Lower Colorado River Multi-Species Conservation Program

Balancing Resource Use and Conservation

Razorback Sucker Studies on Lake Mead, Nevada and Arizona

2019–2020

March 2021

Work conducted under LCR MSCP Work Task D8

Lower Colorado River Multi-Species Conservation Program
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National Park Service
Bureau of Land Management
Bureau of Indian Affairs
Western Area Power Administration

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The Nature Conservancy

Lower Colorado River Multi-Species Conservation Program

Razorback Sucker Studies on Lake Mead, Nevada and Arizona

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ACRONYMS AND ABBREVIATIONS

AIC_c	Akaike's information criterion adjusted for small sample size
ANOVA	analysis of variance
BIO-WEST	BIO-WEST, Inc.
cm	centimeter(s)
CPUE	catch-per-unit effort
CRI	Colorado River inflow area (of Lake Mead)
FL	fork length
GPS	Global Positioning System
hybrid sucker	razorback sucker × flannelmouth sucker
kHz	kilohertz
km	kilometer(s)
LCR MSCP	Lower Colorado River Multi-Species Conservation Program
m	meter(s)
MARK	software application for the analysis of data from marked individuals
mm	millimeter(s)
MS-222	tricaine methanesulfonate
n	sample size
NaCl	sodium chloride
NDOW	Nevada Department of Wildlife
PIT	passive integrated transponder
Q-Q	quartile-quartile
Reclamation	Bureau of Reclamation
SE	standard error
SL	standard length
SNWA	Southern Nevada Water Authority
SUR	submersible ultrasonic receiver
TL	total length
USFWS	US Fish and Wildlife Service

Symbols

°C	degrees Celsius
Δ	delta
=	equal to
$>$	greater than
$<$	less than
≤	less than or equal to
%	percent
±	plus or minus
Φ	survival probability
p	encounter probability
$\hat{c}$	median c-hat

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EXECUTIVE SUMMARY

In 1996, the Southern Nevada Water Authority and Colorado River Commission of Nevada, in cooperation with the Nevada Department of Wildlife, Arizona Game and Fish Department, National Park Service, Bureau of Reclamation (Reclamation), and the U.S. Fish and Wildlife Service initiated a study to develop information about the Lake Mead razorback sucker (*Xyrauchen texanus*) (Abbott 1861) population. BIO-WEST, Inc., under contract with the Southern Nevada Water Authority, designed the study and had primary responsibility for conducting the research. In 2005, Reclamation became the principal source of funding through the Lower Colorado River Multi-Species Conservation Program (LCR MSCP), and the study became primarily a long-term monitoring effort in 2007. In 2012, the LCR MSCP provided funding to continue long-term monitoring, as well as funding to initiate a pilot study for juvenile razorback suckers in Lake Mead. Funding continued from 2015 to 2019 for long-term monitoring efforts at the three established study sites. Again in 2020, the LCR MSCP provided funding to continue long-term monitoring for the 24th year. Information and observations of the long-term monitoring study are provided herein.

During the 2020 study year (July 1, 2019 – June 30, 2020), 10 sonic-tagged fish were detected via telemetry efforts, which resulted in 25 active and 39 passive contacts. By using data gathered from sonic-tagged fish in conjunction with trammel netting and larval sampling data, information regarding primary spawning sites was obtained for three long-term monitoring study areas within Lake Mead (Las Vegas Bay, Echo Bay, and the Virgin River/Muddy River inflow area). Along with primary spawning site information, sonic-tagged fish revealed reservoir-wide movement patterns and seasonal movement patterns within the long-term monitoring study areas.

Thirty-two razorback suckers were captured in trammel nets in 2020 at the combined long-term monitoring sites. Highlights from the 2020 netting efforts include 12 juvenile razorback suckers and an adult bonytail (*Gila elegans*) (first to our knowledge) being captured in Las Vegas Bay. Additionally, 5 razorback suckers from Echo Bay (3 males and 2 females) and 15 razorback suckers from the Virgin River/Muddy River inflow area (11 females, 2 males, and 2 juveniles) were captured during the 2020 spawning period. Ten razorback suckers were recaptured, and 22 were wild, unmarked fish. Additionally, one flannelmouth sucker and two hybrid suckers (razorback sucker × flannelmouth sucker) were captured at the Virgin River/Muddy River inflow area.

Average annual growth during this field season, determined from eight recaptured razorback suckers, was 15.13 millimeters total length (± standard error = 10.59).

Growth rates of Lake Mead razorback suckers continue to be relatively high, suggesting that they are able to naturally maintain a cohort of young, fast-growing fish.

Fin-ray sections were removed for age determination from 24 (22 new and 2 recaptured) wild razorback suckers, bringing the total number of fish aged during the 24-year, long-term monitoring study to 594. Another highlight in 2020 was the capture of 14 age-6 or younger razorback suckers from the long-term monitoring study areas, which further indicates continued recruitment in Lake Mead. Aged fish included a razorback sucker from the 2018 year class – the first from that year.

From combined sampling locations, 538 larval razorback suckers were captured in 2020. When combined with telemetry and adult captures, spawning activity was confirmed at all sites. Larval razorback sucker abundance was used to help better define primary spawning locations in 2020. BIO-WEST, Inc., also worked collaboratively with the Nevada Department of Wildlife and Reclamation biologists to continue Lake Mead larval razorback sucker collection efforts for genetic analysis.

INTRODUCTION

The razorback sucker (*Xyrauchen texanus*) is one of four endemic, “big-river” fish species (along with Colorado pikeminnow [*Ptychocheilus lucius*], bonytail [*Gila elegans*], and humpback chub [*Gila cypha*]) of the Colorado River Basin presently considered endangered by the U.S. Fish and Wildlife Service (USFWS) (USFWS 1991). Historically widespread and common throughout the larger rivers of the basin, the distribution and abundance of the long-lived razorback suckers are now greatly reduced (Albrecht et al. 2010a; Minckley et al. 1991), principally due to anthropogenic causes. One of the major factors causing the decline of razorback suckers and other big-river fishes was the construction of mainstem dams and the resulting cool tailwaters and reservoir habitats, which replaced warm, riverine environments (Holden and Stalnaker 1975; Joseph et al. 1977; Minckley et al. 1991; Wick et al. 1982). Competition with, and predation by, non-native fishes in the Colorado River and its reservoirs have also contributed to the decline of these endemic species (Minckley et al. 1991). Razorback suckers persisted in several reservoirs constructed in the Lower Colorado River Basin; however, these populations consisted primarily of adult fish that likely recruited during the first few years of reservoir formation. The population of long-lived adults then disappeared 40–50 years following reservoir creation (Minckley 1983).

The largest reservoir population of razorback suckers was estimated at 75,000 individuals in the 1980s and occurred in Lake Mohave (Arizona and Nevada), but it had declined to < 3,000 individuals by 2001 (Marsh et al. 2003). Mueller (2005) reports the last wild Lake Mohave razorback sucker population to be near 500 individuals. The Lake Mohave population today is largely supported by routine stocking of captive-reared fish and remains important to the species for the high level of genetic diversity (Marsh and Associates 2016, 2017, 2018; Marsh et al. 2003, 2005, 2015; Miller et al. 2020). Adult razorback suckers are most evident in Lake Mohave from January to April, when they congregate in shallow shoreline areas to spawn, and larvae can be numerous soon after hatching. Predation by black bass (*Micropterus* spp.), common carp (*Cyprinus carpio*), channel catfish (*Ictalurus punctatus*), sunfish (*Lepomis* spp.), and other non-native species appears to be the principal reason for lack of razorback sucker recruitment (Carpenter and Mueller 2008; Ehlo et al. 2017; Marsh et al. 2003, 2015; Minckley et al. 1991; Schooley et al. 2008a). Recently, the Lake Mohave repatriate population estimate was reported at 3,649 individuals (95% confidence interval of 3,552–3,745) (Miller et al. 2020). Despite the demise of the wild population, Lake Mohave remains important for maintaining the genetic diversity of razorback suckers through a wild-born, captive-reared repatriation program (Dowling et al. 2012a, 2012b).

Comparatively, Lake Mead was formed in 1935 when Hoover Dam was completed. Razorback suckers were relatively common in the reservoir throughout the 1950s and 1960s, apparently from reproduction soon after the reservoir was formed. Not surprisingly, the Lake Mead razorback sucker population appeared to follow the trend of other populations in other Lower Colorado River Basin reservoirs: numbers became noticeably reduced in the 1970s, approximately 40 years after closure of the dam (Holden 1994; McCall 1980; Minckley 1973; Minckley et al. 1991; Sjoberg 1995). From 1980 through 1989, neither the Nevada Department of Wildlife (NDOW) nor the Arizona Game and Fish Department collected razorback suckers from Lake Mead (Sjoberg 1995); this was an observed decline from the more than 30 razorback suckers collected during sport fish surveys in the 1970s, but that may have been partially due to changes in the agencies' sampling programs.

After receiving reports in 1990 from local anglers that razorback suckers were still found in two areas of Lake Mead (Las Vegas Bay and Echo Bay), the NDOW initiated targeted sampling. From 1990 to 1996, 61 wild razorback suckers were collected, 34 from the Blackbird Point area of Las Vegas Bay, and 27 from Echo Bay (Holden et al. 1997). Two razorback sucker larvae were collected near Blackbird Point by an NDOW biologist in 1995, confirming suspected spawning in the area. In addition to capturing these wild fish, the NDOW stocked a limited number of adult and juvenile (sexually immature individuals, as defined in Albrecht et al. 2013a) razorback suckers into Lake Mead. All of these stocked fish were implanted with passive integrated transponder (PIT) tags prior to release, allowing for positive identification of stocked versus wild captured fish. Collection of razorback suckers during the 1990s raised questions regarding the size, demographics, and status of the Lake Mead population. In 1996, the Southern Nevada Water Authority (SNWA), in cooperation with the NDOW, initiated a study to attempt to answer some of these questions. BIO-WEST, Inc., (BIO-WEST) was contracted to design and conduct the study with collaboration from the SNWA and NDOW. Other cooperating agencies included the Bureau of Reclamation (Reclamation), which provided funding, storage facilities, and technical support; National Park Service, which provided residence facilities in their campgrounds; Colorado River Commission of Nevada; Arizona Game and Fish Department; and the USFWS.

At the start of the project in October 1996, the primary objectives were to:

- Estimate the population size of razorback suckers in Lake Mead
- Characterize habitat use and life history characteristics of the Lake Mead population
- Characterize the use and habitat of known spawning sites

In 1998, Reclamation agreed to contribute additional financial support to the project to facilitate fulfillment of Provision #10 of the Reasonable and Prudent Alternatives generated by the USFWS's Final Biological and Conference Opinion on Lower Colorado River Operations and Maintenance–Lake Mead to Southerly International Boundary (USFWS 1997). That year, a cooperative agreement between Reclamation and the SNWA was established, specifying that Las Vegas Bay and Echo Bay were to be studied, and it extended the study period into the year 2000.

In addition to the primary study objectives listed above, the two following objectives were added to fulfill Reclamation's needs:

- Search for new razorback sucker population concentrations via larval light-trapping outside of Las Vegas Bay and Echo Bay

- Enhance the sampling efforts for juvenile razorback suckers at both Las Vegas Bay and Echo Bay

If new populations were located by finding larval razorback suckers, trammel netting would be used to capture adults to obtain demographic information, and sonic tagging would be used to evaluate the general range and habitat use of the newly discovered population. In 2002, Reclamation and the SNWA established another cooperative agreement to extend Reclamation funding into 2004. In 2005, a new objective, that of evaluating the reservoir for potential stocking options and locations, was added to the project as a response to a growing number of larval fish that had been, and were slated to eventually be, repatriated to Lake Mead. Also, in 2005, Reclamation became the primary funding agency through the Lower Colorado River Multi-Species Conservation Program (LCR MSCP), and Reclamation requested that a monitoring protocol be established to ensure the success and continuity of the long-term project. In response to the LCR MSCP's request, BIO-WEST developed a monitoring protocol that helped raise data collection efficiency levels while striving to maintain the amount of information that would be gained studying various razorback sucker life stages during future monitoring and research efforts on Lake Mead (Albrecht et al. 2006a). In 2007, the project became primarily a monitoring study. In 2008, the LCR MSCP and SNWA established another cooperative agreement, extending monitoring efforts and following monitoring protocols developed by Albrecht et al. (2006a) through 2011. In 2012, the LCR MSCP provided funding to maintain long-term monitoring efforts through 2014. In 2015, the LCR MSCP determined to continue long-term monitoring efforts but at a reduced level of effort (approximately half compared with previous years). However, after determining that the reduced efforts in 2015 did not provide the necessary data, in 2016–19, Reclamation and NDOW biologists volunteered to sample the weeks that BIO-WEST biologists were not sampling Lake Mead. These efforts were conducted following the methods outlined in

Albrecht et al. (2006a). In 2020, the LCR MSCP provided funding to maintain long-term monitoring efforts through 2024, allowing for sufficient ability to follow monitoring protocols developed by Albrecht et al. (2006a).

Efforts associated with the long-term monitoring have served as a foundation to expand the understanding of razorback suckers at the Colorado River inflow area (CRI) of Lake Mead, in the lower Grand Canyon, and with regard to the juvenile life stage (Albrecht et al. 2017; Kegerries et al. 2016, 2019). However, the primary goals associated with the long-term monitoring efforts, as contained within this report, are to effectively and efficiently monitor the Lake Mead razorback sucker population at Las Vegas Bay, Echo Bay, and the Virgin River/ Muddy River inflow area of Lake Mead.

More specifically, the following tasks are being conducted at these long-term monitoring study areas in Lake Mead:

- Locating and capturing larval, juvenile, and adult razorback suckers
- Identifying annual spawning site locations within the general study areas
- Marking captured juvenile and adult razorback suckers for individual identification (to be accomplished when no pre-existing means of identification are present)
- Monitoring movements and/or movement patterns of adult razorback suckers within the study areas and identifying the general habitat types in which these fish are found
- Recording biological data (e.g., sex, length, weight), and examining and documenting the general health and condition of captured adult razorback suckers
- Providing mean annual growth rates for recaptured razorback suckers
- Providing population and survival estimates for the current razorback sucker population(s) when appropriate
- Characterizing the age structure of the Lake Mead razorback sucker population(s) through appropriate, non-lethal aging techniques
- Collecting tissue samples of captured juvenile and adult razorback suckers for genetic analyses
- Ultimately, achieving a better understanding razorback sucker recruitment in Lake Mead

This annual report presents the results of the 2020 study year (July 2019 – June 2020 sonic telemetry data and January 2020 – April 2020 adult spawning period netting data). Additional information from previous reports is included when pertinent.

STUDY AREAS

All Lake Mead long-term monitoring activities conducted during the 2020 study year occurred at the same general study areas investigated since 1996 and included Echo Bay, Las Vegas Bay, and the Virgin River/Muddy River inflow area (figure 1) (Rogers et al. 2019).

Specific definitions for the various portions of Las Vegas Wash and Las Vegas Bay in which the study was conducted were given in Holden et al. (2000a). The following definitions remain accurate for various portions of the wash:

- Las Vegas Wash is the portion of the channel with stream-like characteristics. In recent years, this section has become a broad, shallow area that is generally inaccessible by boat.

- Las Vegas Bay begins where the flooded portion of the channel widens and the current velocity is reduced. Las Vegas Bay can have a flowing (lotic) and non-flowing (lentic) portion. The flowing portion is typically short (200–400 meters [m]) and transitory between Las Vegas Wash and Las Vegas Bay. In the non-flowing portion, high turbidity is common despite little current. In 2020, we considered Las Vegas Bay to include the area east of Las Vegas Wash to Sand Island.

Because reservoir elevation fluctuations spatially affect what is called the "wash" or "bay," the above definitions are used to differentiate the various habitats at the time of sampling.

Additionally, the location of wild adult and larval razorback suckers in the northern portion of the Overton Arm necessitates a description of these areas. These location definitions follow those provided in Albrecht and Holden (2005):

- Virgin River/Muddy River inflow area (the lentic and littoral habitats located around the Virgin River confluence and Muddy River confluence with Lake Mead at the upper end of the Overton Arm)

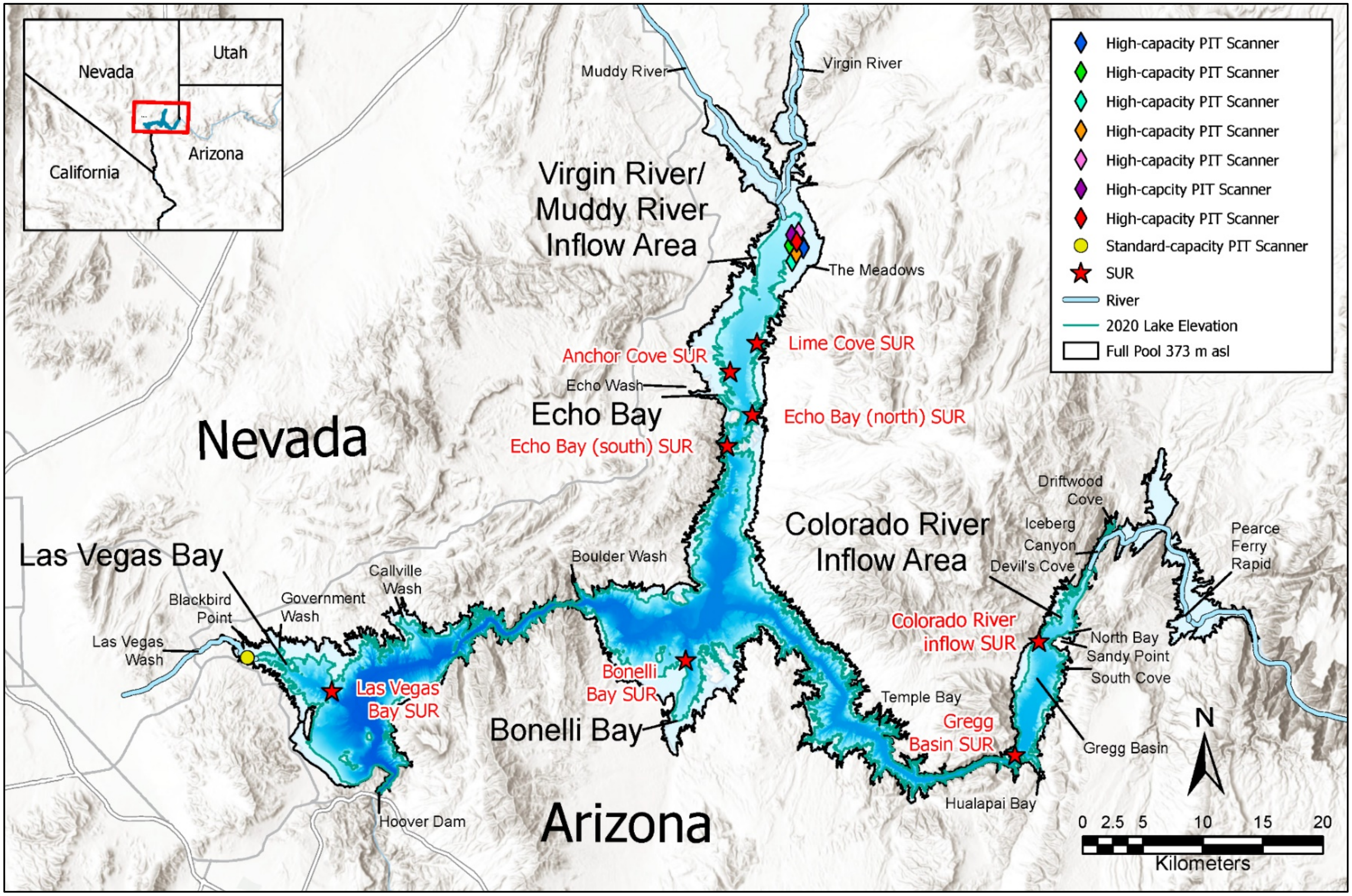

Figure 1.—Long-term monitoring study areas within Lake Mead, along with geographic landmarks.
Red stars indicate locations of long-term monitoring submersible ultrasonic receivers. Diamonds represent high-capacity PIT scanners. Circles represent standard-capacity PIT scanners.

- Fish Island (located between the Virgin River and Muddy River inflows, bounded on the east by the Virgin River and on the west by the Muddy River inflow area; however, this location was dry for the entirety of sampling detailed herein)

- Virgin River and Muddy River proper (the flowing, riverine portions that comprise the Virgin and Muddy Rivers, respectively).

METHODS

Reservoir Elevation

Month-end (1935–2020) and daily reservoir elevations for the 2020 study year (July 1, 2019 – June 30, 2020) were measured in meters above mean sea level and obtained from Reclamation's Lower Colorado Regional Office website. Projected values described below were also taken from Reclamation's regularly updated 24-month study (Reclamation 2020).

Sonic Telemetry

Sonic telemetry data for the long-term monitoring study were collected from July 1, 2019, to June 30, 2020, from razorback suckers previously implanted with coded sonic tags to assess movement throughout the study period. At least every week during the intensive field season (January – April), attempts were made to locate sonic-tagged fish during each sampling trip, depending on the field schedule and project goals. During the remainder of the year (May – December), sonic-tagged fish were typically searched for on a monthly basis.

Active Sonic Telemetry

Active sonic telemetry searches were usually conducted along shorelines, with listening points spaced approximately 0.8 kilometer (km) apart, or as needed, depending on shoreline configuration and other factors that could impact signal reception. Sonic surveillance is line-of-sight; therefore, any obstruction can reduce or block signals. The effectiveness of a sonic telemetry signal is also often reduced in shallow, turbid, and flowing environments (M. Gregor 2010, personal communication; personal experiences of the authors). Additionally, because sonic-tagged razorback suckers can be present within areas of Lake Mead that are inaccessible by boat (e.g., shallow peripheral habitats, flowing portions of inflow areas), the range of observed movements may not always fully represent razorback sucker use of those particular areas. Active tracking consisted of listening underwater for coded sonic tags using a Sonotronics USR-08 model of ultrasonic receiver and a DH4 hydrophone. The hydrophone was lowered just below the water's surface and rotated 360 degrees to detect sonic-tagged fish. Once detected, the position of the sonic-tagged fish was pinpointed by lowering the gain (sensitivity) of the receiver and moving in the direction of the fish until the signal was heard in all directions with the same intensity. Once pinpointed, the fish's sonic tag number, Global Positioning System (GPS) location, and depth were recorded. In all cases, when sonic-tagged fish were located within shallow habitats or within inflow riverine portions of Lake Mead (e.g., Las Vegas Wash, Virgin River inflow), individual fish locations were recorded at the closest point accessible by boat.

Passive Sonic Telemetry

Along with active tracking methods, submersible ultrasonic receivers (SURs) were deployed in various locations throughout Lake Mead, which helped provide a larger area of surveillance for monitoring reservoir-wide movements of razorback suckers. The advantage of a SUR is its ability to continuously record sonic telemetry data over an approximate 9-month battery life. Most importantly, a SUR facilitates an understanding of large-scale razorback sucker movements during monthly tracking events. Five SURs were maintained during the 2020 field season (see figure 1).

Each SUR was programmed to detect implanted, active sonic transmitter frequencies using Sonotronics' SURsoft software. The SURs were deployed using weights along a lead of vinyl-coated steel cable secured to the SUR and then attached and concealed on shore. The SURs were allowed to sink to the reservoir bottom. The SURs were inspected frequently by pulling them into the boat and downloading the data via Sonotronics's SURsoft software. The data were processed through Sonotronics's SURsoftDPCsa software to ascertain the time and date of positive sonic-tagged fish detections within 2-millisecond interval units (e.g., a range of 898 to 902 for a 900-interval tag). Only after running the confidence scan was a record reported as a positive contact of a sonic-tagged razorback sucker (D. White 2019, personal communication).

Adult Sampling

Trammel Netting

Trammel netting occurred from January 20 to April 7, 2020, in Las Vegas Bay, from January 21 to April 8, 2020, in the Virgin River/Muddy River inflow area, and from January 22 to March 19, 2020, in Echo Bay. Two sizes of trammel nets were used to sample for adult fish; 91.4 m long by 1.8 m deep and 45.7 m long by 1.8 m deep. Both nets had internal panels of 2.54-centimeter (cm) mesh and external panels of 30.48 cm mesh. Nets were generally set with one end near shore, with the net stretched perpendicular to shore into deeper areas. All trammel nets were set in late afternoon (prior to sundown) and pulled the next morning (shortly after sunrise). Set and pull times were recorded to the closest minute. Netting locations within each long-term monitoring study area were dictated by historical knowledge of the system, the presence of sonic-tagged fish, and/or high concentrations of razorback sucker larvae. To avoid unnecessary handling stress on native suckers, trammel netting was typically not conducted when surface water temperatures were > 20 degrees Celsius (°C) (Hunt et al. 2012).

All captured fish were removed from nets and held in live wells filled with reservoir water. Native suckers were isolated from other fish species and held in aerated live wells. Typically, the first five individuals of each non-native fish species were measured for total length (TL) and fork length (FL) (in millimeters [mm]), weighed (in grams), and released at the capture location. The remaining non-native species were enumerated and returned to the reservoir. Razorback suckers, flannelmouth suckers (*Catostomus latipinnis*), suspected hybrid suckers, and bonytail were scanned for PIT tags, PIT tagged if they were not recaptured fish, measured (for TL, FL, and standard length [SL]), weighed, and assessed for sexual maturity, overall health, and reproductive readiness. Razorback suckers that were not sexually defined and did not exhibit sexual maturity (e.g., they did not exhibit nuptial tubercles, color, or ripeness) and were > 450 mm TL were labeled as unidentified, and fish < 450 mm TL were labeled as juveniles. Individuals that were sexually defined were labeled according to their sex regardless of size. Suspected hybrid suckers were keyed based on descriptions and meristic counts provided in Hubbs and Miller (1953). Razorback suckers that had not been previously aged were processed for pectoral fin-ray collection as described in the "Age Determination and Year-Class Strength" section below. As requested by the Lake Mead Work Group, genetic material was removed from newly captured, wild razorback suckers. Genetic samples consisted of removing an approximately 5-mm section of caudal fin and preserving the sample in 95% genetics-grade ethanol. After all necessary biological information was collected, the fish were released unharmed at the point of capture. All genetic samples were delivered to Reclamation biologists for analyses following the field season.

Remote Passive Integrated Transponder Scanning

Four submersible, high-capacity battery, long-term, remote PIT scanning units were deployed from January 16 to March 30, 2020, south of the Virgin River/ Muddy River inflow area along the eastern shoreline near areas where sonic-tagged fish were frequently contacted. The submersible units have an internal logger and an approximate 2-week-lifespan battery encased in a waterproof housing. Reclamation biologists routinely downloaded data, changed batteries, and maintained these units.

Additionally, four mobile remote PIT scanning units (with standard-capacity battery for overnight and short-term deployment) were utilized within Las Vegas Wash to detect previously PIT-tagged fish. Each of the mobile antennas were self-contained submersible units in a rectangular polyvinyl chloride housing. Mobile scanners were occasionally deployed by Reclamation biologists during the spawning season, and in most cases, this type of remote unit was retrieved within 3 days.

For both types of scanning units, information recorded included a general location description, GPS location, date, deployment depth, and start and end scanning times. Scanner data were combined for analyses and limited to determining PIT-tagged fish movements and to identifying fish that were not captured via trammel nets in 2020. These data were not used in population or survival estimates in 2020 so as to maintain protocols of past years and because Lake Mead contains wild, untagged razorback suckers that are undetectable by this method.

Growth

Razorback sucker annual growth was calculated for recaptured individuals previously tagged during trammel netting between 1996 and 2019 using the difference in TL between capture periods. Individuals that were recaptured < 365 days apart were not used to calculate annual growth. Additionally, negative growth values were excluded because they likely resulted from field measurement errors. Recaptured individuals from the 2020 field season were measured only once during the spawning season to avoid handling stress. Because wild or stocked razorback suckers in Lake Mead have not shown a significant difference in growth (Mohn et al. 2015), annual growth and mean annual growth was calculated for both wild and stocked individuals.

Larval Sampling

The primary larval sampling method followed the method developed by Burke (1995) and other researchers at Lake Mohave. The procedure uses the positive phototactic response of larval razorback suckers to capture them. After sundown, two underwater fishing lights were connected to a 12-volt, lead-acid battery, placed over each side of the boat, and submerged to a depth of 10–25 cm. Two field crew members 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 netted out of the water and placed into a holding bucket. Typically, three to five sites were sampled each night that sampling was conducted, and the procedure was repeated for 15 minutes at each site. At each site, the GPS location, start and end time, depth, substrate, and the temperature were recorded. Larvae were identified and enumerated as they were placed in the holding bucket and then released at the point of capture when sampling at a site was completed. As requested, and in cooperation with the NDOW and Reclamation, in some cases a subset of larvae was collected for genetic analyses depending on the site and project goals. In Las Vegas Bay, up to 200 larvae per month were to be collected after the NDOW and Reclamation stocked 13 razorback suckers of Lake Mohave origin into Las Vegas Bay in 2018 (Rogers et al. 2018). For this effort, larval samples were preserved in 95% genetics grade ethanol, labeled with date and location information, and then provided to Reclamation biologists at the end of the field season.

Catch-Per-Unit Effort Data Analysis

In order to be consistent with past annual reports, catch-per-unit effort (CPUE) for adult razorback sucker captures via trammel netting (combined 91.4 and 45.7 m nets) was calculated as the mean total number of fish captured per net-hour fished regardless of how many times an individual was captured in a given year. Additionally, CPUE effort for larval razorback sucker captures via active light sampling was calculated as the mean number of fish captured per light-minute. As non-normality and unequal variances are common with datasets related to low-density fish species, a quartile-quartile (Q-Q) plot was examined, and it showed deviation from linearity, indicating the data were not normally distributed (Thode 2002). Data were further tested for normality using a Shapiro-Wilk test. Given both the Q-Q plots and the results from the Shapiro-Wilk test showed a non-normal distribution of data ($P < 0.05$), the data were transformed [Ln(CPUE+1)]. Hereafter, all mentions of CPUE in the context of adult trammel netting and larval sampling represent captures that are log-transformed data. All statistical analyses were performed using the program Statistix 8.1. An analysis of variance (ANOVA), which is considered robust to violations of the normality assumption (Lumley et al. 2002), was used to test for yearly differences in mean CPUE for each sampling site following recommendations of Hubert and Fabrizio (2007). The ANOVA was limited to test for annual differences in mean CPUE from 2015 to 2020 for each individual sampling site as well as among the long-term monitoring study areas. When an ANOVA detected significant differences of less than or equal to an alpha value of 0.05, a Tukey's Honestly Significant Difference test was used to examine all possible pairwise comparisons.

Primary Spawning Site Identification and Observations

It has been found that multiple methods are needed to identify and pinpoint annual spawning sites in Lake Mead (Albrecht and Holden 2005; Albrecht et al. 2010b; Albrecht et al. 2017; Rogers et al. 2019). The basic, most effective spawning site identification procedure has been to track sonic-tagged fish and identify their most frequented areas. Once a location is identified as heavily used by sonic-tagged fish, particularly during crepuscular hours, trammel nets are typically set in that area in an effort to capture adult razorback sucker. Captured fish are then evaluated for signs of ripeness, which are indicative of spawning. After the initial identification of a possible spawning site through sonic-tagged razorback sucker habitat use and other, untagged juvenile or adult trammel-net captures, larval sampling is conducted to validate whether successful spawning occurred. Examples of the effectiveness of these techniques are evident in the descriptions provided by Albrecht and Holden (2005) regarding the documentation of a new spawning aggregate near the Virgin River/Muddy River inflow area in the Overton Arm as well as documentation of a new spawning aggregation at the CRI (Albrecht et al. 2010c). This same general approach was used at the long-term monitoring study areas in 2020.

Age Determination and Year-Class Strength

A non-lethal aging technique employing fin-ray sections was developed in 1999 by BIO-WEST (Holden et al. 2000b). As in past years, an emphasis for the 2020 long-term monitoring efforts involved collecting fin-ray sections from wild razorback suckers for aging purposes. During the 2020 study year, previously unaged, wild razorback suckers captured via trammel netting were anesthetized, and a single (approximately 5-mm long) segment of the second, left pectoral fin ray was surgically removed. Fish were anesthetized in reservoir water containing MS-222, NaCl, and slime-coat protectant to reduce surgery-related stresses, aid in recovery, and avoid accidental injury to fish during surgical procedures. During the surgery, fish were weighed, measured (for TL, FL, and SL), PIT tagged, a genetic sample was collected, and a fin-ray sample was surgically collected 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 connective tissue between fin rays was cut using a scalpel blade, and the section was placed in a labeled envelope for drying. All surgical equipment was cold sterilized with iodine and 90% isopropyl alcohol before each use, and the resulting incisions were packed with antibiotic ointment to minimize post-surgical bacterial infections and promote rapid healing. All razorback suckers undergoing fin-ray extraction techniques were immediately placed in a recovery tank filled with fresh reservoir water, slime-coat protectant, and NaCl. They were allowed to recover and were released at their point of capture as soon as they regained equilibrium. Vigilant monitoring was conducted during all phases of the procedure. No fish were harmed or held for an extended period of time during these procedures.

In the laboratory, fin-ray segments were embedded in thermoplastic epoxy resin and heat-cured. This technique allowed the fin rays to be perpendicularly sectioned using a Buhler isomet low-speed saw. Resultant sections were then mounted on microscope slides, sanded, polished, and examined under a stereo-zoom microscope. Each sectioned fin ray was examined independently by three readers. Sections were then reviewed by the readers in instances when the assigned age was not agreed upon (attachment 1). If age discrepancies remained after the second reading, all readers collectively assigned an age.

In order to more accurately assess year-class strength in Lake Mead, researchers used the residuals of the "catch-curve" regression method proposed by Maceina (1997) and outlined by Ogle (2016). From the combined five study areas (Las Vegas Bay, Echo Bay, Virgin River/Muddy River inflow area, the CRI, and Bonelli Bay), a histogram was used to examine the frequency of fish aged from 1999 to 2020 in order to determine the ages that are most vulnerable to capture. Because previous observations have shown razorback suckers moving between the long-term monitoring study areas and the CRI and Bonelli Bay, and they have similar age structures, we included those results in the analysis (Rogers et al. 2017, 2018, 2019). The histogram demonstrated that razorback suckers aged > 5 years old were more commonly captured in trammel nets at Lake Mead (attachment 2). Furthermore, fish older than 20 years were removed from this analysis because they are rarely captured, and can be difficult to definitively age, and other studies have found that ages of older fish are often underestimated (Koenigs et al. 2015).

The catch-curve regression model requires aging information of multiple razorback suckers from multiple year classes during a given sampling year. During the study years 1999 and 2000, only one fish was captured each year, while in 2001 and 2005, only one fish was captured from each year class contacted; therefore, captures from those study years were excluded from the analysis. For each individual sampling year, the number of razorback suckers at each age were transformed to a log base-10 scale and fitted to a linear model. For each sampling year, the studentized residual (residuals standardized to have a standard deviation of 1) values were calculated for each year class. Studentized residuals follow a t-distribution with n-1 degrees of freedom (n = number of year classes); therefore, where a studentized residual falls on a t-distribution can help to easily identify outliers (Ogle 2016). The mean of the studentized residuals from each year class was calculated and graphed along with an identification of the upper 80th percentile and lower 20th percentile for each year class (Ogle 2016). Values that fell outside these percentiles (outliers) were identified as "very strong" or "very weak" year classes, respectively. Program R version 3.1.2 (R Core Team 2014) and R studio was used for all analyses as well as the "FSA," "plyr," "dplyr," and "countreg" packages.

Population and Survival Estimation

Population Estimates

To assess the Lake Mead razorback sucker population size, program MARK (MARK) (Cooch and White 2013) was utilized to produce an estimate from mark-recapture data spanning from 2018 to 2020. This timespan was selected to ensure sufficient data and to maintain consistency with past estimates where 3-year datasets were used in an effort to have a comparable estimate through time (Albrecht et al. 2008b, 2014a; Holden et al. 2001). A similar approach, in terms of maintaining consistency, has been used in the lower basin to track population dynamics through time by other researchers (e.g., Marsh et al. 2003). Razorback suckers captured during trammel netting efforts at the five combined study areas (long-term monitoring combined with CRI and Bonelli Bay) in Lake Mead were used to produce the estimate. All capture occasions during the 2018–20 spawning seasons (January – April) were included in four, full-likelihood, closed-capture models, which were designed to allow for individual differences in behavior (*Mb*), varying capture probability through time (*Mt*), constant parameters (*Mo*), or individual heterogeneity (*Mh*) (Cooch and White 2013). The population estimate models were compared according to Akaike's information criterion (AIC_c) values, which adjusts for small sample size. The model with the highest-ranking (i.e., smallest) AIC_c value is reported within. No model averaging was conducted when a single model (*Mt*) carried all, or nearly all, the AIC_c weight.

Survival Estimates

Annual apparent survival (Φ) estimates the probability of an individual being alive and available for capture from one year to the next (Cooch and White 2013; Zelasko et al. 2011). Annual apparent survival of adult razorback sucker in Lake Mead was estimated in program MARK for the entire mark-recapture study period spanning from 1996 to 2020, with combined data from the long-term monitoring and CRI study areas (to maintain consistency with previous reports). A Cormack-Jolly-Seber live recapture model (Cormack 1964; Jolly 1965; Seber 1965) was used to obtain a reservoir-wide estimate (combined data from long-term monitoring [1996–2020], the CRI [2010–20] and Bonelli Bay [2019–20]). Razorback suckers that were captured in trammel nets were used to produce this model. Twenty-five annual capture events were included in which each individual was counted only once per year regardless of how many times the individual was captured during a season (similar to Marsh et al. 2005). Models for annual apparent survival and recapture (p, the probability of being captured from one year to the next year) were used in the Cormack-Jolly-Seber survival estimator, so that the parameters (Φ and p) were held either constant (.) or variable through time (t), producing a combination of four model iterations. The models were compared according to AIC_c values (to adjust for small sample size), where the best-fitting models have the lowest AIC_c scores. The saturated model (Φ *[t]p[t]*) was then tested for goodness-of-fit by estimating the over-dispersion parameter using median c-hat ($\hat{c}$) within program MARK (Cooch and White 2013).

In Lake Mead, razorback suckers < 450 mm TL are generally immature fish (< 4 years old) (Albrecht et al. 2013a, 2014b). As such, and in an effort to be comparable with other razorback sucker populations in the Upper and Lower Colorado River Basins (Zelasko et al. 2011), annual apparent survival was calculated for adult razorback suckers > 450 mm TL. A separate analysis was conducted on juvenile fish and described below in the "Juvenile Razorback Sucker Life History Traits in Lake Mead" section. Stocked razorback suckers were not included in the estimate unless they met the size criteria and had survived a minimum of 1 year in Lake Mead. The annual apparent survival estimate, spanning the majority of the study period at Lake Mead (1996–2020), facilitates comparison of survival for Lake Mead razorback suckers with other prominent razorback sucker populations such as those in the upper Colorado River subbasins (Bestgen et al. 2009; Roberts and Moretti 1989; Zelasko et al. 2011) and Lake Mohave (Kesner et al. 2012).

Juvenile Razorback Sucker Life History Traits in Lake Mead

Due to what appeared to be an elevated number of juvenile razorback suckers captured in 2020, a more detailed investigation of juvenile razorback sucker life history traits was conducted. Additional analyses focused on juvenile survival into adulthood, annual growth rates, mean TL, and mean age at capture in Lake Mead from 1997 to 2020. This time period was chosen because it was the first year juvenile razorback suckers were captured in Lake Mead as part of this study. In order to determine juvenile razorback sucker survival into adulthood, fish < 450 mm TL and sexually immature at time of capture, then recaptured as adults, were used in the Cormack-Jolly-Seber live recapture model (described above for the adult-only survival model). Growth was also calculated in a similar manner to that described above in which previously tagged individuals from trammel netting efforts between 1997 and 2019 were used to determine the difference in TL between capture periods, and then that growth was divided by 365 to calculated growth per year. Individuals that were recaptured < 365 days apart were not used to calculate annual growth, and negative growth values were excluded because they likely resulted from field measurement errors.

RESULTS

Lake Elevation

Since 2000, reservoir elevations have generally declined (figure 2). However, in 2019, reservoir elevations remained stable throughout summer and increased from October 2019 through March 2020 before peaking at 334.9 m in March (figure 3). In 2020, reservoir elevations remained stable during the spawning season (January – April) before decreasing approximately 3.5 m in June (figure 3). Biologists observed inundated vegetation in the littoral areas throughout the spawning period.

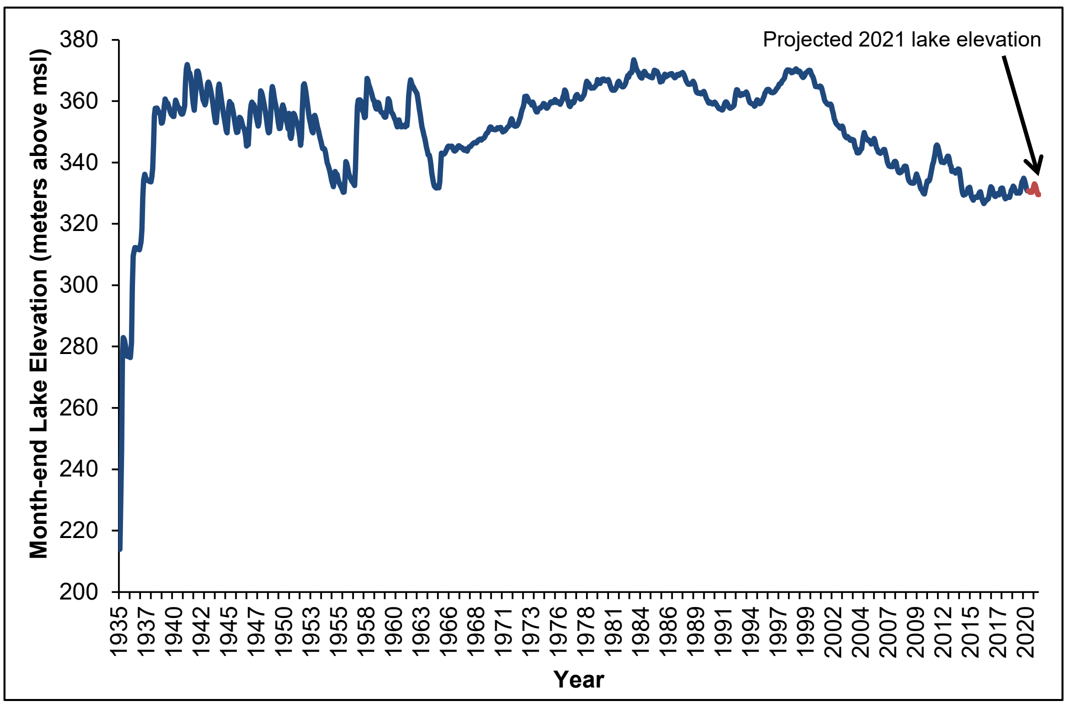

Figure 2.—Month-end Lake Mead reservoir elevations, 1935–2020, with projected reservoir elevations for 2021 study year in red (Reclamation 2020).

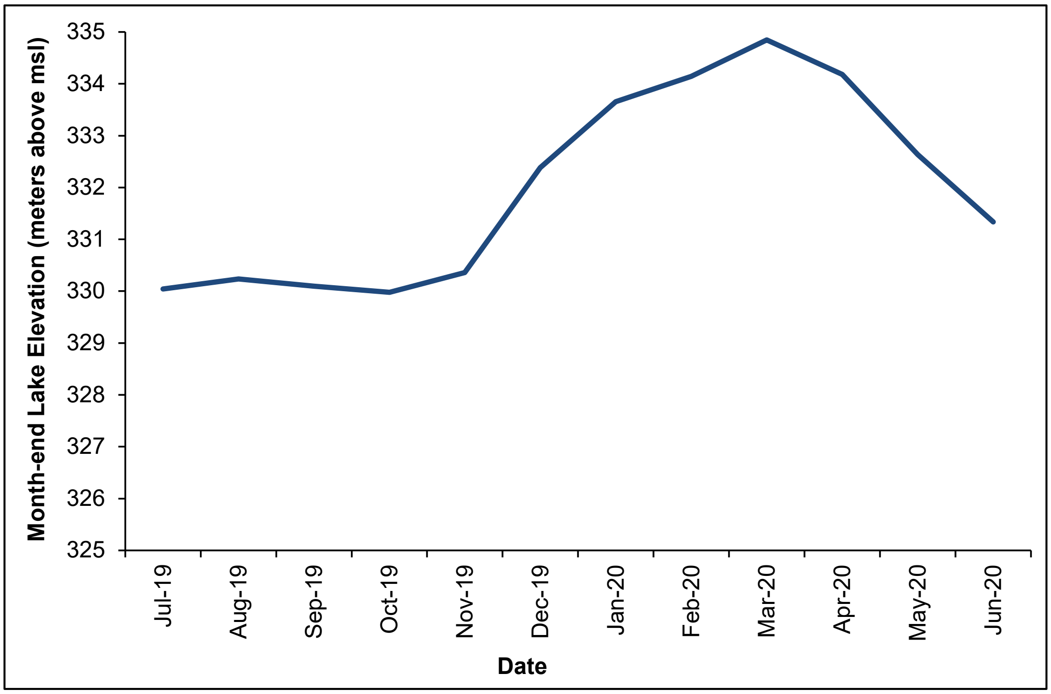

Figure 3.—Month-end Lake Mead reservoir water elevations, July 2019 – June 2020 (Reclamation 2020).

Sonic Telemetry

Over the course of this study, 116 adult razorback suckers (58 wild and 58 hatchery reared) have been equipped with sonic transmitters for the purposes of long-term monitoring and research throughout the study area; however, no razorback suckers were sonic tagged during the 2020 study year.

At the combined three long-term monitoring study areas, 10 unique sonic-tagged razorback suckers (tagged from 2017 to 2019) were detected using active and/or passive telemetry methods during the 2020 study year. Twenty-five active contacts were made with 10 individual sonic-tagged razorback suckers (table 1). This includes three active contacts with r-coded, sonic-tagged fish, which were unable to be decoded by the sonic receiver (noted as 30XX in table 1) in Las Vegas Bay, while two sonic-tagged fish were contacted passively via SUR 39 times at the Las Vegas Bay SUR (n = 33) and at the Echo Bay North SUR (n = 6) (table 1).

The majority of sonic-tagged fish detected via active telemetry were found along the southern shore of Echo Bay across from the boat ramp (figure 4). At the Virgin River/Muddy River inflow area, the majority of sonic-tagged razorback suckers were contacted off the eastern shore approximately 3 km south of the Virgin River inflow (figure 5). The majority of sonic-tagged fish were contacted in the western portion of Las Vegas Bay during the 2020 study year outside of Las Vegas Wash (figure 6).

Table 1.—Initial tagging and stocking information, location, date of last contact, and status of sonic-tagged razorback suckers in Lake Mead, July 2019 – June 2020

Capture location[a]	Date tagged	Sonic code	TL (mm) at tagging	Sex[b]	Release location[a]	Last location[a]	Date of last contact	Contacts made: active (passive)	Current tag status[c]
2017									
LB	12/6/17	3109	513	F	LB	LB	3/4/2020	1 (0)	Active
LB	12/6/17	3428	478	F	LB	LB	7/8/2019	1 (0)	Active
OA	2/20/2017	3768	576	M	OA	EB	7/18/2019	1 (6)	Active
2018									
CPD	1/5/2018	3430	481	M	LB	LB	4/13/2020	0 (33)	Active
CPD	1/5/2018	3438	582	F	LB	LB	1/27/2020	1 (0)	Active
CPD	1/5/2018	30XX	Unknown	U	LB	LB	Unknown	3 (0)	Active
CPD	2/5/2018	488	491	F	LB	LB	10/8//2019	2 (0)	Active
CPD	2/5/2018	555	472	M	LB	LB	8/8/2019	2 (0)	Active
2019									
EB	3/5/19	3476	565	M	EB	EB	4/18/2020	6 (0)	Active
OA	2/20/19	3444	545	M	OA	OA	1/22/2020	1 (0)	Active
OA	2/20/19	5776	546	M	OA	AC	2/29/2020	7 (0)	Active

[a] AC = Anchor Cove, CPD = Center Pond in the Overton Wildlife Management Area, EB = Echo Bay, LB = Las Vegas Bay, and OA = Overton Arm (Virgin River/Muddy River inflow area).
[b] Sex: F = female, M = male, and U = unconfirmed r-code fish.
[c] Active = fish considered active and moving.

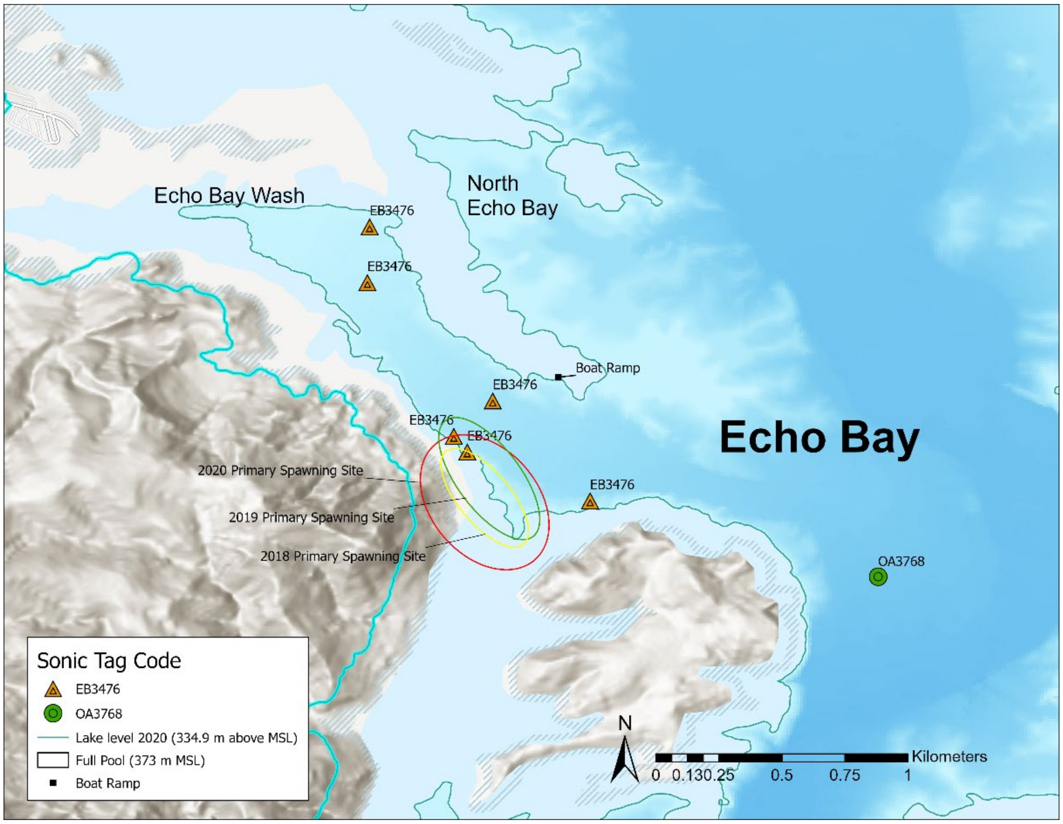

Figure 4.—Distribution of sonic-tagged razorback suckers located through active sonic telemetry in Echo Bay, July 2019 – June 2020.
Symbols for each tag code are unique to their original tagging location, which is noted on the map as the tag code (e.g., fish OA3768 was originally tagged at the Virgin River/ Muddy River inflow area).

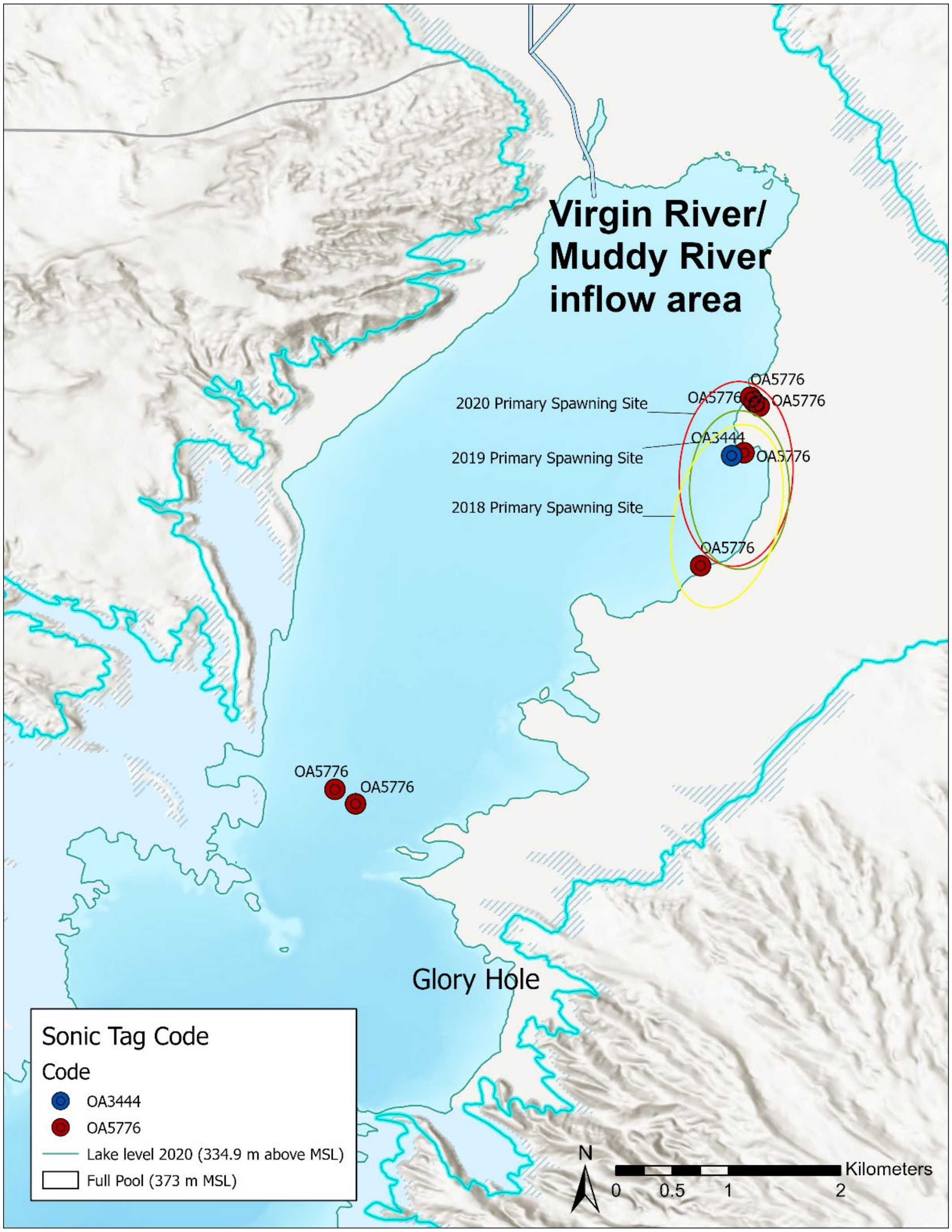

Figure 5.—Distribution of sonic-tagged razorback suckers located through active sonic telemetry near the Virgin River/Muddy River inflow area, July 2019 – June 2020.
Symbols for each tag code are unique to their original tagging location, which is noted on the map as the tag code (e.g., OA3444 was originally tagged at the Virgin River/Muddy River inflow area).

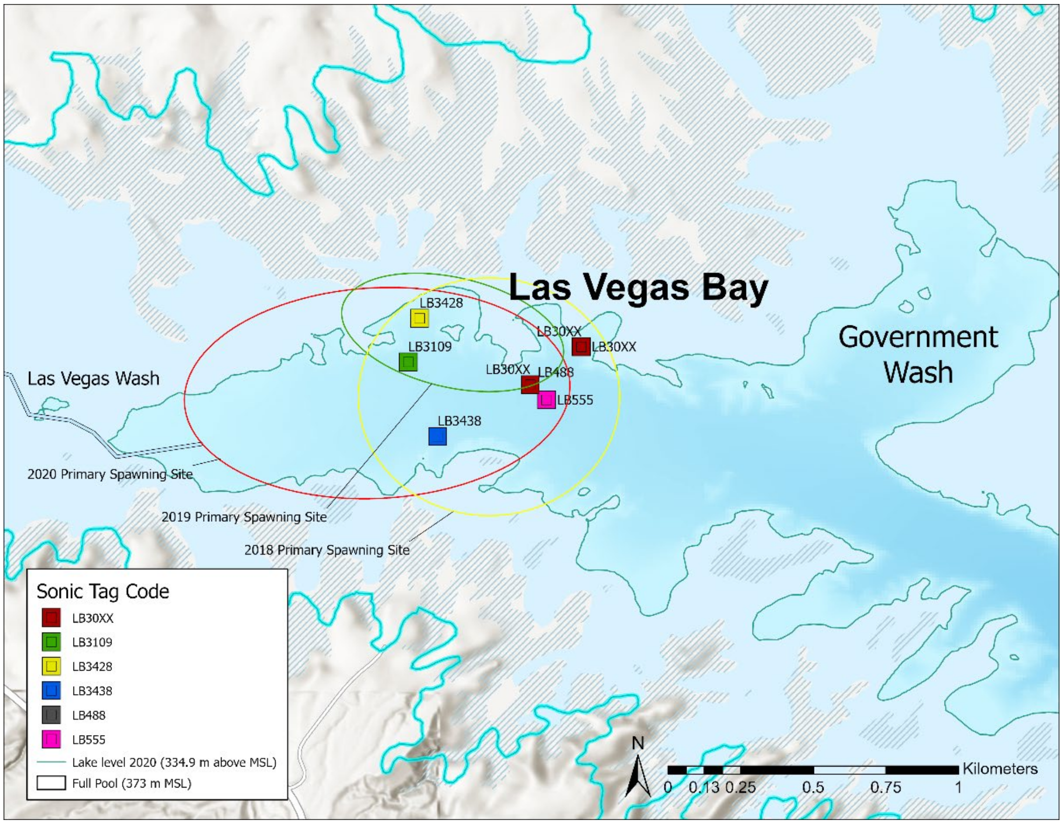

Figure 6.—Distribution of sonic-tagged razorback suckers located through active sonic telemetry in Las Vegas Bay, July 2019 – June 2020.
Symbols for each tag code are unique to their original tagging location, which is noted on the map as the tag code (e.g., LB3438 was originally tagged within Las Vegas Bay).

Adult Sampling

Trammel Netting

Trammel netting was conducted from January 20 to April 7, 2020, and consisted of 73 net sets totaling 1,129.2 net-hours (table 2; figures 7–9). This total includes the collaborative efforts of BIO-WEST and Reclamation. During these trammel netting efforts, 32 razorback suckers were captured (table 3). One bonytail was captured in Las Vegas Bay. One flannelmouth sucker and two hybrid suckers were captured at the Virgin River/ Muddy River inflow area. The first male razorback sucker expressing milt was captured at the Virgin River/Muddy River inflow area on January 22, 2020, and the first female expressing eggs was captured on January 23, 2020, in Echo Bay.

Table 2.—Trammel netting efforts (number of nets and net-hours) on Lake Mead, January – April 2020

Month	Las Vegas Bay	Echo Bay	Virgin River/Muddy River inflow area	Total
January	5	9	2	16
February	7	12	12	31
March	6	9	6	21
April	2	0	3	5
Total number of nets	**20**	**30**	**23**	**73**
Total net-hours	**319.8**	**445.1**	**364.3**	**1,129.2**

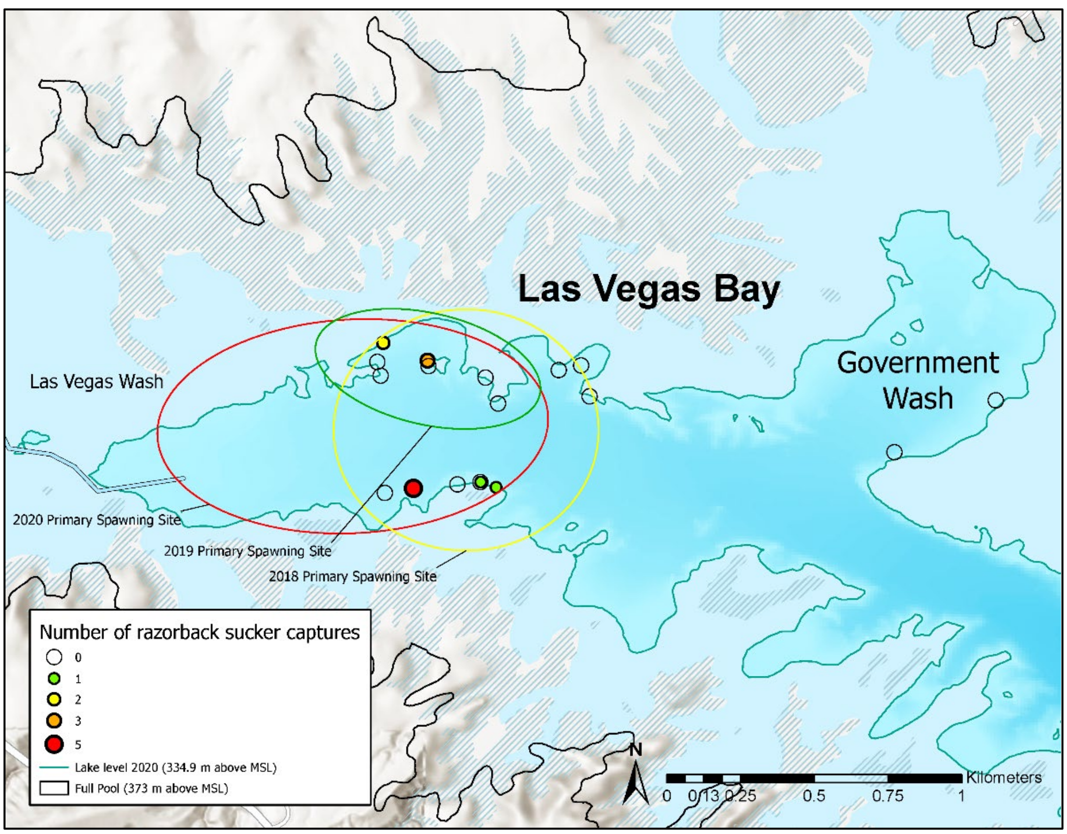

Figure 7.—Locations of trammel netting efforts and numbers of razorback suckers captured in Las Vegas Bay, January – April 2020.

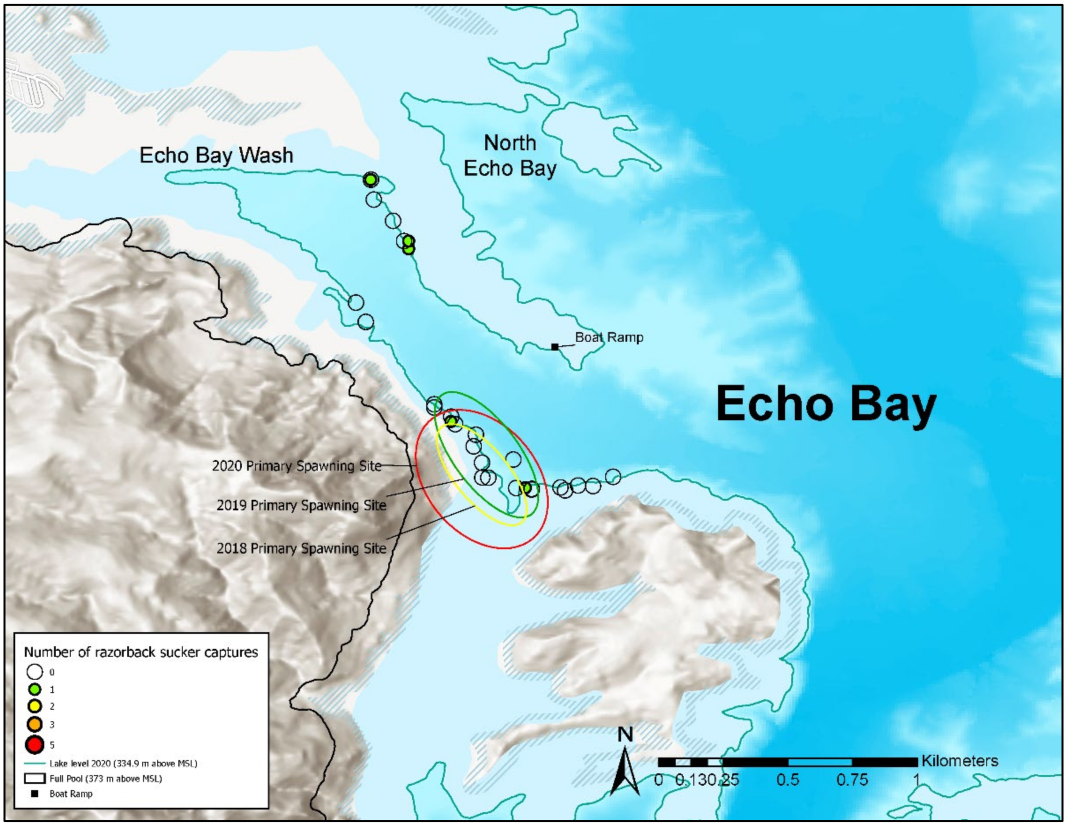

Figure 8.—Locations of trammel netting efforts and numbers of razorback suckers captured in Echo Bay, January – April 2020.

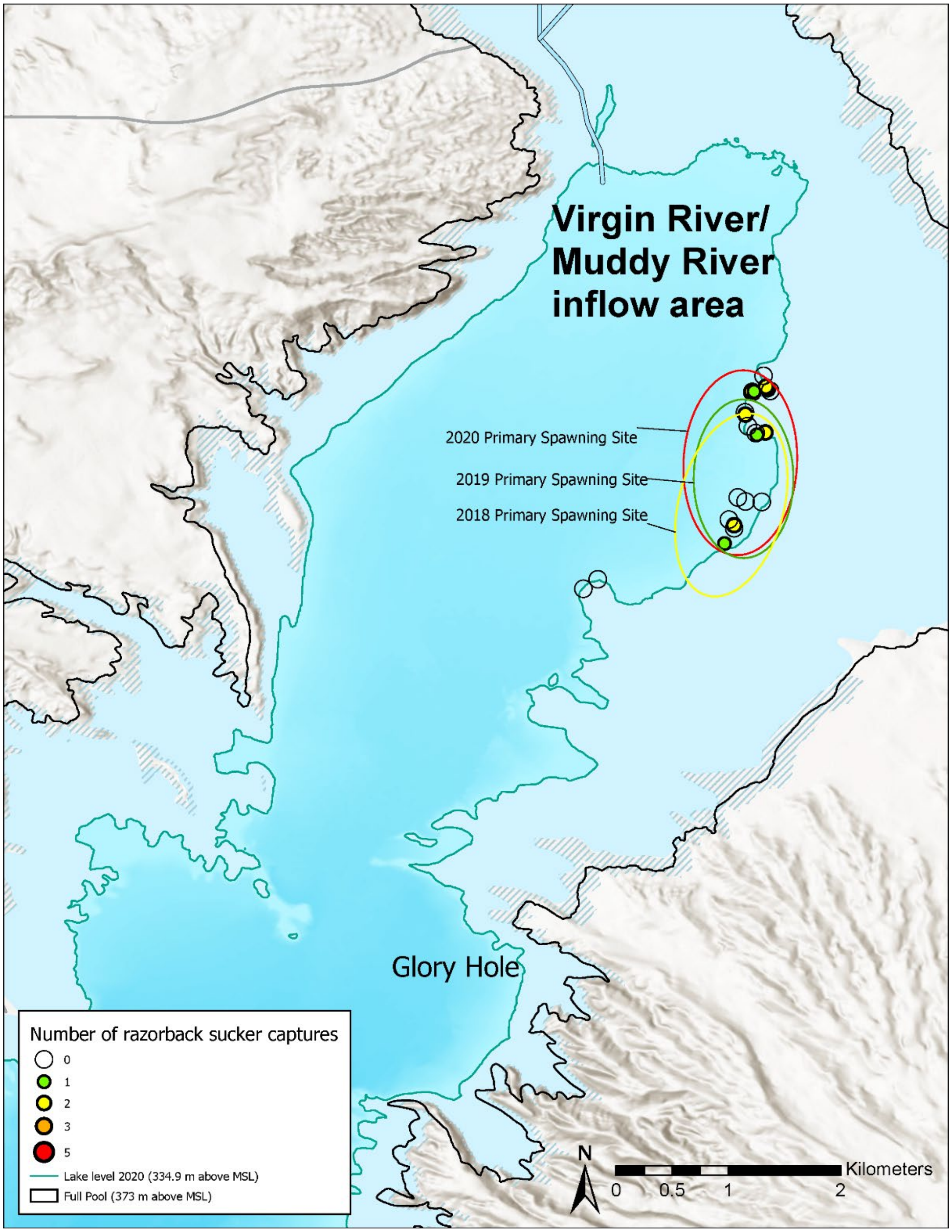

Figure 9.—Locations of trammel netting efforts and numbers of razorback suckers captured at the Virgin River/Muddy River inflow area, January – April 2020.

Table 3.—Capture location, tagging, and size for razorback suckers, flannelmouth suckers, hybrid suckers, and bonytail captured January 20 – April 7, 2020

Date	Capture Location[a]	Date tagged or stocked[b]	Sonic code	PIT tag	Species[c]	Recapture	TL (mm)	FL (mm)	SL (mm)	Weight (grams)	Sex[d]	Origin
01/22/20	OA	02/09/10		3D9.257C633584	HYB	Y	621	575	534	2,563	F	Wild
01/22/20	OA	02/16/16		3DD.003BA74927	RZ	Y	541	494	462	1,692	M	Wild
01/22/20	OA	01/22/20		3DD.003BCB9390	RZ	N	593	555	525	2,708	F	Wild
01/22/20	OA	01/22/20		3DD.003BCB93BE	RZ	N	656	595	571	3,584	F	Wild
01/23/20	EB	04/05/16		3DD.003BCB938F	RZ	Y	671	623	581	3,648	F	Wild
01/28/20	LB	01/28/20		3DD.003BCB9382	RZ	N	381	349	322	658	I	Wild
01/28/20	LB	01/28/20		3DD.003BCB939D	RZ	N	425	392	365	868	I	Wild
01/28/20	LB	01/28/20		3DD.003BCB939E	RZ	N	356	325	302	558	I	Wild
01/28/20	LB	01/28/20		3DD.003BCB93B6	RZ	N	389	356	330	644	I	Wild
01/28/20	LB	01/28/20		3DD.003BCB93B8	RZ	N	343	312	289	478	I	Wild
01/28/20	LB	01/28/20		3DD.003BCB93C8	RZ	N	356	326	305	502	I	Wild
01/28/20	LB	01/28/20		3DD.003BCB93D2	RZ	N	329	304	282	408	I	Wild
02/05/20	EB	02/12/14	4656	384.1B7969DE0B	RZ	Y	641	581	543	2,908	M	Wild
02/06/20	LB	01/28/20		3DD.003BCB939D	RZ	Y	–	–	–	–	I	Wild
02/06/20	LB	02/05/20		3DD.003BCB93B4	RZ	N	392	361	331	652	I	Wild
02/11/20	EB	04/22/10		3D9.257C612FA9	RZ	Y	606	560	531	2,468	M	Wild
02/11/20	EB	02/11/20		3DD.003BCB93D3	RZ	N	684	637	602	3,378	F	Wild
02/12/20	OA	03/02/17		3DD.003BA62D4C	RZ	Y	661	621	593	3,856	F	Wild
02/12/20	OA	02/12/20		3DD.003BCB9391	RZ	N	301	278	253	254	I	Wild
02/12/20	OA	02/12/20		3DD.003BCB9399	RZ	N	662	618	571	3,298	F	Wild
02/12/20	OA	02/12/20		3DD.003BCB93B9	RZ	N	616	567	533	2,668	F	Wild
02/18/20	LB	02/17/20		3DD.003BCB9385	BY	N	454	406	391	724	U	Wild
02/18/20	LB	02/18/20		3DD.003BCB93A2	RZ	N	376	345	318	670	I	Wild
02/18/20	LB	02/18/20		3DD.003BCB93D4	RZ	N	319	294	283	366	I	Wild
02/18/20	LB	02/18/20		3DD.003BCB93D9	RZ	N	401	368	340	778	I	Wild
02/19/20	OA	03/21/13		384.1B7969E7AA	RZ	Y	650	610	569	2,898	F	Wild
02/19/20	OA	02/19/20		3DD.003BCB937D	RZ	N	605	565	526	2,372	F	Wild
02/19/20	OA	03/07/18		3DD.003BCB939A	RZ	Y	595	556	517	2,568	F	Wild
02/19/20	OA	02/19/20		3DD.003BCB93A4	RZ	N	557	479	413	2,098	F	Wild
02/26/20	OA	03/15/12		384.1B7969D849	RZ	Y	642	601	561	3,218	F	Wild
02/26/20	OA	02/26/20		3DD.003BCB93AF	RZ	N	635	591	536	2,968	F	Wild
03/03/20	EB	02/22/11	3476	3D9.257C60BE38	RZ	Y	550	509	477	1,938	M	Wild
03/04/20	OA	03/04/20		3DD.003BCB93A3	RZ	N	317	292	265	336	I	Wild
03/04/20	OA	03/04/20		3DD.003BCB93CF	RZ	N	541	495	464	1,728	M	Wild
03/11/20	OA	02/09/10		3D9.257C633584	HYB	Y	617	581	532	2,688	F	Wild

[a] EB = Echo Bay, LB = Las Vegas Bay, and OA = Overton Arm (Virgin River/Muddy River inflow area).
[b] Date the fish was first captured in the wild or stocked into Lake Mead.
[c] BY = bonytail, FM = flannelmouth sucker, HYB = hybrid sucker, and RZ = razorback sucker.
[d] Sex: F = female, M = male, I = immature and U = undetermined.

Lake Mead razorback sucker captures from the combined long-term monitoring study areas consisted of 13 females, 5 males, and 14 juveniles (see table 3). Ten razorback suckers were recaptured, and 22 were wild, unmarked fish (see table 3). Twelve wild juveniles were captured in Las Vegas Bay ranging in size from 319 to 425 mm TL (see table 3 and figure 7). Five adult razorback suckers were captured in Echo Bay; two females and three males (see table 3 and figure 8). Razorback suckers captured south of the Virgin River/Muddy River inflow area comprised 11 females and 2 males, and 2 juveniles were captured at the Virgin River/Muddy River inflow area ranging in size from 301 to 317 mm TL (see table 3 and figure 9).

Efforts in Las Vegas Bay focused on the western shore of the bay outside of Las Vegas Wash (see figure 7). Twelve wild juvenile razorback suckers were captured as a result of 319.8 net-hours (see tables 2 and 3). This effort yielded a mean CPUE of 0.0329 (± standard error [SE] = 0.53) for Las Vegas Bay in 2020 (figure 10). In general, the mean CPUE value in Las Vegas Bay during 2020 falls within the historical context of this study period, and appears to have increased from last year, and represents the highest CPUE since 2010 (figure 10).

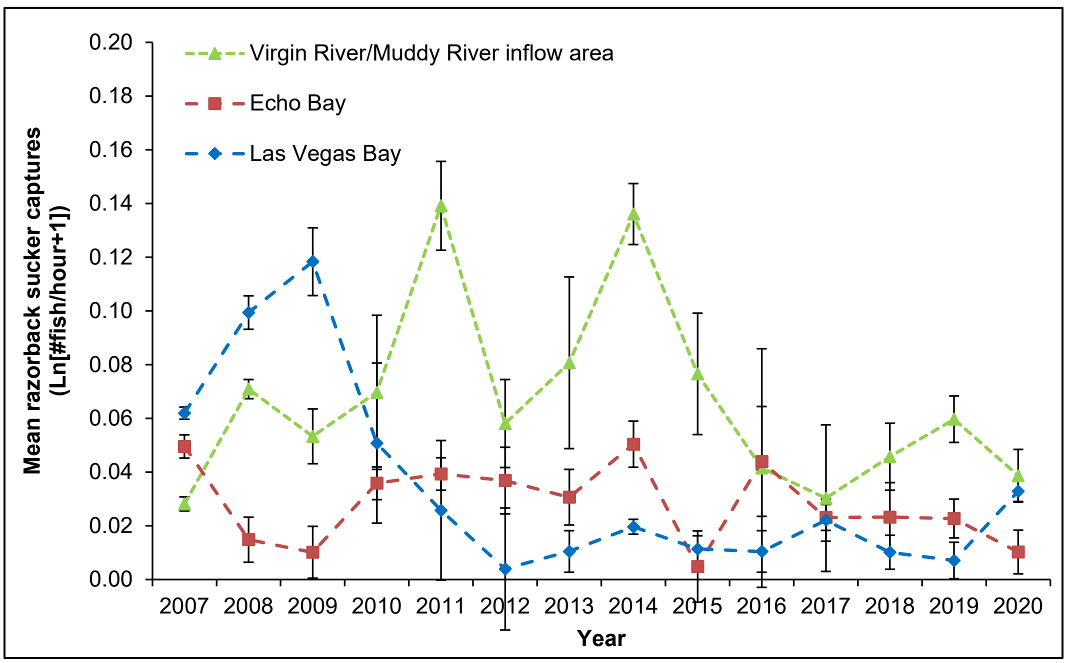

Figure 10.—Trammel netting mean CPUE (Ln[#fish/hr+1]) with associated SE of razorback suckers at long-term monitoring study areas in Lake Mead, 2007–20.

During the 2020 effort, one untagged bonytail was captured in Las Vegas Bay yielding a mean CPUE of 0.0029. This individual was captured in the northwest portion of Las Vegas Bay just outside the wash on February 18, 2020. The sex of this specimen was undetermined at the time of capture and had a TL of 454 mm and weighed 724 grams (see table 3). Aging and genetics data were obtained for this individual, and it was released with a PIT tag for individual identification in the future. To the knowledge of the researchers, this is the first bonytail to be captured in Lake Mead in at least 24 years, if not since the 1950s (BIO-WEST data; Mueller and Marsh 2002).

Trammel netting efforts in Echo Bay focused primarily on the western shoreline across from the boat ramp as well as the western portion of Echo Bay during the latter part of the netting season. These efforts resulted in the capture of five razorback suckers from 445.1 net-hours (see figure 8 and tables 2 and 3). Echo Bay had a mean razorback sucker CPUE of 0.0102 (± SE = 0.0043) in 2020 (see figure 10). Again, the 2020 CPUE appears to fall within the historical context of netting efforts at Echo Bay, albeit a decrease from the mean CPUE of 2019 (see figure 10). Despite this, Echo Bay has been a consistent spawning location for razorback suckers since the earliest years of this study (see figure 10).

Trammel netting within the Virgin River/Muddy River inflow area resulted in the capture of 15 razorback suckers from 364.3 net-hours and yielded a mean CPUE of 0.0387 (± SE = 0.0109) in 2020 (see figure 10 and tables 2 and 3). Sampling at the Virgin River/Muddy River inflow area occurred primarily along the eastern shoreline over gravel bars, approximately 3 km south of the mouth of the Virgin River, and net sets were often dependent on the presence of sonic-tagged fish (see figure 9).

The Virgin River/Muddy River inflow area has shown relatively dramatic increases and decreases of mean CPUE through time (see figure 10). Lastly, one flannelmouth sucker (CPUE = 0.0027) and two hybrid suckers (CPUE = 0.005 [± SE = 0.0038]) were captured at the Virgin River/Muddy River inflow area (see table 3).

CPUE was compared by study areas to determine if there was a statistical difference among sites in 2020. The mean 2020 CPUE values showed no significant difference among the long-term monitoring study areas (ANOVA: $F_{2,70} = 2.54$, P = 0.0862). The 2015–20 time period was used to determine trends through time because lake conditions and study sites have been quite consistent during this time period. The annual mean CPUE was analyzed but did not statistically differ among years over the period 2015–20 within any of the monitoring areas (Las Vegas Bay, ANOVA: $F_{5,155} = 1.64$, P = 0.1533; Echo Bay, ANOVA: $F_{5,184} = 1.94$, P = 0.0903; Virgin River/Muddy River inflow area, ANOVA: $F_{5,145} = 1.01$, P = 0.4119) (see figure 10). Furthermore, annual CPUE by study area was compared to determine if there was a statistical difference among study areas by year (2015–20). The mean CPUE values varied annually by site among long-term monitoring study areas (ANOVA: $F_{17,484} = 2.69$, P = 0.0003). Post-hoc pairwise comparisons showed that the

Virgin River/Muddy River inflow area in 2015 had a higher CPUE than Las Vegas Bay in 2018 and 2019 and Echo Bay in 2020 (see figure 10).

Trammel netting efforts this year also documented movement between study areas as three wild adult razorback suckers were captured away from their original tagging location. One female razorback sucker tagged at the CRI in 2012 was recaptured at the Virgin River/Muddy River inflow area. Another female razorback sucker that was tagged in Echo Bay in 2017 was recaptured at the Virgin River/Muddy River inflow area. Lastly, a male razorback sucker tagged at the Virgin River/Muddy River inflow area in 2011 was recaptured in Echo Bay.

Remote Passive Integrated Transponder Scanning

Remote PIT scanning efforts were conducted for a total 6,430.3 hours in Las Vegas Wash (215.7 hours) and at the Virgin River Muddy River inflow area (6,214.6 hours) and resulted in the detection of 82 unique razorback suckers (n = 68 wild origin razorback suckers and n = 14 stocked razorback suckers) and 1 female hybrid sucker. Based on previous trammel netting data, these fish consisted of female (n = 33), male (n = 44), unknown sex (n = 2), and 3 juvenile fish (table 4). At the two long-term monitoring study areas where scanning was conducted, 3 of the 82 razorback suckers and the 1 hybrid sucker, which were contacted via PIT scanning, were captured in trammel nets in 2020 (table 4). The average days between detections for razorback suckers was 1,539.3 days (± SE = 112.6). Four razorback suckers were detected in Las Vegas Wash. Of these, one was a razorback sucker that was stocked by the Lake Mead Work Group on January 12, 2017, as a juvenile into Las Vegas Wash (Rogers et al. 2017). The three other razorback suckers detected were wild fish originally tagged in Las Vegas Bay (table 4). The overwhelming majority (93.6%) of razorback suckers scanned at the Virgin River/Muddy River inflow area were detected in January (n = 44) and February (n = 29) (table 4). In addition to detecting razorback suckers that have not been observed for several years, scanners were able to document the movement of 12 razorback suckers from Echo Bay, north to the Virgin River/Muddy River inflow area (table 4). The 2020 scanner detection rate was 0.013 razorback sucker per hour, which is lower than the 2019 scanner detection rate of 0.015 individuals per hour and higher than the scanner detection rate in 2018 (Rogers et al. 2018, 2019). Lastly, two common carp tagged in the Grand Canyon (tagged in 2014 and 2015) and two unknown fish were detected on scanners (table 4). One carp that was detected (3DD.003BCA7EC1) has been detected annually since 2018, while one of the unknown fish (3DD.003BCB937F) was detected in 2018 (table 4) (Rogers et al. 2018, 2019). Lastly, during the same time period in Las Vegas Bay and at the Virgin River/Muddy River inflow area, 24 razorback suckers that were not detected with scanners were captured via trammel nets.

Table 4.—Remote PIT tag scanner detections at long-term monitoring study areas with scanner locations, last capture date, original tagging location, and days between detection of each individual PIT-tagged species detected in 2020

Remote PIT tag detections	Date scanned	Scanner location[a]	Last date captured or stocked[e]	Last capture or stocking location[a,e]	Days between detection[b]	Species[c,e]	Sex[d]	Origin
384.1B7969CC00	1/16/2020	OA	2/7/2019	OA	343	RZ	F	Wild
384.1B7969ECFB	1/16/2020	OA	2/15/2018	OA	700	RZ	M	Wild
384.1B796EEDB4	1/16/2020	OA	1/4/2011	OA	3,299	RZ	M	Stocked
3D9.1C2C83C396	1/16/2020	OA	2/7/2012	OA	2,900	RZ	M	Wild
3D9.1C2C841C6D	1/16/2020	OA	3/7/2012	EB	2,871	RZ	M	Wild
3D9.1C2D261224	1/16/2020	OA	4/5/2011	OA	3,208	RZ	F	Wild
3D9.1C2D2617E7	1/16/2020	OA	3/5/2013	OA	2,508	RZ	M	Wild
3D9.257C608715	1/16/2020	OA	2/1/2011	OA	3,271	RZ	M	Wild
3D9.257C60A1F0	1/16/2020	OA	3/28/2018	EB	659	RZ	M	Wild
3DD.003BCB9396	1/16/2020	OA	2/20/2019	OA	330	RZ	M	Wild
384.1B7969DF01	1/17/2020	OA	4/3/2013	OA	2,480	RZ	M	Wild
3D9.1C2D63A99F	1/17/2020	OA	1/20/2016	OA	1,458	RZ	M	Stocked
3D9.257C62B527	1/17/2020	OA	2/3/2010	OA	3,635	RZ	U	Wild
3DD.003BC89EB4	1/17/2020	OA	2/18/2015	OA	1,794	RZ	F	Wild
384.1B7969D27B	1/18/2020	OA	2/20/2017	OA	1,062	RZ	M	Wild
3D9.1C2D263000	1/18/2020	OA	3/7/2018	OA	682	RZ	F	Wild
3DD.003BA2FA7E	1/18/2020	OA	2/7/2019	OA	345	RZ	F	Wild
3DD.003BA2FA86	1/18/2020	OA	2/29/2016	EB	1,419	RZ	M	Wild
3DD.003BA639A5	1/19/2020	OA	2/6/2015	OA	1,808	RZ	F	Stocked
3DD.003BCB93AB	1/19/2020	OA	2/7/2019	OA	346	RZ	F	Wild
3DD.003BA74901	1/20/2020	OA	2/17/2016	OA	1,433	RZ	M	Wild
3DD.003BC89F07	1/20/2020	OA	2/4/2017	OA	1,080	RZ	F	Wild
384.1B7969E16B	1/21/2020	OA	3/15/2012	OA	2,868	RZ	F	Wild
3DD.003BA63971	1/22/2020	OA	2/6/2015	OA	1,811	RZ	M	Stocked
384.1B796EE4CF	1/23/2020	OA	2/6/2015	OA	1,812	RZ	F	Stocked
3D9.1C2C843FA8	1/23/2020	OA	2/8/2012	OA	2,906	RZ	M	Wild
3D9.1C2C83C054	1/24/2020	OA	2/7/2019	OA	351	RZ	F	Wild
3D9.1C2C7F47CD	1/25/2020	OA	3/1/2011	OA	3,252	RZ	F	Wild
384.1B796EF3CF	1/26/2020	OA	2/6/2015	OA	1,815	RZ	M	Stocked
3DD.003BA7687D	1/27/2020	OA	4/24/2019	OA	278	RZ	F	Wild
3DD.003BCB9389	1/27/2020	OA	2/7/2018	OA	719	RZ	I	Wild

Table 4.—Remote PIT tag scanner detections at long-term monitoring study areas with scanner locations, last capture date, original tagging location, and days between detection of each individual PIT-tagged species detected in 2020

Remote PIT tag detections	Date scanned	Scanner location[a]	Last date captured or stocked[e]	Last capture or stocking location[a,e]	Days between detection[b]	Species[c,e]	Sex[d]	Origin
3D9.257C60EB46	1/28/2020	OA	2/20/2017	OA	1,072	RZ	M	Wild
3D9.2794EA27D6	1/28/2020	OA	3/5/2019	EB	329	RZ	F	Wild
3DD.003BA2FA78	1/28/2020	OA	3/20/2014	OA	2,140	RZ	F	Wild
3DD.003BA2FAA8	1/28/2020	OA	3/12/2014	EB	2,148	RZ	F	Wild
3DD.003BA63970	1/28/2020	OA	2/6/2015	OA	1,817	RZ	M	Stocked
3DD.003BCB931A	1/28/2020	OA	2/22/2018	OA	705	RZ	M	Wild
3DD.003BCB939B	1/28/2020	OA	3/8/2018	OA	691	RZ	U	Wild
3DD.003BCB93C4	1/29/2020	OA	4/16/2019	EB	288	RZ	M	Wild
3D9.1C2D63ADCD	1/30/2020	OA	2/6/2015	OA	1,819	RZ	F	Stocked
3DD.003BA62D4C	1/30/2020	OA	2/12/2020	OA	-13	RZ	F	Wild
3DD.003BC89EBC	1/30/2020	OA	3/4/2015	OA	1,793	RZ	M	Wild
3DD.003BC89EDD	1/30/2020	OA	2/20/2019	OA	344	RZ	M	Wild
3D9.257C608F32	1/31/2020	OA	2/17/2010	OA	3,635	RZ	M	Wild
3D9.1C2C8412CB	2/1/2020	OA	2/22/2011	OA	3,266	RZ	M	Wild
3D9.2794E27D5A	2/1/2020	OA	3/7/2018	OA	696	RZ	M	Wild
3DD.003BCB9318	2/1/2020	OA	2/22/2018	OA	709	RZ	F	Wild
3DD.003BA62D53	2/2/2020	OA	3/24/2016	OA	1,410	RZ	M	Wild
3D9.257C61DD61	2/3/2020	OA	4/8/2010	EB	3,588	RZ	M	Wild
3DD.003BA2FA66	2/3/2020	OA	3/6/2014	OA	2,160	RZ	F	Wild
3DD.003BA2FA73	2/3/2020	OA	3/20/2014	OA	2,146	RZ	F	Wild
3DD.003BCB937B	2/3/2020	OA	4/18/2018	OA	656	RZ	I	Wild
3D9.1C2D268469	2/4/2020	OA	3/29/2012	EB	2,868	RZ	F	Wild
3DD.003BCB93BE	2/4/2020	OA	1/22/2020	OA	13	RZ	F	Wild
3D9.1C2C857F86	2/5/2020	OA	3/2/2011	EB	3,262	RZ	M	Wild
3DD.003BCB93C3	2/6/2020	OA	2/7/2019	OA	364	RZ	M	Wild
384.1B7969D59B	2/7/2020	OA	2/17/2016	OA	1,451	RZ	F	Wild
3DD.003BA639A8	2/7/2020	OA	2/6/2015	OA	1,827	RZ	M	Stocked
3D9.1C2C7F4A82	2/8/2020	OA	3/20/2014	OA	2,151	RZ	M	Wild
3D9.025893A7D7	2/9/2020	OA	3/3/2017	OA	1,073	RZ	F	Wild
3D9.1C2C83E120	2/9/2020	OA	3/22/2012	EB	2,880	RZ	F	Wild
3DD.003BA639B1	2/9/2020	OA	2/6/2015	OA	1,829	RZ	M	Stocked

Table 4.—Remote PIT tag scanner detections at long-term monitoring study areas with scanner locations, last capture date, original tagging location, and days between detection of each individual PIT-tagged species detected in 2020

Remote PIT tag detections	Date scanned	Scanner location[a]	Last date captured or stocked[e]	Last capture or stocking location[a,e]	Days between detection[b]	Species[c,e]	Sex[d]	Origin
3DD.003BE8F357	2/9/2020	OA	3/5/2019	OA	341	RZ	M	Wild
3D9.1C2D69596A	2/10/2020	OA	2/6/2015	OA	1,830	RZ	M	Stocked
3DD.003BCB937A	2/10/2020	OA	2/7/2019	OA	368	RZ	M	Wild
3DD.003BCB9395	2/10/2020	OA	2/24/2016	OA	1,447	RZ	F	Wild
3DD.003BA63989	2/12/2020	OA	2/6/2015	OA	1,832	RZ	M	Stocked
3D9.1C2D279A4D	2/13/2020	OA	3/22/2016	EB	1,423	RZ	F	Wild
3DD.003BA63996	2/13/2020	OA	2/6/2015	OA	1,833	RZ	M	Stocked
3DD.003BA7688C	2/14/2020	OA	3/3/2017	OA	1,078	RZ	M	Wild
3D9.2794E9F9EE	2/20/2020	OA	3/28/2018	EB	694	RZ	M	Wild
3DD.003BA2FAC1	2/22/2020	OA	3/24/2016	OA	1,430	RZ	F	Wild
384.1B7969D573	2/25/2020	OA	4/4/2012	OA	2,883	RZ	F	Wild
3D9.2794E2399F	3/2/2020	LVW	2/27/2018	LB	734	RZ	M	Wild
3D9.2794E3A40C	3/2/2020	LVW	1/12/2017	LB	1,145	RZ	I	Stocked
3DD.003BC89ED3	3/2/2020	LVW	1/10/2017	LB	1,147	RZ	M	Wild
3DD.003BCB935F	3/2/2020	LVW	4/4/2017	LB	1,063	RZ	M	Wild
3D9.1C2C841581	3/5/2020	OA	2/28/2018	OA	736	RZ	F	Wild
3DD.003BCB9380	3/8/2020	OA	2/24/2016	OA	1,474	RZ	M	Wild
3DD.003BCB93B9	3/10/2020	OA	2/12/2020	OA	27	RZ	F	Wild
3DD.003BCB9381	3/12/2020	OA	4/3/2019	OA	344	RZ	F	Wild
3DD.003BC89EDE	3/13/2020	OA	3/4/2015	OA	1,836	RZ	M	Wild
3D9.257C633584	1/18/2020	OA	3/11/2020	OA	-53	HYB	F	Wild
3DD.003BCA7EC1	3/12/2020	OA	4/5/2015	GC	1,803	CP	U	Wild
3DD.003BCAA481	3/16/2020	OA	12/1/2014	GC	1,932	CP	U	Wild
3DD.003BCB937F	1/20/2020	OA	Unknown	Unknown	Unknown	Unknown	U	Unknown
3D9.257C60F1CB	1/28/2020	OA	Unknown	Unknown	Unknown	Unknown	U	Unknown

[a] EB = Echo Bay, GC = Grand Canyon-Bright Angel Creek, LB = Las Vegas Bay, LVW = Las Vegas Wash, and OA = Overton Arm (Virgin River/Muddy River inflow area).

[b] Negative values for days between detection indicates that a fish was scanned before being recaptured via trammel net during the 2020 netting field season.

[c] CP = common carp, HYB = hybrid sucker, and RZ = razorback sucker.

[d] F = female, M = male, I = immature, and U = undetermined.

Growth

Annual growth rates for razorback suckers were calculated using eight individuals recaptured from Echo Bay and the Virgin River/Muddy River inflow area because no fish were recaptured in Las Vegas Bay in 2020 (table 5). Razorback sucker annual growth at Echo Bay was 0.67–11.92 mm TL, with a mean annual growth rate of 5.79 mm TL per year (± SE = 2.34) (table 5). Razorback suckers in the Virgin River/Muddy River inflow area had an annual growth rate range of 2.52–64.92 mm TL, with a mean annual growth rate of 24.46 mm TL per year (± SE = 14.08) (table 5). For fish recaptured during 2020 in the two combined long-term monitoring study areas, the mean annual growth rate was 15.13 mm TL per year (± SE = 10.59). One hybrid sucker was recaptured in 2020 at the Virgin River/Muddy River inflow area that was originally tagged at the CRI had an annual growth rate of 17.15 mm TL per year.

Table 5.—Lake Mead razorback sucker growth histories for recaptured fish, January – April 2020

PIT tag number[a]	Original capture or stock date[b]	Location captured[c]	Captured TL (mm)	Sex[d]	Last date recaptured[e]	Location recaptured[d]	Recaptured TL (mm)	TL change (mm)[f]	Days between measurements	Origin	Annual growth (mm/year)[g]
Echo Bay											
384.1B7969DE0B	02/12/14	EB	637	M	02/05/20	EB	641	4	2,184	Wild	0.67
3D9.257C60BE38	02/22/11	EB	509	M	03/03/20	OA	550	41	3,297	Wild	4.54
3D9.257C612FA9	04/22/10	EB	489	M	02/11/20	EB	606	117	3,582	Wild	11.92
3DD.003BCB938F	04/05/16	EB	648	F	01/23/20	EB	671	23	1,388	Wild	6.05
Mean annual growth											**5.79 (± SE = 2.34)**
Virgin River/Muddy River inflow area											
384.1B7969D849	03/15/12	OA	574	F	02/26/20	OA	642	68	2,904	Wild	8.55
384.1B7969E7AA	03/20/12	CI	630	F	02/19/20	OA	650	20	2,892	Wild	2.52
3DD.003BA74927	02/16/16	OA	455	M	01/22/20	OA	541	86	1,436	Wild	21.86
3DD.003BCB939A	03/07/18	OA	468	F	02/19/20	OA	595	127	714	Wild	64.92
Mean annual growth											**24.46 (± SE = 14.08)**
Mean annual growth (EB and OA sites combined)											**15.13 (± SE = 10.59)**

[a] Two PIT tag numbers may be present in older, recaptured individuals that were marked originally with an older style PIT tag (e.g., 400 kilohertz [kHz]) and recently tagged again with a new, 12.5-mm, 134.2-kHz style PIT tag.
[b] Date originally captured or originally stocked.
[c] CI = Colorado River inflow area, EB = Echo Bay, and OA = Overton Arm (Virgin River/Muddy River inflow area).
[d] F = female, and M = male.
[e] Date of most recent recapture.
[f] Difference in TL from date of capture/stocking to date of most recent recapture.
[g] Annual growth was calculated as the difference in TL from date of stocking to date of most recent recapture divided by the number of days between captures and multiplied by 365.

Larval Sampling

Larval Captures

Larval razorback sucker sampling in long-term monitoring study areas was initiated on January 20, 2020, in Las Vegas Bay; on January 21, 2020, at the Virgin River/Muddy River inflow area; and on January 22, 2020, in Echo Bay.

The first larvae were collected on January 20, 2020, in Las Vegas Bay and were routinely captured over boulder, cobble, gravel, sand, and silt substrates when temperatures were between 12.6 and 18.8 °C (figure 11). Sampling for larvae was conducted throughout Las Vegas Bay; however, the majority of larvae collected were found in the western portions of the bay (figure 12). Larvae were often collected near sonic-tagged fish and where juvenile and adult razorback suckers were captured (see figures 6 and 7; figure 12). In all, Las Vegas Bay yielded 417 razorback sucker larvae captured during 938 minutes of sampling for a mean CPUE of 0.2997 larvae per minute (± SE = 0.0809), which falls within the historical context of this site (figure 13).

In Echo Bay, the first razorback sucker larvae of the sampling season were captured on January 22, 2020. Larval collections were made primarily over cobble, gravel, sand, and silt, and occasionally over boulder substrates at temperatures ranging from 12.0 to 15.5 °C (figure 11). The highest concentration of larvae was found on the southern shoreline of Echo Bay, but some larvae were located toward the western end of the bay outside the old marina in 2020 (figure 14). The collection of 111 larval razorback suckers within 1,326 minutes at Echo Bay resulted in a mean CPUE of 0.0578 larvae per minute (± SE = 0.0163) (figure 13). The mean CPUE in 2020 falls within the historical context for this site, despite what appears to be a consistent annual decline in mean CPUE since 2016 (see figure 13).

At the Virgin River/Muddy River inflow area, the first razorback sucker larva of the sampling season was captured on March 10, 2020, over cobble and gravel substrates at temperatures ranging from 15.6 to 19.8 °C (figure 11). Larvae were collected approximately 3.5 km south of the Virgin River/Muddy River inflow area along the eastern shoreline near the Meadows (figure 15). In the Virgin River/Muddy River inflow area, 10 larvae were collected during 906 minutes of sampling, which resulted in a mean CPUE of 0.0109 larva per minute (± SE = 0.0039). The 2020 mean CPUE appears to be similar to the mean larval CPUE since 2017 (figure 13).

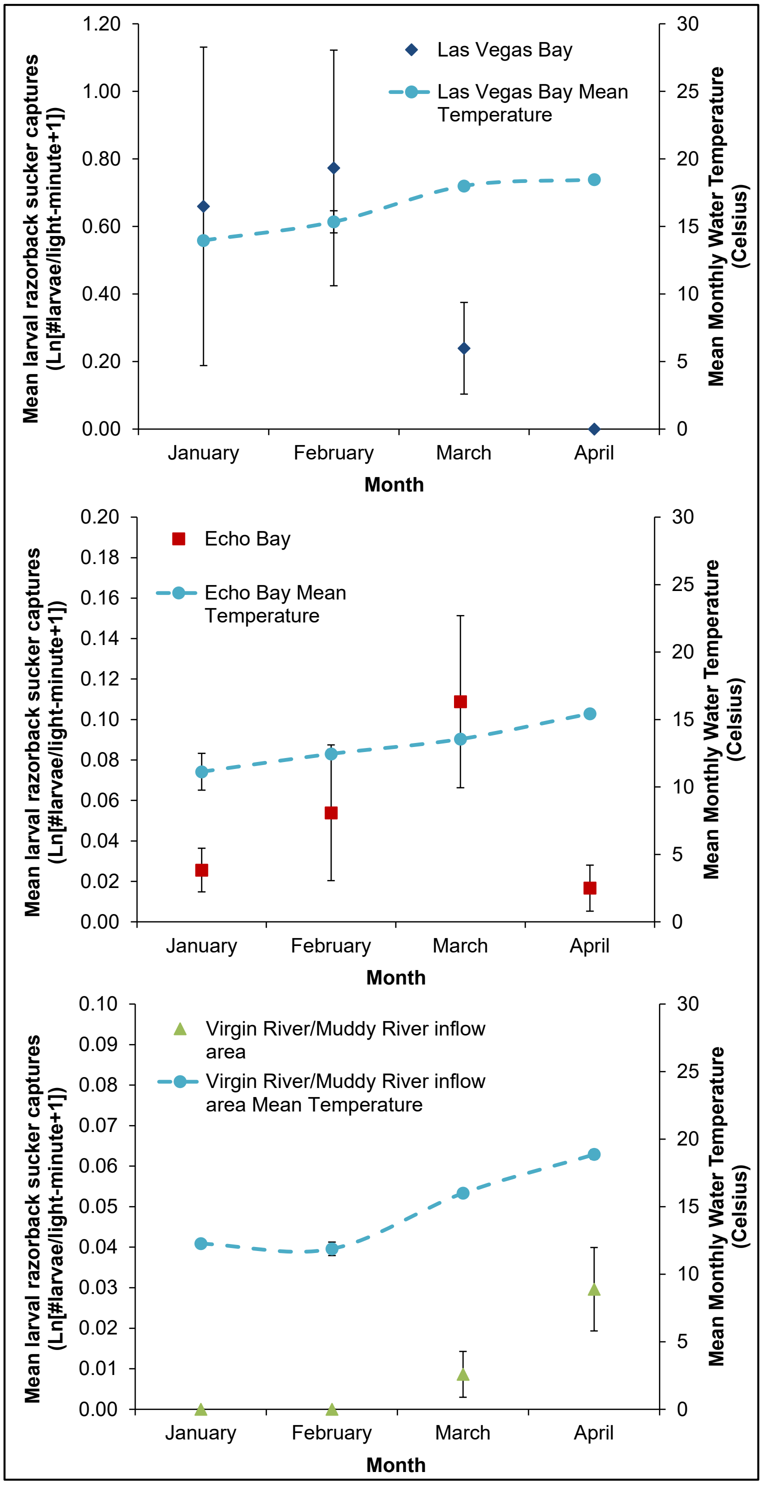

Figure 11.—Mean (±SE) monthly CPUE (Ln[#larvae/light-minute+1]) and temperature at long-term monitoring sites from January – April 2020.
Please note difference in mean larval CPUE scale.

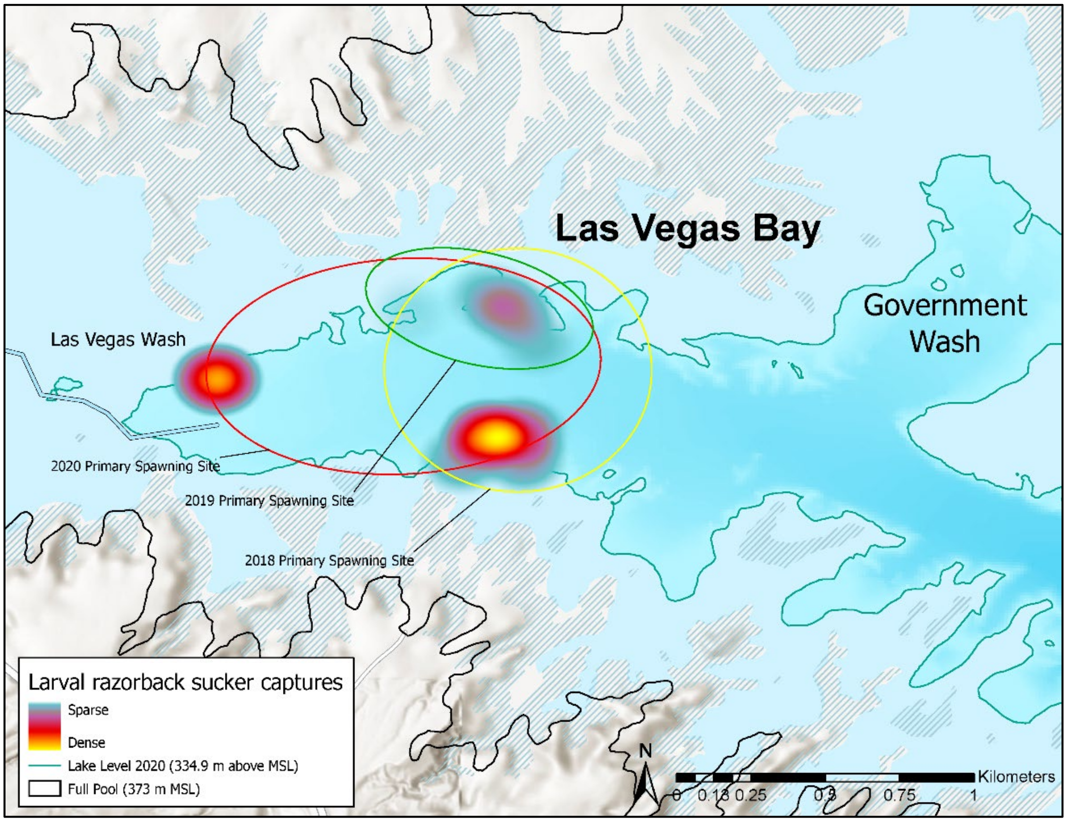

Figure 12.—Locations of larval razorback sucker sampling efforts and capture numbers in Las Vegas Bay, January – April 2020.

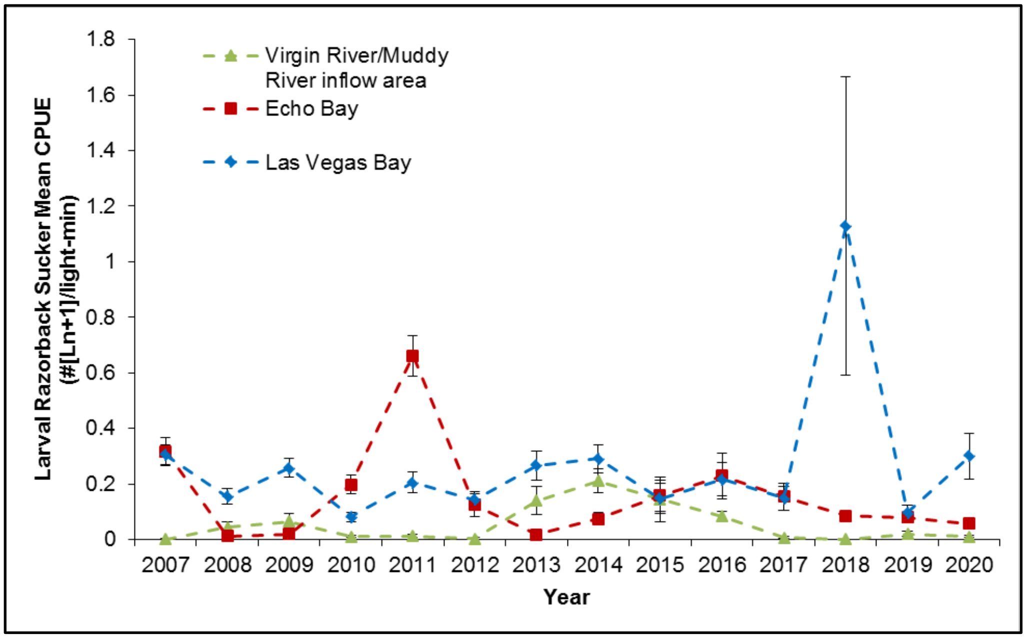

Figure 13.—Larval razorback sucker mean catch per light-minute rates (Ln[#larvae/light-minute+1]) at long-term monitoring study areas in Lake Mead, 2007–20, with associated SE.

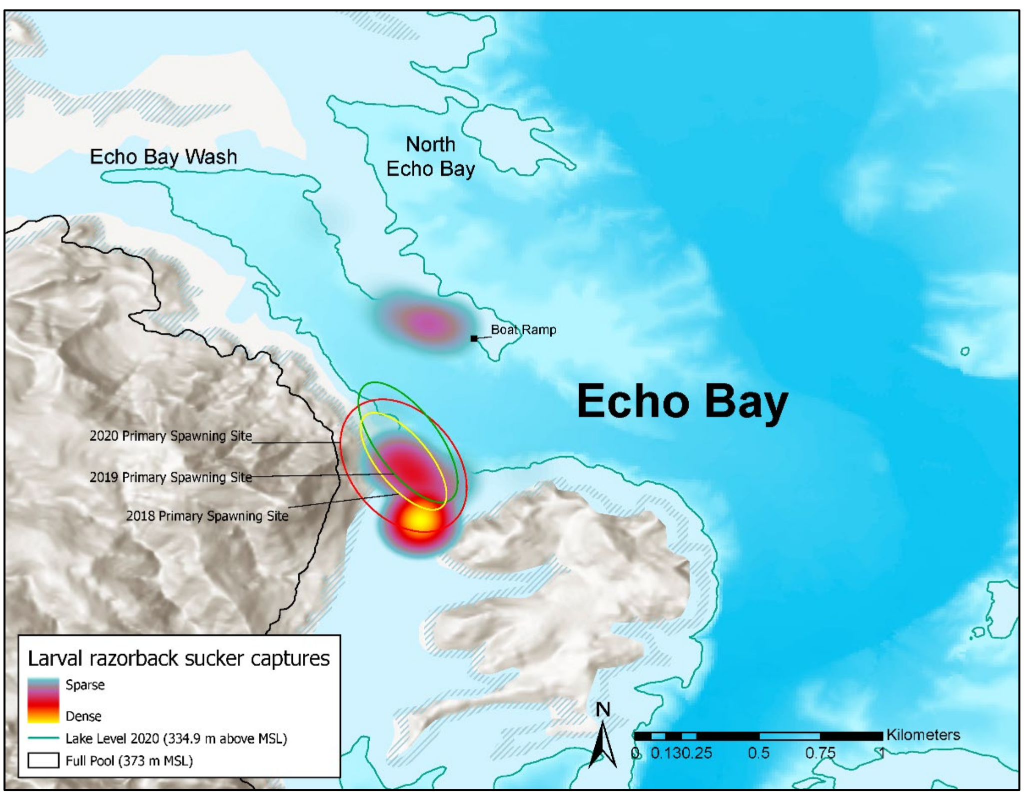

Figure 14.—Locations of larval razorback sucker sampling and capture numbers in Echo Bay, January – April 2020.

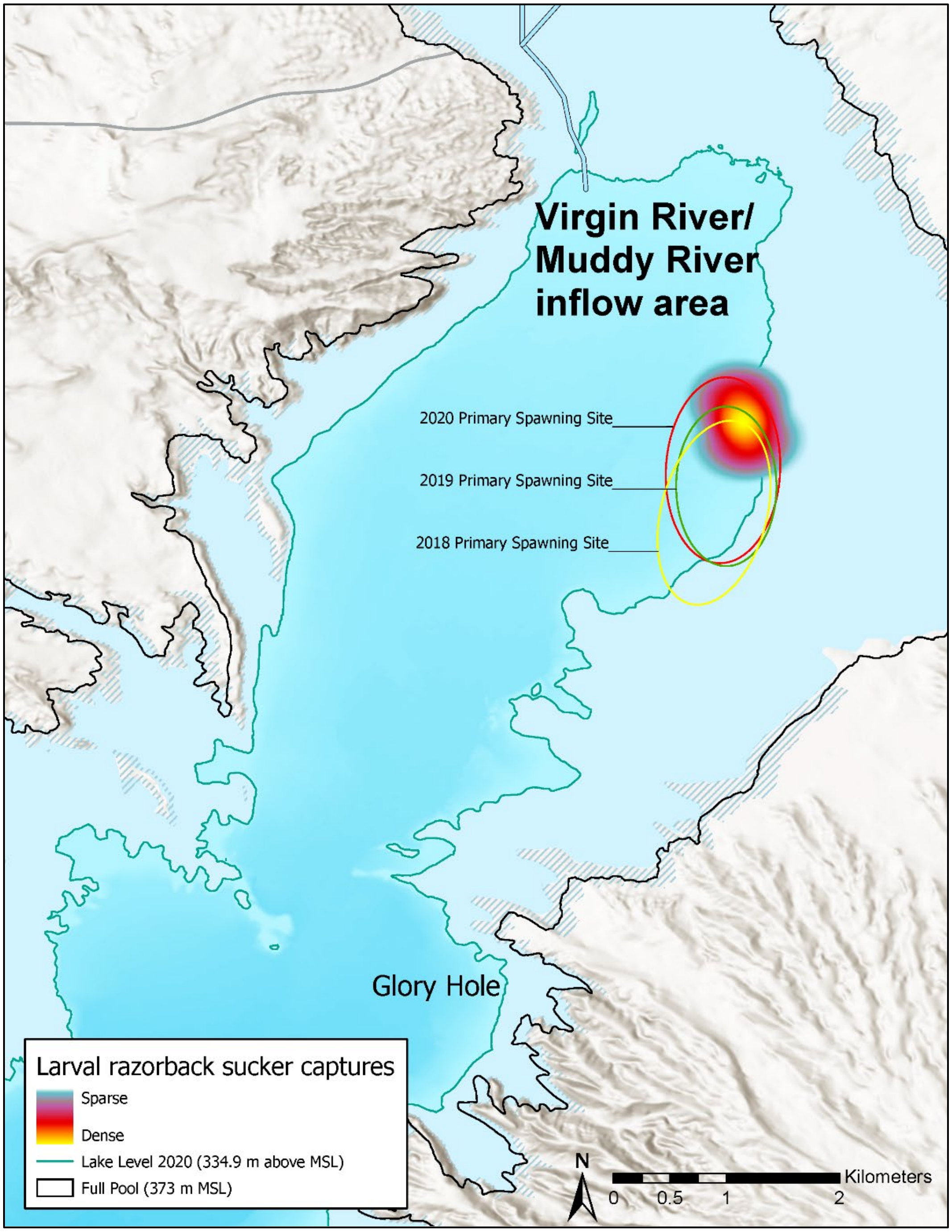

Figure 15.—Locations of larval razorback sucker sampling and captures at the Virgin River/Muddy River inflow area, January – April 2020.

Primary Spawning Site Identification and Observations

For the past decade, fluctuating reservoir elevations in Lake Mead have influenced habitat conditions in all areas where razorback sucker sampling activities have occurred. As a result, Lake Mead razorback suckers have continually shifted spawning sites to accommodate for varying environmental conditions (Albrecht and Holden 2005; Albrecht et al. 2006a, 2006b, 2007, 2008a, 2008b, 2010a, 2010b, 2013a, 2013b, 2014a; Kegerries et al. 2009; Mohn et al. 2015; Shattuck et al. 2011; Welker and Holden 2003, 2004). However, since 2016, the elevation of Lake Mead has remained relatively stable, and the spawning areas have remained largely the same (Mohn et al. 2016; Rogers et al. 2017, 2018, 2019) (see figures 12, 14, and 15).

Secchi disk readings were taken weekly at the long-term monitoring study areas with depths ranging from 0.7–17.1 m. In Las Vegas Bay, Secchi depths ranged from 0.9 to 10.2 m near spawning areas. Successful trammel netting efforts did occur in Las Vegas Bay during the 2020 spawning season, with captures being 12 juvenile razorback suckers and a bonytail in January and February, all found toward the western portion of the bay (see figure 7). This area was also the primary location for the collection of larval razorback suckers in Las Vegas Bay (see figure 12). The 2020 spawning area was similar to the 2016–19 spawning areas, which again demonstrates the importance of this bay for razorback sucker spawning and recruitment (see figure 12 and table 3).

The primary Echo Bay spawning site in 2020 was located off the southern shore, across from the boat ramp, in a location similar to the 2016–19 primary spawning locations (see figures 8 and 14). Razorback suckers were captured consistently throughout the spawning season in Echo Bay off the southern shore as well as in the western portion of Echo Bay. Spawning was evident by the consistent larval captures in this area and helped define the spawning area in 2020 (see figures 4, 8, and 14). The spawning area can best be described as an area of relatively shallow shoreline with cobble and gravel substrates. In Echo Bay, Secchi disk visibility ranged from 5.6–17.1 m, the deepest of the long-term monitoring areas.

In 2020, the lowest mean larval razorback sucker CPUE was observed at the Virgin River/Muddy River inflow area, as compared to the other long-term monitoring study areas (see figure 13). Larval collection rates at this site have been historically low; however, the collection of numerous adults that were reproductively ready signified that spawning was likely occurring on a kilometer-long section of the eastern shoreline, located about 3–3.5 km south of the Virgin River (see figure 9). This area has primarily cobble and gravel substrates, covered with a relatively thin layer of sand and silt, as deposited by the adjacent river inflow and wave action. Secchi depths ranged from 0.7–4.6 m, making this the most turbid of the three long-term monitoring areas during the 2020 spawning season.

Age Determination and Year-Class Strength

To date, definitive ages have been determined for 594 razorback suckers from long-term monitoring study areas in Lake Mead. Ages were obtained from 24 razorback suckers captured in trammel nets at long-term monitoring study areas during the 2020 spawning season (8 razorback suckers were aged from the CRI and Bonelli Bay; more details about these fish are reported in Kegerries et al. 2020 (attachment 1). In 2020, fish were aged at 2 years old (n = 1), 3 years old (n = 4), 4 years old (n = 6), 5 years old (n = 1), 6 years old (n = 2), 7 years old (n = 2), 9 years old (n = 2), 10 years old (n = 4), 11 years old (n = 1), and the oldest fish aged was 13 years old (n = 1), and they ranged in size from 301 to 684 mm TL (attachment 1). These razorback suckers represent year classes 2007–18 as well as the first fish from the 2018 year class (attachment 1).

The cumulative dataset shows that most individuals (n = 436) were spawned from 2000 to 2011. Within this period, 113 individuals (including 3 from the CRI) were aged from the 2005 year class alone. Even more recently, fish from year-classes 2013–16 are starting to be captured fairly regularly (figure 16). Most noteworthy is that the 2018 year class was represented for the first time this year. This individual was one of two juveniles captured at the Virgin River/Muddy River inflow area (301–317 mm TL).

Year-class strength results showed that annual recruitment in Lake Mead is not homogenous (figure 17). Razorback suckers from the 2005, 2007, 2008, 2010, and 2013 year classes were some of the strongest observed, while the 2006, 2009, 2011, 2014, and 2015 year classes were weaker (figure 17). It appears that recruitment in Lake Mead experienced a decline between 1990 and 1998 and a gradual increase in recruitment from 1999 to 2013 (again, with the exceptions of the 2006, 2009, 2011, 2014, and 2015 year classes) (figure 17). As more data are added to this model, it will likely become more refined.

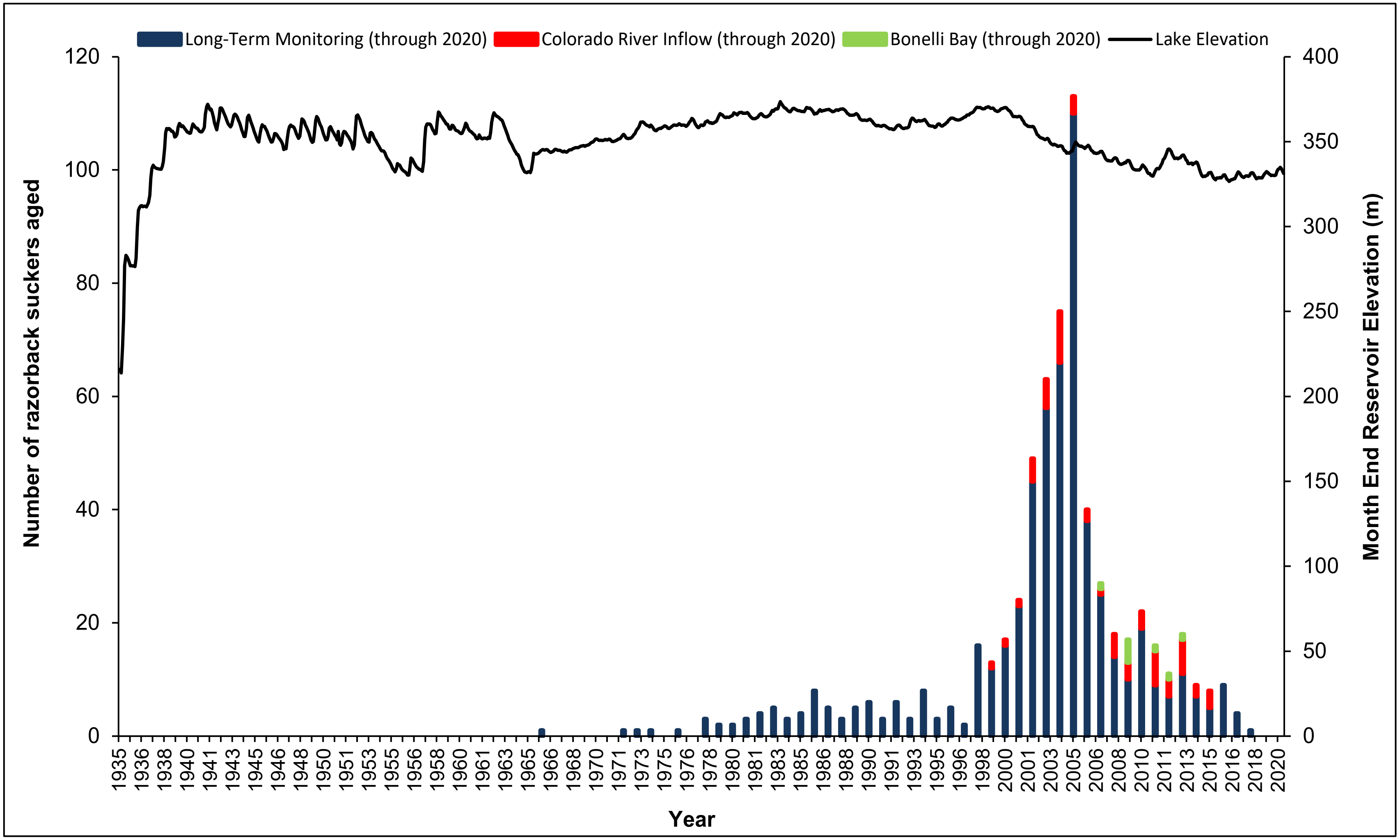

Figure 16.—Cumulative number of razorback suckers back-calculated to year spawned for individuals aged with corresponding Lake Mead month-end reservoir elevations, January 1935 – June 2020.
Blue bars denote individuals aged during long-term monitoring efforts, 1999–20. Red bars denote individuals aged during efforts at the CRI, 2010–20. Green bars denote individuals aged during efforts in Bonelli Bay, 2019–20.

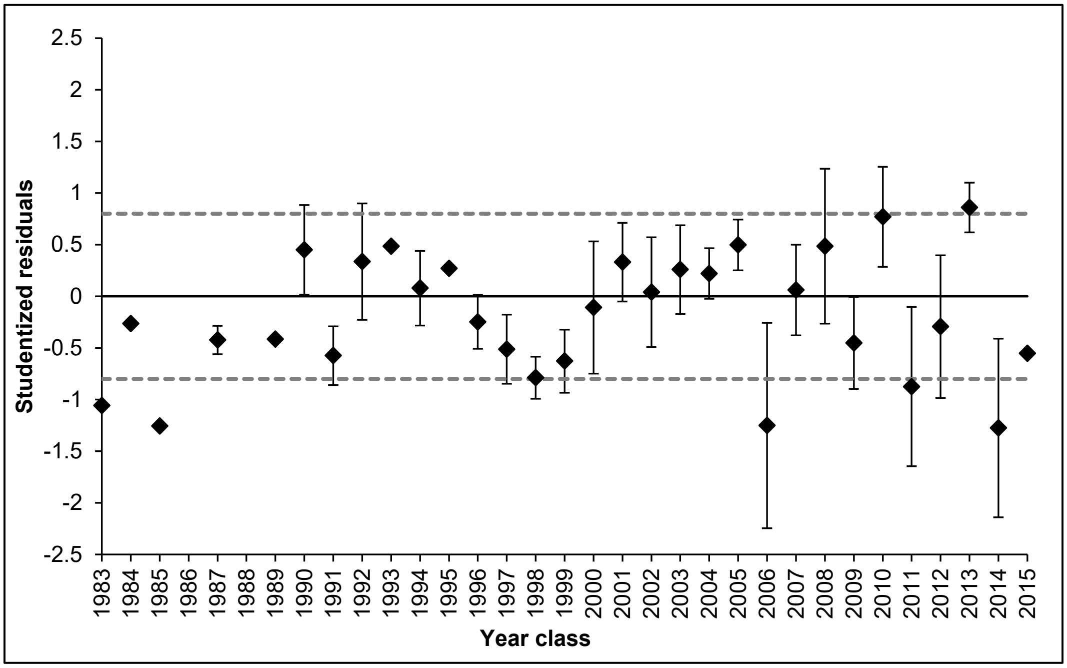

Figure 17.—Studentized residuals obtained from razorback sucker age data following the method proposed by Maceina (1997), plotted with ±1 SE. Dotted lines represent the upper 80th and lower 20th percentile bounds of this data in a *t*-distribution.

Population and Survival Estimation

Population Estimates

The top model for reservoir-wide population estimates included time-varying capture probability (*Mt*) (attachment 3). Using 42 capture occasions from 2018 to 2020, the population model produced a point estimate of 247 razorback suckers (± SE = 55) with a 95% confidence interval of 160–381 (table 6). Model ranking according to the AIC_c weights and model likelihoods for estimates produced in program MARK can be found in attachment 3.

Table 6.—Reservoir-wide population estimates for Lake Mead razorback suckers using mark-recapture data from 2018 to 2020 from program MARK

Model	Population estimate (95% confidence interval)	Capture events	Standard error
Reservoir-wide population estimate			
Mt	247 (160–381)	42	55

Survival Estimates

Twenty-five annual capture events were used in an annual apparent survival model. In goodness-of-fit testing, the saturated model (attachment 4) produced an estimated $\hat{c}$ value of 1.1 (± SE = 0.01). The top model was $\Phi(.)\ p(t)$ (annual survival is constant through time, and recapture probability varied through time), which carried the majority (93%) of the AIC_c weight; therefore, no model average was conducted (attachment 4) (Burnham and Anderson 2004; Mohn et al. 2016; Zelasko et al. 2011). The top model had calculated an annual apparent survival of 0.77 with a 95% confidence interval of 0.75–0.80 (table 7). The recapture probabilities varied from year to year and ranged in value from 0.05 to 0.44 (table 7; attachment 5).

Table 7.—Annual apparent survival rate estimate for razorback suckers in Lake Mead produced in program MARK using adult (> 450 mm TL) mark-recapture data, 1996–2020

Model	Annual apparent survival rate estimate (95% confidence interval)	Capture events	Standard error	Min/max recapture probability
Cormack-Jolly-Seber				
$\Phi\ (.)\ p\ (t)$	0.77 (0.75–0.80)	25	0.01	0.05–0.44

Juvenile Razorback Sucker Life History Traits in Lake Mead

Since 1997, 111 wild juvenile razorback suckers have been captured in Lake Mead. Juvenile razorback suckers have been captured near annually since 1997, with several years showing elevated captures, including 2008, 2009, and most recently in 2020 when compared to the other years (figure 18). The majority have been captured in Las Vegas Bay (n = 76), while the Virgin River/Muddy River inflow area has produced 25 juvenile razorback suckers. Ten juveniles have been captured in Echo Bay (n = 5) and the CRI (n = 5), in aggregate. The mean TL of juvenile razorback sucker captured from 1997 to 2020 was 378.9 mm (± SE = 4.6) and ranged in size from 215–446 mm TL. The mean age of juvenile razorback suckers was 3.8 years old (± SE = 0.10) at the time of capture, and juvenile age ranged from 2 to 6 years at the time of capture.

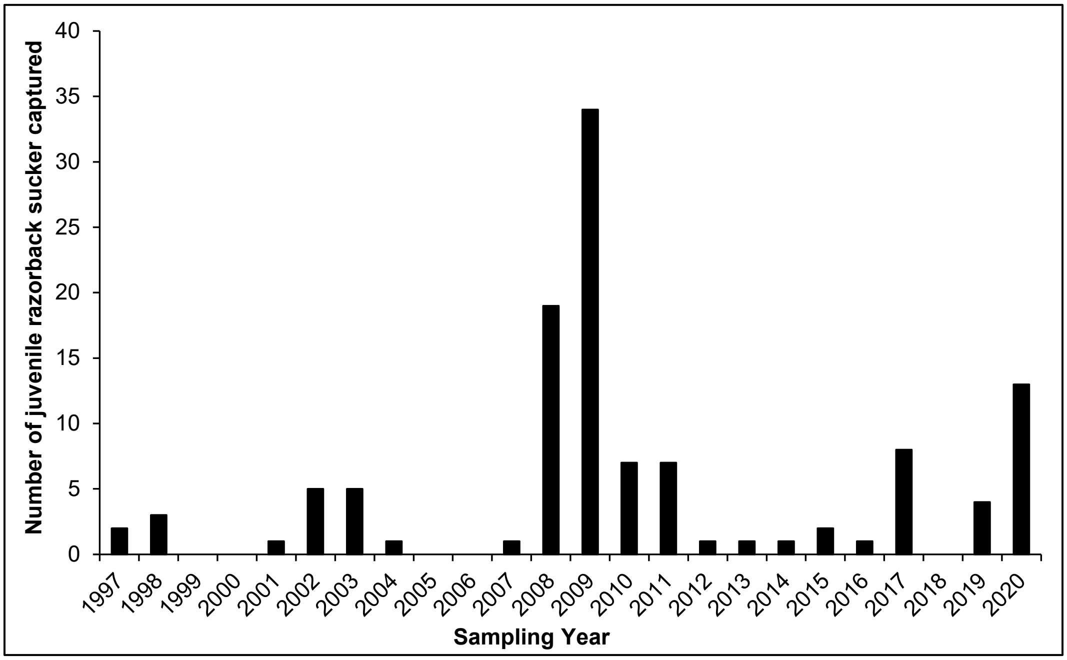

Figure 18.—Number of juvenile razorback sucker captured per year, 1997–2020.

Much like adults, juvenile razorback suckers exhibit general site fidelity and remain relatively elusive to capture. However, five individual juvenile razorback suckers have been observed moving among sampling sites in Lake Mead. One wild razorback sucker that was tagged as a juvenile at the Virgin River/Muddy River inflow area was recaptured as an adult at the CRI 2 years later. Another juvenile demonstrating movement was a sonic-tagged razorback sucker that was stocked at the Virgin River/Muddy River inflow area and recaptured as an adult at the CRI 4 years later (table 8). Additionally, a juvenile razorback sucker that was implanted with a sonic tag and stocked into Echo Bay in 2014 was detected via active tracking methods at the CRI in 2015. And lastly, two juveniles detected via PIT scanners at the Virgin River/Muddy River inflow area were tagged at the CRI and Las Vegas Bay in 2012 and 2017, respectively.

All wild Lake Mead juvenile razorback suckers, and stocked juvenile fish that survived at least 1-year post-stocking, were included in growth analysis and annual apparent survival estimates. A total of 17 juvenile razorback suckers have been recaptured, but due to field measurement errors or lack of time elapsing between tagging and recapture, 12 individuals were used for annual growth analysis. Juvenile razorback suckers had a mean annual growth of 78.4 mm TL per year (± SE = 10.2). Of these 12 individuals, 5 were wild individuals, which had a mean annual growth of 56.2 mm TL per year (± SE = 16.3), and 7 were stocked juvenile razorback suckers, which exhibited a mean annual growth of 94.3 mm TL per year (± SE = 11.3) (table 8).

Table 8.–Lake Mead razorback sucker growth histories for recaptured juvenile razorback suckers, 1997–2020

Pit tag number[a]	Original capture or stock date[b]	Location captured[c]	Captured TL (mm)	Sex[d]	Last date recaptured[e]	Location recaptured[c]	Recaptured TL (mm)	Change in TL (mm)[f]	Days between measurements	Origin	Annual growth (mm/year)[g]
Wild											
3D9.1C2D268918	2/10/1998	EB	347	I	2/14/2013	EB	638	291	5,483	Wild	19.4
5324102B1D	2/12/2008	LB	425	I	3/3/2009	LB	535	110	385	Wild	104.3
3D9.1C2C83BE24	2/24/2009	LB	438	I	3/3/2010	LB	514	76	372	Wild	74.6
3D9.1C2C841AF7	3/3/2009	LB	340	I	3/4/2014	LB	651	311	1,827	Wild	62.1
3D9.257C6093E8	2/3/2010	OA	441	I	3/20/2014	OA	526	85	1,506	Wild	20.6
Mean annual growth											**56.2 (± SE = 16.3)**
Stocked											
1F482B046A	9/30/2002	LB	245	I	2/21/2005	LB	529	284	875	Stocked	118.5
1F4A1C4A31	9/30/2002	LB	269	I	4/23/2008	LB	560	291	2,032	Stocked	52.3
384.1B7969CCA6	5/8/2013	OA	237	I	2/2/2017	CI	565	328	1,366	Stocked	87.6
384.1B7969DE17	5/8/2013	LB	289	I	5/7/2013	LB	495	206	553	Stocked	136.0
3DD.003BA2FA91	5/6/2014	EB	290	I	3/8/2016	EB	290	207	672	Stocked	112.4
3DD.003BA2FA94	5/6/2014	EB	300	I	3/8/2016	EB	300	163	672	Stocked	88.5
3D9.2794E34D5C	1/12/2017	LB	408	I	10/30/2019	LB	408	181	1,021	Stocked	64.7
Mean annual growth											**94.3 (± SE = 11.3)**
Mean annual growth (wild and stocked juveniles combined)											**78.4 (± SE = 10.2)**

[a] Two PIT tag numbers may be present in older, recaptured individuals that were marked originally with an older-style PIT tag (e.g., 400 kilohertz [kHz]) and recently tagged again with a new, 12.5-mm, 134.2-kHz style PIT tag.
[b] Date originally stocked or originally captured.
[c] CI = Colorado River inflow, LB = Las Vegas Bay, EB = Echo Bay, and OA = Overton Arm (Virgin River/Muddy River inflow area).
[d] I = Immature.
[e] Date of most recent recapture.
[f] Difference in TL from date of stocking to date of most recent recapture.
[g] Annual growth was calculated as the difference in TL from date of stocking to date of most recent recapture divided by the number of days between captures and multiplied by 365.

Twenty-four annual capture events (1997–2020) were used in an annual apparent survival model. In goodness-of-fit testing, the saturated model (attachment 6) produced an estimated $\hat{c}$ value of 1.6 (± SE = 0.02). The top model was Φ (.) p (.) (annual survival and recapture probability are constant through time), which carried the majority (99.9%) of the AIC_c weight, so no model average was conducted (attachment 6) (Burnham and Anderson 2004; Mohn et al. 2016; Zelasko et al. 2011). The top model had calculated an annual apparent survival of 0.65 (± SE = 0.06) with a 95% confidence interval of 0.51–0.76 (table 10). The recapture probability was 0.13 (± SE = 0.04) with a 95 % confidence interval of 0.07–0.22 (table 9).

Table 9.—Annual apparent survival rate estimate for razorback suckers in Lake Mead produced in program MARK using juvenile (< 450 mm TL) mark-recapture data, 1997–2020

Model	Annual apparent survival rate estimate (95% confidence interval)	Capture events	Standard error	Recapture probability (95% confidence bounds)
Cormack-Jolly-Seber				
Φ (.) *p* (.)	0.65 (0.51–0.76)	24	0.06	0.13 (0.07–0.22)

DISCUSSION AND CONCLUSIONS

Long-term monitoring data collected during the 2020 study year (the 24th field season) increased our knowledge of razorback sucker spawning behavior, year-round movement between study areas, annual growth rate, and juvenile life history traits in Lake Mead. Information was also gained regarding population abundance, adult and juvenile survival rates, and razorback sucker responses to changing reservoir elevations and habitat conditions. Sonic telemetry, trammel netting, and larval collection data continue to emphasize the importance of Las Vegas Bay, Echo Bay, and the Virgin River/Muddy River inflow area to spawning razorback suckers in Lake Mead. To date, these data help demonstrate near-annual recruitment and continued production of new, wild razorback suckers in Lake Mead. These processes have not been documented to this degree, for this species, anywhere else in the Colorado River Basin. The continued collection of these data will further enhance our understanding of this unique population of recruiting razorback suckers, which will hopefully serve as an example for the species' conservation and recovery. Long-term monitoring continues to be vital to understanding not only the Lake Mead razorback sucker population, but also how the fish community in this large and dynamic river-reservoir system functions, particularly when considering connections to the Grand Canyon and Colorado River, as documented in this and other past annual reports.

Reservoir Elevation

Reservoir elevations fluctuated throughout the 2020 study year and could be characterized by a general increase in elevation that inundated littoral habitats and remained relatively stable during most of the spawning season, followed by declining reservoir levels from March through June 2020. Continued monitoring will be crucial to determine the relative importance of each monitoring location, shifts in spawning site use, and variations in annual recruitment as Lake Mead continues to display fluctuations in reservoir elevation (Reclamation 2020). Despite changes in reservoir elevation, the razorback sucker population in Lake Mead persists in finding suitable spawning habitat at the long-term monitoring study areas and continues to demonstrate recruitment.

Sonic Telemetry

While contacts were relatively low during the 2020 study year (likely due to some expired sonic tag batteries), active sonic telemetry continues to be a vital tool to help define spawning sites, place trammel nets and PIT tag scanners, find larval fish, and document reservoir-wide movement of razorback suckers. Generally speaking, fish implanted with sonic tags and released into a particular locality of Lake Mead often remained within the general release area; however, small- and large-scale movements were observed in 2019–20, which again demonstrated the interconnectedness of the system. Sonic-tagged fish have proven to be valuable for finding new spawning aggregations. Albrecht and Holden (2005) observed sonic-tagged fish moving from Echo Bay north to the Virgin River/Muddy River inflow area, which has since become one of the most productive spawning areas in the long-term monitoring study. Using sonic-tagged fish was also successful in determining spawning activity at the CRI (Albrecht et al. 2010c). With forward-thinking study designs and experienced field crews, sonic-tagged fish may be able to help researchers identify new spawning aggregates in Lake Mead during future efforts.

Passive telemetry via SURs has also proven to be a helpful tool for assessing the timing of returning sonic-tagged fish to spawning sites as well as the timing of post-reproductive movement into foraging and resting areas during the summer and fall months. The ability to monitor areas remotely helped researchers detect individuals that remained elusive for long periods of time, especially during the non-spawning season. The strategically placed SURs have been effective at documenting both small- and large-scale movements. It has been observed that some individuals are detected by either passive or active telemetry but not necessarily by both methods, which could be related, but not limited to: (1) some sonic-tagged fish exhibit small home ranges and never reach a SUR; (2) some individuals are only mobile during times when active telemetry is not taking place or rarely takes place (e.g., night); or (3) there may be other important areas of Lake Mead that are not regularly searched for sonic-tagged razorback suckers but that may hold groups of razorback suckers. The plausibility of the above (or other unmentioned) possibilities demonstrates that there is more to learn from researching and monitoring this species in Lake Mead. The sonic telemetry data collected over successive seasons and years have helped identify areas of importance within Lake Mead not only during spawning but also during periods of environmental stress (e.g., hot summers, cold winters) and continual habitat change (e.g., fluctuating reservoir elevations). By collecting data over a reservoir-wide scale, as with the use of SURs, movement and habitat association information may be better understood, ultimately lending insight as to why natural recruitment continues to occur within the Lake Mead razorback sucker population.

As reservoir elevations continue to fluctuate, continued monitoring of movement, habitat use, and spawning sites will help identify important areas for razorback suckers in Lake Mead throughout the year. Furthermore, wild razorback suckers were captured quite consistently alongside sonic-tagged individuals, whereas sonic-tagged fish themselves are relatively rarely recaptured. Despite being constantly targeted during trammel netting in 2020, no active sonic-tagged fish were captured, demonstrating the elusiveness of the species.

Adult Sampling and Spawning Site Observations

In summary, 1,338 razorback sucker captures have identified 784 unique individual razorback suckers at long-term monitoring study areas during this 24-year (1996–2020), multi-agency study (BIO-WEST, NDOW, Reclamation, and USFWS). These data do not include 94 captures of 88 unique individuals from 1990 to 1995 (Holden et al. 1997), which were documented by the NDOW before long-term monitoring began. Trammel netting in 2020 documented the continued presence of wild razorback suckers at all three long-term monitoring sites. A total of 32 razorback suckers were captured at the 3 long-term monitoring sites combined, indicating the importance of all the long-term monitoring study areas to this species. In Las Vegas Bay, 12 juvenile razorback suckers were captured in January and February, making it important to continue to sample at this long-term monitoring study area earlier in the season. Similar results were observed in Echo Bay and at the Virgin River/Muddy River inflow area.

Spawning was documented, evinced by the capture larvae, at all long-term monitoring study areas in 2020. Larvae were captured earlier this year at all the long-term monitoring sites compared to 2019, demonstrating again that sampling in January is valuable to understanding razorback sucker spawning behavior. Razorback suckers have a propensity to migrate to specific spawning sites (Mueller et al. 2000; Tyus and Karp 1990); this finding is supported not only by sonic-tagged fish movements but also through the recapture of individuals, whether by trammel nets or PIT scanners, in Lake Mead. The primary spawning sites in 2020 were similar to spawning sites in 2016–19, as the elevation of the reservoir was fairly similar between these study years (Mohn et al. 2016; Rogers et al. 2017, 2018, 2019). However, this pattern of low, yet relatively stable, reservoir elevations has not been the norm on Lake Mead since 2000. Fluctuating reservoir elevations and shifting spawning sites have been more common, and maintaining active, sonic-tagged fish will help identify razorback sucker habitat use and locate spawning aggregates in Lake Mead. Additionally, compared to 2019, Secchi depths were deeper in 2020 at all three long-term monitoring sites in the first half of the spawning season, likely due to the reservoir being relatively stable. Given that some level of natural razorback sucker recruitment occurs nearly every year in Lake Mead, regardless of reservoir elevation (see figures 16 and 17), there is reason for optimism about the success of the 2016–20 year classes.

The 2020 primary spawning area in Las Vegas Bay followed patterns similar to those detailed in past reports (e.g., Rogers et al. 2019). This year, as in the recent past, sonic-tagged fish were found using deeper habitats near Government Wash (pre-spawning season) and moved west toward Las Vegas Wash at the beginning of the spawning season (January – February). During the height of spawning season (noted by high larval captures at the end of February through the beginning of March), larval capture locations near the inflow of Las Vegas Wash into Las Vegas Bay, coupled with the absence of sonic-tagged fish and the documentation of sonic-tagged and PIT-tagged fish in Las Vegas Wash (see tables 1 and 4), again suggested razorback sucker use of Las Vegas Wash (which is inaccessible by boat). This follows a pattern of behavior suggested in past years through netting, sonic telemetry, and larval sampling methods in this same location (Mohn et al. 2015, 2016; Rogers et al. 2017, 2018, 2019). Use of Las Vegas Wash by Lake Mead razorback suckers is something that can be explored further with technologies like PIT scanners, additional telemetry, and increased sampling efforts within the wash proper. In Las Vegas Bay, the mean CPUE in 2020 was the highest it has been since 2010, once again demonstrating that this site remains an important spawning and recruitment area for the Lake Mead razorback sucker population. Future research and monitoring in Las Vegas Bay will be critical to determine if the Lake Mohave sonic-tagged fish integrated and contributed genetically to the local population and when and how those sonic-tagged fish distributed within or out of Las Vegas Bay. Continued larval sampling, directed to this end, should be continued for the foreseeable future.

Data from 2020 and past years indicate that the razorback sucker spawning aggregates at Echo Bay and the Virgin River/Muddy River inflow area are two of the largest, and the most connected, in Lake Mead (Mohn et al. 2016). As documented in previous reports (e.g., Rogers et al. 2017, 2018, 2019), razorback suckers often use both Echo Bay and the Virgin River/Muddy River inflow area during the same study year. The primary 2020 spawning site in Echo Bay was identified through a combination of sonic-tagged fish locations, larval fish collections, and adult fish collections. For many years, the primary spawning location was in the western part of Echo Bay; however, in 2020, as in 2016 through 2019, the spawning site was located on the southern side of the bay, near the mouth of Echo Bay. This relatively shallow, littoral area is adjacent to an area of steep bathymetry where razorback suckers may retreat to and seek cover during daylight hours. This demonstrates that razorback suckers can find suitable spawning habitat as the reservoir elevation fluctuates.

The 2020 Virgin River/Muddy River inflow area spawning site was primarily defined based on adult captures, but also based on the detections of nearby sonic-tagged fish, and larval collection data. Sonic-tagged fish were contacted within and near the designated spawning site at the Virgin River/Muddy River inflow area, and the placement of trammel nets near these sonic-tagged fish yielded adult razorback suckers exhibiting reproductive readiness (e.g., colored and/or tuberculated individuals freely expressing milt or eggs). Numbers of larval razorback suckers have historically been lower when compared to the other long-term monitoring study areas, and collections in 2020 were no exception. High winds, a long fetch, and associated wave action common near the Virgin River/Muddy River inflow area, coupled with turbidity and cover (inundated vegetation) are believed to have aided in the distribution and elusiveness of razorback sucker larvae at this study area (Albrecht et al. 2010b, 2013a; Golden and Holden 2003; Shattuck et al. 2011). In Lake Mohave and Oregon's Upper Klamath Lake, high winds were also a likely cause of larval catostomid mortality and dispersal from rearing grounds (Bozek et al. 1990; Cooperman et al. 2010). While larval captures in 2020 were relatively low, spawning locations were still defined by using a multiple-methods approach that must be practiced consistently in order to monitor and study this unique population.

Like sonic telemetry and trammel netting, PIT scanners yielded important movement data for previously marked native and non-native species present throughout Lake Mead. For example, PIT scanners deployed at the two long-term monitoring study areas contacted several previously tagged individuals that were present on a spawning site this season, but were not captured during trammel netting efforts, reiterating the elusiveness of this species. Additionally, insights into the movement patterns of both Lake Mead razorback suckers and Grand Canyon common carp were gained using this technology. This method, if repeated through time as a consistent, set methodology, should contribute additional knowledge pertaining to unknown movement and spawning behavior of previously marked fish in Lake Mead. For instance, PIT scanners may be able to detect razorback sucker movements from other long-term monitoring study areas, timing of those movements, as well as movements from the CRI and Grand Canyon. That information, coupled with netting data from unmarked fish, could be insightful to future netting efforts to obtain demographic data from marked and unmarked razorback suckers in Lake Mead. However, there are still limitations to the use of this technology, particularly pertaining to population/survival estimation for razorback suckers, as Lake Mead continues to harbor a wild, untagged razorback sucker population. Despite such limitations, this technology, particularly when coupled with sonic telemetry, might be useful at exploring new potential spawning areas in Lake Mead (e.g., additional wash inflow areas). If razorback suckers are identified through these techniques, biologists could then validate potential spawning locations by netting and larval sampling to further our understanding of recruitment patterns in Lake Mead.

Growth and Aging

The relatively high mean annual growth rates of eight recaptured razorback suckers in Lake Mead (15.13 mm TL per year [± SE = 10.59]) continues to indicate a fairly youthful population of this species within the reservoir. Growth rates in 2020 appear to be similar to those reported in the recent past (e.g., Mohn et al. 2015, 2016; Rogers et al. 2017, 2018), but twice as high as those reported in 2019 (7.8 mm TL/year [± SE = 1.35]). Overall, Lake Mead growth rates continue to surpass the growth rates (< 2.0 mm/year) reported for razorback suckers in Lake Mohave (Pacey and Marsh 1998) and the Green River (McAda and Wydoski 1980; Tyus 1987).

Through 2020, 594 razorback suckers from long-term monitoring study areas have been aged from 2 to 36 years old. Prior to 2000, the majority of fish aged were spawned during high water levels in the reservoir, while the reservoir was relatively stable around full-pool elevation (see figure 16). However, recent data show that fish older than the 2000 year class, which coincided with an overall, long-term period of declining reservoir elevations and frequent annual fluctuations in the reservoir's level, were readily captured (see figures 2 and 16). While the 2005 spawning season remains as one of the more abundant year classes in Lake Mead (Albrecht et al. 2010a, 2010b, 2010c, 2013a, 2013b, 2014a, 2014b; Kegerries et al. 2009; Mohn et al. 2015, 2016; Rogers et al. 2017, 2018, 2019; Shattuck et al. 2011) to date, the year classes spanning 2001 to 2007 are all well represented through aging techniques. Fish that were spawned more recently (2016–18) were also captured in 2020. Perhaps most noteworthy is that this report now provides evidence of the 2018 year class, the youngest known year class of Lake Mead razorback suckers observed to date. Based on previous observations, as well as the year-class strength analysis from this year, it typically takes at least 4–5 years for razorback suckers to be susceptible to the methods and gear used to conduct long-term monitoring on Lake Mead. Although the number of fish captured for a single year class can allude to the strength and likelihood that that year class will survive, it does not account for the annual irregularity in which some year classes are represented (i.e., not all year classes are captured in the same proportion each year). Thus, analyzing catch-curve residuals helps to determine year-class strength and better define recruitment in Lake Mead. When considered with CPUE, age data suggests that while we have aged fewer fish from the 2011–15 year classes (see figure 16), recruitment continues to occur (see figure 17). Aging and CPUE combined with year-class strength (through catch-curve analyses) confirms continued recruitment within Lake Mead and lends hope to the prospect of species conservation and recovery. This observation emphasizes the importance of long-term monitoring to verify continued recruitment of this unique population (Rogers et al. 2017, 2018, 2019). Aging the Lake Mead razorback sucker population, using non-lethal methods, remains paramount for tracking continued natural recruitment and elucidating the factors contributing to recruitment success.

Population and Survival Estimation

Several assumptions must be met for a closed population estimate to be unbiased: (1) the population is closed to birth, death, immigration, and emigration; (2) animals have equal probability of capture; and (3) tags are not lost and are accurately recorded (Cooch and White 2013). The assumption of natality and mortality were thought to have been somewhat mitigated by using 3 years of research data for each reported population estimate. The razorback sucker is a long-lived species, and turnover in the adult population likely occurs at a slow rate; this likely increases the probability of survival between sampling occasions (Minckley 1983). By combining all study areas (long-term monitoring, CRI, and Bonelli Bay) to construct a reservoir-wide estimate, immigration and emigration may be accounted for to some degree. For example, the reservoir-wide population estimate includes efforts at the CRI and Bonelli Bay because of confirmed fish movement between the CRI, Bonelli Bay, and long-term monitoring study areas. Additionally, to meet the assumption that all animals have equal probability to be captured, PIT-scanner data were not used for this year's estimate because over half (approximately 69%) of the of the razorback suckers captured this year were unmarked, wild fish that could never be detected by PIT scanning equipment (see table 3). Lastly, tag loss is minimal for bluehead suckers (*Catostomus discobolus*) and Lost River suckers (*Deltistes luxatus*) (Burdick 2011; Ward and David 2006), so it seems reasonable to assume tag loss is also minimal for razorback suckers. Furthermore, field crews diligently minimize tag recording errors; despite this, both tag loss and data entry/recording errors likely do occur periodically. Methods used to produce the 2018–20 reservoir-wide population estimate in program MARK have been identical since 2016 (Mohn et al. 2015, 2016; Rogers et al. 2017, 2018, 2019), and they were similar (other than reduced netting efforts in 2015) to previous reports (Albrecht et al. 2012, 2013a, 2014a; Shattuck et al. 2011). Useful estimates were obtained for this year and were similar to last year's estimate. Rogers et al. (2019) report that the population estimate has been decreasing since 2010; however, the estimates remain within the historical context of Lake Mead.

Throughout the Colorado River Basin, annual survival has typically been reported between 0.70 and 0.94 for most populations of stocked, adult razorback suckers (> 450 mm TL) (Kesner et al. 2012; Zelasko et al. 2011); however, this rate dramatically declines to 0.03 and 0.29 for smaller razorback suckers (< 450 mm TL) (Kesner et al. 2012; Schooley et al. 2008b; Zelasko et al. 2011). The annual apparent survival rate reported for 2020 remains consistent with rates reported since 2014 in Lake Mead (Albrecht et al. 2014a; Mohn et al. 2015, 2016; Rogers et al. 2017, 2018, 2019) and is similar to rates for other razorback sucker populations mentioned above. The Lake Mead annual apparent survival estimate (0.77 [95% confidence interval of 0.75–0.80]) was calculated only for razorback suckers > 450 mm TL in Lake Mead. Again, survival estimates observed to date have been stable through time, which is not all that surprising given researchers target healthy, breeding adults.

Juvenile Razorback Sucker Life History Traits in Lake Mead

Fourteen juvenile razorback suckers were captured in 2020 at the long-term monitoring study areas – 12 were captured in Las Vegas Bay, and 2 were captured at the Virgin River/Muddy River inflow area. Since 1997, 111 (8.3% of the overall catch) wild, juvenile (≤ 450 mm TL and sexually immature) razorback suckers have been captured in Lake Mead, and all but 5 of these individuals were captured from long-term monitoring study areas. While 8.3% of the catch may appear to be a relatively low proportion of the overall catch, these juvenile razorback suckers should be considered “by-catch” due to the methodology of targeting the adult population as they congregate during the spawning period. Juvenile razorback sucker presence on spawning grounds is an understudied topic; however, Kegerries et al. (2016) did observe that juveniles and adults appear to use similar habitats to some degree. Additional studies that build on the framework from previous studies regarding younger age classes of razorback sucker (Albrecht et al. 2013b; Kegerries et al. 2015, 2016; Shattuck and Albrecht 2014) could result in new insights into why this species successfully recruits in Lake Mead.

Growth rates of juvenile razorback suckers appear to be quite high compared to adults in Lake Mead, which is not surprising considering younger fish grow faster than adult/mature fish. Furthermore, the average age at capture (3.8 years old) again supports the justifications for using older fish in the catch-curve analyses of year-class strength. It also provides further optimism for the success of 2016 year classes because the fish in those year classes will soon be more susceptible to the current sampling methods used at the long-term monitoring sites.

As stated above, survival rates for younger fish in other portions of the basin are dramatically lower than both their adult counterparts and the rates observed in this analysis (Kesner et al. 2012; Schooley et al. 2008b; Zelasko et al. 2011). This is not surprising because juveniles are more vulnerable to predation and competition (Minckley et al. 2003; Kesner et al. 2014; Marsh et al. 2015). Furthermore, as discussed above, annual apparent survival of Lake Mead juvenile razorback sucker appears to be considerably higher when compared to many areas in the basin (Kesner et al. 2012; Schooley et al. 2008b; Zelasko et al. 2011). Targeting these more vulnerable age classes (e.g., juvenile fish) in Lake Mead to assess survival rates may provide valuable insights about how wild razorback suckers have recruited throughout the long-term monitoring study, which could ultimately serve as a model to help inform other systems in the Colorado River Basin regarding this understudied and difficult-to-capture life stage (Albrecht et al. 2013b; Kegerries et al. 2015, 2016; Shattuck and Albrecht 2014).

Kegerries et al. (2016) observed juvenile razorback suckers using shallow, turbid environments with dense, inundated vegetation, as well as deep habitats, depending on the time of year. Reservoir elevations increased in 2016, inundating large portions of the Virgin River/Muddy River inflow area and Las Vegas Bay. Since 2016, the reservoir elevation has remained relatively stable, and these areas remained inundated for several years. When the relatively high number of juveniles captured in the past 2 years is considered with this year's capture of an individual from the 2018 year class, it appears that the current environment may be conducive to a pulse of recruitment in Lake Mead.

Drivers of Lake Mead Recruitment

The unexpected initiation of Lake Mead razorback sucker recruitment has been attributed to changes in the management of Lake Mead (Holden et al. 2001). From the 1930s to 1963, Lake Mead was either filling (a time when initial recruitment likely occurred and created the original reservoir population of razorback suckers), or it was operated with a sizable annual fluctuation. The reservoir was drawn down approximately 30.5 m in the mid-1960s as Lake Powell filled and, as previously discussed, since that time it has been operated with relatively small annual changes but relatively large multi-year fluctuations. Shoreline vegetation that grew when Lake Mead's elevation was low remained intact for many years and provided cover in coves and other habitats that young razorback suckers may inhabit. Before 1970, vegetation was unlikely to establish because of relatively large, annual reservoir fluctuations. The presence of individual razorback suckers older than 30 years indicates that limited recruitment may have occurred from 1966 to 1978, a period of slowly rising reservoir elevations. Reservoir elevations were highest from 1978 to 1987, when the maximum amount of intact inundated vegetation probably existed in the reservoir. More recently, in 2005, 2011, 2016, 2017, 2018, 2019, and 2020, reservoir elevations have increased during the spawning period (Albrecht and Holden 2005; Rogers et al. 2017, 2018, 2019; Shattuck et al. 2011). Since at least 2005, razorback sucker recruitment seems to have increased, though not homogenously through the years, evident by the increased number of captured individuals from the 2005 year class, increased year-class strength in 2007, 2008, 2010, and again in 2013. During stronger year classes, the increasing reservoir levels during the spawning season may give the deposited razorback sucker eggs a chance to hatch before the reservoir recedes and dries out the spawning areas and may provide cover for juvenile razorback suckers (Albrecht and Holden 2005; Welker and Holden 2004).

In 2020, as in past years (Albrecht et al. 2017; Mohn et al. 2016), the overwhelming majority (> 99% [unpublished data]) of the fish captured were non-native species. Despite numerical domination by the non-native fish community, razorback suckers continue to recruit and coexist in Lake Mead. The potential for new threats from non-native species remains an important factor to track and understand in terms of impacts on razorback sucker recruitment success.

It has been accepted for years that turbidity plays a role in the predation susceptibility of native Colorado River fishes (Albrecht et al. 2010a, 2017; Johnson and Hines 1999; Ward and Vaage 2019; Ward et al. 2016). Complex habitats and cover (in the form of turbidity and inundated vegetation) have been hypothesized as the elements that allow for native fishes to coexist with non-native fishes in Lake Mead (Albrecht et al. 2017, 2020; Golden and Holden 2003; Kegerries et al. 2017b; Ward and Vaage 2019). Albrecht et al. (2010a) showed that cover, in the forms of turbidity and inundated vegetation, was significantly higher in Lake Mead long-term monitoring study areas compared with coves on Lake Mohave. Albrecht et al. (2017) hypothesize that complex habitats with high turbidity and debris near river inflow areas and large, intermittent washes may function as the once-common historical habitats (i.e., backwaters, flooded wetlands, slackwaters, and off-channel habitats) that provided refuge for spawning and recruitment of razorback suckers. Moreover, complex habitats near inflow areas provide unique conditions that can support large numbers of species and life stages through habitat diversity and associated increases in niche availability (Albrecht et al. 2017; Kaemingk et al. 2007). With Lake Mead being at near historically low levels, the inflow areas have become vast, dynamic delta systems that could be functioning as the warm, turbid, lentic, nursery habitats that razorback suckers use for recruitment (Albrecht et al. 2017; Kegerries et al. 2017b). Additionally, high-flow events that bring woody debris and fine sediments into Lake Mead may play an important role in providing even more cover. Shattuck and Albrecht (2014) were among the first to quantify the use of cover by juvenile razorback suckers and underscore the importance of cover, turbidity, and complex habitats to this life stage in Lake Mead, which is particularly relevant considering the sizable non-native fish presence. Research in Lake Mead continues to show a dense and predatory fish community, but it also shows annual recruitment of razorback suckers. As previously discussed, understanding the interactions between the physical environment—such as the timing of reservoir elevation changes, habitat characteristics (e.g., cover in the form of turbidity and/or vegetation), and habitat complexities (e.g., inflow areas)—may be essential to understanding (and perhaps enhancing) species survival and recruitment throughout the Colorado River Basin and, at a minimum, suggest a relatively positive future for this rare species in Lake Mead. In Lake Mead for example, under current low reservoir conditions, substantial amounts of shoreline vegetation is being established. If Lake Mead begins to fill again, this vegetation should be present to provide cover to future year classes of razorback suckers, a potentially positive outlook for this endangered species.

Presently, recruitment in Lake Mead appears to be most common in areas with perennial sources of flowing water (e.g., Las Vegas Wash, Virgin and Muddy Rivers, CRI). Sonic-tagged razorback suckers have regularly been documented moving upstream into Las Vegas Wash and the CRI, or using the shallow delta habitats at the Virgin River/Muddy River inflow area (Albrecht et al. 2012; Kegerries et al. 2017a; Rogers et al. 2017, 2018, 2019; Shattuck and Albrecht 2014) and presumably spawning in flowing water, based on the distribution patterns of larvae that likely drifted into the reservoir near these inflows (e.g., Las Vegas Wash, CRI). However, spawning and recruitment appear to be occurring in Echo Bay, which is somewhat unique among the other known spawning areas because it is an intermittent wash that flows and deposits sediments from a large drainage basin during rain events or possibly through wave action during storms. There are numerous other areas in Lake Mead that appear somewhat similar to Echo Bay, such as Bonelli and Callville Bays. Future exploration and targeted sampling in these areas may reveal additional spawning aggregates of razorback suckers in Lake Mead. Previous study efforts showed that sonic-tagged razorback suckers used Bonelli Bay for at least some part of the year (Albrecht et al. 2012; Shattuck et al. 2011), and during the 2018 spawning season, NDOW biologists found razorback sucker larvae in Bonelli Bay (D. Herndon 2018, personal communication). Most recently, in 2019–20, collaborative efforts between BIO-WEST and the NDOW resulted in the capture of several wild, unmarked adult razorback suckers, along with the capture of more larvae (Kegerries et al. 2019, 2020). With currently available technology (particularly PIT scanners, reliable sonic tags, and SURs) and a refined approach, perhaps using targeted trammel netting and larval sampling, it may be time to explore some of these other areas of Lake Mead for razorback sucker presence. Furthermore, a group of scuba divers allegedly observed razorback suckers during a dive near Kingman Wash, Arizona, an intermittent wash that flows into Lake Mead near Hoover Dam (B. Senger 2020, personal communication). Exploring other potential spawning areas throughout Lake Mead was suggested by the Lake Mead Work Group as a management action item that should occur (Albrecht et al. 2009), and doing so could add to the body of knowledge about razorback sucker habitat associations, help to refine current population and survival estimates, and further the collective understanding of growth, habitat use, and movement patterns of razorback suckers in Lake Mead.

Conclusions

All long-term monitoring objectives for the 2020 study year were met, as had been the case since the inception of this study in 1996. Multiple life stages of razorback suckers were captured, sampled, and surveyed using a wide variety of methodologies in dynamic and, at times, difficult-to-sample environments. The importance of continuing to monitor the Lake Mead razorback sucker population using the same methods simply cannot be understated and will serve to increase our understanding of the species and the potential reasons razorback sucker recruitment continues in Lake Mead. The continued pulses of newly captured, young razorback suckers at all Lake Mead long-term monitoring study areas in recent years support the concept that Lake Mead continues to harbor the only known, naturally recruiting, and largely wild population of razorback suckers in the Colorado River Basin (Albrecht et al. 2006b, 2010a). Recruitment of razorback suckers in Lake Mead has been documented to occur on a nearly annual basis since the 1960s, a time period that contained a broad range of biotic and abiotic conditions. With the capture of larval fish at all known spawning sites, coupled with the direct capture of additional wild, juvenile razorback suckers in 2020, projections regarding the status of the species within Lake Mead remain fairly optimistic. Based on over two decades of trammel netting experience, year-class strength modeling, and observations concerning juvenile razorback suckers, it typically takes 4–5 years for a razorback sucker to reach a size that is readily susceptible to sampling in Lake Mead. It is anticipated that fish spawned and recruited in 2017 will become more susceptible to sampling in the near future, and more fish from 2015–16 will become more commonly captured during future netting efforts. This context again underscores the importance of maintaining long-term monitoring efforts and continuing to build long-term datasets in order to track this important razorback sucker population and to ultimately better understand it. When viewed cumulatively, the information in this annual report indicates that the Lake Mead razorback sucker population appears generally young and resilient. This alone demonstrates the importance of the Lake Mead razorback sucker population and provides a positive outlook for an endangered species. Understanding recruitment in Lake Mead presents an unequaled, if not the last opportunity, to discover possible mechanisms for promoting recruitment in locations throughout the Colorado River Basin and studying even the rarest life stages of this species more thoroughly.

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ATTACHMENT 1

Razorback Sucker (*Xyrauchen texanus*) Aging Data

Table 1-1.—Ages determined from razorback sucker (*Xyrauchen texanus*) pectoral fin-ray sections collected from Lake Mead – **Las Vegas Bay**

Date collected	Total length (mm[a])	Age	Presumptive year spawned
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

Attachment 1 – Razorback Sucker (*Xyrauchen texanus*) Aging Data

Table 1-1.—Ages determined from razorback sucker (*Xyrauchen texanus*) pectoral fin-ray sections collected from Lake Mead – **Las Vegas Bay**

Date collected	Total length (mm[a])	Age	Presumptive year spawned
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
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

Table 1-1.—Ages determined from razorback sucker (*Xyrauchen texanus*) pectoral fin-ray sections collected from Lake Mead – **Las Vegas Bay**

Date collected	Total length (mm[a])	Age	Presumptive year spawned
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
4/03/2008	619	7	2001
4/03/2008	640	10	1998

Table 1-1.—Ages determined from razorback sucker (*Xyrauchen texanus*) pectoral fin-ray sections collected from Lake Mead – **Las Vegas Bay**

Date collected	Total length (mm[a])	Age	Presumptive year spawned
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

Table 1-1.—Ages determined from razorback sucker (*Xyrauchen texanus*) pectoral fin-ray sections collected from Lake Mead – **Las Vegas Bay**

Date collected	Total length (mm[a])	Age	Presumptive year spawned
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
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

Table 1-1.—Ages determined from razorback sucker (*Xyrauchen texanus*) pectoral fin-ray sections collected from Lake Mead – **Las Vegas Bay**

Date collected	Total length (mm[a])	Age	Presumptive year spawned
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
1/29/2019	311	3	2016
1/29/2019	390	3	2016

Table 1-1.—Ages determined from razorback sucker (*Xyrauchen texanus*) pectoral fin-ray sections collected from Lake Mead – **Las Vegas Bay**

Date collected	Total length (mm[a])	Age	Presumptive year spawned
2/19/2019	402	3	2016
01/28/20	425	5	2015
01/28/20	381	4	2016
01/28/20	356	4	2016
01/28/20	389	4	2016
01/28/20	356	4	2016
01/28/20	343	3	2017
01/28/20	329	3	2017
02/06/20	392	4	2016
02/18/20	376	6	2014
02/18/20	401	4	2016
02/18/20	319	3	2017

Table 1-1.—Ages determined from razorback sucker (*Xyrauchen texanus*) pectoral fin-ray sections collected from Lake Mead – **Echo Bay**

Date collected	Total length (mm[a])	Age	Presumptive year spawned
1/22/1998	381	5	1993
1/09/2000	527	13	1987
1/09/2000	550	13	1987
1/09/2000	553	13	1987
1/09/2000	599	12–14	1986–1988
1/27/2000	557	13	1986
1/28/2000	558	14	1985
1/27/2000	710	19+	1979–1981
2/09/2001	641	13	1988
2/24/2001	577	18+	1980–1982
2/24/2001	570	8	1992
2/24/2001	576	15	1986
2/24/2001	553	18	1983
12/18/2001	672	13	1988
2/27/2002	610	18–20	1982–1984
3/26/2002	623	16	1986
4/02/2002	617	35+	1966–1968
4/17/2002	583	20[b]	1982
5/02/2002	568	18–19	1983–1984
11/18/2002	551	13	1989
12/04/2002	705	26	1976
1/21/2003	591	16	1986
2/03/2003	655	27–29	1974
2/03/2003	580	13	1989
4/02/2003	639	19–20	1982
4/02/2003	580	23–25	1978
4/23/2003	584	10	1992
5/06/2003	507	9+	1993

Table 1-1.—Ages determined from razorback sucker (*Xyrauchen texanus*) pectoral fin-ray sections collected from Lake Mead – **Echo Bay**

Date collected	Total length (mm[a])	Age	Presumptive year spawned
5/06/2003	594	20	1982
12/18/2003	522	20	1982
1/14/2004	683	14	1989
2/18/2004	613	10	1993
3/17/2004	616	19	1983
3/17/2004	666	17	1985
3/17/2004	618	9	1994
4/06/2004	755	17	1985
3/02/2005	608	15	1990
3/02/2005	624	8	1996
1/10/2006	630	12	1994
2/01/2006	705	16	1990
2/16/2006	601	22	1984
1/11/2007	535	5	2002
1/11/2007	493	5	2002
2/01/2007	637	7	2000
2/08/2007	609	12	1995
2/14/2007	501	4	2003
3/02/2007	590	11	1996
3/09/2007	660	12	1995
3/16/2007	691	21	1986
3/28/2007	564	13	1994
2/28/2008	640	25	1983
2/29/2008	635	8	2000
3/05/2008	653	24	1984
3/19/2008	532	6	2002
3/19/2008	510	7	2001
2/20/2009	602	7	2002

Table 1-1.—Ages determined from razorback sucker (*Xyrauchen texanus*) pectoral fin-ray sections collected from Lake Mead – **Echo Bay**

Date collected	Total length (mm[a])	Age	Presumptive year spawned
2/26/2009	662	16	1993
2/18/2010	520	7	2003
2/25/2010	465	5	2005
3/10/2010	535	7	2003
3/10/2010	530	9[f]	2001
3/24/2010	451	4	2006
3/24/2010	465	5	2005
3/24/2010	466	5	2005
4/08/2010	470	5	2005
4/08/2010	540	8	2002
4/22/2010	538	7	2003
4/22/2010	489	8	2002
4/22/2010	460	9	2001
2/09/2011	529	7	2004
2/09/2011	524	7	2004
2/24/2011	555	7	2004
3/02/2011	513	6	2005
4/07/2011	533	7	2004
4/07/2011	522	7	2004
4/19/2011	537	6	2005
4/19/2011	540	7	2004
4/19/2011	515	6	2005
2/09/2012	619	10	2002
2/09/2012	644	29	1983
2/16/2012	559	9	2003
2/16/2012	565	12	2000
2/22/2012	589	10	2002
2/22/2012	548	12	2000

Table 1-1.—Ages determined from razorback sucker (*Xyrauchen texanus*) pectoral fin-ray sections collected from Lake Mead – **Echo Bay**

Date collected	Total length (mm[a])	Age	Presumptive year spawned
3/01/2012	585	7	2005
3/07/2012	663	12	2000
3/29/2012	571	12	2000
3/29/2012	595	13	1999
4/12/2012	610	13	1999
4/12/2012	571	14	1998
2/07/2013	670	8	2005
2/07/2013	579	10	2003
2/07/2013	655	7	2006
2/14/2013	692	17	1996
2/27/2014	703	15	1999
3/12/2014	554	8	2006
3/13/2014	594	10	2004
3/25/2014	594	8	2006
3/25/2014	630	9	2005
2/16/2016	540	7	2009
2/18/2016	634	9	2007
2/29/2016	631	9	2007
3/08/2016	544	9	2007
3/08/2016	612	10	2006
3/08/2016	650	12	2004
3/22/2016	476	6	2010
3/22/2016	545	8	2008
3/22/2016	545	9	2007
3/22/2016	570	11	2005
3/22/2016	634	12	2004
4/05/2016	591	10	2006
4/05/2016	648	11	2005

Table 1-1.—Ages determined from razorback sucker (*Xyrauchen texanus*) pectoral fin-ray sections collected from Lake Mead – **Echo Bay**

Date collected	Total length (mm[a])	Age	Presumptive year spawned
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
4/17/2018	634	9	2009
2/27/2019	552	6	2013
3/5/2019	554	7	2012
4/16/2019	519	5	2014
02/05/20	641	13	2007
02/11/20	684	9	2011

Table 1-1.—Ages determined from razorback sucker (*Xyrauchen texanus*) pectoral fin-ray sections collected from Lake Mead – **Virgin River/Muddy River inflow area**

Date collected	Total length (mm[a])	Age	Presumptive year spawned
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

Table 1-1.—Ages determined from razorback sucker (*Xyrauchen texanus*) pectoral fin-ray sections collected from Lake Mead – **Virgin River/Muddy River inflow area**

Date collected	Total length (mm[a])	Age	Presumptive year spawned
4/01/2008	548	6	2002
4/01/2008	518	7	2001
4/01/2008	530	7	2001
4/01/2008	494	8	2000
4/01/2008	535	9	1999
4/01/2008	559	10	1998
4/22/2008	533	6	2002
4/22/2008	504	6	2002
2/04/2009	496	9	2000
2/12/2009	553	10	1999
2/12/2009	505	8	2001
2/19/2009	464	5	2004
2/25/2009	549	7	2002
3/11/2009	585	8	2001
3/11/2009	552	8	2001
3/24/2009	366	3	2006
3/24/2009	572	9	2000
4/08/2009	348	3	2006
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

Table 1-1.—Ages determined from razorback sucker (*Xyrauchen texanus*) pectoral fin-ray sections collected from Lake Mead – **Virgin River/Muddy River inflow area**

Date collected	Total length (mm[a])	Age	Presumptive year spawned
2/03/2010	475	5	2005
2/03/2010	441	5	2005
2/03/2010	495	7	2003
2/03/2010	532	8	2002
2/09/2010	491	5	2005
2/09/2010	444	5	2005
2/09/2010	500	5	2005
2/09/2010	464	6	2004
2/09/2010	471	6	2004
2/17/2010	494	6	2004
2/17/2010	470	7	2003
2/17/2010	479	7	2003
2/17/2010	425	7	2003
2/17/2010	483	7	2003
2/24/2010	234	4	2006
3/17/2010	477	4	2006
3/17/2010	465	5	2005
3/17/2010	485	5	2005
3/17/2010	499	6	2004
3/17/2010	491	6	2004
3/17/2010	600	9	2001
3/18/2010	452	5	2005
3/18/2010	473	5	2005
3/24/2010	485	5	2005
2/01/2011	601	7	2004
2/01/2011	571	6	2005
2/01/2011	556	7	2004
2/01/2011	586	6	2005
2/01/2011	506	8	2003

Table 1-1.—Ages determined from razorback sucker (*Xyrauchen texanus*) pectoral fin-ray sections collected from Lake Mead – **Virgin River/Muddy River inflow area**

Date collected	Total length (mm[a])	Age	Presumptive year spawned
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

Table 1-1.—Ages determined from razorback sucker (*Xyrauchen texanus*) pectoral fin-ray sections collected from Lake Mead – **Virgin River/Muddy River inflow area**

Date collected	Total length (mm[a])	Age	Presumptive year spawned
3/09/2011	556	7	2004
3/09/2011	534	6	2005
3/09/2011	549	7	2004
3/09/2011	494	4	2007
3/09/2011	505	6	2005
3/15/2011	575	8	2003
3/15/2011	551	8	2003
3/15/2011	515	7	2004
3/15/2011	558	8	2003
3/15/2011	576	8	2003
3/15/2011	587	8	2003
3/15/2011	572	7	2004
3/15/2011	575	10	2001
3/15/2011	551	7	2004
3/15/2011	561	7	2004
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

Table 1-1.—Ages determined from razorback sucker (*Xyrauchen texanus*) pectoral fin-ray sections collected from Lake Mead – **Virgin River/Muddy River inflow area**

Date collected	Total length (mm[a])	Age	Presumptive year spawned
2/21/2012	590	10	2002
3/13/2012	555	9	2003
3/13/2012	521	9	2003
3/13/2012	618	9	2003
3/13/2012	610	12	2000
3/14/2012	539	7	2005
3/14/2012	530	9	2003
3/15/2012	546	7	2005
3/15/2012	576	10	2002
3/15/2012	574	10	2002
3/21/2012	559	7	2005
3/28/2012	575	8	2004
4/04/2012	551	6	2006
4/04/2012	575	7	2005
4/11/2012	535	9	2003
2/06/2013	519	9	2004
2/13/2013	630	10	2003
2/21/2013	546	7	2006
2/21/2013	544	8	2005
2/21/2013	584	8	2005
2/21/2013	606	11	2002
2/21/2013	549	8	2005
3/05/2013	567	10	2003
3/05/2013	537	10	2003
3/05/2013	621	10	2003
3/05/2013	558	8	2005
3/05/2013	601	8	2005
3/14/2013	600	12	2001
3/14/2013	616	9	2004

Table 1-1.—Ages determined from razorback sucker (*Xyrauchen texanus*) pectoral fin-ray sections collected from Lake Mead – **Virgin River/Muddy River inflow area**

Date collected	Total length (mm[a])	Age	Presumptive year spawned
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

Table 1-1.—Ages determined from razorback sucker (*Xyrauchen texanus*) pectoral fin-ray sections collected from Lake Mead – **Virgin River/Muddy River inflow area**

Date collected	Total length (mm[a])	Age	Presumptive year spawned
3/20/2014	532	8	2006
3/20/2014	561	9	2005
3/20/2014	592	8	2006
3/20/2014	637	10	2004
3/20/2014	567	9	2005
3/20/2014	574	10	2004
3/20/2014	541	10	2004
3/20/2014	614	9	2005
4/03/2014	572	6	2008
4/03/2014	615	7	2007
4/10/2014	651	7	2007
4/16/2014	504	6	2008
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

Table 1-1.—Ages determined from razorback sucker (*Xyrauchen texanus*) pectoral fin-ray sections collected from Lake Mead – **Virgin River/Muddy River inflow area**

Date collected	Total length (mm[a])	Age	Presumptive year spawned
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
3/06/2018	611	13	2005
3/07/2018	468	4	2014
3/08/2018	481	6	2012
4/18/2018	454	5	2013
2/07/2019	579	6	2013
2/07/2019	671	8	2011
2/07/2019	654	10	2009
2/07/2019	498	6	2013
2/07/2019	599	7	2012
2/20/2019	546	7	2012
2/20/2019	545	6	2013

Table 1-1.—Ages determined from razorback sucker (*Xyrauchen texanus*) pectoral fin-ray sections collected from Lake Mead – **Virgin River/Muddy River inflow area**

Date collected	Total length (mm[a])	Age	Presumptive year spawned
2/20/2019	676	8	2011
2/26/2019	680	9	2010
2/26/2019	643	7	2012
2/26/2019	639	9	2010
3/05/2019	535	6	2013
3/05/2019	582	5	2014
4/03/2019	601	7	2012
01/22/20	656	10	2010
01/22/20	541	9	2011
01/22/20	593	7	2013
02/12/20	662	11	2009
02/12/20	616	10	2010
02/12/20	301	2	2018
02/19/20	557	7	2013
02/19/20	605	6	2014
02/26/20	635	10	2010
03/04/20	541	10	2010
03/04/20	317	3	2017
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

Table 1-1.—Ages determined from razorback sucker (*Xyrauchen texanus*) pectoral fin-ray sections collected from Lake Mead – **Virgin River/Muddy River inflow area**

Date collected	Total length (mm[a])	Age	Presumptive year spawned
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
3/07/2017	598	11	2006
4/18/2017	401	6	2011

Table 1-1.—Ages determined from razorback sucker (*Xyrauchen texanus*) pectoral fin-ray sections collected from Lake Mead – **Virgin River/Muddy River inflow area**

Date collected	Total length (mm[a])	Age	Presumptive year spawned
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
4/18/2018	454	5	2013
5/02/2018	473	5	2013
2/06/2019	570	8	2011
2/06/2019	526	5	2014
3/27/2019	517	6	2013
4/11/2019	432	4	2015
02/25/20	532	7	2013
02/26/20	556	10	2010
03/12/20	491	5	2015
04/07/20	648	8	2012
04/09/20	503	7	2013
04/09/20	558	7	2013

Table 1-1.—Ages determined from razorback sucker (*Xyrauchen texanus*) pectoral fin-ray sections collected from Lake Mead – **Bonelli Bay**

Date collected	Total length (mm[a])	Age	Presumptive year spawned
2/12/2019	700	12	2007
2/12/2019	625	10	2009
2/12/2019	670	10	2009
2/20/2019	656	10	2009
2/20/2019	571	7	2012
3/14/2019	590	6	2013
03/05/2020	710	11	2009
03/05/2020	560	9	2011

[a] mm = millimeters.

[b] Fish stocked from Echo Bay larval fish captured in 1999 and raised at Nevada Department of Wildlife Lake Mead Fish Hatchery.

[c] Fish stocked from Floyd Lamb Park ponds (1982 Dexter National Fish Hatchery cohort placed in Floyd Lamb Park ponds in 1984).

[d] Fish was aged at 33 years of age, ±2 years.

[e] Fish was a mortality; found dead in net.

[f] Fish stocked from Floyd Lamb Park ponds (from an unknown 2001–03 cohort stocking event).

[g] Fish stocked from Floyd Lamb Park ponds, sonic tagged.

ATTACHMENT 2

Histogram of Razorback Suckers (*Xyrauchen texanus*) Aged in Lake Mead from 1999 to 2020

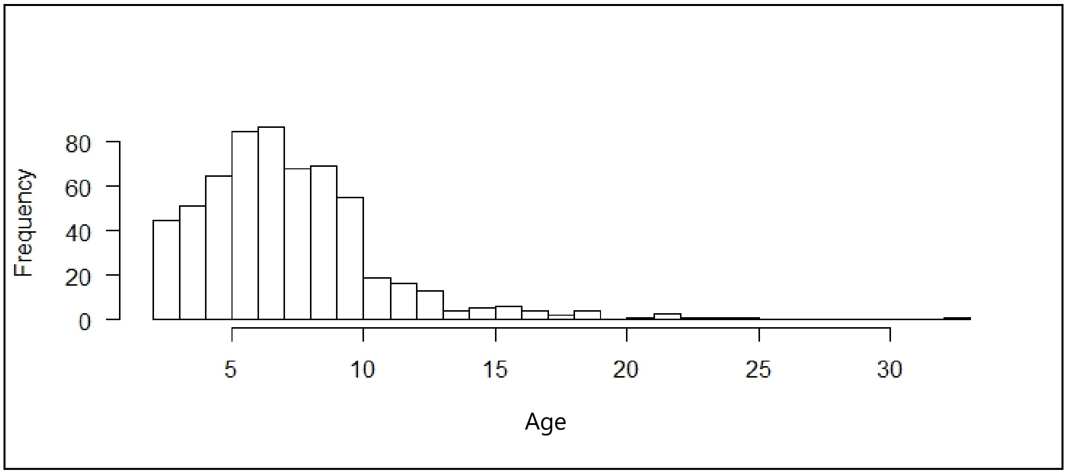

Figure 2-1.—Histogram of razorback sucker (*Xyrauchen texanus*) ages from 1999 to 2020, determining age when fish are most vulnerable for capture.

ATTACHMENT 3

Razorback Sucker (*Xyrauchen texanus*) Population Estimate (2018–2020) – Model Selection Summary

Table 3-1.—Model selection summary information for closed-capture populations of razorback suckers (*Xyrauchen texanus*) in Lake Mead using 42 mark-recapture netting-only capture occasions data from 2018 to 2020 and generated in program MARK

Model[a]	AIC_c[b]	ΔAIC_c[c]	AIC_c weight[d]	Model likelihood[e]	Number of parameters	Deviance[f]
Full likelihood						
Mt	207.6205	0.0000	1.00000	1.0000	35	261.1880
Mo	321.0977	113.4772	0.00000	0.0000	2	441.0603
Mh	321.0977	113.4772	0.00000	0.0000	2	441.0603
Mb	323.0548	115.4343	0.00000	0.0000	3	441.0155

[a] Otis et al. 1978 abundance models (*in* Cooch and White 2013).
[b] Akaike's information criterion adjusted for small sample size.
[c] AIC_c minus the minimum AIC_c.
[d] Ratio of ΔAIC_c relative to the entire set of candidate models.
[e] Ratio of AIC_c weight relative to the AIC_c weight of the best model.
[f] Log-likelihood of model minus log-likelihood of the saturated model (Zelasko et al. 2011).

ATTACHMENT 4

Razorback Sucker (*Xyrauchen texanus*) Annual Apparent Survival Rate Estimate – Model Selection Summary

Table 4-1.—Cormack-Jolly-Seber model selection summary of annual apparent survival rate estimates for razorback suckers (*Xyrauchen texanus*) in Lake Mead produced in program MARK using adult (> 450 millimeters total length) annual mark-recapture data, 1996–2020

Model[a]	AIC_c[b]	ΔAIC_c[c]	AIC_c weight[d]	Model likelihood[e]	Number of parameters	Deviance[f]
Cormack-Jolly-Seber						
Φ (.)$p(t)$	2403.5991	0.0000	0.92980	1.0000	25	690.9915
Φ $(t)p(t)$	2408.7663	5.1672	0.07020	0.0755	47	648.8520
Φ $(t)p$(.)	2429.4291	25.8300	0.00000	0.0000	25	716.8215
Φ (.)p(.)	2443.2468	39.6477	0.00000	0.0000	2	777.9249

[a] Φ = survival, (.) = parameter consistent through time, ρ = recapture probability, and (t) = parameter variable through time.

[b] Akaike's information criterion adjusted for small sample size.

[c] AIC_c minus the minimum AIC_c.

[d] Ratio of ΔAIC_c relative to the entire set of candidate models.

[e] Ratio of AIC_c weight relative to the AIC_c weight of the best model.

[f] Log-likelihood of model minus log-likelihood of the saturated model (Zelasko et al. 2011).

ATTACHMENT 5

Recapture Probability Estimate of Adult (> 450 Millimeters Total Length) Razorback Suckers (*Xyrauchen texanus*) in Lake Mead, 1996–2020, Produced in Program MARK

Table 5–1.—Recapture probability estimate value by year for adult (> 450 millimeters total length) razorback suckers (*Xyrauchen texanus*) in Lake Mead produced in program MARK (Cormack-Jolly-Seber model) with mark-recapture data, 1996–2020

Year	Recapture probability estimate value	Standard error
1996–1997	0.26	0.17
1997–1998	0.28	0.08
1998–1999	0.16	0.06
1999–2000	0.38	0.09
2000–2001	0.31	0.08
2001–2002	0.21	0.07
2002–2003	0.31	0.07
2003–2004	0.21	0.06
2004–2005	0.09	0.04
2005–2006	0.44	0.09
2006–2007	0.30	0.07
2007–2008	0.23	0.05
2008–2009	0.13	0.04
2009–2010	0.05	0.03
2010–2011	0.09	0.03
2011–2012	0.12	0.03
2012–2013	0.13	0.03
2013–2014	0.25	0.04
2014–2015	0.07	0.02
2015–2016	0.24	0.04
2016–2017	0.14	0.03
2017–2018	0.22	0.04
2018–2019	0.15	0.04
2019–2020	0.19	0.04

ATTACHMENT 6

Juvenile Razorback Sucker (*Xyrauchen texanus*) Annual Apparent Survival Rate Estimate – Model Selection Summary

Table 6-1.–Cormack-Jolly-Seber model selection summary of annual apparent survival rate estimates for razorback suckers (*Xyrauchen texanus*) in Lake Mead produced in program MARK using juvenile (< 450 millimeters total length) annual mark-recapture data, 1997–2020

Model	AIC_c[a]	Delta AIC_c	AIC_c weight	Likelihood	Parameters	Deviance
Φ (.) p (.)	191.5238	0.0000	0.99993	1.0000	2	114.2850
Φ (.) p (t)	210.6439	19.1201	0.00007	0.0001	24	77.8506
Φ (t) p (.)	227.7102	36.1864	0.00000	0.0000	24	94.9169
Φ (t) p (t)	261.7247	70.2009	0.00000	0.0000	41	66.5354

[a] Akaike's information criterion adjusted for small sample size.