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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

2018 FINAL ANNUAL REPORT

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Prepared by:

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

([1] BIO-WEST, Inc.; [2] American Southwest Ichthyological Researchers, L.L.C.; [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 near Lower Garnet. *Bottom left*: Larval Razorback Sucker sampling in the Grand Canyon. *Bottom center left*: Razorback Sucker captured from the Colorado River inflow area. *Bottom center*: Larval Razorback Sucker from the Grand Canyon. *Bottom center right:* Small-bodied 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). 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 support 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, L.L.C., (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, USFWS, and Nevada Department of Wildlife (NDOW). These groups are represented on, participate in, and comprise the LMWG, a multiagency group dedicated to conserving Razorback Sucker and contributing to species recovery. This cooperative approach was paramount in providing the means to assess Razorback Sucker use of 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 fifth year of a current 5-year study. Data stemming from the CRI are presented as Chapter 1. Chapter 2 covers small-bodied and larval fish community sampling conducted within the Grand Canyon in 2018. 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 1,463 trammel net-hours at the CRI in 2018, 32 Razorback Suckers, 35 Razorback Sucker × Flannelmouth Sucker *Catostomus latipinnis* hybrids, and 12 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 2018 spawning period (February–May) resulted in the capture of three larval Razorback Sucker from the CRI.

Since 2010, 129 Razorback Suckers and 86 Razorback Sucker × Flannelmouth Sucker hybrids have been captured via trammel netting, including three juvenile Razorback Suckers (age-2 and age-3). Additionally, 319 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 Razorback Sucker with sonic tags, which resulted in the surgical implantation of one wild fish at the CRI. Ten additional wild Razorback Suckers were implanted with sonic tags at the CRI, two in 2014, three in 2015, two in 2016, and three in 2018. Additionally, 10 hatchery-reared fish were successfully implanted with sonic tags in 2013 and released below Separation Canyon. Nine hatchery-reared fish were implanted with sonic tags and released just below Lava Falls in 2014, 10 hatchery-reared fish were implanted with dual radio/sonic tags and released at Diamond Creek in 2016, and 10 hatchery-reared fish were implanted with dual radio/sonic tags and released at Bright Angel Creek in 2018. 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 technology.

Grand Canyon

Grand Canyon small-bodied fish community sampling in 2018 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.

For the fifth consecutive year, larval fish sampling verified Razorback Sucker spawning and larval production in the Colorado River within Grand Canyon National Park. Additionally, larval fish sampling documented magnitude and duration of reproduction by Humpback Chub and other members (native and nonnative) of the ichthyofaunal community throughout the lower 191 river miles of the Colorado River within Grand Canyon. In 2018, larval Razorback Suckers (n=10) were captured during the first four monthly surveys (March–June) and were distributed from RM 144.8 to RM 269.0. The capture of Razorback Sucker (n=1) at RM 144.8 is the upstream-most Razorback Sucker larva capture within expanded study area (2016–2018; RM 88.6–279.0). This finding increases the distribution of age-0 Razorback Sucker 20 RM farther upstream than previously documented. Captures of larval Razorback Sucker were similar across months (March n=3, April n=2, May n=2, and June n=3). Larval Razorback Sucker collected were of two ontogenetic phases (protolarvae and mesolarvae). The majority of Razorback Suckers captured were mesolarvae (60%; n=6), all of which were of the earlier flexion mesolarval subphase. Single protolarva were taken during each of the four monthly surveys (March–June). Back-calculated length-based hatching dates of Razorback Sucker encompassed 14-weeks, from 21 February to 2 June, 2018.

Age-0 Humpback Chubs were captured during four (May–August) of the six monthly 2018 larval fish surveys. Similar to the results from previous annual Grand Canyon larval fish surveys (2014–2017), an age-0 Humpback Chub was first captured during the May survey. During 2018, age-0 Humpback Chubs (n=110) were distributed over more than 150 river miles (RM 122.2–279.0). Humpback Chubs were taken in 32 (of 56) unique generalized random tessellation stratified (GRTS) segments and 13 of those segments produced age-0 Humpback Chub in more than one monthly survey. Larval Humpback Chub were represented by all ontogenetic phases (protolarvae–metalarvae) with the majority (52%) of individuals being mesolarvae. This year (2018) was the first time Humpback Chub protolarvae have been captured during the larval surveys (2014–2018). Back-calculated length based hatching dates of Humpback Chub spanned slightly more than 12 weeks, from 24 April to 20 June, 2018.

During the first three 2018 monthly surveys, the larval fish catch was numerically dominated by native catostomids. Flannelmouth Sucker was the most abundant species captured followed immediately by Bluehead Sucker. Interestingly, the 2018 distribution and first occurrence of the larvae of these two relatively common suckers differed slightly from patterns observed in 2016 and 2017 samples. Notably, the initial capture of age-0 specimens at RM 104.8 was the first time that age-0 Flannelmouth Sucker and Bluehead Sucker were captured above RM 167.7 in March. The overwhelming majority of March 2018 age-0 catostomids were captured below RM 167.7, reinforcing the 2016–2017 spatial abundance pattern of catostomid larvae occurring in high numbers in GRTS segments downstream of Havasu Creek. 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 fish comprised 99.8% of the cumulative 2018 larval fish catch from the six months surveyed (March–August).

Over the duration of the larval fish surveys (2014–2018) five native species, including endangered Humpback Chub and Razorback Sucker, have been documented annually. While intraspecific age-0 fish densities (catch per unit effort [CPUE]) have varied across years, a single year (2014) had higher densities for all five species. Interestingly, this pattern (increased densities in 2014) was observed in two families (Cyprinidae and Catostomidae) despite their distinct spawning periods. Similarly, water temperature, discharge, and amplitude of hydropeaking varied both within and among years, and 2014 was different compared to other years of this study, with elevated water temperatures, lower discharge, and reduced hydropeaking magnitude in most months (March–August). Multiple linear regression models were used to investigate relationships between annual age-0 cyprinid and catostomid densities versus water temperature, discharge, and hydropeaking amplitude. While there are limitations to these methods (see Discussion), there were strong positive relationships between annual cyprinid and catostomid densities as a result of increased water temperature, decreased discharge, and hydropeaking amplitude.

Overall Findings

Major findings for this study to date include (1) multiple age 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 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, assuming Pearce Ferry Rapid is not a barrier to upstream movement.

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.

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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 have also declined as recruitment has not occurred at significant levels since the construction of mainstem dams (Bestgen et al. 2011). Under current conditions, which have increased lentic habitats and altered temperature and flow regimes, it is thought that predation by bass *Micropterus* spp., Common Carp *Cyprinus carpio*, Channel Catfish *Ictalurus punctatus*, sunfish *Lepomis* spp., and other nonnative species is the primary reason for the lack of Razorback Sucker recruitment throughout its original distribution (Minckley et al. 1991; Marsh et al. 2003).

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, 2017; Kegerries et al. 2009, 2015a, 2017a; Shattuck et al. 2011; Shattuck and Albrecht 2014; Mohn et al. 2015, Rogers et al. 2017, 2018).

Larval Razorback Suckers were found in the Colorado River Inflow Area of Lake Mead (CRI) during 2000 and 2001, but despite opportunistic netting efforts, no adult Razorback Suckers were captured at that time (Holden et al. 2001; Abate et al. 2002; Albrecht et al. 2008a). In 2008 the Arizona Game and Fish Department (AZGFD) captured a large adult Razorback Sucker during annual gill-netting efforts in Gregg Basin, and NDOW captured two adults in the Virgin Basin. 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 in 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). It also serves as a guide for future Razorback Sucker studies on Lake Mead (Albrecht et al. 2009). The LMWG consists of several agencies including Reclamation, USFWS, NPS, NDOW, and AZGFD working cooperatively to study Lake Mead's Razorback Sucker population.

One of the major tasks of the management plan is to explore other locations in Lake Mead for existing Razorback Sucker populations. Based on the location of known populations, which occur in areas with some turbidity and (at times) vegetative cover, the CRI was identified as the most logical area to investigate first. In addition, 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 a population exists within the upper end of Lake Mead. This was the first new task in the management plan to be implemented and is one of the first steps in meeting the conservation measure 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). Those three reports were (1) a review and summary of Razorback Sucker habitat throughout its range in the Colorado River (Valdez et al. 2012a), (2) a report on the potential habitat within the lower Grand Canyon (LGC) based on expert opinion (Valdez et al. 2012b), and (3) a possible strategy for establishing Razorback Sucker in the LGC/CRI through either natural expansion of the Lake Mead population or possible augmentation (Valdez et al. 2012c).

As recently as 2009 there was an apparent expansion in Razorback Sucker recruitment, and the observed 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 sonic tags, it was concluded that renewed efforts in the CRI would help clarify whether a spawning population existed within this area of Lake Mead (Albrecht et al. 2008a; Kegerries et al. 2009). Thus, initiating telemetry and limited sampling efforts in the CRI were 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 a 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 has and 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 reservoir levels, Razorback Sucker spawning habitats and locations have changed. Habitat in the CRI has changed during the past decade at a larger spatial scale than at some of the other spawning areas throughout the reservoir (e.g., Las Vegas Bay, Echo Bay, Virgin River/Muddy River inflow area). For example, reservoir elevation dropped from approximately 365 m in 2001 to below 329 m above mean sea level (msl) in 2018. With that decline in elevation, the reservoir receded from the confined canyon reach of the LGC to the more open area of the CRI basin, thereby exposing shallow cobble/gravel shoals.

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. This provided a unique opportunity to evaluate Razorback Sucker use of an area that has been drastically modified and remained dynamic since the river was impounded. Monitoring efforts in the CRI may also provide insight into what can and should be expected in terms of future spawning activity, particularly at the Virgin River/Muddy River inflow area and other known spawning locations within the reservoir—if reservoir levels continue to decline.

Mainstem dams along the Colorado River corridor are recognized as one of the reasons for the failed reproductive success of the Colorado River’s big river fishes (Holden 1979; Minckley et al. 1986). These structures impede migration of adults to spawning grounds and alter or eliminate the historic hydrologic cycle, in which peak discharges were common in spring during snowmelt and again in summer during monsoonal flooding. Hypolimnetic releases from dams drastically alter river temperatures, turbidity, and food bases (Mueller and Marsh 2002; Gloss et al. 2005). Management of mainstem dams to mimic historical flow conditions has been used to maintain cues for activities such as spawning and migration of native fishes, create and maintain nursery habitat for larval fishes, and suppress nonnative fish populations (Nesler et al. 1988; Bestgen and Williams 1994; Poff et al. 1998; Bestgen et al. 2011; LaGory et al. 2012). Natural flow regimes promote downstream displacement or drifting behavior of larval fishes and exploitation of premium feeding and rearing areas (Muth and Schmulbach 1984; Pavlov 1994). In many western river systems, higher spring and early summer flows increase sediment transport and turbidity, which reduce the predation of larvae (Johnson and Hines 1999). Sediment transport during high spring flows also scours substrates, providing critical spawning habitat for native catostomids (Osmundson et al. 2002). 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.

The life history of the Razorback Sucker is closely linked to the dynamic 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) (Muth et al. 1998). The larvae emerge and are transported downstream, where they become entrained in floodplains, which are inundated during spring runoff and reconnect to the main river channel. These floodplains are rich, productive nursery habitats where the young feed on plankton, insects, crustaceans, and detritus (Muth et al. 1998). In reservoirs of the lower Colorado River basin, spawning occurs in March and April, and adults congregate to spawn on shallow gravel shorelines where emerging young find food and shelter from predators in complex, rocky shorelines and vegetation (Albrecht et al. 2008a; Kegerries et al. 2009). The 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, 2015). Postlarval Razorback Suckers 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).

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 (RM 157) 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 (Clarkson and Childs 2000). However, more recently, two adult Razorback Suckers were captured by AZGFD in 2012 and 2013 below Spencer Creek (Bunch et al. 2012; Rogowski and Wolters 2014; Kegerries et al. 2017b), renewing questions about Razorback Sucker habitat use in this section of river.

Research concerning early life history of Razorback Sucker within Lake Mead and the LCG was conducted from 2014 through 2018, 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. Future decreases in reservoir elevation 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, the 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 (1) capitalize on the sampling opportunity presented by recent Razorback Sucker recruitment, (2) cover more area, and (3) increase the likelihood of capturing more individuals. With this increased effort, more resources were expended in the Colorado River proper trying to understand the relationship between the riverine environment and lentic habitat utilization of Razorback Sucker during the spawning season.

In 2014 at the CRI, all sampling efforts were 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 2014 resembled more of a monitoring-type effort.

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

- conducting larval and small-bodied fish studies to quantitatively assess annual fish reproduction, spawning, and nursery areas in 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) to provide expertise specific to the larval sampling, as well as personnel from Reclamation, NPS, USFWS, AZGFD, and NDOW for support, expertise and logistics. In addition, Dr. Rich Valdez and Dr. Paul Holden were added as team members to provide historical context, species expertise, and peer review. 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, 2017a, 2017b).

Following the goals of the initial study, this report contains information from the fifth year of this 5-year study while providing a more comprehensive analysis of data collected from 2014–2018. More specifically, information stemming from sampling in the CRI is presented as Chapter 1, while Chapter 2 covers sampling conducted in the Grand Canyon. Because of the interconnectedness between the reservoir and river, Chapter 3 provides telemetry findings in a holistic and seamless manner. While this report presents interesting and new information pertaining to the status of Razorback Sucker in 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 RIVER INFLOW AREA OF LAKE MEAD (CRI)

INTRODUCTION

This chapter presents findings from the ninth year of study within the Colorado River Inflow Area (CRI) and the fifth year under the current study objectives. The results presented are based on trammel netting and larval fish sampling within the reservoir and opportunistic sampling within the Colorado River proper. Following Kegerries and Albrecht (2013b), data for the CRI portions of this project are reported from July 1, 2017, through June 30, 2018.

In addition to this study at the CRI, annual, long-term monitoring (LTM) of Lake Mead Razorback Sucker *Xyrauchen texanus* occurs at Las Vegas Bay, Echo Bay, and the Virgin River/Muddy River inflow area, and the findings from those locations lend additional, critical insight into this wild, recruiting population of Razorback Sucker (Rogers et al. 2018). 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 hope 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 2017–2018 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 boats.
- The *interface* is the area where the river proper meets the reservoir proper. This area may or may not have flow, is typically turbid, and is transitory and highly dynamic.

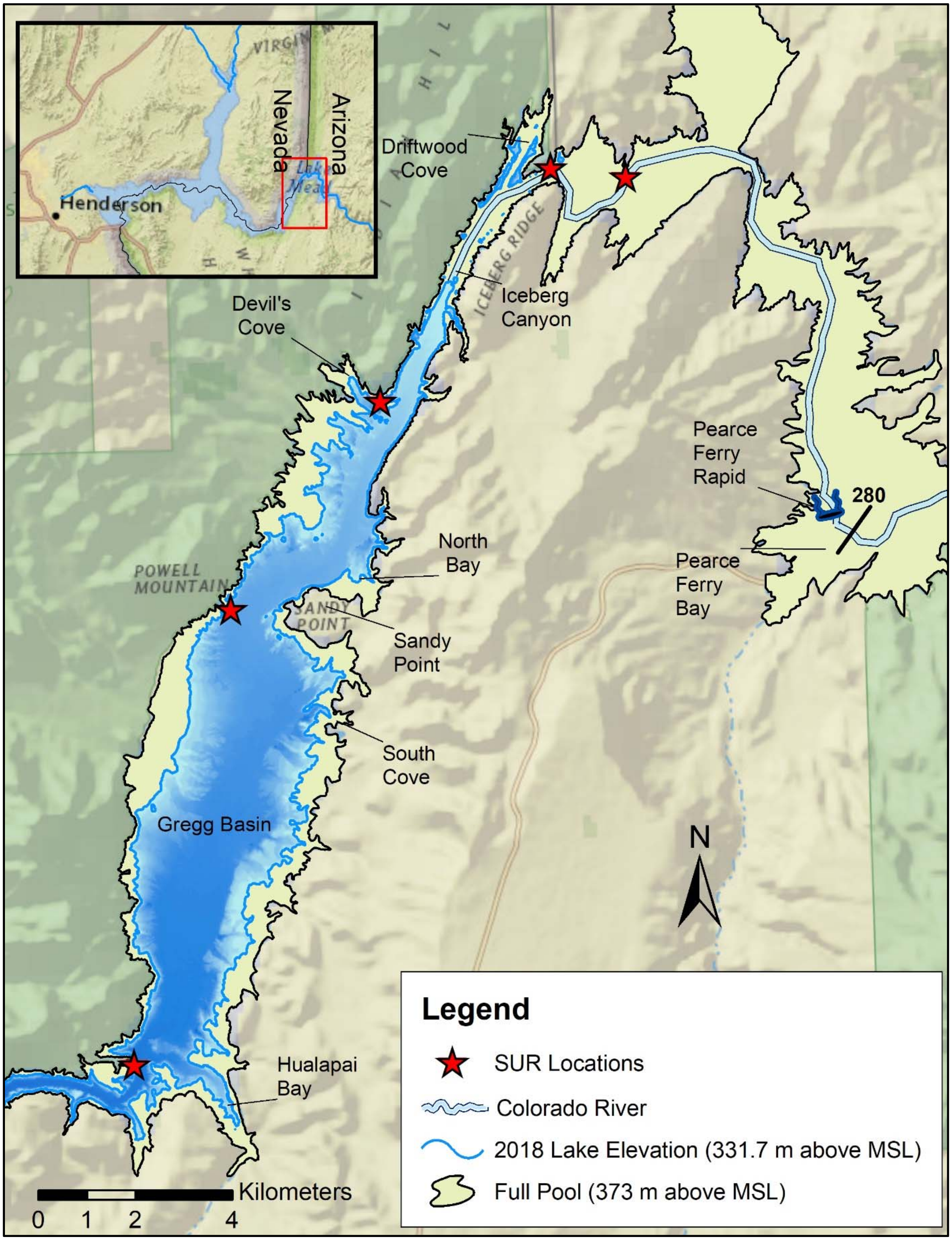

Figure 1.1. **General study area and submersible ultrasonic receiver (SUR) location at the Colorado River Inflow Area (CRI) of Lake Mead.**

METHODS

Reservoir Elevation

Month-end and projected reservoir elevations (February 1, 1935–June 30, 2018) were reported in meters above msl and obtained from the U.S. Bureau of Reclamation's (Reclamation's) Lower Colorado Regional Office website (Reclamation 2018).

Adult Studies

Trammel Netting

Adult fish were captured using trammel nets. These nets were either 91.4 m long by 1.8 m deep, or 45.7 m long by 1.2 m deep. Both net types had internal panels of 2.54-cm mesh and external panels of 30.48-cm mesh. Nets were generally set with one end near shore, with the net stretched out into deeper habitats. Most trammel nets were set in the late afternoon just before sundown and pulled the next morning shortly after sunrise. Netting locations were selected based on the locations of sonic-tagged Razorback Sucker individuals, the presence of concentrated larval fish, and previous knowledge of Razorback Sucker capture locations.

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

Catch per unit effort (CPUE) for Razorback Suckers captured via trammel netting 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 ($\ln[1+\text{CPUE}]$). An analysis of variance (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.

Length and Growth

Razorback Sucker annual growth was calculated from recaptured individuals in trammel-netting collections. Recaptured individuals were measured only once during the spawning season to avoid handling stress, and they were only used for annual growth analysis if 1 year had passed between capture occasions. Recently stocked individuals were excluded from the dataset and analyses to account for discrepancies in environmental conditions (e.g., 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, considered the likely result of field-measurement errors. Annual growth for Razorback Sucker was calculated for each individual using the difference in TL (mm) between capture periods. These data should not be used to assume typical average growth; rather they should be used in conjunction with growth reported during past field efforts on Lake Mead for a more complete understanding of Lake Mead Razorback Sucker growth. Furthermore, Mohn et al. (2015) showed that growth rates did not significantly vary between wild and stocked Razorback Sucker in Lake Mead, so the mean growth rate for 2018 were calculated by combining wild and stocked fish. Length and growth rates were also assessed for the study period from 2010 to 2018. The lengths of all wild Razorback Sucker captured via trammel netting to date and growth rates for recaptured fish are reported.

Remote Passive Integrated Transponder (PIT) Scanning

A 36-inch, round, fully-submersible PIT-scanning antenna was deployed in numerous locations and for varying time periods throughout the CRI from January to May 2018. The submersible units have an internal logger and an approximate 2-week battery life incased inside a waterproof housing.

The information recorded for each fish contacted included general location description, GPS location, date, deployment depth, and start/end scanning times. Scanner data were combined for analysis and limited to determining PIT-tagged fish movements and to identify fish that were not captured via trammel nets in 2018. Because Lake Mead contains wild, untagged Razorback Suckers, and in keeping with past year’s protocols, these data were not used in population or survival estimate models (below).

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, enumerated, and placed into a holding bucket. Larvae were retained and preserved in 10% formalin for species verification as described below. The procedure was repeated for 15 minutes at 2–6 sampling sites on each night attempted.

Because of the vast sampling area, turbidity, flowing water, and the potential for larval drift at the CRI, larval light traps were also deployed as a method to capitalize on efforts to collect catostomid larvae. The larval light traps were deployed by tying a lead 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 following day. The catch bowls were checked for larval fish and all larvae were retained in 10% formalin for species verification as described below.

Because other native sucker species are present at the CRI, preserved larval suckers were retained for laboratory microscopic verification using a key to catostomid fish larvae developed by Snyder and Muth (2004). 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 were sent to ASIR for further 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 dataset 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 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 trammel-net captures, larval sampling is conducted to validate whether successful spawning occurred. Examples of the effectiveness of these techniques are evident in the descriptions provided by Albrecht and Holden (2005) regarding the documentation of a new spawning aggregation near Fish Island in the Overton Arm of Lake Mead. This same general approach has also been used effectively at the CRI since 2010 (e.g., Kegerries et al. 2017a).

Age Determination

A nonlethal technique using fin ray sections to age captured wild Lake Mead Razorback Suckers was developed in 1999 (Holden et al. 2000a). As in past Lake Mead Razorback Sucker studies, an emphasis of the 2018 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 2018 spawning period, new fish captured via trammel nets were anesthetized and a single, approximately 5 mm-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, 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 reservoir water containing slime-coat protectant and NaCl, allowed to recover, and released as soon as they regained equilibrium and appeared recovered from the anesthesia. Vigilant monitoring was conducted during all phases of the procedure.

In the laboratory, fin ray segments were embedded in thermoplastic epoxy resin and heat-cured. This technique allowed the fin rays to be perpendicularly sectioned using a Buhler isomet low-speed saw. Resultant sections were then mounted on microscope slides, sanded, polished, and examined under a stereo-zoom microscope. At least two readers independently aged each sectioned fin ray. 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 Annual Apparent Survival Estimation

Because stocked and wild Razorback Suckers have been observed moving between all study locations within Lake Mead (i.e., Mohn et al. 2016), the population was assessed at the reservoir-wide scale. As such, a population and annual apparent survival estimate specific to the CRI is not included herein. Razorback Sucker capture and recapture data stemming from the CRI were included as part of the reservoir-wide population and annual survival estimates provided in Rogers et al. (2018).

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 mesh 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 4.5-m long and 0.6 m tall 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 (g), 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 (g) 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 95% ethanol solution. For each seine haul, a discrete suite of data was recorded on data sheet that included 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

Reservoir Elevation

The highest Lake Mead elevation during the study period was in March 2018 at approximately 331.7 m above msl. Declining by about 3.5 m from March to the end of June, the reservoir elevation receded steadily to approximately 328.2 m above msl (Figure 1.2).

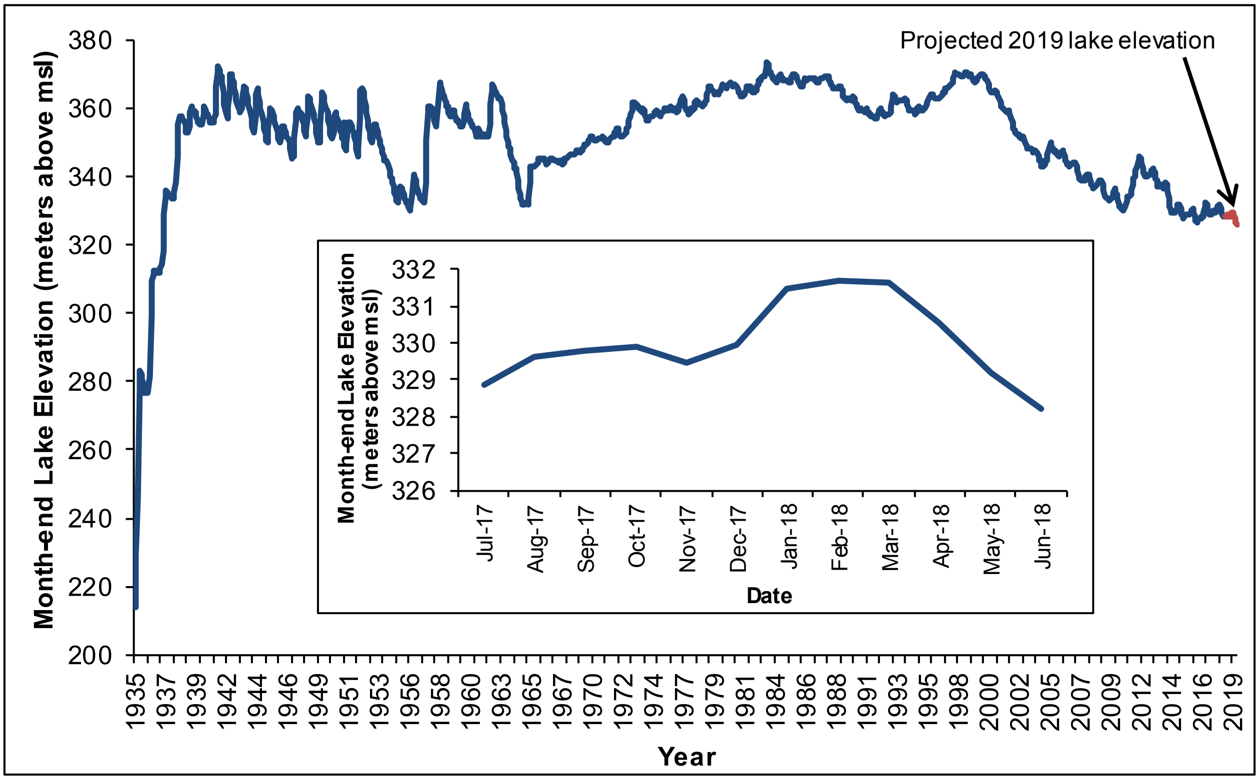

Figure 1.2. **Lake Mead month-end elevations in meters above mean sea level (msl) from February 1935 to June 2018 with projected elevation in red. The inset graph depicts reservoir elevations during the study period, (July 2017 to June 2018).**

During the first sampling event in February 2018, the reservoir elevation was 0.5 m lower than in February 2017 (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.

Adult Studies

Trammel Netting

During the 2018 field season, 99 nets were set for a total 1,462.36 net-hours, the majority of which occurred in February and March (Table 1.1). Netting was generally concentrated near the CRI, more specifically within the area known as "Lunch Cove" (Figure 1.3) (1) because this area was frequented by sonic-tagged Razorback Suckers and (2) because of previous successes capturing Razorback Suckers at this location during past field seasons. Three nets were also set farther south along the western shoreline within Gregg Basin, but not shown in Figure 1.3 as they did not capture Razorback Sucker.

Table 1.1. Trammel netting effort in the Colorado River Inflow Area of Lake Mead (CRI) during 2018, showing total nets set and net-hours by month.

MONTH	TOTAL NET SETS	TOTAL NET-HOURS
January	8	118.13
February	45	686.28
March	30	433.03
April	12	169.55
May	4	55.20
TOTAL	**99**	**1,462.36**

A total of 32 Razorback Suckers, representing 19 unique individuals, were captured during the 2018 spawning season at the CRI (Table 1.2). Twenty-five were wild fish and the remaining seven were stocked fish from previous releases for telemetry purposes. Seven of the fish captured were untagged individuals first encountered during the 2018 sampling efforts.

Of the 19 unique fish, 7 were female, 11 were male, and 1 was undetermined as it was not expressing gametes at the time of capture (Table 1.2). Razorback Suckers were captured throughout the spawning season from January 30 through May 2, 2018. Two, wild Razorback Suckers originally tagged in the Overton Arm (2009 and 2013) were recaptured at the CRI in 2018. One Razorback Sucker that was originally tagged from Floyd Lamb State Park and released into the Overton Arm in 2015 was recaptured at the CRI in 2018. Additionally, one fish released into the Grand Canyon at Diamond Creek for telemetry purposes was recaptured at CRI numerous times during the 2018 field season.

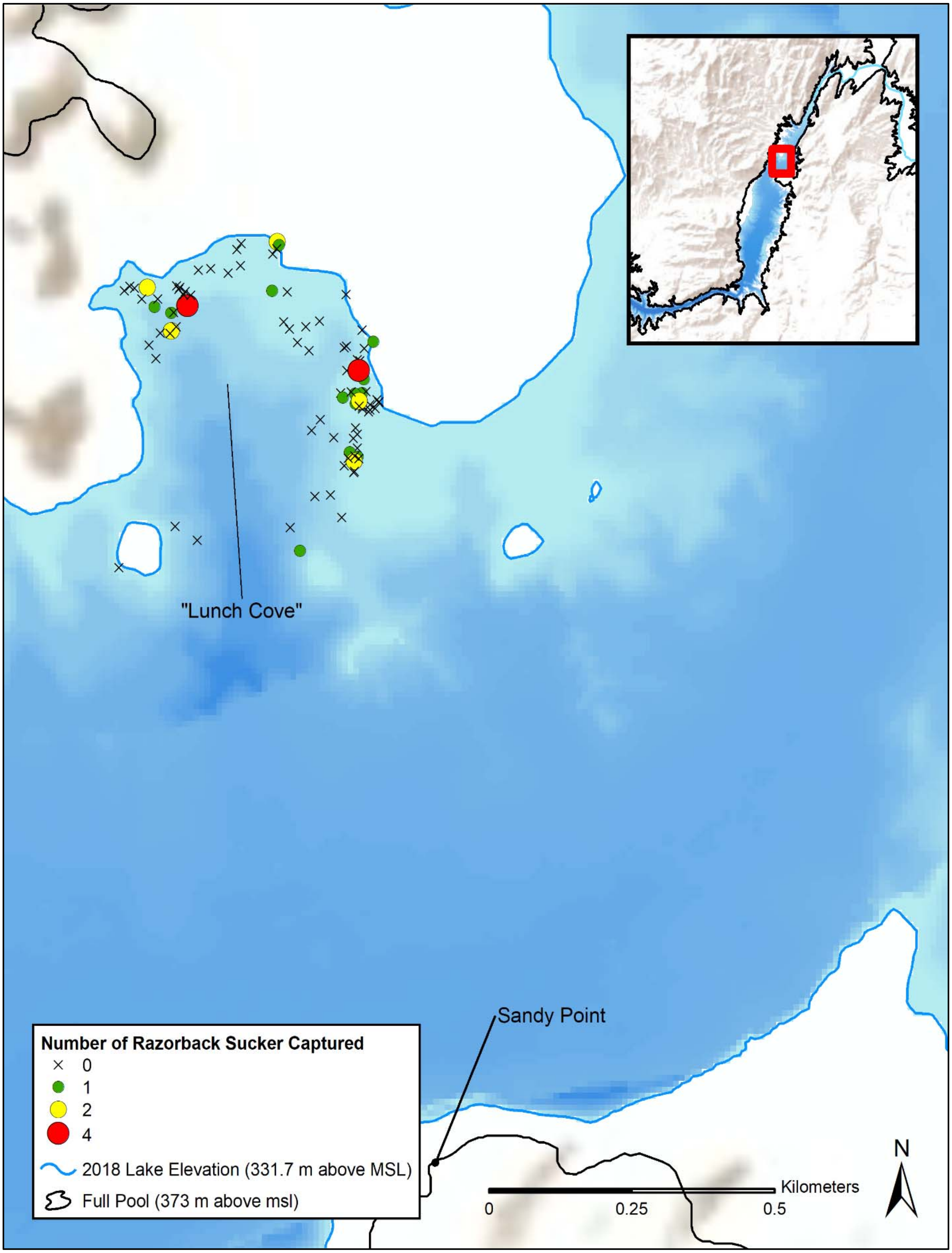

Figure 1.3. **Trammel-netting locations and numbers of fishes captured in the Colorado River Inflow Area of Lake Mead (CRI), January–May 2018.**

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 2018.

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]
01/30/18	RBS	384.1B7969CFBA	3466	03/21/13	YES (WILD)	606	555	528	2450	M
01/30/18	RBS	3D9.1C2C8572E3		02/04/09	YES (WILD)	654	602	565	2980	F
01/30/18	RBS	3DD.003BA208F2	3465	02/24/15	YES (WILD)	576	530	497	2505	M
01/30/18	RBS	3DD.003BA20A1C	3567	01/30/18	NO (WILD)	521	480	399	1460	M
01/30/18	RBS	3DD.003BA2FAA5	5777	03/17/15	YES (WILD)	603	555	524	2465	F
01/30/18	RBS	3DD.003BCBF7FA	3076	02/22/16	YES (STOCKED)	528	482	447	1730	F
01/30/18	RBS	3DD.003BCBF7FA	3076	02/22/16	YES (STOCKED)	–[h]	–[h]	–[h]	–[h]	F
02/01/18	RBS	3D9.1C2C8572E3		02/04/09	YES (WILD)	–[h]	–[h]	–[h]	–[h]	F
02/01/18	RBS	3DD.003BA20A53		02/01/18	NO (WILD)	566	524	491	2190	M
02/01/18	RBS	3DD.003BA2F9D9		01/05/11	YES (STOCKED)	540	496	465	1775	M
02/07/18	RBS	3D9.1C2D2683FE	3446	02/08/11	YES (WILD)	674	620	583	3335	F
02/07/18	RBS	3DD.003BA2091F	3367	02/26/15	YES (WILD)	661	619	586	2875	F
02/13/18	RBS	3DD.003BA2FAA5	5777	03/17/17	YES (WILD)	–[h]	–[h]	–[h]	–[h]	F
02/21/18	RBS	384.1B796EE9AA		03/20/12	YES (WILD)	648	593	564	2785	M
02/23/18	RBS	3DD.003BA208F2	3465	02/24/15	YES (WILD)	–[h]	–[h]	–[h]	–[h]	M
02/23/18	RBS	3DD.003BE8F1D7		01/19/17	YES (WILD)	639	598	561	2890	F
02/23/18	RBS	3DD.003C06F118		02/28/18	NO (WILD)	448	416	384	1260	M
02/27/18	RBS	3DD.003BA2FAA5	5777	03/17/15	YES (WILD)	–[h]	–[h]	–[h]	–[h]	F
03/01/18	RBS	3DD.003C06F0DA		03/01/18	NO (WILD)	606	556	521	2350	M
03/01/18	RBS	3DD.003C06F118		02/28/18	YES (WILD)	–[h]	–[h]	–[h]	–[h]	M
03/05/18	RBS	3DD.003BA2FAA5	5777	03/17/15	YES (WILD)	–[h]	–[h]	–[h]	–[h]	F
03/06/18	RBS	3DD.003BA2091F	3367	02/26/15	YES (WILD)	–[h]	–[h]	–[h]	–[h]	F
03/07/18	RBS	384.1B7969CFBA	3466	03/21/13	YES (WILD)	–[h]	–[h]	–[h]	–[h]	M
03/07/18	RBS	384.1B7969CFBA	3466	03/21/13	YES (WILD)	–[h]	–[h]	–[h]	–[h]	M
03/07/18	RBS	384.1B796EE629	6678	01/05/11	YES (STOCKED)	581	522	491	2635	M
03/07/18	RBS	3DD.003BA20A2D		03/07/18	NO (WILD)	579	543	505	2220	F
03/07/18	RBS	3DD.003BA20A4A		03/07/18	NO (WILD)	558	514	480	1985	M
03/07/18	RBS	3DD.003BA6399D		02/06/15	YES (STOCKED)	573	523	487	2165	M
03/07/18	RBS	3DD.003BCBF7FA	3076	02/22/16	YES (STOCKED)	–[h]	–[h]	–[h]	–[h]	F
03/13/18	RBS	384.1B7969CFBA	3466	03/21/13	YES (WILD)	–[h]	–[h]	–[h]	–[h]	M
03/13/18	RBS	3DD.003BCBF7FA	3076	02/22/16	YES (STOCKED)	–[h]	–[h]	–[h]	–[h]	F
05/02/18	RBS	3DD.003BA2FA76		05/02/18	NO (WILD)	473	444	405	1495	U
01/17/18	H	3DD.003BA20890		04/19/16	YES (WILD)	575	–[h]	–[h]	1835	F
01/18/18	H	3DD.003BA2089E		04/19/16	YES (WILD)	489	–[h]	–[h]	1150	M
01/30/18	H	3DD.003BA20A1B		02/15/17	YES (WILD)	557	524	485	1810	F
01/30/18	H	3DD.003BA2FAB4		03/17/16	YES (WILD)	502	466	435	1200	M

Table 1.2. (Cont.)

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]
01/30/18	H	3DD.003BA20890		04/19/16	YES (WILD)	568	528	496	1880	M
02/01/18	H	3DD.003BA2FAB4		03/17/16	YES (WILD)	–[h]	–[h]	–[h]	–[h]	–[h]
02/01/18	H	3DD.003BE8F551		02/10/16	YES (WILD)	567	541	505	2045	F
02/01/18	H	3DD.003C06EDF5		02/01/18	NO (WILD)	425	–[h]	–[h]	800	M
02/06/18	H	3DD.003BE8F551		02/16/10	YES (WILD)	–[h]	–[h]	–[h]	–[h]	F
02/06/18	H	3DD.003BE8F22C		01/18/17	YES (WILD)	–[h]	–[h]	–[h]	–[h]	F
02/06/18	H	3DD.003BA20A69		02/06/18	NO (WILD)	562	525	486	1680	F
02/07/18	H	3DD.003BA2FAB4		01/30/18	YES (WILD)	–[h]	–[h]	–[h]	–[h]	M
02/14/18	H	3DD.003BA20A69		02/06/18	YES (WILD)	–[h]	–[h]	–[h]	–[h]	F
02/14/18	H	3DD.003BA2FAB4		03/17/17	YES (WILD)	–[h]	–[h]	–[h]	–[h]	M
02/21/18	H	3DD.003BE8F551		02/10/16	YES (WILD)	–[h]	–[h]	–[h]	–[h]	F
02/22/18	H	3DD.003BE8F551		02/10/16	NO (WILD)	–[h]	–[h]	–[h]	–[h]	F
02/23/18	H	3DD.003BE8F22C		01/18/17	YES (WILD)	–[h]	–[h]	–[h]	–[h]	F
02/23/18	H	3DD.00.BA20890		04/19/16	YES (WILD)	–[h]	–[h]	–[h]	–[h]	F
02/23/18	H	3DD.003BE8F22C		01/18/17	YES (WILD)	–[h]	–[h]	–[h]	–[h]	F
02/23/18	H	3DD.003BA2FAB4		03/17/17	YES (WILD)	–[h]	–[h]	–[h]	–[h]	M
02/27/18	H	3DD.003BE8F551		02/10/16	NO (WILD)	–[h]	–[h]	–[h]	–[h]	F
03/01/18	H	3DD.003BA769EA		01/20/17	YES (WILD)	537	504	471	1665	M
03/01/18	H	3DD.003BA20890		04/19/16	YES (WILD)	–[h]	–[h]	–[h]	–[h]	F
03/01/18	H	3DD.003BE8F551		02/10/16	YES (WILD)	–[h]	–[h]	–[h]	–[h]	M
03/05/18	H	3DD.003BA20A1B		02/15/17	NO (WILD)	–[h]	–[h]	–[h]	–[h]	F
03/06/18	H	3DD.003BE8F53D		01/21/16	YES (WILD)	470	432	402	940	U
03/06/18	H	3DD.003BE8F22C		01/18/17	YES (WILD)	–[h]	–[h]	–[h]	–[h]	F
03/07/18	H	3DD.003BA2FAB4		03/17/17	YES (WILD)	–[h]	–[h]	–[h]	–[h]	M
03/07/18	H	3DD.003BA20890		04/19/16	YES (WILD)	–[h]	–[h]	–[h]	–[h]	M
03/07/18	H	3DD.003BA20890		04/19/16	YES (WILD)	–[h]	–[h]	–[h]	–[h]	M
03/07/18	H	3DD.003BA20890		04/19/16	YES (WILD)	–[h]	–[h]	–[h]	–[h]	M
03/13/18	H	3DD.003BE8F53D		01/21/16	YES (WILD)	–[h]	–[h]	–[h]	–[h]	I
03/13/18	H	3DD.003BE8F551		02/18/16	YES (WILD)	–[h]	–[h]	–[h]	–[h]	F
03/22/18	H	3DD.003BE8F53D		01/21/16	YES (WILD)	–[h]	–[h]	–[h]	–[h]	U
04/05/18	H	3DD.003C06F134		04/05/18	NO (WILD)	533	494	455	1690	U

[a] Species: RBS=Razorback Sucker, H=hybrid sucker. [b] Date originally stocked or originally captured. [c] TL=total length. [d] FL=fork length. [e] SL=standard length. [f] WT=weight. [g] Sex: F=female, M=male, I=immature, U=undetermined. [h] =Not recorded, typically to avoid excessive handling stress.

The Razorback Sucker mean catch rate at the CRI in 2018 was 0.021 (SE ± 0.005) fish per net-hour (Table 1.3 and Figure 1.4); the highest catch rate calculated since the project's inception. A significant difference in mean annual catch rates was detected (ANOVA, $F_{8,1008}$=4.17, P<0.0001). Post hoc analysis (Tukey's HSD) determined the mean 2018 catch rate was higher than all other annual catch rates except for 2010, 2012, and 2015 (Figure 1.4). Mean catch rates at the CRI have become more similar to catch rates at other spawning areas within Lake Mead.

Table 1.3. Number and catch rate of Razorback Suckers, Flannelmouth Suckers, and hybrid suckers captured from 2010 to 2018.

YEAR	NUMBER RAZORBACK SUCKER CAPTURED	RAZORBACK SUCKER CPUE[a] (±SE)	NUMBER FLANNELMOUTH SUCKER CAPTURED	FLANNELMOUTH SUCKER CPUE[a] (±SE)	NUMBER HYBRID SUCKER CAPTURED	HYBRID SUCKER CPUE[a] (±SE)
2010	3	0.009 (0.007)	51	0.113 (0.023)	3	0.007 (0.005)
2011	15	0.005 (0.002)	110	0.036 (0.004)	9	0.003 (0.001)
2012	33	0.011 (0.002)	191	0.060 (0.007)	1	0.000 (<0.001)
2013	4	0.004 (0.002)	271	0.208 (0.031)	2	0.002 (0.001)
2014	6	0.005 (0.002)	254	0.151 (0.021)	7	0.009 (0.005)
2015	17	0.010 (0.003)	129	0.081 (0.013)	3	0.001 (0.001)
2016	7	0.003 (0.001)	113	0.056 (0.007)	7	0.004 (0.002)
2017	12	0.007 (0.002)	68	0.041 (0.007)	18	0.014 (0.005)
2018	32	0.021 (0.005)	12	0.008 (0.003)	35	0.020 (0.004)

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

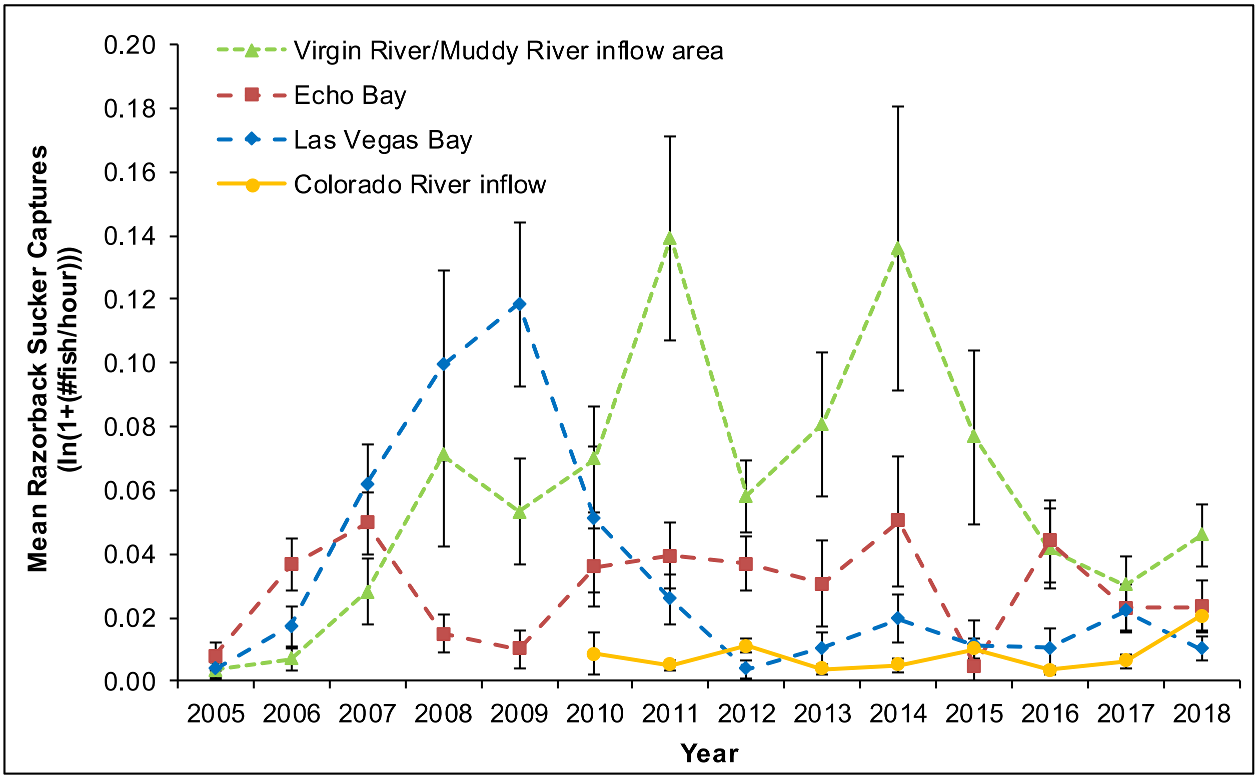

Figure 1.4. Trammel-netting catch per unit effort (CPUE expressed as the mean ln(1+(#Razorback Sucker/hour)) (±SE)) values from the Colorado River Inflow Area of Lake Mead (CRI) and long-term monitoring (LTM) sites throughout Lake Mead, 2005–2018.

Thirty-five wild hybrid suckers were captured at the CRI in 2018 (Table 1.2), resulting in a mean catch rate of 0.020 (SE ± 0.004) (Table 1.3). Since 2010, 81 hybrid suckers have been captured at the CRI with a sex ratio of approximately 1:1.6 (male:female), and adults of both sexes typically exhibited signs of sexual maturity at time of capture.

Additionally, in 2018, 12 Flannelmouth Suckers were captured (Appendix A), resulting in a mean catch rate of 0.008 (SE ± 0.003) (Table 1.3). Flannelmouth Sucker mean catch rates have varied by year and where netting occurs. Many of these fish were either immature or their sex was not readily identifiable at the time of capture; thus, sex ratios are not included (Appendix A). Since 2010, 1,199 Flannelmouth Suckers have been captured at the CRI.

Length and Growth Information

Razorback Suckers captured in 2018 ranged in size from 448 to 674 mm (TL) (Figure 1.5) with a mean TL of 580.7 mm (SE± 14.1). Since 2010, 104 wild, Razorback Suckers captured in trammel nets have been measured. Lengths ranged from 215–674 mm (TL) with a mean TL of 571.5 mm (SE± 9.2). The hybrid suckers captured at the CRI in 2018 ranged from 425 to 568 mm (TL) with a mean TL of 524.6 mm (SE± 16.6). Finally, Flannelmouth Suckers captured in 2018 at the CRI ranged in size from 259 to 551 mm (TL) with a mean TL of 455.2 mm (SE± 27.2).

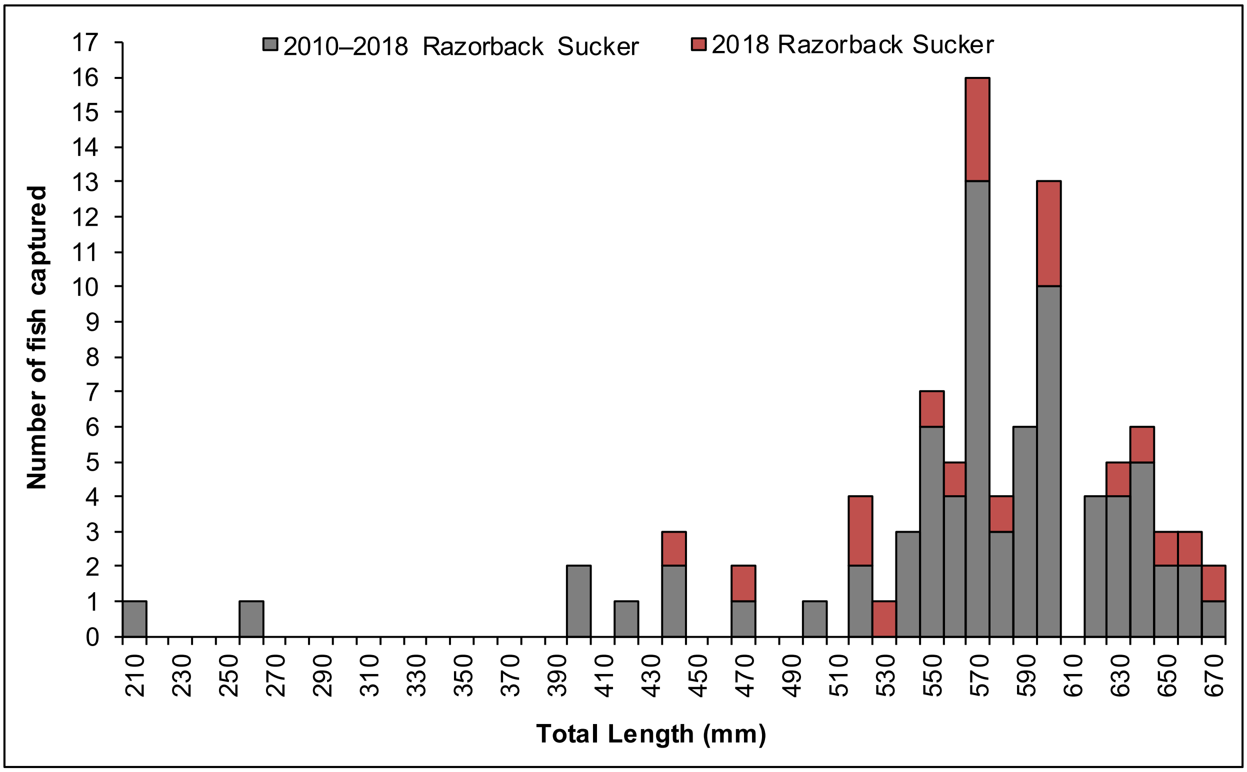

Figure 1.5. Length-frequency (total length) distributions for Razorback Suckers captured at the Colorado River Inflow Area of Lake Mead (CRI) in 2018 (red bars) and combined from 2010–2018 (gray bars).

Although 32 Razorback Suckers were captured at the CRI in 2018, annual growth rate analyses were performed using data from 11 recaptured Razorback Sucker (seven wild and four stocked) (Tables 1.3 and 1.4). The mean annual growth at the CRI was 8.7 mm (TL) (SE ± 1.1 mm) in 2018 (Table 1.4). For comparison, mean annual growth of all Razorback Suckers captured from LTM locations in Lake Mead during 2018 was 10.0 mm (TL) (SE ± 1.3 mm) (Rogers et al. 2018). Since 2010, mean annual growth have ranged from 8.4 mm (TL) (SE± 5.2) to 31.9 mm (TL) (SE± 7.8) per year. Individual Razorback Sucker growth rates for the study have ranged from 0–87.6 mm (TL) with mean growth calculated at 15.9 mm (TL) (SE± 2.7).

Table 1.4. Growth histories of applicable Razorback Sucker recaptured at the Colorado River Inflow Area of Lake Mead (CRI) in 2018.

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	02/04/09	602	01/30/18	654	52	3,284	5.8
384.1B7969CFBA	03/21/13	570	01/30/18	606	36	1,818	7.2
384.1B796EE9AA	03/20/12	630	02/21/18	648	18	2,164	3.0
3D9.1C2D2683FE	02/08/11	594	02/07/18	674	80	2,556	11.4
3DD.003BA2091F	02/26/15	634	02/07/18	661	27	1,104	8.9
3DD.003BA2FAA5	03/17/15	572	01/30/18	603	31	1,084	10.4
3DD.003BE8F1D7	01/19/17	624	02/23/18	639	15	400	13.7
Stocked Fish							
3DD.003BCBF7FA	02/22/16	505	01/30/18	528	23	750	11.2
3DD.003BA6399D	02/06/15	539	03/07/18	573	34	1,125	11.0
3DD.003BA2F9D9	01/05/11	462	02/01/18	540	78	2,584	11.0
384.1B796EE629	01/05/11	565	03/07/18	581	16	2,618	2.2
Mean annual growth- All Fish							**8.7 (SE ± 1.1)**

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

Remote Passive Integrated Transponder (PIT) Scanning

Submersible PIT-scanning efforts were conducted for 537.8 hours and resulted in the detection of 14 unique Razorback Suckers (n=8, wild and n=6, stocked), five wild, hybrid suckers, four wild Flannelmouth Suckers, and one Common Carp (Table 1.5). Five of the Razorback Suckers contacted were not captured in trammel nets in 2018. One Razorback Sucker contacted was originally tagged in the Overton Arm in 2011. Two others were sonic-tagged fish originally released in the Grand Canyon near Lava Falls and Diamond Creek in 2014 and 2016, respectively. The Common Carp was originally PIT-tagged in the Grand Canyon, at Bright Angel Creek, Arizona in 2015 (Table 1.5).

Table 1.5. Remote PIT tag scanner detections at the Colorado River Inflow Area of Lake Mead (CRI) showing contact date, last capture date, original tagging location, and days at large of each individual species detected in 2018.

PIT TAG NUMBER	DATE SCANNED	DATE OF LAST CAPTURE	ORIGINAL TAGGING LOCATION	DAYS AT LARGE	SPECIES	ORIGIN
384.1B796EE9AA	3/06/2018	2/21/2018	CRI	13	RZ	Wild
3DD.003BA20A1C	3/12/2018	1/30/2018	CRI	41	RZ	Wild
384.1B796EFA81	3/13/2018	3/18/2015	CRI	1,091	RZ	Stocked
3DD.003C06F0DA	3/13/2018	3/01/2018	CRI	12	RZ	Wild
384.1B796EE629	3/14/2018	3/07/2018	CRI	7	RZ	Stocked
384.1B796EEEB3	3/14/2018	4/03/2012	CRI	2,171	RZ	Wild
3DD.003BA20A53	3/14/2018	2/01/2018	CRI	41	RZ	Wild
384.1B796EDB73	3/15/2018	3/10/2011	CRI	2,562	RZ	Wild
3DD.003BA2F9D9	3/15/2018	2/01/2018	CRI	42	RZ	Stocked
3DD.003BCBF7FA	3/16/2018	3/13/2018	GC	3	RZ	Stocked
3D9.1C2D6964A6	3/17/2018	1/05/2011	CRI	2,628	RZ	Stocked
3D9.1C2D6D102B	3/17/2018	3/16/2014	GC	1,462	RZ	Stocked
384.1B7969CFBA	3/18/2018	3/13/2018	OA	5	RZ	Wild
3D9.1C2D2683FE	3/19/2018	2/07/2018	CRI	40	RZ	Wild
3DD.003BE8F53D	3/06/2018	3/22/2018	CRI	-16	HYB	Wild
3DD.003BA20890	3/12/2018	3/07/2018	CRI	5	HYB	Wild
3DD.003BA20A69	3/13/2018	2/14/2018	CRI	27	HYB	Wild
3DD.003BE8F551	3/13/2018	3/13/2018	CRI	0	HYB	Wild
3DD.003BA20A79	3/15/2018	3/21/2017	CRI	359	HYB	Wild
3DD.003C06F121	3/12/2018	4/05/2018	CRI	-24	FM	Wild
384.1B796EDDFE	3/17/2018	3/13/2018	CRI	4	FM	Wild
384.36F2B25F2F	3/17/2018	2/01/2018	CRI	44	FM	Wild
3DD.003BA208C7	3/18/2018	12/20/2017	CRI	88	FM	Wild
3DD.003BCAB65B	3/19/2018	4/13/2015	GC	1,071	CP	Wild

Larval Sampling

Sampling for Razorback Sucker larvae began on January 29, 2018, and continued through May 1, 2018. Larval sampling was conducted near areas where sonic-tagged fish were contacted, where adult Razorback Suckers were captured, and in coves near the river outflow (Figure 1.6). Much of the effort was focused in and around Lunch Cove and at the river/reservoir interface. Additional sampling took place around a sonic-tagged fish in the southern end of Gregg Basin; however, no larvae were found in this southern location.

Active larval sampling in 2018 consisted of 1,941 minutes and resulted in the capture of three Razorback Sucker larvae. Additionally, eight Flannelmouth Sucker and one Bluehead Sucker larvae were captured during active sampling. The first larval Razorback Sucker capture during active sampling occurred on March 27, 2018, when surface water temperature was 14.8°C. All Razorback Sucker larvae were captured within a 2-day period when water surface temperatures ranged from 14.3 to 17.3°C at sampling sites (Figure 1.6).

The mean larval Razorback Sucker catch rate was 0.001 (SE ±0.001) in 2018, with significant differences found between years from 2010 through 2018 (ANOVA, $F_{8,987} = 12.6$, $P<0.0001$) (Figure 1.7). Although significant differences occurred, post hoc pairwise comparisons could not determine which years were different.

Lastly, to increase larval sampling efforts and cover more area for longer periods of time, 21 passive light traps were deployed in 2018. No larvae were captured during the 17,913 larval light-trap minutes.

Spawning-Site Identification and Observations

The larval Razorback Suckers collected at the CRI in 2018 were found within Lunch Cove (Figure 1.6). The additional presence of sonic-tagged fish (see Chapter 3) and ripe adults suggests that spawning likely occurred at the CRI in 2018. More specifically, it appears that the east shore of Lunch Cove would be considered the primary spawning area. Although there were low numbers of captured larvae, the consistent use of this habitat by adults in spawning conditions indicates its use as a spawning area, regardless of whether spawning and hatching was successful.

Razorback Sucker Aging

Fin ray sections from seven Razorback Suckers and one hybrid sucker were obtained for aging in 2018 bringing the total number of aged Razorback Suckers from the CRI to 46. The seven Razorback Suckers were age-5 (*n*=1; 2013 year-class), age-6 (*n*=1; 2012 year-class), age-8 (*n*=1; 2010 year-class), age-9 (*n*=1; 2009 year-class), age-10 (*n*=2; 2008 year-class) and age-14 (*n*=1; 2004 year-class) (Figure 1.8 and Appendix B). The hybrid sucker was determined to be age-4, from the 2013 year-class.

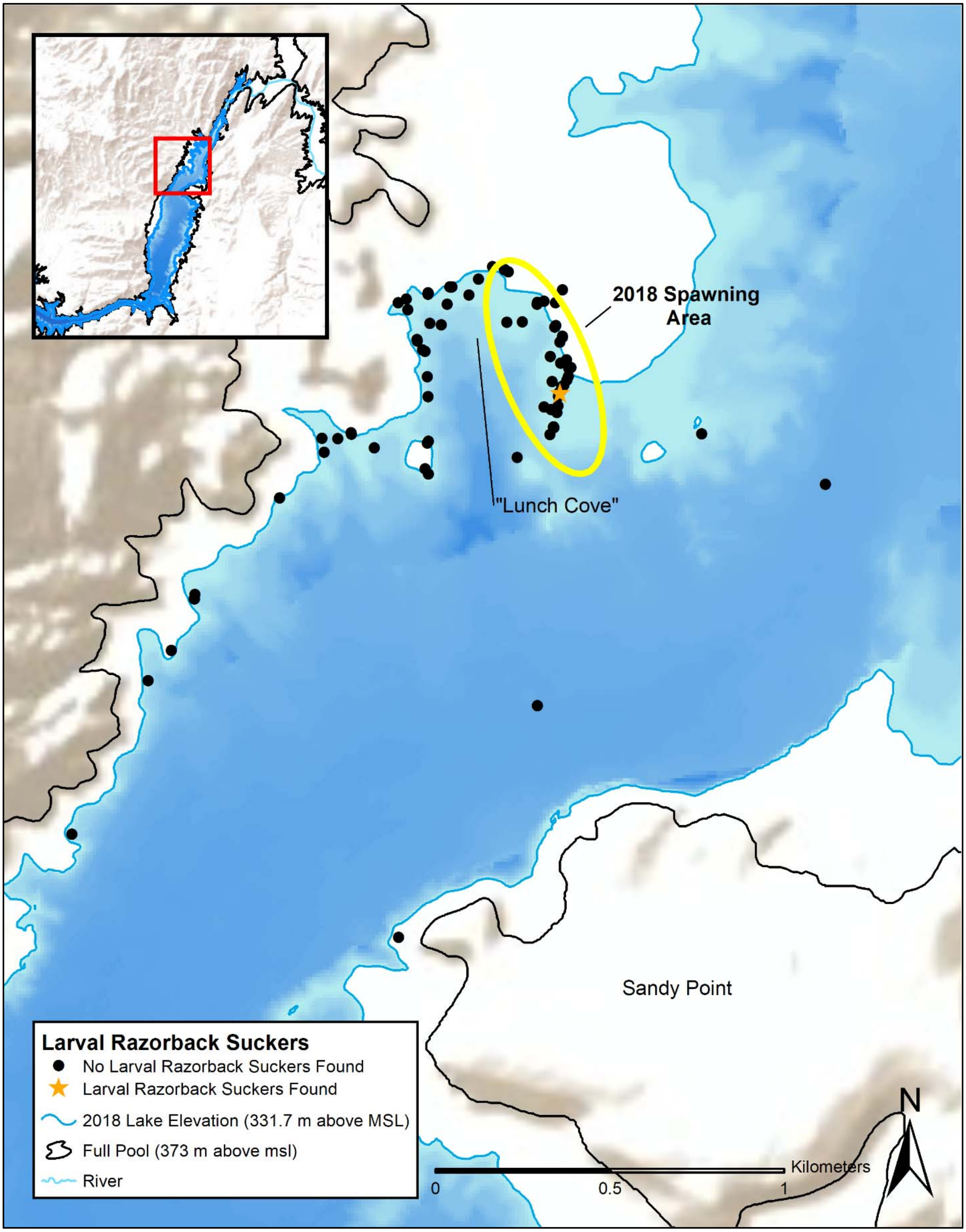

Figure 1.6. Larval Razorback Sucker sample and capture locations in the Colorado River Inflow Area of Lake Mead (CRI), 2018.

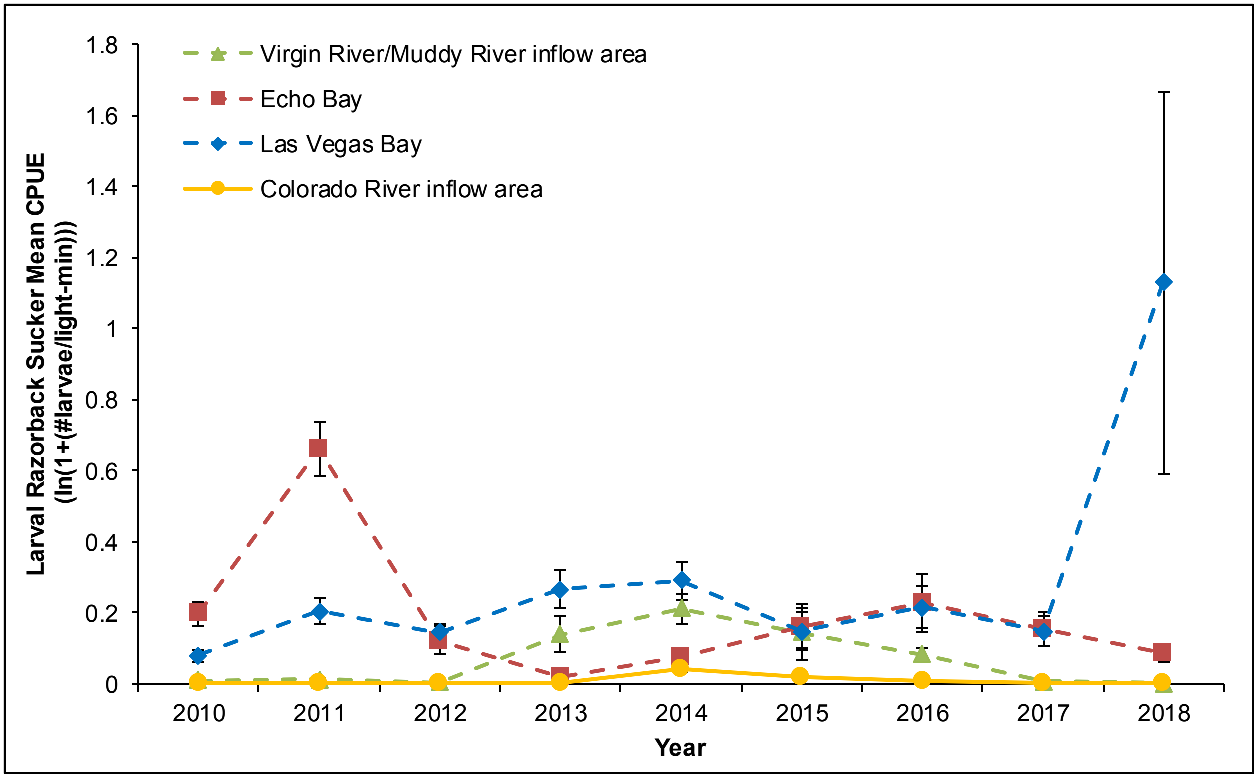

Figure 1.7. **Larval Razorback Sucker mean catch per unit effort (CPUE) (ln(1+(number larvae/light-minute sampled)) (±SE)) comparisons by primary sampling location on Lake Mead for 2010–2018.**

To put the data into a population-based perspective, since Razorback Suckers move from various spawning locations and between the reservoir and river proper, Figure 1.8 presents cumulative Lake Mead Razorback Sucker aging data from all sampling locations (see Rogers et al. 2018). To date, all aged fish were spawned from 1972 to 2015, with the exception of one fish, which was spawned around 1966 (Appendix B). Until recently, the majority of fish aged were spawned during high reservoir 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 were spawned and survived to adult fish after 1999, which coincides with the steady decline in reservoir elevation through 2010. With the inclusion of this year's data, 2001–2007 appear to be some of the more abundant age classes, which alludes to better periods for Lake Mead Razorback Sucker recruitment, despite dropping reservoir elevations (Figure 1.8). When combined with the LTM data, aged fish captured in the CRI coincide with strong cohorts observed from other areas of the reservoir (Figure 1.8).

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

Efforts conducted in the Colorado River below Pearce Ferry Rapid downstream to the CRI from March to May 2018 resulted in the capture of both native and nonnative fish species using multiple capture methods and gears (Table 1.6).

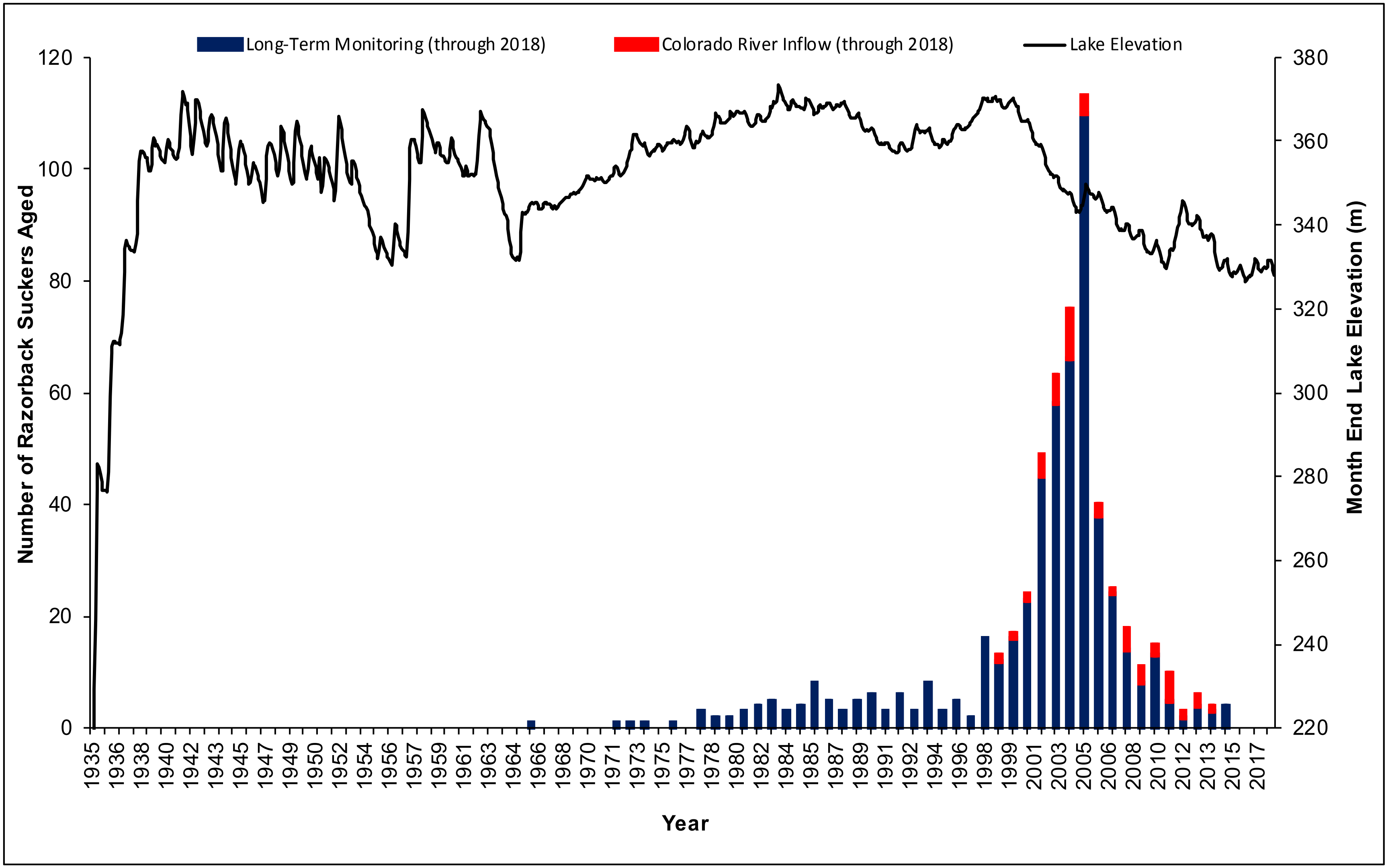

Figure 1.8. Lake Mead hydrograph from January 1935 to June 2018, with the number of aged Razorback Suckers spawned each year through 2018. Red bars denote the Razorback Suckers aged from the Colorado River Inflow Area of Lake Mead (CRI), while blue bars denote Razorback Suckers aged from the long-term monitoring (LTM) study.

Table 1.6. Small-bodied and larval fish supplemental sampling between Pearce Ferry Rapid and the Colorado River Inflow Area of Lake Mead (CRI) from March to May 2018.

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										
3/8/2018	1.2x4.6 m seine	12	0	4	0	1	0	3	76	9.5
3/18/2018	1.2x4.6 m seine	2	0	0	0	0	0	1	4	20.0
6/6/2018	1.2x4.6 m seine	61	0	140	0	0	0	11	365	26.4
3/20/2018	fyke net	1	0	0	0	0	1	0	0	100.0
	hoop net	3	0	4	0	0	0	0	1	80.0
3/14/2018	hoop net	8	0	28	0	0	4	8	1	97.6
3/15/2018	hoop net	9	0	26	0	0	5	17	0	100.0
3/28/2018	hoop net	2	0	0	0	0	0	1	0	100.0
	trammel net	8	0	7	0	0	0	0	19	26.9
4/3/2018	hoop net	11	0	2	0	0	2	0	22	15.4
Total Fish			0	211	0	1	12	41	488	35.2
Larval Fish Sampling										
3/8/2018	larval seine	2	1	2	0	0	0	0	0	100.0
3/28/2018	larval seine	3	0	0	0	0	0	0	1	0.0
4/4/2018	larval seine	6	0	2	0	0	0	0	22	8.3
5/1/2018	larval seine	12	1	22	0	9	2	0	1	97.1
Total Fish[a]			2	26	0	9	2	0	24	61.9

[a] Not all fish captured were larvae. Many were identified and released juveniles.

During supplemental small-bodied sampling efforts between Pearce Ferry and the river outflow, 265 native fishes were captured and made up 35.2% of the catch (Table 1.6). Flannelmouth Suckers were the most commonly captured native species (*n*=211) and ranged in size from 14 to 492 mm TL with a mean TL of 74.7 mm (SE ± 7.0). Forty-one Speckled Dace *Rhinichthys osculus* were captured, and they ranged in size from 24 to 90 mm TL with a mean TL of 62.8 mm (SE ± 2.5). Twelve Humpback Chub *Gila cypha* (54–324 mm TL; 131.8 mm mean TL [SE ± 30.4]) were captured, along with one Bluehead Sucker *Catostomus discobolus* (55 mm TL) (Table 1.6). In addition to small and juvenile fish sampled by seining and netting, two larval Razorback Suckers were captured via larval seining along with several Flannelmouth and Bluehead suckers.

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. These findings also underscore the apparent importance of inflow habitats to Razorback Sucker as a species (Albrecht et al. 2017). It remains unclear to what degree Razorback Sucker recruitment occurs within the lacustrine versus riverine portions of the area; however, age-0, juveniles (*n*=2, 23 and 34 mm [TL]) (Albrecht et al. 2014a), an age-2 juvenile (Kegerries and Albrecht 2013b), as well as several younger Razorback and hybrid suckers aged between 3 and 5 years, have been found occupying CRI and riverine habitat in Iceberg Canyon habitat over the 9-year study period. 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 Studies 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 number 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 [RM 179]), but limited evidence was found for spawning within the CRI (Albrecht et al. 2014a). In 2015, spawning evidence was discovered in riverine and reservoir locations (Kegerries et al. 2015a), while in 2016 and 2017 spawning was confirmed only within the river (Kegerries et al. 2016b and 2017a). In 2018 we captured few Razorback Sucker larvae, but did document spawning adults at the CRI and observed 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 in 2018 was a 5-year-old individual captured at the CRI. 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, several backwater and slackwater habitats occurred in Iceberg Canyon, which is where two of the age-0 juvenile Razorback Suckers were captured (Albrecht et al. 2014a). It is possible that changes in the river allow for better-targeted sampling of prime recruitment habitat suck as oxbow-like areas. These sporadic findings highlight the cryptic nature of juvenile Razorback Suckers and the difficult-to-sample habitats they seem to occupy.

Captures of Flannelmouth Suckers and hybrid suckers have been relatively common at the CRI since 2010 (Albrecht et al. 2010a, 2014a; Kegerries and Albrecht 2011, 2013a, 2013b; Kegerries et al. 2015a, 2016, 2017). Although hybridization between Flannelmouth Sucker and Razorback Sucker has been extensively documented, the reasons for hybridization between these species at the CRI and within the Grand Canyon are not clearly understood (Bestgen 1990). However, at the CRI, habitat alterations could potentially reduce reproductive isolation, thereby increasing the likelihood of hybridization (Muhlfeld et al. 2009). Hybridization between these two species has also been documented on the San Juan River, where Razorback Suckers are stocked into areas with large Flannelmouth Sucker populations (Ryden 2006). It is unclear whether hybridization will negatively impact the wild Razorback Sucker population at the CRI or within Lake Mead. 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, and the preservation and conservation of native species is certainly a NPS mission focus (NPS 2013a), 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.

Lake Mead reservoir elevation will likely continue to fluctuate over the next several years. If this occurs, Razorback Suckers at the CRI are likely to change spawning site locations to adapt to the variable conditions imposed by these fluctuations and Colorado River dynamics, as they have done in preceding years throughout the lake (e.g., Rogers et al. 2017). Given the relatively large inflow area and the delta formed by the Colorado River proper, as well as the magnitude of change that has occurred at the CRI, shifts in spawning site location may be observed during future field seasons. These changes necessitate continued and careful monitoring of this relatively understudied Razorback Sucker spawning aggregation, both within the reservoir 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. Their capture 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, 2017; Kegerries et al. 2015a, 2017b).

2. Razorback Suckers occur in the CRI and were found in spawning condition during the spawning period. The number of Razorback Suckers at this location varies, and the timing and intensity of spawning appears to be more 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 reservoir conditions, including inter-annual and intra-annual river and reservoir elevation 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.

3. Wild Razorback Suckers, including juveniles of various ages, have been captured at different locations in the CRI for nine 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. Because juvenile Razorback Suckers appear

to be highly cryptic, 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, similar to the upper Colorado River basin. Hybridization of Razorback Sucker and Flannelmouth Sucker has been documented by the capture of hybrid suckers at the CRI.

Larval Sampling

Although Razorback Sucker spawning activity in 2018 was documented based on the capture of ripe fish, few larvae were captured. Larval Razorback Sucker captures at the CRI in 2018 could be the result of downstream drift from the Grand Canyon (see Chapter 2). The adult Razorback Sucker captures in 2018 were within Lunch Cove, adjacent to the flowing river where larvae could have escaped flow. It is difficult to discern whether the lack of larvae equates to poor hatch success, or is more related to larval drift.

Larval Razorback Sucker captures at the CRI from 2010 to 2018 are similar to those observed during larval sampling in the Virgin River/Muddy River inflow area in 2005–2008 (Albrecht et al. 2014a). Catch rates of larvae, juveniles, and adults in the Virgin River/Muddy River inflow area increased over time through 2014 (Albrecht et al. 2010b, 2013a, 2013b, 2014; Shattuck et al. 2011). 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 2018, it appears that growth rates in this area are slightly lower than those observed at the combined long-term monitoring study areas (e.g., Rogers et al. 2018); 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 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, 2018). The capture of juvenile Razorback Suckers at the CRI suggests that the population is relatively young and suggests natural recruitment likely occurs at the CRI or at least within Lake Mead or the Colorado River proper. These findings should be considered significant to managers, and as future research and monitoring efforts evolve, it will be interesting to see whether additional evidence of recruitment is obtained from the CRI.

Determining the ages of six wild CRI Razorback Suckers during the 2018 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, 2018) (Appendix B). At the CRI to date, fish from 10 age classes (1999–2014) have been collected and identified. Interestingly, many of the Razorback Suckers aged at the CRI correspond with more abundant age classes across Lake

Mead. Based on reservoir-wide data collected to date, some of the most pronounced recruitment occurred from 2001 to 2007; 389 Razorback Suckers have been captured from those spawning events alone. These data along with catch-curve analysis (Rogers et al. 2018) suggest a strong, recent recruitment trend. This pulse of young fish indicates that successful spawning and recruitment are occurring during declining and fluctuating reservoir elevations. Finally, as more specimens are obtained from all areas of Lake Mead, including the CRI, conditions that promote recruitment pulses can be further investigated. Collection of additional data from the CRI should help clarify results from study efforts throughout Lake Mead.

Future Considerations

After 9 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, and young fish (less than 5 year old Razorback Sucker) appear to be fairly common at the CRI, which supports the hypothesis of natural recruitment in this area of Lake Mead. Although much has been answered from the observations during the 2010–2018 sampling efforts at the CRI, many new questions have resulted. For example: are there unexplored areas of the reservoir or flowing portions of the river that have suitable Razorback Sucker habitat and spawning aggregates? What role does the river play in wild Razorback Sucker recruitment? What is the long-term use of the lower portions of the Colorado River proper during both spawning and nonspawning periods of the year? Does Razorback Sucker use of habitats above Pearce Ferry Rapid vary depending on overall amounts of water released from Glen Canyon Dam, timing of those releases, specific reservoir elevations, conditions at the Pearce Ferry Rapid, or some combination of those or additional factors?

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

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 2018? How common are juvenile Razorback Suckers at the CRI compared with other locations in Lake Mead? With more sampling and a long-term dataset, comparisons regarding recruitment patterns could be made with other Lake Mead locations used by Razorback Suckers.

Study results from the last 9 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 have been historically, occupied by the species. This study at the CRI, combined with the LTM study on Lake Mead, has brought us much closer to understanding and identifying wild recruitment while placing these processes in context within and throughout the historic range of the Razorback Sucker. At a minimum, these efforts have spurred research in other, similar areas (e.g., Lake Powell, Grand Canyon) (Albrecht et al. 2017). 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, Bluehead Sucker, Humpback Chub, and perhaps other native species, will also need to be considered.

2018–2019 COLORADO RIVER INFLOW AREA OF LAKE MEAD (CRI) STUDY RECOMMENDATIONS

1. Maintain sampling efforts at the CRI and within the Grand Canyon. The telemetry (see Chapter 3), trammel netting, larval-fish sampling, and aging techniques outlined in this report are effective and essential tools for documenting Razorback Sucker habitat use 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 reservoir-wide 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). All of this becomes particularly important as releases from Glen Canyon Dam change (e.g., high-flow events, “bug flows”, etc.).

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 (Rogowski et al. 2018) and within the broader study area during the past 5 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 and additional submersible ultrasonic receivers (SURs) 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 the 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 is 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; Rogers et al. 2018). This effort would require additional time and support, but it also falls under recommendations contained in the current version of the Lake Mead Razorback Sucker Conservation and Management Plan. Given that efforts to find a new Razorback Sucker population at CRI were successful in this regard (Kegerries et al. 2016a), it may be time to revisit some of the reservoir-wide searches for other Razorback Sucker aggregates.

4. Finally, we recommend taking a comprehensive approach to synthesizing the data collected on Lake Mead Razorback Sucker over the past two decades. 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 using the Grand Canyon, because a substantial link apparently exists between Razorback Suckers that inhabit the reservoir and those that inhabit river. A holistic assessment of wild Razorback Sucker recruitment in the greater Lake Mead and Grand Canyon continuum over the last two decades 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 2018). This chapter also presents results from previous study years (October 2013 through September 2017) within the Grand Canyon for comprehensive reporting efforts. 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 2018 (Table 2.1). More specifically, the intent of this study is to help describe the overall fish community within the Grand Canyon, allow for the capture of young Razorback Sucker and Humpback Chub, if present, and better understand the reproductive success, habitat use, and movement of, 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, 2018.

MONTH	SAMPLING DATES	TRIP PURPOSE
March	3/07/2018 through 3/15/2018	Larval fish community sampling (GRTS[a]).
April	4/11/2018 through 4/17/2018	Telemetry, small-bodied, and larval fish community sampling (GRTS)
May	5/09/2018 through 5/15/2018	Telemetry, small-bodied, and larval fish community sampling (GRTS)
June	6/13/2018 through 6/19/2018	Telemetry, small-bodied, and larval fish community sampling (GRTS)
July	7/11/2018 through 7/16/2018	Telemetry, small-bodied, and larval fish community sampling (GRTS)
August	8/08/2018 through 8/14/2018	Telemetry, small-bodied, and larval fish community sampling (GRTS)
September	9/06/2018 through 9/11/2018	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 small-bodied and larval fish sampling trips was reduced from seven to six to accommodate the increased sampling area while maintaining the same number of sites sampled in 2014 and 2015. The September sampling trip was eliminated from the larval fish portion of the project because 2014–2015 efforts documented a marked reduction in the catch rate of larval fish in the system during that month. As with the larval fish sampling effort, the least informative of the seven monthly trips to sample small-bodied fish was March, and it was therefore eliminated in 2016.

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.

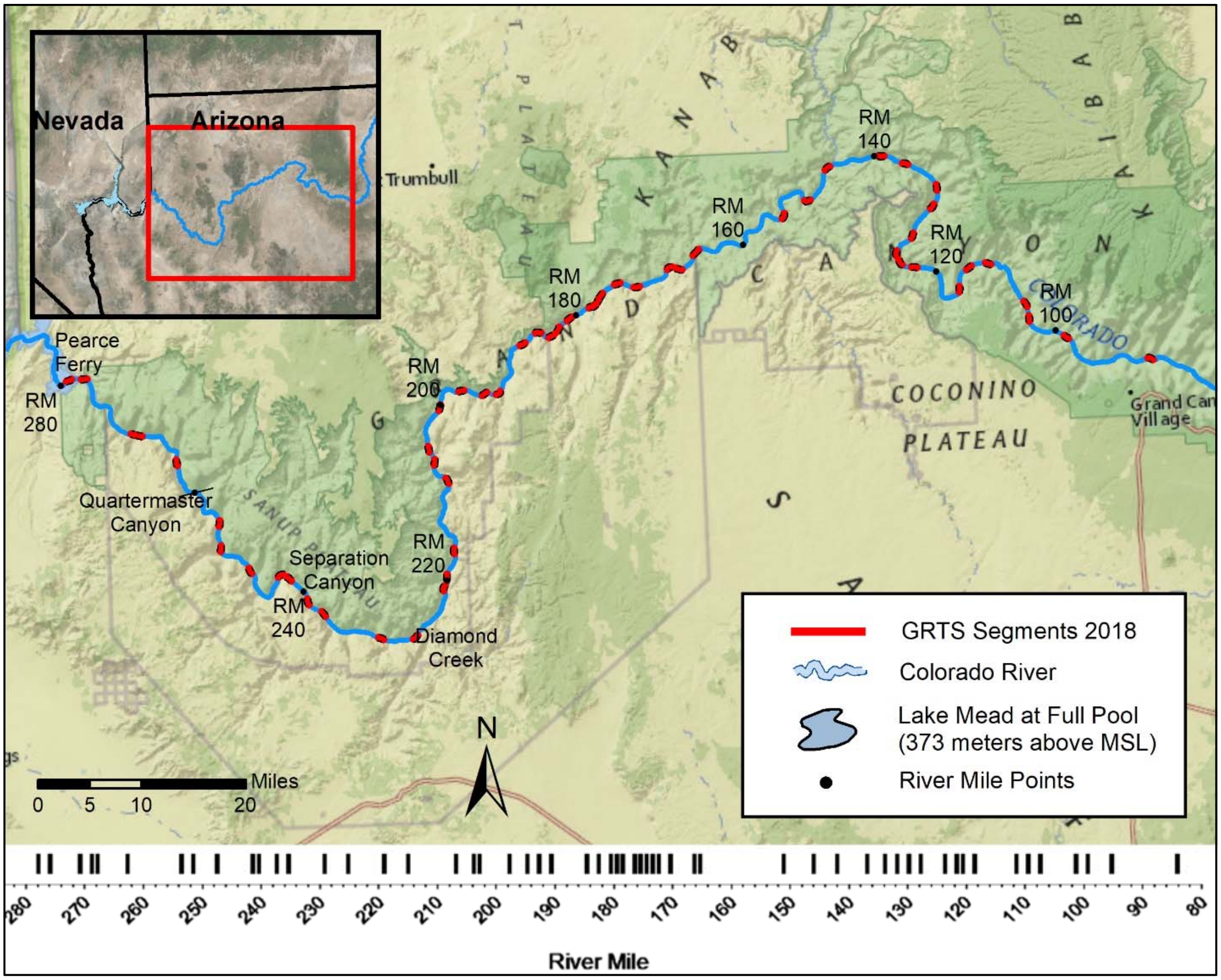

Figure 2.1. **The general study area within the Grand Canyon and the 56 generalized random tessellation stratified (GRTS) design segments (red) located in the 191.4 river mile study area from below Phantom Ranch to just above Pearce Ferry in 2018 (some GRTS segments are adjoining). Tick marks denote linear distribution of GRTS segments.**

METHODS

2018 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, 2017, through September 30, 2018. 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

Sampling sites in the Grand Canyon for the larval and small-bodied fish surveys were replicated in 2018 from those sampled in 2016 and 2017. All sites were selected using a generalized random tessellation stratified (GRTS) design to maintain an unbiased probability of sampling at river segments that support differing densities of fishes (Stevens and Olsen 1999, 2003, 2004). The GRTS method is a form of spatially balanced sampling that is a true probability design, as each point has a known, nonzero probability of being included in the sampling effort. This monitoring method yields statistically rigorous data because sites are randomly selected. This method is well established in the scientific community and used by the NPS for monitoring (NPS 2013b).

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

The initial step for GRTS segment selection was to determine the appropriate length of the sampling segment in order to determine how many segments would be used in the randomized model. The sampling unit 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.

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 likely to hold young, endangered fishes. These included backwaters formed in off-channel lateral canyons, tributary mouths, other locations offering habitat complexity and diversity, and 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, 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 2018 all captured Razorback Suckers and Humpback Chub over approximately 80 mm TL were PIT tagged if no mark was present.

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

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

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

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

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

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

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

Finally, comparisons have been made between historic data and data collected in this study since 2014. Small-bodied catch data from 2014 through 2018 was examined for holistic trends. However, most statistical comparisons were limited to data from 2016 through 2018 when the study area and effort remained relatively consistent.

Larval Fish Community Sampling

The 2018 study area encompassed 191 river miles from immediately downstream of the Bright Angel Creek-Colorado River confluence (RM 88.5) near Phantom Ranch to Pearce Ferry (RM 280.0). Following the expansion of the study area in 2016, the study reach was again divided into 385 separate 800-m sampling segments from which 56 sampling segments were randomly identified (using GRTS) as permanent sampling segments. Larval fish surveys (n=6) were conducted once each month from March through August. All GRTS sampling locations remained the same throughout the 2018 Grand Canyon larval sampling efforts.

Sampling for larval fish was conducted using a short- and fine-mesh seine (ca. 1 m x 1 m x 0.8 mm-mesh) and primarily occurred in low-to-zero-velocity habitats. Four samples, each consisting of one seine haul, 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, FL was recorded (mm) 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 a 95% solution of ethanol (EtOH) from March through May, or a 5% solution of buffered formalin (June–August). Samples were stored in a Whirl-pak® 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 were 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.

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

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

At each site, at least one digital photograph of the habitat sampled was recorded. Additional data acquired at each site 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.

Hobo® Tidbit water temperature data loggers, set to record once every hour, were placed with each SUR (see Chapter 3) to document the longitudinal temperature gradient from near Phantom Ranch (RM 89) downstream to Pearce Ferry (RM 280). Data loggers in place from the previous year (August 2017) were downloaded and replaced during the subsequent April survey, and the April data loggers were replaced during the August survey.

Retained fish samples were accessioned into the Museum of Southwestern Biology (MSB), Division of Fishes, at the University of New Mexico, immediately after each field survey. At MSB, samples and associated field tags were removed from Whirl-paks®, larval fish were separated from debris, the field fixative was replaced with 95% EtOH (March–May) or 5% buffered formalin (June–August), and specimens were stored in museum-quality glass jars to await identification. After samples were cleaned, ASIR staff with Colorado River Basin larval fish identification expertise identified specimens to species. Stereomicroscopes equipped with transmitted light bases (light and dark fields) and polarized filters 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 (YOY, i.e., age-0) specimens were included in analysis of the larval fish portion of this study. The terms YOY and age-0 are synonymous and include both larval and juvenile fishes. These terms refer to any fish, regardless of ontogenetic developmental phase, between hatching or parturition and the beginning of the next calendar year (1 January). Conversely "larval fish" is a specific developmental (morphogenetic) period between hatch and transformation to juvenile stage (juvenile fish are no longer larval fish). Larval fish developmental terminology used in this report follows Snyder (1981), which recognizes three distinct, sequential larval developmental phases: protolarvae, mesolarvae, and metalarvae. Mesolarvae are further divided into two sequential subphases: flexion mesolarvae and postflexion mesolarvae. Fishes in any of 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), and minimum and maximum SL lengths were recorded for each species in each sample. Standard length was recorded using an electronic caliper or ocular micrometer. 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, Snyder et al. 2016). Similarly, fishes released in the field were assigned an ontogenetic phase (when appropriate) based on species-specific length at stages. Length measurements (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 (Bluehead Sucker and Flannelmouth Sucker).

Hatch date 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 per 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).

Catch rates of fish were described using CPUE. These data (CPUE) were transformed (natural log(1+CPUE)) prior to statistical analysis to stabilize variance and better approximate normality. Catch per unit effort was calculated as the number of fish captured in each seine haul/surface area (m^2) sampled. Differences in mean CPUE, mean discharge, mean water temperature, and diel fluctuation in discharge (hydropeaking amplitude) were tested using ANOVA. When ANOVA detected differences of $\alpha \leq 0.05$, a Tukey's HSD test was used to examine all possible pair-wise comparisons. The effect of hydrologic (mean discharge and mean diel fluctuation) and physicochemical (mean temperature) interannual variability on mean CPUE was assessed with multiple linear regressions. Full models (all variables included) were subjected to forward and backward stepwise model selection using Akaike information criterion (AIC) values to assess the relative quality of models and produce the final models (Akaike 1973). Only final models were included in results. Analyses were performed using the statistical software JMP®, Version 11.

RESULTS

2018 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, 2017, through September 30, 2018, was variable both within and between sampling events (Figure 2.2).

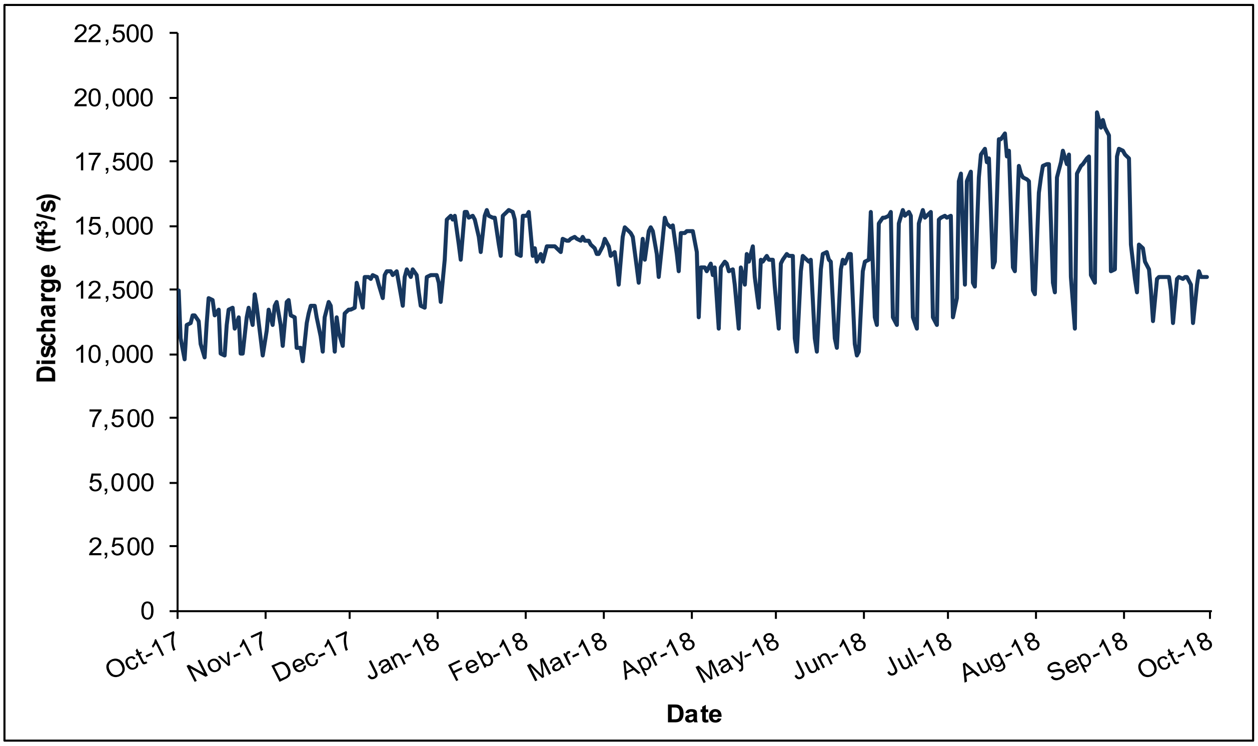

Figure 2.2. **Mean daily discharge in ft^3/sec of the Colorado River for the period of October 1, 2017, through September 30, 2018, recorded at the United States Geological Survey (USGS) gage above Diamond Creek (#09404200).**

Regulated increases in mean daily discharge and increased daily flow fluctuations were experienced during the June–September trips, along with varied turbidity throughout the study area. Discharges remained between 9,970 and 19,400 ft^3/sec during sampling events (Figure 2.2).

Small-bodied Fish Community Sampling

Generalized random tessellated stratified sites were sampled each month from April to September 2018 (Table 2.5). Monthly effort during the study ranged from 4,544.7 to 8,950.8 m^2 (274–352 seine hauls). In addition to the 56 standard GRTS segments, 46 seine hauls were conducted opportunistically in various habitats from April to September.

Table 2.5. **Sampling effort from 2018 small-bodied fish surveys.**

SAMPLING MONTH	DATES OF SAMPLING	NUMBER OF HAULS	EFFORT (m^2) AT GRTS[a] SEGMENTS	GRTS SEGMENTS SAMPLED
March	7–15	Small-bodied sampling was not conducted		
April	11–17	282	8,202.2	55
May	9–15	331	4,692.8	56
June	13–19	274	6,176.0	56
July	11–16	352	8,950.8	55
August	8–14	317	4,544.7	56
September	6–11	348	8,017.5	56

[a] GRTS=generalized random tessellation stratified.

Opportunistic captures were not included in the 2018 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). Native species, primarily Flannelmouth Sucker and Speckled Dace *Rhinichthys osculus* comprised nearly 78% of the small-bodied fish captured during opportunistic sampling.

During small-bodied fish community sampling efforts in 2018, 21,920 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 98% of the total catch. Although other catostomid fishes were captured, no Razorback Suckers were captured during small-bodied seining efforts within the study area.

The following eight nonnative fish species were captured during small-bodied fish community sampling in 2018: Rainbow Trout *Oncorhynchus mykiss*, Fathead Minnow *Pimephales promelas*, Plains Killifish *Fundulus zebrinus*, Western Mosquitofish *Gambusia affinis*, Red Shiner *Cyprinella lutrensis*, Brown Trout *Salmo trutta*, Green Sunfish *Lepomis cyanellus*, 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 ($\ln(1+(\#/m^2))$) of native and nonnative fishes captured in 2018 demonstrates dominance and significantly higher catch rates of native, small-bodied fish species in the Grand Canyon (ANOVA, $F_{1,3711}=538$, $P<0.0001$) (Figure 2.3). When evaluated by trip, significant differences were found in native catch rates (ANOVA, $F_{55240}=88.9$, $P<0.0001$) (Figure 2.3). Post hoc analysis revealed that July catch rates for native fish were higher than in all other months, while June, August, and September were higher than April and May.

Combined data from 2016–2018 mimicked the 2018 results with significantly higher native catch rates (ANOVA, $F_{1,10483}=1120$, $P<0.0001$) and significant differences among sampling trip with July being higher than all other trips (ANOVA, $F_{5,5240}=88.9$, $P<0.0001$). When comparing native or nonnative catch rates by year (Figure 2.4) catch rates of both differed. In comparing 2016–2018 data, native catch rates were significantly lower in 2016 compared to the other 2 years (ANOVA, $F_{2,5240}=83.1$, $P<0.0001$) while nonnative catch rates did not differ (ANOVA, $F_{2,5240}=0.08$, $P=0.9188$) (Figure 2.4).

Native fish catch rates differed among sampling segments in 2018 (ANOVA, $F_{55,1855}=7.63$, $P<0.0001$) (Figure 2.5). Post hoc analysis revealed differences in catch rates among sampling segments, but there was no clear pattern or indication that catch rates differed significantly from upstream to downstream. Similar results were found for the combined data from 2016–2108 with differences among segments, but it is difficult to determine where those differences occurred (ANOVA, $F_{62,5240}=11.4$, $P<0.0001$).

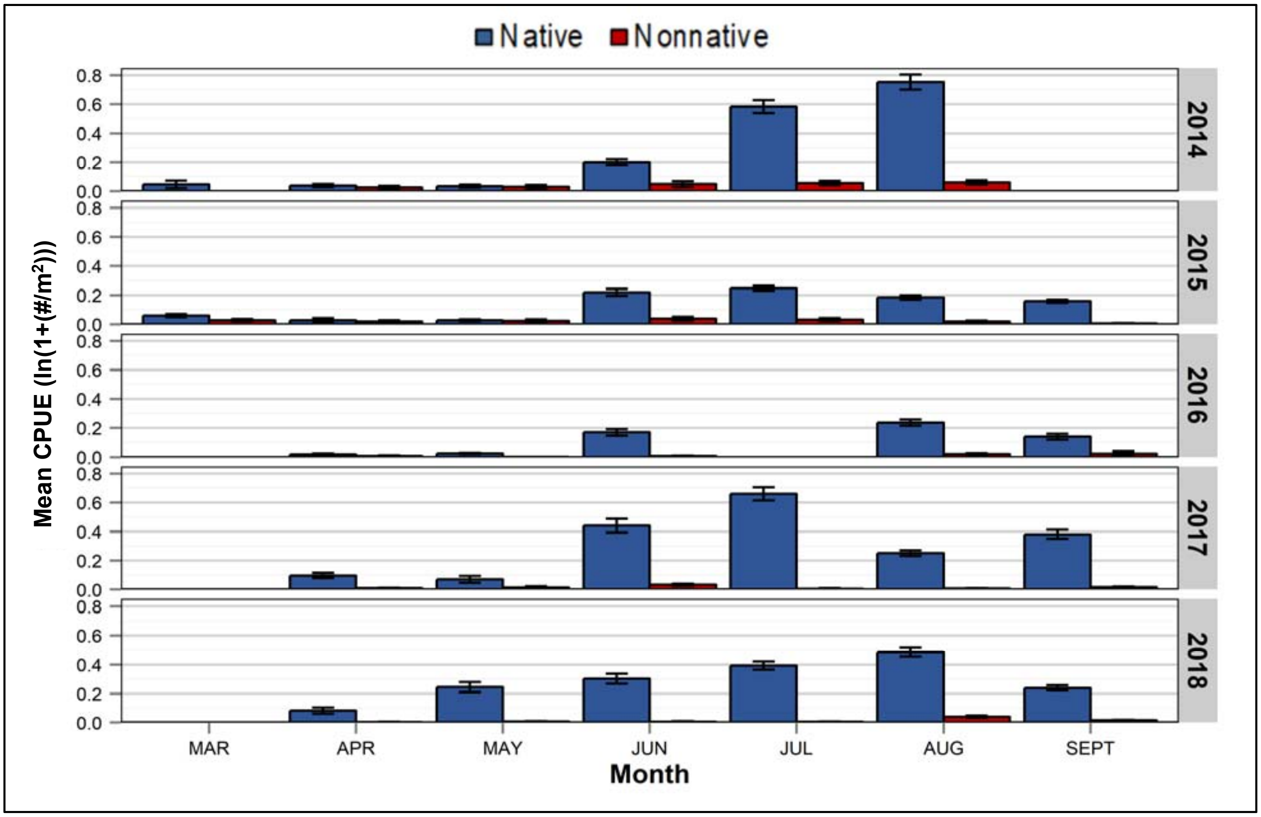

Figure 2.3. **Mean native and nonnative fish catch per unit effort (CPUE) (ln(1+(#/m^2))) by sampling trip for 2014–2018. Error bars are ± 1 SE.**

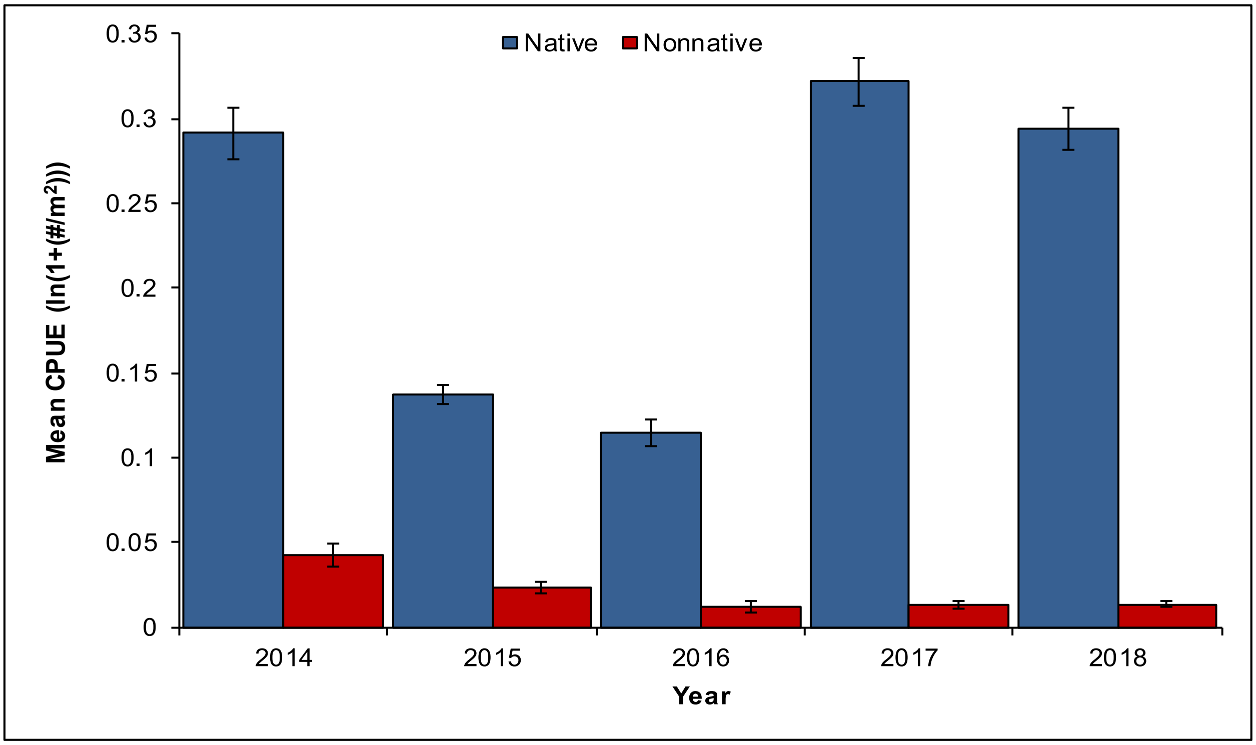

Figure 2.4. **Mean native and nonnative fish catch per unit effort (CPUE) (ln(1+(#/m^2))) by sampling year for 2014–2018. Error bars are ± 1 SE.**

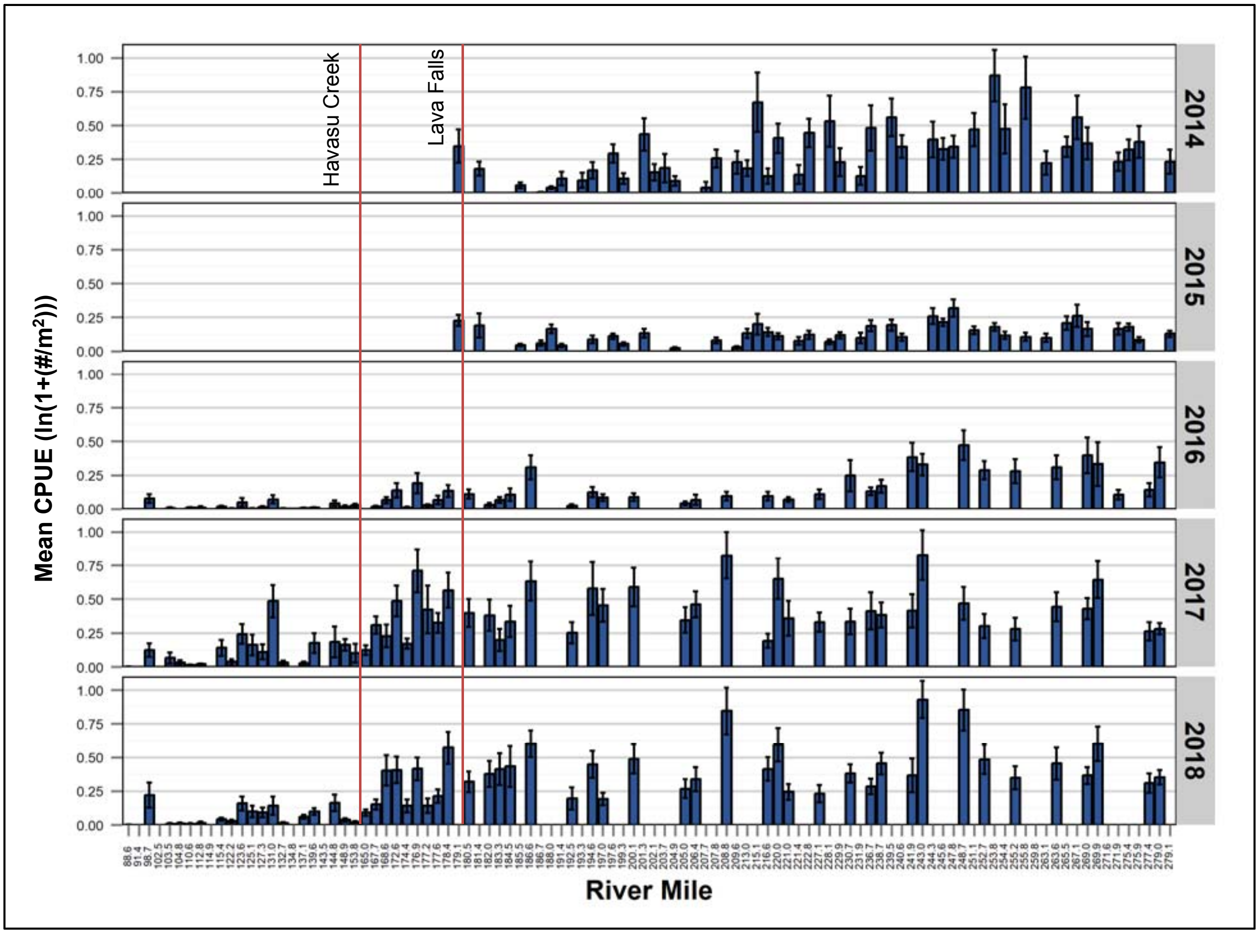

Figure 2.5. Mean native fish catch per unit effort (CPUE) (ln(1+(#/m^2))) by river mile (generalized random tessellation stratified [GRTS] design segment) upstream to downstream separated by sampling year (Red lines designate Havasu Creek and Lava Falls). Error bars are ± 1 SE.

To better assess mean catch rates longitudinally for segments, catch in the upper half and lower half of the study area for 2016–2018 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 (ANOVA, $F_{1,5240}=265$, $P<0.0001$). It appeared that catch rates increased below Havasu Creek (Figure 2.5); thus, catch rates in segments 2016–2018 above Havasu Creek versus below were compared. Mean catch rates for native fish were significantly higher below Havasu Creek than above it (ANOVA, $F_{1,5240}=334$, $P<0.0001$).

Native fish numbers and their total length varied by sampling trip. Total length ranged from 12–492 mm ($\bar{x}$=50.9 mm [SE±0.39]). Although a large range in native fish length, there is no indication that size class is different throughout the study area and among sampling segments. A least squares regression found no significant difference among native fish total length compared to river mile ($R^2=0.0000$, $F_{1,31158}=0.65$, $P=0.4192$).

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 that were 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).

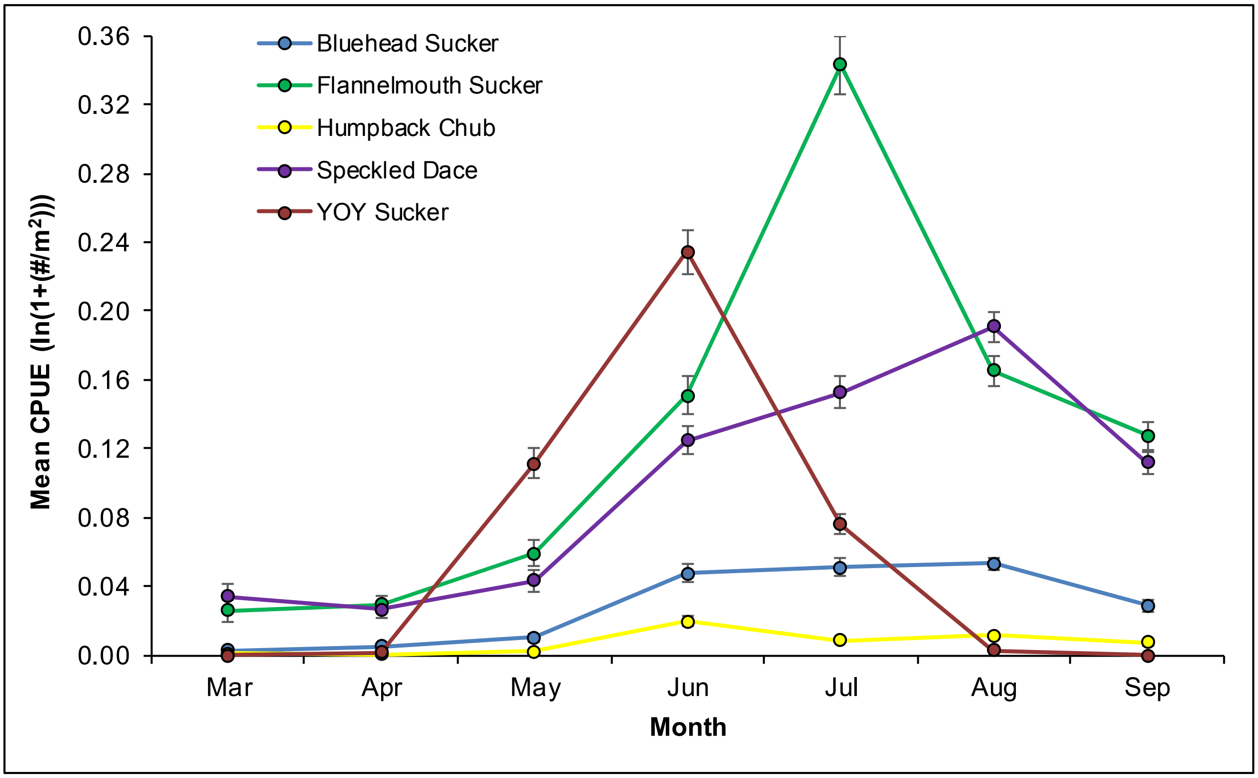

Figure 2.6. Mean native fish CPUE (ln(1+(#/m^2))) by sampling trip separated according to species for 2016–2018 data combined. Error bars are ± 1 SE

Humpback Chub catch rates differed each year from 2016 to 2018, with 2017 being the highest and 2016 the lowest (ANOVA, $F_{1,5240}$=334, P<0.0001). During small-bodied sampling since 2014, 1,408 Humpback Chub (16–369 mm TL; $\bar{x}$=50.1 mm TL [SE±0.84]) were captured at GRTS segments; 66% (n=940) of which came from 2017 sampling efforts (Appendix D). Catch rate analysis by river mile shows an increase in the relative abundance of Humpback Chub moving downstream with varying catch rates throughout the study area and among years (Figure 2.7).

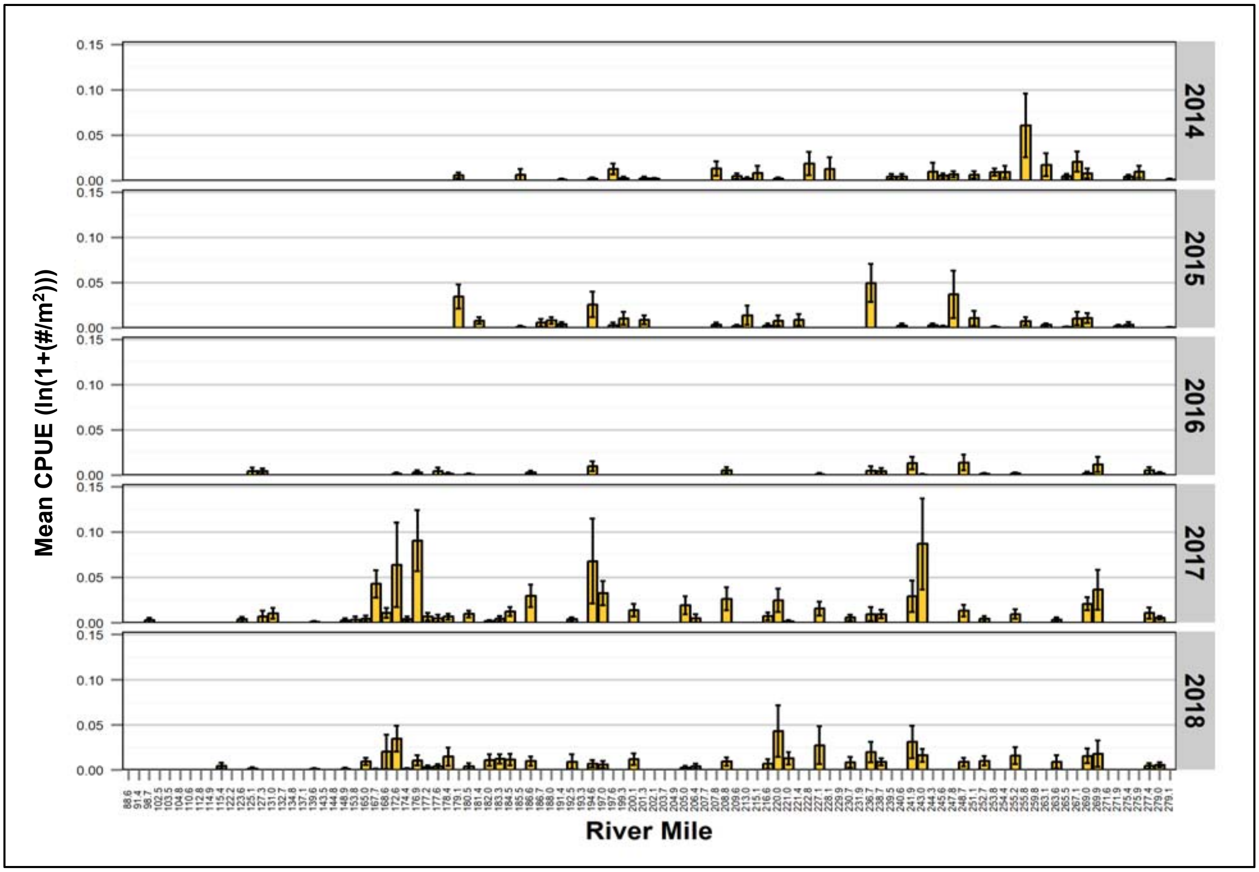

Figure 2.7. Mean Humpback Chub catch per unit effort (CPUE) (ln(1+(#/m^2))) by river mile (generalized random tessellation stratified [GRTS] design segment) upstream to downstream 2016–2018. Error bars are ± 1 SE.

Habitat

Because Razorback Suckers were not captured during small-bodied fish community sampling in 2014–2018, habitat data collected for this study are analyzed only in relation to the collected native fish species. From 2014–2018, most (51.5%) habitats samples were slackwaters, followed by runs and pools (16.7 and 11.3%, respectively). These habitats also provide low-velocity conditions conducive to seining. Fine substrates, such as sand and silt, covered 88.4% of the habitat sampled during all seine hauls. While forms of cover varied, boulders were the most prevalent cover type, although 30.2% of the sampling occurred where no cover was present (Figure 2.8).

Native fish catch rates differed significantly among target habitats (ANOVA, $F_{9,8173}$=28.5, P<0.0001) with embayments and backwaters significantly higher than other habitat types (Figure 2.9). Native fish catch rates were highest in gravel and silt. Significant differences were calculated but homogenous groups could not be identified through post hoc analysis (ANOVA, $F_{7,8173}$=19.1, P<0.0001) (Figure 2.9). An assessment of cover revealed that catch rates were generally higher when cover was present, and catch rates were highest when inundated and overhanging vegetation were present even though homogenous groups could not be identified through post hoc analysis (ANOVA, $F_{8,8173}$=31.0, P<0.0001) (Figure 2.9).

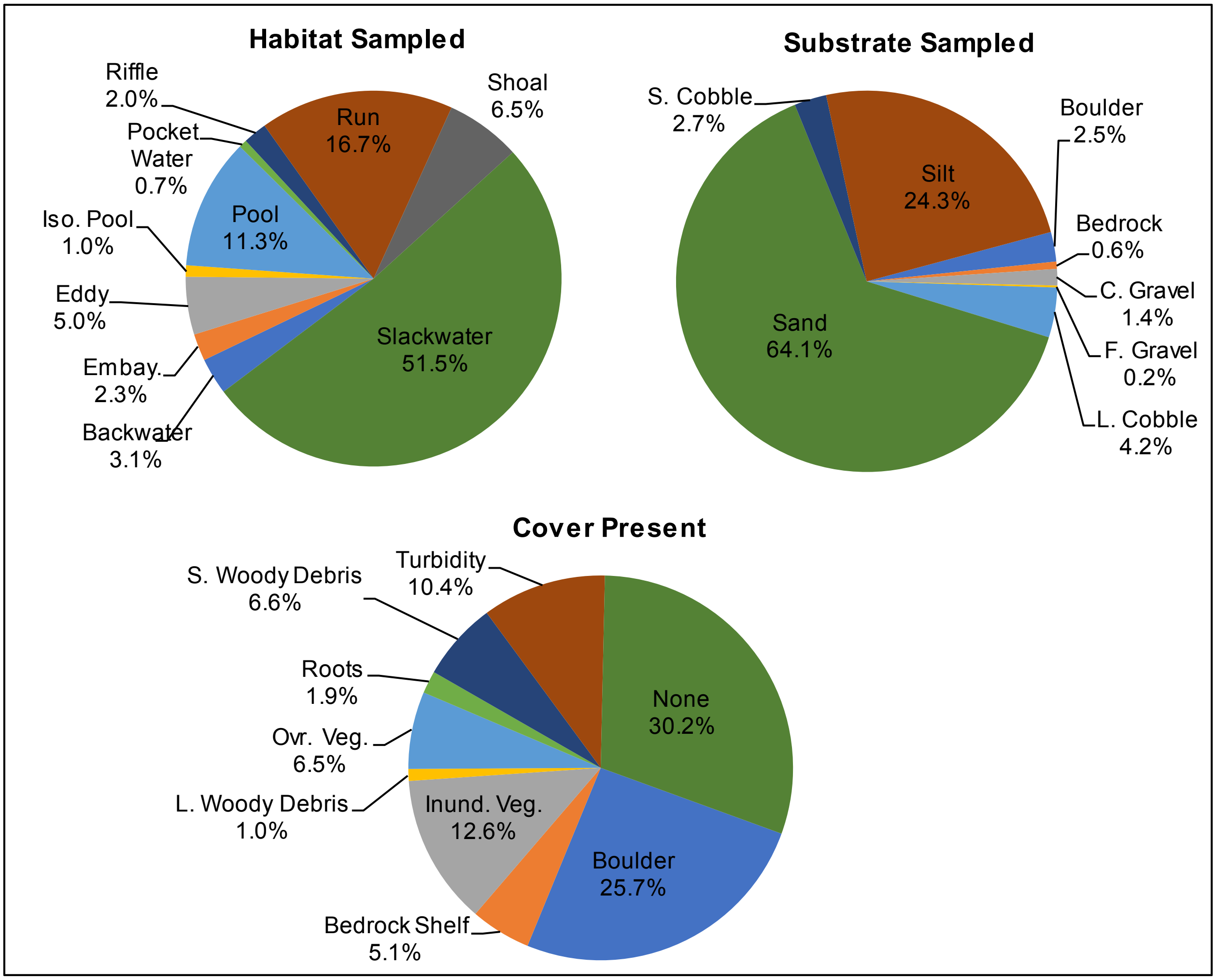

Figure 2.8. **Frequency distribution of habitat, substrate, and cover present for samples at generalized random tessellation stratified (GRTS) segments during the 2018 small-bodied fish survey.**

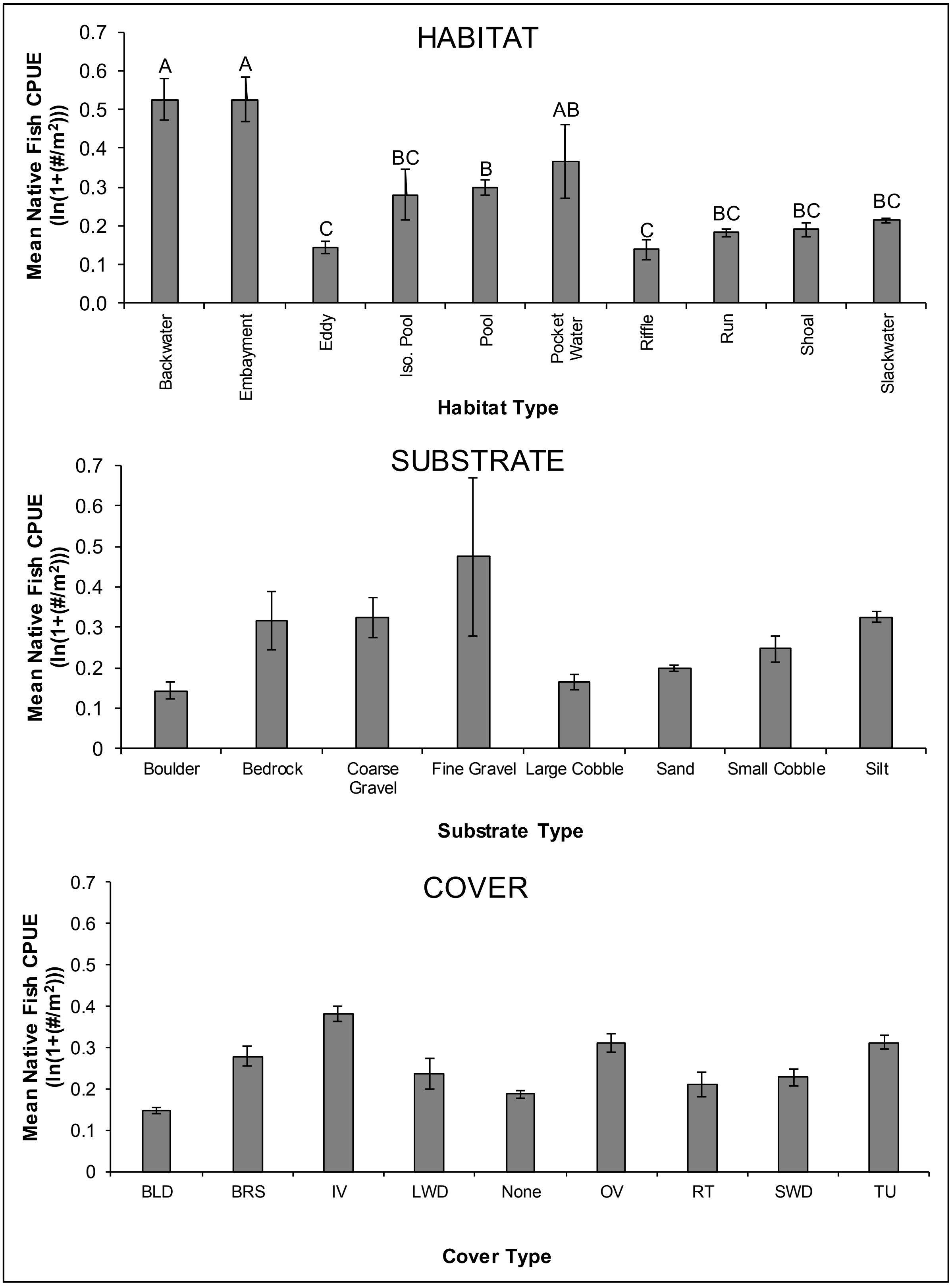

Figure 2.9. Mean native fish catch per unit effort (CPUE) ($\ln(1+(\#/m^2))$) for all sampling within each target habitat, substrate, and cover type 2014–2018. Error bars are ± 1 SE and letters denote statistical groupings.

Historic Perspective

Sampling efforts from 2014–2018 yielded 19 fish species captured with four being native (Table 2.6). Various studies since the 1990s have documented between eight and 16 nonnative fish species throughout the study areas (Table 2.6). Although the native species richness has remained nearly the same in all studies, proportional abundance has increased both above and below Diamond Creek. Above Diamond Creek, native fish abundance increased from approximately 41% to 90%, and native fish captures that were once rare below Diamond Creek in 1992–1995 have increased to nearly 93% of the catch in 2014–2018. Since the 1990s, native fish abundance was higher above Diamond Creek, while the most current data shows a shift to higher native proportional abundance below Diamond Creek (Figure 2.10). Nonnative fish once dominated the Colorado River in the Grand Canyon; however, over the last two decades the proportion of native fish has increased to exceed that of nonnative fish.

Table 2.6. Colorado River native and nonnative fish species present in studies from 1990–2018 throughout the Grand Canyon.

SPECIES	VALDEZ AND RYEL (1995)	VALDEZ et al. (1995)	ACKERMAN et al. (2006)	ACKERMAN (2008)	BIO-WEST (2014–2018)
NATIVE SPECIES					
Humpback Chub (HC)	X	X	X	X	X
Speckled Dace (SD)	X	X	X	X	X
Bluehead Sucker (BH)	X	X	X	X	X
Flannelmouth Sucker (FM)	X	X	X	X	X
NONNATIVE SPECIES					
Black Bullhead (BB)	X	X		X	
Black Crappie (BC)		X			
Bluegill (BG)		X	X		
Brook Trout (BK)	X				
Brown Trout (BT)	X			X	X
Channel Catfish (CC)	X	X	X	X	X
Common Carp (CP)	X	X	X	X	X
Fathead Minnow (FH)	X	X	X	X	X
Golden Shiner (GO)		X			
Green Sunfish (GS)	X	X	X	X	X
Largemouth Bass (LB)		X			
Plains Killifish (PK)	X	X	X	X	X
Rainbow Trout (RB)	X	X	X	X	X
Red Shiner (RS)		X	X	X	X
Smallmouth Bass (SM)			X		
Striped Bass (SB)	X	X	X		
Threadfin Shad (TS)		X	X		
Walleye (WE)	X	X			
Western Mosquitofish (WM)		X	X		X
NATIVE COUNT	**4**	**4**	**4**	**4**	**4**
NONNATIVE COUNT	**11**	**16**	**12**	**9**	**9**

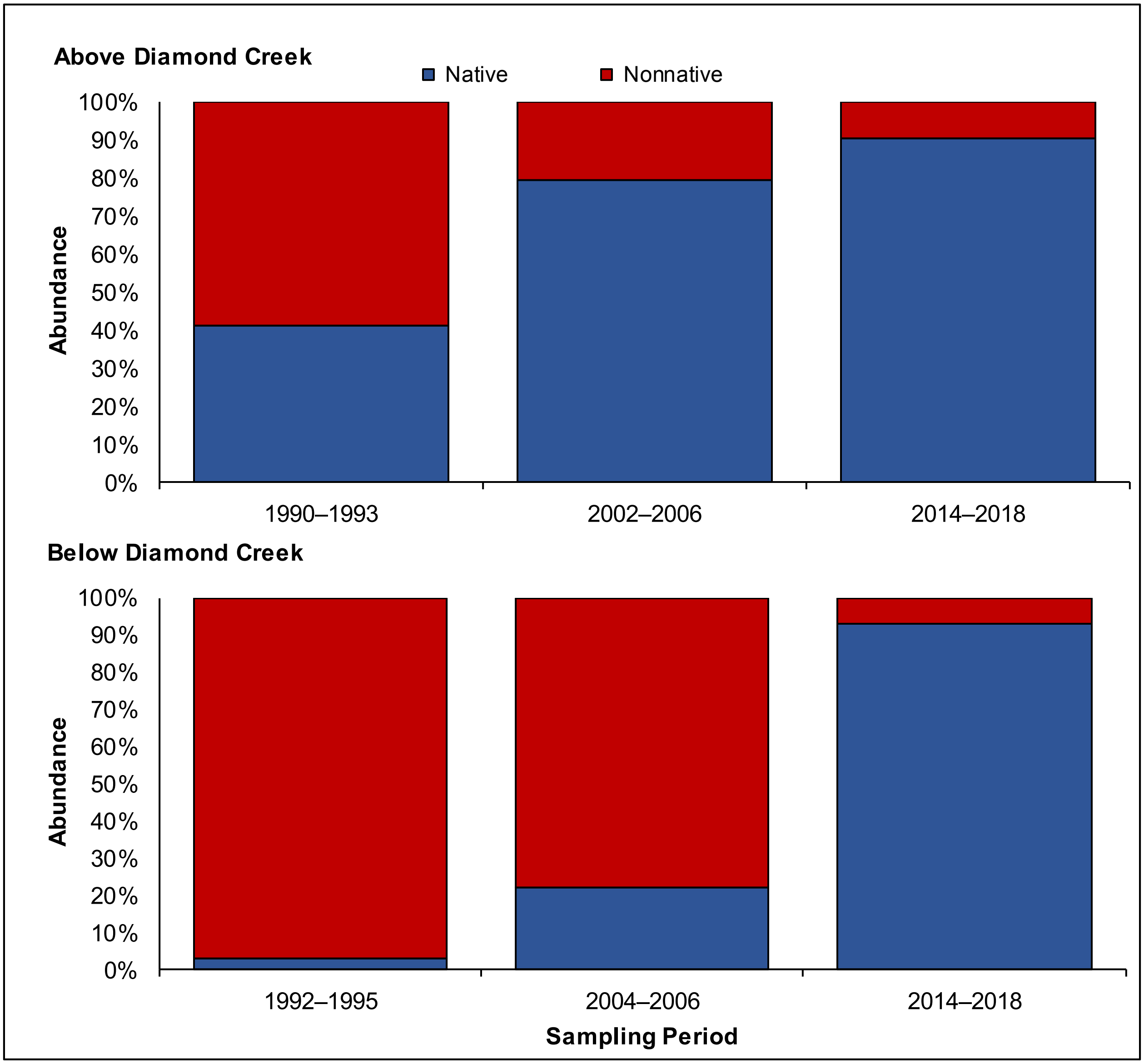

Figure 2.10 Percent of native and nonnative fish captured above and below Diamond Creek in the Colorado River, Grand Canyon 1990–1993 (Valdez and Ryel 1995), 1992–1995 (Valdez et al. 1995), 2002–2006 (Ackerman et al. 2006), 2004–2006 (Ackerman 2006), and 2014–2018.

Along with changing proportions of native and nonnative fish abundance, species composition has differed through time in this study comparison. Sampling above Diamond Creek to better characterize the Humpback Chub community in the early 1990s resulted in Rainbow Trout being the most abundant species (39%). Native species included Humpback Chub and Flannelmouth Sucker representing another 32%. From 2002–2006, native fish (Flannelmouth Sucker, Speckled Dace, and Humpback Chub) represented 76% of the proportional abundance. Similarly, from 2014–2018 Flannelmouth Sucker and Speckled Dace were the two most abundant species while Humpback Chub dropped below 5% in abundance (Figure 2.11).

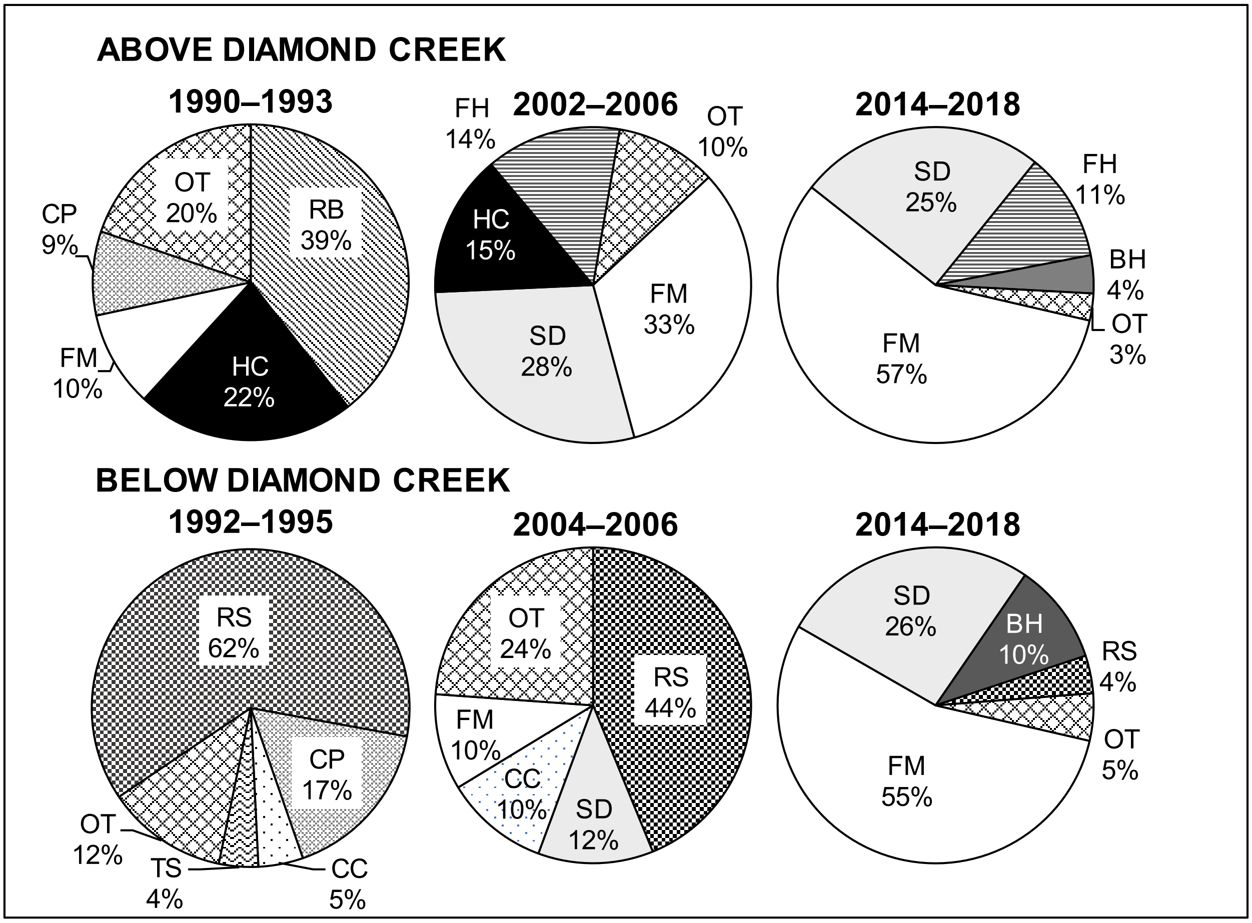

Figure 2.11. Percent composition showing the four most abundant species captured above and below Diamond Creek in 1990–1993 (Valdez and Ryel 1995), 1992–1995 (Valdez et al. 1995), 2002–2006 (Ackerman et al. 2006), 2004–2006 (Ackerman 2006), and 2014–2018. See Table 2.10 for species codes. OT= all other species combined.

From 1992 to 2006, Red Shiner were the most abundant species captured. Other species included Common Carp *Cyprinus carpio*, Channel Catfish *Ictalurus punctatus*, Flannelmouth Sucker, Speckled Dace, and Threadfin Shad *Dorosoma petenense*. In contrast, sampling during 2014–2017 below Diamond Fork Creek, resulted in native species dominance with 55% of the catch represented by Flannelmouth Sucker and an additional 38% being Speckled Dace and Bluehead Sucker. Red Shiner were rare and represented 2% of the catch (Figure 2.11).

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 2.12A). Median mean daily discharge from 1991 through 2002 was 13,000 ft^3/sec compared with 12,100 ft^3/sec from 2003 to 2018. Under slightly lower mean daily peak flows, maximum mean daily water temperatures were also higher from 2003 to 2017 compared with 1991–2002 (Figure 2.12B).

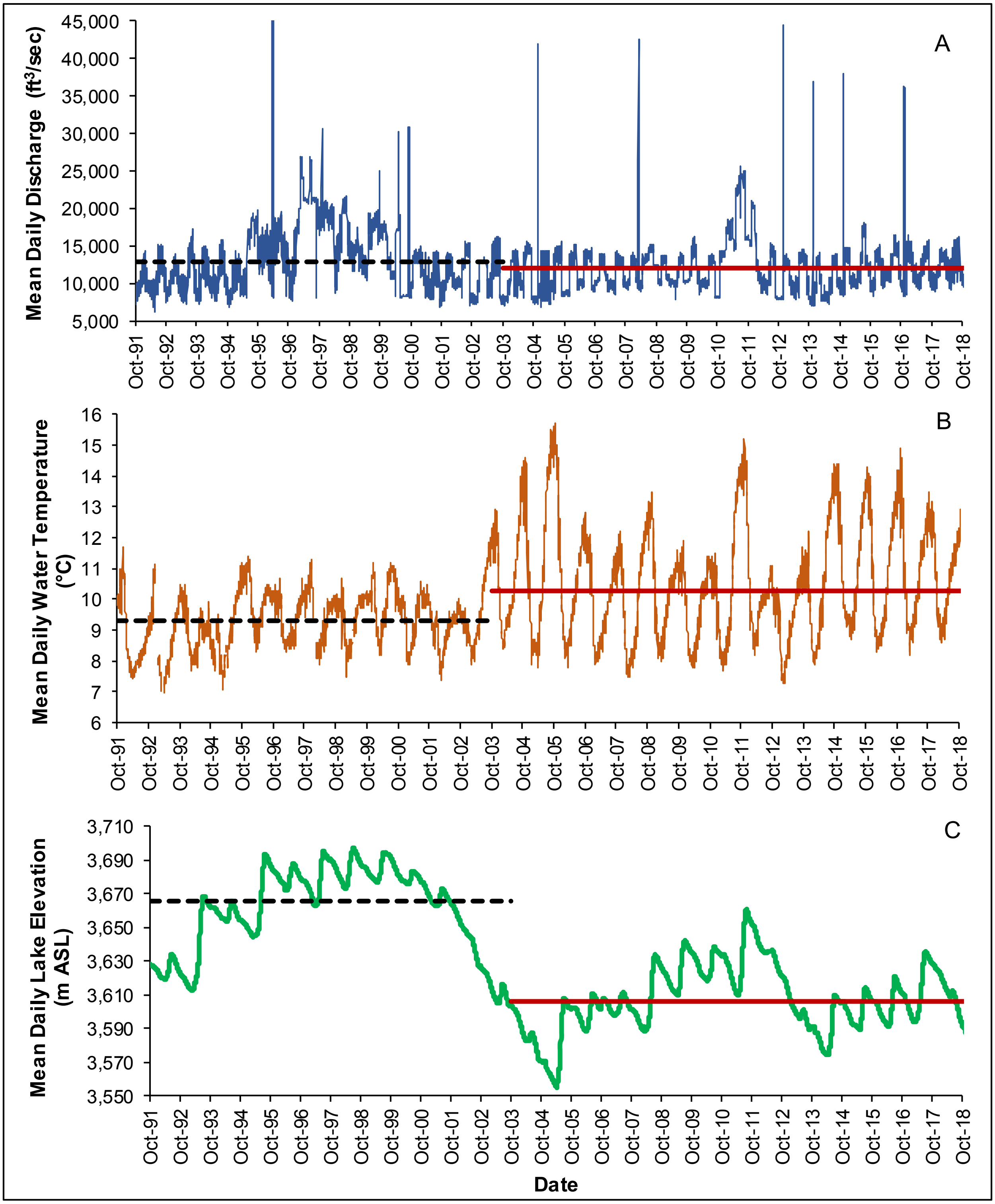

Figure 2.12. **Mean daily discharge at Lee's Ferry (USGS gage 09380000) from 1991 to 2018 (A), mean daily water temperature at Lee's Ferry (USGS gage 09380000) from 1991 to 2018 (B), and mean daily Lake Powell water elevation (Reclamation 2017) (C). Median value from 1991 to 2002 shown as dashed black lines and median value from 2003 to 2018 shown as solid red lines.**

The median mean daily stream temperature at Lee's Ferry from 1991 to 2002 was 9.3°C, compared with 10.3°C from 2003 to 2018. Lake Powell experienced a decline in lake elevation in 2001 through 2005, and lake elevations have remained relatively lower since that time (Figure 2.12C). The median Lake Powell mean daily elevation from 1991 through 2002 was 3,665.4 m above msl compared with 3,606.1 m above msl from 2003 to 2018.

Discharge

In an effort to better assess the physical habitat as it relates to small-bodied catch, we assessed discharge from 2014 to 2018 measured near Diamond Creek in the Grand Canyon, because that gage is within the study area and most representative of typical flows during sampling events. Although annual discharge appears to be similar, mean discharge differed each year during this study (ANOVA, $F_{4,171960}$=1575, P<0.0001) with 2018 being the highest, followed by 2016, 2017, 2015, and 2014 (Figures 2.13 and 2.14). Three high-flow events also occurred during the study period (November 2014, 2016, and 2018) (Figure 2.13).

A comparison of mean annual native fish catch rates from the 2016–2018 study years (years with consistent study area) with mean annual discharge for the same year did not reveal any significance between discharge and small-bodied native fish catch rates (R^2=0.0005, $F_{1,2}$=0.00, P=0.9862).

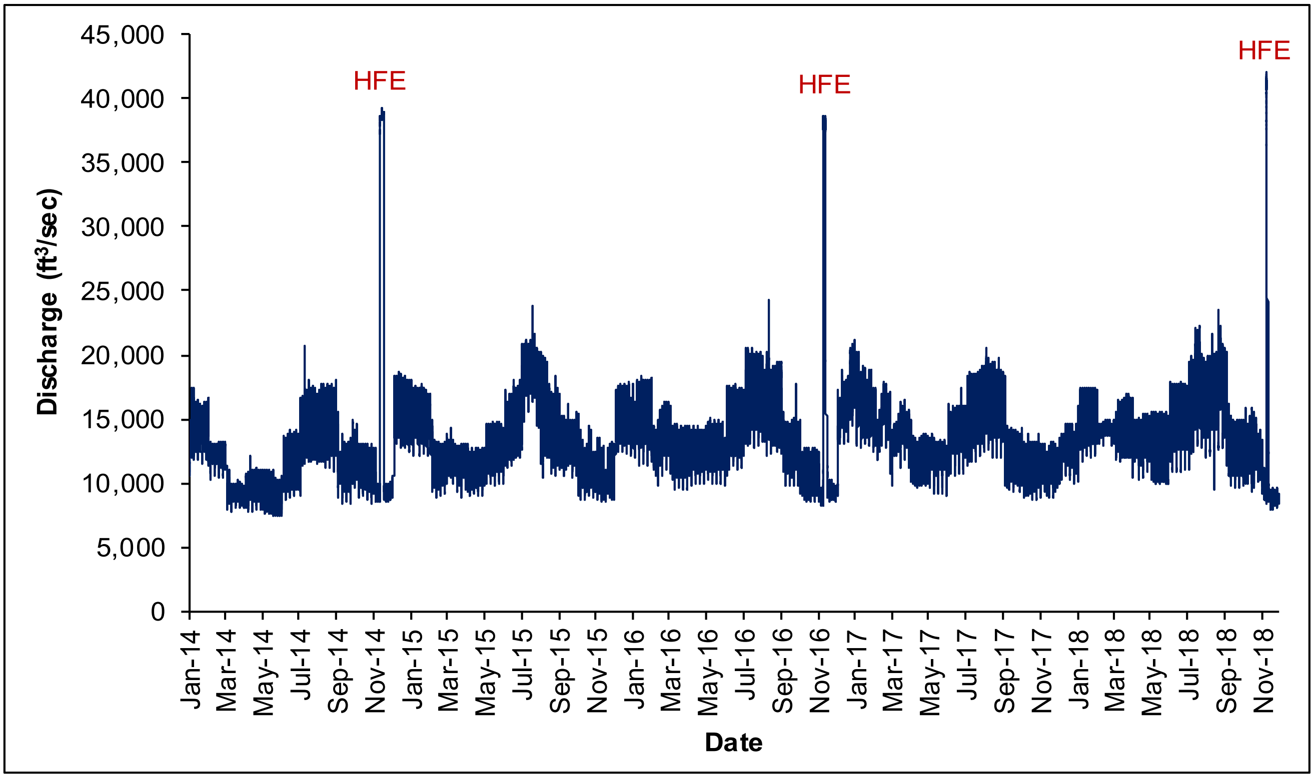

Figure 2.13. Discharge near Diamond Creek (USGS gage 9404200) from 2014–2018 showing high-flow events (HFE).

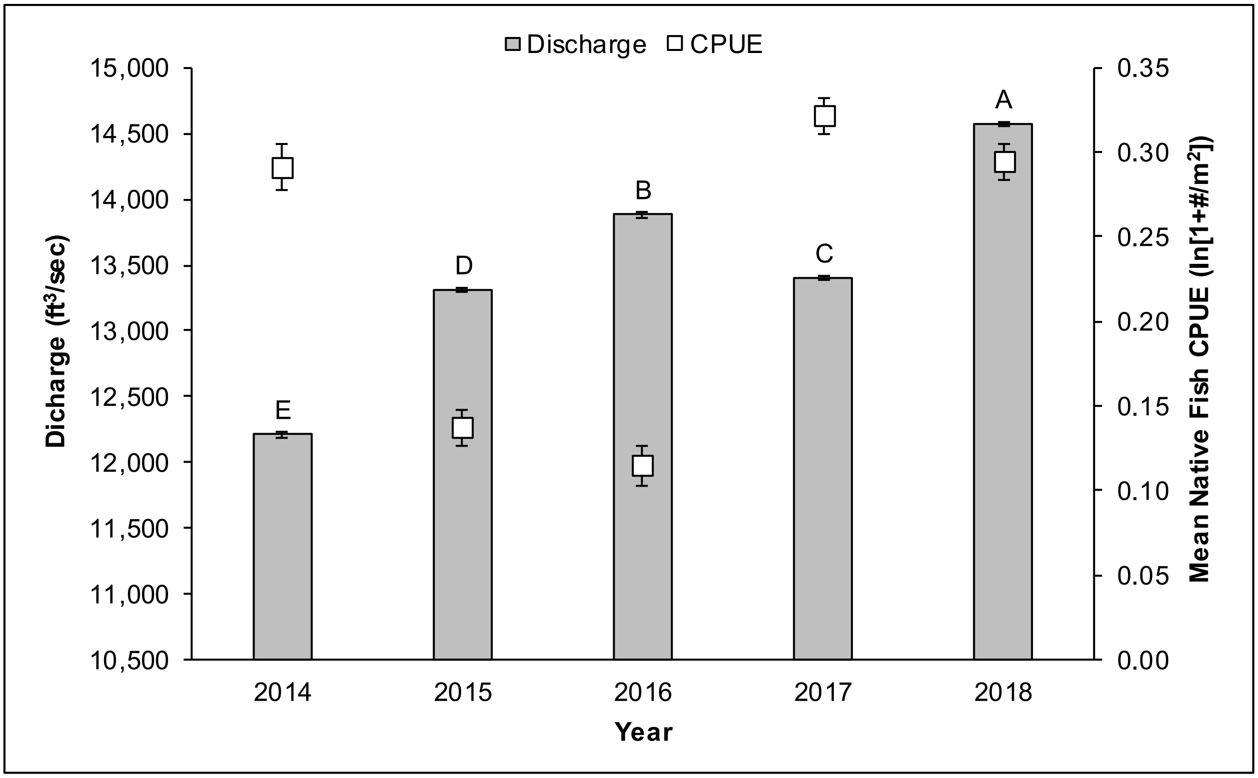

Figure 2.14. **Mean annual discharge near Diamond Creek (USGS gage 9404200) and mean annual native fish catch per unit effort (CPUE) [ln(1+#/m^2)] from 2014–2018. Error bars are ± 1 SE.**

Larval Fish Community Sampling

2018 Sampling

Six larval fish surveys were conducted in 2018, one survey during each month from March through August (Table 2.7, Figure 2.15). During the 2018 monthly surveys, 56 GRTS segments were sampled (Table 2.8). A total of 224 seine hauls were made during each monthly sample resulting in 1,775–2,176 m^2 of larval fish habitat sampled (March–August).

Table 2.7. Sampling effort from monthly 2018 larval fish surveys.

SAMPLING MONTH	SAMPLE DATES	NUMBER OF HAULS	EFFORT (m^2) AT GRTS SITES[a]	GRTS SEGMENTS SAMPLED
March	07–15 March	224	1,967	56
April	11–17 April	224	2,176	56
May	09–15 May	224	1,927	56
June	13–19 June	224	1,961	56
July	11–16 July	224	1,775	56
August	08–14 August	224	1,983	56

[a] GRTS= generalized random tessellation stratified

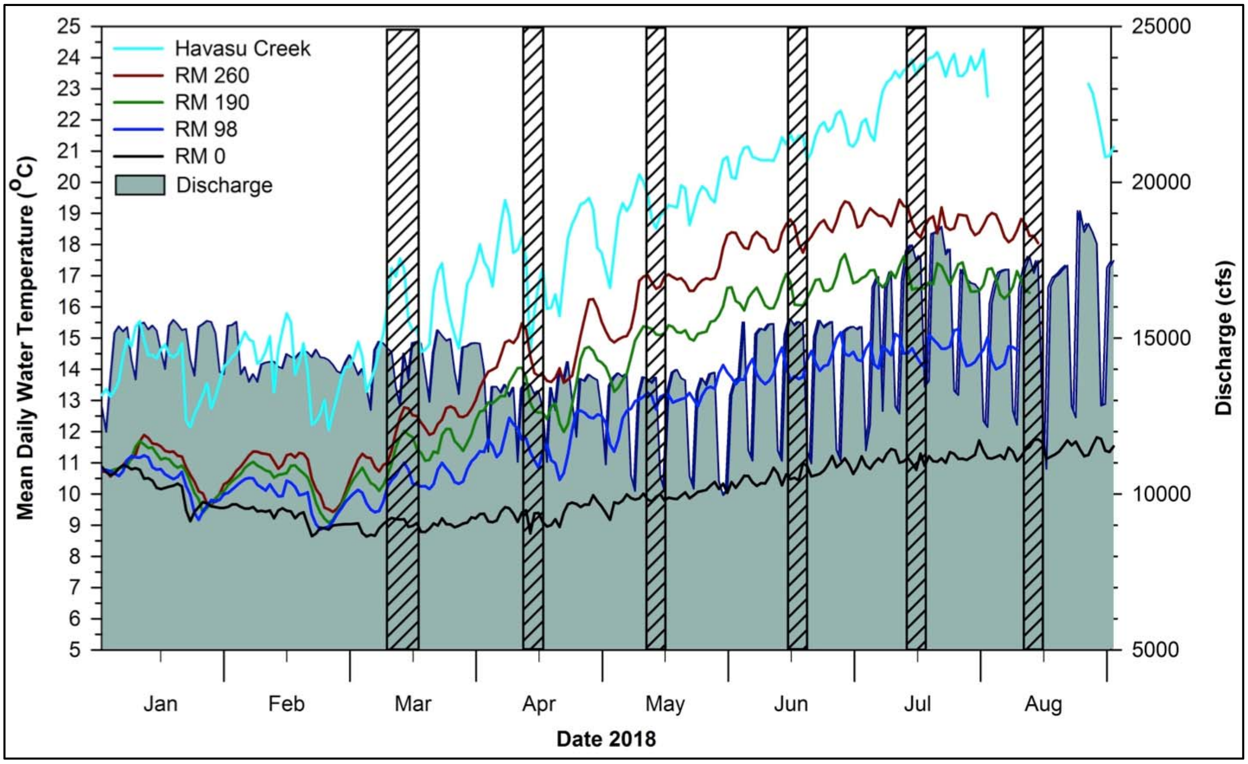

Figure 2.15. Discharge upstream of Diamond Creek (USGS gage 09404200) and water temperature from Lee's Ferry (USGS gage 09380000, RM 0) and temperature loggers recorded during the 2018 sampling period. Vertical bars denote larval survey trip dates.

2018 Capture Summary

March: The first larval fish survey in 2018 (Phantom Ranch [RM 89] to Pearce Ferry [RM 280]) occurred 07–15 March (Table 2.8). During the sampling period, mean daily discharge from Glen Canyon Dam, as measured upstream of Diamond Creek (USGS gage 09404200), fluctuated between 12,822 and 14,848 ft^3/sec and exhibited diel fluctuation of 3,450 ± 784 ft^3/sec (mean ± SD). Secchi disk visibility varied (mean=94 cm; range 16 to >100 cm) throughout the study area. Mean formazin nephelometric units (FNU) at USGS gage 09404200 during the March sampling period were 4.8 FNU. Mean daily water temperature near the middle of the study area (RM 190) was 11.4°C and ranged from 10.3 to 12.0°C (Figure 2.15).

The first March collection of larval fish was at RM 104.8. Low densities of larval fish collected during the March survey included Bluehead Sucker, Flannelmouth Sucker, and Razorback Sucker (Figures 2.16, 2.17, 2.18, and 2.19, and Appendix E.1) with Flannelmouth Sucker comprising 97.1% of the total catch (n=523). The majority (98.7%) of Flannelmouth Suckers were collected from GRTS segments downstream of Havasu Creek. Flannelmouth Suckers were recorded at 51.8% (n=29, RM 104.8–279.0) of the 56 GRTS segments sampled in March (Figure 2.18). Bluehead Suckers composed 2.3% of the total catch and were recorded at 16.1% (n=9, RM 123.6–243.0) of the GRTS sites.

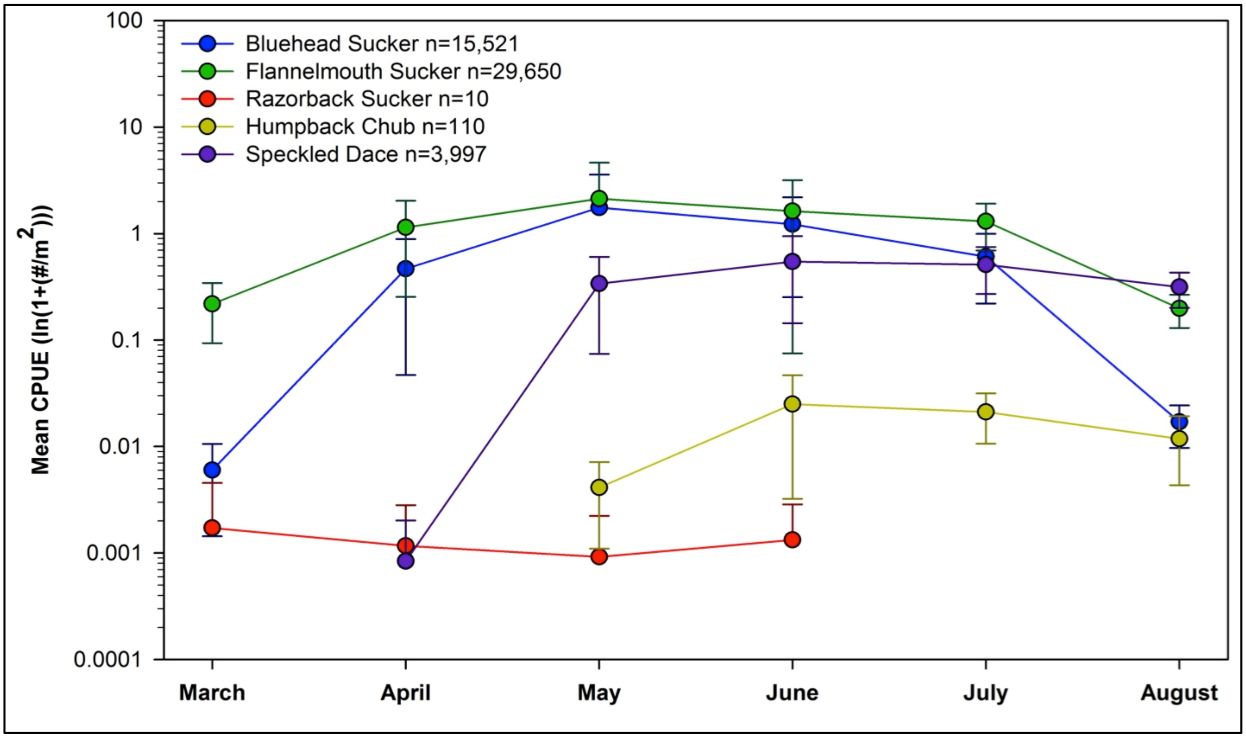

Figure 2.16. Mean CPUE of age-0 fishes by sampling trip (month) during the 2018 larval fish survey. *y*-axis scale is $\log_{10}$ and error bars are ± 1 SE.

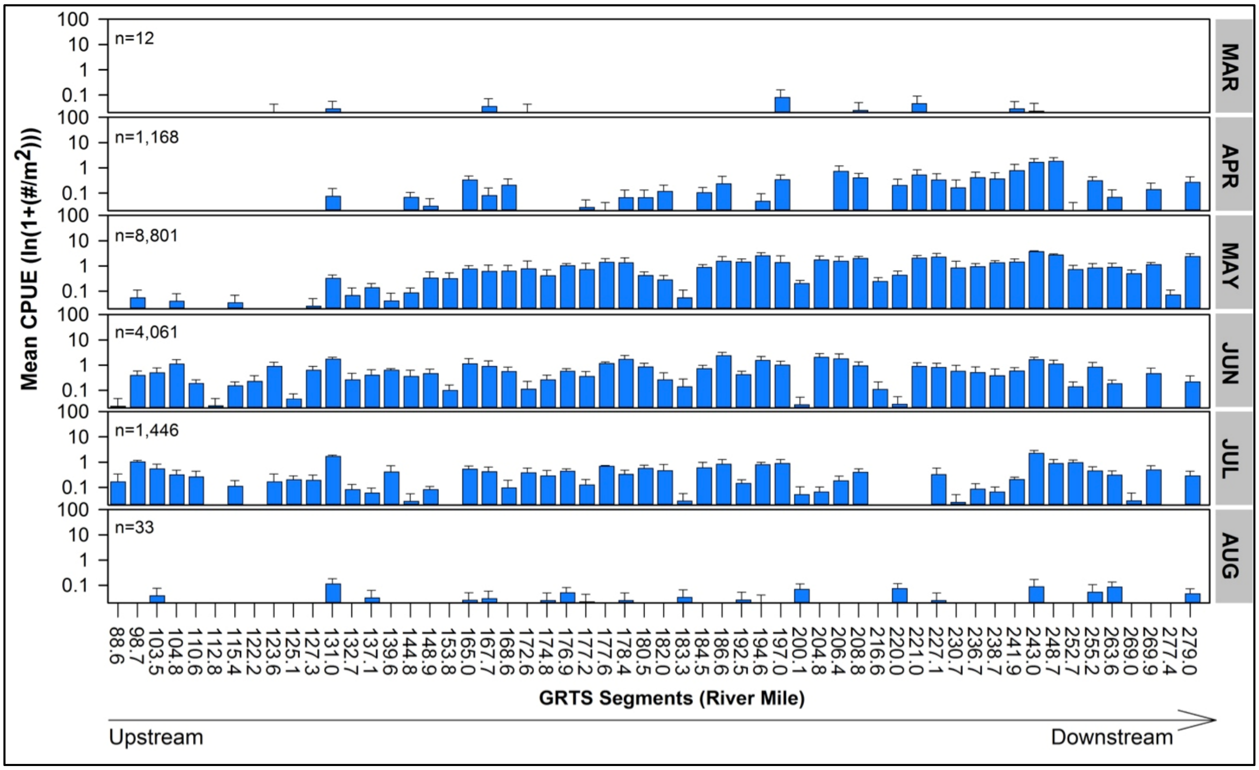

Figure 2.17. Mean catch per unit effort (CPUE) of age-0 Bluehead Sucker by 2018 sampling trip (month) and generalized random tessellation stratified (GRTS) segment. The *y*-axis scale is $\log_{10}$ and error bars are ± 1 SE.

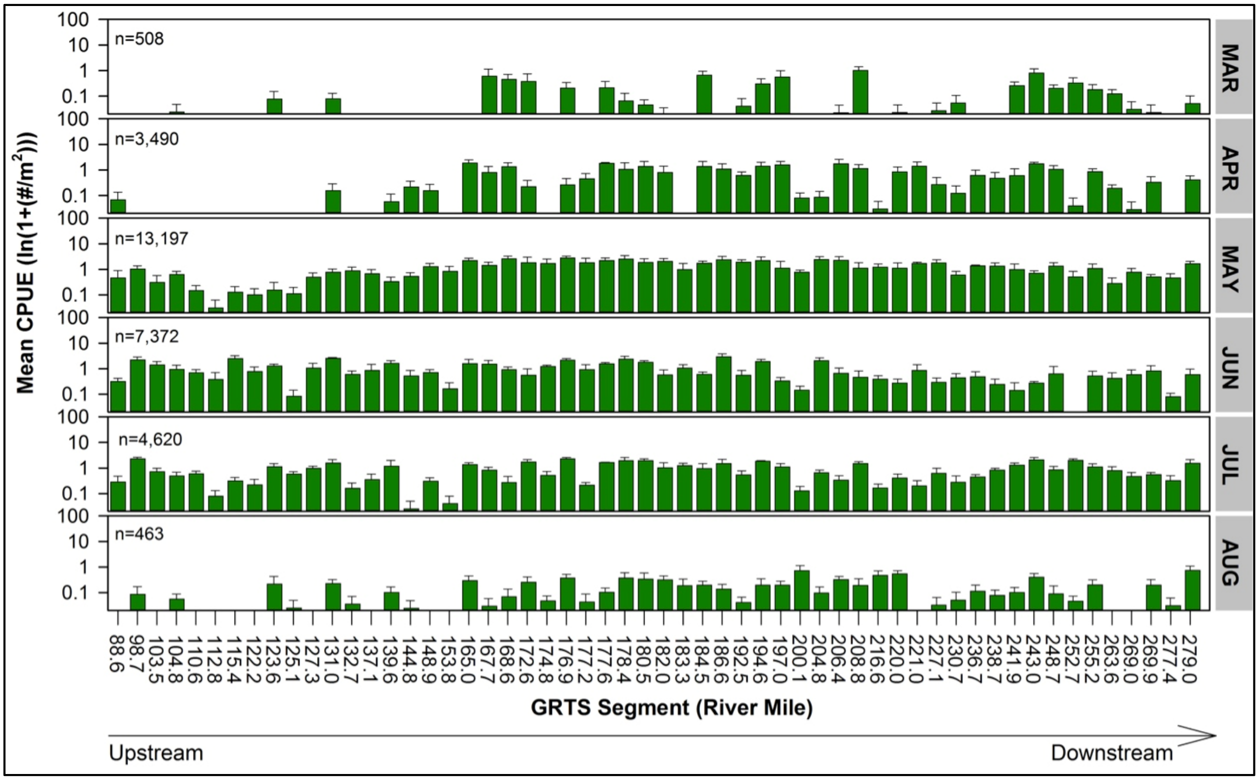

Figure 2.18. **Mean catch per unit effort (CPUE) of age-0 Flannelmouth Sucker by 2018 sampling trip (month) and generalized random tessellation stratified (GRTS) segment. The *y*-axis scale is $\log_{10}$ and error bars are ± 1 SE.**

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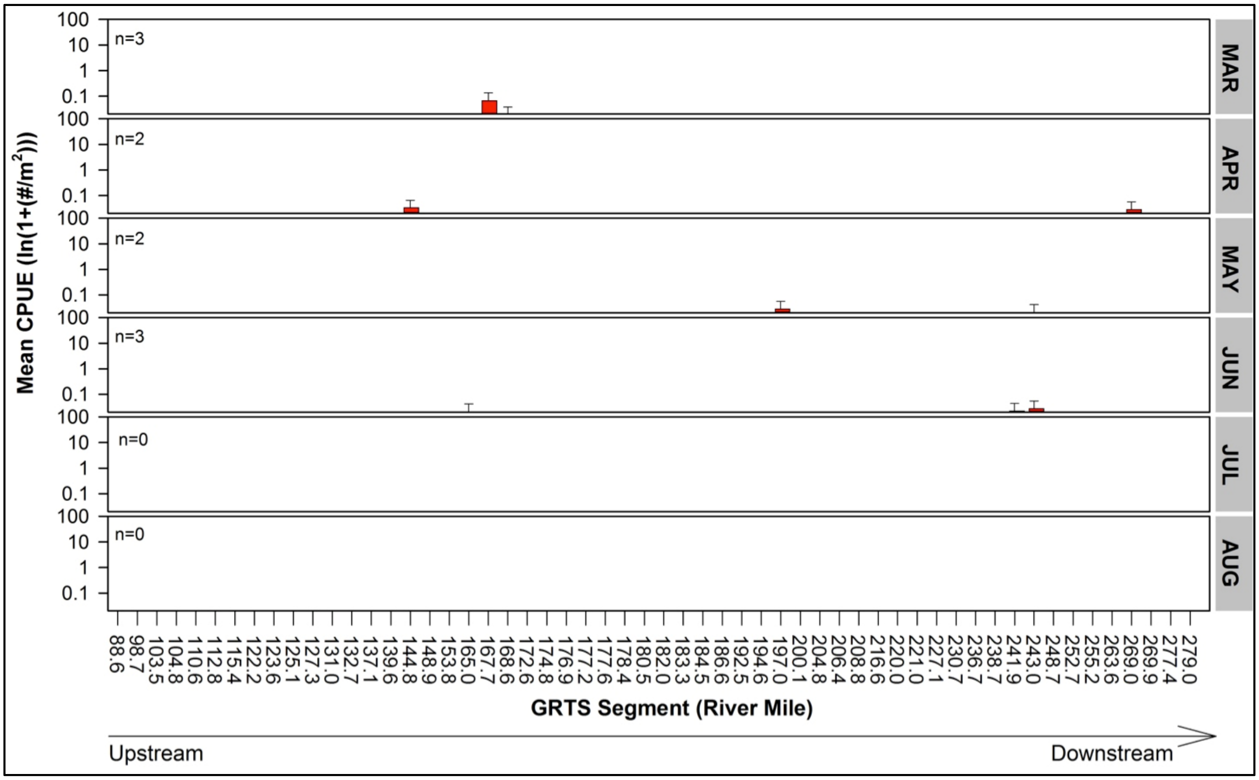

Figure 2.19. Mean catch per unit effort (CPUE) of age-0 Razorback Sucker by 2018 sampling trip (month) and generalized random tessellation stratified (GRTS) segment. The *y*-axis scale is $\log_{10}$ and error bars are ± 1 SE.

The first March capture of Razorback Sucker was at RM 167.7, approximately 10 river miles downstream of Havasu Creek. Razorback Suckers (n=3) were captured at two GRTS segments (160 [RM 167.7] and 162 [RM 168.6]) in March (Figure 2.19). Ontogenetic phases of March Razorback Sucker larvae captured were protolarvae (n=1) and flexion mesolarvae (n=2).

Age-1 incidental native fish captures during the March larval fish survey were native Speckled Dace, Bluehead Sucker, and Flannelmouth Sucker. Nonnatives during the same period were Fathead Minnow, Red Shiner, Plains Killifish, and Western Mosquitofish (Appendix F.1).

April: The April survey occurred 11–17 April, 2018 (Table 2.8). Mean daily discharge during the April survey ranged from 11,031 to 13,566 ft^3/sec with diel fluctuations of 2,757±836 ft^3/sec (mean ± SD). Water clarity (interpreted from Secchi disk readings) decreased slightly compared to the March survey (mean=64 cm; range 12 to >100 cm). Mean turbidity recorded at USGS gage upstream of Diamond Creek (09404200) was 17.1 FNU. Mean daily water temperature recorded near the middle of the study area (RM 190) during the April survey was 13.0°C; a 1.6°C increase from the March survey (Figure 2.15).

An increase in the upstream distribution and abundance of age-0 fishes was documented in April relative to March (Figures 2.16–2.18 and Appendix E.2). The upstream-most capture of larval catostomids expanded 16.2 river miles, to the upstream-most GRTS segment (#2 [RM 88.6]), when compared to the March survey. Catostomidae was the most abundant family collected during the April survey, comprising 99.9% of age-0 fishes, which included two unidentifiable catostomid larvae. These two individuals could not be accurately identified beyond family level and are reported herein as Catostomidae. Flannelmouth Suckers were the most abundant catostomid captured in April (74.9%; n=3,490), while Bluehead Suckers were 25.1% (n=1,168) of the catostomid catch. Razorback Suckers were less than 1% (n=2) of the April catostomid catch and were collected at RM 269.0 and RM 144.8, about 23 river miles upstream of the upstream-most Razorback Sucker larvae taken in March (Figure 2.19). In April, Razorback Sucker larvae captured during sampling were the two earliest ontogenetic phases (protolarvae and flexion mesolarva). The remaining 0.04% of age-0 fishes were Speckled Dace (n=2) taken at RM 248.7 (Figure 2.20).

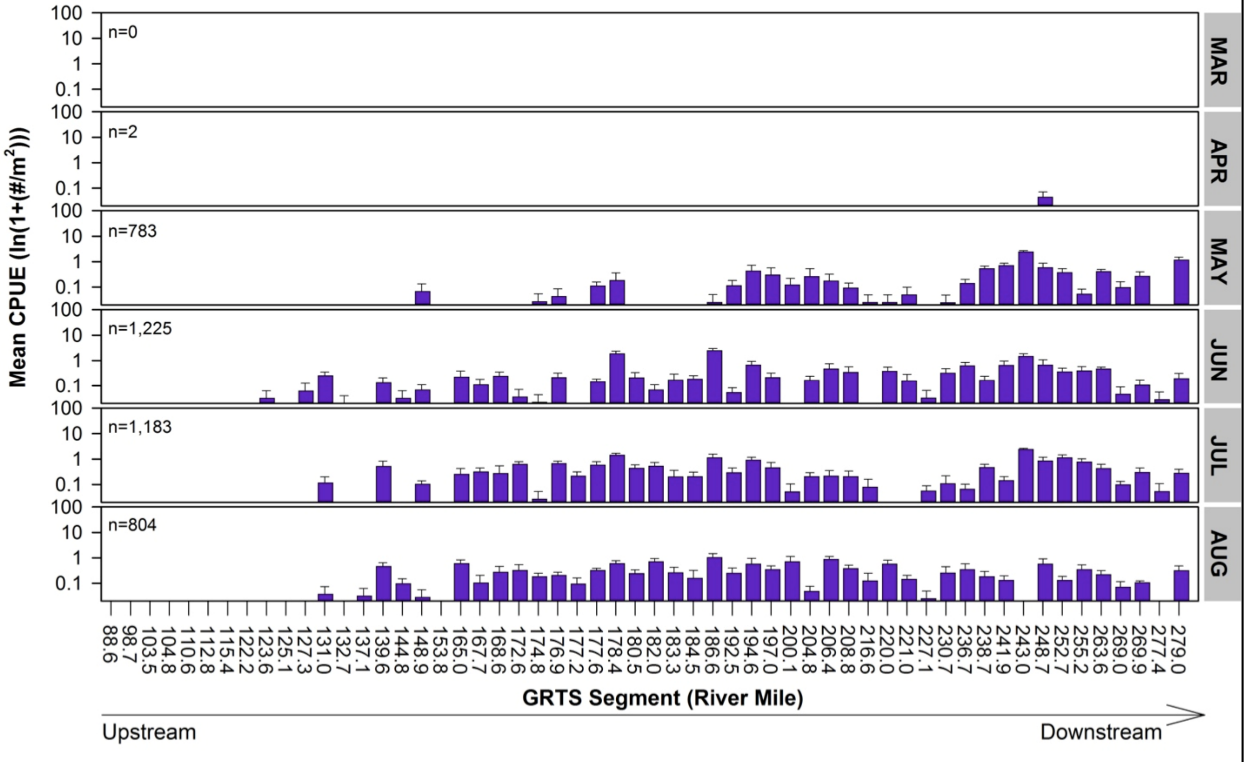

Figure 2.20. Mean catch per unit effort (CPUE) of age-0 Speckled Dace by 2018 sampling trip (month) and generalized random tessellation stratified (GRTS) segment. The *y*-axis scale is $\log_{10}$ and error bars are ± 1 SE.

The species composition of Age-1 fishes captured during April was similar to the March survey with the exception of Bluehead Sucker (age-1), which was not taken in April (Appendix F.2). Overall, age-1 fishes (n=70) incidentally taken during the April larval fish survey represented less than 2% of the larval fish capture and Speckled Dace (n=47) and Flannelmouth Suckers (n=18) made up the overwhelming majority (94.2%) of the age-1 fishes captured.

May: The third larval survey occurred 09–15 May, 2018 (Table 2.8). Mean daily discharge during the May survey ranged from 10,117 to 13,752 ft^3/sec with diel fluctuations of 3,276 ±1,631 ft^3/sec (mean ± SD). Water clarity was similar to the March and April surveys (mean=88 cm; range 14 to >100 cm). Mean water turbidity recorded at USGS gage upstream of Diamond Creek (09404200) was 9.7 FNU. During the May survey, mean daily water temperature (15.2°C) near the middle of the study area (RM 190) was approximately 2–3°C warmer than the prior two months (Figure 2.15).

The May larval fish survey documented an increase in the longitudinal distribution and abundance of age-0 fishes in the study area (Figure 2.2–2.6 and Appendix E.3). May had the highest catch rates among monthly surveys in 2018 and was significantly different from all months except June (ANOVA, $F_{5,6720}$ =93.0372, P<0.0001, Tukey's HSD). Age-0 fishes were captured at every GRTS segment (RM 88.6–279). Catostomidae was the numerically dominant family captured during May, comprising 96.5% of age-0 fishes (Appendix E.3). Age-0 Red Shiner (n=3), Humpback Chub (n=9), and Speckled Dace (n=783) were the remaining 3.5% of the May age-0 fish capture. The catostomid capture consisted primarily of Bluehead Suckers 40.0% (n=8,801) and Flannelmouth Suckers 59.9% (n=13,197); the remainder (0.1 %) consisted of Razorback Suckers (n=2) and one unidentifiable catostomid larva. (This individual could not be accurately identified further than the family level and is reported herein as Catostomidae). Razorback Suckers were captured at 3.6% (n=2) of the 56 GRTS segments located at RM 197.0 and RM 243.0 and were the two earliest ontogenetic phases (protolarvae and flexion mesolarvae).

The cyprinid capture consisted mainly of Speckled Dace (98.5%; n=783), while Humpback Chub (n=9) and Red Shiner (n=3) comprised the remaining cyprinid captures. May was the first month that larval Humpback Chub were collected with the first Humpback Chub captured near RM 192.5 (Figure 2.21). All age-0 Humpback Chub collected were mesolarvae; the majority [88.9% (n=8)] were flexion mesolarvae the remaining individual (n=1) was postflexion mesolarvae. Humpback Chub were taken in 10.7% (n=6) of GRTS segments and distributed over 86 river miles (192.5–279.0).

Age-1 fishes captured in May included Speckled Dace, Bluehead Sucker, and Flannelmouth Sucker. Plains Killifish (n=3) was the only nonnative age-1 fish captured during May larval fish sampling. Speckled Dace (n=13) and Flannelmouth Suckers (n=29), both natives, constituted the majority (91.4%) of the age-1 fish captures (Appendix F.3).

June: The fourth larval fish survey occurred 13–19 June 2018 (Table 2.8). Mean daily discharge during this survey increased, compared to the previous three 2018 surveys, and ranged from 10,982 to 15,623 ft^3/sec with diel fluctuation of 4,114 ± 2,242 ft^3/sec (mean ± SD). Water clarity at GRTS segments ranged from 12 to >100 cm (mean=94 cm). Mean turbidity recorded at the USGS gage upstream of Diamond Creek (09404200) was 5.3 FNU during the June sampling period. Mean daily water temperature near the middle of the study area (RM 190) was 1.3°C warmer compared to the May survey and averaged 16.5°C (Figure 2.15).

Capture rates of age-0 fishes remained high during the June survey and were significantly greater than all months except May (ANOVA, $F_{5,6720}$ =93.0372, P<0.0001, Tukey's HSD; Figure 2.18, Appendix E.4). Catostomids were distributed throughout the study area and continued to numerically dominate the collections, comprising nearly 90% (n=17,792) of the total age-0 catch. Similar to the May survey, Flannelmouth Suckers (n=12,662) were captured at nearly all (98.2%) of the GRTS segments and were the most abundant (64.5%) catostomid captured, while Bluehead Sucker (35.5%; n=4,061) and Razorback Sucker (0.1%; n=3) comprised the remainder.

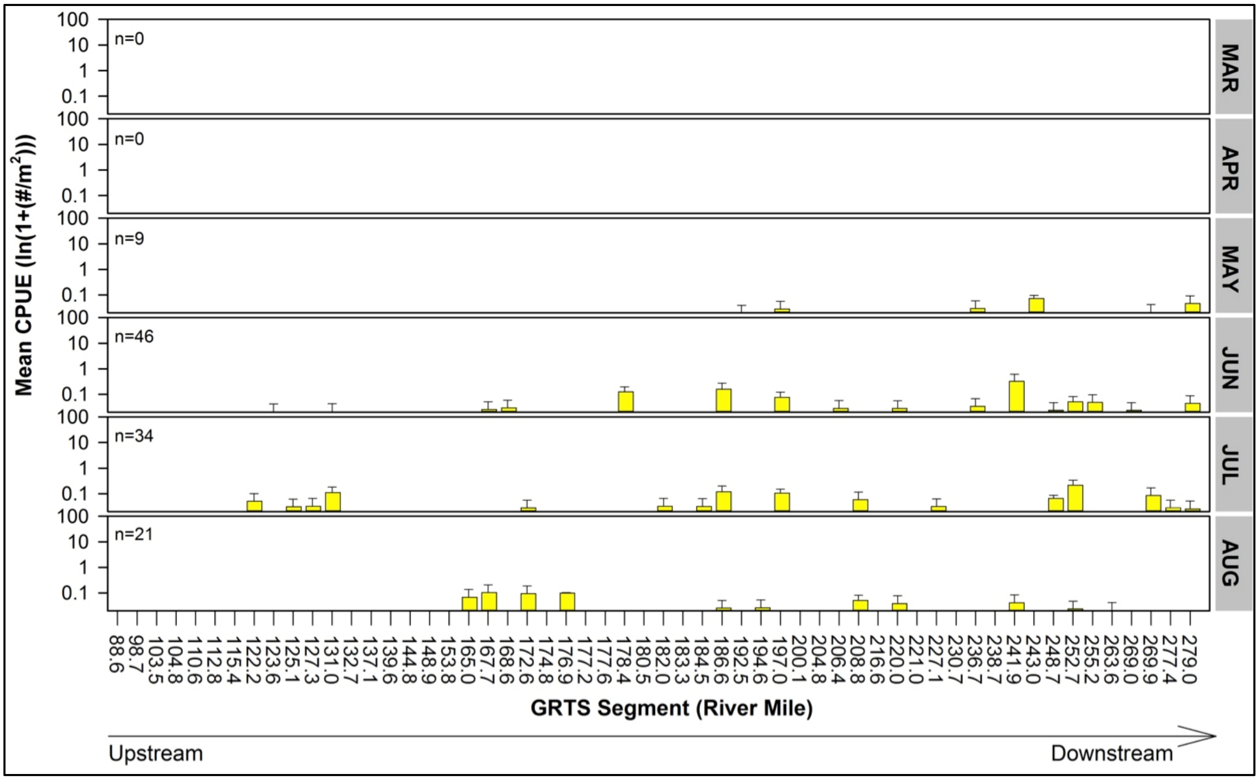

Figure 2.21. Mean catch per unit effort (CPUE) of age-0 Humpback Chub by 2018 sampling trip (month) and generalized random tessellation stratified (GRTS) segment. The *y*-axis scale is $\log_{10}$ and error bars are ± 1 SE.

Razorback Sucker was captured at three GRTS segments (155 [RM 165.0.7], 308 [RM 241.9], and 310 [RM 243.0]). Similar to previous months, Razorback Sucker larvae were of the two earliest ontogenetic phases; protolarvae (n=1) and flexion mesolarvae (n=2). The June survey was the last in 2018 to yield Razorback Sucker. There was no significant difference in Razorback Sucker capture rates between months (March–June; ANOVA, $F_{3,891} = 0.4613$, P=0.7094). Humpback Chub (n=46) were taken at 16 GRTS segments across 155.4 river miles (RM 123.6–279.0). While June produced the numerically highest catch rate for Humpback Chub and significant differences were detected in monthly catch rates (ANOVA, $F_{3,892}=2.9759$, P=0.0308 Tukey's HSD), there were no significant differences revealed in post hoc analysis (Figure 2.21). Similar to the May survey, June sampling documented low numbers of age-0 nonnative fishes. Fathead Minnow (n=1) and Western Mosquitofish (n=1) were each collected at a single GRTS segment and together they represent 0.01% of the total June age-0 captures.

Age-1 incidental captures during June consisted entirely of native fishes (Appendix F.4). Speckled Dace (88.8%; n=16) were the most frequently captured age-1 fishes. Bluehead Suckers (5.6%; n=1) and Flannelmouth Sucker (5.6%; n=1) were the only other age-1 fish incidentally captured in June.

July: The July larval fish survey occurred 11–16 July 2017 (Table 2.8). Mean daily discharge increased from previous surveys and ranged from 13,447 to 17,990 ft3/sec with diel fluctuation of 5,767 ± 2,105 ft3/sec (mean ± SD). Water clarity at sampling locations was decreased from previous monthly surveys (mean=12, range 2 to >80 cm). Turbidity measurements were not available from the July survey at USGS gage (09404200) upstream of Diamond Creek. Mean daily water temperature recorded near RM 190 increased slightly (0.5°C) from the June survey and averaged 16.9°C (Figure 2.15).

Capture rates of age-0 fishes were similar to the previous month (ANOVA, $F_{5,6720}$ =93.0372, P<0.0001, Tukey's HSD; Figure 2.18). Catostomids continued to be the most numerous and widely distributed age-0 fishes captured (Appendix E.5). Bluehead Sucker (n=1,446) and Flannelmouth Sucker (n=4,620) occurred in nearly every segment sampled (n=56 and 49, respectively) and composed 83% of the total age-0 captures (Figures 2.17 and 2.18). Razorback Sucker was not captured during the July survey (Figure 2.19). Humpback Chub (n=34) and Speckled Dace (n=1,183) were the two most numerous age-0 cyprinids captured (Appendix E.5). Humpback Chub was captured in 16 of 56 (28.6%) GRTS segments and distributed over 156 river miles (RM 122.2–279.0; Figure 2.21). All developmental phases (protolarval to juvenile) were represented by the Humpback Chub taken, with metalarvae (n=15) comprising the majority (44.1%). This was the first time that protolarval Humpback Chubs (n=2) were captured during the 2014–2018 larval fish surveys. Nonnative fish captures remained extremely low and were 0.05% of the total age-0 fish captured (Appendix E.5).

In July, 212 age-1 fishes were incidentally captured. Age-1 fish taken were primarily Speckled Dace (41.9%) and Flannelmouth Sucker (38.7%; Appendix F.5). Humpback Chub (n=33), the next most abundant incidental catch, were captured at 9 of 56 (16% GRTS segments) and ranged from 47 to 105 mm TL.

August: The final larval fish survey of 2018 occurred 08–14 August (Table 2.8). Mean daily discharge during the August survey ranged from 10,814 to 17,620 ft3/sec and averaged 15,661 ft3/sec. Diel fluctuation was 5,291 ± 2,139 ft3/sec (mean ± SD). Water clarity in August was low relative to previous sample months as indicated by decreased Secchi disk depths (12–34 cm). Turbidity measurements were not available from the August survey period at the Diamond Creek USGS gage (09404200). Water temperature near the middle of the study area (RM 190) decreased slightly (0.6°C) from the July survey and averaged 16.3°C (Figure 2.15).

August larval fish capture rates were the lowest of all 2018 surveys and were not statistically different from those from March and April (ANOVA, $F_{5,6720}$ =93.0372, P<0.0001, Tukey's HSD). Speckled Dace (n=804) was the most abundant species documented, comprising slightly more than half (57.4%) of the total fish capture (Appendix E.6). Flannelmouth Sucker (n=463) was the second most abundant (33.1%) native species, followed by Bluehead Sucker (n=33; 2.4%). Razorback Sucker was not collected in August. Humpback Chub (n=21) were distributed from RM 165.0–241.9, were captured in 11 of 56 (19.6%) GRTS segments, and comprised 1.5% of the catch. The majority (61.9%; n=13) of Humpback Chub taken in August were juveniles; the remainder (n=8) were metalarvae. Nonnative age-0 fishes comprised 5.6% of the total fish captured. Fathead Minnow (n=62) comprised the overwhelming majority (78%) of the age-0 nonnative fishes.

August age-1 incidental captures consisted mainly of native fishes (81%); Speckled Dace (53.6%; n=52) and Flannelmouth Sucker (18.5%; n=18) comprised the majority. Age-1 Humpback Chubs (n=7) were captured at 4 of 56 GRTS segments between RM 165.0 and 263.6.

Nonnative age-1 captures were Fathead Minnow (n=7), Brown Trout (n=1), and Plains Killifish (n=10). The Brown Trout captured at RM 144.8 was 104 mm TL.

Native and nonnative fishes: Ten species of age-0 fish were captured during the 2018 larval fish surveys. Five of the 10 species were native fishes representing two families: Catostomidae (n=3 species) and Cyprinidae (n=2 species). Native fishes numerically dominated the monthly captures and were taken at all 56 GRTS segments (RM 88.6–279.0; Figure 2.22). Bluehead Suckers (n=15,521) and Flannelmouth Suckers (n=29,650) were the two most commonly captured age-0 species. Nonnative fishes captured were represented by three families: Cyprinidae, Fundulidae, and Poeciliidae. Nonnative fishes were found in extremely low densities in 20 of 56 GRTS segments (RM 98.7–279.0; Figure 2.22). Fathead Minnows (n=63) and Plains Killifish (n=15) were the two most abundant nonnative age-0 fishes captured. Overall, nonnative age-0 fishes (n=88) represented an exceedingly small portion (0.18%) of the total age-0 capture (n=49,379; Appendix E1–6).

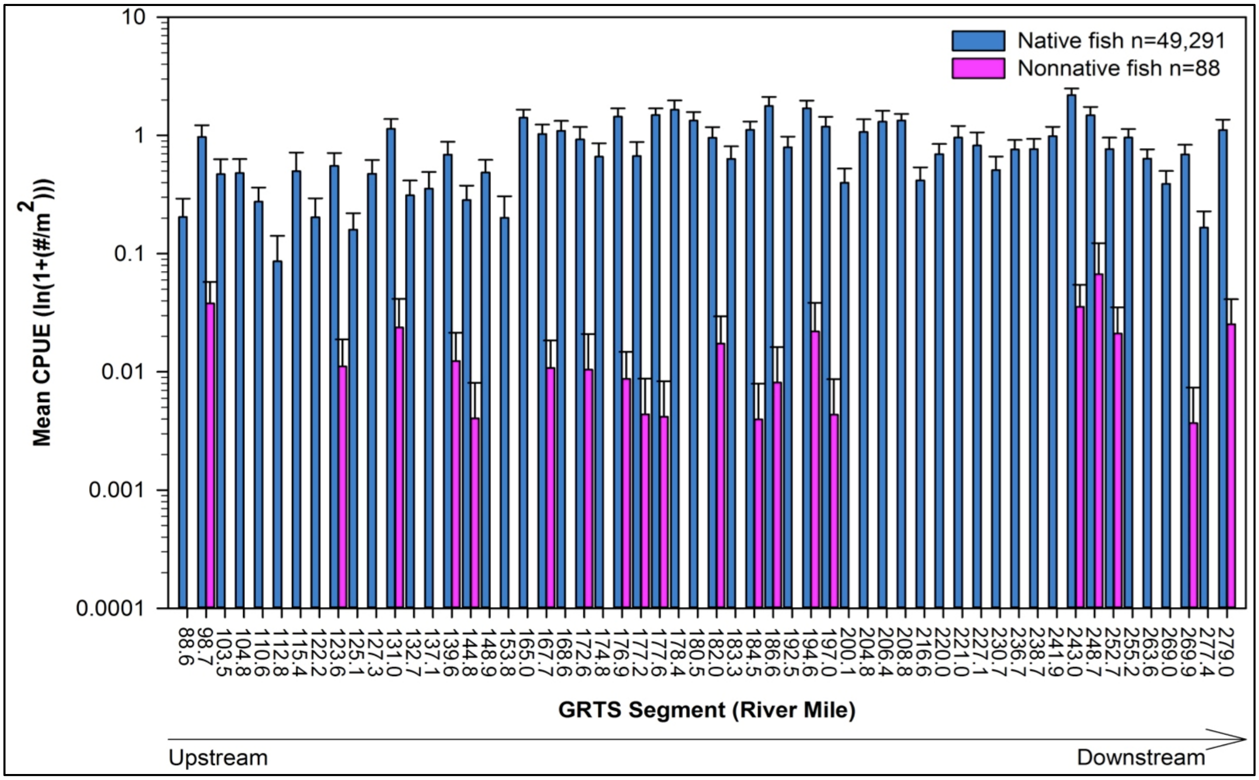

Figure 2.22. Mean catch per unit effort (CPUE) of age-0 native and nonnative fishes by generalized random tessellation stratified (GRTS) segment for survey months (March–August) combined. The *y*-axis scale is $\log_{10}$ and error bars are ± 1 SE.

Razorback Sucker

Larval Razorback Suckers have been collected in Grand Canyon for five consecutive years (2014–2018). In the 2 years immediately prior to 2018 (2017 and 2016), the first appearance and upstream-most capture of Razorback Sucker in the expanded study area (RM 88.6–279.0) occurred at GRTS sites downstream of Havasu Creek at or near RM 167.7. In 2018, Razorback Sucker larvae were also first encountered at RM 167.7 (Figure 2.19). This locality is where initial captures of catostomid (Flannelmouth and Bluehead Sucker) larvae first occurs during larval surveys (2016–2018), which indicates upstream catostomid spawning.

In 2018, 10 larval Razorback Suckers were captured from March to June. Larval Razorback Suckers were dispersed across the lower 124.2 river miles of the study area (RM 144.8–269.0). Razorback Suckers were taken from eight unique GRTS segments, and only two GRTS segments produced larval Razorback Suckers in more than one monthly survey (Figure 2.23). Three larvae were documented in March between two GRTS segments (RM 167.7 and 168.6). Interestingly, in April, Razorback Sucker larvae were taken from two geographically disjunct sites near RM 144.8 (n=1) and 269.0 (n=1). The capture of age-0 Razorback Sucker at RM 144.8 is the most upstream capture to date, an increase of 23 river miles further upstream than previous years. The May survey documented two larvae, one at each site, from RM 197.0 to RM 243.0). June was the last month in which larvae of the species were documented. Three fish were captured during the June survey at three localities (RM 165.0–243.0). There was no significant difference in larval fish CPUE (ANOVA, $F_{3,891} = 0.4613$, P=0.7094) among the four months during which this species was captured.

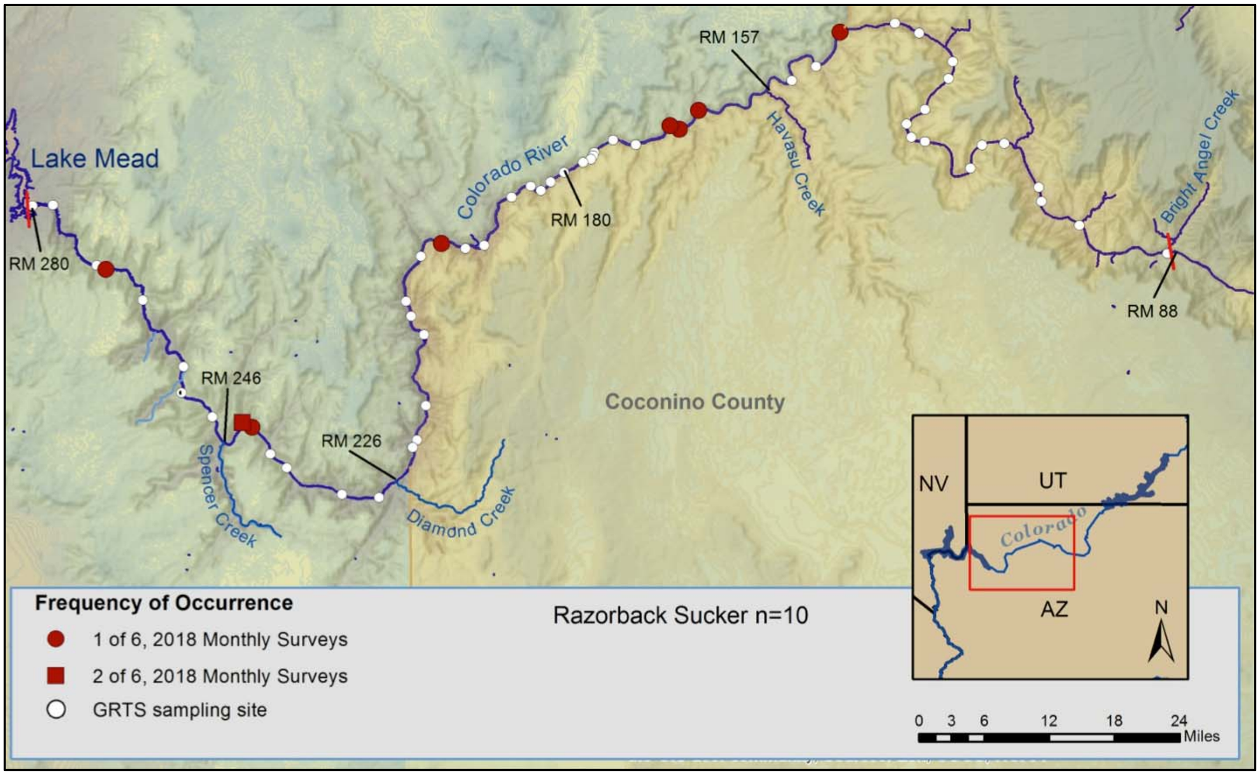

Figure 2.23. Frequency of occurrence of larval Razorback Sucker at generalized random tessellation stratified (GRTS) segments during the 2018 larval fish survey.

Larval Razorback Sucker captured ranged from 11.7 to 13.6 mm TL (Figure 2.24). Razorback Sucker represented the two earliest larval ontogenetic phases during 2018 (protolarvae, mesolarva). Single protolarval specimens, the earliest life phase, were present in each of the March through June surveys. The other six specimens were the earliest subphase of mesolarvae (flexion mesolarvae) and were present in each of the March–June samples. Protolarval and mesolarval specimens were nearly uniformly distributed geographically (Figure 2.25). This was the first year that postflexion mesolarvae were not documented in the larval surveys. As in previous years, juvenile Razorback Sucker was not detected.

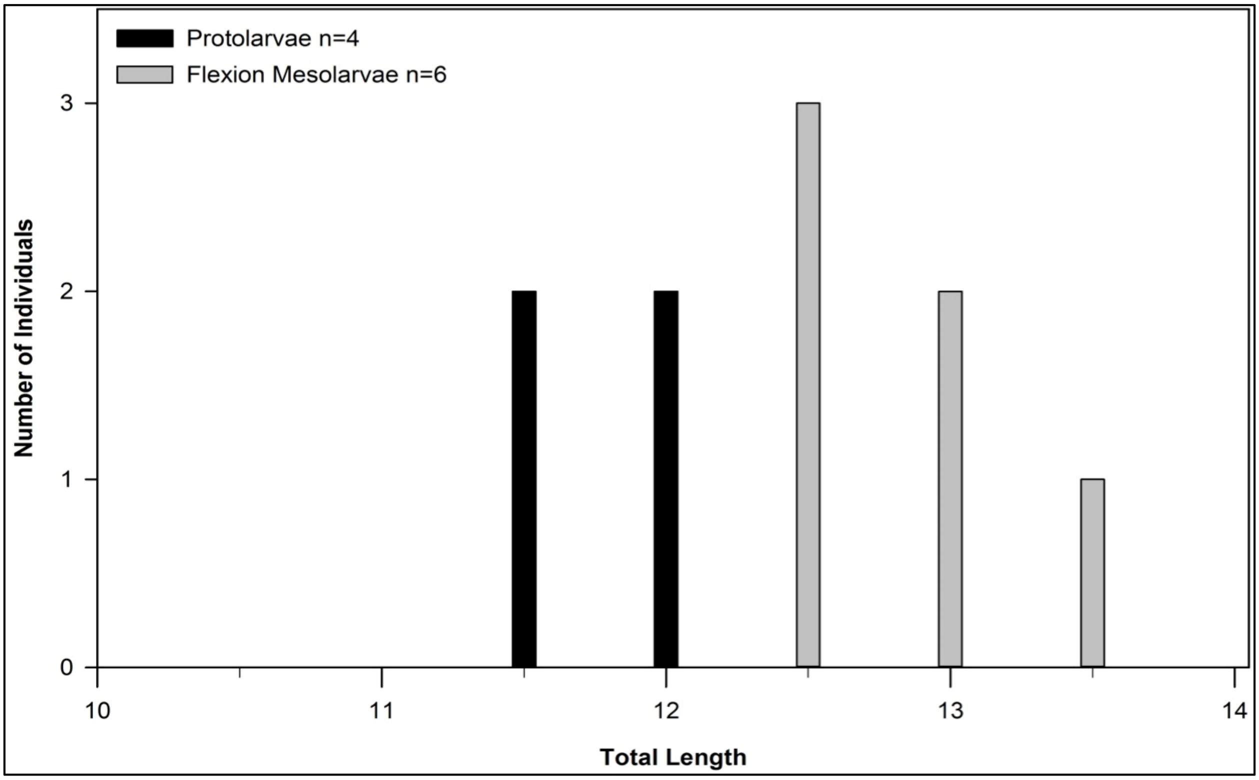

Figure 2.24. Distribution of total lengths (TL) of larval Razorback Sucker captured during the 2018 larval fish survey.

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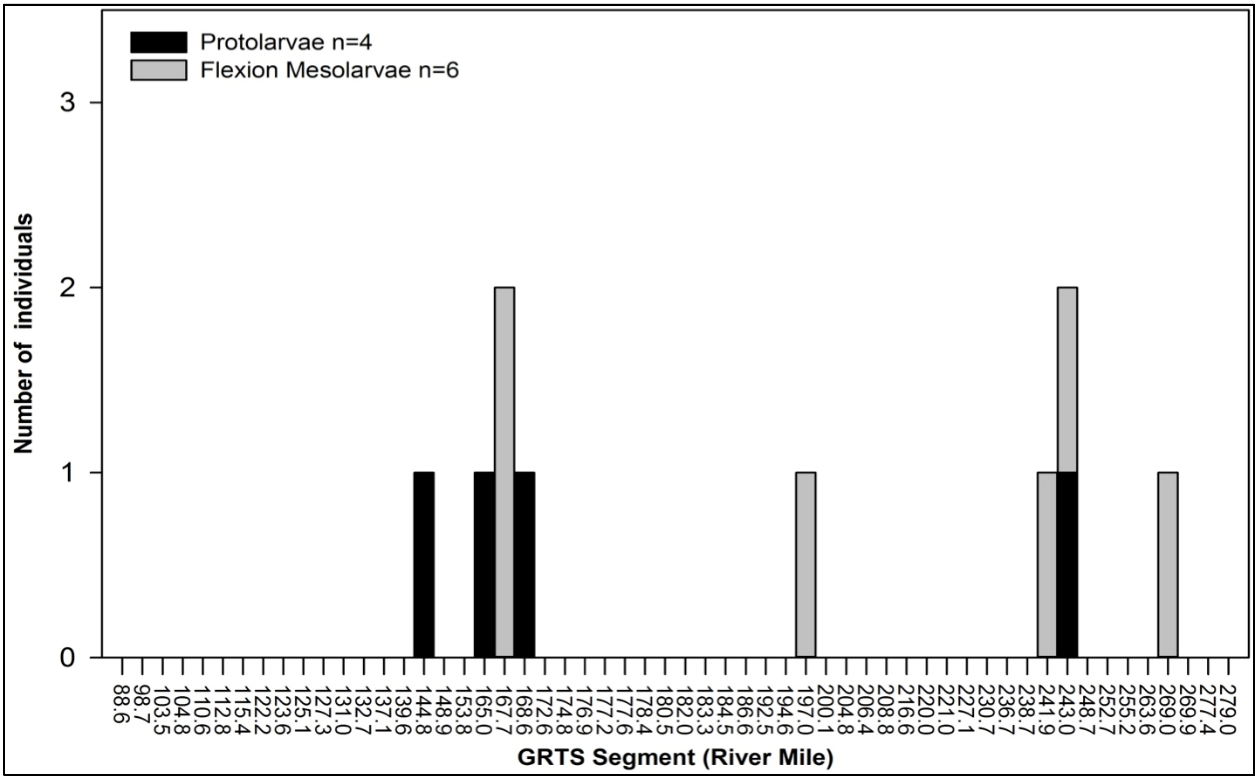

Figure 2.25. Spatial and ontogenetic stage distribution of larval Razorback Sucker captured during the 2018 larval fish survey.

Length-based (TL) back-calculated hatching dates encompassed 14 weeks, from 21 February to 2 June, 2018. Due to the low number of Razorback Sucker larvae collected and the protracted period of larval hatch, a hatching peak is not apparent (Figure 2.26). The initial captures of larval Razorback Sucker in 2018 were downstream of Havasu Creek, which is typically warmer than the Colorado River. Mean daily water temperatures in the Colorado River (just upstream of Diamond Creek) during the first hatching period were near 10°C while mean daily water temperatures in Havasu Creek exceed 12°C at the initiation of the hatching period. During the putative hatching period of Razorback Sucker, mean daily water temperatures in Havasu Creek were, on average, 3.6°C warmer than the Colorado River (Figure 2.26).

Humpback Chub

Age-0 Humpback Chub (n=110) were captured in four of the six monthly 2018 surveys (May–August) and in 57.1% of the GRTS segments in 2018 (Appendix E.3–6). Humpback Chubs were taken from 32 unique GRTS segments, 13 of which produced age-0 Humpback Chub in more than one monthly survey (Figure 2.27). While the 2018 monthly catch rates of age-0 Humpback Chub were statistically different (ANOVA, $F_{3,892}$=2.9759, P=0.0308, Tukey's HSD), the between-month comparisons were not significant.

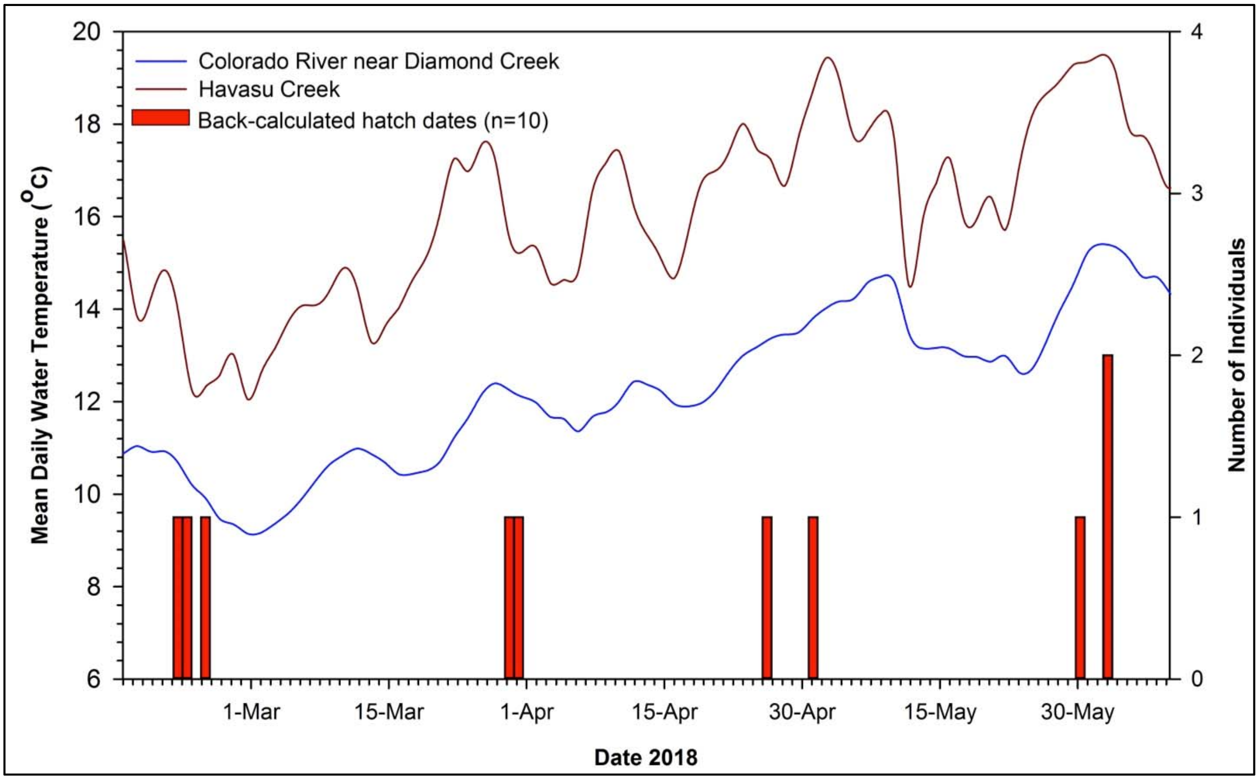

Figure 2.26. **Water temperature of Havasu Creek and the Colorado River upstream of Diamond Creek (USGS gage 09404200) displayed with the back-calculated hatching dates of Razorback Sucker based on 2018 larval fish standard length (SL).**

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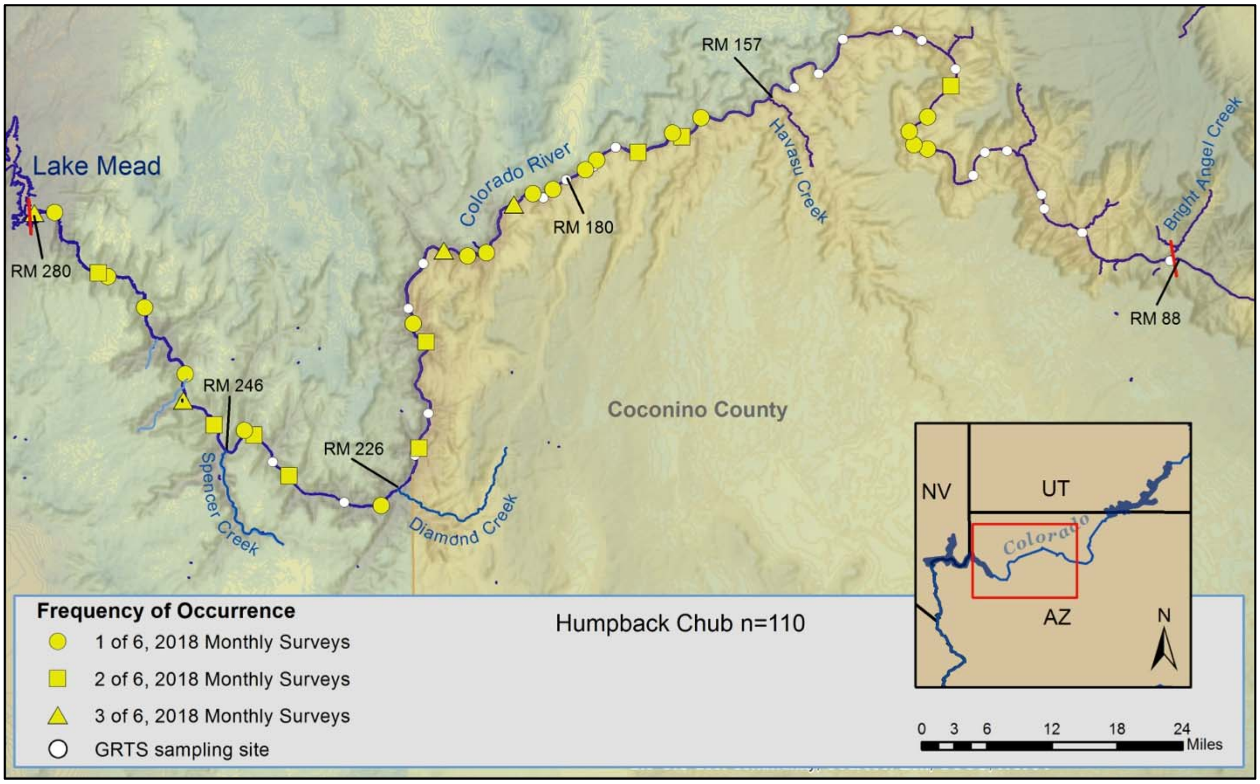

Figure 2.27. Frequency of occurrence of larval Humpback Chub at generalized random tessellation stratified (GRTS) segments during the 2018 larval fish survey.

Age-0 Humpback Chub captured in 2018 ranged in size from 9.3 to 35.0 mm TL (Figure 2.28). The distribution of July Humpback Chub (n=34) was similar, in comparison with June, (RM 122.2–279.9) except the larvae exhibited a broader range of development than during June. The July Humpback Chub sample included two protolarvae collected at two GRTS segments (RM 127.3 and RM 197.0) and a single juvenile taken near RM 125.1. The remaining July larvae consisted of nearly equal portions of mesolarvae (n=16; 47.0%) and metalarvae (n=15; 44.1%). Metalarvae (n=9; 42.9%) and juveniles (n=12; 57.1%) were the only Humpback Chub developmental stages taken in August, and they were distributed from RM 165.0 to RM 263.6. There were no clear distributional or abundance patterns in ontogenetic phases of age-0 Humpback Chubs collected during 2018 (Figure 2.29). Back-calculated hatch dates for Humpback Chub in 2018 spanned more than 12 weeks, from 24 April 24 to 20 July 2018. The distribution of hatch dates suggests at least two peaks in hatching occurred, most from late May to mid June (Figure 2.30).

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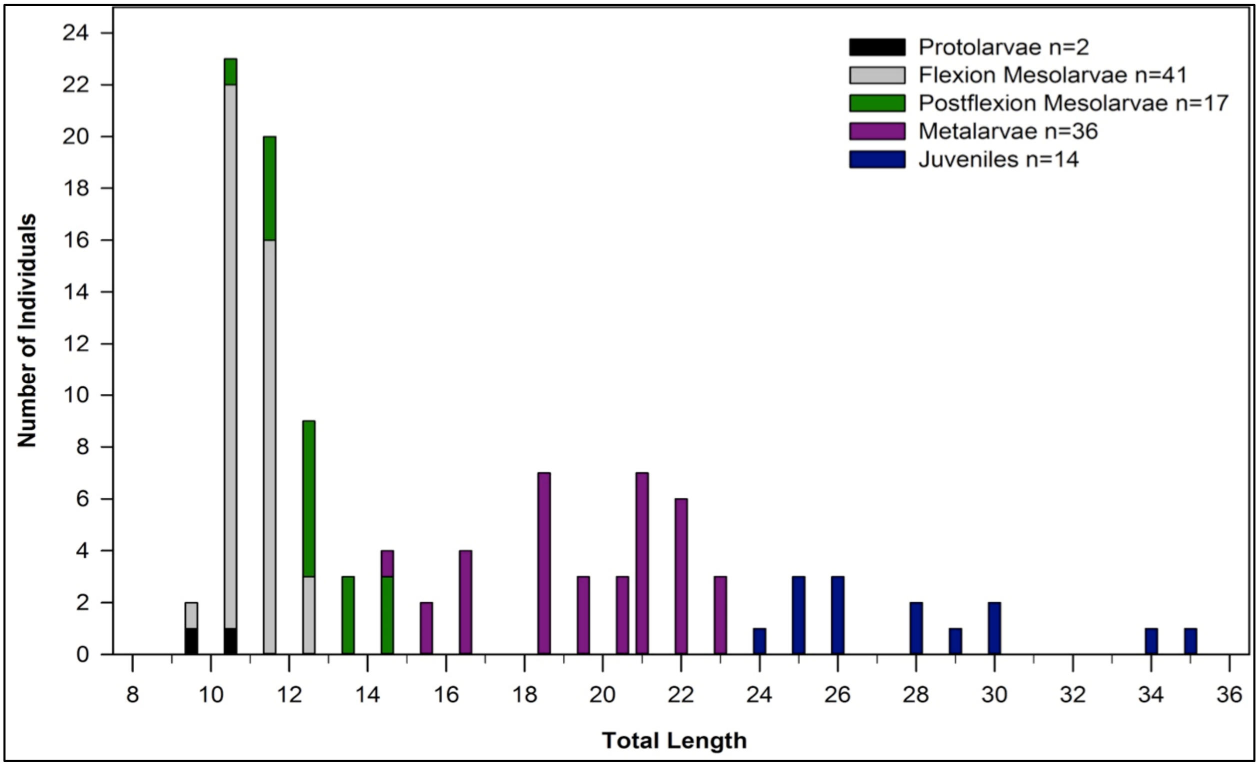

Figure 2.28. Distribution of total lengths (TL) of Humpback Chub captured during the 2018 larval fish survey.

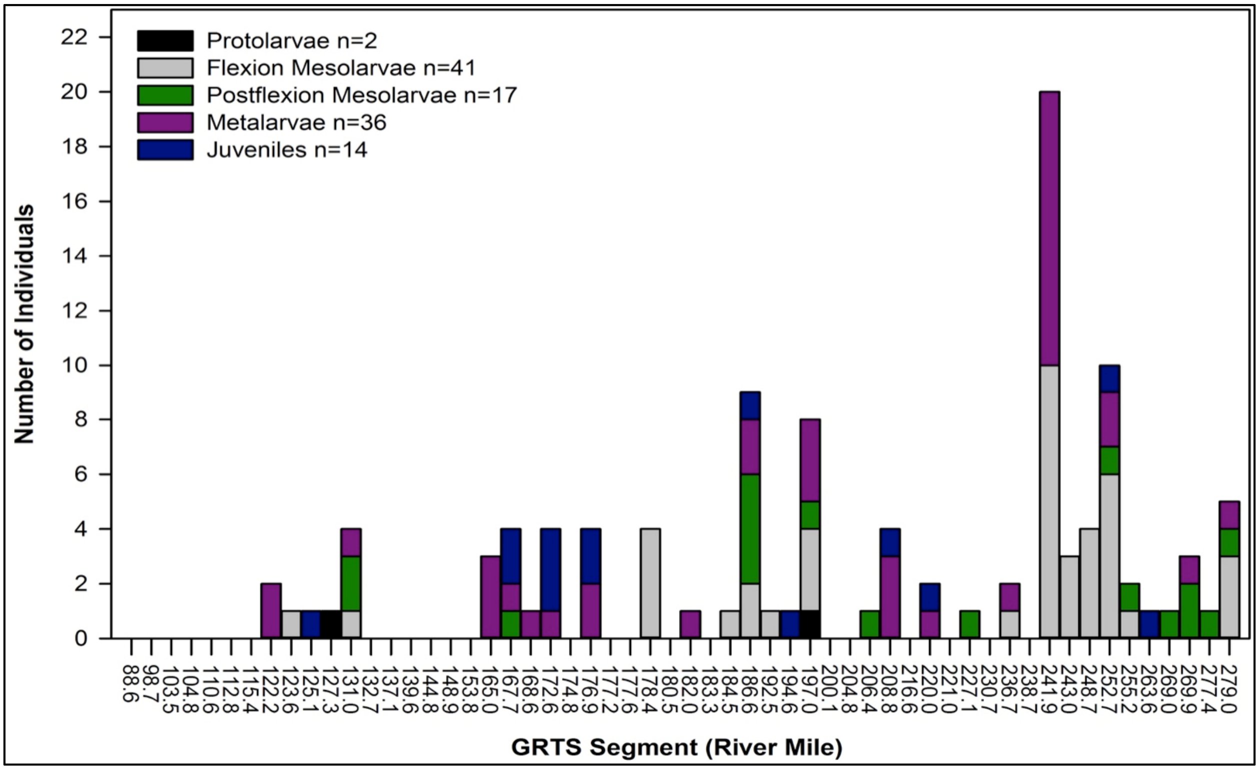

Figure 2.29. Spatial and ontogenetic stage distribution of Humpback Chub captured during the 2018 larval fish survey.

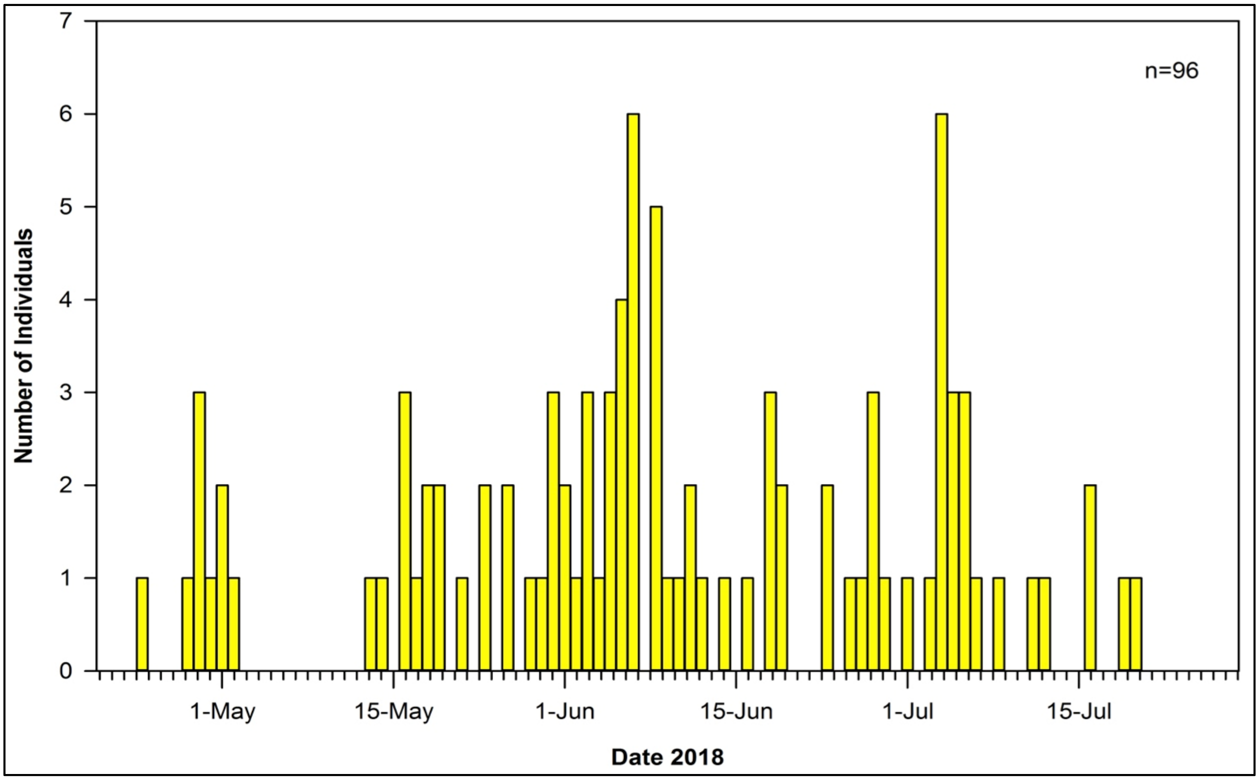

Figure 2.30. Back-calculated hatch dates of Humpback Chub based on 2018 larval fish standard lengths.

Habitat

Ten mesohabitat types were sampled during the 2018 larval fish survey (Figure 2.31). Habitats sampled in 2018 were present in relatively similar proportions as in 2016 and 2017 (Table 2.8). Slackwaters (40.8%), sand shoals (22.2%), and pools (20.2%) comprised the majority (83.2%) of 2018 habitats. Catch rates of larval fish varied between habitats (ANOVA, $F_{9,6710}$=21.1058, P=<0.0001, Tukey's HSD) and while larval fish catch rates where highest in backwater habitats, backwater catch rates were only significantly higher than catch rates in slackwater and sandshoal habitats. Razorback Suckers were captured in four low-velocity habitat types: backwaters, embayments, pools, and slackwaters. The highest CPUE of larval Razorback Sucker occurred in backwaters (n=4) and embayments (n=3). However, the low number of Razorback Sucker collected (n=10) precluded determination of trends. Bluehead and Flannelmouth suckers were captured in nearly every habitat type; however, Bluehead Suckers were not captured in runs (Figure 2.32).

Humpback Chub and Speckled Dace were collected in nearly every habitat type with the exception of runs. Humpback Chub were not collected in pocketwaters, and most Humpback Chub captures (55.4%) occurred in pools (33.6%; n=37) or slackwaters (21.8%; n=24). Mean catch rates for Humpback Chub were highest in isolated pools and pool habitats. With the exception of pocketwaters, isolated pool catch rates were significantly higher than all habitat types (ANOVA, $F_{8,887}$=4.0479, P=<0.0001, Tukey's HSD).

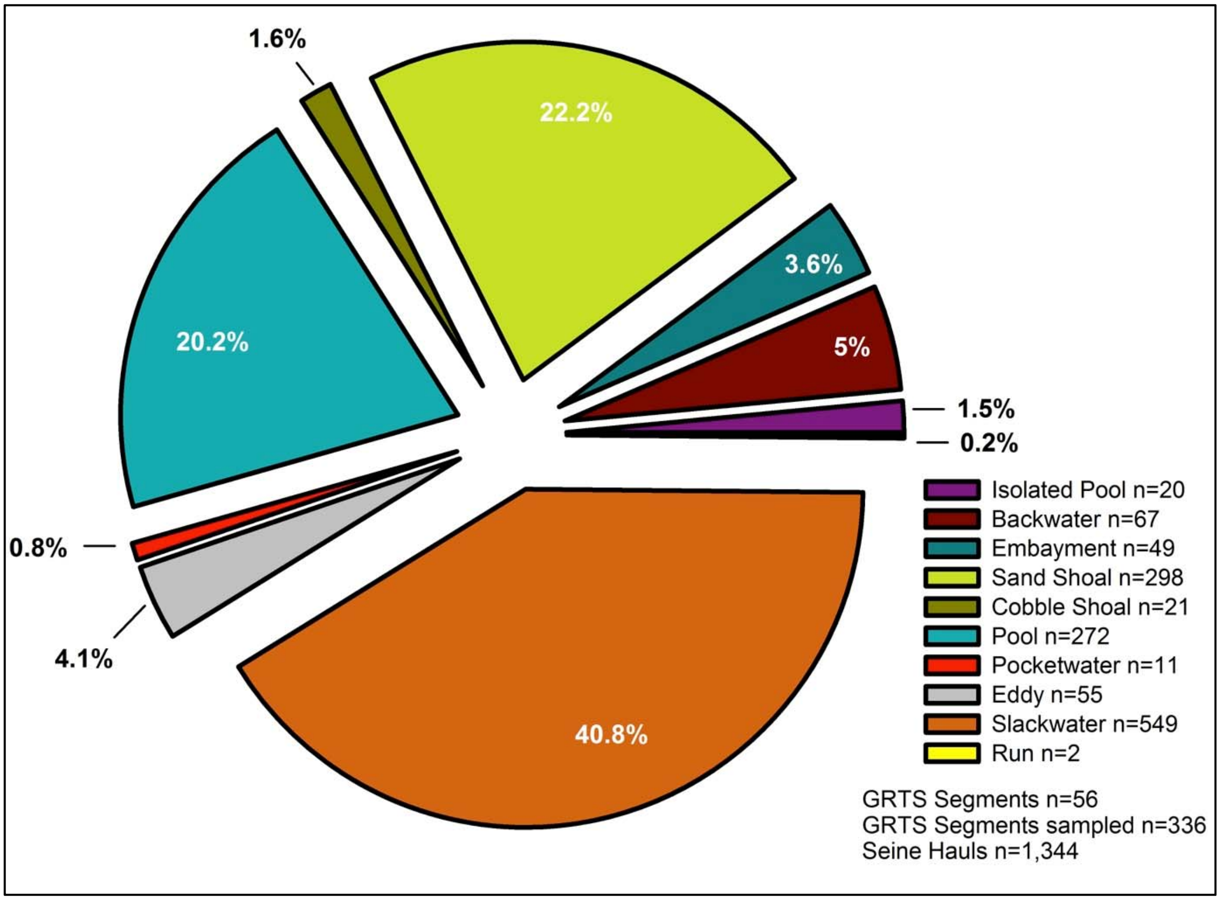

Figure 2.31. Frequency distribution of habitats sampled at generalized random tessellation stratified (GRTS) segments during the 2018 larval fish survey.

Table 2.8. Habitats sampled (percent) from monthly 2016–2018 larval fish surveys.

HABITAT	HABITAT SAMPLED 2016	HABITAT SAMPLED 2017	HABITAT SAMPLED 2018	PERCENT CHANGE[a] 2016–2018
Isolated Pool	1.46 %	1.35 %	1.49%	0.11
Backwater	6.11 %	6.29 %	4.99%	0.17
Embayment	4.01 %	6.29 %	3.65%	2.27
Sandshoal	20.99 %	23.28 %	22.17%	2.29
Cobbleshoal	1.09 %	1.27 %	1.56%	0.18
Pool	16.88 %	19.24 %	20.23%	2.36
Pocketwater	4.29 %	2.40 %	0.82%	1.89
Slackwater	40.33 %	37.28 %	40.85%	3.05
Eddy	3.65 %	1.70 %	4.09%	1.93
Run	1.19 %	0.90 %	0.15%	0.29

[a] Percent change: current year percent sampled subtracted from the mean of previous years percent sampled.

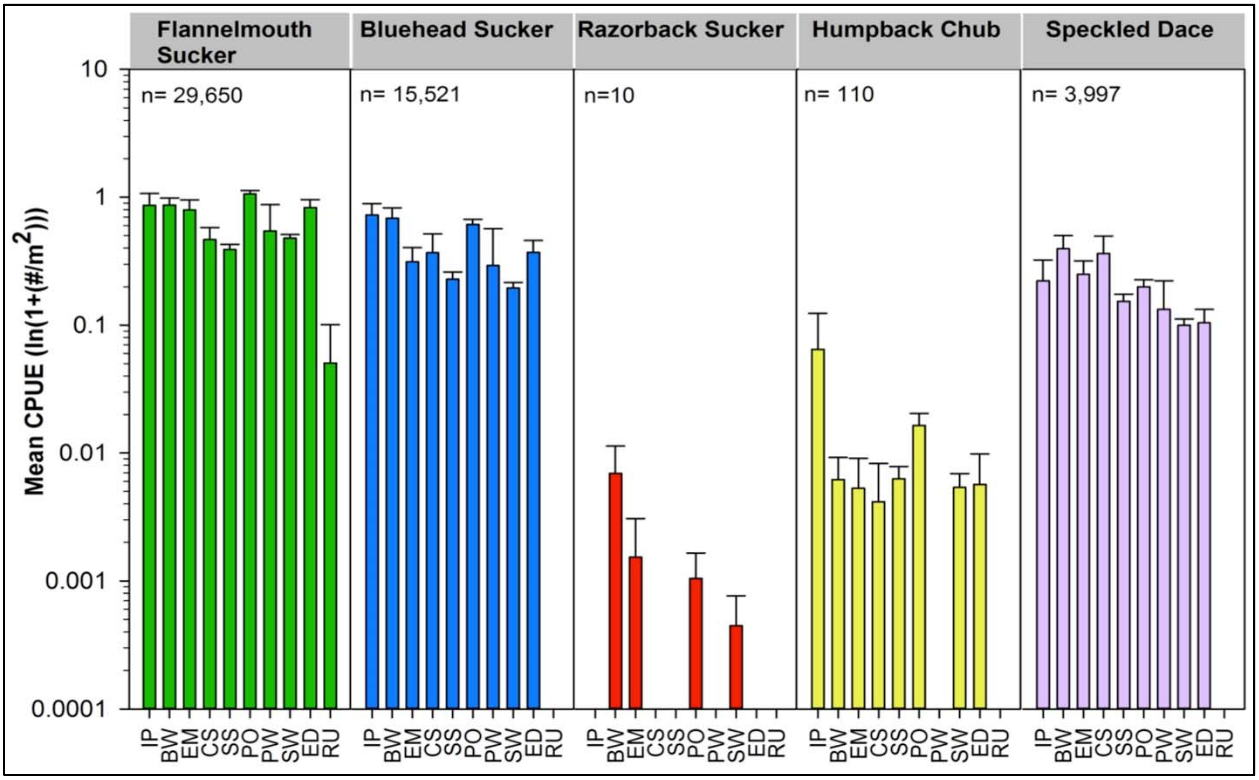

Figure 2.32. Mean catch per unit effort (CPUE) by species and habitat type during the 2018 larval fish survey. The *y*-axis scale is $\log_{10}$ and error bars are ± 1 SE.

Ontogenetic Phase Distributions

Native fishes documented in the 2018 larval fish survey, with the exception of Razorback Sucker, were represented by specimens from the earliest larval ontogenetic phases through transition to early juvenile. Throughout the 2018 survey the catostomid developmental stages captured progressed from young to older along a longitudinal gradient of sampling sites. This pattern of late-stage larvae increasing in percent of total capture in downstream sites is evident for both Flannelmouth and Bluehead Suckers, but not apparent for either Razorback Suckers or Humpback Chub captures (Figures 2.33, 2.34, 2.35, and 2.36). In all years when all catostomids were ontogenetically staged (2016–2018), this pattern was apparent.

In addition to temporal and spatial patterns of larval development described above, during both larval fish surveys in recent years (2016–2018) the initial captures of catostomid larvae occurred at sites downstream of Havasu Creek. The first occurrence of catostomid larvae upstream of Havasu Creek during March surveys was recorded in 2018. The majority of catostomid larvae (98.1%) were taken in the lower 111 river miles (RM 167.7–279.0) during the March survey. In April, captures of Bluehead Sucker and Flannelmouth Sucker larvae both expanded upstream. By May, larval catostomids increased in distribution and abundance and encompassed the entire study area (Figures 2.33 and 2.34). A similar temporal pattern of initial larval fish distribution was observed in Humpback Chub with larvae occurring in May in the lowermost 86.5 river miles (RM 192.5–279.0; Figure 2.21). Captures expanded upstream in June to include approximately 155 river miles for Humpback Chub and remained similar in following months (July and August).

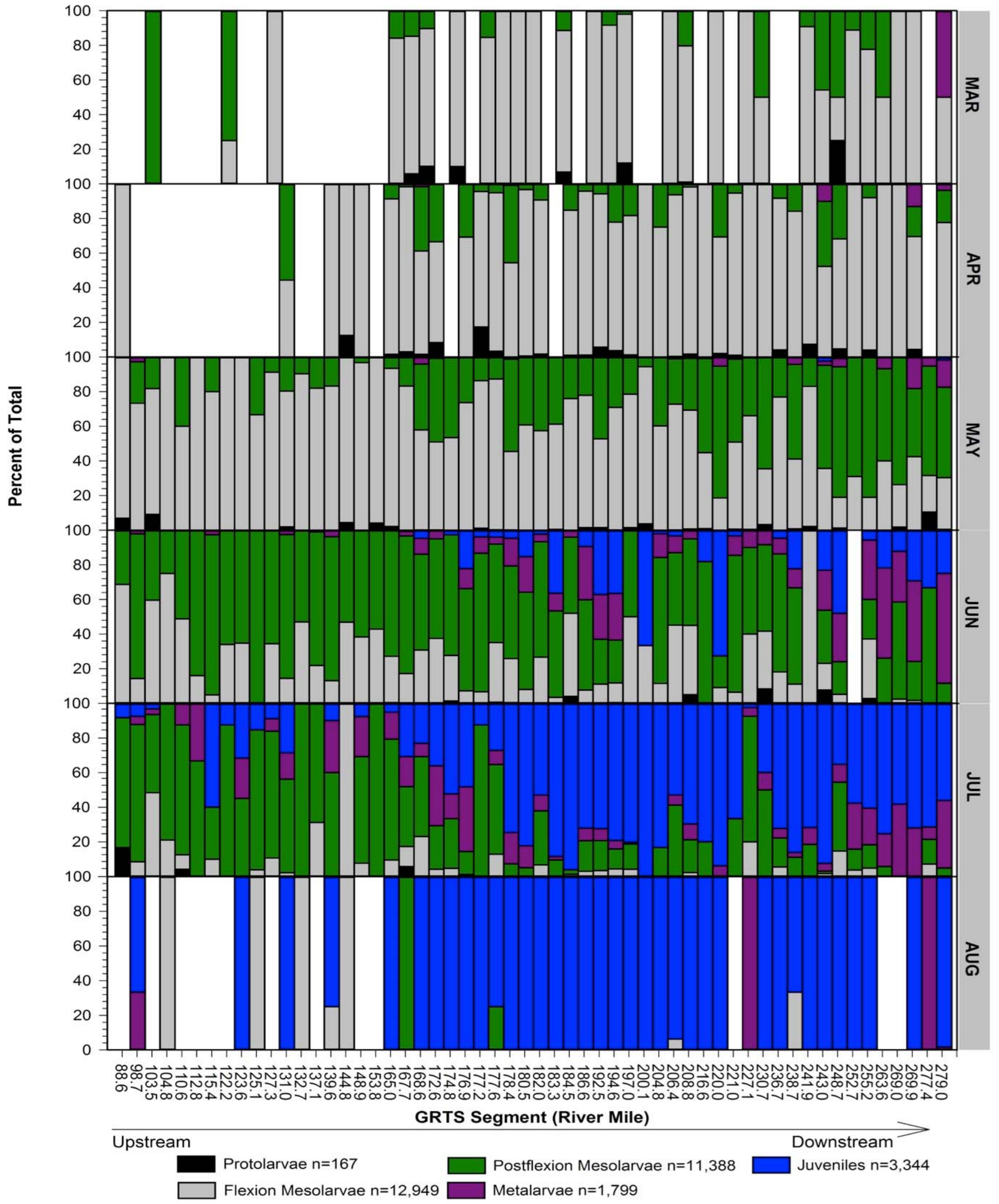

Figure 2.33. **Longitudinal distribution of ontogenetic phases of age-0 Flannelmouth Sucker by 2018 sampling trip (month) and generalized random tessellation stratified (GRTS) segment.**

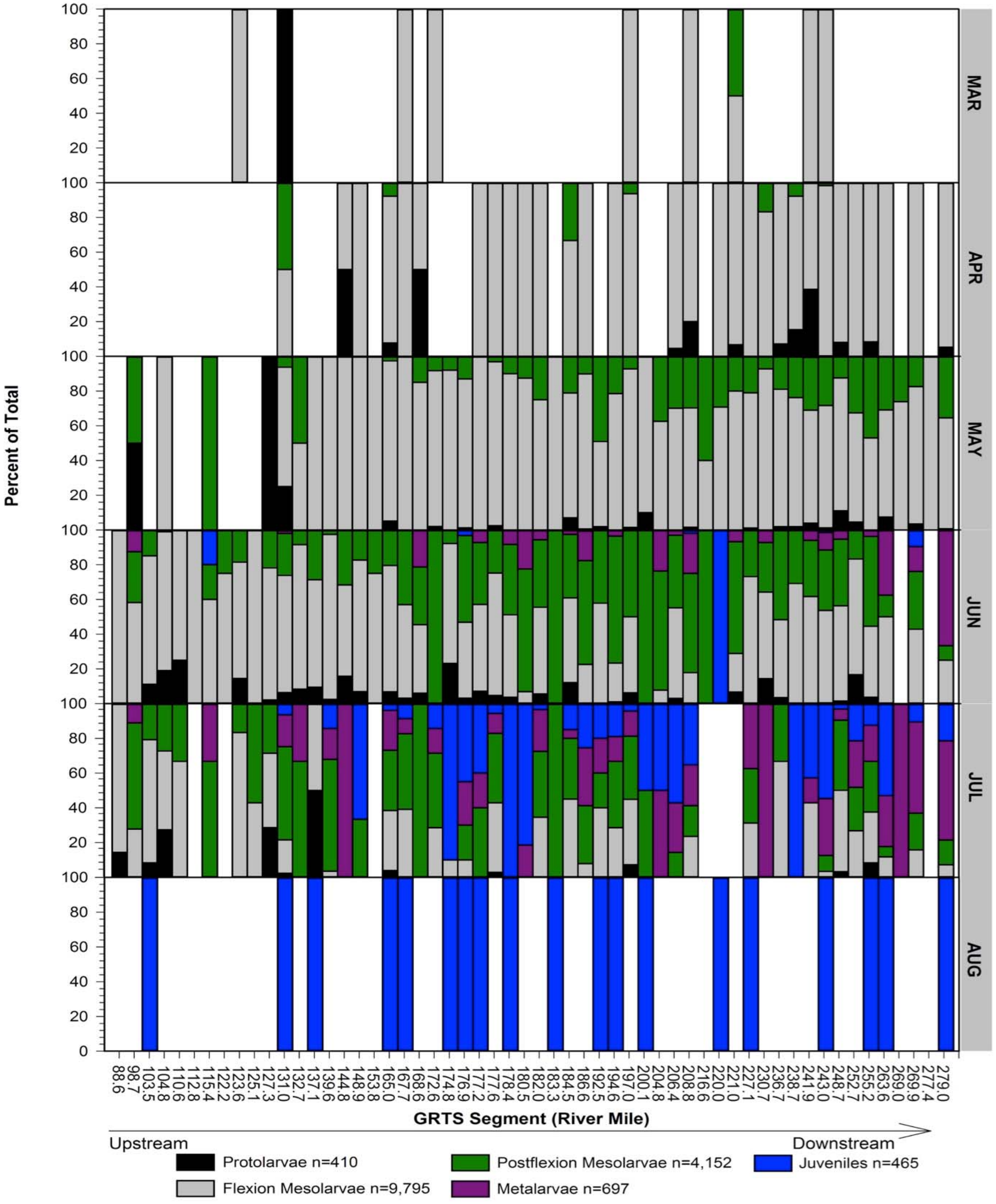

Figure 2.34. Longitudinal distribution of ontogenetic phases of age-0 Bluehead Sucker by 2018 sampling trip (month) and generalized random tessellation stratified (GRTS) segment.

Distribution of protolarvae, the earliest developmental stage, can be used to infer spatial patterns of spawning over time. The protolarval stage is the shortest of the developmental phases and recently hatched larvae spend much of that stage in the interstitial zones of spawning bars. The hypothesis is that captured protolarvae are likely taken in relatively close proximity to the parental spawning area. 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). While Razorback Sucker larvae abundance was very low in 2018, the distribution of their protolarvae may indicate two spatially distinct spawning events (Figure 2.35).

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 Bluehead Sucker and Flannelmouth Sucker (Figures 2.33 and 2.34), might also be indicative of drift (active and passive) of age-0 fish. The 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 later in the year (May–August; Figure 2.36).

The absence of late-phase larvae and recently transformed juvenile Razorback Sucker is noteworthy (Figure 2.35). Only four metalarval Razorback Sucker have been collected during the tenure of this project (2014 n=3, 2017 n=1). Humpback Chub, also federally endangered and the second-least abundant native fish during larval fish surveys, displayed the full range of larval ontogenetic phases, including early juvenile, during all survey years (Figure 2.36). The lack of more-developed larvae and early juvenile Razorback Suckers may relate to their truncated larval distribution, compared with the other native species or possibly the result of larvae failing to transition to more developed stages.

Larval Fish Survey Summary (2014–2018)

Over the duration of the larval fish surveys (2014–2018), reproduction by five native species, including endangered Humpback Chub and Razorback Sucker, have been documented annually. While intraspecific age-0 fish densities (CPUE) have varied across years, a single year (2014) yielded significantly higher densities for all five species. The exception to that pattern was that 2014 Flannelmouth Sucker densities were similar to 2016 and 2017 catch rates (ANOVA, $F_{4,5671}$=12.1999, P=<0.0001; Figure 2.37). Interestingly, this pattern is evident across both Cyprinidae and Catostomidae and appears independent of spawning period (Figure 2.38).

Previous reports have focused on interspecific and intraspecific variation of larval fish density (CPUE) within the sampling year. These comparisons can be used to relate spatial and temporal patterns of larval fish abundance to intra-annual variability of key explanatory variables (e.g., habitat quality, habitat availability, and physicochemical and hydrological variables). However, when examined across years, it is sometimes possible to gain insight into variables that may influence the annual densities of age-0 fishes within Grand Canyon. Generally, water temperature and discharge of the Colorado River within the Grand Canyon are highly regulated and are impacted by seasonally variable demands for hydropower. Water temperature, discharge, and amplitude of hydropeaking varied within and among years (2014–2018; Figure 2.39). During the 2014 sampling period, water temperatures were elevated, discharge was lower, hydropeaking magnitude reduced (in most months, March–August) relative to other years (2015–2018).

To investigate the roles of water temperature, discharge, and hydropeaking amplitude on age-0 fish densities between years, CPUE results were combined and analyzed at the family level to accommodate for variation in spawning strategies and periodicity. Family level analyses were restricted to four months that spawning is known to occur (April–June) and (May–August) for Catostomids and Cyprinids, respectively. March and September were excluded from the analysis due to the low abundance of larval specimens and because larval surveys did not occur those months in all years (Kegerries et al 2017).

Multiple linear regression models were performed to predict mean annual CPUE of age-0 catostomids and cyprinids based on the continuous variables of mean temperature, mean discharge, and mean hydropeaking amplitude. For catostomids, water temperature and amplitude of hydropeaking were included in the final model (see methods) and produced a significant result ($F_{2,2}$=38.29, P=0.02545) with an adjusted R^2 of 0.94, though temperature was the only significant ($P<0.05$) predictor of annual catostomid CPUE. A nearly linear positive relationship was observed between mean annual temperature and mean annual catostomid CPUE (Figure 2.40). For cyprinids, discharge was included in the final model and produced a significant result ($F_{1,3}$=100.9, P=0.00210), with an adjusted R^2 of 0.96. Despite the results of the regression model, the linear relationship between mean annual discharge and mean annual cyprinid CPUE appears dubious. Given that the disparate data points resulted in two discreet and disjunct groupings, with 2014 having high leverage, these results will require cautious interpretation (Figure 2.40).

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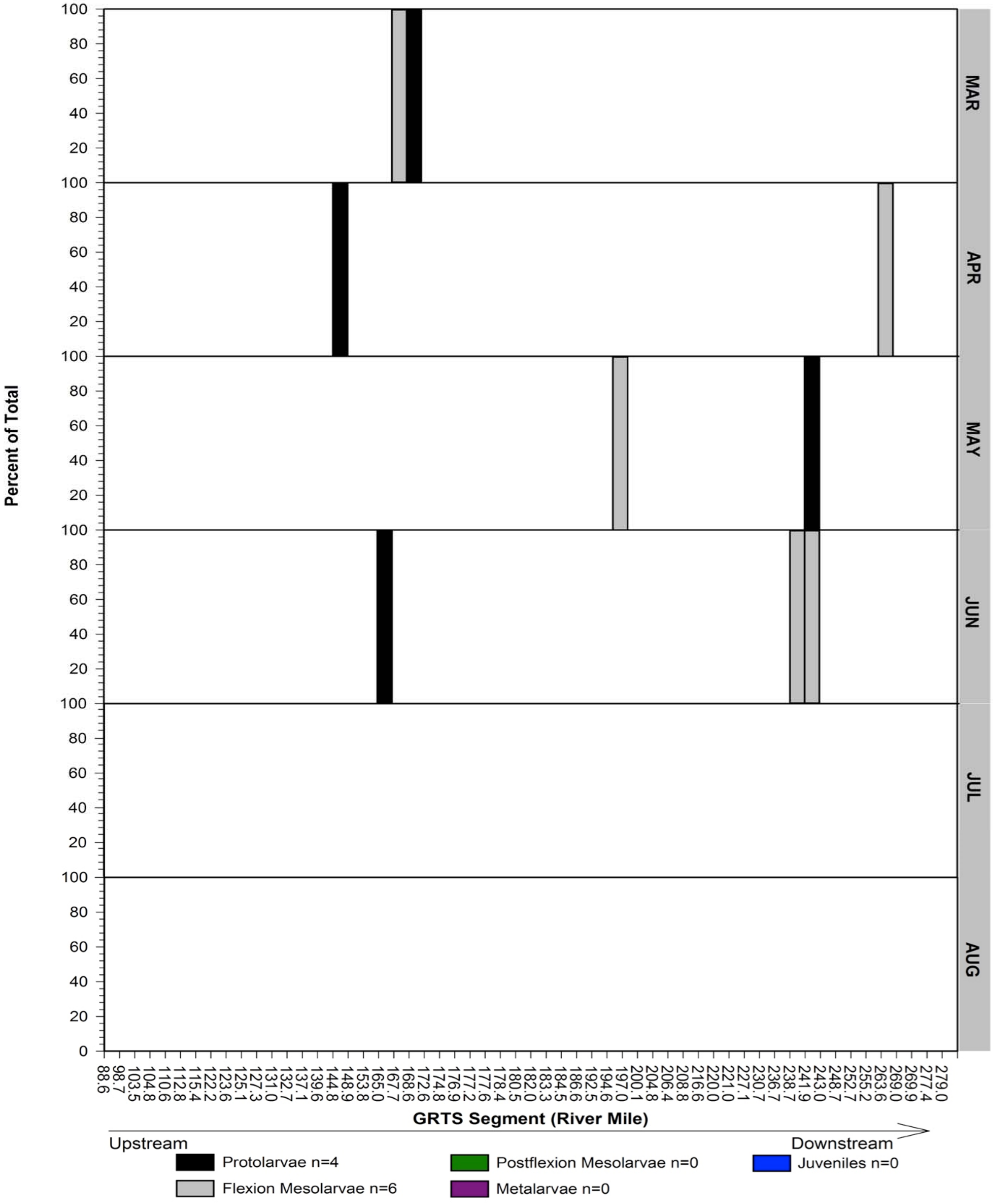

Figure 2.35. Longitudinal distribution of ontogenetic phases of age-0 Razorback Sucker by 2018 sampling trip (month) generalized random tessellation stratified (GRTS) segment.

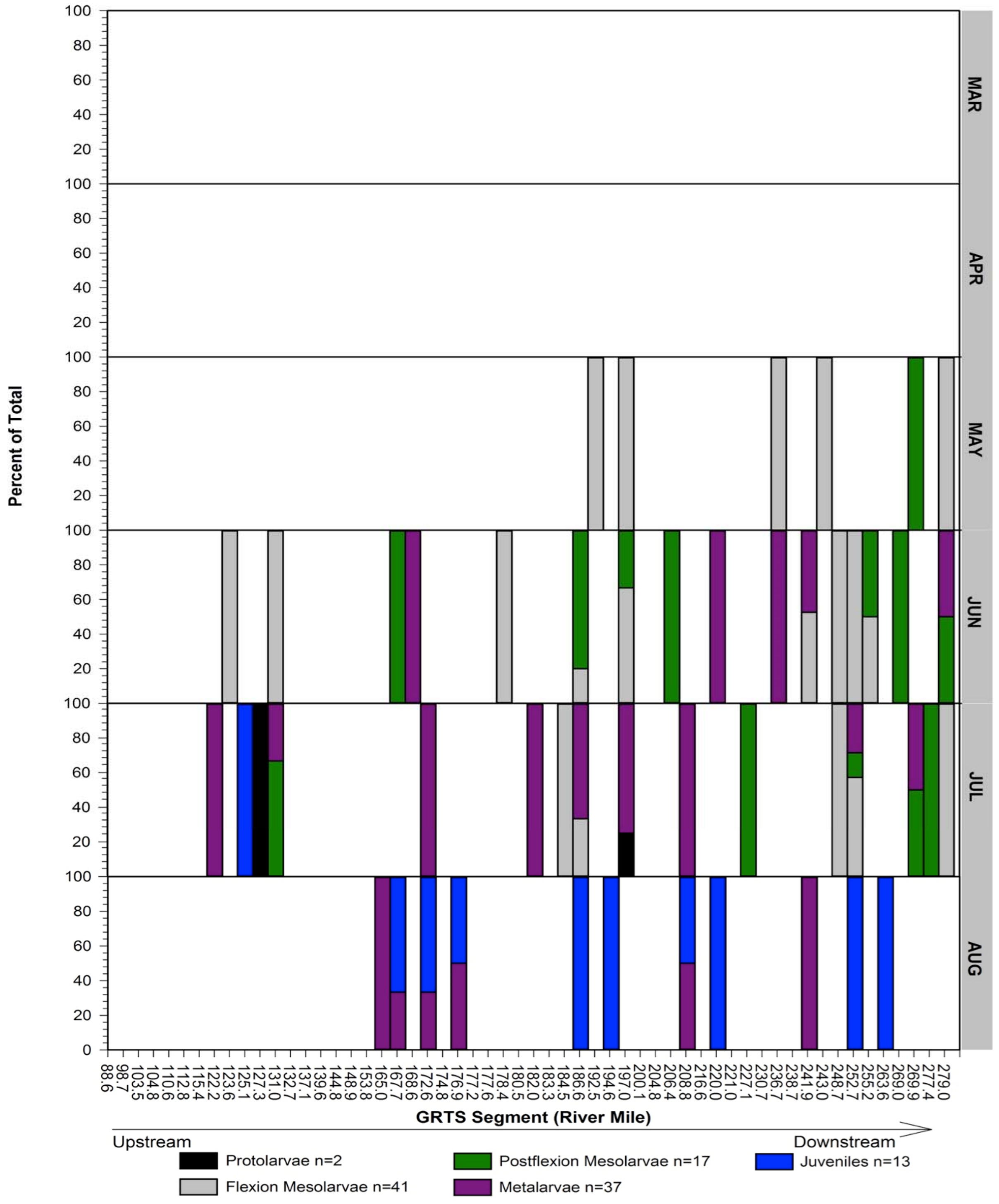

Figure 2.36. Longitudinal distribution of ontogenetic phases of age–0 Humpback Chub by 2018 sampling trip (month) and generalized random tessellation stratified (GRTS) segment.

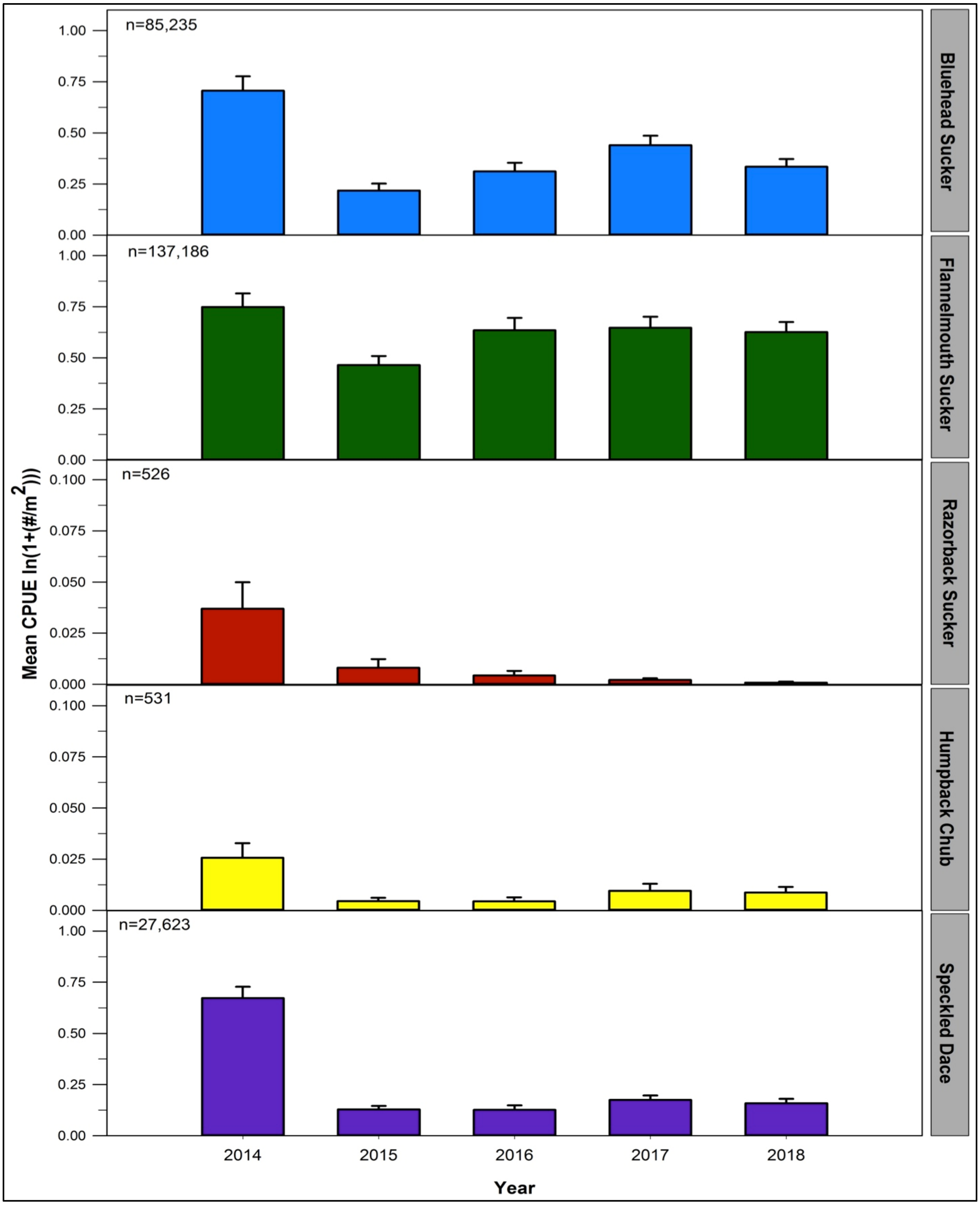

Figure 2.37. Mean catch per unit effort (CPUE) of age-0 native fishes by year. The *y*-axis scales for Razorback Sucker and Humpback Chub are, compared to other species, reduced one order of magnitude. Error bars are 95% confidence intervals.

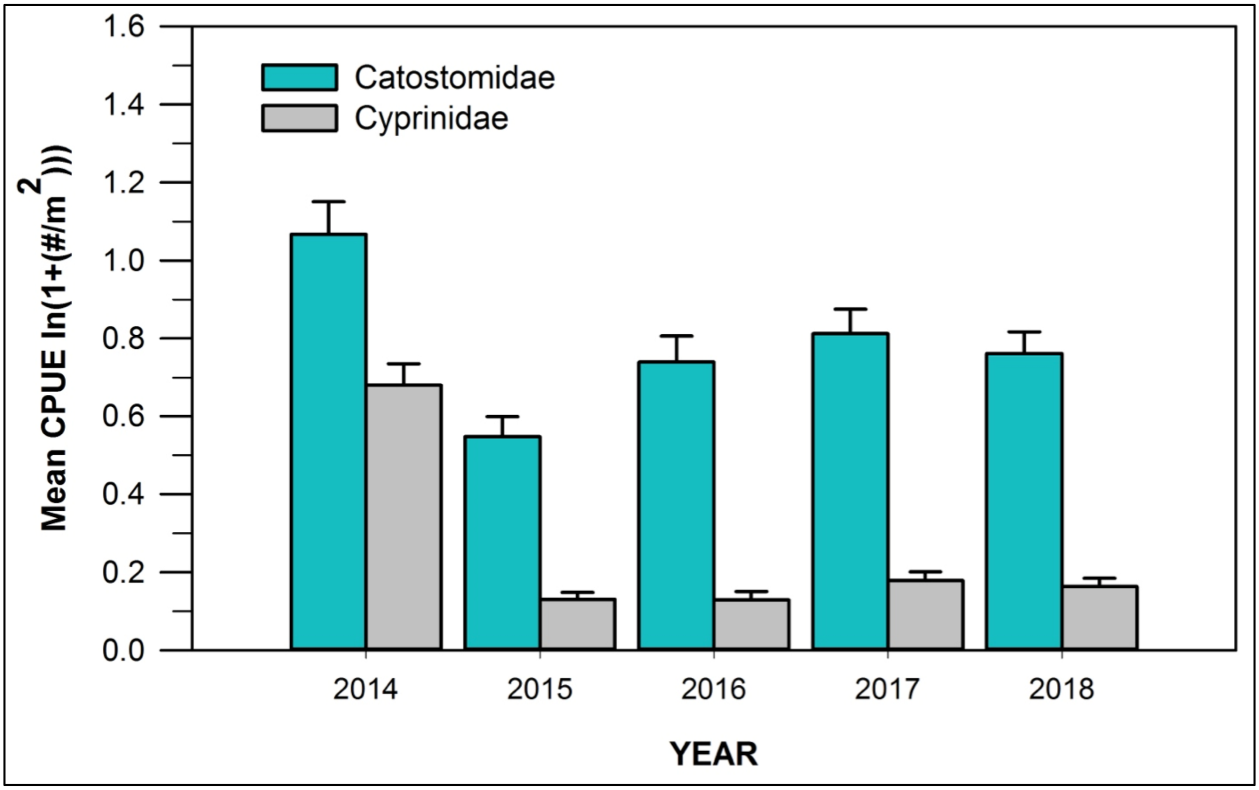

Figure 2.38. Annual mean catch per unit effort CPUE of native age-0 catostomids and cyprinids. Error bars are 95% confidence intervals.

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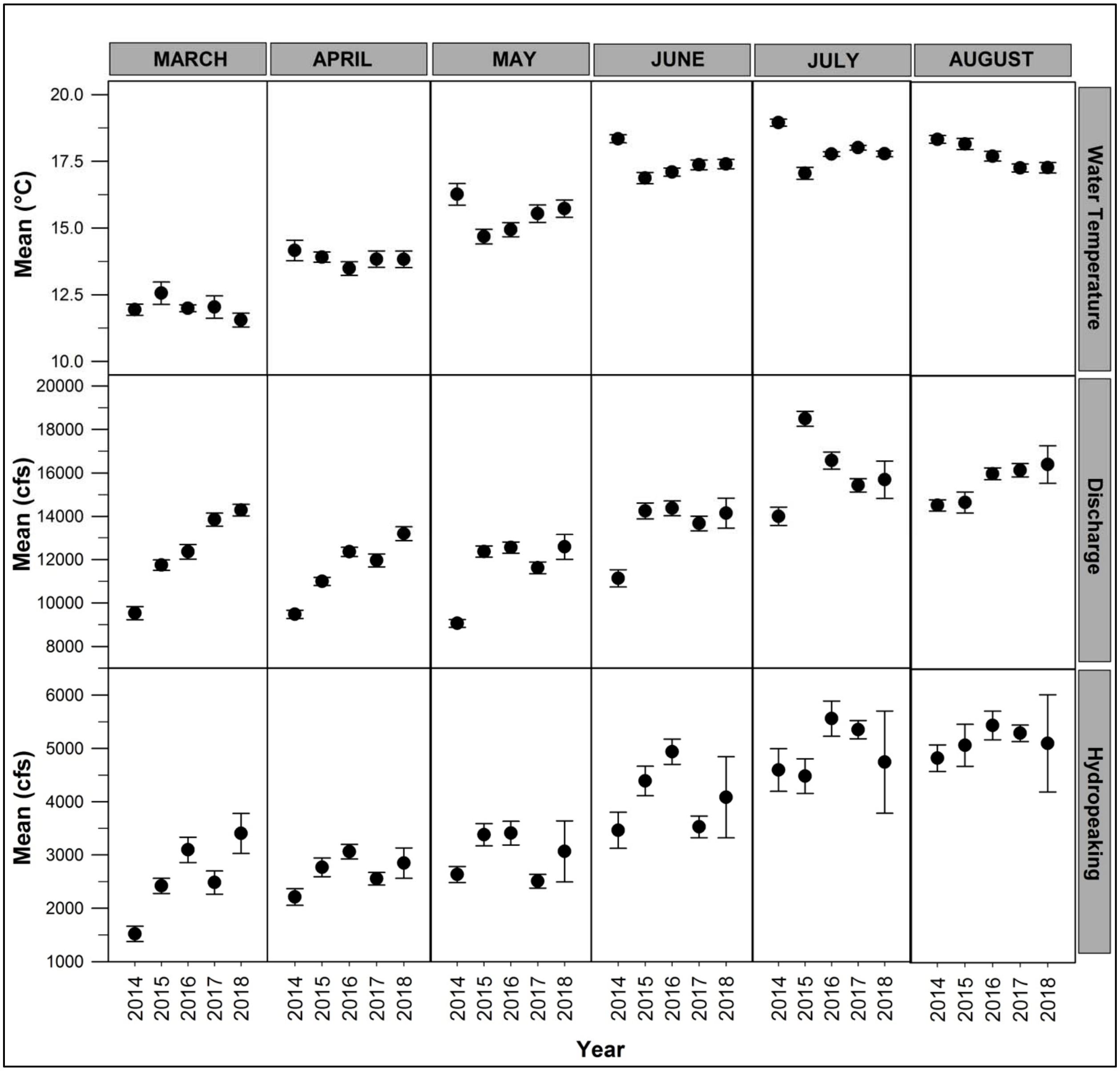

Figure 2.39. **Monthly mean water temperature (°C), discharge, and hydropeaking recorded upstream of Diamond Creek (USGS gage 09404200). Error bars are 95% confidence intervals.**

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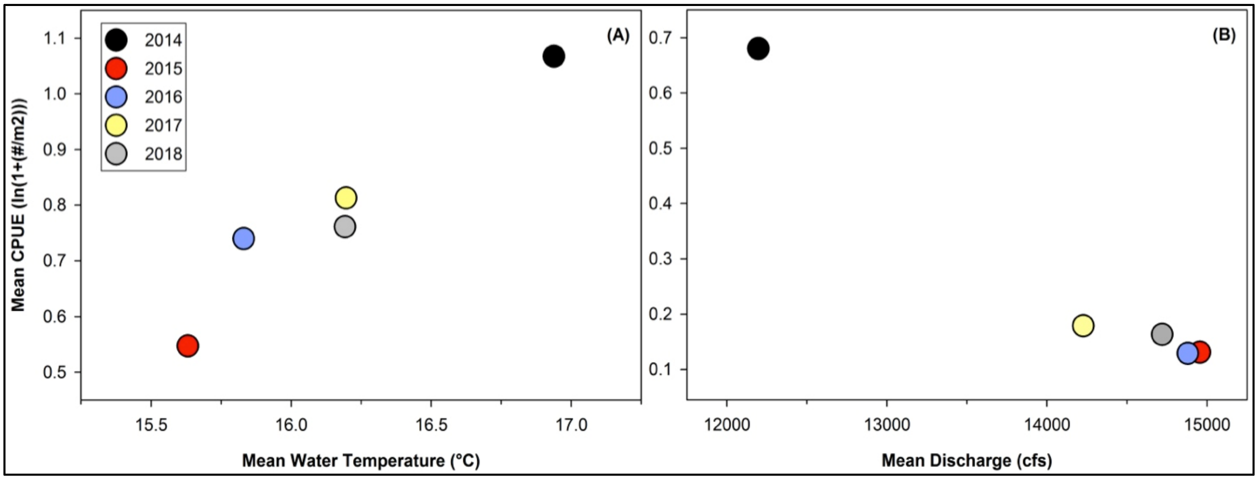

Figure 2.40. Mean annual catch per unit effort CPUE of catostomids (panel A) plotted against mean annual water temperature (April–July) and mean cyprinid CPUE (panel B) plotted against mean annual discharge (May–August) recorded just upstream of Diamond Creek (USGS gage 09404200).

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 spatial or temporal catch rates. 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. Perhaps this study's biggest strength is that current methods represent a robust, repeatable, statistically sound, and relevant way to track both the native and nonnative fish communities over time within the study area. Given the importance and demands placed on the Colorado River and the uniqueness of the Grand Canyon, this information will undoubtedly be useful for those managing the system in the future.

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 and within the overall study area of this project (e.g., Kegerries and Albrecht 2013b).

The capture of Humpback Chub is a fairly regular occurrence during small-bodied fish community sampling within the Grand Canyon. Young Humpback Chub have been 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 should 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 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 throughout 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, which could hinder native fish reproduction, growth, and survival. Flow regulation has reduced annual peak flows, raised minimum flows, and increased the daily flow fluctuation because of hydropower demand (Topping et al. 2003; Voichick and Wright 2007); all of which are potentially detrimental to the Grand Canyon fish community, especially 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 species over native fishes, which are adapted to turbid river conditions (Valdez and Ryel 1995; Gloss et al. 2005). Although cooler water temperatures can impact native species reproduction, growth, and survival, these species continue to persist within the Colorado River in 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 age classes of Humpback Chub are present throughout the mainstem Colorado River, while Razorback Sucker are now spawning within Grand Canyon. Warming water temperatures within the mainstem is a likely cause for native fish success, but it does not fully explain the more recent decline in nonnative fish abundance. Most of the nonnative fish species found within 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. The amount of turbidity created in the lower Grand Canyon as erosion occurs through the historic Lake Mead sediment could also be a factor limiting the utilization by nonnative fish; especially sight dependent predators (Albrecht et al. 2017; Ward and Vaage 2018). 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

Since its inception in 2014, there have been several adaptive changes to the timing and spatial extent of the larval Razorback Sucker survey in Grand Canyon. These changes have been initiated after detailed review of previous field data. 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 all three catostomids, not just Razorback Sucker.

A second major modification to the project was the 2016 expansion of study area. In 2015, larval Razorback Sucker were documented at the uppermost site of the former study area (RM 179.0), thereby confirming spawning by adult Razorback Suckers upstream of the study area. To identify the upstream extent of spawning Razorback Suckers, the study area was expanded an additional 91 river miles. Expansion of the study area in 2016 from just above Lava Falls Rapid (RM 179.9) upstream to Phantom Ranch (RM 88.6) helped to clarify spatial patterns of distribution for the early life history phases of this species. With the exception of two larval Razorback Sucker in 2018, the upstream-most capture of Razorback Sucker larvae (2016–2018) was at RM 167.7. River mile 167.7 also represents the site where larval catostomid captures are typically first recorded annually or where larval catostomid captures begin to increase in frequency and abundance relative to upstream sites (2016–2018). These patterns suggest catostomids are spawning in close proximity (i.e., immediately upstream) of RM 167.7. The first 2018 larval fish survey (March) documented Razorback Sucker larvae at nearly the same location as the previous two years (RM 167.7). However, in April 2018, a single protolarval Razorback Sucker was captured about 23 river miles farther upstream (RM 144.8) of the former upstream-most collection site for this species. The June 2018 sample yielded a single larval Razorback Sucker from RM 165.0, which was almost 3 river miles further upstream than recorded during prior to 2018. The March 2018 larval survey also documented age-0 Bluehead Suckers and Flannelmouth Suckers higher in the system than recorded in previous years during the sampling period. The increased range of Razorback Sucker larvae and the earlier detection of Bluehead Sucker and Flannelmouth Sucker larvae indicate earlier spawning by catostomids than what has been observed during past surveys within the expanded study and suggest possible upstream movement by reproducing adults.

The 2018 larval fish survey results support the hypothesis that Havasu Creek plays an important role in initial spawning of Grand Canyon catostomids due to March and April captures of larval suckers in close proximity to the mouth of this tributary. Spawning of catostomids is inferred by the presence of early larval developmental stages downstream of Havasu Creek and the upstream absence (or near absence) of specimens. Results from the 2018 larval fish survey closely resembled the 2016 and 2017 spatial and temporal distribution of larval catostomids and provided additional information on spawning periodicity of catostomids. Similarly, the overwhelming majority of 2016–2018 Razorback Sucker larvae have been captured downstream of Havasu Creek, which further supports 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 of 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 (Marsh 1985; Bozek et al. 1990). The March 2018 detection of catostomid larvae upstream of Havasu Creek documents that spawning occurred further upstream, either in the mainstem Colorado River or its tributary.

In previous years (2014–2016), spawning dates of Razorback Sucker were back-calculated using larval Razorback Sucker TL and mainstem Colorado River water temperatures. Given the hypothesized importance of Havasu Creek to Razorback Sucker spawning and discordance between temperatures in Havasu Creek and mainstem Colorado River, hatching dates were calculated, instead of spawning dates, for the 2018 analysis. Length-based, back-calculated hatching dates do not incorporate water temperature and are a conservative calculation.

Development of age-0 fish through the larval period and into the juvenile phase is essential for recruitment. A multitude of factors affect mortality of larval fish including hatching success, starvation, predation, and competition. Transition into the juvenile phase has been documented for Humpback Chub, Speckled Dace, Bluehead Sucker, and Flannelmouth Sucker. 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. 2017). 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 while late-phase Razorback Sucker are not. Important differences between spawning periodicity of Razorback Sucker and Humpback Chub are timing (earlier spawning for Razorback Sucker) and spatial extent of spawning. Mean daily water temperatures in the Colorado River were cooler during March and April when larval Razorback Suckers were present. While the only two Razorback Sucker larvae have been documented upstream of RM 167.7, 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 distribution of the fishes but also on the drifting behavior of early ontogenetic phases and availability of larval fish nursery habitat. A review of 2016–2018 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.

A review of the 2014–2018 larval fish surveys provided valuable insight into relationships between mean age-0 fish densities and physicochemical and hydrological conditions (water temperature, discharge, and hydropeaking amplitude). There is strong evidence that increased densities of cyprinids and catostomids observed in 2014 were influenced by increased water temperatures, decreased discharge, and reduced hydropeaking amplitude. Though these relationships were analyzed at the family level, based on the observed patterns of species-specific densities, they are likely applicable to densities of all species. These results assume a linear relationship between larval fish densities and explanatory variables. Additional sampling during years when physicochemical and hydrological conditions are similar to 2014 or vary from more recent surveys (2016–2018) will lend greater insight into whether these relationships are in fact linear or follow other response curve (e.g., exponential, sigmoidal, and logarithmic).

Further, the complex ecological interactions that occur to produce the patterns of fish densities are likely over simplified. Two of the variables (water temperature and discharge) are correlated, with increased warming downstream during periods of decreased discharge, thus clouding interpretation of their independent impacts (Wright et al. 2008). Furthermore, though 2014 and 2015 were compared with other years, they occurred within a truncated study area relative to 2016–2018, so comparison of larval fish densities across all years may incorporate spatial biases. Despite different length of study areas, it was important to include 2014 and 2015 due to high age-0 fish densities recorded in 2014. Water temperature, discharge, and hydropeaking amplitude were relatively consistent in 2016–2018 and 2014 and 2015 provided variation that enabled comparative analyses.

The results of these analyses are supported by well understood ecological dynamics of larval fish growth, development, and survival; where increased water temperatures increase hatching success, growth, swimming performance, development rate, and feeding performance of age-0 fishes (Govoni et al. 1986; Bozek et al. 1990; Clarkson and Childs 2000; Schiemer et al. 2002; Ward et al. 2002). Elevated water temperature increases growth rate resulting in decreased predation pressure on larvae (Bestgen 2008). Though contemporary water temperatures of the Colorado River in the Grand Canyon are lower than historic values (Wright et al. 2008), this 5-year summary reveals that fishes can positively respond with even a small increase in temperature.

Future annual larval fish monitoring will continue to reveal causal effects on age-0 abundance and inform the discussion on endangered fish conservation in the Grand Canyon. Those studies will continue sampling GRTS segments to provide a long-term comparative data to further elucidate trends. The Colorado River in western Grand Canyon continues to support reproduction and most often larval recruitment for native fishes including endangered Razorback Sucker and Humpback Chub.

2018–2019 GRAND CANYON SMALL-BODIED AND LARVAL FISH COMMUNITY STUDY RECOMMENDATIONS

The results of the 2018 and comprehensive 2014–2018 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 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.

   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 2019 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 continue assessing the larval and small-bodied fish community in relation to high-flow events in spring and fall, equalization flows, and trout-management flows. The NPS also has shown interest in this study by providing larval and small-bodied fish community information to help serve as an early warning method to consistently and routinely track changes and threats imparted by nonnative fishes, something that this study design can do well, and can be used to place future findings into a more historical context.

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. Collect additional 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 samples were collected in 2018 for the investigation of hybridization between Flannelmouth Sucker and Razorback Sucker in the Grand Canyon. Since few samples were obtained in 2018, additional collections could occur in 2019, if desired. This would require a 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 ninth study year at the CRI and the fifth 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 2017 through June 2018. Telemetry data collected from the Grand Canyon are reported from October 2017 through September 2018.

Sonic-telemetry data collected during Lake Mead Razorback Sucker studies have provided valuable information on spawning, movement patterns, and shifts in spawning-sites over time and under varying habitat conditions. These data have also demonstrated that tracking sonic-tagged Razorback Sucker preceding spawning activity can be a highly effective method for locating new spawning areas and maintaining effective monitoring, particularly when coupled with other methodologies (i.e., Albrecht et al. 2017). 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 2018 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

The project team successfully implanted and released 10 sonic-tagged Razorback Suckers into the Colorado River in Grand Canyon near Phantom Ranch at the confluence of Bright Angel Creek during February 2018. This release was conducted in cooperation with the U.S. Bureau of Reclamation, NPS, USFWS, NDOW, and AZGFD. Seven of those fish were flow-conditioned (described below) at the Lake Mead Fish Hatchery prior to their release. We anticipate that these fish will integrate with wild Razorback Suckers and help to better identify areas within the Grand

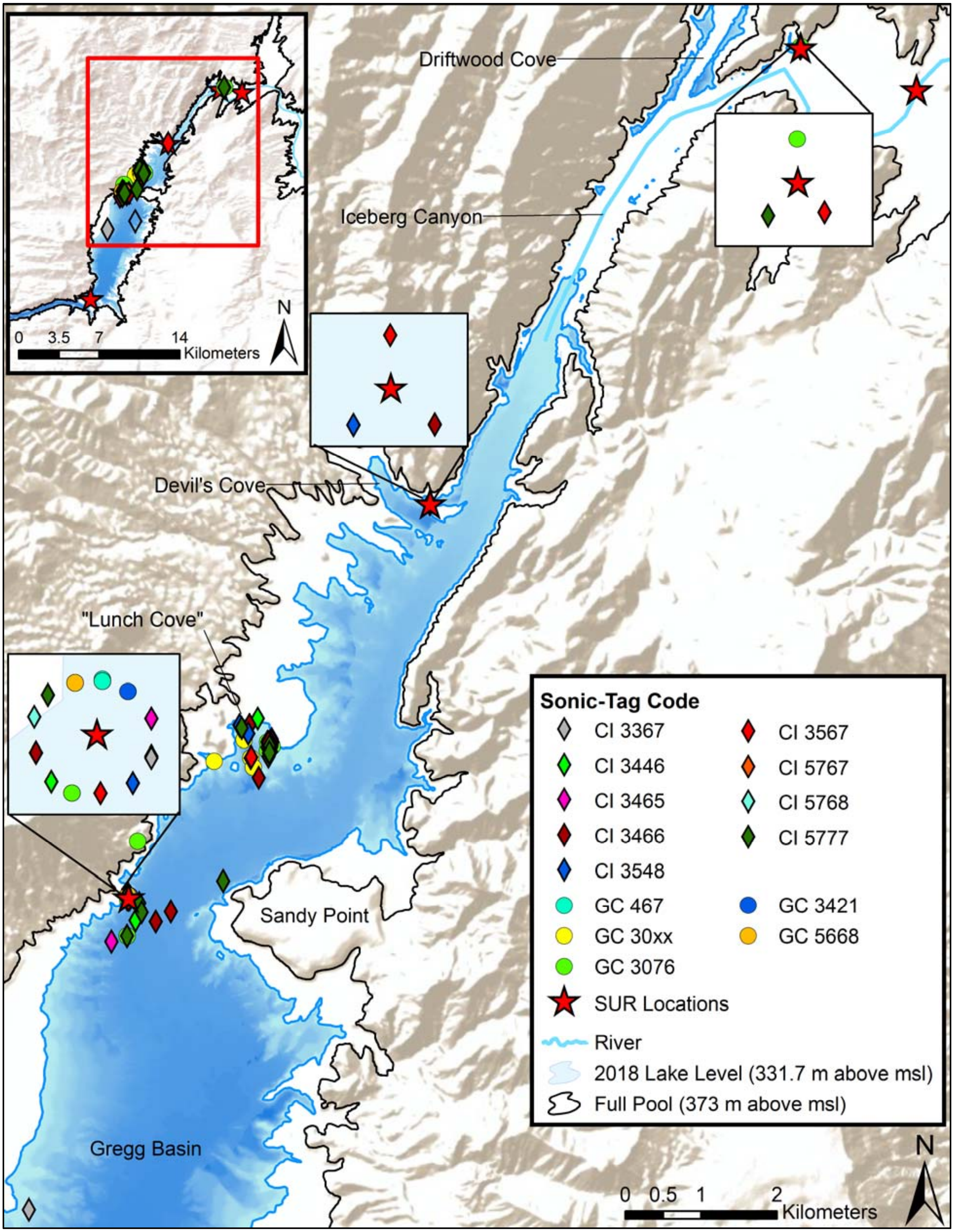

Figure 3.1. General Colorado River Inflow Area of Lake Mead (CRI) study area with the distribution of sonic-tagged fish contacts and submersible ultrasonic receiver (SUR) locations.

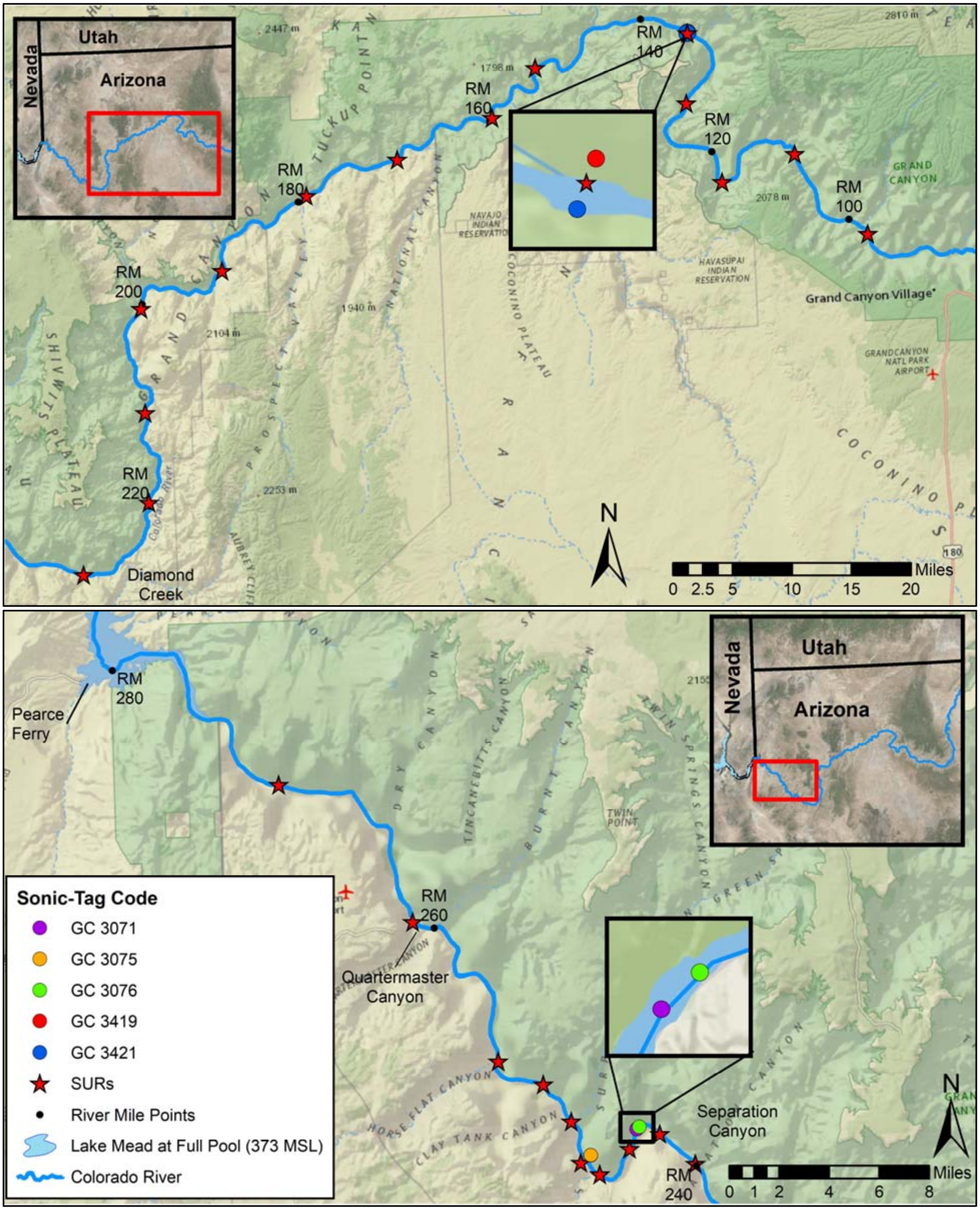

Figure 3.2. General Grand Canyon study area with the distribution of sonic-tagged fish contacts and submersible ultrasonic receiver (SUR) locations. Top section is approximately river mile (RM) 80–230. Bottom section is approximately river mile (RM) 240–280.

Canyon that the species occupies and where it spawns, particularly when correlated with larval, juvenile, and adult captures in 2018 and beyond.

In addition, and at the CRI, two previously captured, wild Razorback Suckers and one newly captured wild Razorback Sucker from the 2018 sampling season were implanted with sonic tags and released back into the CRI during February 2018. Much like the fish released into the Grand Canyon, our hope is that these newly implanted wild fish will help lead us to additional conspecifics and will help further demonstrate the Lake Mead and Grand Canyon connection as broadened habitat for Razorback Sucker.

Razorback Suckers released in the Grand Canyon were implanted with Sonotronics model ART-01 (36-month) sonic-tags and Razorback Suckers implanted at the CRI were implanted with Sonotronics model CT-05 (48-month) sonic-tags. Prior to surgery, the fish were placed into a designated tank containing fresh reservoir or hatchery water, and all sonic tags were checked for full function and identification. All surgical instruments were cold-sterilized with iodine and 90% isopropyl alcohol and allowed to air dry on a disposable, sterile cloth. Razorback Suckers were initially anaesthetized in 10 L of reservoir water with a 50 mL/L-1 clove oil/ethanol mixture (0.5 mL clove oil [Anderson et al. 1997] emulsified in 4.5 mL ethanol) (Anderson et al. 1997; Bunt et al. 1999). After anesthesia was induced, TL, FL, SL, and weight (g) were recorded. The individual was placed dorsal-side down on a padded surgical cradle for support during surgery with head and gills submerged in 8 L of fresh water and a maintenance concentration of 25 mL/L-1 clove oil/ethanol anesthetic (Bunt et al. 1999). Following introduction to the maintenance anesthetic, the surgeon made a 10–15 mm incision on the left side, posterior to the left pelvic girdle. A PIT tag was inserted into the incision followed by the sonic tag, which was placed between the pelvic girdle and urogenital pore. The incision was closed with two to three 3-0 Monocryl Plus absorbable poliglecaprone 25 sutures using an attached PS-1 reverse-cutting, curved needle. Surgery times typically ranged from 2 to 5 minutes per fish.

Once surgical implantation was complete, the individual was allowed to recover in fresh reservoir/hatchery water until regaining equilibrium. Prior to release, the individual was re-examined for signs of stress, and sonic tags were rechecked for functionality. Wild Razorback Sucker were released at their capture location, and no Razorback Suckers were held for an extended period of time or harmed during these efforts. Fish sonic tagged in the hatchery were released into the Grand Canyon as a cooperative effort between BIO-WEST and state and federal agency personnel.

Flow Conditioning

Studies have shown that Razorback Suckers benefit from exposure to flowing water conditions (Avery 2009; Mueller et al. 2007). In a previous experimental study, flowing raceways were designed and constructed to evaluate how rearing Razorback Suckers in flowing raceways affect swimming stamina, growth, food-conversion efficiency, foraging ability, predator avoidance, disease treatment, and post-stocking dispersal (Senger and Sjoberg 2011). The study showed the feasibility and effectiveness of flow conditioning in a hatchery setting with increases in swimming performance, growth, and food-conversion efficiency of conditioned Razorback Sucker. In an effort to assess the feasibility and effectiveness of conditioned Razorback Sucker used for telemetry purposes, NDOW flow conditioned 7 of the 10 fish released in the Grand Canyon in 2018 for 34 days prior to their stocking. As these fish are contacted, we hope to be able to assess the applicability and benefit of conditioning before fish are released into the wild.

Flow conditioning was conducted in one rectangular, fiberglass raceway (30 feet long) located within the Lake Mead Fish Hatchery. The raceway was customized based on the specifications in Senger and Sjoberg (2011) in order to produce higher flows. Both raceways were divided down the middle by cinder blocks, but were left open at the front and end of the raceway to allow water to circulate throughout and fish to move to either side of the cinder blocks. Flows in each treatment were produced by in-tank propeller pumps, which were needed to achieve the high flows desired for this study. A pump was located at each end of the raceway and on opposite sides to achieve a flow up one side and down the other in the raceway. Flows during the conditioning averaged approximately 42.5 cm per second.

The Razorback Suckers were exposed to acclimation flows on January 1, 2018, when they were treated with flow for 2 hours. They were then exposed to 6 hours of flow the following day. For the remaining 34 days the fish were exposed to 18 hours of flow with 6 hours of rest. There were 2 days when flow was not applied due to water outages at the hatchery. The treatment commenced on February 7, 2018, before the fish were stocked on February 8, 2018.

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

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 2018 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. In cases when the unique tag code could not be determined, but the radio-frequency (RF) signal was present, 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 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 reservoir levels and optimize data collection as the location of the river/reservoir 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. Three additional SURs were deployed upstream of the CRI and below Pearce Ferry in an effort to extend the coverage between riverine and reservoir habitats (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 river miles apart, except between RM 240.0 (near Separation Canyon) and RM 250.6 (below Surprise Canyon) where SURs were approximately 5 river miles apart. This was 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 2018 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. In 2018, eight additional SURs were deployed between RM 8 and RM 50 primarily to expand the coverage for assessing Brown Trout movement (Figure 3.2). Additional SUR data were collected opportunistically in 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 reservoir/river bottom. The cable was secured on shore and concealed. The SURs were downloaded frequently by pulling the SUR into the boat and downloading the data via Sonotronics's SURsoft software. These data were then processed through Sonotronics's SURsoftDPC software to ascertain the time, date, and frequency of positive sonic-tagged fish detections within 2-millisecond interval units (e.g., a range of 898–902 for a 900-interval tag). To avoid any false-positive contacts due to environmental "noise" in data analysis, at least two records were required within 60 minutes of one another for a SUR record to be considered valid. Once data were validated through the software's confidence scanning feature, the resulting dataset was further scrutinized against active sonic-telemetry records. This was done to establish movement timelines of individual sonic-tagged fish and further solidify all positive SUR contacts.

RESULTS

Through collaborative research and monitoring efforts, 66 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, 2016, and 2018 (Albrecht et al. 2010c; Kegerries and Albrecht 2011, 2013b, 2014a; Kegerries et al. 2015a, Kegerries et al. 2016a) (Table 3.1). Three wild fish were captured, implanted with sonic tags, and released in the CRI in January and February 2018. Ten Razorback Suckers were implanted with dual radio/acoustic tags and released at Bright Angel Creek in the Grand Canyon in February 2018 (Table 3.1).

In total, 14 unique sonic-tagged fish were contacted 74,498 times (56 active contacts, 74,442 passive contacts) from July 2017 to June 2018 at the CRI and from October 2017 to September 2018 in the Grand Canyon (Figures 3.1 and 3.2, Table 3.1). Of these 14 fish, 1 was released just below Separation Canyon in the Grand Canyon in 2013, 1 was released just below Lava Falls in the Grand Canyon in 2014, 2 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, 2 were implanted and released at Bright Angel Creek in the Grand Canyon in 2018, and 3 were implanted and released at the CRI in 2018 (Table 3.1). In summary, of the 66 fish that have been tagged and released in the CRI or Grand Canyon since 2010, 14 are confirmed active and 27 are of unknown status (not detected in 2018) but still presumed active.

Only six sonic-tagged Razorback Suckers showed noticeable movement throughout the reporting period. Most fish did not show any movement over 1 km between contacts. The largest distance traveled (approximately 256.2 km [159.2 miles]) was from a 2018 released Razorback Sucker near Bright Angel Creek moving downstream to the CRI. That fish was flow-conditioned in the hatchery prior to its release. The other fish from that cohort that was detected in 2018 was also flow-conditioned but moved only about 76.4 km (47.5 miles) downstream. Four additional fish were detected moving to and from near Driftwood Cove to the CRI with movements of approximately 15.0 km (9.3 miles) (Figure 3.1).

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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 2013 to 2018.

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 2018										
NDOW	12/8/2018	3414	566	F	GC	GC	2/8/2018	0 (0)	Active	2021
NDOW	12/8/2018	3415	573	F	GC	GC	2/8/2018	0 (0)	Active	2021
NDOW	12/8/2018	3416	583	F	GC	GC	2/8/2018	0 (0)	Active	2021
NDOW	12/8/2018	3417	584	F	GC	GC	2/8/2018	0 (0)	Active	2021
NDOW	12/8/2018	3418	582	F	GC	GC	2/8/2018	0 (0)	Active	2021
NDOW	12/8/2018	3419	581	F	GC	GC	3/8/2018	0 (1)	Active	2021
NDOW	12/8/2018	3420	577	F	GC	GC	2/8/2018	0 (0)	Active	2021
NDOW	12/8/2018	3421	574	F	GC	CRI	4/30/2018	0 (16)	Active	2021
NDOW	12/8/2018	3422	584	F	GC	GC	2/8/2018	0 (0)	Active	2021
NDOW	12/8/2018	3423	561	F	GC	GC	2/8/2018	0 (0)	Active	2021
CRI	2/272018	3367	661	F	CRI	CRI	10/10/2018	5 (101)	Active	2019
CRI	1/30/2018	3466	606	M	CRI	CRI	5/1/2018	15 (10,453)	Active	2022
CRI	1/30/2018	3567	521	M	CRI	CRI	7/17/2018	7 (3,015)	Active	2022
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	5/16/2016	8 (2,215)	Active	2020
NDOW	2/22/2016	3075	521	M	GC	GC	8/24/2016	0 (5)	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	2/22/2016	2 (0)	Active	2020
CRI	2/22/2016	3446	662	F	CRI	CRI	5/18/2016	2 (9,427)	Active	2020
CRI	2/22/2016	5777	571	F	CRI	CRI	5/18/2016	9 (37,964)	Active	2020
Fish Tagged in 2015										
CRI	3/17/2015	5587	609	M	CRI	CRI	5/18/2016	0 (0)	Active	2019
CRI	3/18/2015	3548	643	M	CRI	CRI	10/10/2018	5 (6,571)	Active	2019
CRI	3/18/2015	3465	581	M	CRI	CRI	2/26/2018	3 (2,733)	Active	2019

Table 3.1. (Cont.)

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 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	10/27/2017	0 (823)	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
NDOW	5/6/2014	3028	293	I	LVB	CRI	4/29/2015	0 (0)	Unknown	2015
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	8/24/2016	0 (0)	Unknown	2017
NDOW	4/9/2013	4455	484	F	CRI	CRI	6/26/2016	0 (0)	Unknown	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
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	7/1/2017	0 (1,118)	Active	2017

[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.

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, 2017; 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, reservoir levels, and changes in habitat. For example, despite receding reservoir 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 or 2018, but sonic-telemetry data showed no movement of fish upstream of the CRI into the Grand Canyon. The number of contacts with fish above the Pearce Ferry Rapid since 2014 has declined exponentially despite stocking events within the Grand Canyon in 2016 and 2018 suggesting at minimum, that Pearce Ferry Rapid may be serving as a movement deterrent.

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. Given the above findings, coupled with observations from the San Juan River near Lake Powell where Razorback Sucker appear to aggregate at a waterfall (Cathcart et al. 2018), additional research efforts at the Pearce Ferry Rapid are likely warranted to investigate the feature as a fish barrier to upstream movement.

In addition to illustrating movement patterns and providing habitat-use data, sonic-tagged fish helped determine the placement of trammel nets for the successful capture of wild Razorback Suckers at the CRI in nearly all years of this study (see Chapter 1). As reservoir levels fluctuate, sonic-tagged fish will continue to provide valuable data on changes in Razorback Sucker movement patterns, habitat use, and spawning-site selection within Lake Mead and 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 2018, 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 combined are likely important to the wild Razorback Sucker in this system. In fact, past movements of fish from the CRI to just below Spencer Creek and Separation Canyon during the spawning season suggest that this area may be important for Razorback Sucker reproduction and 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 because 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, 2016, and 2018. These efforts could have created habitat more suitable for Razorback Sucker within the Grand Canyon or prompted upstream movement. As studies continue at the CRI and in the Grand Canyon, it will be important to maintain the ability to track Razorback Sucker and sample areas they frequent to answer questions regarding how they 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. The two fish that did show movement within the Grand Canyon were flow conditioned prior to release. The intent of that flow conditioning was to maintain Razorback Sucker within the river and reduce downstream movement after release. More data and contacts will be needed to assess the effectiveness of flow conditioning prior to releasing Razorback Sucker in the Grand Canyon, but it is feasible to do so at the Lake Mead Fish Hatchery.

Since the beginning of its use as a monitoring tool, telemetry has been valuable 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 in informing sampling should be continued within the greater study area.

Finally, the network of SURs now in place and maintained by this study, within the Grand Canyon has provided important insight into not only Razorback Sucker, but also now into Humpback Chub (USFWS unpublished data), as well as nonnative Brown Trout (NPS unpublished data). Continued use and maintenance of this telemetry network could prove highly beneficial for these ongoing studies, and well as any future question where telemetry could help in assessing movement within the Grand Canyon and greater Lake Mead system.

2018–2019 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. Because using SURs within the CRI and Grand Canyon is critical to locating fish as they move throughout the study area, the SURs should be downloaded and maintained regularly during sampling events to ensure their efficacy. The continued use of telemetry throughout 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. It may be informative to release sonic-tagged Razorback Sucker near Havasu Creek as larvae have been collected just downstream and spawning appears to be occurring within that region of the Grand Canyon.

3. Additionally, smaller juvenile fish, if and when available, can and 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.

5. As mentioned, it is currently unknown whether the Pearce Ferry Rapid is a barrier to fish movement, or if it at least serves as a deterrent to upstream fish movement under recent (2017 and 2018) conditions. Given the findings of limited movement above the rapid during 2017 and 2018, coupled with observations from the San Juan River waterfall near Lake Powell (Cathcart et al. 2018), additional research efforts at the base of Pearce Ferry

Rapid are likely warranted and could include the use submersible PIT scanners and SURs.

6. Finally, the network of SURs now in place and maintained by this study, within the Grand Canyon has provided important insight into not only Razorback Sucker, but also now into Humpback Chub (USFWS unpublished data), as well as nonnative Brown Trout (NPS unpublished data). Continued use and maintenance of this telemetry network could prove highly beneficial for these ongoing studies, and well as any future question where telemetry could help in assessing movement within the Grand Canyon and greater Lake Mead system.

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. 2017). 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 (Albrecht et al. 2017; Kegerries et al. 2017b).

Valdez et al. (2012a) suggest that the distances from spawning locations to floodplains in the middle Green River system range from 6 to 60 miles and that the distance from a potential spawning area in 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 miles 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. 2017b).

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. 2017b). Finally, because there are complex habitat and cover types within the overall system, as well as diverse niche space near the changing inflow areas that benefit all native fish species (Albrecht et al. 2017), there is hope for this population. Such logic may help us understand the paucity of juvenile Razorback Sucker captures in the Grand Canyon through 2018, particularly when coupled with differential use of adult sonic-tagged Razorback Sucker.

Unlike Razorback Sucker, juvenile Humpback Chub have been present during 2014–2018 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 age classes, of Humpback Chub are being captured on a fairly routine basis throughout the riverine portions of the study area, including below Pearce Ferry. 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, 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 more than two decades (Holden et al. 1997, 1999, 2000a, 2000b, 2001; Abate et al. 2002; Welker and Holden 2003, 2004; Albrecht and Holden 2005; Albrecht et al. 2006a, 2006b, 2007, 2008a, 2008b, 2010a, 2010b, 2013a, 2013b, 2014b, 2017; Kegerries et al. 2009; Shattuck et al. 2011; Shattuck and Albrecht 2014; Mohn et al. 2015, 2016; Rogers et al. 2017, 2018). 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, 2018], 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. 2010b, 2013a, 2017; Shattuck and Albrecht 2014; Kegerries et al. 2015a, 2016a, 2017b).

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. 2017) of Lake Mead has been documented in the recent habitat associations of sonic-tagged, juvenile Razorback Suckers (Shattuck and Albrecht 2014; Kegerries et al. 2015b, 2016). Clearly, sonic-tagged 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. 2017b). 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. 2017).

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. 2017b). 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, or its tributaries (i.e., Havasu Creek), 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 (1) establishing the upstream Grand Canyon boundary of tagged Razorback Sucker habitat use, (2) documenting all spawning locations of the species within the Grand Canyon, and (3) better characterizing the wild recruitment observed within the expanded study area through the continued use of nonlethal aging techniques. In conclusion, 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 and at the same time has provided substantial insight into Humpback Chub and the overall small-bodied fish community of the Grand Canyon. This study is highly repeatable, statistically sound, and one that can be used to track trends of both native and nonnative fishes in the future.

In addition to various annual reports prepared from this project, several peer-reviewed journal publications have stemmed from the combined Lake Mead and Grand Canyon study efforts in recent years. For those interested, please reference Albrecht et al. (2010c), Kegerries et al. (2017b), and Albrecht et al. (2017). Additional publications are underway, in-review, or forthcoming from these comprehensive efforts and we thank all involved with these efforts.

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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), 2018

DATE	SPECIES	PIT-TAG NUMBER	FIRST DATE CAPTURED[a]	RECAPTURED	TL[b] (mm)	FL[c] (mm)	SL[d] (mm)	WT[e] (g)	SEX[f]
01/17/18	FM	3DD.003C06ED91	01/17/18	NO	484	- -[g]	- -[g]	925	M
01/17/18	FM	3DD.003C06EDAB	01/17/18	NO	436	- -[g]	- -[g]	715	M
01/17/18	FM	384.1B796EDDFE	02/15/12	YES	491	- -[g]	- -[g]	1110	M
01/17/18	FM	3DD.003C06EDA8	01/17/18	NO	313	- -[g]	- -[g]	245	U
01/17/18	FM	3DD.003C06EDA5	01/17/18	NO	480	- -[g]	- -[g]	980	M
01/18/18	FM	3DD.003BCB38BD	01/18/18	YES	432	- -[g]	- -[g]	625	F
01/18/18	FM	3DD.003C06ED98	01/18/18	NO	455	- -[g]	- -[g]	830	M
01/18/18	FM	3DD.003C06EDA3	01/18/18	NO	500	- -[g]	- -[g]	1045	M
01/18/18	FM	3DD.003BE8F379	02/02/17	YES	512	- -[g]	- -[g]	1215	F
01/18/18	FM	3DD.003BA2089A	03/03/16	YES	500	- -[g]	- -[g]	1145	M
01/19/18	FM	3DD.003C06ED99	01/19/18	NO	339	- -[g]	- -[g]	265	U
01/19/18	FM	384.36F2B25F1B	03/26/13	YES	535	- -[g]	- -[g]	1170	F
01/19/18	FM	3DD.003C06ED9D	01/19/18	NO	310	- -[g]	- -[g]	205	U
01/19/18	FM	3DD.003BE8F526	12/20/17	YES	525	- -[g]	- -[g]	1155	F
01/19/18	FM	3DD.003C06ED8E	01/19/18	NO	485	- -[g]	- -[g]	960	F
02/01/18	FM	3DD.003BE8F22C	01/18/17	YES	551	516	480	1798	F
02/01/18	FM	384.36F2B25F2F	04/30/13	YES	504	482	450	1225	F
02/27/18	FM	3DD.003C06F133	02/27/18	NO	259	241	220	155	I
03/01/18	FM	3DD.003C06F121	03/01/18	NO	459	434	400	845	M
03/13/18	FM	384.1B796EDDFE	02/15/12	YES	481	451	421	1095	M
03/27/18	FM	3DD.003C06F10F	03/27/18	NO	446	415	385	825	M
04/05/18	FM	3DD.003C06F12F	04/05/18	NO	451	423	389	820	I
04/05/18	FM	3DD.003C06F121	03/01/18	NO	- -[g]	- -[g]	- -[g]	- -[g]	M
04/05/18	FM	3DD.003C06F0F9	04/05/18	NO	503	474	446	- -[g]	I
04/05/18	FM	3DD.003C06F106	04/05/18	NO	443	409	380	- -[g]	I
01/17/18	FM	3DD.003C06ED91	01/17/18	NO	484	- -[g]	- -[g]	925	M
01/17/18	FM	3DD.003C06EDAB	01/17/18	NO	436	- -[g]	- -[g]	715	M
01/17/18	FM	384.1B796EDDFE	02/15/12	YES	491	- -[g]	- -[g]	1110	M
01/17/18	FM	3DD.003C06EDA8	01/17/18	NO	313	- -[g]	- -[g]	245	U
01/17/18	FM	3DD.003C06EDA5	01/17/18	NO	480	- -[g]	- -[g]	980	M
01/18/18	FM	3DD.003BCB38BD	01/18/18	YES	432	- -[g]	- -[g]	625	F
01/18/18	FM	3DD.003C06ED98	01/18/18	NO	455	- -[g]	- -[g]	830	M
01/18/18	FM	3DD.003C06EDA3	01/18/18	NO	500	- -[g]	- -[g]	1045	M
01/18/18	FM	3DD.003BE8F379	02/02/17	YES	512	- -[g]	- -[g]	1215	F
01/18/18	FM	3DD.003BA2089A	03/03/16	YES	500	- -[g]	- -[g]	1145	M
01/19/18	FM	3DD.003C06ED99	01/19/18	NO	339	- -[g]	- -[g]	265	U
01/19/18	FM	384.36F2B25F1B	03/26/13	YES	535	- -[g]	- -[g]	1170	F
01/19/18	FM	3DD.003C06ED9D	01/19/18	NO	310	- -[g]	- -[g]	205	U
01/19/18	FM	3DD.003BE8F526	12/20/17	YES	525	- -[g]	- -[g]	1155	F
01/19/18	FM	3DD.003C06ED8E	01/19/18	NO	485	- -[g]	- -[g]	960	F
02/01/18	FM	3DD.003BE8F22C	01/18/17	YES	551	516	480	1798	F
02/01/18	FM	384.36F2B25F2F	04/30/13	YES	504	482	450	1225	F
02/27/18	FM	3DD.003C06F133	02/27/18	NO	259	241	220	155	I
03/01/18	FM	3DD.003C06F121	03/01/18	NO	459	434	400	845	M
03/13/18	FM	384.1B796EDDFE	02/15/12	YES	481	451	421	1095	M
03/27/18	FM	3DD.003C06F10F	03/27/18	NO	446	415	385	825	M

DATE	SPECIES	PIT-TAG NUMBER	FIRST DATE CAPTURED[a]	RECAPTURED	TL[b] (mm)	FL[c] (mm)	SL[d] (mm)	WT[e] (g)	SEX[f]
04/05/18	FM	3DD.003C06F12F	04/05/18	NO	451	423	389	820	I
04/05/18	FM	3DD.003C06F121	03/01/18	NO	- -[g]	- -[g]	- -[g]	- -[g]	M
04/05/18	FM	3DD.003C06F0F9	04/05/18	NO	503	474	446	- -[g]	I
04/05/18	FM	3DD.003C06F106	04/05/18	NO	443	409	380	- -[g]	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
2/27/2018	615	9	2009
4/10/2018	600	9	2009

DATE COLLECTED	TOTAL LENGTH (mm[a])	AGE	PRESUMPTIVE YEAR SPAWNED
		ECHO 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
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
3/06/2018	472	5	2013
3/22/2018	469	8	2010
3/28/2018	479	5	2013
3/28/2018	489	5	2013
3/28/2018	581	7	2011

DATE COLLECTED	TOTAL LENGTH (mm[a])	AGE	PRESUMPTIVE YEAR SPAWNED
4/17/2018	634	9	2009
Virgin River/Muddy River Inflow Area			
2/23/2005	608	6	1998
2/22/2006	687	33[d]	1973
2/22/2007	452	4	2003
2/22/2007	542	5	2002
2/22/2007	476	5	2002
2/22/2007	459	4	2003
2/22/2007	494	5	2002
3/01/2007	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

DATE COLLECTED	TOTAL LENGTH (mm[a])	AGE	PRESUMPTIVE YEAR SPAWNED
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
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

DATE COLLECTED	TOTAL LENGTH (mm^a)	AGE	PRESUMPTIVE YEAR SPAWNED
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
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

DATE COLLECTED	TOTAL LENGTH (mm[a])	AGE	PRESUMPTIVE YEAR SPAWNED
3/15/2011	558	8	2003
3/15/2011	576	8	2003
3/15/2011	587	8	2003
3/15/2011	572	7	2004
3/15/2011	575	10	2001
3/15/2011	551	7	2004
3/15/2011	561	7	2004
3/15/2011	566	9	2002
3/15/2011	542	6	2005
3/15/2011	577	8	2003
4/05/2011	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

DATE COLLECTED	TOTAL LENGTH (mm^a)	AGE	PRESUMPTIVE YEAR SPAWNED
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
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

DATE COLLECTED	TOTAL LENGTH (mm[a])	AGE	PRESUMPTIVE YEAR SPAWNED
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
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
2/07/2018	451	4	2014
2/07/2018	535	6	2012
2/15/2018	630	9	2009
2/15/2018	614	8	2010
2/22/2018	655	10	2008
2/22/2018	455	8	2010

DATE COLLECTED	TOTAL LENGTH (mm[a])	AGE	PRESUMPTIVE YEAR SPAWNED
3/06/2018	611	13	2005
3/07/2018	468	4	2014
3/08/2018	481	6	2012
4/18/2018	454	5	2013
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
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

DATE COLLECTED	TOTAL LENGTH (mm[a])	AGE	PRESUMPTIVE YEAR SPAWNED
3/07/2017	598	11	2006
4/18/2017	401	6	2011
1/30/2018	521	10	2008
2/01/2018	566	10	2008
2/23/2018	448	6	2012
3/01/2018	606	14	2004
3/07/2018	579	8	2010
3/07/2018	558	9	2009

[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, 2018

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, 2018

TRIP GRTS SEGMENT	Bluehead Sucker	Flannelmouth Sucker	Humpback Chub	Speckled Dace	YOY Sucker	Brown Trout	Channel Catfish	Common Carp	Fathead Minnow	Plains Killifish	Western Mosquitofish	Red Shiner	Rainbow Trout
April	**89**	**373**	**2**	**249**	**4**	**5**	**0**	**0**	**6**	**10**	**9**	**2**	**0**
2	1	0	0	0	0	0	0	0	0	0	0	0	0
22	0	2	0	15	0	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0	0	1	0	0	0
46	0	0	0	0	0	0	0	0	0	0	0	0	0
50	1	0	0	0	0	0	0	0	0	0	0	0	0
55	0	0	0	3	0	0	0	0	0	0	0	0	0
69	0	2	0	0	0	0	0	0	0	0	0	0	0
72	1	17	0	17	0	0	0	0	0	0	0	0	0
74	2	1	0	6	0	0	0	0	0	0	0	0	0
79	0	7	0	0	0	0	0	0	0	0	0	0	0
90	0	0	0	4	0	0	0	0	0	0	0	0	0
98	2	1	0	3	0	0	0	0	0	0	0	0	0
103	0	0	0	1	0	5	0	0	0	2	0	0	0
114	0	0	0	1	0	0	0	0	0	0	0	0	0
122	0	0	0	0	0	0	0	0	0	0	0	0	0
132	0	2	0	1	0	0	0	0	0	0	0	0	0
155	0	0	1	3	0	0	0	0	0	0	0	0	0
160	0	2	1	8	0	0	0	0	0	0	0	0	0
162	1	5	0	2	0	0	0	0	0	0	0	0	0
170	0	0	0	0	0	0	0	0	0	0	0	0	0
174	0	0	0	0	0	0	0	0	0	0	0	0	0
178	0	4	0	2	0	0	0	0	0	0	0	0	0
179	0	0	0	0	0	0	0	0	0	0	0	0	0
180	0	0	0	0	0	0	0	0	0	0	0	0	0
181	0	0	0	0	0	0	0	0	0	0	0	0	0
186	0	0	0	2	0	0	0	0	0	0	0	0	0
189	1	0	0	0	0	0	0	0	0	0	0	0	0
191	0	0	0	0	0	0	0	0	0	0	0	0	0
194	0	18	0	30	0	0	0	0	0	0	0	0	0
198	0	2	0	4	0	0	0	0	0	0	0	0	0
210	1	0	0	0	0	0	0	0	0	0	0	0	0
213	0	0	0	0	0	0	0	0	0	0	0	0	0
218	0	0	0	1	0	0	0	0	0	0	0	0	0
225	0	1	0	1	0	0	0	0	0	0	0	0	0
234	0	0	0	0	0	0	0	0	0	0	0	0	0
237	0	0	0	1	0	0	0	0	0	0	0	0	0
242	0	10	0	0	0	0	0	0	0	0	0	0	0
258	0	0	0	0	0	0	0	0	0	0	0	0	0
264	0	0	0	0	0	0	0	0	0	0	0	0	0
266	1	7	0	0	1	0	0	0	0	0	0	0	0
278	1	0	0	0	0	0	0	0	0	0	0	0	0
285	0	0	0	0	0	0	0	0	0	0	0	0	0
298	0	0	0	0	0	0	0	0	0	0	0	0	0
302	0	0	0	0	0	0	0	0	0	0	0	0	0

TRIP GRTS SEGMENT	Bluehead Sucker	Flannelmouth Sucker	Humpback Chub	Speckled Dace	YOY Sucker	Brown Trout	Channel Catfish	Common Carp	Fathead Minnow	Plains Killifish	Western Mosquitofish	Red Shiner	Rainbow Trout
308	0	3	0	1	1	0	0	0	0	0	0	0	0
310	0	96	0	16	1	0	0	0	0	0	0	0	0
322	1	5	0	83	0	0	0	0	0	1	0	1	0
330	0	1	0	1	1	0	0	0	0	1	0	0	0
335	0	1	0	0	0	0	0	0	0	0	0	0	0
353	0	2	0	0	0	0	0	0	0	0	0	0	0
364	0	2	0	0	0	0	0	0	0	0	0	0	0
365	11	47	0	33	0	0	0	0	0	3	6	1	0
382	0	0	0	0	0	0	0	0	0	0	0	0	0
385	65	135	0	10	0	0	0	0	6	2	3	0	0
May	**131**	**1,698**	**12**	**1,015**	**1,389**	**1**	**0**	**0**	**17**	**3**	**0**	**3**	**2**
2	0	1	0	0	0	0	0	0	0	0	0	0	0
22	0	2	0	0	0	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0	0	0	0	0	0
46	0	0	0	0	0	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0	0	0	0	0	0
55	0	0	0	0	0	0	0	0	0	0	0	0	0
69	0	0	0	2	0	0	0	0	1	0	0	0	0
72	0	0	0	5	0	0	0	0	0	0	0	0	0
74	0	2	0	0	1	0	0	0	0	0	0	0	0
79	0	0	0	0	0	0	0	0	0	0	0	0	0
86	0	0	0	0	0	0	0	0	0	0	0	0	0
90	0	0	0	0	0	0	0	0	0	0	0	0	0
98	3	0	0	2	0	0	0	0	0	0	0	0	0
103	0	0	0	0	0	0	0	0	0	0	0	0	2
114	0	2	0	32	0	0	0	0	0	0	0	0	0
122	0	0	0	0	1	0	0	0	0	0	0	0	0
132	0	2	0	0	0	0	0	0	0	0	0	0	0
155	0	5	0	0	11	0	0	0	0	0	0	0	0
160	0	22	0	27	6	1	0	0	0	0	0	0	0
162	1	0	0	5	4	0	0	0	0	0	0	0	0
170	0	6	0	2	40	0	0	0	0	1	0	0	0
174	0	0	0	8	18	0	0	0	0	0	0	0	0
178	1	43	0	18	6	0	0	0	0	0	0	0	0
179	0	0	0	1	2	0	0	0	0	0	0	0	0
180	0	2	0	5	9	0	0	0	0	0	0	0	0
181	0	36	0	45	23	0	0	0	0	0	0	0	0
186	5	36	0	34	58	0	0	0	0	0	0	0	0
189	8	6	2	35	2	0	0	0	0	0	0	0	0
191	0	16	2	75	0	0	0	0	0	0	0	0	0
194	3	116	0	140	10	0	0	0	0	0	0	0	0
198	5	34	1	29	49	0	0	0	1	0	0	0	0
210	4	69	2	68	2	0	0	0	1	0	0	0	0
213	1	12	0	8	8	0	0	0	0	0	0	0	0

TRIP GRTS SEGMENT	Bluehead Sucker	Flannelmouth Sucker	Humpback Chub	Speckled Dace	YOY Sucker	Brown Trout	Channel Catfish	Common Carp	Fathead Minnow	Plains Killifish	Western Mosquitofish	Red Shiner	Rainbow Trout
218	0	2	0	2	92	0	0	0	0	0	0	0	0
225	6	93	1	59	48	0	0	0	0	0	0	0	0
234	0	0	0	0	27	0	0	0	0	0	0	0	0
237	0	0	0	0	26	0	0	0	0	0	0	0	0
242	37	570	0	32	426	0	0	0	0	0	0	0	0
258	0	14	0	2	2	0	0	0	0	0	0	0	0
264	5	40	3	24	38	0	0	0	0	0	0	0	0
266	0	0	0	0	46	0	0	0	0	0	0	0	0
278	0	0	0	0	29	0	0	0	0	0	0	0	0
285	0	0	0	1	35	0	0	0	0	0	0	0	0
298	0	0	0	0	17	0	0	0	0	0	0	0	0
302	1	1	0	0	5	0	0	0	0	0	0	0	0
308	0	5	0	1	88	0	0	0	0	0	0	0	0
310	0	202	1	5	50	0	0	0	10	2	0	1	0
322	18	185	0	139	25	0	0	0	3	0	0	2	0
330	1	9	0	14	13	0	0	0	0	0	0	0	0
335	1	2	0	3	100	0	0	0	0	0	0	0	0
353	15	62	0	110	23	0	0	0	1	0	0	0	0
364	2	9	0	5	8	0	0	0	0	0	0	0	0
365	6	79	0	25	11	0	0	0	0	0	0	0	0
382	6	3	0	11	0	0	0	0	0	0	0	0	0
385	2	10	0	41	30	0	0	0	0	0	0	0	0
June	**885**	**2,436**	**148**	**779**	**4,261**	**0**	**0**	**0**	**2**	**8**	**10**	**0**	**0**
2	0	0	0	0	0	0	0	0	0	0	0	0	0
22	3	13	0	0	4	0	0	0	0	0	0	0	0
31	0	2	0	0	1	0	0	0	0	0	0	0	0
34	1	1	0	0	0	0	0	0	0	0	0	0	0
46	0	0	0	0	0	0	0	0	0	0	0	0	0
50	2	2	0	0	7	0	0	0	0	0	0	0	0
55	0	1	0	0	1	0	0	0	0	0	0	0	0
69	0	2	0	0	5	0	0	0	0	0	0	0	0
72	18	57	0	15	214	0	0	0	0	0	0	0	0
74	1	4	1	0	205	0	0	0	0	0	0	0	0
79	2	4	0	0	0	0	0	0	0	0	0	0	0
86	0	10	0	0	16	0	0	0	0	0	0	0	0
90	0	0	0	0	3	0	0	0	0	0	0	0	0
98	1	1	0	0	0	0	0	0	0	0	0	0	0
103	0	15	1	1	74	0	0	0	0	0	0	0	0
114	0	0	0	0	1	0	0	0	0	0	0	0	0
122	0	1	0	0	4	0	0	0	0	0	0	0	0
132	0	0	0	0	2	0	0	0	0	0	0	0	0
155	0	2	4	0	21	0	0	0	0	0	0	0	0
160	2	1	0	2	3	0	0	0	0	0	0	0	0
162	233	725	24	122	954	0	0	0	1	0	0	0	0
170	64	230	5	1	345	0	0	0	0	0	0	0	0

TRIP GRTS SEGMENT	Bluehead Sucker	Flannelmouth Sucker	Humpback Chub	Speckled Dace	YOY Sucker	Brown Trout	Channel Catfish	Common Carp	Fathead Minnow	Plains Killifish	Western Mosquitofish	Red Shiner	Rainbow Trout
174	1	1	1	1	3	0	0	0	0	0	0	0	0
178	33	139	4	39	319	0	0	0	0	0	0	0	0
179	29	5	1	7	64	0	0	0	0	0	0	0	0
180	1	7	1	0	17	0	0	0	0	0	0	0	0
181	36	54	2	11	102	0	0	0	0	0	0	0	0
186	24	5	0	4	49	0	0	0	0	0	0	0	0
189	16	43	3	21	244	0	0	0	0	0	0	0	0
191	1	68	0	26	10	0	0	0	0	0	0	0	0
194	1	0	0	1	2	0	0	0	0	0	0	0	0
198	23	32	2	5	440	0	0	0	0	0	0	0	0
210	2	3	1	0	0	0	0	0	0	0	0	0	0
213	81	103	6	27	380	0	0	0	0	0	0	0	0
218	5	9	3	2	69	0	0	0	1	0	0	0	0
225	8	25	1	50	31	0	0	0	0	0	0	0	0
234	8	40	0	7	18	0	0	0	0	0	0	0	0
237	2	3	1	7	89	0	0	0	0	0	0	0	0
242	61	143	2	33	164	0	0	0	0	0	0	0	0
258	2	3	1	1	6	0	0	0	0	0	0	0	0
264	20	50	2	11	45	0	0	0	0	0	0	0	0
266	2	4	2	7	9	0	0	0	0	0	0	0	0
278	5	9	15	4	27	0	0	0	0	0	0	0	0
285	4	8	3	5	5	0	0	0	0	0	0	0	0
298	3	11	2	5	20	0	0	0	0	0	0	0	0
302	11	28	2	44	28	0	0	0	0	0	0	0	0
308	10	149	4	14	107	0	0	0	0	0	0	0	0
310	61	181	22	72	63	0	0	0	0	0	0	0	0
322	50	59	2	112	15	0	0	0	0	1	0	0	0
330	0	0	1	4	5	0	0	0	0	0	0	0	0
335	1	5	5	4	7	0	0	0	0	0	0	0	0
353	12	14	3	10	20	0	0	0	0	0	0	0	0
364	4	5	7	8	20	0	0	0	0	0	0	0	0
365	28	147	5	17	4	0	0	0	0	7	10	0	0
382	3	0	2	63	1	0	0	0	0	0	0	0	0
385	10	12	7	16	18	0	0	0	0	0	0	0	0
July	**486**	**5,278**	**48**	**1,589**	**12**	**1**	**0**	**1**	**11**	**1**	**1**	**33**	**3**
2	0	0	0	0	0	0	0	0	0	0	0	0	0
22	3	89	0	0	1	0	0	0	0	0	0	0	0
31	0	3	0	0	0	0	0	0	0	0	0	0	0
34	0	4	0	0	0	0	0	0	0	0	0	0	0
46	0	0	0	0	0	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0	0	0	0	0	0
55	0	8	2	0	0	0	0	0	0	0	0	0	0
69	0	0	0	0	0	0	0	0	0	0	0	0	0
72	1	36	0	0	0	0	0	0	0	0	0	0	0
74	0	18	1	0	0	0	0	0	0	0	0	0	0

TRIP GRTS SEGMENT	Bluehead Sucker	Flannelmouth Sucker	Humpback Chub	Speckled Dace	YOY Sucker	Brown Trout	Channel Catfish	Common Carp	Fathead Minnow	Plains Killifish	Western Mosquitofish	Red Shiner	Rainbow Trout
79	1	34	0	1	0	0	0	0	0	0	0	0	0
90	0	4	0	2	0	0	0	0	0	0	0	0	1
98	0	1	0	1	0	0	0	0	0	0	0	0	1
103	0	28	0	0	0	0	0	0	0	0	0	0	0
114	0	5	0	3	0	0	0	0	0	0	0	0	0
122	0	9	0	2	0	0	0	0	0	0	0	0	1
132	1	4	0	1	0	0	0	0	1	0	0	0	0
155	0	24	2	8	0	0	0	0	1	0	0	0	0
160	0	18	0	11	0	0	0	0	0	0	0	0	0
162	1	130	0	58	0	0	0	0	0	0	0	0	0
170	0	383	4	53	1	1	0	0	1	0	0	0	0
174	0	4	0	9	0	0	0	0	0	0	0	0	0
178	1	106	2	6	0	0	0	0	1	0	0	0	0
179	0	4	0	2	0	0	0	0	0	0	0	0	0
180	0	90	0	5	0	0	0	0	0	0	0	0	0
181	0	59	0	2	0	0	0	0	0	0	0	0	0
186	1	117	1	19	0	0	0	0	0	0	0	0	0
189	2	96	0	78	2	0	0	0	0	0	0	0	0
191	0	93	2	21	0	0	0	0	0	0	0	0	0
194	1	17	1	0	6	0	0	0	0	0	0	0	0
198	0	153	2	100	0	0	0	0	1	0	0	0	0
210	0	71	0	1	0	0	0	0	0	0	0	0	0
213	0	194	2	51	1	0	0	0	0	1	0	0	0
218	5	147	3	33	0	0	0	0	0	0	0	0	0
225	20	47	0	53	0	0	0	0	0	0	0	0	0
234	9	21	1	12	0	0	0	0	0	0	0	0	0
237	3	140	0	14	0	0	0	0	0	0	0	0	0
242	0	314	1	10	0	0	0	0	0	0	0	0	0
258	0	15	0	0	0	0	0	0	0	0	0	0	0
264	1	51	1	2	0	0	0	0	0	0	0	0	0
266	1	97	0	15	0	0	0	0	1	0	0	0	0
278	4	75	0	8	1	0	0	0	0	0	0	0	0
285	3	34	0	22	0	0	0	0	0	0	0	0	0
298	0	42	8	2	0	0	0	1	0	0	0	0	0
302	0	88	6	56	0	0	0	0	1	0	0	0	0
308	0	59	0	9	0	0	0	0	0	0	0	0	0
310	5	1,227	1	503	0	0	0	0	0	0	0	9	0
322	95	162	3	216	0	0	0	0	4	0	0	22	0
330	183	239	1	105	0	0	0	0	0	0	0	1	0
335	36	112	0	25	0	0	0	0	0	0	0	0	0
353	63	188	0	22	0	0	0	0	0	0	0	0	0
364	12	111	3	12	0	0	0	0	0	0	1	0	0
365	22	196	1	8	0	0	0	0	0	0	0	1	0
382	3	4	0	20	0	0	0	0	0	0	0	0	0
385	9	107	0	8	0	0	0	0	0	0	0	0	0

TRIP GRTS SEGMENT	Bluehead Sucker	Flannelmouth Sucker	Humpback Chub	Speckled Dace	YOY Sucker	Brown Trout	Channel Catfish	Common Carp	Fathead Minnow	Plains Killifish	Western Mosquitofish	Red Shiner	Rainbow Trout
Aug.	**356**	**2,177**	**47**	**1,439**	**29**	**2**	**0**	**3**	**179**	**36**	**17**	**31**	**4**
2	0	0	0	0	0	0	0	0	0	0	0	0	0
22	8	12	0	26	0	0	0	0	18	8	0	0	0
31	0	0	0	0	0	0	0	0	0	1	0	0	1
34	0	0	0	0	0	0	0	0	1	0	0	0	0
46	2	0	0	1	0	0	0	0	1	0	0	0	0
50	0	0	0	1	0	0	0	0	0	0	0	0	0
55	2	4	0	1	0	0	0	0	0	0	0	0	0
69	0	3	0	5	0	0	0	0	1	0	0	0	0
72	3	2	0	7	0	0	0	0	1	0	0	0	0
74	0	26	0	7	1	0	0	0	1	1	0	0	0
79	1	25	0	17	5	0	0	0	8	0	0	0	0
86	0	12	0	0	1	0	0	0	6	0	0	0	0
90	0	0	0	0	0	0	0	0	0	0	0	0	0
98	6	0	0	17	0	0	0	0	0	0	0	0	2
103	0	9	0	8	6	2	0	0	0	1	0	0	1
114	0	1	0	31	0	0	0	0	0	1	0	0	0
122	0	1	1	8	0	0	0	0	2	0	0	0	0
132	0	1	0	1	0	0	0	0	0	0	0	0	0
155	2	6	0	5	6	0	0	0	0	0	0	0	0
160	0	3	0	12	0	0	0	0	2	0	0	0	0
162	4	77	2	48	6	0	0	0	0	2	0	0	0
170	0	58	14	31	0	0	0	0	0	2	0	0	0
174	4	6	0	50	0	0	0	0	0	0	0	0	0
178	0	60	1	28	0	0	0	0	0	1	0	0	0
179	0	35	1	29	0	0	0	0	0	0	0	0	0
180	0	17	1	20	0	0	0	0	1	1	0	0	0
181	0	119	2	39	0	0	0	0	25	0	0	0	0
186	1	13	0	4	0	0	0	0	0	0	0	0	0
189	0	80	1	62	0	0	0	0	4	1	0	0	0
191	1	41	1	30	0	0	0	0	0	0	0	0	0
194	0	7	4	36	2	0	0	0	0	0	0	0	0
198	0	17	0	61	0	0	0	0	0	1	0	0	0
210	4	10	0	9	0	0	0	0	0	0	0	0	0
213	1	99	0	18	0	0	0	0	8	1	0	0	0
218	2	10	0	40	1	0	0	0	1	0	0	0	0
225	9	138	3	118	0	0	0	0	0	0	0	0	0
234	0	39	0	31	0	0	0	0	0	0	0	0	0
237	36	4	0	38	0	0	0	0	0	0	0	0	0
242	14	160	0	67	0	0	0	0	0	0	0	0	0
258	0	51	1	6	0	0	0	0	0	0	0	0	0
264	0	13	2	10	0	0	0	0	0	0	0	0	0
266	5	6	2	9	0	0	0	0	0	0	0	0	0
278	0	2	0	4	0	0	0	0	0	0	0	0	0
285	0	15	0	49	0	0	0	0	0	0	0	0	0
298	0	11	0	12	0	0	0	0	2	0	0	1	0
302	0	43	0	52	1	0	0	0	2	0	0	0	0

TRIP GRTS SEGMENT	Bluehead Sucker	Flannelmouth Sucker	Humpback Chub	Speckled Dace	YOY Sucker	Brown Trout	Channel Catfish	Common Carp	Fathead Minnow	Plains Killifish	Western Mosquitofish	Red Shiner	Rainbow Trout
308	1	36	1	12	0	0	0	0	1	0	0	0	0
310	190	561	3	107	0	0	0	2	75	9	0	30	0
322	18	63	1	112	0	0	0	0	6	2	0	0	0
330	2	47	4	38	0	0	0	0	4	3	15	0	0
335	9	50	1	26	0	0	0	0	0	0	0	0	0
353	3	9	1	31	0	0	0	0	1	0	0	0	0
364	2	56	0	8	0	0	0	0	1	0	1	0	0
365	12	27	0	8	0	0	0	1	6	1	1	0	0
382	6	6	0	14	0	0	0	0	0	0	0	0	0
385	8	86	0	35	0	0	0	0	1	0	0	0	0
Sept.	**136**	**1,653**	**33**	**861**	**0**	**0**	**0**	**0**	**59**	**22**	**16**	**5**	**19**
2	0	0	0	0	0	0	0	0	0	0	0	0	0
22	1	3	0	0	0	0	0	0	8	0	0	0	0
31	0	0	0	0	0	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0	0	5	0	0	2
46	0	0	0	0	0	0	0	0	0	0	0	0	1
50	0	1	0	2	0	0	0	0	0	0	0	0	1
55	0	3	0	0	0	0	0	0	1	3	0	0	3
69	0	2	0	0	0	0	0	0	0	0	0	0	0
72	0	182	0	0	0	0	0	0	1	1	0	0	0
74	0	3	0	0	0	0	0	0	0	0	0	0	0
79	0	4	0	0	0	0	0	0	0	0	0	0	1
86	0	4	0	5	0	0	0	0	2	1	0	0	0
90	0	0	0	0	0	0	0	0	0	0	0	0	2
98	1	1	0	7	0	0	0	0	0	0	0	0	2
103	2	12	0	9	0	0	0	0	0	3	0	0	2
114	1	1	0	2	0	0	0	0	0	0	0	0	2
122	0	1	0	0	0	0	0	0	0	0	0	0	1
132	0	3	0	0	0	0	0	0	0	0	0	0	0
155	0	9	0	1	0	0	0	0	3	0	0	0	1
160	2	16	0	8	0	0	0	0	0	2	0	0	0
162	2	12	0	14	0	0	0	0	0	0	0	0	0
170	2	22	5	4	0	0	0	0	0	2	0	0	0
174	0	2	0	1	0	0	0	0	0	0	0	0	0
178	1	41	0	3	0	0	0	0	0	0	0	0	0
179	2	7	0	5	0	0	0	0	0	0	0	0	0
180	0	3	0	25	0	0	0	0	0	0	0	0	0
181	6	28	1	15	0	0	0	0	1	0	0	0	0
186	2	44	1	21	0	0	0	0	0	1	0	0	0
189	0	8	0	18	0	0	0	0	0	0	0	0	0
191	0	13	1	15	0	0	0	0	0	0	0	0	1
194	0	4	1	8	0	0	0	0	0	0	0	0	0
198	4	73	1	44	0	0	0	0	0	0	0	0	0
210	0	4	0	10	0	0	0	0	0	0	0	0	0

TRIP GRTS SEGMENT	Bluehead Sucker	Flannelmouth Sucker	Humpback Chub	Speckled Dace	YOY Sucker	Brown Trout	Channel Catfish	Common Carp	Fathead Minnow	Plains Killifish	Western Mosquitofish	Red Shiner	Rainbow Trout
213	0	21	0	31	0	0	0	0	0	0	0	0	0
218	0	6	0	4	0	0	0	0	0	1	0	0	0
225	2	11	0	40	0	0	0	0	0	0	0	0	0
234	1	106	1	13	0	0	0	0	0	0	0	0	0
237	2	32	1	7	0	0	0	0	0	0	0	0	0
242	0	67	2	36	0	0	0	0	10	0	0	0	0
258	0	162	0	31	0	0	0	0	0	0	0	0	0
264	0	55	0	13	0	0	0	0	1	0	0	0	0
266	0	11	1	5	0	0	0	0	0	0	0	0	0
278	1	33	1	23	0	0	0	0	0	0	0	0	0
285	1	25	0	19	0	0	0	0	0	0	0	0	0
298	0	12	1	15	0	0	0	0	0	0	0	4	0
302	0	26	1	34	0	0	0	0	0	0	0	0	0
308	2	85	8	15	0	0	0	0	0	0	0	0	0
310	0	82	0	25	0	0	0	0	0	0	0	1	0
322	22	99	4	226	0	0	0	0	26	0	0	0	0
330	23	24	0	38	0	0	0	0	0	0	4	0	0
335	10	31	2	25	0	0	0	0	0	0	0	0	0
353	0	30	0	4	0	0	0	0	0	1	0	0	0
364	14	66	0	13	0	0	0	0	0	0	12	0	0
365	5	68	1	2	0	0	0	0	1	2	0	0	0
382	7	13	0	21	0	0	0	0	0	0	0	0	0
385	20	82	0	4	0	0	0	0	5	0	0	0	0
Grand Totals	**2083**	**13615**	**290**	**5932**	**5695**	**9**	**0**	**4**	**274**	**80**	**53**	**74**	**28**

OPPORTUNISTIC	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	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
May	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
June	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
July	**17**	**121**	**6**	**139**	**3**	**0**	**0**	**1**	**36**	**52**	**0**	**0**	**4**
August	**27**	**130**	**1**	**158**	**0**	**0**	**1**	**20**	**39**	**12**	**0**	**0**	**0**
September	**20**	**18**	**0**	**13**	**0**	**0**	**0**	**0**	**6**	**14**	**0**	**0**	**0**
Grand Totals	**64**	**269**	**7**	**310**	**3**	**0**	**1**	**21**	**81**	**78**	**0**	**0**	**4**

APPENDIX E: AGE-0 FISH CAPTURED BY TRIP AT GENERALIZED RANDOM TESSELLATION STRATIFIED (GRTS) SEGMENTS DURING LARVAL FISH COMMUNITY SAMPLING IN THE GRAND CANYON, 2018

Appendix E.1. Age-0 fish captured during the 07–15 March 2018 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	12	2.29	[d]	9	16.07
Catostomus latipinnis Flannelmouth Sucker	N	508	97.13	0.24	29	51.79
Xyrauchen texanus Razorback Sucker	N	3	0.57	[d]	2	3.57
Topminnows						
Fundulus zebrinus Plains Killifish	I	–	–	–	–	–
Livebearers						
Gambusia affinis Western Mosquitofish	I	–	–	–	–	–
TOTAL		**523**				

[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=54 GRTS sample segments

[d] Value is <0.05

Appendix E.2. Age-0 fish captured during the 11–17 April 2018 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	2	0.04	[d]	1	1.79
Suckers						
Catostomidae sp.	N	2	[d]	[d]	2	3.57
Catostomus discobolus Bluehead Sucker	N	1,168	25.04	0.60	31	55.36
Catostomus latipinnis Flannelmouth Sucker	N	3,490	74.83	2.14	40	71.43
Xyrauchen texanus Razorback Sucker	N	2	[d]	[d]	2	3.57
Topminnows						
Fundulus zebrinus Plains Killifish	I	–	–	–	–	–
Livebearers						
Gambusia affinis Western Mosquitofish	I	–	–	–	–	–
TOTAL		**4,664**				

[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.3. Age-0 fish captured during the 09–15 May 2018 survey.

SPECIES COMMON NAME	RESIDENCE STATUS[a]	NUMBER OF SPECIMENS	PERCENT OF TOTAL	MEAN CPUE[b]	FREQUENCY OF OCCURRENCE[c]	PERCENT FREQUENCY OF OCCURRENCE[c]
Carps and Minnows						
Cyprinella lutrensis Red Shiner	I	3	[d]	[d]	1	1.79
Cyprinus carpio Common Carp	I	–	–	–	–	–
Gila cypha Humpback Chub	N	9	[d]	[d]	6	10.71
Pimephales promelas Fathead Minnow	I	–	–	–	–	–
Rhinichthys osculus Speckled Dace	N	783	3.43	0.40	28	50.00
Suckers						
Catostomidae sp.	N	1	[d]	[d]	1	1.79
Catostomus discobolus Bluehead Sucker	N	8,801	38.61	4.77	49	87.50
Catostomus latipinnis Flannelmouth Sucker	N	13,197	57.89	7.39	56	100.00
Xyrauchen texanus Razorback Sucker	N	2	[d]	[d]	2	3.57
Topminnows						
Fundulus zebrinus Plains Killifish	I	–	–	–	–	–
Livebearers						
Gambusia affinis Western Mosquitofish	I	–	–	–	–	–
TOTAL		**22,796**				

[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 fish captured during the 13–19 June 2018 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	46	0.36	[d]	16	28.57
Pimephales promelas Fathead Minnow	I	1	[d]	[d]	1	1.79
Rhinichthys osculus Speckled Dace	N	1,225	9.64	0.73	42	75.00
Suckers						
Catostomidae sp.	N	–	–	–	–	–
Catostomus discobolus Bluehead Sucker	N	4,061	31.95	2.40	54	96.43
Catostomus latipinnis Flannelmouth Sucker	N	7,372	58.01	4.10	55	98.21
Xyrauchen texanus Razorback Sucker	N	3	[d]	[d]	3	5.36
Topminnows						
Fundulus zebrinus Plains Killifish	I	–	–	–	–	–
Livebearers						
Gambusia affinis Western Mosquitofish	I	1	[d]	[d]	1	1.79
TOTAL		**12,709**				

[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.5. Age-0 fish captured during the 11–16 July 2018 survey.

SPECIES **COMMON NAME**	**RESIDENCE STATUS**[a]	**NUMBER OF SPECIMENS**	**PERCENT OF TOTAL**	**MEAN CPUE**[b]	**FREQUENCY OF OCCURRENCE**[c]	**PERCENT FREQUENCY OF OCCURRENCE**[c]
Carps and Minnows						
Cyprinella lutrensis Red Shiner	I	–	–	–	–	–
Cyprinus carpio Common Carp	I	2	[d]	[d]	2	3.57
Gila cypha Humpback Chub	N	34	0.47	[d]	16	28.57
Pimephales promelas Fathead Minnow	I	–	–	–	–	–
Rhinichthys osculus Speckled Dace	N	1,183	16.23	0.67	39	69.64
Suckers						
Catostomidae sp.	N	–	–	–	–	–
Catostomus discobolus Bluehead Sucker	N	1,446	19.84	0.84	49	87.50
Catostomus latipinnis Flannelmouth Sucker	N	4,620	63.40	2.69	56	100.00
Xyrauchen texanus Razorback Sucker	N	–	–	–	–	–
Topminnows						
Fundulus zebrinus Plains Killifish	I	–	–	–	–	–
Livebearers						
Gambusia affinis Western Mosquitofish	I	2	[d]	[d]	1	[d]
TOTAL		**7,287**				

[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 fish captured during the 08–14 August 2018 survey.

SPECIES COMMON NAME	RESIDENCE STATUS[a]	NUMBER OF SPECIMENS	PERCENT OF TOTAL	MEAN CPUE[b]	FREQUENCY OF OCCURRENCE[c]	PERCENT FREQUENCY OF OCCURRENCE[c]
Carps and Minnows						
Cyprinella lutrensis Red Shiner	I	1	[d]	[d]	1	1.79
Cyprinus carpio Common Carp	I	–	–	–	–	–
Gila cypha Humpback Chub	N	21	1.50	[d]	11	19.64
Pimephales promelas Fathead Minnow	I	62	4.43	[d]	14	25.00
Rhinichthys osculus Speckled Dace	N	804	57.43	0.38	41	73.21
Suckers						
Catostomidae sp.	N	–	–	–	–	–
Catostomus discobolus Bluehead Sucker	N	33	2.36	[d]	19	33.93
Catostomus latipinnis Flannelmouth Sucker	N	463	33.07	0.23	43	76.79
Xyrauchen texanus Razorback Sucker	N	–	–	–	–	–
Topminnows						
Fundulus zebrinus Plains Killifish	I	15	1.07	[d]	9	16.07
Livebearers						
Gambusia affinis Western Mosquitofish	I	1	[d]	[d]	1	1.79
TOTAL		**1,400**				

[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, 2018

Appendix F.1. Age-1+ fish captured during the 07–15 March 2018 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	2.50	[d]	1	1.79
Gila cypha Humpback Chub	N	–	–	–	–	–
Pimephales promelas Fathead Minnow	I	7	17.50	[d]	3	5.36
Rhinichthys osculus Speckled Dace	N	8	20.0	[d]	4	7.14
Suckers						
Catostomus discobolus Bluehead Sucker	N	3	7.50	[d]	3	5.36
Catostomus latipinnis Flannelmouth Sucker	N	11	27.50	[d]	7	12.50
Trouts						
Salmo trutta Brown Trout	I	–	–	–	–	–
Topminnows						
Fundulus zebrinus Plains Killifish	I	4	10.0	[d]	4	7.14
Livebearers						
Gambusia affinis Western Mosquitofish	I	6	15.0	[d]	3	5.36
TOTAL		**40**				

[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.2. Age-1+ fish captured during the 11–17 April 2018 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	1.45	[d]	1	1.79
Gila cypha Humpback Chub	N	–	–	–	–	–
Pimephales promelas Fathead Minnow	I	–	–	–	–	–
Rhinichthys osculus Speckled Dace	N	47	68.12	0.02	20	35.71
Suckers						
Catostomus discobolus Bluehead Sucker	N	–	–	–	–	–
Catostomus latipinnis Flannelmouth Sucker	N	18	26.08	0.01	8	14.29
Trouts						
Salmo trutta Brown Trout	I	–	–	–	–	–
Topminnows						
Fundulus zebrinus Plains Killifish	I	2	2.90	[d]	2	3.57
Livebearers						
Gambusia affinis Western Mosquitofish	I	1	1.45	[d]	1	1.79
TOTAL		**69**				

[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.3. Age-1+ fish captured during the 09–15 May 2018 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	–	–	–	–	–
Gila cypha Humpback Chub	N	–	–	–	–	–
Pimephales promelas Fathead Minnow	I	–	–	–	–	–
Rhinichthys osculus Speckled Dace	N	20	37.74	[d]	4	7.14
Suckers						
Catostomus discobolus Bluehead Sucker	N	1	1.88	[d]	1	1.79
Catostomus latipinnis Flannelmouth Sucker	N	29	54.72	0.01	8	14.29
Trouts						
Salmo trutta Brown Trout	I	–	–	–	–	–
Topminnows						
Fundulus zebrinus Plains Killifish	I	3	5.66	[d]	2	3.57
Livebearers						
Gambusia affinis Western Mosquitofish	I	–	–	–	–	–
TOTAL		**53**				

[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+ fish captured during the 13–19 June 2018 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	–	–	–	–	–
Gila cypha Humpback Chub	N	–	–	–	–	–
Pimephales promelas Fathead Minnow	I	–	–	–	–	–
Rhinichthys osculus Speckled Dace	N	16	88.88	[d]	7	12.50
Suckers						
Catostomus discobolus Bluehead Sucker	N	1	5.56	[d]	1	1.79
Catostomus latipinnis Flannelmouth Sucker	N	1	5.56	[d]	1	1.79
Trouts						
Salmo trutta Brown Trout	I	–	–	–	–	–
Topminnows						
Fundulus zebrinus Plains Killifish	I	–	–	–	–	–
Livebearers						
Gambusia affinis Western Mosquitofish	I	–	–	–	–	–
TOTAL		**18**				

[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.5. Age-1+ fish captured during the 11–16 July 2018 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	0.47	[d]	1	1.79
Gila cypha Humpback Chub	N	33	15.57	0.02	9	16.07
Pimephales promelas Fathead Minnow	I	1	0.47	[d]	1	1.79
Rhinichthys osculus Speckled Dace	N	89	41.98	0.05	7	12.50
Suckers						
Catostomus discobolus Bluehead Sucker	N	6	2.83	[d]	5	8.92
Catostomus latipinnis Flannelmouth Sucker	N	82	38.68	0.05	21	37.50
Trouts						
Salmo trutta Brown Trout	I	–	–	–	–	–
Topminnows						
Fundulus zebrinus Plains Killifish	I	–	–	–	–	–
Livebearers						
Gambusia affinis Western Mosquitofish	I	–	–	–	–	–
TOTAL		**212**				

[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+ fish captured during the 08–14 August 2018 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	–	–	–	–	–
Gila cypha Humpback Chub	N	7	7.21	[d]	4	7.14
Pimephales promelas Fathead Minnow	I	7	7.21	[d]	5	8.93
Rhinichthys osculus Speckled Dace	N	52	53.62	0.03	21	37.5
Suckers						
Catostomus discobolus Bluehead Sucker	N	2	2.06	[d]	2	3.57
Catostomus latipinnis Flannelmouth Sucker	N	18	18.56	0.01	6	10.71
Trouts						
Salmo trutta Brown Trout	I	1	1.03	[d]	1	1.79
Topminnows						
Fundulus zebrinus Plains Killifish	I	10	10.31	[d]	5	8.93
Livebearers						
Gambusia affinis Western Mosquitofish	I	–	–	–	–	–
TOTAL		97				

[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