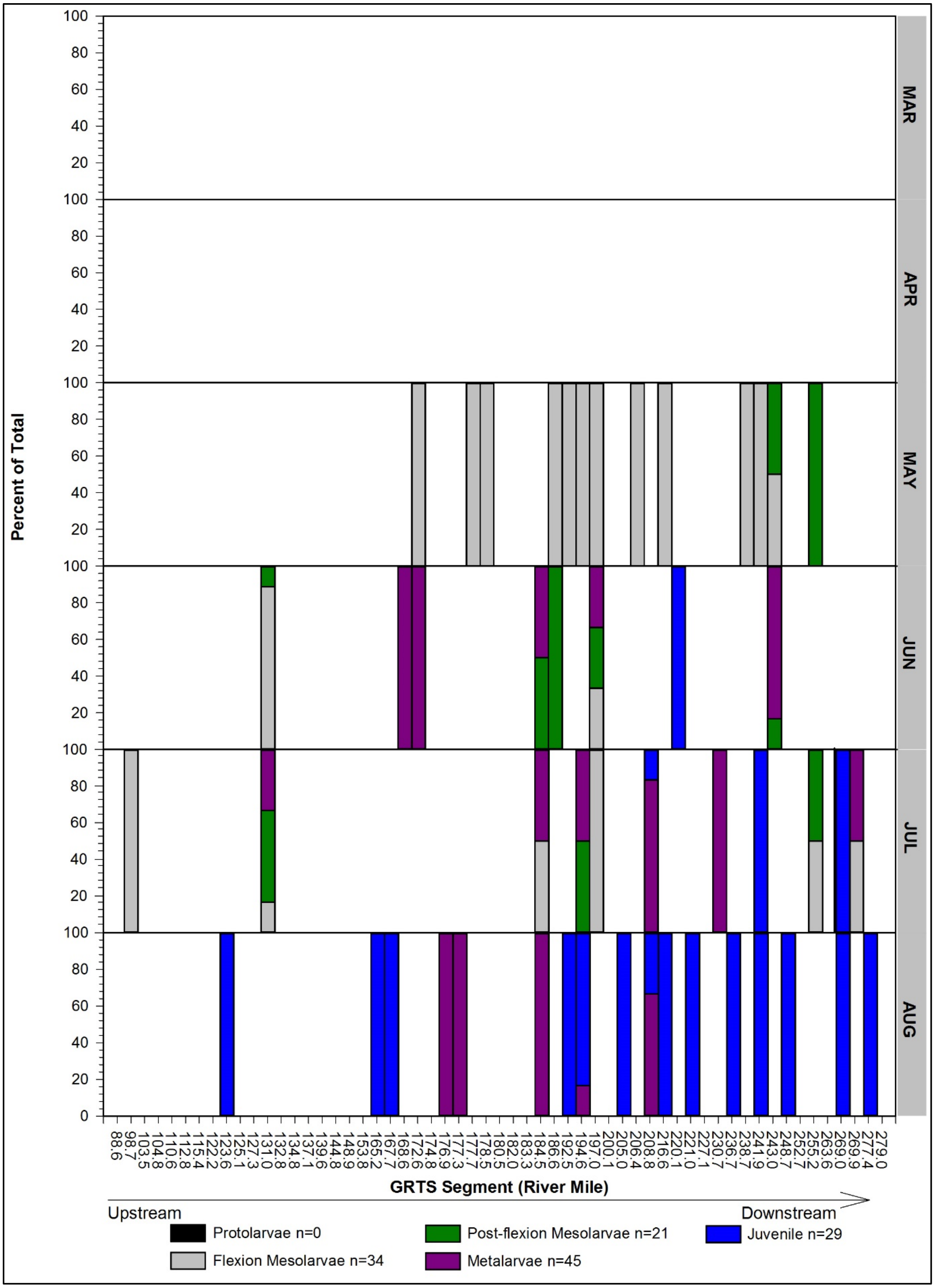

Figure 2.38. **Longitudinal distribution of ontogenetic phases of age–0 Humpback Chub by 2017 sampling trip (month) and generalized random tessellation stratified (GRTS) segment.**

DISCUSSION

Small-bodied Fish Community Sampling

Whether assessing overall or relative abundance, native fishes dominated the small-bodied fish catch throughout the Grand Canyon regardless of differing catch rates among sampling trips or sampling sites. The sampling design allowed us to track monthly recruitment as age-0 suckers began appearing in early samples and became identifiable as the season progressed. Maintaining consistent effort and sampling all segments during subsequent sampling trips will be important in tracking temporal and spatial trends over time. A lack of Razorback Sucker captures later in the sampling year in the Grand Canyon indicates that there is a very low probability that unidentifiable age-0 suckers are Razorback Suckers; they are most likely Flannelmouth or Bluehead Suckers.

Native fish-length frequency data suggest that if juvenile Razorback Suckers are present in the Grand Canyon, sampling methods should allow multiple size and age classes to be captured when efforts are focused on small, young fish. This also assumes that appropriate young Razorback Sucker habitats are being sampled under the GRTS sampling design. The capture of larval Razorback Suckers is promising; it shows that conditions are favorable for spawning within the Grand Canyon and there is potential for in-river recruitment. Little suggests that Razorback Suckers are not or cannot recruit within the Grand Canyon, or perhaps the CRI, as previous data confirm juvenile fish presence at the CRI (Kegerries and Albrecht 2013b).

The capture of Humpback Chub is a fairly regular occurrence during small-bodied fish community sampling within the Grand Canyon. In fact, the abundance and longitudinal continuity of captures was much higher in 2017 than in all other years sampled. Young Humpback Chub were widely distributed, relatively common, and appeared to be using nursery and rearing habitats throughout the study area and within the full pool footprint of Lake Mead. Young Humpback Chub varied in size both within and between trips, which likely indicates variable hatching times and drift rates, different growth rates of captured individuals, and some level of mainstem recruitment. The collected data could be useful to those researching, managing, and recovering this endangered species.

Habitat data will become more valuable as juvenile or adult Razorback Suckers are captured in the 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 endangered 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, at this juncture it is difficult to identify which habits and characteristics are most important. Therefore, continual, consistent habitat data collection is critical to documenting study area habitat changes and identifying minute differences that may influence recruitment. First and foremost, it will be critical to identify where these Razorback Suckers are spawning to try and determine whether this is a relatively new phenomenon, and potentially a mechanism of change, that has allowed spawning to occur.

The comparisons of species' composition through time have provided insight into the community shift of native and nonnative fishes within the Grand Canyon over the last three decades. More recent fish surveys, which included portions of the upper Grand Canyon, also indicated a community numerically 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 the native fish community is currently dominating the catch below Diamond Creek when Red Shiner, Common Carp, and Channel Catfish were the dominant species through the mid-2000s. During that time, the Colorado River in the lower Grand Canyon 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. This change lends hope for Razorback Sucker reproduction, recruitment, and ultimately helping to achieve recovery goals.

Identification of the mechanism(s) responsible for changes in the Grand Canyon fish community is 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 all impact the fish community. Since the closing of Glen Canyon Dam, the Colorado River downstream has experienced cooler summer flows that could hinder native fish reproduction, growth, and survival. Flow regulation has reduced annual peak flows, raised minimum flows, and increased the daily flow fluctuation through hydropower demand (Topping et al. 2003; Voichick and Wright 2007); all of which have the potential to be detrimental to the Grand Canyon fish community, especially early life-stages. Mainstem water temperatures that once ranged from 0 to 30°C were confined to 7.2–12.2°C when Lake Powell was at full pool. During historic low lake elevations (2005) the annual maximum daily mean release temperature increased to 16.1°C (Ross and Vernieu 2013). Dam-released water also reduced turbidity within the river, which likely favored nonnative sight predators like trout over native fishes that 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 the Grand Canyon. Recent data suggest that nonnative fish abundance is declining while native fish abundance is increasing. In fact, the data presented from this study since 2014 have shown that multiple year 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 doesn't fully explain the more recent decline in nonnative fish abundance. Most of the nonnative fish species found within the Grand Canyon are warm water species. However, many of these species prefer more lentic habitats. As Lake Mead water elevation continues to recede, a major source of nonnative fish species is moved further downstream from the Grand Canyon. This change in proximity alone could hinder nonnative fish abundance within the Grand Canyon. The 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. Changes within habitats throughout the mainstem river are perhaps less understood, but they could be favoring native fish species. If the elevations of Lakes Powell and Mead continue to recede, water temperatures within the Grand Canyon will likely continue to warm. Although warmer water temperatures could benefit native fish species, warm water nonnative species could also benefit. It is likely that flows, water temperatures, and habitat conditions are currently favoring native fishes while disadvantaging nonnative fishes. 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

There have been several adaptive changes to the timing and spatial extent of the larval Razorback Sucker survey project in Grand Canyon since its inception in 2014. These changes have been initiated after review of the data gathered in the field. The addition of an earlier sampling trip (March) beginning in 2015 was an effort to better identify the initiation of catostomid spawning. That change has been instrumental in understanding spawning periodicity of Razorback Sucker and Flannelmouth Sucker.

A second modification to the project was the 2016 expansion of study area. In 2015, larval Razorback Suckers were documented at the uppermost site of the study area (RM 179.0), thereby documenting spawning by adult Razorback Sucker upstream of that site. To identify the upstream extent of spawning Razorback Sucker, the study area was expanded an additional 91 river miles. In 2016, larval Razorback Suckers were not collected upstream of RM 168.6. The 2017 larval fish surveys showed a nearly identical pattern of initial larval fish captures within the study area and subsequent expansion upstream by the common catostomids, which reinforced the 2016 larval dispersion patterns.

The 2016 larval fish survey lead to the hypothesis that, due to the proximity of initial larval sucker captures in March and April, Havasu Creek was important to initial spawning activities of Grand Canyon catostomids. Spawning is inferred by the presence of early larval developmental stages downstream of Havasu Creek and the upstream absence of those specimens. Results from the 2017 larval fish survey mirrored the 2016 distribution and spawning periodicity of catostomids. Larval Razorback Sucker was not documented upstream of Havasu Creek in 2016 or 2017, further supporting the hypothesis that Havasu Creek may be a source of spawning for this species. Havasu Creek has warmer mean daily water temperatures compared with the Colorado River, particularly during the initial spawning months (February–April). The warm water in Havasu Creek is generally consistent with water temperatures of spawning catostomids (Bozek et al 1990; Tyus and Carp 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 (Bozek et al. 1990).

In previous years, spawning dates of Razorback Sucker were back-calculated using larval Razorback Sucker TL and mainstem Colorado River water temperatures. Given the hypothesized importance of Havasu Creek to Razorback Sucker spawning, hatching dates were calculated, instead of spawning dates, for the 2017 analysis. Length-based, back-calculated hatching dates do not incorporate water temperature and are a conservative estimate.

Development of age-0 fish through the larval period and into the juvenile phase is essential for recruitment. There are a multitude of factors that affect mortality of larval fish including hatching success, starvation, predation, and competition. Transition into the juvenile phase has been documented for Flannelmouth Sucker, Bluehead Sucker, Speckled Dace, and Humpback

Chub. Juvenile Razorback Suckers have not been taken in either small-bodied monitoring or larval fish monitoring above Pearce Ferry in the Grand Canyon since the inception of this project; however, they have been captured at the CRI and within the Colorado River proper below Pearce Ferry (see Chapter 1 and Kegerries et al. 2016a). It is intriguing that while Humpback Chub and Razorback Sucker have similar catch rates among years, late-phase larvae and juvenile Humpback Chub are collected. Important differences between spawning periodicity of Razorback Sucker and Humpback Chub are timing (earlier spawning for Razorback Sucker) and spatial extent of spawning. Mean daily water temperatures in the Colorado River were cooler during March and April when larval Razorback Suckers were present. While Razorback Sucker larvae have not been documented upstream of RM 168.6, Humpback Chub larvae have been documented near the top of the study area (RM 88.6) and known reproducing populations exist further upstream. 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, which increases the likelihood for recruitment to the adult population.

Retention of larval fishes within a river system is dependent not only on their distribution but also on the drifting behavior of early ontogenetic phases and availability of larval fish nursery habitat. A review of 2016–2017 larval ontogenetic stage distribution presents a downstream temporal and longitudinal pattern of increasingly developed larvae. These results support the hypothesis that the increased water temperatures of the Grand Canyon into downstream Lake Mead support recruitment of larval native Colorado River fishes.

2017–2018 GRAND CANYON SMALL-BODIED AND LARVAL FISH COMMUNITY STUDY RECOMMENDATIONS

The results of the 2017 small-bodied and larval fish community sampling have provided valuable information regarding the early life stages of the native fish fauna in the Grand Canyon. The 2017 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 endangered 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 was confirmed, and additional data were collected on the native fish community throughout the Grand Canyon. This includes information pertaining to timing and distribution of larval fishes within the study area, particularly Razorback Sucker and Humpback Chub spawning and recruitment on a temporal and longitudinal scale. It is important to conduct sampling consistent with methods described in this report, and it is particularly important to follow the GRTS segment sampling protocols that have been used. This will facilitate better comparisons within and between years as the study continues, allow for direct comparisons, and facilitate learning. It is recommended that collaborative planning and logistics be initiated this winter to begin year five of this project.

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 2018 without further adjustments, as was recommended by the science panel (Reclamation 2017) to better assess differences in catch rates, habitat occupancy, and abiotic factors such as discharge and temperature.

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

   Similarly, longitudinal differences in larval and small-bodied catches could be assessed over time and related to dam operations. It would be particularly important to assess the larval and small-bodied fish community in relation to high-flow events in the spring and fall, equalization flows, and proposed trout management flows. The NPS also has shown interest 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.

3. 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 Museum of Southwestern Biology. Because these larval fish have been persevered 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 the Grand Canyon. A logical first step might be to conduct a literature review of all available information regarding food resources that would focus on the Grand Canyon, but the study might also be broadened to include other portions of the Colorado River basin.

4. 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 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.

5. Develop a study to collect samples specifically for genetic evaluation (genetic evaluation for hybridization or genetic N_e evaluation for population size). This recommendation was discussed by the science panel (Reclamation 2017), and proposals are currently being considered by Reclamation to investigate hybridization between Flannelmouth Sucker and Razorback Sucker in the Grand Canyon. If pursued, this project would require a 1-year shift from current larval fish preservation protocol (formalin) of preservation in 95% ethanol. The current charge of this project is to identify larval fish based on

morphomeristic characters, and the use of formalin as a preservative is “the gold standard” for that technique. While the quality of the specimens would be reduced, temporarily changing preservatives would allow for genetic analysis of larvae as well 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.

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

INTRODUCTION

This chapter presents telemetry results for the eighth study year at the CRI and the fourth study year in the 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 2016 through June 2017. Telemetry data collected from the Grand Canyon are reported from October 2016 through September 2017.

Sonic-telemetry data collected during Lake Mead Razorback Sucker studies have provided valuable information on spawning, movement patterns, and shifts in spawning-sites in varying habitats. These data have also demonstrated that tracking sonic-tagged Razorback Sucker preceding spawning activity can be a highly effective method for locating new spawning areas and maintaining effective monitoring. Monitoring sonic-tagged fish can increase the efficiency of field efforts and provide substantial data related to Razorback Sucker habitat use.

Because movement to and from the Colorado River proper was previously documented (Albrecht et al. 2010a; Kegerries and Albrecht 2011, 2013a, 2013b, 2014a; Kegerries et al. 2015a), this chapter combines sonic-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 2017 CRI study activities occurred within Gregg Basin of Lake Mead and the Colorado River upstream to Pearce Ferry Rapid in the Grand Canyon (Figure 3.1). Sonic-telemetry efforts within the Grand Canyon encompassed the Colorado River from Pearce Ferry Rapid upstream to RM 97.5 (just below Boucher Rapid) (Figure 3.2).

METHODS

Sonic Tagging

No Razorback Suckers were surgically implanted with acoustic or radio tags during the 2016–2017 field season.

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. Fish searches 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

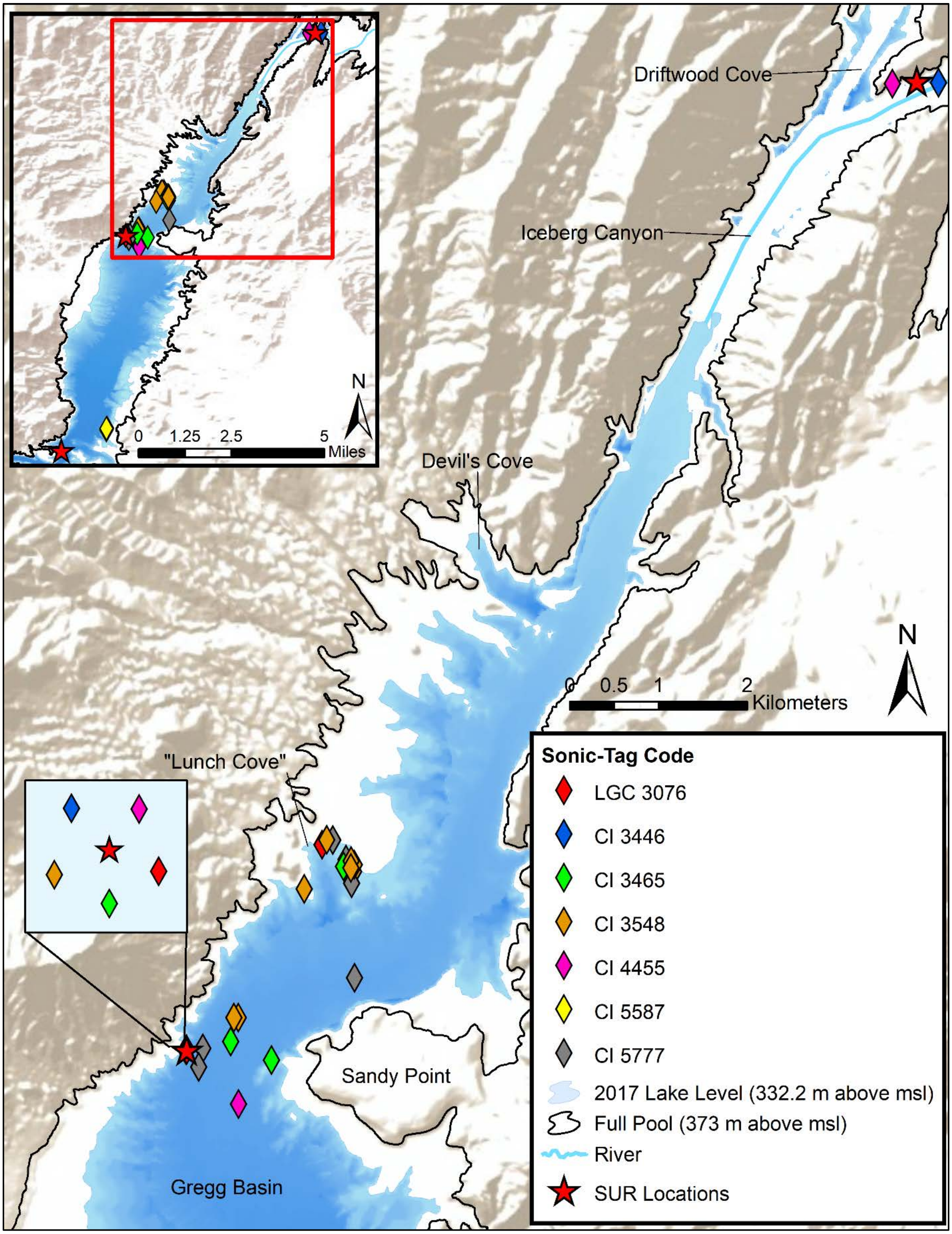

Figure 3.1. General Colorado River Inflow Area of Lake Mead (CRI) study area with the distribution of sonic-tagged fish contacts and submersible ultrasonic receiver (SUR) locations.

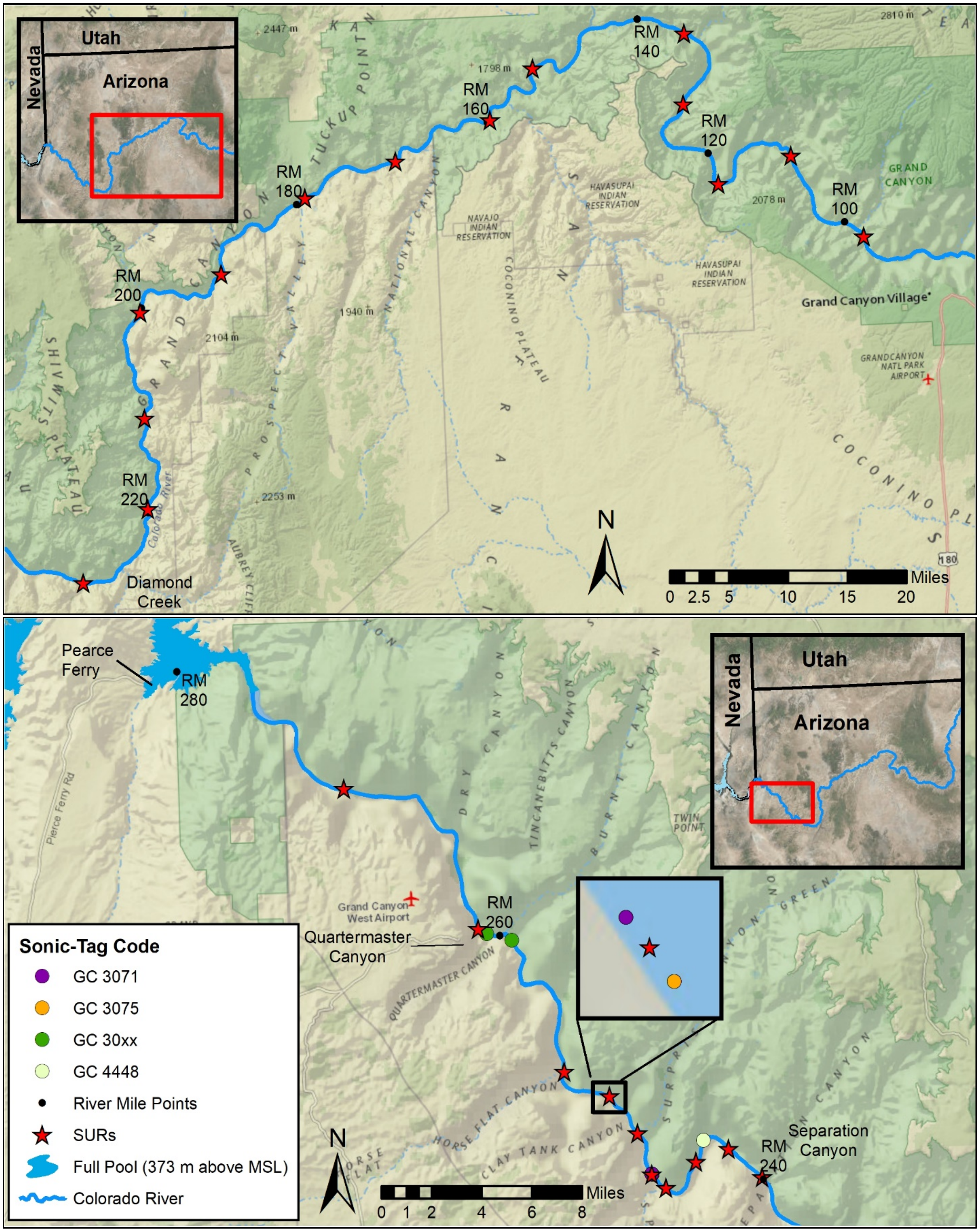

Figure 3.2. **General Grand Canyon study area with the distribution of sonic-tagged fish contacts and submersible ultrasonic receiver (SUR) locations. Top section is approximately RMs 80–230. Bottom section is approximately RMs 240–280.**

reduce or block reception. Also, sonic-telemetry signals are often reduced in shallow-, turbid-, and swift-water environments.

Active tracking consisted of listening underwater for coded sonic tags using a Sonotronics USR-08 ultrasonic receiver and DH4 directional or TH-2 omnidirectional hydrophone for acoustic signals. 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 the Grand Canyon was conducted opportunistically and when logistically feasible for each of the trips conducted to date. The primary active method for listening throughout the study area in 2017 was to use a Lotek SRX 400a and a Telonics RA-2AK VHF antenna to track Razorback Suckers implanted with dual radio/sonic tags within the Grand Canyon. 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. On five occasions the unique tag code could not be determined, but the radio-frequency (RF) signal was present. In those cases, the tag code was reported as 30xx in the results. Additional efforts using the Sonotronics USR-08 ultrasonic receiver and DH4 directional or TH-2 omnidirectional hydrophone were conducted near known areas frequented by Razorback Sucker.

Passive Sonic Telemetry and Data Collection

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

One SUR has remained near the CRI, although its placement has changed several times since 2010 to adjust for changing lake levels and optimize data collection as the location of the river/lake interface changed (Kegerries and Albrecht 2013a, 2013b; Albrecht et al. 2014; Kegerries et al. 2015a, 2016). For purposes of this report, the CRI SUR remained deployed off of the west shoreline across from and northwest of Sandy Point (Figure 3.1).

In 2015, SURs were distributed to encompass the Grand Canyon from RM 97.5 (below Boucher Rapid downstream to Pearce Ferry) to RM 280.0 (Figure 3.2). These SURs were deployed approximately 10 RMs apart, except between RM 240.0 (near Separation Canyon) and RM 250.6 (below Surprise Canyon) where SURs were approximately 5 RMs apart. This was done to ensure contact with fish that may be aggregating just below Spencer Creek, as they have in past years. The SURs within the Grand Canyon remained in the same locations in the 2015 through 2017 study years. In cooperation with NPS, and primarily to assess Brown Trout movement, two additional SURs were installed near the confluence of the Little Colorado River in June 2017, one above and one below. In August 2017, and in cooperation with the USFWS, five additional SURs were installed between RM 242 and 253 for upcoming Humpback Chub research (Figure 3.2). Additional SUR data were collected opportunistically in the Grand Canyon as a result of deploying an SUR from the boat while camping overnight. The deployment and retrieval times, along with location information, were recorded to cross-reference contact data.

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 lake/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 5 minutes of one another for a SUR record to be considered valid. Once data were validated, the resulting dataset was further scrutinized against active sonic-telemetry records. This was done to establish movement timelines of individual sonic-tagged fish and further solidify all positive SUR contacts.

RESULTS

Through collaborative research and monitoring efforts, 53 sonic- and radio-tagged fish have been released into the CRI and Grand Canyon since 2010; stocking events occurred in 2010, 2011, 2013, 2014, 2015, and 2016 (Albrecht et al. 2010c; Kegerries and Albrecht 2011, 2013b, 2014a; Kegerries et al. 2015a) (Table 3.1). Two wild fish were captured, implanted with sonic tags, and released in the CRI in February 2016 (Table 3.1). Ten Razorback Suckers were implanted with dual radio/acoustic tags and released at Diamond Creek in the Grand Canyon in February 2016.

In total, 14 unique sonic-tagged fish were contacted 33,489 times (46 active contacts, 33,443 passive contacts) from July 2016 to June 2017 at the CRI and from October 2016 to September 2017 in the Grand Canyon (Figures 3.1 and 3.2, Table 3.1). Of these 14 fish, 1 was released at the CRI in 2011, 2 were released just below Separation Canyon in the Grand Canyon in 2013, 1 was implanted at the CRI in 2013, 1 was released just below Lava Falls in the Grand Canyon in 2014, 1 was implanted and released in Echo Bay in 2014, 3 were implanted and released at the CRI in 2015, 3 were released at Diamond Creek in the Grand Canyon in 2016, and 2 were implanted and released at the CRI in 2016 (Table 3.1). In summary, of the 53 fish that have been tagged and released in the CRI or Grand Canyon since 2010, 14 are confirmed active and 24 are of unknown status (not detected in 2017) but still presumed active.

Five sonic-tagged Razorback Suckers showed noticeable movement (approximately 25.0–61.0 km) throughout the reporting period, although most fish did not show any movement over 1 km between contacts. The largest distance traveled (approximately 61.0 km) was from fish 3375, which was located at the CRI in September 2016 and returned to Echo Bay in December 2016. Other movement was recorded between the SURs in Iceberg Canyon and the CRI.

Table 3.1. Tagging and stocking information, location, date of last contact, and current status of sonic-tagged fish released into the Colorado River Inflow Area of Lake Mead (CRI) and the Grand Canyon (GC) from 2010 to 2017.

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 2016										
NDOW	2/22/2016	3081	562	F	GC	GC	2/22/2016	0 (0)	Unknown	2020
NDOW	2/22/2016	3080	500	M	GC	GC	2/22/2016	0 (0)	Unknown	2020
NDOW	2/22/2016	3079	506	M	GC	GC	2/22/2016	0 (0)	Unknown	2020
NDOW	2/22/2016	3078	554	F	GC	GC	5/7/2016	0 (0)	Unknown	2020
NDOW	2/22/2016	3077	526	F	GC	GC	2/22/2016	0 (0)	Unknown	2020
NDOW	2/22/2016	3076	505	M	GC	CRI	6/12/2017	3 (5,186)	Active	2020
NDOW	2/22/2016	3075	521	M	GC	GC	3/21/2017	0 (156)	Active	2020
NDOW	2/22/2016	3074	521	M	GC	GC	2/22/2016	0 (0)	Unknown	2020
NDOW	2/22/2016	3072	529	M	GC	GC	2/22/2016	0 (0)	Unknown	2020
NDOW	2/22/2016	3071	506	M	GC	GC	7/11/2017	0 (480)	Active	2020
NDOW	2/22/2016	30xx[e]	--	--	GC	GC	10/13/2016	5 (0)	Active	2020
CRI	2/22/2016	3446	662	F	CRI	CRI	6/12/2017	3 (6,768)	Active	2020
CRI	2/22/2016	5777	571	F	CRI	CRI	6/12/2017	7 (9,044)	Active	2020
Fish Tagged in 2015										
CRI	3/17/2015	5587	609	M	CRI	CRI	3/20/2017	3 (0)	Active	2019
CRI	3/18/2015	3548	643	M	CRI	CRI	6/12/2017	12 (6,549)	Active	2019
CRI	3/18/2015	3465	581	M	CRI	CRI	6/12/2017	5 (938)	Active	2019
Fish Tagged in 2014										
CRI	2/26/2014	468	592	M	CRI	LB	2/2/2015	0 (0)	Deceased	2018
CRI	2/18/2014	3547	574	M	CRI	CRI	12/10/2015	0 (0)	Unknown	2018
NDOW	3/16/2014	346	460	M	GC	GC	5/14/2015	0 (0)	Unknown	2018
NDOW	3/16/2014	347	501	M	GC	GC	3/16/2014	0 (0)	Unknown	2018
NDOW	3/16/2014	378	461	M	GC	GC	3/16/2014	0 (0)	Unknown	2018
NDOW	3/16/2014	384	469	M	GC	GC	5/9/2014	0 (0)	Unknown	2018
NDOW	3/16/2014	467	481	M	GC	CRI	6/11/2017	3 (2,052)	Active	2018
NDOW	3/16/2014	576	465	M	GC	GC	3/16/2014	0 (0)	Unknown	2018
NDOW	3/16/2014	5586	450	M	GC	GC	3/16/2014	0 (0)	Unknown	2018
NDOW	3/16/2014	6767	498	M	GC	GC	5/18/2014	0 (0)	Unknown	2018
NDOW	3/16/2014	6768	488	M	GC	GC	3/16/2014	0 (0)	Unknown	2018
EB	2/12/2014	3375[f]	598	M	EB	CRI	9/11/2016	1 (0)	Active	2018
Fish Tagged in 2013										
CRI	3/27/2013	367	560	M	CRI	CRI	4/4/2014	0 (0)	Unknown	2017
NDOW	4/9/2013	3747	521	F	CRI	CRI	5/6/2016	0 (0)	Unknown	2017
NDOW	4/9/2013	4448	475	F	GC	GC	4/12/2017	1 (0)	Active	2017
NDOW	4/9/2013	4455	484	F	CRI	CRI	5/4/2017	3 (1,632)	Active	2017
NDOW	4/9/2013	3338	464	F	GC	CRI	3/8/2014	0 (0)	Unknown	2017
NDOW	4/9/2013	4555	484	F	GC	GC	6/26/2016	0 (0)	Unknown	2017
NDOW	4/9/2013	4658	510	F	GC	GC	5/7/2013	0 (0)	Unknown	2017
NDOW	4/9/2013	4666	479	M	GC	GC	06/08/216	0 (0)	Unknown	2017

Table 3.1. Continued.

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
NDOW	4/9/2013	5556	500	F	GC	GC	4/23/2013	0 (0)	Unknown	2017
NDOW	4/9/2013	5557	479	M	GC	GC	6/18/2013	0 (0)	Unknown	2017
NDOW	4/9/2013	5668	532	F	GC	GC	5/26/2016	0 (630)	Active	2017
Fish Tagged in 2011										
FDLB	1/5/2011	447	505	M	CRI	CRI	2/19/2013	0 (0)	Expired	2015
FDLB	1/5/2011	3546	496	M	CRI	CRI	2/9/2017	0 (8)	Active	2015
FDLB	1/5/2011	3666	504	M	CRI	CRI	8/17/2011	0 (0)	Expired	2015
FDLB	1/5/2011	3774	509	M	CRI	CRI	2/16/2016	0 (0)	Expired	2015
FDLB	1/5/2011	5578	487	M	CRI	CRI	4/10/2013	0 (0)	Expired	2012
FDLB	1/5/2011	5767	515	M	CRI	CRI	5/21/2012	0 (0)	Expired	2012
FDLB	1/5/2011	5768	530	F	CRI	CRI	8/17/2011	0 (0)	Expired	2012
FDLB	1/5/2011	6678	565	M	CRI	CRI	2/8/2012	0 (0)	Expired	2012

[a] Locations: FDLB=Floyd Lamb State Park, LVB=Las Vegas Bay, CRI=Colorado River Inflow Area of Lake Mead, GB=Gregg Basin near Scanlon Bay, GC= Grand Canyon above Pearce Ferry, NDOW=Nevada Department of Wildlife Lake Mead fish hatchery, OA=Overton Arm.
[b] Sex: F=female, M=male, I=immature.
[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, Expired=tag was not located during the tracking season and is beyond the battery's expiration date.
[e] Fish from the 2016 cohort, but we were unable to decipher unique tag code.
[f] Data only reflect contacts at the CRI or Grand Canyon. Additional information regarding contacts during long-term monitoring (LTM) efforts refers to Mohn et al. (2016).

DISCUSSION

Observations from the CRI reinforce the importance of inflow areas to Razorback Sucker. Large inflow areas have been documented to contain increased fish species diversity and reproduction and allow for recruitment of native fishes in a variety of systems (Kaemingk et al. 2007; Albrecht et al. 2010c; Schreck 2010). It was 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 differing flows, lake levels, and changes in habitat. For example, despite receding lake levels and perhaps increased velocities and turbulence at the Pearce Ferry Rapid, sonic-tagged fish were able to navigate above the rapid and into the Grand Canyon during the 2013–2014 field season. It is unknown whether this rapid is a barrier to upstream fish movement during lake levels or flow conditions lower than those observed during 2017, but sonic-telemetry data showed no movement of fish upstream of the CRI into the Grand Canyon. It is also important to continue searching for sonic-tagged fish to see whether they return to previously utilized spawning areas during similar water years or shift spawning locations based on water levels.

In addition to illustrating movement patterns and providing habitat-use data, sonic-tagged fish helped determine the placement of trammel nets for the successful capture of wild Razorback Suckers at the CRI in 2017 (see Chapter 1). As water levels fluctuate, sonic-tagged fish will continue to provide valuable data on changes in Razorback Sucker movement patterns, habitat use, and spawning-site selection within Lake Mead and the Grand Canyon.

Finding fish that were stocked in other parts of the lake at the CRI during this study confirms large-scale movements of Razorback Sucker within Lake Mead. Aside from the sonic-tagged fish from Echo Bay found at the CRI in September 2016, wild Razorback Suckers originally captured and PIT tagged at the Virgin River/Muddy River inflow area in 2009 and 2014 were recaptured at the CRI in 2012 and 2016. In fact, the fish recaptured in 2012 was also recaptured in Echo Bay in 2009, shortly after being captured at the Virgin River/Muddy River inflow area (Kegerries and Albrecht 2013a). The question of wild fish movement and use of multiple spawning locations is being researched by sonic-tagging and tracking wild Lake Mead Razorback Suckers of various size classes, similar to efforts conducted during the earlier years of this study (e.g., Holden et al. 1997). By sonic-tagging additional wild Razorback Suckers, other questions posed in this report could be addressed, such as whether wild fish also use the flowing portions of the Colorado River proper. Perhaps this question has already been answered, as AZGFD captured two wild Razorback Suckers in the Grand Canyon, one in 2012 and one in 2013 (Bunch et al. 2012; Rogowski and Wolters 2014). In fact, the wild, adult fish captured in 2013 was very near hatchery-reared, sonic-tagged fish just below Spencer Creek. During the same sampling event, one of the sonic-tagged fish released in the Grand Canyon in 2013 (3747) was also captured (Rogowski and Wolters 2014). Additionally, the use of stocked Razorback Sucker to locate wild fish has been successful in Lake Mead; this led to the discovery of the Virgin River/Muddy River and CRI spawning aggregates (Albrecht and Holden 2005; Albrecht et al. 2010a), which suggests that stocked fish behave similarly to wild fish.

Although sonic-tagged fish have been documented using flowing portions of the Colorado River proper since 2011, the scale of documented movement has differed among individual fishes and years (i.e., Kegerries et al. 2016a). So far, most of the fish released in the Grand Canyon have remained in the river proper, and not all of the fish released in the CRI have utilized the Grand Canyon. However, in past years many of the fish released at the CRI appeared to take periodic, longer-term residency in the Grand Canyon. 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 the Grand Canyon in 2013 traveled downstream to the CRI during the spawning season and returned to the river in May 2014 (Albrecht et al. 2014a). Through 2017, five fish that were released in the Grand Canyon have been located at the CRI. Comprehensive movement data suggest there may be a seasonal pattern in sonic-fish activity and movement (Kegerries et al. 2016a). At this time, it appears that wild fish and hatchery-reared fish utilized for telemetry purposes use habitats similarly. Regardless, the amount of time sonic-tagged fish spend in the flowing portion of the Colorado River and their movements into and out of the area suggest that the habitats offered by the lake and river combination 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 warrant future attention. Continuing to monitor these areas for adult, juvenile, larval, and sonic-tagged individuals will be critical in regard to habitat use determination and protection. Fluctuating water levels may change the quality of spawning habitat found within the CRI from year to year; this also applies to the Grand Canyon, as flows vary and the interaction between the lake and the river changes dynamically over time. Examples of the dynamic processes within the lake and river were the high-flow experiments conducted in November 2012, 2013, 2014, and 2016. These efforts could have created habitat more suitable for Razorback Sucker within the Grand Canyon or prompted upstream movement patterns. As studies continue at the CRI and in the Grand Canyon, it will be important to maintain the ability to track fish and sample areas they frequent to answer questions regarding how this rare species might use each area.

Telemetry in the 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 fish indicate that sonic-tagged Razorback Suckers are able to incorporate with conspecifics and seek out habitat used by other Razorback Suckers. Although some of the sonic-tagged fish released in the Grand Canyon were not contacted this season, it is likely that these individuals are not making the large-scale movements that allow for passive detection. Manual detection can be difficult, given the canyon's depths and river conditions. Tag failure is possible but rather unlikely; we have not experienced this during recent years in which over 100 fish have been tagged for Lake Mead research and monitoring efforts.

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

2017–2018 TELEMETRY STUDY RECOMMENDATIONS

Given (1) the holistic findings from the CRI, (2) locating larval Razorback Suckers in the Grand Canyon, and (3) tracking fish movement within both the CRI and the 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. Since 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 the Grand Canyon from Lee's Ferry to Pearce Ferry is also recommended to help identify adult and juvenile Razorback Sucker spawning site and habitat use.

2. Continue to implant fish with sonic tags using the methods described herein on an as-needed basis. For the CRI, it is recommended that wild fish be implanted rather than using hatchery-reared individuals to help locate lake spawning aggregations. For the Grand Canyon, Lake Mead Razorback Suckers could be supplied by the NDOW Fish Hatchery, as supported by the LMWG, and tagged and released. Use of CT-05-48-I (48-month) tags or dual-function tags is recommended for the CRI, while dual-function tags are recommended for the Grand Canyon. The dual-function tag is advantageous because it provides the ability to concurrently track fish from a boat while rafting the river using the RF antenna and locate fish via SURs. Disadvantages of the RF tags are potentially shorter battery lives and decreased RF signals in deep and turbid water. Both types of tags have been used with success at the CRI and in the Grand Canyon during past study years and could easily be implemented, as desired. Use of dual-function tags would certainly assist with opportunistic adult sampling in the Grand Canyon.

3. If sonic-tagged fish are released into the Grand Canyon, it is recommended that they be released in the upper end of the study area near Phantom Ranch. Contact made with telemetered fish near Pipe Creek (RM ~89.5) in 2016 documented upstream movement to the top of the current study area. Expanding fish release sites farther upstream may allow fish to find conspecifics more effectively.

4. Additionally, smaller juvenile fish should be used for telemetry purposes to determine whether recruitment habitat exists within the CRI and the 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.

CONCLUSIONS AND FUTURE CONSIDERATIONS

An important goal for the CRI and Grand Canyon investigations was to ascertain whether Razorback Sucker recruitment was occurring there. The captures of an age-2 juvenile Razorback Sucker at the CRI in 2013 (Kegerries and Albrecht 2013b), age-3 immature Razorback Suckers at the CRI in 2014 (Albrecht et al. 2014a) and 2017, 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's attraction to inflow and flowing-water habitats as documented in this report and by others working with the species (Albrecht et al. in press). Data collected to date show steady numbers of wild, adult Razorback Suckers, spawning areas within the CRI and Grand Canyon, and presence of all life stages within the greater study area.

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 (Kegerries et al. 2017).

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 the Grand Canyon could be very 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 less than estimates put forth by Valdez et al. (2012a). Even larval fish produced at the top of the current Grand Canyon study reach, assuming an average river drift speed of 2.5 mi per hour (Valdez et al. 2012a), could easily reach the lake proper 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 the Grand Canyon could also reach Lake Mead and its backwater and oxbow-like habitats before starvation is likely (Kegerries et al. 2017). Furthermore, during their review and summary of Razorback Sucker habitat in the Colorado River system as it pertains to the 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 lower Grand Canyon, 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 . . .

Furthermore, 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 the 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. 2017). Finally, since 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 fish species, there is hope for this population. Such logic may help us understand the paucity (so far) of juvenile Razorback Sucker captures in the Grand Canyon through 2017, particularly when coupled with differential use of adult sonic-tagged Razorback Sucker.

Unlike Razorback Sucker, juvenile Humpback Chub have been present during 2014–2017 Grand Canyon sampling efforts. Although their abundance is lower than that of other native fish species, they appear to occur throughout the study area, especially after June. 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 year classes, of Humpback Chub are being captured relatively routinely throughout the riverine portions of the study area, including below Pearce Ferry. Larval Humpback Chub have also been present in larval samples but in less abundance than Razorback Sucker larvae. The dichotomy between finding more Razorback Sucker larvae than Humpback Chub larvae and not capturing juvenile Razorback Suckers while juvenile Humpback Chub are being routinely captured is likely a function of life history. Humpback Chub are considered a more riverine species while early life stage Razorback Suckers will seek out more lentic environments (Minckley and Marsh 2009). It is plausible that their recruitment habitat is in Lake Mead (as has been documented) and perhaps in other riverine, off-channel habitats that are not being sampled under the current study design. During investigations at the CRI, very few Flannelmouth Sucker larvae and only three documented Bluehead Sucker larvae were found (Kegerries and Albrecht 2011 and 2013a; Kegerries et al. 2015a). If these species, along with Humpback Chub, are spawning in the 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. 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 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 2 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; Kegerries et al. 2009; Shattuck et al. 2011; Shattuck and Albrecht 2014; Mohn et al. 2015, 2016; Rogers et al. 2017). Through this research, many aspects of the demography and life history of the population of Razorback Sucker in Lake Mead have been found to be somewhat unique throughout the species' current distribution (e.g., high growth rate indicative of a young population [Kegerries and Albrecht 2013a, 2013b; Albrecht et al. 2013a, 2013b, 2014], near-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], and the continued collection of sexually immature juvenile individuals [Kegerries and Albrecht 2013b; this report]). Furthermore, it has been documented that, in spite of nonnative predatory pressures, natural recruitment appears to continue 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. 2013a; Shattuck and Albrecht 2014; Kegerries et al. 2015a, 2016a, 2017).

The specific dynamics of potential recruitment through forms of cover, primarily at inflow areas, remain unknown. However, a strong affinity for inflow areas (Albrecht et al. in press) 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 adult Razorback Suckers use the Colorado River throughout the Grand Canyon and the CRI, and some Razorback Sucker reproduction is occurring within the river proper (Kegerries et al. 2017). Moreover, movement of sonic-tagged Razorback Suckers throughout Lake Mead and the Grand Canyon during this study has proven that the system is more connected than previously known. Larval Razorback Sucker collections documented individuals of a range of sizes upstream and downstream in the Grand Canyon study area, which implies that there may be numerous aggregations of Razorback Sucker spawning in the Grand Canyon—as is apparent with Humpback Chub—or at least one Razorback Sucker aggregation is spawning in multiple areas. The level of exchange that occurs between individuals spawned in the 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. in press).

The overall shift in community composition of both native and nonnative fish species within the Grand Canyon in the past two decades is worth noting. 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 lower Grand Canyon, 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 lower Grand Canyon—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 as 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 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 the 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 the Grand Canyon (Kegerries et al. 2017). 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 the Grand Canyon, we suggest that (1) the need for stocking the species should be considered a low priority at this time, but (2) the need to better understand the existing wild population, under variable conditions and new management strategies (DOI 2016), remains a high priority into the foreseeable future. Items of particular investigatory interest at this time include but are not limited to establishing the upstream Grand Canyon boundary of tagged Razorback Sucker habitat use, documenting all spawning locations of the species within the Grand Canyon, and better characterizing the wild recruitment observed within the expanded study area through the continued use of nonlethal aging techniques. In conclusion, this study, along with the LTM study on Lake Mead, has helped bring us closer to identifying and perhaps establishing a workable model for understanding and promoting wild recruitment throughout the Razorback Sucker's historic range.

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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), 2017

DATE	SPECIES	PIT-TAG NUMBER	FIRST DATE CAPTURED[a]	RECAPTURED	TL[b] (mm)	FL[c] (mm)	SL[d] (mm)	WT[e] (g)	SEX[f]
2/2/2017	FM	384.36F2B25F2F	4/30/2013	YES	- -[g]	- -[g]	- -[g]	- -[g]	U
2/2/2017	FM	3DD.003BA2F9EA	3/19/2014	YES	508	- -[g]	- -[g]	1090	U
2/2/2017	FM	3DD.003BA711B2	1/28/2015	YES	495	- -[g]	- -[g]	1030	U
2/3/2017	FM	384.36F2B25F3F	3/13/2013	YES	520	- -[g]	- -[g]	1170	U
2/3/2017	FM	3DD.003BA208E4	3/25/2015	YES	540	- -[g]	- -[g]	1345	U
2/3/2017	FM	3DD.003BA2FA80	3/6/2014	YES	495	- -[g]	- -[g]	970	U
2/14/2017	FM	3DD.003BA711B2	1/28/2015	YES	494	464	426	995	U
2/15/2017	FM	3DD.003BA20832	3/25/2014	YES	526	498	460	1165	U
2/15/2017	FM	3DD.003BA2088B	2/15/2017	NO	481	455	426	1005	U
3/1/2017	FM	3DD.003BA20A45	3/1/2017	NO	440	411	377	645	I
3/1/2017	FM	3DD.003BA20A49	3/1/2017	NO	470	441	410	930	U
3/7/2017	FM	384.36F2B25F2F	4/30/2013	YES	503	479	445	1140	U
3/7/2017	FM	3DD.003BA20A49	3/1/2017	YES	471	439	405	930	U
3/7/2017	FM	3DD.003BA2FAC0	3/7/2017	NO	476	446	414	1110	U
3/21/2017	FM	384.36F2B25F3F	3/13/2013	YES	520	470	452	1145	U
3/21/2017	FM	3DD.003BA20A24	3/21/2017	NO	493	459	427	945	M
3/21/2017	FM	3DD.003BA20A3A	3/21/2017	NO	500	466	443	1220	U
3/21/2017	FM	3DD.003BA20A3B	3/21/2017	NO	471	440	407	760	M
3/21/2017	FM	3DD.003BA20A74	3/21/2017	NO	467	438	402	665	U
3/22/2017	FM	3DD.003BA20A54	3/22/2017	NO	440	413	384	685	U
3/28/2017	FM	3DD.003BA20A38	3/29/2017	NO	496	461	424	1075	F
3/28/2017	FM	3DD.003BA20A50	3/28/2017	NO	499	465	432	1000	M
3/29/2017	FM	3DD.003BA20A40	3/29/2017	NO	475	446	409	985	M
3/29/2017	FM	3DD.003BA20A49	3/1/2017	YES	472	451	419	1030	F
3/29/2017	FM	3DD.003BA20A4E	3/29/2017	NO	498	472	433	1080	F
3/29/2017	FM	3DD.003BA20A67	3/29/2017	NO	492	466	437	990	M
3/29/2017	FM	3DD.003BA20A68	3/29/2017	NO	314	292	266	260	I
3/29/2017	FM	3DD.003BA20A6A	3/29/2017	NO	265	248	226	160	I
3/29/2017	FM	3DD.003BA2FAC0	3/7/2017	YES	488	460	425	1195	F
3/30/2017	FM	3DD.003BA2094C	2/12/2015	YES	448	415	379	765	M
3/30/2017	FM	3DD.003BA20A75	3/30/2017	NO	484	455	420	1010	F
4/4/2017	FM	3DD.003BA20A2B	4/4/2017	NO	491	456	411	1085	U
4/4/2017	FM	3DD.003BA20A30	4/4/2017	NO	454	405	394	854	M
4/4/2017	FM	3DD.003BA20A4E	3/29/2017	YES	- -[g]	- -[g]	- -[g]	- -[g]	U
4/4/2017	FM	3DD.003BA20A5F	4/4/2017	NO	461	426	399	820	M
4/4/2017	FM	3DD.003BA20A65	4/4/2017	NO	420	404	375	670	U
4/4/2017	FM	3DD.003BA20A67	3/29/2017	YES	- -[g]	- -[g]	- -[g]	- -[g]	U
4/5/2017	FM	3DD.003BA20A1D	4/5/2017	NO	489	458	423	960	U
4/5/2017	FM	3DD.003BA20A29	4/5/2017	NO	415	386	358	580	U
4/5/2017	FM	3DD.003BA20A3E	4/5/2017	NO	492	463	430	1170	U
4/6/2017	FM	3DD.003BA20A21	4/6/2017	NO	440	418	385	555	I
4/6/2017	FM	3DD.003BA20A25	4/6/2017	NO	292	275	250	200	I
4/6/2017	FM	3DD.003BA20A2A	4/6/2017	NO	234	220	205	120	I
4/6/2017	FM	3DD.003BA20A48	4/6/2017	NO	344	318	292	335	I
4/6/2017	FM	3DD.003BA20A7B	4/6/2017	NO	290	268	242	210	I

DATE	SPECIES	PIT-TAG NUMBER	FIRST DATE CAPTURED[a]	RECAPTURED	TL[b] (mm)	FL[c] (mm)	SL[d] (mm)	WT[e] (g)	SEX[f]
4/11/2017	FM	3DD.003BA20919	4/11/2017	NO	463	436	402	886	U
4/11/2017	FM	3DD.003BA20A2C	4/11/2017	NO	484	454	418	855	U
4/11/2017	FM	3DD.003BA20A3D	4/11/2017	NO	478	454	410	946	M
4/11/2017	FM	3DD.003BA20A6D	4/11/2017	NO	422	395	360	630	U
4/11/2017	FM	3DD.003BA20A78	4/11/2017	NO	514	486	446	995	U
4/12/2017	FM	3D9.1C2D261A95	4/5/2012	YES	499	468	432	1008	M
4/12/2017	FM	3DD.003BA208A8	4/12/2017	NO	473	442	406	775	U
4/12/2017	FM	3DD.003BA208C7	4/12/2017	NO	327	298	275	255	I
4/13/2017	FM	3DD.003BA20A1E	4/13/2017	NO	438	414	384	670	U
4/13/2017	FM	3DD.003BA20A2F	4/13/2017	NO	460	436	406	840	U
4/13/2017	FM	3DD.003BA20A46	4/13/2017	NO	326	302	276	270	I
4/13/2017	FM	3DD.003BA20A51	4/13/2017	NO	266	248	225	170	I
4/13/2017	FM	3DD.003BA20A64	4/13/2017	NO	326	305	276	265	I
4/18/2017	FM	3DD.003BA20A26	4/18/2017	NO	346	320	295	320	I
4/19/2017	FM	3DD.003BA20A33	4/19/2017	NO	432	412	383	795	M
4/19/2017	FM	3DD.003BA20A3F	4/19/2017	NO	502	473	440	1090	U
4/19/2017	FM	3DD.003BA20A4C	4/19/2017	NO	500	486	447	1065	F
4/19/2017	FM	3DD.003BA20A4E	3/29/2017	YES	- - [g]	- - [g]	- - [g]	- - [g]	F
4/19/2017	FM	3DD.003BA20A59	4/19/2017	NO	459	435	398	885	M
4/19/2017	FM	3DD.003BA20A6B	4/19/2017	NO	481	454	414	965	M
4/20/2017	FM	3DD.003BA20A36	4/20/2017	NO	353	328	302	340	I
4/20/2017	FM	3DD.003BA20A52	4/20/2017	NO	378	355	324	440	I
4/20/2017	FM	3DD.003BA20A7C	4/20/2017	NO	263	246	220	150	I

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

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

DATE COLLECTED	TOTAL LENGTH (mm[a])	AGE	PRESUMPTIVE YEAR SPAWNED
Las Vegas Bay			
5/10/1998	588	10[b]	1987
12/14/1999	539	13	1986
12/14/1999	606	17+	1979–1982
12/14/1999	705	19+	1977–1980
1/08/2000	650	18+	1978–1981
2/27/2000	628	17+	1979–1982
1/09/2001	378	6	1994
2/07/2001	543	11	1989
2/22/2001	585	13	1987
12/01/2001	576	8–10	1991–1993
12/01/2001	694	22	1979
12/01/2001	553	10	1991
2/02/2002	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
5/07/2002	641	15	1986
6/07/2002	407	6	1995
6/07/2002	619	20[b]	1982
6/07/2002	642	20[b]	1982
12/03/2002	354	4	1998
12/06/2002	400	4	1998
12/06/2002	376	4	1998
12/19/2002	395	4	1998
1/07/2003	665	16	1986
1/22/2003	394	4	1998
2/05/2003	385	4	1998
2/18/2003	443	5	1997
3/04/2003	635	19	1983
3/20/2003	420	4	1998
4/08/2003	638	21[b]	1982
4/17/2003	618	10	1992
4/22/2003	650	20–22	1980–1982
5/04/2003	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

DATE COLLECTED	TOTAL LENGTH (mm[a])	AGE	PRESUMPTIVE YEAR SPAWNED
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
4/04/2006	629	6	2000
4/25/2006	452	4	2002
4/25/2006	463	4	2002
1/30/2007	514	5	2002
2/06/2007	519	5	2002
2/06/2007	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
3/06/2007	515	4	2003
3/06/2007	611	13	1994
3/06/2007	565	6	2001
3/13/2007	586	7	2000
3/13/2007	636	25	1982
3/13/2007	524	5	2002
4/02/2007	704	9	1998
4/09/2007	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
4/03/2008	468	4	2004

DATE COLLECTED	TOTAL LENGTH (mm[a])	AGE	PRESUMPTIVE YEAR SPAWNED
4/03/2008	619	7	2001
4/03/2008	640	10	1998
4/03/2008	560	11	1997
4/08/2008	423	3	2005
4/08/2008	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
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
3/03/2009	416	4	2005
3/03/2009	565	8	2001
3/03/2009	431	5	2004
3/03/2009	340	5	2004
3/03/2009	539	8	2001
3/03/2009	521	8	2001
3/03/2009	419	6	2003
3/03/2009	535	6	2003
3/03/2009	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
4/06/2009	546	8	2001
4/13/2009	536	7	2002
4/13/2009	510	7	2002
4/13/2009	451	4	2005

DATE COLLECTED	TOTAL LENGTH (mm[a])	AGE	PRESUMPTIVE YEAR SPAWNED
4/13/2009	578	13	1996
2/02/2010	531	5	2005
2/02/2010	391	5	2005
2/02/2010	342	5	2005
2/11/2010	351	3	2007
3/03/2010	485	5	2005
3/03/2010	553	6	2004
3/03/2010	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
2/08/2011	587	8	2003
2/10/2011	574	12[g]	1999
3/03/2011	364	7	2004
3/03/2011	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
2/05/2013	510	10	2003
2/19/2013	512	7	2006
2/26/2013	500	7	2006
4/16/2013	561	8	2005
3/04/2014	576	7	2007
3/11/2014	649	9	2005
3/27/2014	567	7	2007
3/27/2014	525	5	2009
2/17/2015	468	5	2010
4/28/2015	547	7	2008
2/09/2016	569	11	2005
4/19/2016	599	11	2005
1/10/2017	305	2	2015
1/04/2017	361	2	2015
1/10/2017	586	6	2011
1/11/2017	357	2	2015
2/03/2017	301	2	2015
2/22/2017	586	9	2008
4/04/2017	564	10	2007
Echo Bay			
1/22/1998	381	5	1993

DATE COLLECTED	TOTAL LENGTH (mm[a])	AGE	PRESUMPTIVE YEAR SPAWNED
1/09/2000	527	13	1987
1/09/2000	550	13	1987
1/09/2000	553	13	1987
1/09/2000	599	12–14	1986–1988
1/27/2000	557	13	1986
1/27/2000	710	19+	1979–1981
2/09/2001	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
4/02/2002	617	35+	1966–1968
4/17/2002	583	20[b]	1982
5/02/2002	568	18–19	1983–1984
11/18/2002	551	13	1989
12/04/2002	705	26	1976
1/21/2003	591	16	1986
2/03/2003	655	27–29	1974
2/03/2003	580	13	1989
4/02/2003	639	19–20	1982
4/02/2003	580	23–25	1978
4/23/2003	584	10	1992
5/06/2003	507	9+	1993
5/06/2003	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
4/06/2004	755	17	1985
3/02/2005	608	15	1990
3/02/2005	624	8	1996
1/10/2006	630	12	1994
2/01/2006	705	16	1990
2/16/2006	601	22	1984
1/11/2007	535	5	2002
1/11/2007	493	5	2002
2/01/2007	637	7	2000

DATE COLLECTED	TOTAL LENGTH (mm[a])	AGE	PRESUMPTIVE YEAR SPAWNED
2/08/2007	609	12	1995
2/14/2007	501	4	2003
3/02/2007	590	11	1996
3/09/2007	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
3/05/2008	653	24	1984
3/19/2008	532	6	2002
3/19/2008	510	7	2001
2/20/2009	602	7	2002
2/26/2009	662	16	1993
2/18/2010	520	7	2003
2/25/2010	465	5	2005
3/10/2010	535	7	2003
3/10/2010	530	9[†]	2001
3/24/2010	451	4	2006
3/24/2010	465	5	2005
3/24/2010	466	5	2005
4/08/2010	470	5	2005
4/08/2010	540	8	2002
4/22/2010	538	7	2003
4/22/2010	489	8	2002
4/22/2010	460	9	2001
2/09/2011	529	7	2004
2/09/2011	524	7	2004
2/24/2011	555	7	2004
3/02/2011	513	6	2005
4/07/2011	533	7	2004
4/07/2011	522	7	2004
4/19/2011	537	6	2005
4/19/2011	540	7	2004
4/19/2011	515	6	2005
2/09/2012	619	10	2002
2/09/2012	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
3/01/2012	585	7	2005
3/07/2012	663	12	2000

DATE COLLECTED	TOTAL LENGTH (mm[a])	AGE	PRESUMPTIVE YEAR SPAWNED
3/29/2012	571	12	2000
3/29/2012	595	13	1999
4/12/2012	610	13	1999
4/12/2012	571	14	1998
2/07/2013	670	8	2005
2/07/2013	579	10	2003
2/07/2013	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
3/08/2016	544	9	2007
3/08/2016	612	10	2006
3/08/2016	650	12	2004
3/22/2016	476	6	2010
3/22/2016	545	8	2008
3/22/2016	545	9	2007
3/22/2016	570	11	2005
3/22/2016	634	12	2004
4/05/2016	591	10	2006
4/05/2016	648	11	2005
4/05/2016	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
3/02/2017	664	12	2005
3/09/2017	642	9	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

DATE COLLECTED	TOTAL LENGTH (mm[a])	AGE	PRESUMPTIVE YEAR SPAWNED
2/22/2007	459	4	2003
2/22/2007	494	5	2002
3/01/2007	477	5	2002
3/01/2007	512	4	2003
3/08/2007	463	5	2002
3/08/2007	455	4	2003
3/15/2007	516	4	2003
4/03/2007	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
4/01/2008	229	2	2006
4/01/2008	370	3	2005
4/01/2008	360	3	2005
4/01/2008	385	4	2004
4/01/2008	514	5	2003
4/01/2008	536	5	2003
4/01/2008	514	6	2002
4/01/2008	548	6	2002
4/01/2008	518	7	2001
4/01/2008	530	7	2001
4/01/2008	494	8	2000
4/01/2008	535	9	1999
4/01/2008	559	10	1998
4/22/2008	533	6	2002
4/22/2008	504	6	2002
2/04/2009	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
4/08/2009	348	3	2006

DATE COLLECTED	TOTAL LENGTH (mm[a])	AGE	PRESUMPTIVE YEAR SPAWNED
4/08/2009	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
2/03/2010	455	3	2007
2/03/2010	475	5	2005
2/03/2010	441	5	2005
2/03/2010	495	7	2003
2/03/2010	532	8	2002
2/09/2010	491	5	2005
2/09/2010	444	5	2005
2/09/2010	500	5	2005
2/09/2010	464	6	2004
2/09/2010	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
2/01/2011	601	7	2004
2/01/2011	571	6	2005
2/01/2011	556	7	2004
2/01/2011	586	6	2005
2/01/2011	506	8	2003
2/01/2011	572	8	2003
2/01/2011	500	6	2005

DATE COLLECTED	TOTAL LENGTH (mm[a])	AGE	PRESUMPTIVE YEAR SPAWNED
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
3/01/2011	510	10	2001
3/01/2011	573	9	2002
3/01/2011	518	8	2003
3/01/2011	538	6	2005
3/01/2011	532	9	2002
3/01/2011	553	6	2005
3/01/2011	595	6	2005
3/01/2011	563	6	2005
3/01/2011	555	6	2005
3/01/2011	483	7	2004
3/01/2011	599	9	2002
3/01/2011	560	5	2006
3/09/2011	556	7	2004
3/09/2011	534	6	2005
3/09/2011	549	7	2004
3/09/2011	494	4	2007
3/09/2011	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

DATE COLLECTED	TOTAL LENGTH (mm[a])	AGE	PRESUMPTIVE YEAR SPAWNED
3/15/2011	566	9	2002
3/15/2011	542	6	2005
3/15/2011	577	8	2003
4/05/2011	521	7	2004
4/05/2011	495	6	2005
4/12/2011	572	8	2003
1/31/2012	604	7	2005
1/31/2012	570	7	2005
2/01/2012	525	12	2000
2/07/2012	525	9	2003
2/08/2012	536	7	2005
2/08/2012	501	9	2003
2/08/2012	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
4/04/2012	551	6	2006
4/04/2012	575	7	2005
4/11/2012	535	9	2003
2/06/2013	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
3/05/2013	567	10	2003
3/05/2013	537	10	2003
3/05/2013	621	10	2003
3/05/2013	558	8	2005
3/05/2013	601	8	2005
3/14/2013	600	12	2001

DATE COLLECTED	TOTAL LENGTH (mm[a])	AGE	PRESUMPTIVE YEAR SPAWNED
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
4/03/2013	554	8	2005
4/03/2013	542	7	2006
4/10/2013	560	10	2003
4/10/2013	598	9	2004
2/26/2014	570	12	2002
2/26/2014	626	10	2004
3/06/2014	657	9	2005
3/06/2014	521	9	2005
3/06/2014	591	8	2006
3/06/2014	591	9	2005
3/06/2014	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
4/03/2014	572	6	2008
4/03/2014	615	7	2007
4/10/2014	651	7	2007
4/16/2014	504	6	2008

DATE COLLECTED	TOTAL LENGTH (mm[a])	AGE	PRESUMPTIVE YEAR SPAWNED
2/04/2015	638	9	2006
2/18/2015	650	9	2006
3/04/2015	558	8	2007
3/04/2015	586	8	2007
3/18/2015	644	9	2006
3/31/2015	560	8	2007
2/09/2016	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
2/04/2017	541	6	2011
2/14/2017	624	9	2008
3/03/2017	541	8	2009
3/03/2017	642	7	2010
3/03/2017	586	7	2010
3/22/2017	319	3	2014
Colorado River Inflow Area			
4/20/2010	563	6	2004
4/20/2010	508	6	2004
4/20/2010	568	11	1999
2/08/2011	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

DATE COLLECTED	TOTAL LENGTH (mm[a])	AGE	PRESUMPTIVE YEAR SPAWNED
3/01/2012	546	8	2004
3/01/2012	559	9	2003
3/06/2012	535[g]	11	2001
3/06/2012	573	6	2006
3/06/2012	572	7	2005
3/08/2012	557	8	2004
3/20/2012	630	10	2002
3/20/2012	548	8	2004
3/21/2012	571	9	2003
3/28/2012	572	8	2004
4/03/2012	602	9	2003
4/24/2012	555[e]	9	2003
3/05/2013	215	2	2011
5/14/2014	429	3	2011
2/24/2015	581	10	2005
2/26/2015	634	7	2008
3/03/2015	624	5	2010
3/17/2015	572	6	2009
3/18/2015	595	6	2009
1/21/2016	585	9	2007
3/08/2016	604	10	2006
2/14/2017	268	3	2014
2/15/2017	621	6	2011
3/29/2017	602	10	2007
3/08/2017	556	6	2011
3/07/2017	598	11	2006
4/18/2017	401	6	2011

[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, 2017

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

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

APPENDIX D: FISH CAPTURED BY TRIP AT EACH GENERALIZED RANDOM TESSELLATION STRATIFIED (GRTS) DESIGN SEGMENT AND OPPORTUNISTIC SAMPLING LOCATION DURING SMALL-BODIED FISH COMMUNITY SAMPLING IN THE GRAND CANYON, 2017

TRIP GRTS[a] SEGMENT	BLUEHEAD SUCKER	FLANNELMOUTH SUCKER	HUMPBACK CHUB	SPECKLED DACE	YOUNG OF YEAR SUCKERS	BROWN TROUT	CHANNEL CATFISH	COMMON CARP	FATHEAD MINNOW	PLAINS KILLIFISH	WESTERN MOSQUITOFISH	RED SHINER	RAINBOW TROUT
April	**27**	**981**	**8**	**400**	**0**	**0**	**0**	**0**	**13**	**15**	**15**	**18**	**4**
2													
22		1		1									
31													
34													
46													
50				1									
55													
69													
72		6		5									
74	1			1									
79													
86		2											
90													
94													
98		1		6									
103		4											2
114				2									1
122													
132													
160	2	24	1	5									
162		7	1	9									
170	1	90	5	26					4				1
174		1		1									
178		50	1	35									
179		11		48									
180													
181		5		2									
186		1											
189													
191													
194	1	1		8									
198		5		3									
210	2	36		5									
213	2	144		104									
218		24		6									
225	1	7		4									
234		1		6									
237		21		7									
242	2	25		10									
258		4		1									

TRIP GRTS[a] SEGMENT	BLUEHEAD SUCKER	FLANNELMOUTH SUCKER	HUMPBACK CHUB	SPECKLED DACE	YOUNG OF YEAR SUCKERS	BROWN TROUT	CHANNEL CATFISH	COMMON CARP	FATHEAD MINNOW	PLAINS KILLIFISH	WESTERN MOSQUITOFISH	RED SHINER	RAINBOW TROUT
264		2											
266	2	11											
278		1		1									
285													
298												1	
302	1			2									
308		47		12								2	
310	8	335		52					1			9	
322	1	2		1								1	
330		3		1									
335		3		1								1	
353		4										1	
364	1	43		5					1		15		
365	1	33		10					6	1		2	
382		1		12									
385	1	25		7					1	14		1	
May	**108**	**1,910**	**26**	**456**	**2,540**	**1**			**5**		**60**	**6**	**1**
2													
22													
31					2								
34													
46													
50													
55					1								
69													
72		4											
74													
79		1											
86		1											
90													
98													1
103					11								
114				2									
122					1								
132					1								
155					12								
160		2		1	48								
162					18								
170		26	2		46	1							
174					19								
178		2			38								

TRIP GRTS[a] SEGMENT	BLUEHEAD SUCKER	FLANNELMOUTH SUCKER	HUMPBACK CHUB	SPECKLED DACE	YOUNG OF YEAR SUCKERS	BROWN TROUT	CHANNEL CATFISH	COMMON CARP	FATHEAD MINNOW	PLAINS KILLIFISH	WESTERN MOSQUITOFISH	RED SHINER	RAINBOW TROUT
179					32								
180					7								
181					45								
186		10		1	85								
189				3	4								
191					40								
194	29	765		133	344				1				
198					59								
210					22								
213		5	1	1	26								
218		54	6	1	87								
225		5		1	24								
234		1			39								
237				1	40								
242	52	689		275	1,106				1				
258		5			63								
264	1				59								
266	10	183		16	25								
278					16								
285					16								
298					51								
302					32							6	
308					2								
310	8	144	14	1	14								
322	1			2	21								
330			1	1	31								
335					10								
353					8						2		
364		1			12						56		
365	1	7		2	10				1		2		
382	5	1	1	3									
385	1	4	1	12	13				2				
June	**1,183**	**9,411**	**495**	**3,931**	**4,953**			**1**	**327**	**1**	**5**	**42**	
2													
22		5											
31													
34		32											
46		1											
50		3			1								
55		66			2								
69		28			6								

TRIP GRTS[a] SEGMENT	BLUEHEAD SUCKER	FLANNELMOUTH SUCKER	HUMPBACK CHUB	SPECKLED DACE	YOUNG OF YEAR SUCKERS	BROWN TROUT	CHANNEL CATFISH	COMMON CARP	FATHEAD MINNOW	PLAINS KILLIFISH	WESTERN MOSQUITOFISH	RED SHINER	RAINBOW TROUT
72		38											
74		91			24								
79		30			5								
86		75			59								
90		4			1								
98		1			1								
103	100	136	1		87								
114		89			66								
122		2			5								
132		3			1								
155		46			22								
160	2	18	32	26	51				1				
162	28	64	12	58	2				1				
170	57	470	207	126	55				104				
174		6	5	10	17				17				
178	70	545	25	126	28				4				
179		2	2						2				
180	1	9	2	11	16								
181		1	1	6					1				
186	2	158	10	107	16				7				
189	1		2	6	26								
191			6	69	52								
194	3	19	10	8	51			1	2				
198	1	162	17	8	71				2				
210	3	159	6	13	106				3				
213	8	124	4	68	257				21				
218	78	405	29	278	432				71				
225	92	655	21	232	501				56				
234	4	56	3	35	96								
237	9	101	7	80	154								
242	59	304	3	221	205				2				
258	2	7	2	4									
264	3	219	4	184	481								
266		2		1	1								
278	7	67	7	63	67				2				
285	2	33	3	23	17				1				
298	17	48		34	23				1				
302	7	72	6	111	53								
308	40	184	6	346	40								
310	522	4,199	24	401	1,572				27			3	
322	7	43	3	263	24				1	1		39	
330		4		19	4								

TRIP GRTS[a] SEGMENT	BLUEHEAD SUCKER	FLANNELMOUTH SUCKER	HUMPBACK CHUB	SPECKLED DACE	YOUNG OF YEAR SUCKERS	BROWN TROUT	CHANNEL CATFISH	COMMON CARP	FATHEAD MINNOW	PLAINS KILLIFISH	WESTERN MOSQUITOFISH	RED SHINER	RAINBOW TROUT
335		7	2	13	6								
353	6	130	2	294	103								
364			1	10							1		
365	44	424	24	512	70						1		
382	1	1		4									
385	7	63	6	161	76				1		3		
July	**814**	**15,582**	**123**	**1,929**	**957**	**0**	**0**	**0**	**10**	**17**	**4**	**32**	**1**
2		2			6								
22	2	76		2	63								
31	1	47			19								
34		9			13								
46		9			13								
50		9			4								
55		7			21								
69		7			9								
72	1	578		1	62								
74		281			22								
79		11											
86		418		1	27								
90		7			1								
98	4	29			5								1
103		63		2	6								
114	1	217		14	17								
122		56			1								
132		16		1	11								
155		5			19								
160	2	323	7	2	85								
162	6	782	2	1	4								
170	2	488			48								
174	1	13		1	51								
178	1	196	16	35	8								
179	1	1,589	2	66	34								
180	2	389		3	59								
181	5	361		75	12								
186		313		2	21								
189		417		5	18								
191	1	3		6									
194	44	352		1	22								
198	4	655		48									
210	4	26		1									
213	19	2,322	77	317	4								

TRIP GRTS[a] SEGMENT	BLUEHEAD SUCKER	FLANNELMOUTH SUCKER	HUMPBACK CHUB	SPECKLED DACE	YOUNG OF YEAR SUCKERS	BROWN TROUT	CHANNEL CATFISH	COMMON CARP	FATHEAD MINNOW	PLAINS KILLIFISH	WESTERN MOSQUITOFISH	RED SHINER	RAINBOW TROUT
218	5	711	3	66									
225	17	796	2	662	1								
234	53	278		68	43								
237	19	348		15	6								
242	77	682	1	111	14								
258	5	128		2	9								
264	99	221		72	2								
266	76	12		18	7								
278	59	65			74								
285	5	138		41	18								
298	7	134	2	48	12								
302	4	35		4	15								
308		21		32	5								
310	244	56		43	17				6			5	
322	25	538		36	5					16		24	
330		428	1	39	4					1		3	
335	1	125	4	26	5								
353		76		4	8								
364	1	289	4	1	3						1		
365	5	391	1	11	17				3		3		
382	2	18		2									
385	9	16	1	44	7				1				
August	**477**	**1,224**	**146**	**1,256**				**1**	**21**	**6**	**34**	**20**	**5**
2													
22		26										1	
31	1	1		1									
34										1		1	
46	1	2											2
50	3			2									
55	3	12		1								5	
69													
72	3	4	6	1									
74	1	3		2									
79	2	3	3	4									
86	19	69	6	66									
90				3									
98	1	2											
103	2	15		12									
114				1					1				
122	1	3		7					2				1
132	1	2		1									

TRIP GRTS[a] SEGMENT	BLUEHEAD SUCKER	FLANNELMOUTH SUCKER	HUMPBACK CHUB	SPECKLED DACE	YOUNG OF YEAR SUCKERS	BROWN TROUT	CHANNEL CATFISH	COMMON CARP	FATHEAD MINNOW	PLAINS KILLIFISH	WESTERN MOSQUITOFISH	RED SHINER	RAINBOW TROUT
155			3	11									
160	3	14	6	7									
162	6	17	1	22									
170	10	75	2	33				1	2				
174		2		14						1			
178	4	138	16	25									
179	1	22	1	17									
180	1	21	2	27									1
181	15	101	4	33									1
186	16	37	3	30									
189	1	6		24					1				
191	6	32		9									
194	1	16	3	2					2				
198	19	44	5	63									
210	18	16		15									
213	2	11	6	5									
218	3	12	4	20									
225	70	63		67									
234	15	13	2	13					1				
237	6	2		9									
242	3	8	1	14									
258	2	12	2	20									
264	23	26	15	92									
266	3	5	1	23					1				
278		6	7	27									
285	6	6		33									
298		1	1	48								3	
302	3	10	2	62									
308	5	31	2	27								1	
310	11	28	18	52					3	1		7	
322	2	14	4	15								2	
330	6	6	3	86						1			
335	2	7	1	46							3		
353	32	79	2	69					1				
364	57	58	7	37					3		8		
365	41	70	3	14					4		3		
382	6	2	4	39									
385	40	71		5						2	20		
September	**441**	**1,878**	**123**	**1,089**	**1**				**16**	**16**	**26**	**10**	
2													
22		1	1						1				

TRIP GRTS[a] SEGMENT	BLUEHEAD SUCKER	FLANNELMOUTH SUCKER	HUMPBACK CHUB	SPECKLED DACE	YOUNG OF YEAR SUCKERS	BROWN TROUT	CHANNEL CATFISH	COMMON CARP	FATHEAD MINNOW	PLAINS KILLIFISH	WESTERN MOSQUITOFISH	RED SHINER	RAINBOW TROUT
31													
34													
46													
50													
55													
69													
72		3		2									
74		18		1									
79													
86		45		35						1			
90													
98													
103		5		6									
122		19	1	6									
132			1	2									
155		17		1									
160		32	2	10					2				
162		2		7									
170	8	243	3	6					9	3			
174	1	19		27									
178	4	170	8	21									
179		5		9									
180	1	58		12									
181	2	78		44									
186		39		5									
189	5	54		24					1				
191		58		19									
194	11	103	3	1									
198	1	9		3	1								
210	5	24		20					2				
213	1	38	1	15									
218		10	1	17									
225	28	79		96									
234	14	26	4	31									
237	3	42		23									
242	21	32	9	63									
258	4	15	2	13									
264	7	86		25									
266		1		8					1				
278		1		32									
285		7		13									
298		3		9								4	

TRIP GRTS[a] SEGMENT	BLUEHEAD SUCKER	FLANNELMOUTH SUCKER	HUMPBACK CHUB	SPECKLED DACE	YOUNG OF YEAR SUCKERS	BROWN TROUT	CHANNEL CATFISH	COMMON CARP	FATHEAD MINNOW	PLAINS KILLIFISH	WESTERN MOSQUITOFISH	RED SHINER	RAINBOW TROUT
302	6	6		13									
308	2	51	9	32									
310	224	231	69	120						2		5	
322	22	13	4	62								1	
330	6	10		41						3	3		
335	6	39		23									
353	31	47		38						2	1		
364	3	48	4	41							11		
365	1	42		48						5	11		
382	2	5		42									
385	22	44	1	23									
Grand Total	**3,050**	**33,209**	**930**	**9,151**	**8,622**	**1**	**0**	**2**	**392**	**55**	**144**	**128**	**11**

[a] generalized random tessellation stratified

OPPORTUNISTIC TRIP	BLUEHEAD SUCKER	FLANNELMOUTH SUCKER	HUMPBACK CHUB	SPECKLED DACE	YOUNG OF YEAR SUCKERS	BROWN TROUT	CHANNEL CATFISH	COMMON CARP	FATHEAD MINNOW	PLAINS KILLIFISH	WESTERN MOSQUITOFISH	RED SHINER	RAINBOW TROUT
April	29	155	1	68					5			7	
May	2	189		135	84			1					
June	2	378	1	14	7		2	4	24				
July													
August	1	12		4					8				
September	49	132	11	55					77	4			
Grand Total	**240**	**780**	**4**	**686**	**188**	**0**	**15**	**5**	**71**	**31**	**30**	**918**	**7**

APPENDIX E: AGE-0 FISH CAPTURED BY TRIP AT GENERALIZED RANDOM TESSELLATION STRATIFIED (GRTS) SEGMENTS DURING LARVAL FISH COMMUNITY SAMPLING IN THE GRAND CANYON, 2017

Appendix E.1. Age-0 fishes captured during the March 9–17, 2017, survey.

SPECIES **COMMON NAME**	**RESIDENCE STATUS**[a]	**NUMBER OF SPECIMENS**	**PERCENT OF TOTAL**	**MEAN CPUE**[b]	**FREQUENCY OF OCCURRENCE**[c]	**PERCENT FREQUENCY OF OCCURRENCE**[c]
Carps and Minnows						
Cyprinella lutrensis Red Shiner	I	–	–	–	–	–
Cyprinus carpio Common Carp	I	–	–	–	–	–
Gila cypha Humpback Chub	N	–	–	–	–	–
Pimephales promelas Fathead Minnow	I	–	–	–	–	–
Rhinichthys osculus Speckled Dace	N	–	–	–	–	–
Suckers						
Catostomidae sp.	N	–	–	–	–	–
Catostomus discobolus Bluehead Sucker	N	–	–	–	–	–
Catostomus latipinnis Flannelmouth Sucker	N	126	94.74	0.07	18	33.33
Xyrauchen texanus Razorback Sucker	N	7	5.26	[d]	6	11.11
Topminnows						
Fundulus zebrinus Plains Killifish	I	–	–	–	–	–
Livebearers						
Gambusia affinis Western Mosquitofish	I	–	–	–	–	–
TOTAL			**133**			

[a] N=native, I = introduced

[b] CPUE = catch per unit effort; mean value based on catch/area sampled (m^2) per haul (n=216 hauls)

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

[d] Value is < 0.05

Appendix E.2. Age-0 fishes captured during the April 8–13, 2017, survey.

SPECIES **COMMON NAME**	**RESIDENCE STATUS**[a]	**NUMBER OF SPECIMENS**	**PERCENT OF TOTAL**	**MEAN CPUE**[b]	**FREQUENCY OF OCCURRENCE**[c]	**PERCENT FREQUENCY OF OCCURRENCE**[c]
Carps and Minnows						
Cyprinella lutrensis Red Shiner	I	–	–	–	–	–
Cyprinus carpio Common Carp	I	–	–	–	–	–
Gila cypha Humpback Chub	N	–	–	–	–	–
Pimephales promelas Fathead Minnow	I	–	–	–	–	–
Rhinichthys osculus Speckled Dace	N	3	0.42	[d]	1	1.76
Suckers						
Catostomidae sp.	N	–	–	–	–	–
Catostomus discobolus Bluehead Sucker	N	111	16.40	0.06	19	33.93
Catostomus latipinnis Flannelmouth Sucker	N	552	81.54	0.26	32	57.14
Xyrauchen texanus Razorback Sucker	N	11	1.62	[d]	10	17.86
Topminnows						
Fundulus zebrinus Plains Killifish	I	–	–	–	–	–
Livebearers						
Gambusia affinis Western Mosquitofish	I	–	–	–	–	–
TOTAL		**677**				

[a] N=native, I = introduced

[b] CPUE = catch per unit effort; mean value based on catch/area sampled (m^2) per haul (n=225 hauls)

[c] Frequency and percent frequency of occurrence are based on n=56 GRTS sample segments

[d] Value is < 0.05

Appendix E.3. Age-0 fishes captured during the May 19–24, 2017, survey.

SPECIES COMMON NAME	RESIDENCE STATUS[a]	NUMBER OF SPECIMENS	PERCENT OF TOTAL	MEAN CPUE[b]	FREQUENCY OF OCCURRENCE[c]	PERCENT FREQUENCY OF OCCURRENCE[c]
Carps and Minnows						
Cyprinella lutrensis Red Shiner	I	–	–	–	–	–
Cyprinus carpio Common Carp	I	–	–	–	–	–
Gila cypha Humpback Chub	N	22	0.06	[d]	13	23.2
Pimephales promelas Fathead Minnow	I	–	–	–	–	–
Rhinichthys osculus Speckled Dace	N	1,214	3.18	0.68	35	62.5
Suckers						
Catostomidae sp.	N	3	0.01	[d]	–	–
Catostomus discobolus Bluehead Sucker	N	15,597	40.85	8.68	52	92.9
Catostomus latipinnis Flannelmouth Sucker	N	21,334	55.88	11.45	56	100.0
Xyrauchen texanus Razorback Sucker	N	7	0.02	[d]	6	10.71
Topminnows						
Fundulus zebrinus Plains Killifish	I	–	–	–	–	–
Livebearers						
Gambusia affinis Western Mosquitofish	I	–	–	–	–	–
TOTAL		**38,177**				

[a] N=native, I = introduced

[b] CPUE = catch per unit effort; mean value based on catch/area sampled (m^2) per haul (n=224 hauls)

[c] Frequency and percent frequency of occurrence are based on n=56 GRTS sample segments

[d] Value is < 0.05

Appendix E.4. Age-0 fishes captured during the June 14–19, 2017, survey.

SPECIES **COMMON NAME**	**RESIDENCE STATUS**[a]	**NUMBER OF SPECIMENS**	**PERCENT OF TOTAL**	**MEAN CPUE**[b]	**FREQUENCY OF OCCURRENCE**[c]	**PERCENT FREQUENCY OF OCCURRENCE**[c]
Carps and Minnows						
Cyprinella lutrensis Red Shiner	I	–	–	–	–	–
Cyprinus carpio Common Carp	I	–	–	–	–	–
Gila cypha Humpback Chub	N	45	0.23	0.03	8	14.29
Pimephales promelas Fathead Minnow	I	2	0.01	0.00	1	1.79
Rhinichthys osculus Speckled Dace	N	1,531	7.90	0.84	43	76.79
Suckers						
Catostomidae sp.	N	–	–	–	–	–
Catostomus discobolus Bluehead Sucker	N	5,130	26.46	3.23	54	96.43
Catostomus latipinnis Flannelmouth Sucker	N	12,662	65.31	7.50	56	100.00
Xyrauchen texanus Razorback Sucker	N	2	0.01	0.00	2	3.57
Topminnows						
Fundulus zebrinus Plains Killifish	I	–	–	–	–	–
Livebearers						
Gambusia affinis Western Mosquitofish	I	16	0.08	0.01	1	1.79
TOTAL		**19,388**				

[a] N=native, I = introduced

[b] CPUE = catch per unit effort; mean value based on catch/area sampled (m^2) per haul (n=223 hauls)

[c] Frequency and percent frequency of occurrence are based on n=56 GRTS sample segments

[d] Value is < 0.05

Appendix E.5. Age-0 larval fishes captured during the July 11–17, 2017, survey.

SPECIES COMMON NAME	RESIDENCE STATUS[a]	NUMBER OF SPECIMENS	PERCENT OF TOTAL	MEAN CPUE[b]	FREQUENCY OF OCCURRENCE[c]	PERCENT FREQUENCY OF OCCURRENCE[c]
Carps and Minnows						
Cyprinella lutrensis Red Shiner	I	–	–	–	–	–
Cyprinus carpio Common Carp	I	–	–	–	–	–
Gila cypha Humpback Chub	N	31	0.37	0.02	11	19.64
Pimephales promelas Fathead Minnow	I	20	0.24	0.01	6	10.71
Rhinichthys osculus Speckled Dace	N	1,046	12.57	0.52	46	82.14
Suckers						
Catostomidae sp.	N	–	–	–	–	–
Catostomus discobolus Bluehead Sucker	N	2,716	32.64	1.39	55	98.21
Catostomus latipinnis Flannelmouth Sucker	N	4,504	54.13	2.38	56	100.00
Xyrauchen texanus Razorback Sucker	N	–	–	–	–	–
Topminnows						
Fundulus zebrinus Plains Killifish	I	–	–	–	–	–
Livebearers						
Gambusia affinis Western Mosquitofish	I	4	0.05	0.00	2	3.57
TOTAL		**8,321**				

[a] N =native, I =introduced

[b] CPUE = catch per unit effort; mean value based on catch/area sampled (m^2) per haul (n=224 hauls)

[c] Frequency and percent frequency of occurrence are based on n=56 GRTS sample segments

[d] Value is < 0.05

Appendix E.6. Age-0 larval fishes captured during the August 16–23, 2017, survey.

SPECIES COMMON NAME	RESIDENCE STATUS[a]	NUMBER OF SPECIMENS	PERCENT OF TOTAL	MEAN CPUE[b]	FREQUENCY OF OCCURRENCE[c]	PERCENT FREQUENCY OF OCCURRENCE[c]
Carps and Minnows						
Cyprinella lutrensis Red Shiner	I	–	–	–	–	–
Cyprinus carpio Common Carp	I	–	–	–	–	–
Gila cypha Humpback Chub	N	31	1.59	0.02	17	30.4
Pimephales promelas Fathead Minnow	I	4	0.21	0.00	4	7.1
Rhinichthys osculus Speckled Dace	N	556	28.59	0.30	48	85.7
Suckers						
Catostomidae sp.	N	–	–	–	–	–
Catostomus discobolus Bluehead Sucker	N	276	14.19	0.13	37	66.1
Catostomus latipinnis Flannelmouth Sucker	N	1,077	55.37	0.54	50	89.3
Xyrauchen texanus Razorback Sucker	N	–	–	–	–	–
Topminnows						
Fundulus zebrinus Plains Killifish	I	–	–	–	–	–
Livebearers						
Gambusia affinis Western Mosquitofish	I	1	0.05	0.00	1	1.8
TOTAL		**1,945**				

[a] N=native, I = introduced
[b] CPUE = catch per unit effort; mean value based on catch/area sampled (m^2) per haul (n=224 hauls)
[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, 2017

Appendix F.1. Age-1+ fishes captured during the March 9–17, 2017, survey.

SPECIES **COMMON NAME**	**RESIDENCE STATUS**[a]	**NUMBER OF SPECIMENS**	**PERCENT OF TOTAL**	**MEAN CPUE**[b]	**FREQUENCY OF OCCURRENCE**[c]	**PERCENT FREQUENCY OF OCCURRENCE**[c]
Carps and Minnows						
Cyprinella lutrensis Red Shiner	I	10	1.22	[d]	4	7.41
Gila cypha Humpback Chub	N	18	2.19	0.01	8	14.81
Pimephales promelas Fathead Minnow	I	25	3.05	0.01	7	12.96
Rhinichthys osculus Speckled Dace	N	327	39.83	0.19	33	61.11
Suckers						
Catostomus discobolus Bluehead Sucker	N	28	3.41	0.02	16	29.63
Catostomus latipinnis Flannelmouth Sucker	N	376	45.80	0.21	29	53.70
Trout						
Oncorhynchus mykiss Rainbow Trout	I	3	0.37	[d]	3	5.56
Topminnows						
Fundulus zebrinus Plains Killifish	I	11	1.34	0.01	7	12.96
Livebearers						
Gambusia affinis Western Mosquitofish	I	21	2.56	0.01	4	7.41
Sunfish						
Lepomis cyanellus Green Sunfish	I	1	0.12	[d]	1	1.85
TOTAL		**820**				

[a] N=native, I=introduced

[b] CPUE = catch per unit effort; mean value based on catch/area sampled (m^2) per haul (n=216 hauls)

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

[d] Value is < 0.01

Appendix F.2. Age-1+ fishes captured during the April 8–13, 2017, survey.

SPECIES COMMON NAME	RESIDENCE STATUS[a]	NUMBER OF SPECIMENS	PERCENT OF TOTAL	MEAN CPUE[b]	FREQUENCY OF OCCURRENCE[c]	PERCENT FREQUENCY OF OCCURRENCE[c]
Carps and Minnows						
Cyprinella lutrensis Red Shiner	I	14	4.26	0.01	3	5.36
Gila cypha Humpback Chub	N	2	0.61	[d]	1	1.79
Pimephales promelas Fathead Minnow	I	7	2.13	[d]	5	8.93
Rhinichthys osculus Speckled Dace	N	168	51.06	0.09	25	44.64
Suckers						
Catostomus discobolus Bluehead Sucker	N	5	1.52	[d]	4	7.14
Catostomus latipinnis Flannelmouth Sucker	N	121	36.78	0.07	13	23.21
Trout						
Oncorhynchus mykiss Rainbow Trout	I	2	0.61	[d]	2	3.57
Topminnows						
Fundulus zebrinus Plains Killifish	I	6	1.82	[d]	3	5.36
Livebearers						
Gambusia affinis Western Mosquitofish	I	4	1.22	[d]	1	1.79
Sunfish						
Lepomis cyanellus Green Sunfish	I	–	–	–	–	–
TOTAL		**329**				

[a] N=native, I=introduced

[b] CPUE = catch per unit effort; mean value based on catch/area sampled (m^2) per haul (n=225 hauls)

[c] Frequency and percent frequency of occurrence are based on n=56 GRTS sample segments

[d] Value is < 0.01

Appendix F.3. Age-1+ fishes captured during the May 19–24, 2017, survey.

SPECIES **COMMON NAME**	**RESIDENCE STATUS**[a]	**NUMBER OF SPECIMENS**	**PERCENT OF TOTAL**	**MEAN CPUE**[b]	**FREQUENCY OF OCCURRENCE**[c]	**PERCENT FREQUENCY OF OCCURRENCE**[c]
Carps and Minnows						
Cyprinella lutrensis Red Shiner	I	5	4.72	[d]	1	1.79
Gila cypha Humpback Chub	N	1	0.94	[d]	1	1.79
Pimephales promelas Fathead Minnow	I	6	5.66	[d]	4	7.14
Rhinichthys osculus Speckled Dace	N	60	56.60	0.02	8	14.29
Suckers						
Catostomus discobolus Bluehead Sucker	N	3	2.83	[d]	3	5.36
Catostomus latipinnis Flannelmouth Sucker	N	30	28.30	0.01	8	14.29
Trout						
Oncorhynchus mykiss Rainbow Trout	I	–	–	–	–	–
Topminnows						
Fundulus zebrinus Plains Killifish	I	1	0.94	[d]	1	1.79
Livebearers						
Gambusia affinis Western Mosquitofish	I	–	–	–	–	–
Sunfish						
Lepomis cyanellus Green Sunfish	I	–	–	–	–	–
TOTAL		**106**				

[a] N=native, I=introduced
[b] CPUE = catch per unit effort; mean value based on catch/area sampled (m^2) per haul (n=224 hauls)
[c] Frequency and percent frequency of occurrence are based on n=56 GRTS sample segments
[d] Value is < 0.01

Appendix F.4. Age-1+ fishes captured during the June 14–19, 2017, survey.

SPECIES **COMMON NAME**	**RESIDENCE STATUS**[a]	**NUMBER OF SPECIMENS**	**PERCENT OF TOTAL**	**MEAN CPUE**[b]	**FREQUENCY OF OCCURRENCE**[c]	**PERCENT FREQUENCY OF OCCURRENCE**[c]
Carps and Minnows						
Cyprinella lutrensis Red Shiner	I	2	0.71	[d]	1	1.79
Gila cypha Humpback Chub	N	9	3.19	0.01	3	5.36
Pimephales promelas Fathead Minnow	I	3	1.06	[d]	3	5.36
Rhinichthys osculus Speckled Dace	N	162	57.45	0.11	14	25.00
Suckers						
Catostomus discobolus Bluehead Sucker	N	4	1.42	[d]	3	5.36
Catostomus latipinnis Flannelmouth Sucker	N	84	29.79	0.06	4	7.14
Trout						
Oncorhynchus mykiss Rainbow Trout	I	–	–	–	–	–
Topminnows						
Fundulus zebrinus Plains Killifish	I	1	0.35	[d]	1	1.79
Livebearers						
Gambusia affinis Western Mosquitofish	I	17	6.03	0.01	2	3.57
Sunfish						
Lepomis cyanellus Green Sunfish	I	–	–	–	–	–
TOTAL		**282**				

[a] N=native, I=introduced

[b] CPUE = catch per unit effort; mean value based on catch/area sampled (m^2) per haul (n=223 hauls)

[c] Frequency and percent frequency of occurrence are based on n=56 GRTS sample segments

[d] Value is < 0.01

Appendix F.5. Age-1+ larval fishes captured during the July 11–17, 2017, survey.

SPECIES **COMMON NAME**	**RESIDENCE STATUS**[a]	**NUMBER OF SPECIMENS**	**PERCENT OF TOTAL**	**MEAN CPUE**[b]	**FREQUENCY OF OCCURRENCE**[c]	**PERCENT FREQUENCY OF OCCURRENCE**[c]
Carps and Minnows						
Cyprinella lutrensis Red Shiner	I	1	0.33	[d]	1	1.79
Gila cypha Humpback Chub	N	2	0.66	[d]	1	1.79
Pimephales promelas Fathead Minnow	I	–	–	–	–	–
Rhinichthys osculus Speckled Dace	N	245	80.59	0.16	28	50.00
Suckers						
Catostomus discobolus Bluehead Sucker	N	–	–	–	–	–
Catostomus latipinnis Flannelmouth Sucker	N	6	1.97	[d]	5	8.93
Trout						
Oncorhynchus mykiss Rainbow Trout	I	–	–	–	–	–
Topminnows						
Fundulus zebrinus Plains Killifish	I	9	2.96	0.01	1	1.79
Livebearers						
Gambusia affinis Western Mosquitofish	I	41	13.49	0.02	3	5.36
Sunfish						
Lepomis cyanellus Green Sunfish	I	–	–	–	–	–
TOTAL		**304**				

[a] N=native, I=introduced

[b] CPUE = catch per unit effort; mean value based on catch/area sampled (m^2) per haul (n=224 hauls)

[c] Frequency and percent frequency of occurrence are based on n=56 GRTS sample segments

[d] Value is < 0.01

Appendix F.6. Age-1+ larval fishes captured during the August 16–23, 2017, survey.

SPECIES **COMMON NAME**	**RESIDENCE STATUS**[a]	**NUMBER OF SPECIMENS**	**PERCENT OF TOTAL**	**MEAN CPUE**[b]	**FREQUENCY OF OCCURRENCE**[c]	**PERCENT FREQUENCY OF OCCURRENCE**[c]
Carps and Minnows						
Cyprinella lutrensis Red Shiner	I	1	0.18	[d]	1	1.79
Gila cypha Humpback Chub	N	5	0.91	[d]	5	8.93
Pimephales promelas Fathead Minnow	I	10	1.81	[d]	6	10.71
Rhinichthys osculus Speckled Dace	N	438	79.49	0.24	45	80.36
Suckers						
Catostomus discobolus Bluehead Sucker	N	–	–	–	–	–
Catostomus latipinnis Flannelmouth Sucker	N	46	8.35	0.03	21	37.50
Trout						
Oncorhynchus mykiss Rainbow Trout	I	1	0.18	[d]	1	1.79
Topminnows						
Fundulus zebrinus Plains Killifish	I	10	1.81	[d]	7	12.50
Livebearers						
Gambusia affinis Western Mosquitofish	I	40	7.26	0.02	3	5.36
Sunfish						
Lepomis cyanellus Green Sunfish	I	–	–	–	–	–
TOTAL		**551**				

[a] N=native, I=introduced
[b] CPUE = catch per unit effort; mean value based on catch/area sampled (m^2) per haul (n=224 hauls)
[c] Frequency and percent frequency of occurrence are based on n=56 GRTS sample segments
[d] Value is < 0.01