Lower Colorado River Multi-Species Conservation Program

Balancing Resource Use and Conservation

Razorback Sucker (*Xyrauchen texanus*) Studies on Lake Mead, Nevada and Arizona

2017–2018 Annual Report

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Lower Colorado River Multi-Species Conservation Program

Razorback Sucker (*Xyrauchen texanus*) Studies on Lake Mead, Nevada and Arizona

2017–2018 Annual Report

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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	razorback sucker × flannelmouth sucker
km	kilometer(s)
L	liter(s)
$mL\ L^{-1}$	milliliter(s) per liter
LCR MSCP	Lower Colorado River Multi-Species Conservation Program
LMWG	Lake Mead Work Group
m	meter(s)
mL	milliliter(s)
mm	millimeter(s)
MS-222	tricaine methanesulfonate
n	number of year classes
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	U.S. Fish and Wildlife Service

Symbols

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

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EXECUTIVE SUMMARY

In 1996, the Southern Nevada Water Authority (SNWA) and Colorado River Commission of Nevada, in cooperation with the Nevada Department of Wildlife (NDOW), Arizona Game and Fish Department, National Park Service, Bureau of Reclamation (Reclamation), and 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. (BIO-WEST), under contract with the SNWA, 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. Information and observations from the 22nd season (2017–18) of the long-term monitoring study are provided herein.

During the 22nd field season, 17 sonic-tagged fish were detected via telemetry efforts, which resulted in 55 active and 2,911passive contacts. These fish represented four different sonic tagging events (2011 [n = 1], 2014 [n = 3], 2017 [n = 6], and 2018 [n = 7]). Along with the sonic-tagged razorback suckers released for telemetry purposes in past years, 13 adults of Lake Mohave origin were implanted with sonic tags and stocked into Las Vegas Bay with the goal of these individuals integrating and breeding with the local population to increase genetic diversity in the bay. By using data gathered from sonic-tagged fish in conjunction with trammel netting and larval sampling data, information regarding primary spawning sites was again obtained for the 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.

Forty-five razorback suckers were captured in trammel nets during the 2018 spawning period: 8 from Las Vegas Bay (5 females and 3 males), 13 from Echo Bay (4 females and 9 males), and 24 from the Virgin River/Muddy River inflow area (11 females, 7 males, 2 juveniles, and 4 undetermined sex). A highlight of the 22nd field season was the capture of 2 new juveniles (approximately 450 millimeters [mm] in total length [TL] and sexually immature) and 27 new (unmarked), wild razorback suckers. Eight flannelmouth suckers (*Catostomus latipinnis*) were captured in 2018; one was captured in Las Vegas Bay, one was captured in Echo Bay, and six were captured at the Virgin River/ Muddy River inflow area. Additionally, 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 14 recaptured razorback suckers, was 10.00 mm in TL per year (± standard error = 1.32). Growth rates of Lake Mead razorback suckers continue to be relatively high, suggesting that Lake Mead razorback suckers are able to naturally maintain a fairly strong cohort of young, fast-growing fish.

Additionally, fin ray sections were removed from 19 new, wild razorback suckers for age determination, which when combined with the 531 fish aged during previous field seasons, brings the total number of fish aged during the long-term monitoring study to 550. Another highlight was the capture of eight razorback suckers age-6 or younger from the long-term monitoring study areas, which further indicates continued recruitment in Lake Mead. Through the process of aging razorback suckers, near-annual recruitment in Lake Mead has been documented.

A total of 2,117 larval razorback suckers were captured in 2018 from the combined sampling locations. Nearly 94% of the larvae were found in Las Vegas Bay (n = 1,980). BIO-WEST worked collaboratively with the NDOW and Reclamation biologists to continue Lake Mead larval razorback sucker collection efforts for genetic analysis. Additionally, those efforts were increased in Las Vegas Bay to research the effectiveness of stocking razorback suckers of Lake Mohave origin to potentially increase genetic diversity within the bay. Larval razorback sucker abundance was used to help define primary spawning sites during the 2017–18 field season. Spawning activity (i.e., sonic-tagged fish detections, adult captures, and larval collections) was noted in all three of the long-term monitoring study areas.

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. Department of the Interior (U.S. Fish and Wildlife Service [USFWS 1991]). Historically widespread and common throughout the larger rivers of the basin, the distribution and abundance of the long-lived razorback sucker are now greatly reduced (Albrecht et al. 2010a; Minckley et al. 1991) principally due to anthropogenic causes. One of the major factors that caused 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 was estimated at 75,000 individuals in the 1980s and occurred in Lake Mohave (Arizona and Nevada), but it had declined to less than 3,000 individuals by 2001 (Marsh et al. 2003). Mueller (2005, 2006) reported the wild Lake Mohave razorback sucker population to be near 500 individuals, while the most recent 2018 estimate of wild Lake Mohave razorback suckers was not reported, as no wild fish were captured (Burgad et al. 2019). 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. The Lake Mohave population today is largely supported by routine stocking of captive-reared fish and remains important to the species due to its high level of genetic diversity (Marsh et al. 2003, 2005, 2015; Marsh & Associates, LCC 2016, 2017, 2018). 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). The latest Lake Mohave repatriate population estimate was reported at 3,471 individuals (95% confidence interval of 3,365–3,576) (Burgad et al. 2019). Despite a decreasing wild population, Lake Mohave remains important for the genetic diversity of the extant razorback sucker population, which is maintained through a wild-born, captive-rearing repatriation program (Dowling et al. 2012a, 2012b).

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 that occurred 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; the National Park Service, which graciously provided residence facilities in their campgrounds; the Colorado River Commission of Nevada; the 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 extending the study period into the year 2000.

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

- 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 of evaluating the reservoir for potential stocking options and locations was added to the project as a response to a growing number of larvae that had been, and were slated to, eventually be repatriated into Lake Mead. Also in 2005, Reclamation became the primary funding agency through the Lower Colorado River Multi-Species Conservation Program (LCR MSCP) and 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 decided to continue long-term monitoring efforts but at a reduced level of effort (approximately half compared with previous years). Finally, after determining that the reduced efforts in 2015 did not provide the necessary data, in 2016–18, Reclamation and NDOW biologists completed supplemental sampling during the weeks that BIO-WEST biologists were not sampling Lake Mead. These efforts were conducted following 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 of Lake Mead (CRI), in the lower Grand Canyon, and with regard to the juvenile life stage (Albrecht et al. 2017; Kegerries et al. 2016, 2017a, 2017b). 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
- Ultimately, achieving a better understanding of razorback sucker recruitment in Lake Mead

This annual report presents the results of the 22nd field season (July 2017 – June 2018 sonic telemetry data and January 2018 – April 2018 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 2017–18 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. 2017).

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. (2000b). 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 2018, 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)

- 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 inflow; 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).

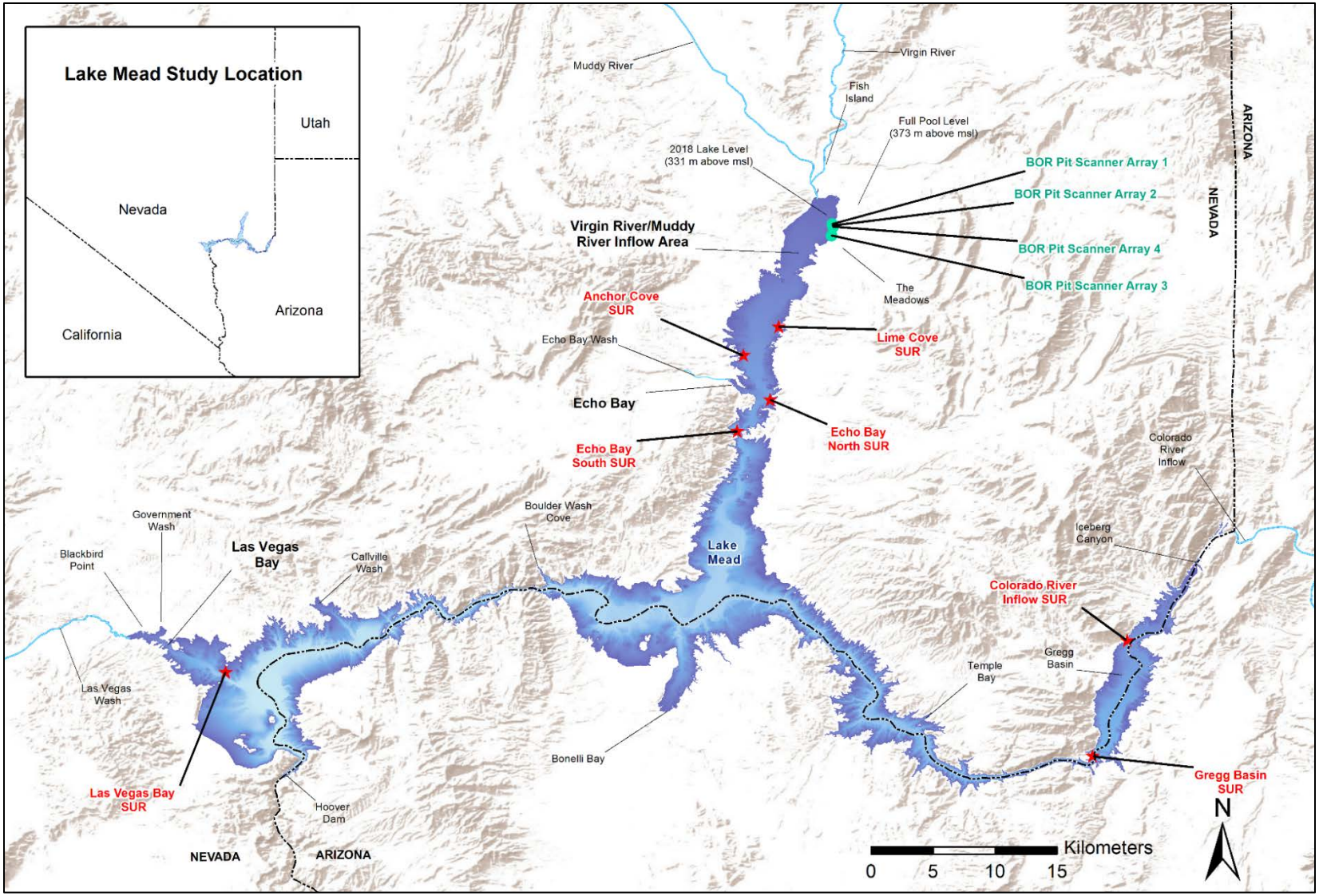

Figure 1.—Long-term monitoring study areas within Lake Mead, along with geographic landmarks.
Red stars indicate locations of long-term monitoring submersible ultrasonic receivers, and green circles represent shore-based PIT scanners.

METHODS

Reservoir Elevation

Month-end (1935–2018) and daily reservoir elevations for the 2017–18 field season (July 1, 2017 – June 30, 2018) 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 2018).

Sonic Telemetry

Sonic telemetry data for the long-term monitoring study were collected from July 1, 2017, to June 30, 2018, to capture movement throughout the study period. At least every other 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.

Sonic Tagging

One wild razorback sucker captured from the Virgin River/Muddy River inflow area was surgically implanted with a Sonotronics model CT-05-48-I (48-month) sonic tag and released at the point of capture. BIO-WEST, upon request, also assisted the NDOW and Reclamation with surgical implantation of Sonotronics model ART-01 (36-month) sonic tags in 13 razorback suckers originally captured as larvae from Lake Mohave and reared in Center Pond at the Overton Wildlife Management Area, Nevada. The NDOW stocked these fish into Las Vegas Bay as part of a multi-agency effort to increase the genetic diversity of razorback suckers in this portion of the lake (Dowling et al. 2017). Prior to surgery, fish were placed into a designated tank containing fresh reservoir or hatchery water, and all sonic tags were checked for full function and identification. All surgical instruments were cold sterilized with iodine and 90% isopropyl alcohol and allowed to air dry on a disposable, sterile cloth. Razorback suckers were initially anaesthetized in 10 liters (L) of reservoir or hatchery water with a 50 milliliter per liter (mL L^{-1}) clove oil/ethanol mixture (0.5 mL clove oil [Anderson et al. 1997] emulsified in 4.5 mL ethanol) (Anderson et al. 1997; Bunt et al. 1999). After anesthesia was induced, total length (TL) in millimeters (mm), fork length (FL) in mm, standard length (SL) in mm, and weight in grams were recorded for each fish. Individual fish were placed dorsal-side down on a padded surgical cradle for support during surgery, with the head and gills submerged in 8 L of fresh water and a maintenance concentration of 25 mL L^{-1} clove oil/ethanol anesthetic (Bunt et al. 1999). Following introduction to the maintenance anesthetic, the surgeon made a 10–15 mm incision on the left side, posterior to the left pelvic girdle. A

PIT tag was inserted into the incision, followed by the sonic tag, which was placed between the pelvic girdle and urogenital pore. The incision was closed with two or three 3-0 Monocryl Plus absorbable poliglecaprone 25 sutures using an attached PS-1 reverse-cutting, curved needle. Surgery times typically ranged from 2 to 5 minutes per fish.

Once surgical implantation was complete, the individual was allowed to recover in fresh reservoir/hatchery water until regaining equilibrium. Prior to release, the individual was re-examined for signs of stress, and sonic tags were rechecked for functionality. Wild razorback suckers were released at their capture location, and no razorback suckers were held for an extended period of time or harmed during these efforts. Fish sonic tagged in the hatchery were released into Lake Mead by agency personnel, depending on project goals.

Active Sonic Telemetry

Active sonic telemetry searches were conducted largely along shorelines, with listening points spaced approximately 0.8 kilometer (km) apart, or as needed, depending on shoreline configuration and other factors that could affect signal reception. Sonic surveillance is line-of-sight, so any obstruction can reduce or block reception of tag signals. The effectiveness of a sonic telemetry signal is also often reduced in shallow, turbid, and/or 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 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 and 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 the 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 deployed during the 2017–18 field season (see figure 1) as part of this long-term monitoring effort.

Each SUR was programmed to detect implanted, active sonic transmitter frequencies using Sonotronics's 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 SURsoftDPC 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). As a quality control check to avoid any false-positive contacts, the confidence scan settings were set to a minimum of two records within 5 minutes of one another. Only after the confidence scan was a record reported as a positive contact of a sonic-tagged razorback sucker.

Adult Sampling

Trammel Netting

Trammel netting occurred from January 3 to April 13, 2018, in Las Vegas Bay, from February 7 to April 18, 2018, in the Virgin River/Muddy River inflow area, and from February 8 to April 17, 2018, in Echo Bay. Two sizes of trammel nets were used to sample for adult fish. The first was 91.4 m long by 1.8 m deep, and the second was 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 fishes, trammel netting was not conducted when surface water temperatures were greater than 20 degrees Celsius (°C) (Hunt et al. 2012).

All captured fishes were removed from nets and held in live wells filled with reservoir water. Native fishes 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 (TL and FL), weighed, and released at the capture location. The remaining non-native species were enumerated and returned to the reservoir. Razorback suckers, flannelmouth suckers (*Catostomus latipinnis*), or suspected razorback sucker × flannelmouth sucker hybrids (hybrids) were

scanned for PIT tags, PIT tagged if they were not recaptured fish, measured (for TL, FL, and SL), weighed, and assessed for sexual maturity, overall health, and reproductive readiness. Individuals that were not sexually defined and did not exhibit sexual maturity (e.g., lack of nuptial tubercles, lack of color, lack of ripeness) and were larger than 450 mm TL were labeled as unidentified, and fish smaller than 450 mm TL were labeled as juveniles. Individuals that were sexually defined were labeled according to their sex despite their size. Suspected hybrids 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 (LMWG), genetic material was removed from newly captured, wild razorback suckers. Genetic samples consisted of removing an approximately 5-mm section of caudal or pectoral fin and preserving the sample in 95% genetics-grade ethanol. After all necessary biological information was collected, fish were released unharmed at the point of capture. All genetic samples were delivered to Reclamation biologists for analyses following the field season.

Data Analysis

In order to be consistent with past annual reports, catch per unit effort (CPUE) for 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. 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 showed deviation from linearity, indicating the data were not normally distributed (Thode 2002). Additionally, data were further tested for normality using a Shapiro-Wilk test. Given that both the Q-Q plots and the results from the Shapiro-Wilk test showed a non-normal distribution of data ($P < 0.05$), the data were transformed [Ln(CPUE+1)]. Hereafter, all mentions of CPUE in the context of adult trammel netting captures are normalized 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 2015–18 for each individual sampling site as well as among the long-term monitoring study areas. The time period 2015–18 was selected for comparison because that is the time period when current long-term monitoring efforts were implemented. 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.

Remote Passive Integrated Transponder Scanning

Four submersible, long-term, remote PIT scanning units were deployed from January 24 to April 24, 2018, south of the Virgin River/Muddy River inflow area along the eastern shoreline near areas were sonic-tagged fish were frequently contacted. The submersible units had 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, mobile remote PIT tag antenna units (with a standard-capacity battery for overnight and short-term deployment) were utilized at each of the three long-term monitoring study areas to detect previously PIT-tagged fish. The mobile antennas were self-contained submersible units in rectangular polyvinyl chloride housing. Mobile scanners were occasionally deployed by Reclamation biologists during the spawning season, often near overnight trammel net sets, and, in most cases, this type of remote unit was retrieved the following day.

With both types of scanning, information recorded included a general location description, GPS location, date, deployment depth, and start and end scanning times. Scanner data were combined for analysis and limited to determining PIT-tagged fish movements and to identifying fish that were not captured via trammel nets in 2018. These data were not used in population or survival estimate models in 2018 in order to maintain protocols of past years and because Lake Mead contains wild, untagged razorback suckers.

Growth

Razorback sucker annual growth was calculated for recaptured individuals previously tagged during trammel netting between 1996 and 2017 using the difference in TL between capture periods. Individuals that were recaptured less than 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 2018 field season were measured only once during the spawning season to avoid handling stress. Because wild or stocked razorback suckers in Lake Mead show no statistical difference in growth (Mohn et al. 2015), annual growth and mean annual growth were calculated for all recaptured fish (both wild and stocked combined) from individual long-term monitoring study areas.

Larval Sampling

The primary larval sampling method followed that 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, two 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 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 analysis 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. The goal was to determine if the introduced fish of Lake Mohave origin would increase genetic diversity in the Las Vegas Bay population (Dowling et al. 2017). 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.

Data Analysis

CPUE for larval razorback sucker captures via active light sampling was calculated as the mean number of fish captured per light-minute. Data were tested for normality using a Shapiro-Wilk test and Q-Q plots in the same manner as the adult sampling data. Given that both methods showed a non-normal distribution of data ($P < 0.05$), the data were transformed [Ln(CPUE+1)]. All mention of CPUE in the context of larval captures represents normalized data. Additionally, larval capture numbers were graphed by date of capture using a kernel density function ("ksmooth" function), where the shape of the curve depends on the density of localized data points in a given area. The default kernel type was used, and the bandwidth was set to a value of 20. The area under each curve on the graph is standardized to equal a value of 1.0. The graph was completed using R version 3.1.2 (R Core Team 2014).

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, 2017). 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 suckers. Captured fish are then evaluated for signs of ripeness,

which are indicative of spawning. After the initial identification of a possible spawning site through sonic-tagged razorback sucker habitat use and other, untagged juvenile or adult trammel-net captures, larval sampling is conducted to validate whether successful spawning occurred. Examples of the effectiveness of these techniques are evident in the descriptions provided by Albrecht and Holden (2005) regarding the documentation of a new spawning 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) of Lake Mead. This same general approach was used at the long-term monitoring study areas in 2018.

Age Determination and Year-Class Strength

A non-lethal aging technique employing fin ray sections was developed in 1999 (Holden et al. 2000a) and has been refined over subsequent years (Albrecht and Holden 2005, Albrecht et al. 2006b, 2008a, 2010a). As in past years, an emphasis for the 2018 long-term monitoring efforts involved collecting fin ray sections from wild razorback suckers for aging purposes.

During the 2018 field season, 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 (tricaine methanesulfonate), NaCl (sodium chloride), 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 (TL, FL, and SL), and 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 isopropyl alcohol before each use, and the resulting incisions were packed with antibiotic ointment to minimize postsurgical 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 held for an extended period of time or harmed 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 at least two readers. Sections were then reviewed by the readers in instances where the assigned age was not agreed upon. If age discrepancies remained after the second reading, all readers collectively assigned an age. Information for all razorback suckers aged since 1999 is listed in attachment 1.

In order to more accurately assess stronger and weaker year classes in Lake Mead, a "catch-curve" method proposed by Maceina (1997) and outlined by Ogle (2016) was used. From the combined four study areas (Las Vegas Bay, Echo Bay, Virgin River/Muddy River inflow area, and CRI), a histogram was used to determine the frequency that fish aged from 1999–2018 were captured in order to determine the ages that are most vulnerable to capture (attachment 2). The histogram demonstrated that razorback suckers aged from 5–20 years old were more commonly captured in trammel nets at Lake Mead (attachment 2). Fish > 20 years old were removed from this analysis because they can be difficult to definitively age, and other studies have found that ages of older fish are often underestimated (Koenigs et al. 2015). The CRI was included in this analysis because previous observations have shown razorback suckers moving between the long-term monitoring study areas and the CRI, and they have similar age structures (Rogers et al. 2017). In order to produce a usable model, multiple razorback suckers from multiple year classes have to be aged in 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 normalized using 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 (Cooch and White 2013) was utilized to produce an estimate from mark-recapture data spanning from 2016 to 2018. This timespan was selected to maintain

consistency with past estimates in which 3-year datasets were used. 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 four combined study areas (long-term monitoring combined with the CRI, to keep with past reports) in Lake Mead were used to produce the estimate. Forty-one capture occasions during the 2016–2018 spawning seasons (January – April) were included in three, full-likelihood, closed-capture models, which were designed to allow for individual differences in behavior (*Mb*), population differences through time (*Mt*), or constant parameters (*Mo*) (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 highest-ranking (i.e., smallest) AIC_c value is reported within. Although considered, no model averaging was conducted because a single model (*Mt*) carried all the AIC_c weight. Model selection rankings and summaries can be found in attachment 3.

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 suckers in Lake Mead was estimated in program MARK for the entire mark-recapture study period spanning from 1996 to 2018 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 [1996–2018] and the CRI [2010–18]). Razorback suckers that were captured in trammel nets were used to produce this model. Twenty-three 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 (ρ, the probability of being recaptured from one year to the next year) were used in the Cormack-Jolly-Seber survival estimator, so that the parameters (φ and ρ) were held either constant (.) or variable through time (t), producing a combination of four model iterations (attachment 4). The models were compared according to AIC_c values, where the best-fitting models have the lowest AIC_c scores. The saturated model ($\phi[t]p[t]$) 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). Although considered, weighted average estimates for φ and p were not calculated for this report because the majority of the weight for the models was carried by a single model ($\phi[.]p[t]$) (attachment 4).

In Lake Mead, razorback suckers smaller than 450 mm TL are generally immature fish (less than 4 years old). As such, and in an effort to be comparable with other razorback sucker populations in the Upper and Lower Colorado River

Basins, annual apparent survival was calculated for adult razorback suckers > 450 mm TL (Albrecht et al. 2013a, 2014b; Zelasko et al. 2011). 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 (1996–2018), 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).

RESULTS

Lake Elevation

Since 2000, reservoir elevations have generally declined; however, during the 2017–18 field season, reservoir elevations increased throughout summer and winter before peaking at 331.7 m in March (figure 2). In 2018, reservoir elevations decreased approximately 1 m during the remainder of the spawning season (March – April) (figure 2). Biologists observed noticeable drying of littoral areas and the loss of expanses of recently inundated terrestrial vegetation within all of the long-term monitoring study areas during these months. The lake elevation decline was particularly noticeable at the Virgin River/Muddy River inflow area, where the reservoir has a more gradual bathymetry.

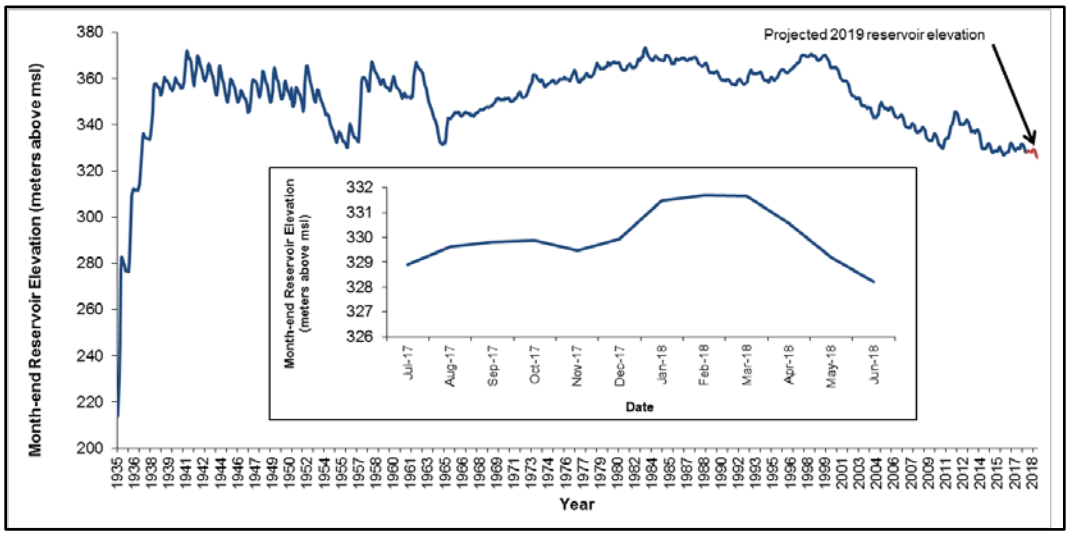

Figure 2.—Lake Mead reservoir elevations, 1935–2018, with projected reservoir elevations for the 2019 study year in red (Reclamation 2018).
Inset shows daily reservoir elevations, July 1, 2017 – June 30, 2018 (Reclamation 2018).

Sonic Telemetry

Over the course of this study, 113 adult razorback suckers (55 wild and 58 hatchery reared) have been equipped with sonic transmitters for the purposes of long-term monitoring and research throughout the study area. This includes one wild razorback sucker that was sonic tagged at the Virgin River/Muddy River inflow area and 13 razorback suckers of Lake Mohave origin that were reared in Center Pond at the Overton Wildlife Management Area and stocked into Las Vegas Bay during the 2018 field season.

Among the three long-term monitoring study areas, 17 unique sonic-tagged fish were detected using active and/or passive telemetry methods during the 2017–18 field season. Fifty-five active contacts were made with 14 individual sonic-tagged razorback suckers, while 3 sonic-tagged fish were only contacted passively via SUR (table 1). In the Overton Arm, 3 SURs contacted 15 sonic-tagged razorback suckers 1,872 times (Lime Cove [n = 1,716], Echo Bay North [n = 83], and Echo Bay South [n = 73] SURs), while the Las Vegas Bay SUR contacted 2 sonic-tagged fish 1,039 times (table 1). No contacts were made on the Anchor Cove SUR.

SUR contacts, in conjunction with active telemetry, are typically used to aide in accounting for difficult-to-locate sonic-tagged fish and better help to define movement patterns. Of the nine sonic-tagged fish contacted in the Overton Arm, seven demonstrated movement between Echo Bay and the Virgin River/Muddy River inflow area (figures 3 and 4; table 1). Additionally, two sonic-tagged fish stocked into Las Vegas Bay remained within the bay throughout the spawning season, and then they were observed entering deeper water in Boulder Basin in the late spring (May – June) (figure 5; table 1).

Fish Sonic Tagged in 2011

During the 2017–18 field season, sonic-tagged fish code 555, which was stocked at the Virgin River/Muddy River inflow area, was contacted 747 times using a combination of active (n = 1) and passive (n = 746) methods (table 1). This fish was last contacted in October 2017 in the northern portion of the Overton Arm by the Lime Cove SUR (table 1; figure 1). It is plausible that this tag is now expired, or should be expiring soon, because its expected battery life has been exceeded.

Table 1.—Initial tagging and stocking information, location, date of last contact, and status of sonic-tagged razorback suckers in Lake Mead, July 2017 – June 2018

Capture location[a]	Date tagged	Sonic code	TL (mm) at tagging[b]	Sex[c]	Release location[a]	Last location[a]	Date of last contact	Contacts made: active (passive)	Current tag status[d]
2011									
FDLB	1/4/2011	334	564	F	LB	LB	2/15/2014	0 (0)	Expired
FDLB	1/4/2011	3545	556	F	LB	LB	7/15/2014	0 (0)	Expired
FDLB	1/4/2011	3584	519	M	LB	LB	6/23/2014	0 (0)	Expired
FDLB	1/4/2011	3775	516	M	LB	LB	1/15/2016	0 (0)	Expired
FDLB	1/4/2011	448	502	M	OA	OA	8/16/2016	0 (0)	Expired
FDLB	1/4/2011	555	504	M	OA	OA	10/12/2017	1 (746)	Unknown
FDLB	1/4/2011	3578	541	F	OA	OA	6/16/2015	0 (0)	Expired
FDLB	1/4/2011	3667	552	F	OA	OA	2/17/2015	0 (0)	Expired
2014									
EB	2/6/2014	586	656	F	EB	EB	6/29/2017	0 (38)	Active
EB	2/12/2014	3375	598	M	EB	EB	3/21/2018	3 (18)	Active
EB	2/12/2014	3447	581	M	EB	AC	4/2/2014	0 (0)	Unknown
EB	2/12/2014	4656	637	M	EB	AC	8/6/2014	0 (0)	Unknown
LB	2/11/2014	3488	626	M	LB	LB	7/11/2016	0 (0)	Unknown
LB	3/11/2014	3566	536	M	LB	LB	6/15/2015	0 (0)	Unknown
CPD	3/16/2014	4778	479	M	LB	LB	9/9/2016	0 (0)	Unknown
OA	2/5/2014	578	520	M	OA	EB	12/19/2017	5 (65)	Active
OA	2/26/2014	3337	589	M	OA	AC	2/16/2016	0 (0)	Unknown
OA	3/6/2014	3374	582	M	OA	EB	7/12/2016	0 (0)	Unknown
OA	3/6/2014	3478	562	M	OA	GH	5/15/2014	0 (0)	Unknown
2017									
LB	1/17/2017	3585	549	M	LB	LB	2/5/2018	7 (0)	Active
LB	4/4/2017	3577	564	M	LB	LB	2/5/2018	9 (0)	Active
EB	2/5/2017	364	582	M	EB	EB	3/5/2018	3 (30)	Active
EB	2/21/2017	3658	628	M	EB	EB	3/21/2018	6 (79)	Active
OA	2/20/2017	6677	585	M	OA	OA	12/5/2017	3 (13)	Active
OA	2/20/2017	3768	576	M	OA	OA	5/3/2018	7 (883)	Active
2018									
CPD	1/5/2018	3109	513	F	LB	LB	1/5/2018	0 (0)	Unknown
CPD	1/5/2018	3110	511	F	LB	LB	4/17/2018	0 (2)	Active
CPD	1/5/2018	3430	481	M	LB	LB	5/17/2018	0 (1,037)	Active
CPD	1/5/2018	3424	504	F	LB	LB	1/5/2018	0 (0)	Unknown
CPD	1/5/2018	3426	457	M	LB	LB	5/2/2018	1 (0)	Active
CPD	1/5/2018	3428	478	F	LB	LB	5/2/2018	4 (0)	Active
CPD	1/5/2018	3431	498	F	LB	LB	5/2/2018	1 (0)	Active
CPD	1/5/2018	3434	534	M	LB	LB	1/5/2018	0 (0)	Unknown
CPD	1/5/2018	3438	582	F	LB	LB	1/5/2018	0 (0)	Unknown
CPD	1/5/2018	3449	472	F	LB	LB	1/5/2018	0 (0)	Unknown
CPD	2/5/2018	488	491	F	LB	LB	1/5/2018	0 (0)	Unknown
CPD	2/5/2018	555	472	M	LB	LB	1/5/2018	0 (0)	Unknown
CPD	2/5/2018	677	505	F	LB	LB	2/20/2018	1 (0)	Active
OA	2/22/2018	487	455	M	OA	OA	5/3/2018	4 (0)	Active

[a] AC = Anchor Cove, CPD = Center Pond in the Overton Wildlife Management Area, EB = Echo Bay, FDLB = Floyd Lamb State Park, GH = Glory Hole, LB = Las Vegas Bay, and OA = Overton Arm (Virgin River/Muddy River inflow area).

[b] TL = Total length in millimeters.

[c] Sex: F = female, and M = male.

[d] Active = Fish considered active and moving, Unknown = fish at-large, and Expired = tag was not located during the tracking season and is well beyond the battery expiration date.

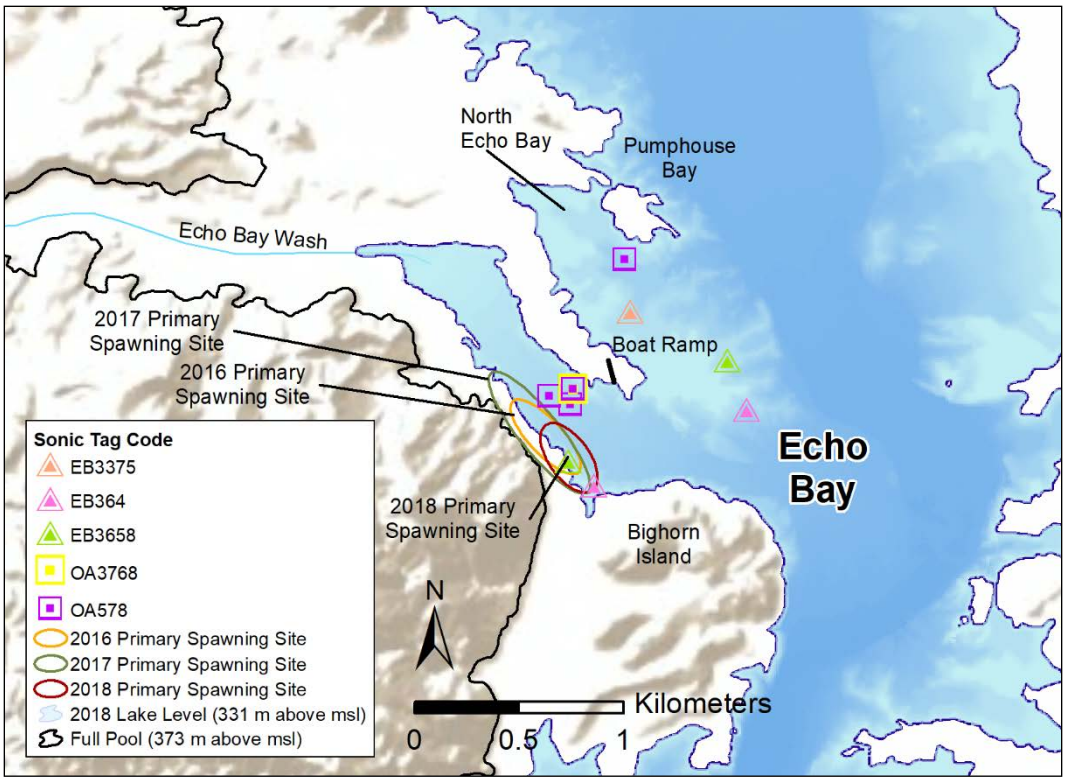

Figure 3.—Distribution of sonic-tagged razorback suckers located through active sonic telemetry in Echo Bay, July 2017 – June 2018.
Symbols for each tag code are unique to their original tagging location, which is noted on the map as the tag code (e.g., fish OA3768 was originally tagged at the Virgin River/ Muddy River inflow area).

Fish Sonic Tagged in 2014

During the 2017–18 field season, 2 of the 11 individuals from the 2014 tagging event were detected 8 times with active sonic telemetry methods (see table 1). Additionally, 3 of the 11 individuals were also passively detected a combined 121 times via three different SURs (see table 1). The contacts were made at the Echo Bay South SUR (n = 54), Echo Bay North SUR (n = 25), and Lime Cove SUR (n = 42) (see table 1; see figure 1 for SUR locations). Individuals that were sonic tagged and released in Echo Bay and the Virgin River/Muddy River inflow area in 2014 were observed moving between their respective release locations during the 2017–18 field season (see figures 3 and 4). One individual (sonic code fish 578) sonic tagged at the Virgin River/Muddy River inflow area in 2014 was contacted near Echo Bay during the spawning season. No sonic-tagged fish from 2014 were detected in Las Vegas Bay (see table 1).

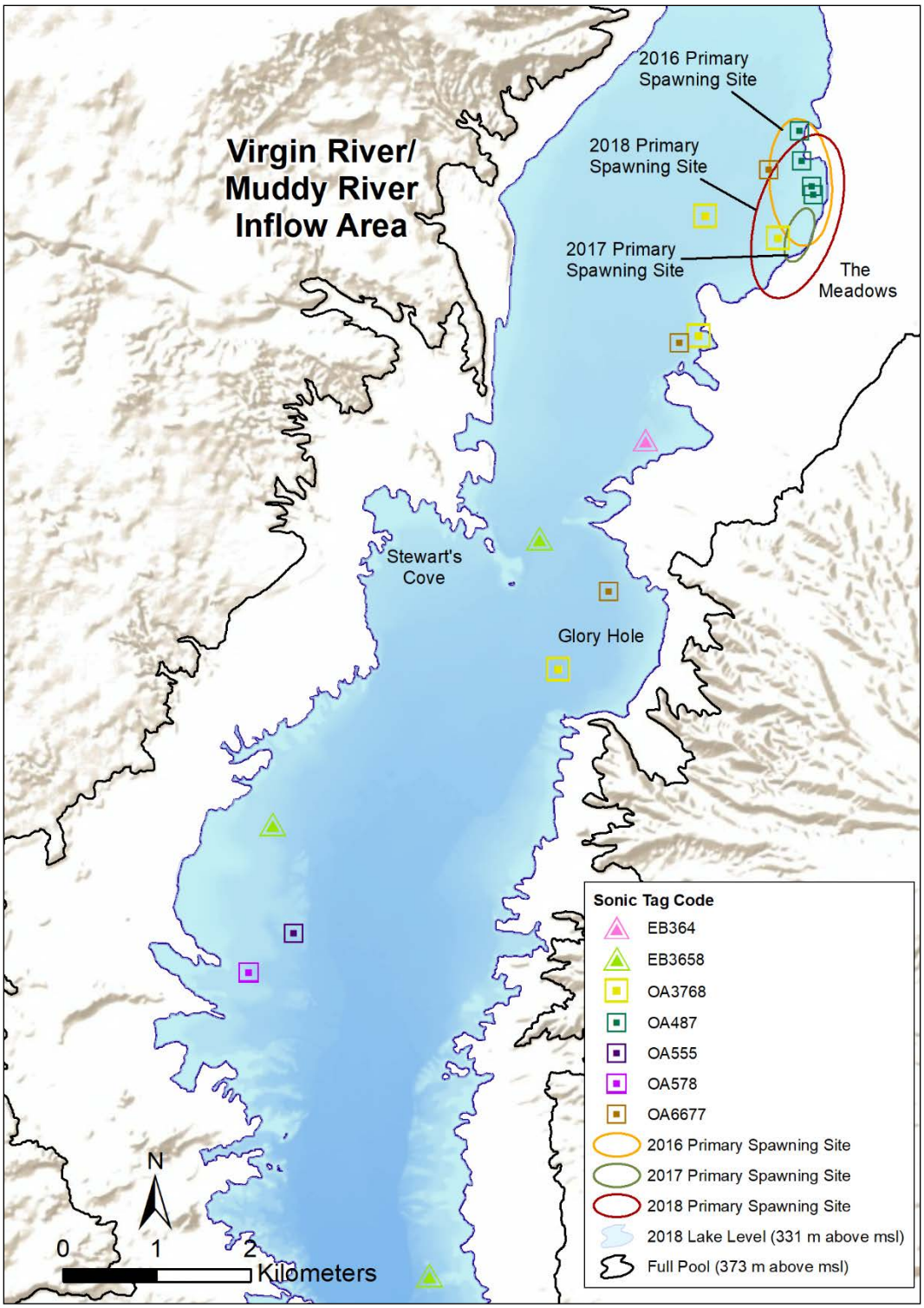

Figure 4.—Distribution of sonic-tagged razorback suckers located through active sonic telemetry near the Virgin River/Muddy River inflow area, July 2017 – June 2018.

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 EB364 was originally tagged at Echo Bay).

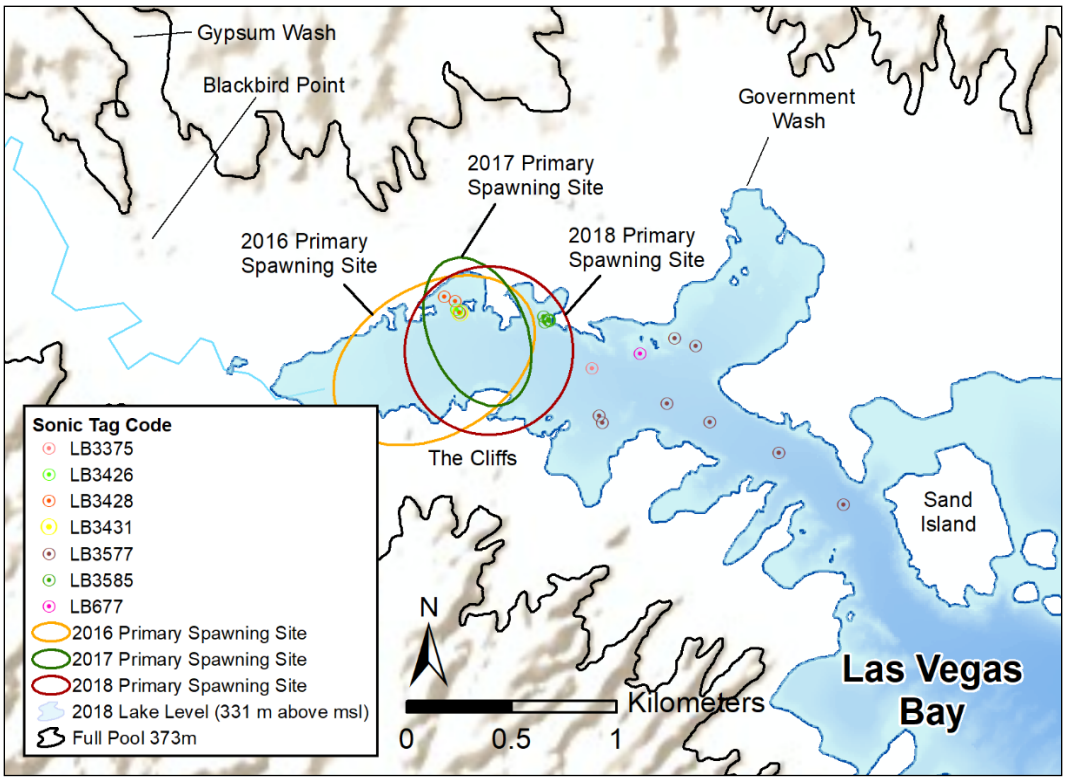

Figure 5.—Distribution of sonic-tagged razorback suckers located through active sonic telemetry in Las Vegas Bay, July 2017 – June 2018.
Symbols for each tag code are unique to their original tagging location, which is noted on the map as the tag code (e.g., LB3585 was originally tagged within Las Vegas Bay).

Fish Sonic Tagged in 2017

All 6 fish sonic tagged in 2017 were contacted 35 times in aggregate via active tracking methods, while 4 fish were contacted 1,005 times via SURs. These fish remained near spawning locations and dispersed into deeper habitats as the spawning period ended (see figures 3–5). In Las Vegas Bay, sonic code fish 3585 was observed moving between deeper mid-channel areas near Government Wash west toward the shallow areas adjacent to Las Vegas Wash throughout the spawning season (see figure 5).

Individuals that were sonic tagged and released in Echo Bay and the Virgin River/Muddy River inflow area in 2017 were observed moving between their respective release locations during the 2017–18 field season (see figures 3 and 4). Four fish (sonic codes 3658, 3768, 364, and 677) were observed moving several times between Echo Bay and the Virgin River/Muddy River inflow area (see figures 3 and 4).

Fish Sonic Tagged in 2018

Fourteen razorback suckers were implanted with sonic tags in 2018. Thirteen were Lake Mohave origin fish reared in Center Pond at the Overton Wildlife Management Area and released by the NDOW as part of an effort by the LMWG to increase razorback sucker genetic diversity in Las Vegas Bay (Dowling et al. 2017). The primary purpose of sonic tagging these individuals was to determine if they had dispersed from Las Vegas Bay. Seven individuals were contacted via either active or passive methods during the study period (see table 1). Active tracking methods observed these fish moving from Government Wash west toward Las Vegas Wash shortly after being stocked. Most of these fish remained near, or presumably within, Las Vegas Wash during the majority of the spawning season. Then, in late spring (May – June 2018), the Las Vegas Bay SUR detected two fish (sonic codes 3430 and 3110) dispersing into the deeper waters of Boulder Basin (see figure 5).

Lastly, during long-term monitoring efforts at the Virgin River/Muddy River inflow area, one wild razorback sucker was captured and implanted with a sonic tag (sonic code 487) in February 2018 and remained near the spawning area for the remainder of the spawning season (see figure 4). This fish was last contacted on May 3, 2018, just south of the Virgin River/Muddy River inflow (see table 1).

Adult Sampling

Trammel Netting

Trammel netting was conducted from January 3 to April 18, 2018, and consisted of 113 net sets totaling 1,748 net-hours (table 2; figures 6–8). This total includes the efforts of BIO-WEST, Reclamation, and the NDOW. During these trammel netting efforts, 45 razorback suckers were captured (table 3). Additionally, eight flannelmouth suckers and two hybrids (razorback sucker × flannelmouth sucker) were captured. The first male razorback sucker expressing milt and the first female expressing eggs were both captured on January 4, 2018, in Las Vegas Bay.

Table 2.—Trammel netting efforts (number of nets and net-hours) on Lake Mead, January – April 2018

Month	Las Vegas Bay	Echo Bay	Virgin River/Muddy River inflow area	Total
January	28	0	0	28
February	10	8	10	28
March	6	19	17	42
April	3	9	3	15
Total number of nets	**47**	**36**	**30**	**113**
Total net-hours	**733.5**	**535.6**	**478.9**	**1,748.0**

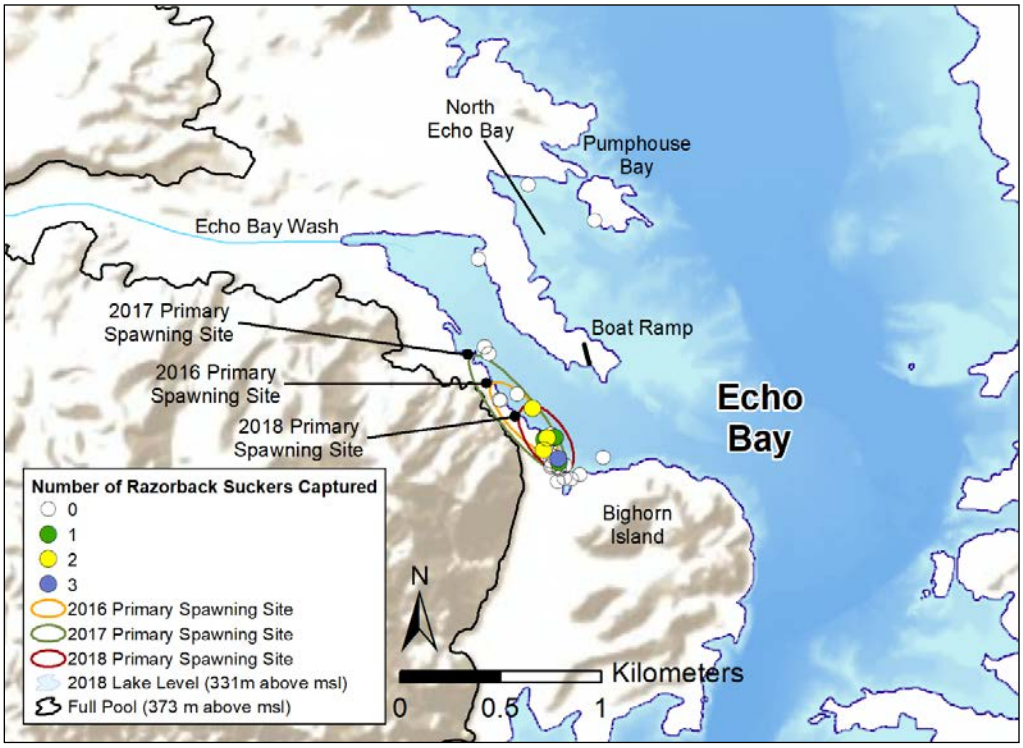

Figure 6.—Locations of trammel netting efforts and numbers of razorback suckers captured in Las Vegas Bay, January – April 2018.

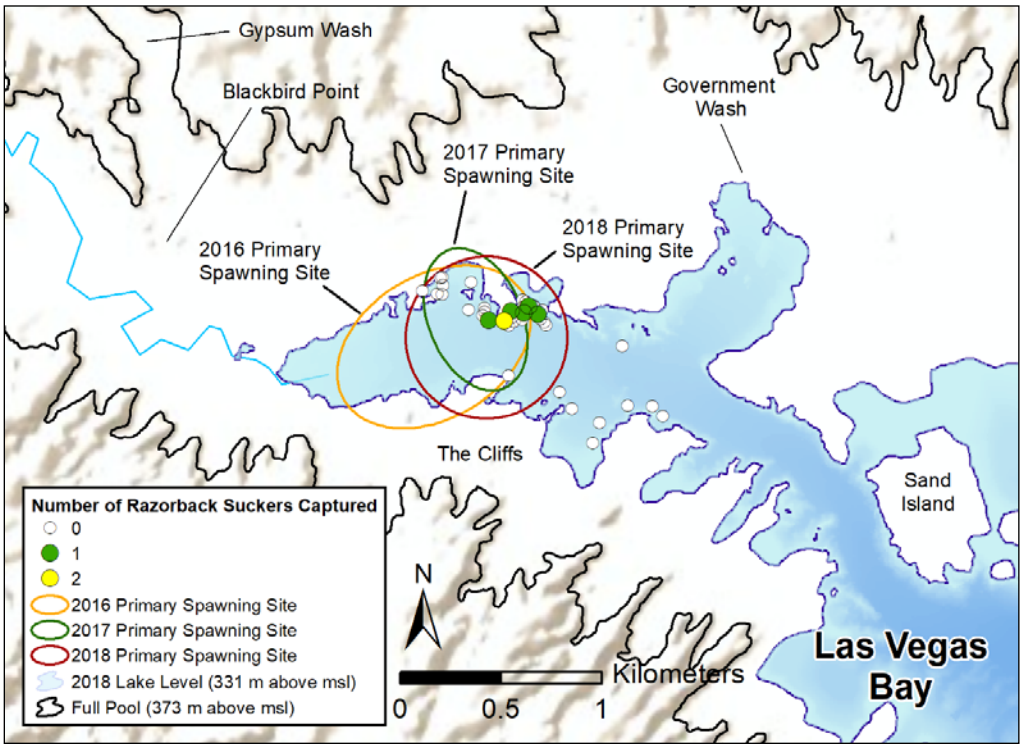

Figure 7.—Locations of trammel netting efforts and numbers of razorback suckers captured in Echo Bay, February – April 2018.

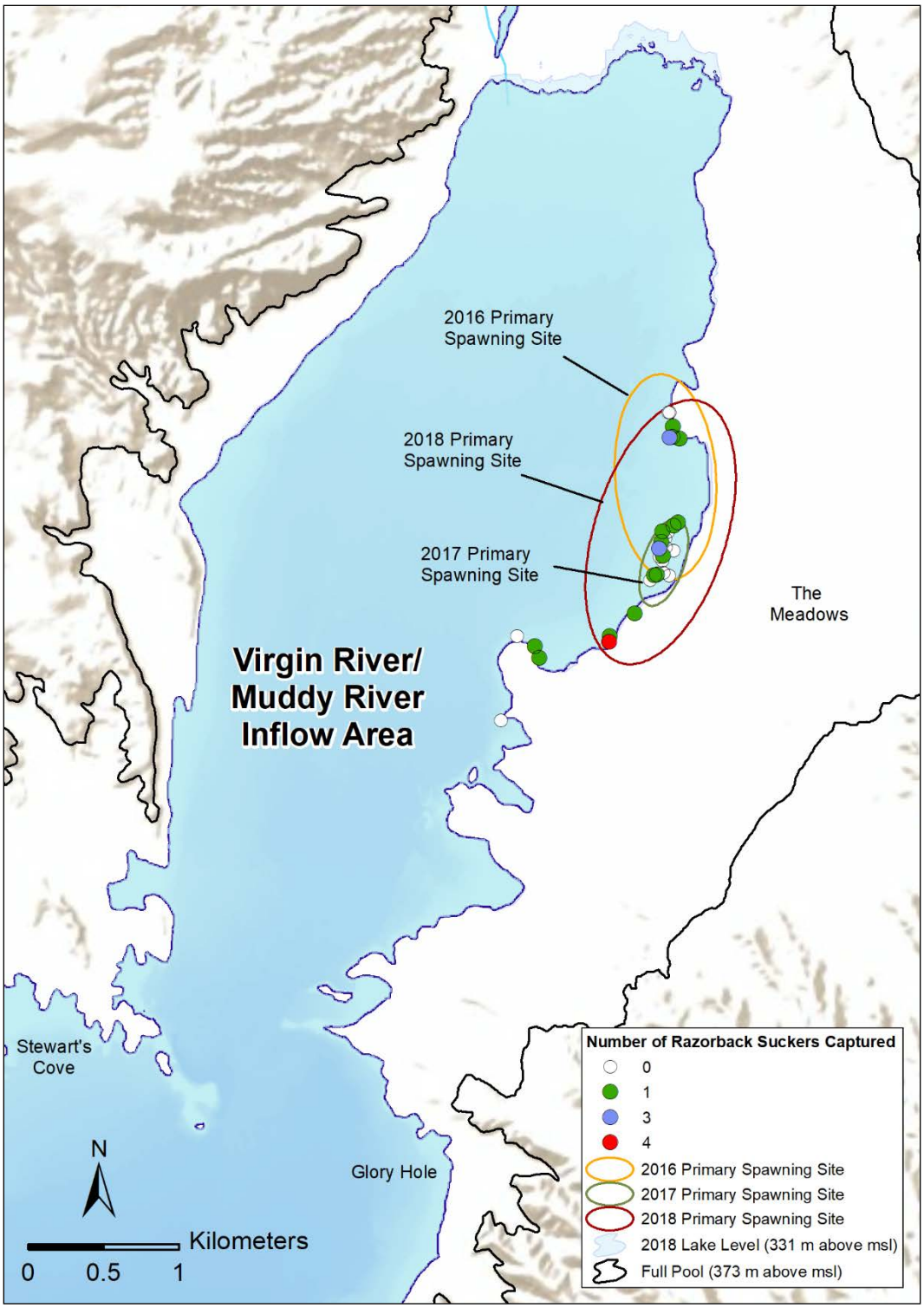

Figure 8.—Locations of trammel netting efforts and numbers of razorback suckers captured at the Virgin River/Muddy River inflow area, February – April 2018.

Table 3.—Capture location, tagging, and size information for razorback suckers captured from January 3 – April 18, 2018

Date	Capture location[a]	Date tagged or stocked[b]	Sonic code	PIT tag	Recapture	TL[c]	FL[d]	SL[e]	WT[f]	Sex[g]	Origin
1/4/2018	LB	2/6/2015		3D9.257C602471	Y	604	561	517	2,328	F	Stocked
1/4/2018	LB	2/6/2015		3D9.1C2D6428BB	Y	Quick release				M	Stocked
1/17/2018	LB	1/17/2018		3DD.003BCB93B3	N	546	504	473	1,868	F	Wild
1/25/2018	LB	1/25/2018		3DD.003BFECC92	N	508	470		1,570	M	Wild
2/7/2018	OA	2/7/2018		3DD.003BCB9389	N	451	421	376	1,120	J	Wild
2/7/2018	OA	2/7/2018		3DD.003BCB937E	N	535	479	436	1,588	M	Wild
2/8/2018	EB	3/22/2016		3DD.003BCB93BF	Y	556	512	483	1,898	M	Wild
2/14/2018	EB	4/5/2016		3DD.003BCB938F	N	600	606		3,015	F	Wild
2/15/2018	OA	2/15/2018		3DD.003BFECCE0	N	529	490		1,935	M	Wild
2/15/2018	OA	3/21/2013		384.1B7969ECFB	Y	590	545		2,550	M	Wild
2/15/2018	OA	3/9/2018		384.1B79697992	Y	673	621		3,470	F	Wild
2/15/2018	OA	2/15/2018		3DD.003BFECCD9	N	469	434		1,025	U	Wild
2/15/2018	OA	2/15/2018		3DD.003BE8F508	N	496	453		1,460	M	Wild
2/15/2018	OA	1/4/2011	3578	3D9.257C6096E1	Y	630	589		3,105	F	Stocked
2/15/2018	OA	2/15/2018		3DD.003BE8F541	N	614	573		2,685	F	Wild
2/22/2018	OA	2/26/2014		3DD.003BA2FA93	Y	615	562	522	2,788	F	Wild
2/22/2018	OA	3/20/2017		3DD.003BCB9318	Y	600	556	516	2,798	F	Wild
2/22/2018	OA	3/11/2009		3D9.1C2C7EF17C	Y	636	588	554	2,798	F	Wild
2/22/2018	OA	2/22/2018		3DD.003BCB934B	N	655	606	570	2,818	F	Wild
2/22/2018	OA	2/22/2018	487	3DD.003BCB931A	N	455	411	389	1,088	M	Wild
2/27/2018	LB	2/6/2015		3D9.257C602471	Y	615	575		2,090	F	Wild
2/27/2018	LB	2/27/2018		3D9.2794E2399F	N	520	475		1,545	M	Wild
2/28/2018	OA	2/28/2018		3DD.003BC89C92	N	455			1,130	U	Wild
2/28/2018	OA	2/28/2018		384.36F2B243B0	N	640			2,765	F	Wild
2/28/2018	OA	3/15/2011		3D9.1C2C841581	Y	655			3,330	F	Wild
3/6/2018	OA	3/22/2016		3DD.003BCB9392	Y	562	520		1,920	M	Wild
3/6/2018	OA	3/6/2018		3DD.003BCB938A	N	611	568	532	2,444	F	Wild
3/6/2018	EB	3/6/2018		3DD.003BC89C90	N	476	435		1,140	M	Wild
3/6/2018	EB	3/6/2018		384.36F2B2435E	N	472	431		1,020	M	Wild
3/7/2018	OA	3/14/2013		3D9.1C2D263000	Y	660	605		2,990	F	Wild
3/7/2018	OA	1/27/2017		3D9.2794E27D5A	Y	600	550		1,945	M	Wild
3/7/2018	OA	3/7/2018		3DD.003BCB939A	N	468	431	402	1,188	U	Wild
3/8/2018	LB	3/8/2018		3DD.003BCB9639	N	630	590		2,525	F	Wild
3/8/2018	OA	3/8/2018		3DD.003BCB939B	N	481	442	406	1,188	U	Wild
3/22/2018	EB	4/10/2013		384.1B7969DEEA	Y	653	600	561	3,238	F	Wild
3/22/2018	EB	2/21/2017		3DD.003BCB9337	Y	564	525	488	1,758	M	Wild
3/22/2018	EB	3/22/2018		3DD.00.BCB93C9	N	469	435	400	1,158	M	Wild
3/28/2018	EB	3/22/2018		3DD.003BCB93C9	Y	466	430		1,185	M	Wild
3/28/2018	EB	2/9/2010		3D9.257C60A1F0	Y	609	559		2,365	M	Wild
3/28/2018	EB	3/28/2018		3D9.2794E9143F	N	479	432		12.5	M	Wild
3/28/2018	EB	3/28/2018		3D9.2794E9F9EE	N	489	450		965	M	Wild
3/28/2018	EB	3/28/2018		3DD.003BCB964C	N	581	535		1,825	F	Wild
4/10/2018	LB	4/10/2018		3D9.2794EA08CA	N	600	565		2,250	F	Wild
4/17/2018	EB	4/17/2018		3DD.003BCB9393	N	634	579	538	2,748	F	Wild
4/18/2018	OA	4/18/2018		3DD.003BCB937B	N	454	435	403	1,346	J	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] TL = Total length (mm).
[d] FL = Fork length (mm).
[e] SL = Standard length (mm).
[f] Wt = Weight (grams).
[g] Sex: F = female, M = male, U = undetermined, and J = juvenile.

Of the captured Lake Mead razorback suckers from combined long-term monitoring study areas, 20 were female, 19 were male, 2 were juvenile, and 4 were of unknown sex at time of capture (see table 3). Eighteen razorback suckers were recaptured fish, and 27 were wild, unmarked fish (see table 3). One fish captured was a stocked, sonic-tagged fish from 2011 (sonic code 3578 – sonic tag battery expired). This individual appeared to be healthy and had presumably integrated with the wild spawning population, as it was captured alongside other, wild, spawning adults. Eight individuals were captured in Las Vegas Bay; five were female and three were male (see table 3; see figure 6). Thirteen adult razorback suckers were captured in Echo Bay; four were female and nine were male (see table 3; see figure 7). Razorback suckers captured south of the Virgin River/Muddy River inflow area comprised 11 females, 7 males, 4 undetermined sex, and 2 juveniles (see table 3; see figure 8).

The combined long-term monitoring 2018 trammel netting efforts in Lake Mead yielded an overall mean razorback sucker CPUE of 0.0238 (± standard error [SE] = 0.0042). In general, the mean CPUE in 2018 fell within the historical context of this study period (figure 9). Efforts in Las Vegas Bay focused on the western shore of the bay outside of Las Vegas Wash (see figure 6). Eight razorback suckers were captured in 733.5 net-hours (see tables 2 and 3). This effort yielded a mean CPUE of 0.0102 (± SE =0.0038) for Las Vegas Bay in 2018 (figure 9). The study years 2007–11 appear to have been particularly successful years for capturing razorback suckers in Las Vegas Bay (figure 9).

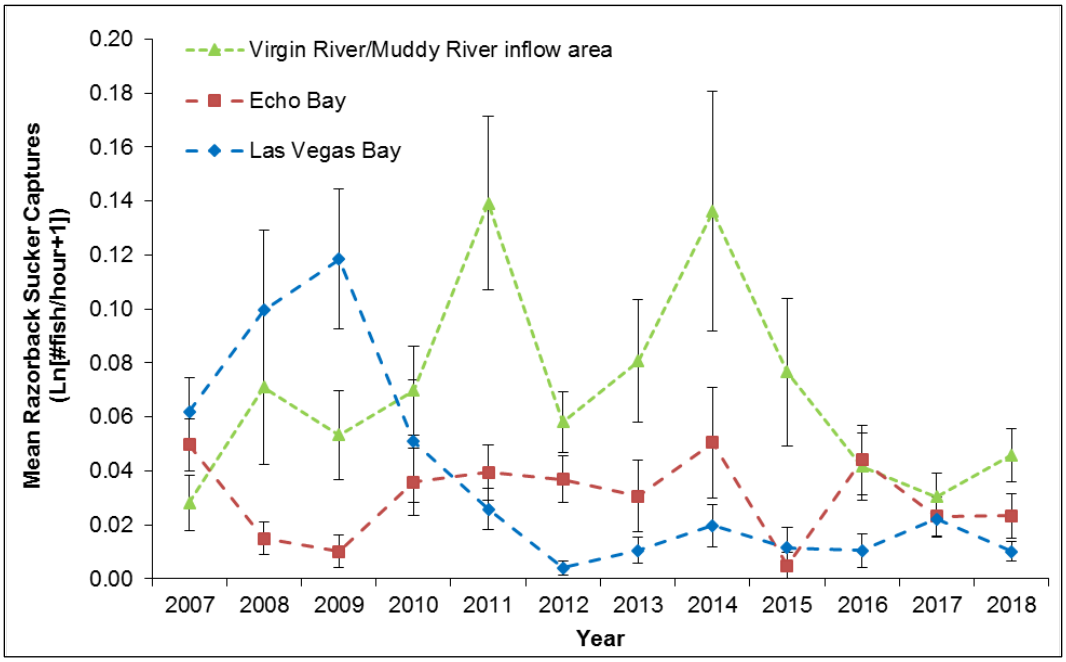

Figure 9.—Trammel netting mean CPUE (Ln[#fish/hr+1]) with associated SE of razorback suckers at long-term monitoring study areas in Lake Mead, 2007–18.

Trammel netting efforts in Echo Bay primarily focused on the western shoreline across from the boat ramp, which resulted in the capture of 13 razorback suckers from 535.6 net-hours (see figure 7; see tables 2 and 3). Echo Bay had a mean razorback sucker CPUE of 0.0233 (± SE = 0.0082) in 2018 (see figure 9). Again, the 2018 CPUE appears to fall within the historical context of Echo Bay netting efforts, and CPUE has been a consistent at this location, with the exception of 2015, when field efforts were reduced (see figure 9). Movement was also documented this year when two wild adult razorback suckers, which were originally captured and tagged at the Virgin River/Muddy River inflow area (in 2010 and 2013, respectively), were recaptured in Echo Bay (see table 5). One fish was an adult male that had been at large for 2,969 days, while the other was an adult female that had been at large for 1,807 days.

Trammel netting within the Virgin River/Muddy River inflow area resulted in the capture of 24 razorback suckers from 478.9 net-hours and yielded a mean CPUE of 0.0458 (± SE = 0.0098) in 2018 (see figure 9; see tables 2 and 3). Sampling at the Virgin River/Muddy River inflow area occurred primarily along the eastern shore 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 8). The Virgin River/Muddy River inflow area has shown relatively dramatic increases and decreases of mean CPUE through time (see figure 9).

The mean 2018 CPUE values significantly varied among the long-term monitoring study areas (ANOVA: $F_{2,110} = 6.44$, $P = 0.0023$). Post-hoc pairwise comparisons showed that the Virgin River/Muddy River inflow area CPUE was significantly higher than the CPUE at Las Vegas Bay (see figure 9). Annual mean CPUE did not statistically differ among years over the period 2015–18 within any of the monitoring areas (Las Vegas Bay, ANOVA: $F_{3,112} = 1.10$, $P = 0.3540$; Echo Bay, ANOVA: $F_{3,130} = 1.80$, $P = 0.1511$; Virgin River/Muddy River inflow area, ANOVA: $F_{3,104} = 1.39$, $P = 0.2509$).

Eight flannelmouth suckers were also captured in 2018. One new flannelmouth sucker was captured in Echo Bay, and one new flannelmouth sucker was captured in Las Vegas Bay. The other six flannelmouth suckers, along with two hybrid suckers, were recaptured at the Virgin River/Muddy River inflow area.

Remote Passive Integrated Transponder Scanning

Within the three long-term monitoring study areas, remote PIT scanning efforts were conducted for 8,737.8 hours and resulted in the detection of 100 unique razorback suckers ($n = 76$, previously tagged, wild razorback suckers and $n = 24$ stocked razorback suckers). At the three long-term monitoring study areas combined, 89 of the razorback suckers contacted were not captured in trammel nets in 2018 (table 4). Scanners deployed in Las Vegas Bay and Echo Bay

Table 4.—Remote PIT tag scanner detections at long-term monitoring study areas with scanner locations, last capture date, original tagging location, and days at large of each individual PIT-tagged species detected in 2018

Remote PIT tag detections	Date scanned	Scanner location[a]	Date of last capture	Original tagging location[a]	Days at large	Species[b]	Origin
3D9.2794E31A6A	1/9/2018	LB	1/12/2017	LB	362	RZ	Stocked
3DD.003BCBFE3F	1/9/2018	LB	1/12/2017	LB	362	RZ	Stocked
3D9.23DB21618D	1/23/2018	LB	1/12/2017	LB	376	RZ	Stocked
3D9.2794D69087	1/23/2018	LB	1/12/2017	LB	376	RZ	Stocked
3D9.1C2C841878	1/25/2018	OA	3/1/2011	OA	2,522	RZ	Wild
3D9.257C619B4D	1/25/2018	OA	3/18/2010	OA	2,870	RZ	Wild
3D9.2794E27E61	1/25/2018	OA	1/12/2017	LB	378	RZ	Stocked
3DD.003BA63970	1/25/2018	OA	2/6/2015	OA	1,084	RZ	Stocked
3DD.003BA63994	1/25/2018	OA	2/6/2015	OA	1,084	RZ	Stocked
3DD.003BA639B1	1/25/2018	OA	2/6/2015	OA	1,084	RZ	Stocked
3DD.003BA76885	1/26/2018	OA	3/24/2016	OA	673	RZ	Wild
3D9.1C2C7F4A82	1/27/2018	OA	3/20/2014	OA	1,409	RZ	Wild
3D9.1C2D27580E	1/27/2018	OA	2/4/2015	OA	1,088	RZ	Wild
3D9.257C60E183	1/27/2018	OA	2/22/2011	OA	2,531	RZ	Wild
3D9.1C2C83B85B	1/28/2018	OA	3/24/2010	EB	2,867	RZ	Wild
3D9.1C2C841AC6	1/28/2018	OA	3/15/2011	OA	2,511	RZ	Wild
3D9.1C2D6974B7	1/28/2018	OA	2/6/2015	OA	1,087	RZ	Stocked
3DD.003BA2FA93	1/28/2018	OA	2/22/2018	OA	-25	RZ	Wild
3DD.003BA62D53	1/28/2018	OA	3/24/2016	OA	675	RZ	Wild
3DD.003BA639A8	1/28/2018	OA	2/6/2015	OA	1,087	RZ	Stocked
3DD.003BA7688C	1/28/2018	OA	3/3/2017	OA	331	RZ	Wild
3D9.257C5F4527	1/29/2018	OA	3/24/2010	EB	2,868	RZ	Wild
3D9.257C6000D6	1/29/2018	OA	2/3/2010	OA	2,917	RZ	Wild
3D9.1C2D262764	1/30/2018	OA	2/17/2016	OA	713	RZ	Wild
3D9.1C2D63A1C2	1/30/2018	OA	2/6/2015	OA	1,089	RZ	Stocked
3DD.003BA63962	1/30/2018	OA	2/6/2015	OA	1,089	RZ	Stocked
3D9.1C2C7F47CD	2/2/2018	OA	3/1/2011	OA	2,530	RZ	Wild
3D9.1C2D695D82	2/2/2018	OA	1/13/2017	OA	385	RZ	Stocked
3D9.257C608715	2/2/2018	OA	2/1/2011	OA	2,558	RZ	Wild
3D9.257C61BD72	2/2/2018	OA	2/1/2011	OA	2,558	RZ	Wild
3DD.003BC89EBC	2/2/2018	OA	3/4/2015	OA	1,066	RZ	Wild
384.1B796EE4CF	2/3/2018	OA	2/6/2015	OA	1,093	RZ	Stocked
3D9.1C2C840DFB	2/3/2018	OA	2/21/2013	OA	1,808	RZ	Wild
3D9.1C2D268EC1	2/3/2018	OA	3/27/2013	OA	1,774	RZ	Wild
384.1B7969D27B	2/4/2018	OA	2/20/2017	OA	349	RZ	Wild
384.1B7969E7AA	2/4/2018	OA	2/26/2014	OA	1,439	RZ	Wild
3D9.1C2C7EF17C	2/4/2018	OA	2/22/2018	OA	-18	RZ	Wild
384.1B7969E26C	2/6/2018	OA	3/20/2014	OA	1,419	RZ	Wild
3DD.003BA74917	2/7/2018	OA	3/24/2016	OA	685	RZ	Wild
3DD.003BA7492E	2/7/2018	OA	2/16/2016	OA	722	RZ	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 at large of each individual PIT-tagged species detected in 2018

Remote PIT tag detections	Date scanned	Scanner location[a]	Date of last capture	Original tagging location[a]	Days at large	Species[b]	Origin
384.1B7969DB4E	2/8/2018	OA	3/13/2012	OA	2,158	RZ	Wild
3D9.1C2D2636A6	2/8/2018	OA	4/12/2012	EB	2,128	RZ	Wild
3D9.1C2D267EBC	2/8/2018	OA	2/6/2013	OA	1,828	RZ	Wild
3D9.1C2D269008	2/8/2018	OA	3/6/2014	OA	1,435	RZ	Wild
3D9.1C2D63A99F	2/8/2018	OA	1/20/2016	OA	750	RZ	Stocked
3D9.1C2D694E50	2/8/2018	OA	2/6/2015	OA	1,098	RZ	Stocked
384.1B7969DA02	2/9/2018	OA	3/3/2017	OA	343	RZ	Wild
3D9.1C2D2633CB	2/9/2018	OA	2/22/2011	OA	2,544	RZ	Wild
3D9.1C2D266829	2/9/2018	OA	3/1/2011	OA	2,537	RZ	Wild
3D9.1C2D269C8A	2/9/2018	OA	4/11/2012	OA	2,130	RZ	Wild
3DD.003BA2FAC1	2/9/2018	OA	3/24/2016	OA	687	RZ	Wild
3DD.003BA63971	2/9/2018	OA	2/6/2015	OA	1,099	RZ	Stocked
3DD.003BC89F07	2/9/2018	OA	2/4/2017	OA	370	RZ	Wild
384.1B796EE08B	2/10/2018	OA	3/1/2012	CI	2,172	RZ	Wild
384.1B796EF3CF	2/10/2018	OA	2/6/2015	OA	1,100	RZ	Stocked
3DD.003BC89EB2	2/10/2018	OA	3/31/2015	OA	1,047	RZ	Wild
3DD.003BCB93BF	2/10/2018	OA	2/8/2018	EB	2	RZ	Wild
3D9.1C2D25DDC6	2/11/2018	OA	2/17/2010	OA	2,916	RZ	Wild
3D9.1C2D263000	2/11/2018	OA	3/7/2018	OA	-24	RZ	Wild
384.1B7969ECFB	2/12/2018	OA	2/15/2018	OA	-3	RZ	Wild
3D9.1C2C8408E1	2/12/2018	OA	2/26/2014	OA	1,447	RZ	Wild
3DD.003BA2FAA2	2/12/2018	OA	2/26/2014	OA	1,447	RZ	Wild
3D9.1C2C841581	2/13/2018	OA	2/28/2018	OA	-15	RZ	Wild
3DD.003BA2FA89	2/13/2018	OA	3/6/2014	OA	1,440	RZ	Wild
3DD.003BCB9395	2/13/2018	OA	2/24/2016	OA	720	RZ	Wild
384.1B796EEDB4	2/14/2018	OA	1/4/2011	OA	2,598	RZ	Stocked
3DD.003BCB963A	2/14/2018	OA	10/21/2015	EB	847	RZ	Wild
384.1B796EDFC4	2/17/2018	OA	10/17/2013	OA	1,584	RZ	Wild
384.1B79697992	2/21/2018	OA	2/15/2018	OA	6	RZ	Wild
3DD.003BA639A5	2/27/2018	OA	2/6/2015	OA	1,117	RZ	Stocked
3D9.1C2C840759	2/28/2018	OA	3/26/2012	EB	2,165	RZ	Wild
3DD.003BA63996	3/1/2018	OA	2/6/2015	OA	1,119	RZ	Stocked
384.1B7969DAE6	3/3/2018	OA	4/10/2013	OA	1,788	RZ	Wild
384.1B796EE7E6	3/3/2018	OA	12/27/2012	OA	1,892	RZ	Wild
3D9.1C2C840860	3/3/2018	OA	2/21/2013	OA	1,836	RZ	Wild
3D9.1C2D261224	3/3/2018	OA	4/5/2011	OA	2,524	RZ	Wild
3D9.1C2D6966BE	3/3/2018	OA	2/6/2015	OA	1,121	RZ	Stocked
3DD.003BCB93A7	3/3/2018	OA	4/5/2016	EB	697	RZ	Wild
384.1B7969D8F2	3/4/2018	OA	3/20/2014	OA	1,445	RZ	Wild
384.1B7969DE0B	3/5/2018	EB	2/21/2017	EB	377	RZ	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 at large of each individual PIT-tagged species detected in 2018

Remote PIT tag detections	Date scanned	Scanner location[a]	Date of last capture	Original tagging location[a]	Days at large	Species[b]	Origin
3D9.1C2C843DBF	3/5/2018	EB	4/10/2014	OA	1,425	RZ	Wild
3D9.1C2D268EAF	3/5/2018	EB	2/16/2012	EB	2,209	RZ	Stocked
3D9.257C60A1F0	3/5/2018	EB	3/28/2018	EB	-23	RZ	Wild
3D9.1C2C83D7FC	3/6/2018	EB	2/12/2014	EB	1,483	RZ	Wild
3D9.257C612FA9	3/6/2018	EB	2/5/2017	EB	394	RZ	Wild
3DD.003BA2FA86	3/6/2018	EB	2/29/2016	EB	736	RZ	Wild
3DD.003BCB9318	3/7/2018	OA	2/22/2018	OA	13	RZ	Wild
3D9.2794DDFD15	3/8/2018	LB	1/12/2017	LB	420	RZ	Stocked
3D9.025893A7D7	3/9/2018	OA	3/3/2017	OA	371	RZ	Wild
3D9.257C60B636	3/28/2018	EB	3/20/2014	OA	1,469	RZ	Wild
3DD.003BA2FA96	3/28/2018	EB	3/22/2016	EB	736	RZ	Wild
3D9.1C2C83C396	4/2/2018	OA	2/7/2012	OA	2,246	RZ	Wild
3D9.1C2C843FA8	4/6/2018	OA	2/8/2012	OA	2,249	RZ	Wild
384.1B7969CC00	4/14/2018	OA	2/21/2012	OA	2,244	RZ	Wild
3DD.003BCB939B	4/16/2018	OA	3/8/2018	OA	39	RZ	Wild
3DD.003BCB9317	4/21/2018	OA	2/21/2017	EB	424	RZ	Wild
3DD.003BCB9380	4/21/2018	OA	2/24/2016	OA	787	RZ	Wild
3DD.003BCB939A	4/21/2018	OA	3/7/2018	OA	45	RZ	Wild
3D9.1C2D265BAF	4/23/2018	OA	3/1/2011	OA	2,610	RZ	Wild
3D9.1C2D26865F	4/23/2018	OA	2/21/2013	OA	1,887	RZ	Wild
3DD.003BCA7E9C	3/22/2018	OA	4/5/2015	GC	1,082	CP	Wild
3DD.003BCA7EC1	3/26/2018	OA	4/5/2015	GC	1,086	CP	Wild
3DD.003BCB93D1	3/6/2018	EB	Unknown	Unknown	Unknown	Unknown	Unknown
3DD.003BCB937F	3/29/2018	OA	Unknown	Unknown	Unknown	Unknown	Unknown

[a] EB = Echo Bay, GC = Grand Canyon-Bright Angel Creek, LB = Las Vegas Bay, and OA = Overton Arm (Virgin River/Muddy River inflow area).
[b] CP = common carp, and RZ = razorback sucker.

scanned for 298.4 and 416.8 hours, respectively. Five razorback suckers (175–461 mm TL, at time of stocking) were detected in Las Vegas Bay, all of which were from the January 12, 2017, LMWG juvenile stocking efforts (Rogers et al. 2017). Ten fish (n = 9 razorback suckers and n = 1 unknown PIT tag) were detected via PIT scanners in Echo Bay during 2018 see (see table 4). Scanners deployed at the Virgin River/Muddy River inflow area scanned for 8,022.6 hours and had the most razorback sucker contacts (n = 86) (see table 4).

Table 5.—Lake Mead razorback sucker growth histories for recaptured fish, January – April 2018

PIT tag number[a]	Date captured[b]	Location captured[c]	Captured TL (mm)[d]	Sex[e]	Date recaptured[f]	Location recaptured[c]	Recaptured TL (mm)[d]	Change in TL (mm)[g]	Days between captures	Origin	Annual growth (mm/year)[h]
Echo Bay											
3D9.257C60A1F0	2/9/2010	OA	500	M	3/1/2818	EB	609	109	2,969	Wild	13.40
384.1B7969DEEA	4/10/2013	OA	598	F	3/22/2018	EB	653	55	1,807	Wild	11.11
3DD.003BCB93CA	2/16/2016	EB	540	M	3/9/2018	EB	547	7	387	Wild	6.60
3DD.003BCB93BF	3/22/2016	EB	545	M	2/8/2018	EB	556	11	688	Wild	5.84
3DD.003BCB9337	2/21/2017	EB	560	M	03/22/18	EB	564	4	394	Wild	3.71
Mean annual growth										**8.13 (±SE = 1.79)**	
Virgin River/Muddy River inflow area											
3D9.1C2C7EF17C	3/11/2009	OA	585	F	2/22/2018	OA	636	51	3,270	Wild	5.69
3D9.257C6096E1	1/4/2011	OA	541	F	2/15/2018	OA	630	89	2,599	Stocked	12.50
3D9.1C2C841581	3/15/2011	OA	576	F	2/28/2018	OA	655	79	2,542	Wild	11.34
3D9.1C2D263000	3/14/2013	OA	616	F	3/7/2018	OA	660	44	1,819	Wild	8.83
384.1B7969ECFB	3/21/2013	OA	551	M	2/15/2018	OA	590	39	1,792	Wild	7.94
3DD.003BA2FA93	2/26/2014	OA	570	F	2/22/2018	OA	615	45	1,457	Wild	11.27
3DD.003BCB9392	3/22/2016	OA	541	M	3/6/2018	OA	562	21	714	Wild	10.74
3D9.2794E27D5A	1/27/2017	OA	592	M	3/7/2018	OA	600	8	404	Wild	7.23
Mean annual growth										**9.44 (±SE = 0.84)**	
Las Vegas Bay											
3D9.257C602471	2/6/2015	LB	542	F	2/27/2018	LB	615	73	1,117	Stocked	23.85
Mean annual growth (all sites)										**10.00 (±SE = 1.32)**	

[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) and recently tagged again with a new, 12.5-mm, 134.2-kilohertz style PIT tag.
[b] Date originally stocked or originally captured.
[c] EB = Echo Bay, LB = Las Vegas Bay, and OA = Overton Arm (Virgin River/Muddy River inflow area).
[d] Total length (mm).
[e] F = female, and M = male.
[f] Date of most recent recapture.
[g] Difference in TL from date of stocking to date of most recent recapture.
[h] Annual growth was calculated as the difference in TL from date of stocking to the date of most recent recapture divided by the number of days between captures and multiplied by 365.

Additionally, two common carp (originally PIT tagged in the Grand Canyon at Bright Angel Creek, Arizona, in 2015) and one unknown PIT tag were detected at the Virgin River/Muddy River inflow area in 2018 (see table 4). PIT scanning provided additional information regarding razorback sucker movement within the Overton Arm because nine fish were observed moving between Echo Bay and the Virgin River/Muddy River inflow area (see table 4). Most noteworthy were two razorback suckers detected at the Virgin River/Muddy River inflow area: one originally tagged in 2017 at Las Vegas Bay and one originally tagged at the Colorado River inflow area in 2012 (see table 4; see figure 1).

Growth

Annual growth rates for razorback suckers were calculated using 14 individuals recaptured during 2018 (see table 5). Razorback sucker annual growth at Echo Bay ranged from 3.71–13.40 mm TL, with a mean annual growth rate of 8.13 mm TL (± SE = 1.79) (see table 5). Razorback suckers in the Virgin River/Muddy River inflow had an annual growth rate range of 5.69–12.50 mm TL, with a mean annual growth rate of 9.44 mm TL (± SE = 0.84) (see table 5). In Las Vegas Bay, the annual growth rate for one individual was 23.85 mm TL per year. For fish recaptured during 2018 in the three combined long-term monitoring study areas, the mean annual growth rate was 10.00 mm TL (± SE = 1.32) (see table 5).

Larval Sampling

Larval Captures

Larval razorback sucker sampling in long-term monitoring study areas was initiated on January 4, 2018, in Las Vegas Bay, and on February 6 and 7, 2018, in the Virgin River/Muddy River inflow area and Echo Bay, respectively.

The first larvae were collected on January 8, 2018, in Las Vegas Bay, and were routinely captured over cobble, gravel, and silt substrates when temperatures were between 11.6 and 22.6 °C (figure 10). Sampling for larvae was conducted throughout Las Vegas Bay; however, the majority of larvae collected were found in the western portions of the bay. Larvae were often collected near sonic-tagged fish or in areas where adult razorback suckers were captured via trammel netting (see figures 5, 6, and 11). Las Vegas Bay yielded 1,980 razorback sucker larvae captured during 1,740 minutes of sampling, for a mean CPUE of 1.1302 (± SE = 0.5373) (figure 12). Generally speaking, 2018 was a successful year for larvae in Las Vegas Bay; however, this apparent increase in CPUE was driven by one evening (February 26, 2018) when the majority of larvae (n = 1,412) were captured in the bay.

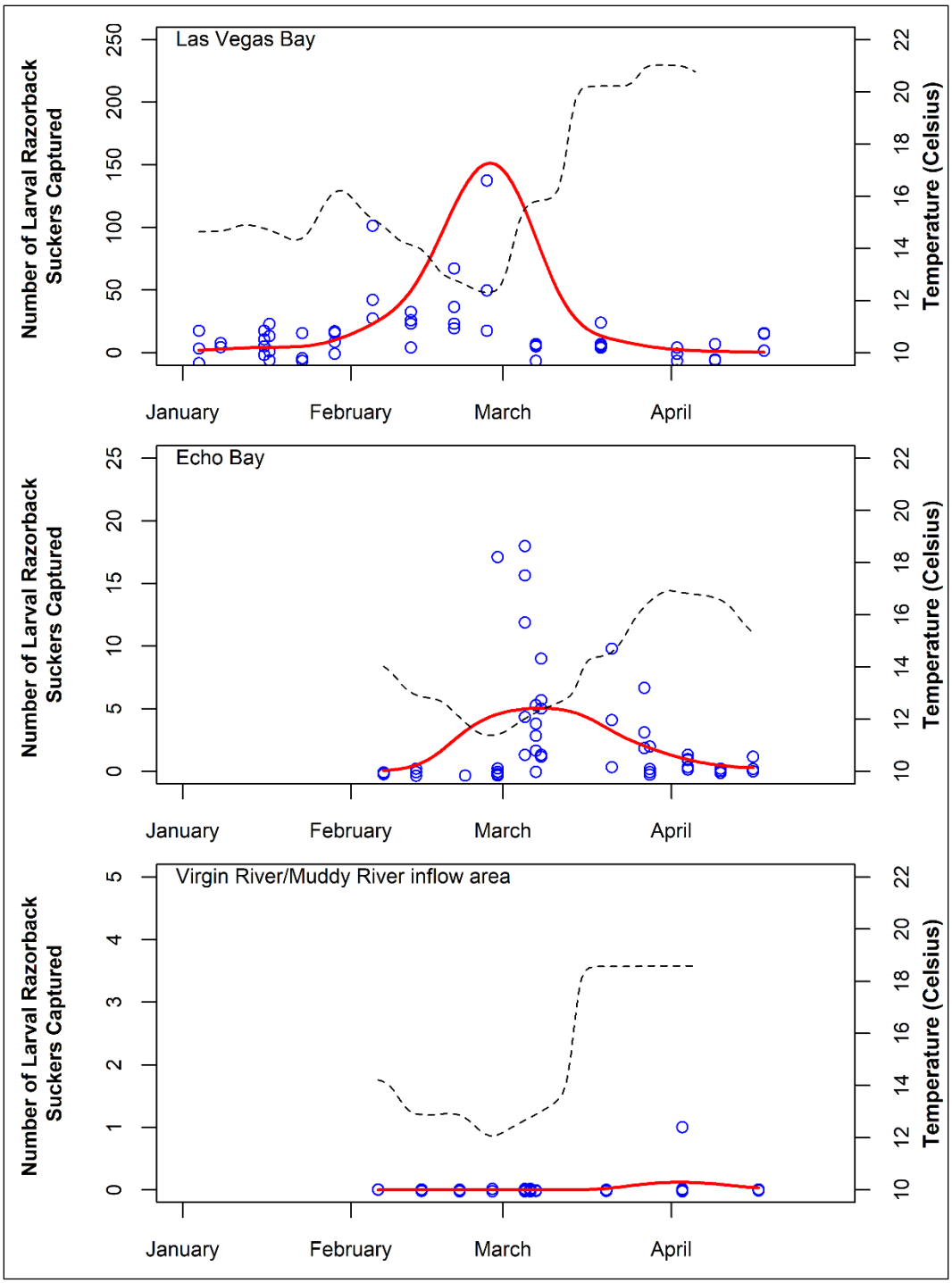

Figure 10.—Individual larval razorback sucker catch numbers (blue dots) obtained at long-term monitoring study areas in Lake Mead, February – April 2018, with a kernel regression line in red.
Associated temperature data at the time of sampling are shown as a dashed kernel density regression line. Please note difference in scales.

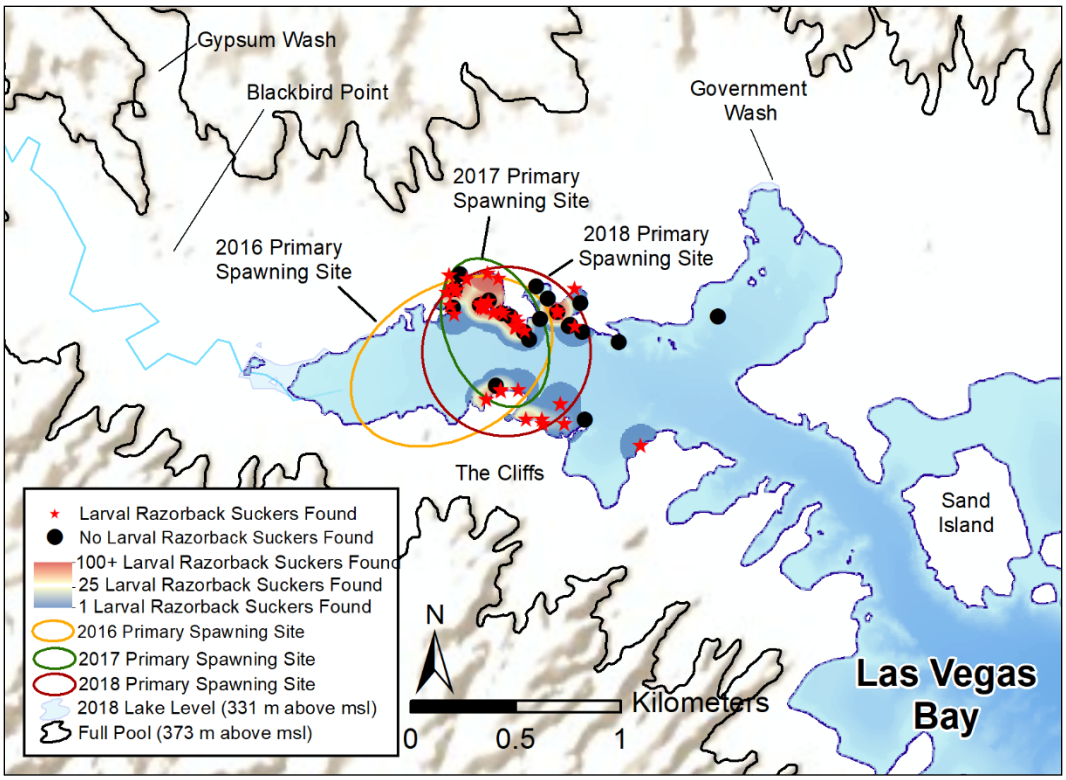

Figure 11.—Locations of larval razorback sucker sampling efforts and capture numbers in Las Vegas Bay, January – April 2018.

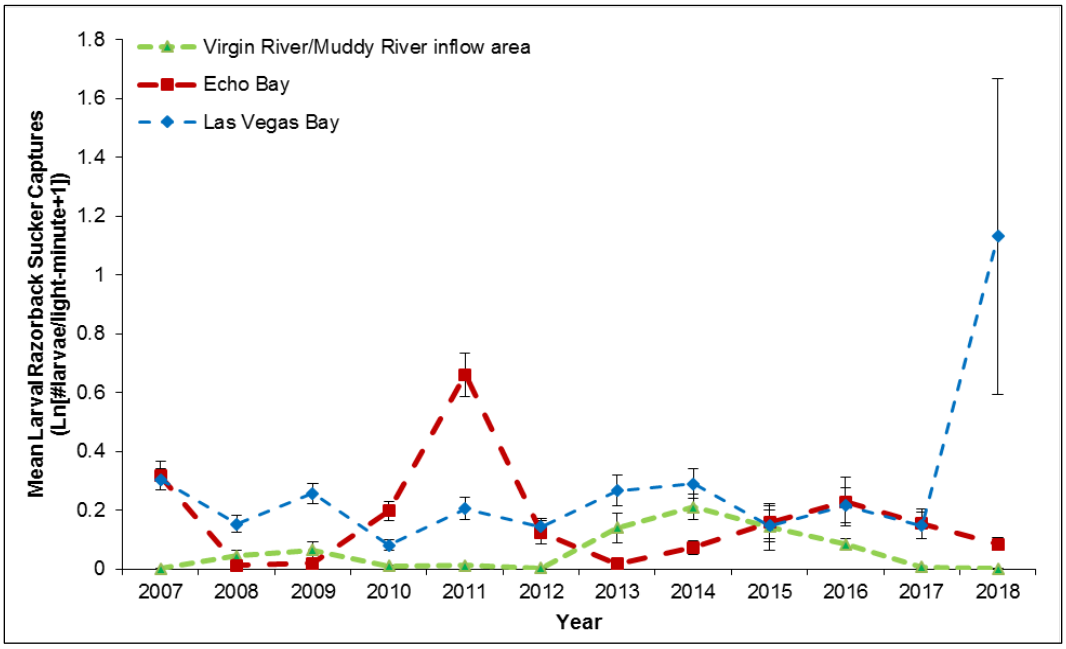

Figure 12.—Larval razorback sucker mean catch per light-minute rates (Ln[#larvae/light-minute+1]) at long-term monitoring study areas in Lake Mead, 2007–18, with associated SE.

In Echo Bay, the first razorback sucker larvae were captured on March 5, 2018. Larval collections were made primarily over gravel and sand, and occasionally over cobble substrates at temperatures ranging from 11.1 to 19.0 °C, and were mostly collected during the first two weeks of March (see figure 10). The highest concentration of larvae was on the southern shoreline of Echo Bay, but larvae were also found toward the western end of the bay outside the old marina (figure 13). The collection of 136 larval razorback suckers within 1,592 minutes at Echo Bay resulted in a mean CPUE of 0.0847 (± SE = 0.0209) (see figure 12). The mean CPUE in 2018 falls within the historical context for this site, but perhaps most importantly, these values confirmed spawning success at Echo Bay.

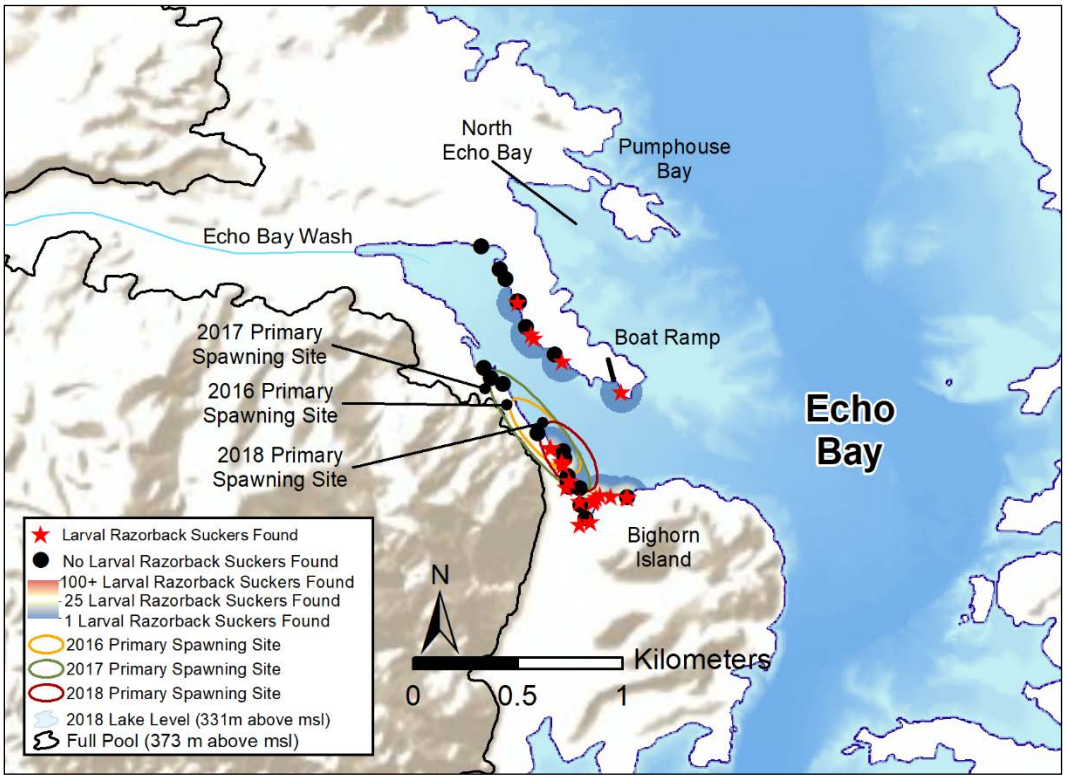

Figure 13.—Locations of larval razorback sucker sampling and capture numbers in Echo Bay, February – April 2018.

At the Virgin River/Muddy River inflow area, the first and only razorback sucker larvae of the sampling season was captured on April 3, 2018, (see figure 10) over cobble and gravel substrate at a temperature of 18.7 °C. This larval fish was collected approximately 3.5 km south of the Virgin River/Muddy River inflow area along the eastern shoreline near The Meadows (figure 14). In the Virgin River/Muddy River inflow area, 1,296 minutes of sampling resulted in a mean CPUE of 0.0008, the lowest mean CPUE for this area to date; however, the 2018 mean CPUE appears similar to the mean larval CPUE in 2007, 2010–12, and 2017 (see figure 12).

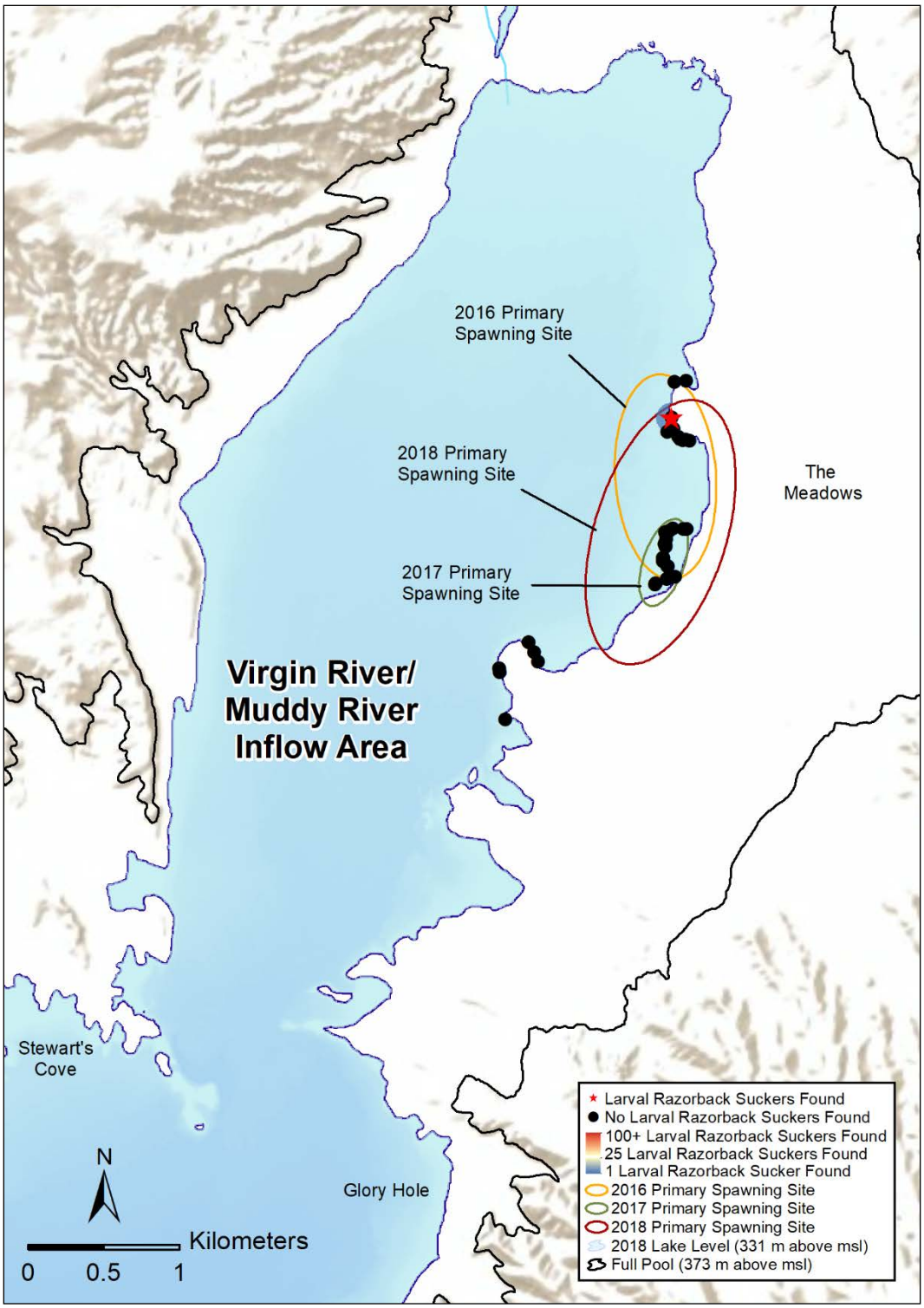

Figure 14.—Locations of larval razorback sucker sampling and captures at the Virgin River/Muddy River inflow area, February – April 2018.

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). Secchi disk readings were taken in a limited capacity at the long-term monitoring study areas with depths ranging from 0.5–6.75 m. In Las Vegas Bay, Secchi depths ranged from 2.7–4.5 m near spawning areas. While successful trammel netting efforts occurred in Las Vegas Bay throughout the 2018 spawning season, most captures occurred in January and February toward the western portion of the bay (see table 3). This area was also the primary location for the collection of larval razorback suckers; however, larvae were found throughout the entirety of Las Vegas Bay (see figure 10). The 2018 spawning area was similar to the 2016 and 2017 spawning areas, which again demonstrates the importance of this bay for razorback sucker spawning and recruitment (see figure 10; see table 3).

The primary Echo Bay spawning site in 2018 was well defined and located off the southern shore across from the boat ramp, in a location similar to the 2016 and 2017 primary spawning locations (see figures 7 and 13). Razorback suckers were captured consistently throughout the spawning season in Echo Bay. Spawning was evident by concentrated, consistent sonic-tagged fish presence, adult captures, and larval captures, all of which helped to define this location as a primary spawning area in 2018 (see figures 5, 8, and 13). In Echo Bay, Secchi disk visibility ranged from 1.5–6.75 m, the deepest of the long-term monitoring areas.

In 2018, the lowest mean larval CPUE was observed at the Virgin River/Muddy River inflow area, as compared to the historical data, as well as to other long-term monitoring study areas (see figure 12). 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 about 3 km south of the Virgin River (see figure 8). This area is primarily cobble substrate covered with a relatively thin layer of sand and silt, which are deposited by the adjacent river inflow. Secchi depths ranged from 0.5–1.5 m, suggesting this area was consistently the most turbid of the three long-term monitoring areas.

Age Determination and Year-Class Strength

To date, definitive ages have been determined for 550 razorback suckers from long-term monitoring study areas in Lake Mead. Ages were obtained from 19 razorback suckers captured in trammel nets at long-term monitoring study areas during the 2018 spawning season (not including 8 individuals aged from the CRI) (attachment 1). In 2018, fish were aged at 4 years old (n = 2), 5 years old (n = 4), 6 years old (n = 2), 7 years old (n = 1), 8 years old (n = 4), 9 years old (n = 4), and 10 years old (n = 1), and the oldest fish aged was 13 years old (n = 1). These fish represent the 2005 year class as well as year classes spanning 2008–14. Razorback suckers ranged in size from 451 to 581 mm TL (attachment 1).

Prior to 2000, the majority of fish aged were spawned during high reservoir elevations while the reservoir was relatively stable around full pool (figure 15). However, recent data show that Lake Mead razorback sucker recruitment readily occurred beyond 2000, which coincided with an overall, long-term period of declining reservoir elevations and common annual reservoir elevation fluctuations (see figures 2 and 15). The cumulative dataset shows that most individuals (n = 420) were spawned from 2000 to 2011. Within this period, 113 individuals (including 3 from the CRI) were aged from the 2005 year class alone. More recently, captures of individuals from the 2012–14 year classes have increased in frequency (figure 15).

Analysis of year-class strength suggests that annual recruitment in Lake Mead is not homogenous (figure 16). The 2005, 2007, and 2010 year classes were some of the strongest observed, while the 2006, 2009, and 2011 year classes were weaker (figure 16). It appears that recruitment in Lake Mead experienced a gradual decline between 1990 and 1998 and an increase in recruitment from 1999 to 2010 (again, with the exceptions of 2006 and 2009 year classes) (figure 16). The increased variance in recent years (e.g., 2006 and 2011) is indicative of a smaller number of individuals from the associated year classes captured to date, so as more data are collected, these year-class rankings could potentially change. Furthermore, the lack of variance (e.g., 1983–85, 1993, 1995, 2012, and 2013) is indicative of only one individual being aged to that respective year class and/or multiple individuals from those year classes being captured during only one sampling year.

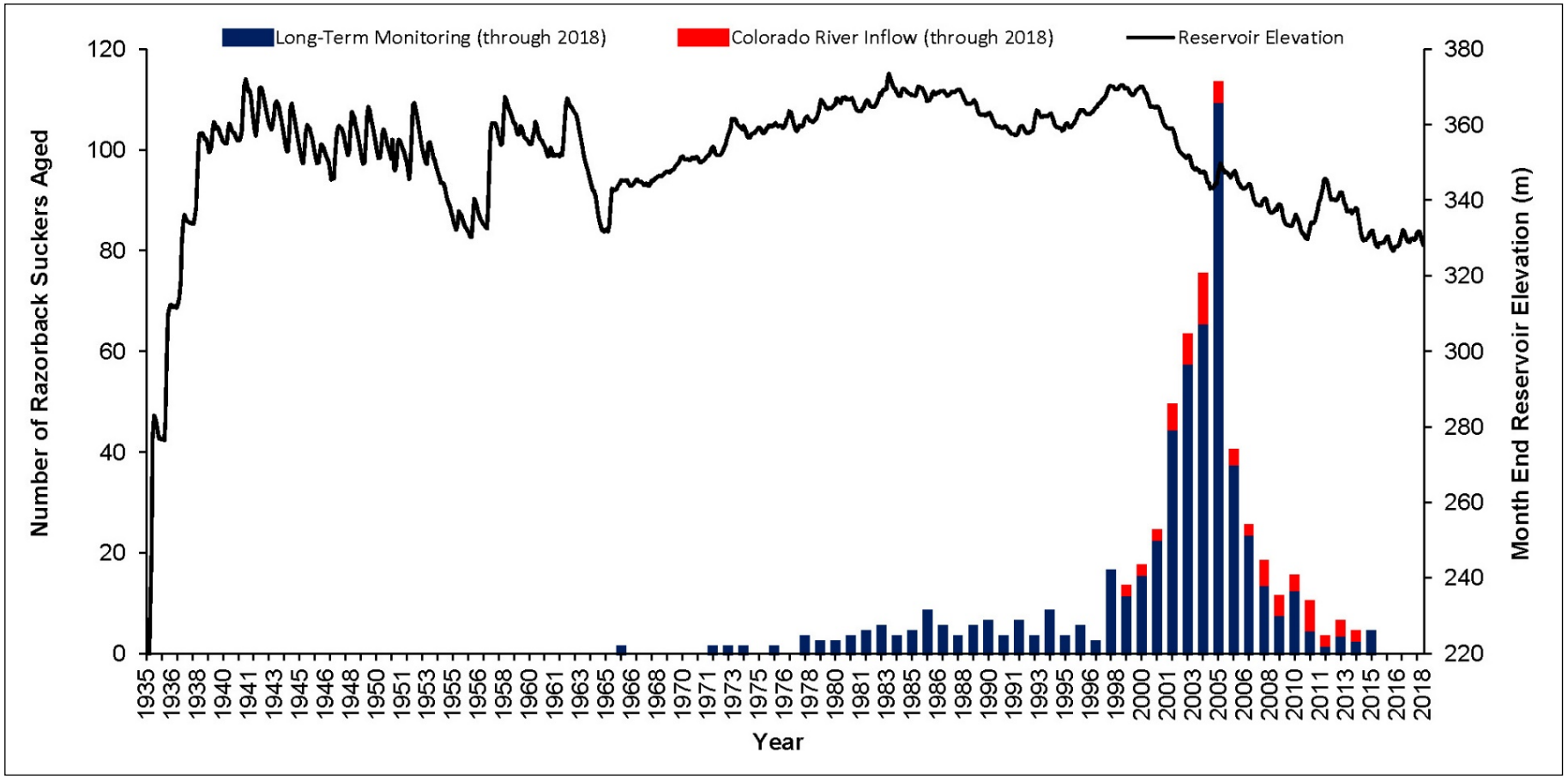

Figure 15.—Cumulative number of razorback suckers back-calculated to year spawned for individuals aged with corresponding Lake Mead month-end reservoir elevations, January 1935 – June 2018.
Blue bars denote individuals aged during long-term monitoring efforts, 1999–2018; red bars denote individuals aged during efforts at the CRI, 2010–18.

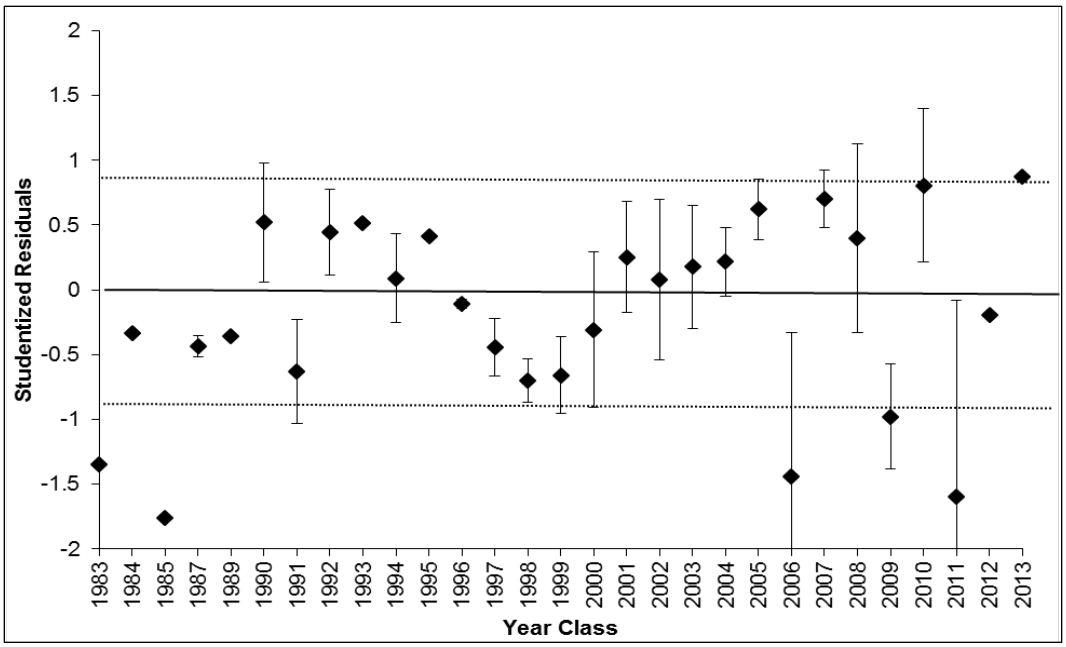

Figure 16.—Studentized residuals obtained from razorback sucker age data following the method proposed by Maceina (1997), plotted with ±1 SE.
Dotted lines represent the upper 80th and lower 20th percentile bounds of these data in a *t*-distribution.

Population and Survival Estimation

Population Estimates

The top model for reservoir-wide population estimates included time-varying capture probability (*Mt*) (attachment 3). Using 41 capture occasions from 2016 to 2018, the population model produced a point estimate of 360 (± SE = 45) with a 95% confidence interval of 289–470 (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 2016 to 2018 from program MARK

Model	Population estimate (95% confidence interval)	Capture events	Standard error
Reservoir-wide population estimate			
Mt	360 (289–470)	41	45

Survival Estimates

Twenty-three 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 [$\phi(.)p(t)$; annual survival is constant through time and recapture probability varied through time] carried the majority (80%) of the AIC_c weight, so model averaging was not used (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 0.74–0.80 (table 7). The recapture probabilities varied from year to year and ranged in value from 0.05 to 0.45 (table 7; attachment 5).

Table 7.—Annual apparent survival rate estimate for razorback suckers in Lake Mead produced in the program MARK using adult (> 450 mm TL) mark-recapture data, 1996–2018

Model	Annual apparent survival rate estimate (95% confidence interval)	Capture events	Standard error	Minimum/ maximum recapture probability
Cormack-Jolly-Seber				
$\phi(.)p(t)$	0.77 (0.74–0.80)	23	0.02	0.05–0.45

Bureau of Reclamation (Lower Colorado Multi-Species Conservation Program) and Nevada Department of Wildlife Lake Mohave Origin Razorback Sucker Stocking Note

Pertinent to long-term monitoring, it should be noted that in 2018 biologists from Reclamation (LCR MSCP) and the NDOW stocked 13 adult razorback suckers into Las Vegas Bay on January 5 (n = 10) and January 19 (n = 3), as discussed by the LMWG during the fall 2017 meeting. These fish were of Lake Mohave origin and were reared in Center Pond at the Overton Wildlife Management Area. This stocking was recommended by Dr. Thomas Dowling (Wayne State University) as an effort to increase genetic diversity and prevent inbreeding within the Las Vegas Bay razorback sucker population (Dowling et al. 2017). The 13 adult razorback suckers were PIT tagged and implanted with sonic tags before being stocked in order to determine their dispersal within and outside Las Vegas Bay. Larval collections for genetic monitoring from 2018 to 2022 will be increased in Las Vegas Bay to determine if these Lake Mohave fish are contributing to the adult spawning population. Results of those genetic monitoring efforts will be reported elsewhere by the LCR MSCP. BIO-WEST assisted with the PIT tagging and sonic tagging, as requested, as well as with field collections of larval

and adult tissue samples through ongoing monitoring efforts. Furthermore, BIO-WEST will continue to support these and other LMWG efforts, when possible, through this long-term monitoring and research project.

DISCUSSION AND CONCLUSIONS

Long-term monitoring data collected during the 2017–18 field season (the 22nd field season) increased knowledge of razorback sucker spawning behavior, year-round movement between study areas, growth, and population demographics in Lake Mead. Information was also gained regarding population abundance, adult survival rates, and razorback sucker response 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 suggest 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 may provide further understanding of this unique population of recruiting razorback suckers, which may serve as a model for conservation and recovery of the species. Non-native fish movement from Bright Angle Creek, Grand Canyon to the Virgin River/Muddy River inflow area in Lake Mead was also documented for the first time during this study year, suggesting that long-term monitoring continues to be vital to understanding not only the Lake Mead razorback sucker population but also how the fish community of this large and dynamic river-reservoir system functions.

Reservoir Elevation

Reservoir elevations fluctuated throughout the 2017–18 field season and could be characterized by a general increase in elevation that inundated littoral habitats, followed by declining reservoir levels from March through June 2018. Continued monitoring efforts may be useful in evaluating the relative importance of each monitoring location, shifts in spawning site use, and variations in annual recruitment as Lake Mead continues to display projected declines in reservoir elevation (Reclamation 2018). Despite changes in reservoir elevation, suitable spawning habitat has been available for the Lake Mead razorback sucker population during each study year, and recruitment continues to be observed even during periods of declining reservoir elevations.

Sonic Telemetry

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 2017–18, again demonstrating the interconnectedness of the system. Interestingly, a fish that was sonic tagged in 2011 was contacted in October 2017. This was an unexpected event, given the anticipated expiration of the tags' 4-year battery life. Another sonic-tagged fish from the 2011 tagging event (sonic code fish 3578) was recaptured in a trammel net this season, and field crews observed that the sonic tag had expired batteries. Furthermore, it was apparent that sonic code fish 3578 had no ill effect from sonic tagging surgery and appeared to have integrated into the wild population of razorback suckers. While three out of the eleven 2014 sonic-tagged fish were contacted during this field season, the batteries from 2014 are nearing their anticipated expiration. One wild razorback sucker (sonic code 478) was tagged in 2018 at the Virgin River/Muddy River inflow area and provided valuable information through the remainder of the field season at this spawning site. Furthermore, 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, especially during the non-spawning season, aided with documenting long-distance razorback sucker movements, even between long-term monitoring study areas, and helped account for individuals that were undetected for relatively long expanses of time. The strategically placed existing 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. This could be related, but not limited to: (1) some sonic-tagged fish exhibit small home ranges and never reach an SUR; (2) some individuals are only mobile during times when active telemetry is not taking place or rarely takes place (i.e., 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 suggests 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 may help identify important areas for razorback suckers in Lake Mead throughout the year. Furthermore, wild razorback suckers were captured consistently alongside sonic-tagged individuals, whereas sonic-tagged fish themselves were rarely recaptured. Despite being constantly targeted during trammel netting in 2018, no active sonic-tagged fish were captured, demonstrating the elusiveness of the species.

Adult Sampling and Spawning Site Observations

In summary, 1,271 razorback sucker captures have identified 743 unique individual razorback suckers at long-term monitoring study areas during this 22-year (1996–2018), 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 2018 documented the continued presence of wild razorback suckers at all 3 long-term monitoring sites, including 5 wild razorback suckers in Las Vegas Bay, 8 in Echo Bay, and 14 at the Virgin River/Muddy River inflow area. Of the 45 razorback suckers captured in 2018, 53% of the catch occurred at the Virgin River/Muddy River inflow area (n = 24), 29% of the catch occurred in Echo Bay (n = 13), and 18% were captured in Las Vegas Bay (n = 8), indicating the importance of all the long-term monitoring study areas to this species. In Las Vegas Bay, four adult razorback suckers were captured, and larvae were already present, in January, suggesting it may be important to continue sampling this long-term monitoring study area earlier in the season.

Two more juvenile fish were captured in 2018 at the Virgin River/Muddy River inflow area. Since 1997, 97 (approximately 8% of the overall catch) wild, juvenile (≤450 mm TL and sexually immature) razorback suckers have been captured in Lake Mead, and all but 9 of these individuals were captured from long-term monitoring study areas. Additional studies that build on the framework from previous studies regarding younger age classes of razorback suckers

(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.

Spawning was documented at all of the long-term monitoring study areas in 2018. 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 2018 were similar to the spawning sites in 2016 and 2017, as reservoir elevation was fairly similar between these field seasons (Mohn et al. 2016; Rogers et al. 2017). However, this pattern of 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 may help identify razorback sucker habitat use and locate spawning aggregates in Lake Mead. Given that some level of natural razorback sucker recruitment occurs nearly every year in Lake Mead, regardless of reservoir elevation (see figure 15 and 18), there is reason for optimism about the success of the 2018 year class, and it is suggested that monitoring of this and other year classes continues into the future.

The 2018 primary spawning area in Las Vegas Bay followed patterns similar to those detailed in past reports (e.g., Rogers et al. 2017). 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 (even the absence of the additional 13 newly sonic-tagged fish of Lake Mohave origin), 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). Use of the Las Vegas Wash by Lake Mead razorback suckers is something that may be explored further with technologies like PIT scanners and increased sampling efforts within the wash proper. Despite the apparently lower mean CPUE in 2018, the capture of razorback suckers in Las Vegas Bay in 2018 once again shows that this site remains an important spawning area for the Lake Mead razorback sucker population. Lastly, 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.

Data from 2018, along with 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, or at least most connected, in Lake Mead. As documented in previous reports (e.g., Rogers et al. 2017), razorback suckers often use both Echo Bay and the Virgin River/Muddy River inflow area during the same study year. The primary 2018 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 2018, as in 2016 and 2017, 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 a steep edge where razorback suckers may retreat during daylight hours. This again shows that razorback suckers can find suitable spawning habitat as the reservoir elevation fluctuates.

The 2018 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. 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 sucker have historically been lower when compared to the other long-term monitoring study areas, and collections in 2018 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 2018 were relatively low, spawning locations were still able to be defined by using a consistent multiple methods approach that has been used to successfully 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 three long-term monitoring study areas contacted several previously tagged individuals that were present at spawning locations 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, may 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 the frequency of razorback sucker movements from other long-term monitoring study areas as well as movements from the CRI and Grand Canyon. However, there are still limitations to the use of this technology, particularly

pertaining to population estimation for razorback suckers, as Lake Mead continues to harbor a wild, untagged razorback sucker population. Despite these limitations, this technology, when coupled with sonic telemetry, might be useful in exploring new potential spawning areas in Lake Mead. If razorback suckers are detected through these techniques, biologists could validate potential spawning locations by netting and larval sampling, which may provide a further understanding of recruitment patterns in Lake Mead.

Growth and Aging

The relatively high mean annual growth rate of 14 recaptured razorback suckers in Lake Mead continues to indicate a fairly youthful population of this species within the reservoir. Growth rates ranged from 8.13 mm TL per year to 23.85 mm TL per year in 2018 and appear to be similar to those reported in the recent past (Mohn et al. 2015, 2016; Rogers et al. 2017). Lake Mead growth rates continue to surpass the growth rates of < 2.0 mm per year reported for razorback suckers in Lake Mohave (Pacey and Marsh 1998) and the Green River (McAda and Wydoski 1980; Tyus 1987).

Through 2018, 550 razorback suckers from long-term monitoring study areas have been aged from 2 to 36 years old. Another 13-year-old fish was captured in 2018, validating the finding that the 2005 spawning season resulted in 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; Shattuck et al. 2011). Fish that were spawned more recently (2008–14) were also captured in 2018. Rogers et al. (2017) documented one 3-year-old and four 2-year-old juvenile razorback suckers, last field season, which comprised the youngest known year classes in Lake Mead (year-classes 2014 and 2015) 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 combined with CPUE, age data suggest that while fewer fish have been aged from the 2011–13 year classes, figure 16 indicates that recruitment continues to take place. Aging and CPUE combined with year-class strength through catch-curve analyses confirms continued recruitment within Lake Mead and lends hope for 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). Aging the Lake Mead razorback sucker population, using non-lethal methods, remains paramount for tracking continued natural recruitment and elucidating the drivers behind recruitment success.

Population and Survival Estimation

Several assumptions have to be met in order for a closed population estimate to be unbiased: (1) the population is closed to birth, death, immigration, and emigration; (2) animals have equal probability to be captured; 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 and CRI) 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 because of confirmed fish movement between the CRI 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 (60%) of the of the razorback suckers captured this year were unmarked, wild fish that are not subject to detection 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 periodically occur. Methods used to produce the 2016–18 reservoir-wide population estimate in program MARK have been identical since 2016 (Mohn et al. 2015, 2016; Rogers et al. 2017), 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, but as is common with low-density organisms, limited recaptures of adult razorback suckers resulted in fairly large confidence intervals. Additional effort and sampling could potentially help to obtain more precise estimates.

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 apparent annual survival rate reported for 2018 remains consistent with rates reported since 2014 in Lake Mead (Albrecht et al. 2014a; Mohn et al. 2015, 2016; Rogers et al. 2017) 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 0.74–0.80]) was calculated only for razorback suckers larger than 450 mm TL in Lake Mead. Again, both the population and survival estimates observed to date have been relatively stable through time, which is not all that surprising given healthy, breeding adults were targeted. Targeting 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).

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 and 2011, reservoir elevations have increased during the spawning period (Albrecht and Holden 2005; Shattuck et al. 2011). Since at least 2005, razorback sucker recruitment seems to have increased, evident by the increased number of captured individuals from the 2005 year class, increased year-class strength through 2010, and year-class strength again in 2013. During stronger year class years, 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 as well as provide cover for juvenile razorback suckers (Albrecht and Holden 2005; Welker and Holden 2004).

In 2018, the overwhelming majority (> 99% [unpublished data]) of the fish captured were non-native species, and previous studies also have shown that the fish community in Lake Mead is dominated by non-native species (Albrecht et al.

2017; Mohn et al. 2016). Despite the non-native fish community, razorback suckers continue to recruit and coexist in Lake Mead. The potential for new, non-native species threats remains an important factor to track and understand in terms of impacts on razorback sucker recruitment success.

It is largely accepted that turbidity plays a role in the susceptibility of native Colorado River fishes to predation (Albrecht et al. 2017; Johnson and Hines 1999; 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; Golden and Holden 2003; Kegerries et al. 2017b). 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) hypothesized 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), providing refuge for spawning and recruitment of razorback suckers. More so, 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 elevations, 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 additional 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 near-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 (i.e., cover in the form of turbidity and/or vegetation), and habitat complexities (i.e., inflow areas)—may be essential to understanding (and perhaps enhancing) species survival and recruitment throughout the Colorado River basin and, at minimum, suggest a relatively positive future for this rare species in Lake Mead.

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, and the 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; 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). A study focusing on razorback sucker inflow/river use could provide additional information concerning spawning habitat association in flowing water tributaries to Lake Mead. However, spawning and recruitment appears to be occurring in Echo Bay, which is somewhat unique among the other known spawning areas in that 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 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 (Debora Herndon 2018, personal communication). With currently available technology (PIT scanners, reliable sonic tags, and SURs) and a refined approach, perhaps using targeted trammel netting and larval sampling, these areas could potentially be explored in greater detail. Exploring other potential spawning areas throughout Lake Mead was suggested by the LMWG, and it could add to the body of knowledge about razorback sucker habitat associations, help to refine current population and survival estimates, and further the understanding of growth, habitat use, and movement patterns of razorback suckers in Lake Mead.

Conclusions

All long-term monitoring objectives for the 2017–18 field season were met. 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. Continuing to monitor the Lake Mead razorback sucker population using the same methods provides continuity across multi-year datasets and may serve to increase 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 near-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 2018, projections regarding the status of the species within Lake Mead remain optimistic. Based on two decades of trammel netting data, it typically takes 4–5 years for a razorback sucker to reach a size that is readily susceptible to the sampling methods used in Lake Mead. It is anticipated that fish

spawned and recruited in 2016 will become susceptible to sampling methods in the near future, and that fish from the 2014–18 year classes 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 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 pectoral fin ray sections collected in Lake Mead, 1998–2018

Date collected	Total length (mm[a])	Age	Presumptive year spawned
Las Vegas Bay			
5/10/1998	588	10[b]	1987
12/14/1999	539	13	1986
12/14/1999	606	17+	1979–82
12/14/1999	705	19+	1977–80
1/08/2000	650	18+	1978–81
2/27/2000	628	17+	1979–82
1/09/2001	378	6	1994
2/07/2001	543	11	1989
2/22/2001	585	13	1987
12/01/2001	576	8–10	1991–93
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	1990–91
3/25/2002	583	22–24	1977–79
3/25/2002	545	20[b]	1982
3/25/2002	576	20	1982
5/07/2002	641	15	1986
6/07/2002	407	6	1995
6/07/2002	619	20[b]	1982
6/07/2002	642	20[b]	1982
12/03/2002	354	4	1998
12/06/2002	400	4	1998
12/06/2002	376	4	1998
12/19/2002	395	4	1998
1/07/2003	665	16	1986
1/22/2003	394	4	1998
2/05/2003	385	4	1998
2/18/2003	443	5	1997
3/04/2003	635	19	1983
3/20/2003	420	4	1998
4/08/2003	638	21[b]	1982
4/17/2003	618	10	1992
4/22/2003	650	20–22	1980–82
5/04/2003	415	3+[c]	1999

Table 1-1.—Ages determined from razorback sucker pectoral fin ray sections collected in Lake Mead, 1998–2018

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

Table 1-1.—Ages determined from razorback sucker pectoral fin ray sections collected in Lake Mead, 1998–2018

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

Table 1-1.—Ages determined from razorback sucker pectoral fin ray sections collected in Lake Mead, 1998–2018

Date collected	Total length (mm[a])	Age	Presumptive year spawned
3/03/2009	340	5	2004
3/03/2009	539	8	2001
3/03/2009	521	8	2001
3/03/2009	419	6	2003
3/03/2009	535	6	2003
3/03/2009	748	17	1992
3/17/2009	377	3	2006
3/17/2009	458	4	2005
3/17/2009	421	4	2005
3/17/2009	369	3	2006
3/17/2009	440	5	2004
4/06/2009	546	8	2001
4/13/2009	536	7	2002
4/13/2009	510	7	2002
4/13/2009	451	4	2005
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[d]	1999
3/03/2011	364	7	2004
3/03/2011	434	4	2007
3/24/2011	411	4	2007
3/24/2011	390	3	2008
3/29/2011	379	6	2005
3/29/2011	346	4	2007
3/29/2011	376	3	2008
2/05/2013	510	10	2003

Table 1-1.—Ages determined from razorback sucker pectoral fin ray sections collected in Lake Mead, 1998–2018

Date collected	Total length (mm[a])	Age	Presumptive year spawned
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
1/17/2018	546	8	2010
2/27/2018	615	9	2009
4/10/2018	600	9	2009
Echo Bay			
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	1986–88
1/27/2000	557	13	1986
1/27/2000	710	19+	1979–81
2/09/2001	641	13	1988
2/24/2001	577	18+	1980–82
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	1982–84
3/26/2002	623	16	1986

Table 1-1.—Ages determined from razorback sucker pectoral fin ray sections collected in Lake Mead, 1998–2018

Date collected	Total length (mm[a])	Age	Presumptive year spawned
4/02/2002	617	35+	1966–68
4/17/2002	583	20[b]	1982
5/02/2002	568	18–19	1983–84
11/18/2002	551	13	1989
12/04/2002	705	26	1976
1/21/2003	591	16	1986
2/03/2003	655	27–29	1974
2/03/2003	580	13	1989
4/02/2003	639	19–20	1982
4/02/2003	580	23–25	1978
4/23/2003	584	10	1992
5/06/2003	507	9+	1993
5/06/2003	594	20	1982
12/18/2003	522	20	1982
1/14/2004	683	14	1989
2/18/2004	613	10	1993
3/17/2004	616	19	1983
3/17/2004	666	17	1985
3/17/2004	618	9	1994
4/06/2004	755	17	1985
3/02/2005	608	15	1990
3/02/2005	624	8	1996
1/10/2006	630	12	1994
2/01/2006	705	16	1990
2/16/2006	601	22	1984
1/11/2007	535	5	2002
1/11/2007	493	5	2002
2/01/2007	637	7	2000
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

Table 1-1.—Ages determined from razorback sucker pectoral fin ray sections collected in Lake Mead, 1998–2018

Date collected	Total length (mm[a])	Age	Presumptive year spawned
3/19/2008	532	6	2002
3/19/2008	510	7	2001
2/20/2009	602	7	2002
2/26/2009	662	16	1993
2/18/2010	520	7	2003
2/25/2010	465	5	2005
3/10/2010	535	7	2003
3/10/2010	530	9[f]	2001
3/24/2010	451	4	2006
3/24/2010	465	5	2005
3/24/2010	466	5	2005
4/08/2010	470	5	2005
4/08/2010	540	8	2002
4/22/2010	538	7	2003
4/22/2010	489	8	2002
4/22/2010	460	9	2001
2/09/2011	529	7	2004
2/09/2011	524	7	2004
2/24/2011	555	7	2004
3/02/2011	513	6	2005
4/07/2011	533	7	2004
4/07/2011	522	7	2004
4/19/2011	537	6	2005
4/19/2011	540	7	2004
4/19/2011	515	6	2005
2/09/2012	619	10	2002
2/09/2012	644	29	1983
2/16/2012	559	9	2003
2/16/2012	565	12	2000
2/22/2012	589	10	2002
2/22/2012	548	12	2000
3/01/2012	585	7	2005
3/07/2012	663	12	2000
3/29/2012	571	12	2000
3/29/2012	595	13	1999
4/12/2012	610	13	1999
4/12/2012	571	14	1998

Table 1-1.—Ages determined from razorback sucker pectoral fin ray sections collected in Lake Mead, 1998–2018

Date collected	Total length (mm[a])	Age	Presumptive year spawned
2/07/2013	670	8	2005
2/07/2013	579	10	2003
2/07/2013	655	7	2006
2/14/2013	692	17	1996
2/27/2014	703	15	1999
3/12/2014	554	8	2006
3/13/2014	594	10	2004
3/25/2014	594	8	2006
3/25/2014	630	9	2005
2/16/2016	540	7	2009
2/18/2016	634	9	2007
2/29/2016	631	9	2007
3/08/2016	544	9	2007
3/08/2016	612	10	2006
3/08/2016	650	12	2004
3/22/2016	476	6	2010
3/22/2016	545	8	2008
3/22/2016	545	9	2007
3/22/2016	570	11	2005
3/22/2016	634	12	2004
4/05/2016	591	10	2006
4/05/2016	648	11	2005
4/05/2016	650	11	2005
4/21/2016	463	6	2010
4/21/2016	561	10	2006
2/15/2017	472	6	2011
2/21/2017	521	9	2008
2/21/2017	646	10	2007
2/21/2017	560	9	2008
2/21/2017	628	8	2009
3/02/2017	664	12	2005
3/09/2017	642	9	2008
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

Table 1-1.—Ages determined from razorback sucker pectoral fin ray sections collected in Lake Mead, 1998–2018

Date collected	Total length (mm[a])	Age	Presumptive year spawned
4/17/2018	634	9	2009
Virgin River/Muddy River Inflow Area			
2/23/2005	608	6	1998
2/22/2006	687	33[g]	1973
2/22/2007	452	4	2003
2/22/2007	542	5	2002
2/22/2007	476	5	2002
2/22/2007	459	4	2003
2/22/2007	494	5	2002
3/01/2007	477	5	2002
3/01/2007	512	4	2003
3/08/2007	463	5	2002
3/08/2007	455	4	2003
3/15/2007	516	4	2003
4/03/2007	508	4	2003
4/11/2007	498	7	2000
2/27/2008	465	4	2004
2/27/2008	670	20	1988
3/25/2008	530	6	2002
3/25/2008	271	2[e]	2006
3/26/2008	345	3	2005
3/26/2008	541	7	2001
3/26/2008	521	7	2001
3/26/2008	665	18	1990
4/01/2008	229	2	2006
4/01/2008	370	3	2005
4/01/2008	360	3	2005
4/01/2008	385	4	2004
4/01/2008	514	5	2003
4/01/2008	536	5	2003
4/01/2008	514	6	2002
4/01/2008	548	6	2002
4/01/2008	518	7	2001
4/01/2008	530	7	2001
4/01/2008	494	8	2000
4/01/2008	535	9	1999
4/01/2008	559	10	1998

Table 1-1.—Ages determined from razorback sucker pectoral fin ray sections collected in Lake Mead, 1998–2018

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

Table 1-1.—Ages determined from razorback sucker pectoral fin ray sections collected in Lake Mead, 1998–2018

Date collected	Total length (mm[a])	Age	Presumptive year spawned
2/24/2010	234	4	2006
3/17/2010	477	4	2006
3/17/2010	465	5	2005
3/17/2010	485	5	2005
3/17/2010	499	6	2004
3/17/2010	491	6	2004
3/17/2010	600	9	2001
3/18/2010	452	5	2005
3/18/2010	473	5	2005
3/24/2010	485	5	2005
2/01/2011	601	7	2004
2/01/2011	571	6	2005
2/01/2011	556	7	2004
2/01/2011	586	6	2005
2/01/2011	506	8	2003
2/01/2011	572	8	2003
2/01/2011	500	6	2005
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

Table 1-1.—Ages determined from razorback sucker pectoral fin ray sections collected in Lake Mead, 1998–2018

Date collected	Total length (mm[a])	Age	Presumptive year spawned
3/01/2011	553	6	2005
3/01/2011	595	6	2005
3/01/2011	563	6	2005
3/01/2011	555	6	2005
3/01/2011	483	7	2004
3/01/2011	599	9	2002
3/01/2011	560	5	2006
3/09/2011	556	7	2004
3/09/2011	534	6	2005
3/09/2011	549	7	2004
3/09/2011	494	4	2007
3/09/2011	505	6	2005
3/15/2011	575	8	2003
3/15/2011	551	8	2003
3/15/2011	515	7	2004
3/15/2011	558	8	2003
3/15/2011	576	8	2003
3/15/2011	587	8	2003
3/15/2011	572	7	2004
3/15/2011	575	10	2001
3/15/2011	551	7	2004
3/15/2011	561	7	2004
3/15/2011	566	9	2002
3/15/2011	542	6	2005
3/15/2011	577	8	2003
4/05/2011	521	7	2004
4/05/2011	495	6	2005
4/12/2011	572	8	2003
1/31/2012	604	7	2005
1/31/2012	570	7	2005
2/01/2012	525	12	2000
2/07/2012	525	9	2003
2/08/2012	536	7	2005
2/08/2012	501	9	2003
2/08/2012	623	12	2000
2/21/2012	566	10	2002
2/21/2012	590	10	2002

Table 1-1.—Ages determined from razorback sucker pectoral fin ray sections collected in Lake Mead, 1998–2018

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

Table 1-1.—Ages determined from razorback sucker pectoral fin ray sections collected in Lake Mead, 1998–2018

Date collected	Total length (mm[a])	Age	Presumptive year spawned
3/27/2013	539	8	2005
3/27/2013	580	10	2003
4/03/2013	554	8	2005
4/03/2013	542	7	2006
4/10/2013	560	10	2003
4/10/2013	598	9	2004
2/26/2014	570	12	2002
2/26/2014	626	10	2004
3/06/2014	657	9	2005
3/06/2014	521	9	2005
3/06/2014	591	8	2006
3/06/2014	591	9	2005
3/06/2014	628	12	2002
3/20/2014	569	7	2007
3/20/2014	624	9	2005
3/20/2014	627	11	2003
3/20/2014	549	7	2007
3/20/2014	531	9	2005
3/20/2014	621	9	2005
3/20/2014	593	10	2004
3/20/2014	532	8	2006
3/20/2014	561	9	2005
3/20/2014	592	8	2006
3/20/2014	637	10	2004
3/20/2014	567	9	2005
3/20/2014	574	10	2004
3/20/2014	541	10	2004
3/20/2014	614	9	2005
4/03/2014	572	6	2008
4/03/2014	615	7	2007
4/10/2014	651	7	2007
4/16/2014	504	6	2008
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

Table 1-1.—Ages determined from razorback sucker pectoral fin ray sections collected in Lake Mead, 1998–2018

Date collected	Total length (mm[a])	Age	Presumptive year spawned
3/31/2015	560	8	2007
2/09/2016	503	6	2010
2/16/2016	455	5	2011
2/16/2016	555	11	2005
2/16/2016	635	11	2005
2/17/2016	545	8	2008
2/24/2016	471	6	2010
2/24/2016	635	10	2006
2/24/2016	559	13	2003
2/24/2016	647	14	2002
3/22/2016	541	10	2006
3/23/2016	577	9	2007
3/24/2016	490	6	2010
3/24/2016	582	8	2008
3/24/2016	562	9	2007
3/24/2016	565	11	2005
1/27/2017	592	7	2010
1/27/2017	657	7	2010
2/04/2017	541	6	2011
2/14/2017	624	9	2008
3/03/2017	541	8	2009
3/03/2017	642	7	2010
3/03/2017	586	7	2010
3/22/2017	319	3	2014
2/07/2018	451	4	2014
2/07/2018	535	6	2012
2/15/2018	630	9	2009
2/15/2018	614	8	2010
2/22/2018	655	10	2008
2/22/2018	455	8	2010
3/06/2018	611	13	2005
3/07/2018	468	4	2014
3/08/2018	481	6	2012
4/18/2018	454	5	2013
Colorado River inflow area			
4/20/2010	563	6	2004
4/20/2010	508	6	2004

Table 1-1.—Ages determined from razorback sucker pectoral fin ray sections collected in Lake Mead, 1998–2018

Date collected	Total length (mm[a])	Age	Presumptive year spawned
4/20/2010	568	11	1999
2/08/2011	594	8	2003
3/10/2011	659	11	2000
3/24/2011	584	9	2002
3/24/2011	530	7	2004
3/24/2011	545	6	2005
4/19/2011	636	9	2002
4/20/2011	570	10	2001
1/26/2012	602	8	2004
2/21/2012	604	10	2002
3/01/2012	546	8	2004
3/01/2012	559	9	2003
3/06/2012	535[d]	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 pectoral fin ray sections collected in Lake Mead, 1998–2018

Date collected	Total length (mm[a])	Age	Presumptive year spawned
1/30/2018	521	10	2008
2/1/2018	566	10	2008
2/23/2018	448	6	2012
3/1/2018	606	14	2004
3/7/2018	579	8	2010
3/7/2018	558	9	2009
4/18/2018	454	5	2013
5/2/2018	473	5	2013

[a] mm = millimeters.
[b] Fish stocked from Echo Bay larval fish captured in 1999 and raised at the 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 stocked from Floyd Lamb Park ponds, sonic tagged.
[e] Fish stocked from Floyd Lamb Park ponds (from an unknown 2001–03 cohort stocking event).
[f] Fish was a mortality; found dead in a net.
[g] Fish was aged at 33 years of age, ±2 years.

ATTACHMENT 2

Histogram of Razorback Suckers (*Xyrauchen texanus*)
Aged in Lake Mead from 1999 to 2018

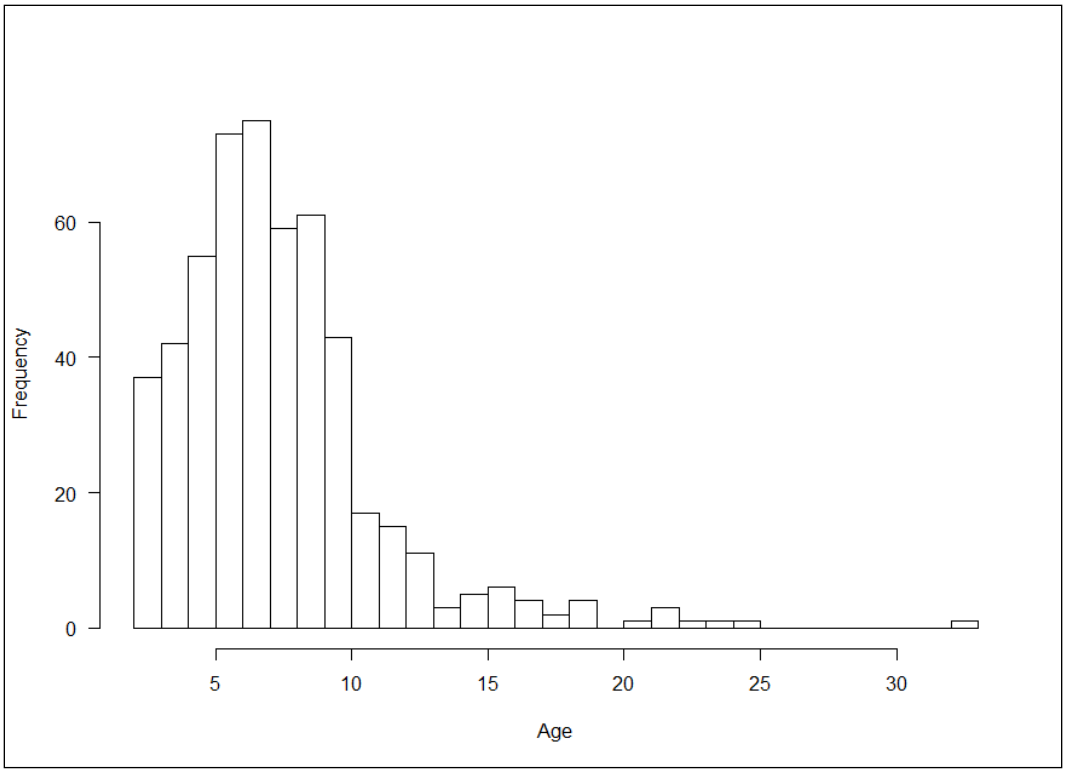

Figure 2-1.–Histogram of razorback sucker ages from 1999 to 2018 determining age when fish are most vulnerable for capture.

ATTACHMENT 3

Razorback Sucker (*Xyrauchen texanus*) Population Estimate (2016–2018) — Model Selection Summary

Table 3-1.—Model selection summary information for closed-capture populations of razorback suckers in Lake Mead using 41 mark-recapture netting-only capture occasions data from 2016 to 2018 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	239.2025	0.0000	1.00000	1.0000	37	309.8874
Mb	362.0644	122.8619	0.00000	0.0000	3	501.1964
Mo	362.6004	123.3979	0.00000	0.0000	2	503.7343

[a] Otis et al. 1978 abundance models (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 in Lake Mead produced in the program MARK using adult (> 450 millimeters total length) annual mark-recapture data, 1996–2018

Model[a]	AIC_c[b]	ΔAIC_c[c]	AIC_c weight[d]	Model likelihood[e]	Number of parameters	Deviance[f]
Cormack-Jolly-Seber						
$\phi(.)p(t)$	2099.4235	0.0000	0.80004	1.0000	23	567.0246
$\phi(t)p(t)$	2102.1966	2.7731	0.19996	0.2499	43	526.7031
$\phi(t)p(.)$	2128.4044	28.9809	0.00000	0.0000	23	596.0055
$\phi(.)p(.)$	2142.7949	43.3714	0.00000	0.0000	2	653.6178

[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 AICc 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 [mm TL]) Razorback Suckers (*Xyrauchen texanus*) in Lake Mead, 1996–2018, Produced in Program MARK

Table 5–1.—Recapture probability estimate value by year for adult (> 450 mm TL) razorback suckers in Lake Mead, produced in program MARK (Cormack-Jolly-Seber model) with mark-recapture data, 1996–2018

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	0.45	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	0.25	0.04
2016–2017	0.14	0.03
2017–2018	0.23	0.04