Lower Colorado River Multi-Species Conservation Program

Balancing Resource Use and Conservation

Razorback Sucker Studies on Lake Mead, Nevada and Arizona

2016–2017 Annual Report

July 2019

Work conducted under LCR MSCP Work Task D08

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Lower Colorado River Multi-Species Conservation Program

Razorback Sucker Studies on Lake Mead, Nevada and Arizona

2016–2017 Annual Report

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July 2019

Rogers, R.J., B. Albrecht, and H.E. Mohn. 2019. Razorback Sucker Studies on Lake Mead, Nevada and Arizona, 2016–2017 Annual Report. Submitted to the Lower Colorado River Multi-Species Conservation Program, Bureau of Reclamation, Boulder City, Nevada, by BIO-WEST, Inc., Logan, Utah, under Contract No. R15PD00015.

ACRONYMS AND ABBREVIATIONS

AIC_c	Akaike's information criterion adjusted for small sample size
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 hybrid
km	kilometer(s)
LCR MSCP	Lower Colorado River Multi-Species Conservation Program
m	meter(s)
$mL\ L^{-1}$	milliliter(s) per liter
mm	millimeter(s)
mm/yr	millimeters per year
MS-222	tricaine methanesulfonate
n	sample size
NaCl	sodium chloride
NDOW	Nevada Department of Wildlife
PIT	passive integrated transponder
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

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EXECUTIVE SUMMARY

In 1996, the Southern Nevada Water Authority and Colorado River Commission of Nevada, in cooperation with the Nevada Department of Wildlife, Arizona Game and Fish Department, National Park Service, Bureau of Reclamation (Reclamation), and the U.S. Fish and Wildlife Service initiated a study to develop information about the Lake Mead razorback sucker (*Xyrauchen texanus*) (Abbott 1861) population. BIO-WEST, Inc. (BIO-WEST), under contract with the Southern Nevada Water Authority, designed the study and had primary responsibility for conducting the research. In 2005, Reclamation became the principal source of funding through the Lower Colorado River Multi-Species Conservation Program, and the study became primarily a long-term monitoring effort in 2007. In 2012, the Lower Colorado River Multi-Species Conservation Program 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 21st season (2016–17) of the long-term monitoring study are provided herein.

During the 21st field season, 14 sonic-tagged fish were detected by active and/or passive telemetry resulting in 44 active contacts and 8,745 passive contacts by 6 submersible ultrasonic receivers. These fish represented three different sonic tagging events (2011 [n = 2], 2014 [n = 6], and 2017 [n = 6]). 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 provided habitat association data, reservoir-wide movement patterns, and seasonal movement patterns within the long-term monitoring study areas.

Trammel netting resulted in the capture of 41 total razorback suckers, 12 from Las Vegas Bay (which included 4 juvenile and 1 recaptured fish from the Colorado River inflow area of Lake Mead), 14 from Echo Bay, and 15 from the Virgin River/Muddy River inflow area (which included 1 juvenile), during the 2017 spawning period. A highlight of the 21st field season was the capture of 5 new juvenile and 16 new (unmarked) adult, wild razorback suckers at long-term monitoring study areas in Lake Mead. Juvenile fish were captured in Las Vegas Bay (n = 4) and the Virgin River/Muddy River inflow area (n = 1). Two flannelmouth suckers (*Catostomus latipinnis*) were captured in 2017; one was captured in Echo Bay, and one was captured at the Virgin River/Muddy River inflow area.

Average annual growth during this field season, as determined from 15 recaptured fish, was 10.6 (± standard error = 1.7) total length millimeters per year (mm/yr). Growth rates of Lake Mead razorback suckers continue to be higher overall than those recorded from other populations within the Colorado River Basin,

suggesting that Lake Mead razorback sucker populations are able to naturally maintain a fairly strong cohort of young, fast-growing fish. Additionally, fin ray sections were removed from 22 (21 new, unmarked fish and 1 recaptured, wild fish that was not previously aged) razorback suckers for age determination which, when combined with the 509 fish aged during previous field seasons, brings the total number of fish aged during the long-term monitoring study to 531. Through the process of aging razorback suckers, biologists have documented near-annual recruitment in Lake Mead.

Larval razorback suckers were documented in all study areas in 2017, and 402 total larvae were captured. BIO-WEST worked collaboratively with the Nevada Department of Wildlife and Reclamation biologists in a continued effort to collect additional Lake Mead larval razorback suckers for genetic analysis. Larval razorback sucker abundance was used to help define primary spawning sites during the 2016–17 field season, and primary spawning sites were identified at all long-term monitoring study areas. The 2017 primary spawning sites were similar to the 2016 primary spawning sites. 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.

Given the potential for continuing reservoir elevation fluctuations during the remainder of 2017 and into 2018, this report reiterates the need to further investigate conditions that promote recruitment patterns of razorback suckers in Lake Mead. Research goals for the 2017–18 field season include three main tasks: (1) continue to monitor razorback suckers at the three long-term monitoring study areas; (2) continue to age wild individual razorback suckers from Lake Mead; and (3) maintain the presence of sonic-tagged razorback suckers to inform sampling efforts, as needed.

INTRODUCTION

The razorback sucker (*Xyrauchen texanus*) is one of four endemic, "big-river" fish species (along with the 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 (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 main stem dams and the resulting cool tailwaters and reservoir habitats, which replaced warm, riverine environments (Holden and Stalnaker 1975; Joseph et al. 1977; Wick et al. 1982; Minckley et al. 1991). Competition with, and predation by, non-native fishes in the Colorado River and its reservoirs have also contributed to the decline of these endemic species (Minckley et al. 1991). Razorback suckers persisted in several reservoirs constructed in the Lower Colorado River Basin; however, these populations consisted primarily of adult fish that likely recruited during the first few years of reservoir formation. The population of long-lived adults then disappeared 40–50 years following reservoir creation (Minckley 1983).

The largest reservoir population of razorback suckers was estimated at 75,000 individuals in the 1980s and occurred in Lake Mohave (Arizona and Nevada), but it had declined to less than 3,000 individuals by 2001 (Marsh et al. 2003). Mueller (2005, 2006) reports the wild Lake Mohave razorback sucker population to be near 500 individuals, while the most recent 2016 estimate of wild Lake Mohave razorback suckers was not reported, as no wild fish were captured (Leavitt et al. 2018). 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 (Marsh et al. 2003, 2005; Wisenall et al. 2019; Leavitt et al. 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 (Minckley et al. 1991; Marsh et al. 2003; Carpenter and Mueller 2008; Schooley et al. 2008a; Ehlo et al. 2017). The 2016 Lake Mohave repatriate population estimate was reported at 3,815 individuals (95% confidence interval of 3,573–4,073) (Leavitt et al. 2018). This population remains one of the most genetically diverse for the species and thereby maintains importance from a conservation genetics perspective (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 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 (Minckley 1973; McCall 1980; Minckley et al. 1991; Holden 1994; Sjoberg 1995). From 1980 through 1989, neither the Nevada Department of Wildlife (NDOW) nor the Arizona Game and Fish Department collected any 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. The 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 the 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 for 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 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 potential 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 larval fish 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 the 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. Finally, in 2015, the LCR MSCP decided to continue long-term monitoring efforts but at a reduced level of effort (approximately one-half compared with previous years). These efforts were conducted following Albrecht et al. (2006a).

Efforts associated with long-term monitoring have served as a foundation to expand the understanding of razorback suckers at the Colorado River inflow area (CRI) of Lake Mead, in the lower Grand Canyon, and with regard to the juvenile life stage (Kegerries et al. 2016; *in press*). 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, and 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 a population estimate 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 21st field season (July 2016 – June 2017 sonic telemetry data and January 2017 – April 2017 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 2016–17 study year occurred at the same study areas used from 1996 to 2016 and included Echo Bay, Las Vegas Bay, and the Virgin River/Muddy River inflow area (figure 1) (Holden et al. 1997, 1999, 2000a, 2000b, 2001; Abate et al. 2002; Welker and Holden 2003, 2004; Albrecht and Holden 2005; Albrecht et al. 2006a, 2006b, 2007, 2008a, 2008b, 2010a, 2010b, 2013a, 2013b, 2014a; Kegerries et al. 2009; Shattuck et al. 2011; Mohn et al. 2015, 2016).

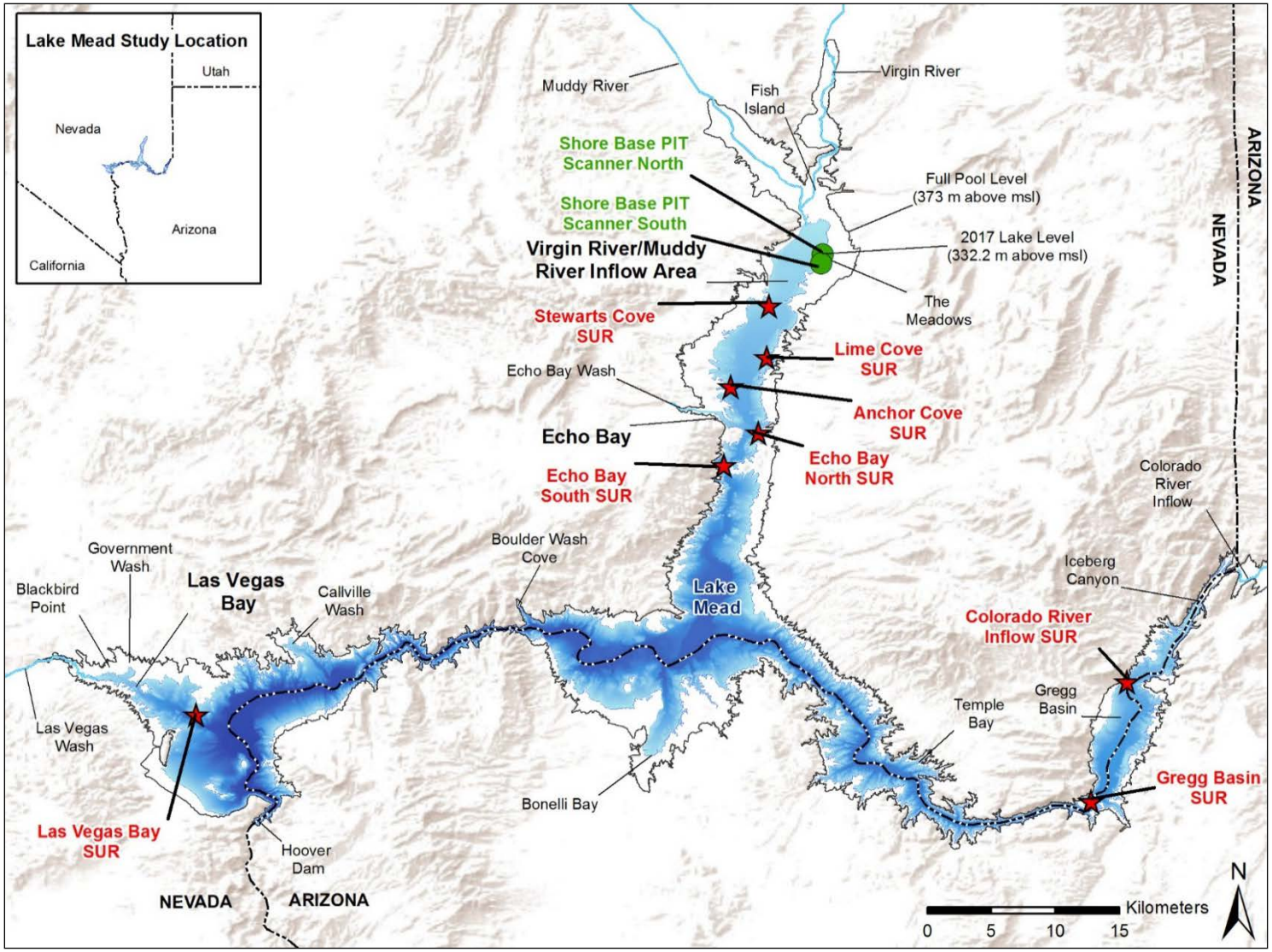

Figure 1.—Long-term monitoring study areas within Lake Mead, along with geographic landmarks.
Red stars indicate locations of long-term monitoring submersible ultrasonic receivers, and green circles represent shore-based PIT scanners.

Most areas of Lake Mead, including the Overton Arm and Boulder Basin, were searched using ultrasonic telemetry equipment. Larval sampling and trammel netting were performed in Echo Bay, Las Vegas Bay, and the Virgin River/ Muddy River inflow area.

Specific definitions for the various portions of Las Vegas Wash and Las Vegas Bay in which the study was conducted are 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.

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)

METHODS

Reservoir Elevation

Month-end (2007–17) and daily reservoir elevations for the 2016–17 field season (July 1, 2016 – June 30, 2017) were measured in meters above mean sea level and obtained from Reclamation's Lower Colorado Regional Office Web site. Projected values described below were also taken from Reclamation's regularly updated 2-year study (Reclamation 2017).

Sonic Telemetry

Sonic telemetry data for the long-term monitoring study were collected from July 1, 2016, to June 30, 2017, to capture movement throughout the study period. During the intensive field season (at least every other week, January – April), attempts were made to locate sonic-tagged fish during each sampling trip (or sometimes daily), 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

At the long-term monitoring study areas, six wild razorback suckers (n = 2 in Las Vegas Bay, n = 2 in Echo Bay, and n = 2 in the Virgin River/Muddy River inflow area) were surgically implanted with Sonotronics model CT-05-48-I (48-month) sonic tags as part of the 2016–17 study year. Prior to surgery, all fish were placed into a designated tank containing fresh reservoir 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 30 liters of reservoir water with a 50 mL L^{-1} clove oil/ethanol mixture (0.5 milliliter of clove oil [Anderson et al. 1997] emulsified in 4.5 milliliters of ethanol) (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 individual fish. Individuals were then placed dorsal-side down on a padded surgical cradle for support during surgery. The head and gills were submerged in 20 liters of fresh reservoir water with 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 0.75–1.00-centimeter (cm) incision on the left side, posterior to the left pelvic girdle. A PIT tag was inserted into the incision followed by the sonic tag, which was placed between the pelvic girdle and urogenital pore. The incision was closed with two to three 3-0 Maxon absorbable poliglecaprone 25 monofilament 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, individuals were allowed to recover in fresh reservoir water until regaining equilibrium. Prior to release, individuals were re-examined for signs of stress, and sonic tags were rechecked for functionality. All 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.

Active Sonic Telemetry

Active sonic telemetry search events 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 impact signal reception. Sonic surveillance is line-of-sight, and any obstruction can reduce or block a signal. 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 or 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 it 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 or the 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. The advantage of using a SUR is the ability to continuously record sonic telemetry data over its approximate 9-month battery life. Most importantly, a SUR facilitates an understanding of large-scale razorback sucker movements during monthly tracking events. Six SURs were explicitly deployed during the 2016–17 field season (see figure 1) as part of this long-term monitoring effort. Information from the SURs was shared between BIO-WEST and the NDOW, as appropriate, and helped provide a larger area of surveillance for monitoring reservoir-wide movements of razorback suckers. Additionally, two SURs were deployed near the CRI; however, any contacts recorded by those SURs are not reported within this document.

The six SURs were set at the following locations: the Las Vegas Bay SUR was located near Black Island east of Las Vegas Bay, the Echo Bay South SUR was located on the western shore south of Echo Bay at the constriction point near Ramshead Island, the Echo Bay North SUR was located near the eastern shore across from the mouth of Echo Bay, the Anchor Cove SUR was located north of Echo Bay off the western shoreline, the Stewart's Cove SUR was located south of Fire Cove off the western shoreline, and finally, the Lime Cove SUR was located off the eastern shore (see figure 1). The Stewart's Cove SUR was stolen despite best efforts to conceal its location. Regardless of this unfortunate occurrence, valuable data were obtained monthly from the Stewart's Cove SUR from June to December 2016. Each SUR was programmed to detect implanted, active sonic transmitter frequencies using Sonotronics's SURsoft software. The SURs were deployed using round weights along a lead of vinyl-coated steel cable secured to the SUR and then concealed on shore. They 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, date, and frequency 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, a minimum of two records were required within 5 minutes of one another for a record to be reported as a positive identification of a sonic-tagged razorback sucker.

Adult Sampling

Trammel Netting

Trammel netting occurred from January 3 to April 4, 2017, in Las Vegas Bay, from January 26 to April 19, 2017, in the Virgin River/Muddy River inflow area, and from February 4 to April 5, 2017, in Echo Bay. Two sizes of trammel nets were the primary gear used to sample for adult fish. One net size measured 91.4 m long by 1.8 m deep with an internal panel of 2.54 cm mesh and external panels of 30.48 cm mesh. The other net size used had dimensions of 45.7 m long by 1.8 m deep with an internal panel of 2.54 cm mesh and external panels of 30.48 cm mesh. The nets were generally set with one end near shore in less than 10 m of water, 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 conducted in a manner that would not subject the fish to surface water temperatures greater than 20 degrees Celsius (°C) (Hunt et al. 2012).

All fish were removed from the nets and held in 94.6-liter live wells filled with reservoir water. Native fishes were isolated from other fish species and held in aerated live wells. The first five non-native fish of each 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, and 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). Native sucker species selected for age determination were anesthetized with tricaine methanesulfonate (MS-222) and placed dorsal-side down on a padded surgical cradle for support while a small segment of the second pectoral fin ray (0.5 cm long) was collected for aging. Samples were placed in a paper envelope and allowed to dry before laboratory analysis. As requested by the Lake Mead Work Group, genetic material was also removed from newly captured, wild razorback suckers. Genetic samples consisted of removing an approximately 0.5-cm 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 analysis following the field season.

Additional Netting Efforts

In addition to biweekly long-term monitoring efforts, trammel netting occurred March 20–24, 2017. These efforts resulted from the collaboration of multiple agencies, including Reclamation, the NDOW, and BIO-WEST. The goal of this additional trammel netting was to capture as many new and previously PIT-tagged razorback suckers as possible in the Overton Arm (Echo Bay and the Virgin River/Muddy River inflow area) in an effort to supplement diminished sampling at the long-term monitoring study areas. Identical methods were used during additional trammel netting sampling, and the data from these efforts were combined with, and are presented as part of, the long-term monitoring results contained herein.

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. Furthermore, numbers of razorback suckers reported herein represent the total number captured unless otherwise noted. As non-normality and unequal variances are common with datasets related to low-density fish species, residual plots were examined for violation of test assumptions. Additionally, data were tested for normality using a Shapiro-Wilk test. Since the residuals were not normally distributed nor showed equal variances, and the results from the Shapiro-Wilk test showed a non-normal distribution of data ($P \leq 0.05$), 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). 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

Two shore-based, remote PIT scanning units were deployed from January 27 to March 23, 2017, south of the Virgin River/Muddy River inflow area along the eastern shore line near areas were sonic-tagged fish were frequently contacted. The shore-based units have a submersible antenna with a built-in scanner connected to a shore-based logger inside a waterproof housing. Reclamation biologists routinely downloaded data and maintained these units.

Additionally, mobile, remote PIT tag antennas were deployed at each of the three long-term monitoring study areas in order 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 were retrieved the following day.

With both types of scanning, information recorded included general location description, GPS location, date, deployment depth, and start and end scanning times. Scanner data were combined for analysis to help determine PIT-tagged fish movements and identify fish that were not captured via trammel nets in 2017.

Growth

Razorback sucker annual growth was calculated for recaptured individuals previously tagged during trammel netting collections between 1996 and 2016 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 in field measure errors. Recaptured individuals from the 2017 field season were only measured once during the spawning season to avoid handling stress. An analysis in a previous study (Mohn et. al 2015) shows that razorback suckers in Lake Mead have no statistical difference in growth depending on whether they are wild or stocked. Therefore, annual growth, as well as mean annual growth, was calculated for recaptured fish (wild and stocked combined) from individual long-term monitoring study areas (i.e., Las Vegas Bay, Echo Bay, and the Virgin River/Muddy River inflow area).

Larval Sampling

The primary larval sampling method followed that developed by Burke (1995) and other researchers on Lake Mohave. The procedure uses the positive phototactic response of larval razorback suckers to capture them. After sundown, two 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. The procedure was repeated for 15 minutes at each site. At each site, 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. In cooperation with the NDOW and Reclamation, in some cases a subset of 1–5 larvae were collected for genetic analysis. Samples were preserved in 95% genetics-grade ethanol, labeled with date and location information, and given to Reclamation biologists at the end of the field season. Furthermore, from March 20–24, 2017, an additional multiagency (Reclamation, the NDOW, and BIO-WEST) effort was also employed to sample as many larval sites as possible in the Overton Arm (Echo Bay and the Virgin River/ Muddy River inflow area).

Data Analysis

The CPUE for larval razorback sucker captures via active light sampling was calculated as the mean number of fish captured per light-minute for analyzing the relative abundance by year throughout the 2007–17 study period. However, given that non-normality and unequal variances are common with datasets related to low-density fish species, residual plots were examined for violation of test assumptions. Additionally, data were tested for normality using a Shapiro-Wilk test. Since the residuals were not normally distributed nor showed equal variances, and the results from the Shapiro-Wilk test showed a non-normal distribution of data ($P \leq 0.05$), the data were transformed [Ln(CPUE+1)].

Hereafter, all mention of CPUE in the context of larval captures represents normalized data. All statistical analyses were performed using the program Statistix 8.1. An 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). 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. 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).

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). 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 2017.

Age Determination

A non-lethal aging technique employing fin ray sections was developed in 1999 (Holden et al. 2000a) and has been refined over subsequent years. As in past years, an emphasis for the 2017 long-term monitoring efforts involved collecting fin ray sections from razorback suckers for aging purposes. During the 2017 field season, previously unaged, wild razorback suckers captured via trammel netting were anesthetized, and a single (approximately 0.5 cm long) segment of the

second, left pectoral fin ray was surgically removed. Fish were anesthetized in reservoir water containing MS-222, sodium chloride (NaCl), and slime-coat protectant to reduce surgery-related stresses, aid in recovery, and avoid accidental injury to fish during surgical procedures. During the surgery, fish were weighed, measured (TL, FL, and SL), PIT tagged, 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 rubbing 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 as soon as they regained equilibrium at their point of capture. 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 aged independently by at least three 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 three readers collectively assigned an age. For further information regarding the development of the fin ray aging technique, please refer to Albrecht and Holden (2005), Albrecht et al. (2006b), Albrecht et al. (2008a), Albrecht et al. (2010a), and other annual Lake Mead razorback sucker reports. Information for all razorback suckers aged since 1999 are listed in attachment 1.

Population and Survival Estimation

Population Estimates

To assess the population of razorback suckers in Lake Mead, program MARK (Cooch and White 2013) was utilized in an attempt to produce an estimate from mark-recapture data spanning from 2015 to 2017. This timespan was selected to maintain consistency with past estimates where 3-year datasets were used. A similar approach to maintain 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 were used to produce the estimate. Thirty-two capture occasions during the 2015–17 spawning seasons (January – April) were included in three full-likelihood closed capture models 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 produced in program MARK were compared according to Akaike's information criterion (AIC_c) values (which adjusts for small sample size). The model with the highest ranking AICc value is reported within. Although considered, no model averaging was conducted because a single model (*Mt*) carried all the AICc weight. Model selection rankings and summaries can be found in attachment 2.

Survival Estimates

Annual apparent survival (φ) estimates the probability of an individual being alive and available for capture from one year to the next (Zelasko et al. 2011; Cooch and White 2013). 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 2017. 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 [1996–2017] and the CRI [2010–17]). Razorback suckers that were captured in trammel nets were used to produce this model. Twenty-two 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 3). The models were compared according to AICc values, where the best fitting models have the highest 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 $\hat{c}$ 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 3).

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 greater than 450 mm TL (Zelasko et al. 2011; Albrecht et al. 2013a, 2014b). 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 (1996–2017), facilitates comparison of survival for Lake Mead razorback suckers with other prominent razorback sucker populations, such as

those in the upper Colorado River subbasins (Roberts and Moretti 1989; Bestgen et al. 2009; Zelasko et al. 2011) and Lake Mohave (Kesner et al. 2012; Marsh & Associates, LLC 2016).

RESULTS

Lake Elevation

For the past 10 years (figure 2), reservoir elevations have generally declined; however, during the 2016–17 field season, reservoir elevations increased throughout summer and winter then reached a peak of 332.2 m in March (figure 2). In 2017, reservoir elevations decreased approximately 3 m during the remainder of the spawning season (March – April) (figure 2). Biologists observed noticeable drying of littoral spawning areas and the loss of expanses of recently inundated terrestrial vegetation within all of the long-term monitoring study areas during these months. Lake elevation drops caused areas to dry, particularly in the Virgin River/Muddy River inflow area where the littoral zone of the reservoir has a more gradual slope, but drying was observed in Las Vegas Bay and Echo Bay as well. Following the peak spawning months (i.e., February, March, and April), reservoir elevation continued to decline through the remainder of the 2016–17 field season (figure 2).

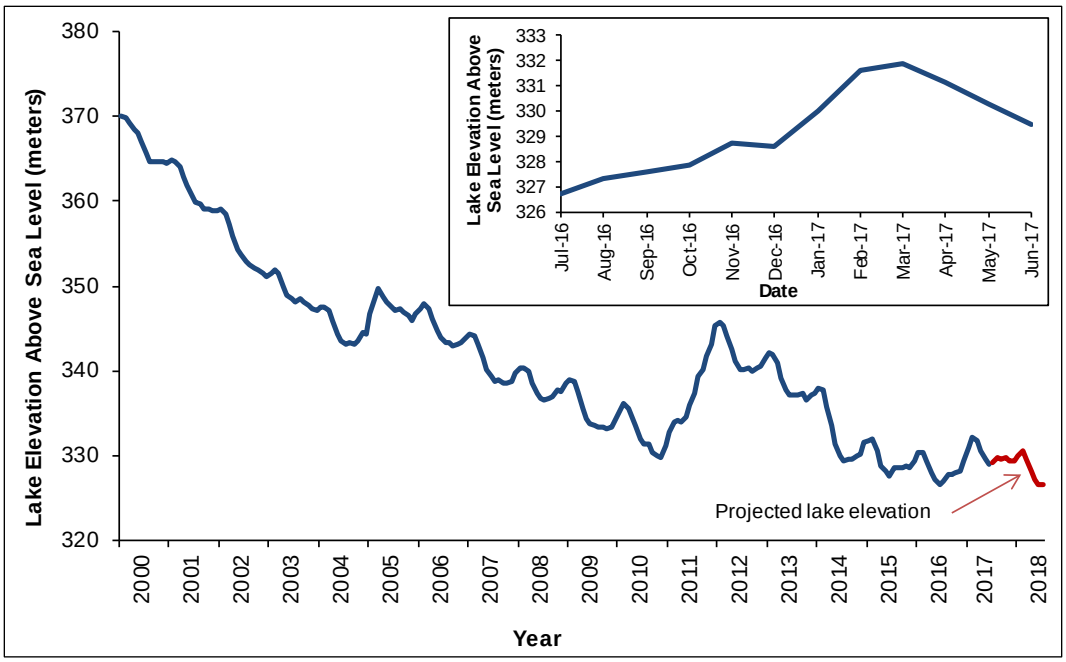

Figure 2.—Lake Mead month-end reservoir elevations, July 2000 – June 2017, with projected reservoir elevations for the July 2017 – June 2018 study year (Reclamation 2017).
Inset shows daily reservoir elevations, July 1, 2016 – June 30, 2017 (Reclamation 2017).

Sonic Telemetry

Over the course of this study, 99 adult razorback suckers (54 wild and 45 hatchery reared) have been equipped with sonic transmitters for the purposes of long-term monitoring and research at Las Vegas Bay, Echo Bay, and the Virgin River/ Muddy River inflow area. This includes six wild razorback suckers that were sonic-tagged in 2017 (n = 2 in Las Vegas Bay, n = 2 in Echo Bay, and n = 2 in the Virgin River/Muddy River inflow area).

Fourteen unique sonic-tagged fish were detected using active and/or passive telemetry methods, at the combined three long-term monitoring study areas during the 2016–17 field season. Forty-four active contacts were made with 13 individual sonic-tagged razorback suckers, while 1 sonic-tagged fish was only contacted passively via SUR (table 1). Of the six long-term monitoring SURs, the five located in the Overton Arm (Echo Bay South, Echo Bay North, Anchor Cove, Stewart's Cove, and Lime Cove SURs) contacted 8 of the 14 sonic-tagged razorback suckers a total of 8,745 times (table 1).

The Stewart's Cove SUR contacted razorback suckers most often (4,344 contacts). The number of SURs and the number of contacts are typically used to define movement, particularly long-distance movements of sonic-tagged individuals, and aide in accounting for difficult-to-locate sonic-tagged fish. Of the 10 sonic-tagged fish released (2011 [n = 4], 2014 [n = 4], and 2017 [n = 2]) in the Overton Arm (Echo Bay and Virgin River/Muddy River inflow area), 4 were detected with either active and/or passive telemetry, moving between Echo Bay and the Virgin River/Muddy River inflow area (see figures 4 and 5; table 1). Another demonstration of movement was documented when sonic code 3375, a wild razorback sucker that was tagged in Echo Bay in 2014, moved to the CRI in September 2016, was found again in Echo Bay in December 2016, where it remained through June 2017. Lastly, the sonic-tagged fish in Las Vegas Bay remained within the bay throughout the field season; therefore, no known sonic-tagged fish were contacted via SUR leaving Las Vegas Bay (figure 3; table 1).

Fish Sonic Tagged in 2011

Eight razorback suckers from Floyd Lamb State Park were sonic tagged and stocked into Lake Mead in January 2011. Four of these individuals were released in Las Vegas Bay, and four individuals were released in the Virgin River/Muddy River inflow area. During the 2016–17 field season, 2 of the fish that were stocked at the Virgin River/Muddy River inflow area were contacted a total of 364 times (table 1) using a combination of active and passive methods. They were last contacted in August 2016 (sonic code 448) and January 2017 (sonic code 555), respectively. Individuals from the 2011 tagging event were contacted primarily by SURs (table 1); the majority of SUR contacts were made by the Echo Bay North SUR (n = 242) and the Stewart's Cove SUR (n = 70) (see figure 1 for SUR locations).

Table 1.—Initial tagging and stocking information, location, date of last contact, and status of sonic-tagged razorback suckers in Lake Mead, July 2016 – June 2017

Capture location[a]	Date tagged	Sonic code	TL (mm) at tagging	Sex[b]	Release location[a]	Last location[a]	Date of last contact	Contacts made: active (passive)	Current tag status[c]
2011									
FDLB	1/4/2011	334	564	F	LB	LB	2/15/2014	(0)	Unknown
FDLB	1/4/2011	3545	556	F	LB	LB	7/15/2014	(0)	Unknown
FDLB	1/4/2011	3584	519	M	LB	LB	6/23/2014	(0)	Unknown
FDLB	1/4/2011	3775	516	M	LB	LB	1/15/2016	(0)	Unknown
FDLB	1/4/2011	448	502	M	OA	OA	8/16/2016	2 (155)	Active
FDLB	1/4/2011	555	504	M	OA	OA	1/26/2017	1 (206)	Active
FDLB	1/4/2011	3578	541	F	OA	OA	6/16/2015	0 (0)	Unknown
FDLB	1/4/2011	3667	552	F	OA	OA	2/17/2015	0 (0)	Unknown
2014									
EB	2/6/2014	586	656	F	EB	EB	2/4/2017	6 (5,725)	Active
EB	2/12/2014	3375	598	M	EB	EB	6/14/2017	5 (0)	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)	Expired
LB	2/11/2014	3488	626	M	LB	LB	7/11/2016	1 (2)	Active
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	3 (0)	Active
OA	2/5/2014	578	520	M	OA	EB	6/14/2017	10 (594)	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	1 (181)	Active
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	4/18/2017	6 (0)	Active
LB	4/4/2017	3577	564	M	LB	LB	4/18/2017	1 (0)	Active
EB	2/5/2017	364	582	M	EB	EB	4/4/2017	2 (0)	Active
EB	2/21/2017	3658	628	M	EB	OA	4/19/2017	3 (1,728)	Active
OA	2/20/2017	6677	585	M	OA	OA	4/19/2017	0 (154)	Active
OA	2/20/2017	3768	576	M	OA	OA	6/14/2017	3 (0)	Active

[a] FDLB = Floyd Lamb State Park, EB = Echo Bay, LB = Las Vegas Bay, CPD = Center Pond in the Overton Wildlife Management Area, OA = Overton Arm (Virgin River/Muddy River inflow area), AC = Ancho Cove, and GH = Glory Hole.
[b] Sex: F = female, and M = male.
[c] Active = fish considered active and moving, Expired = tag was not located during the tracking season and is well beyond the battery expiration date, and Unknown = fish at large.

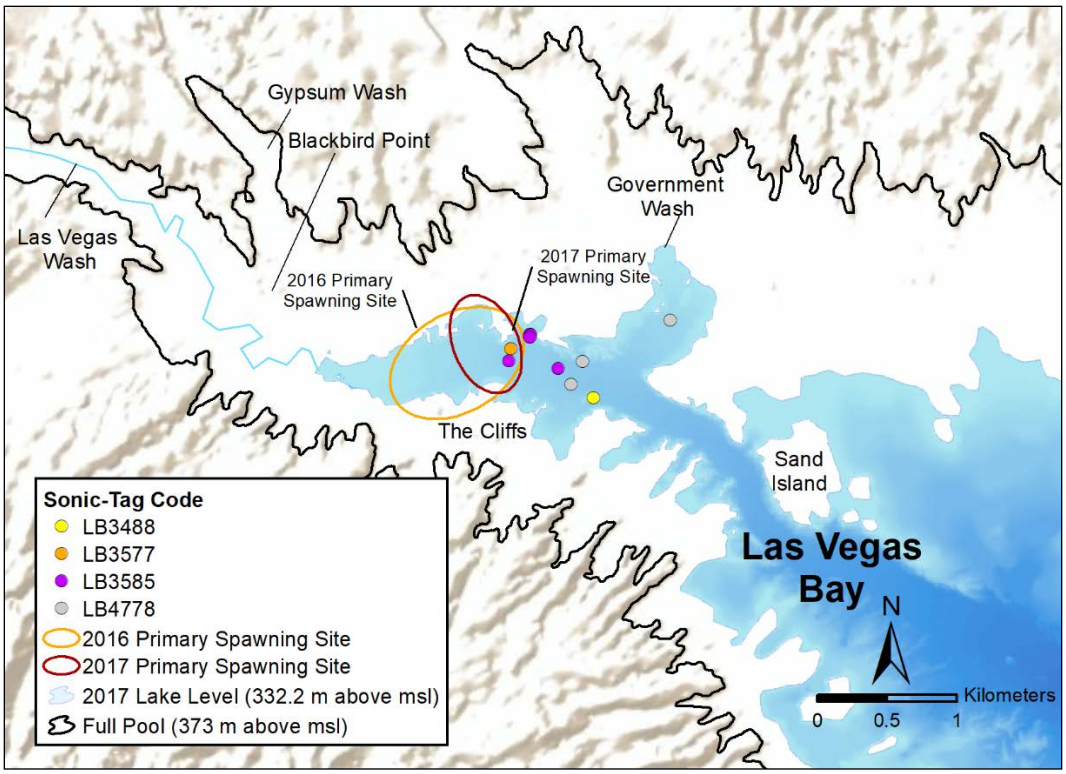

Figure 3.—Distribution of sonic-tagged razorback suckers located through active sonic telemetry in Las Vegas Bay, July 2016 – June 2017.
Symbols for each tag code are unique to their original tagging location, which is noted on the map as the tag code (e.g., LB4778 was originally tagged within Las Vegas Bay).

Additionally, active telemetry efforts detected these individuals three times. Sonic code 448 was found twice near Echo Bay, while sonic code 555 was found once further north near the Meadows (figures 4 and 5).

Fish Sonic Tagged in 2014

Ten wild razorback suckers from Lake Mead were sonic tagged from February through March during the concurrent 2014 long-term monitoring trammel netting efforts in Las Vegas Bay (n = 2), Echo Bay (n = 4), and the Virgin River/Muddy River inflow area (n = 4) (see table 1) (Albrecht et al. 2013a, 2013b). Due to difficulties in capturing suitable wild individuals in Las Vegas Bay, an additional individual from Center Pond at the Overton Wildlife Management Area was sonic tagged at the Lake Mead Fish Hatchery and released into Las Vegas Bay in March 2014 (see table 1).

During the 2016–17 field season, 6 of 11 individuals from the 2014 tagging event were contacted at least once for a total of 26 active sonic telemetry contacts (see table 1). Four of the 11 individuals were also passively contacted a combined 6,502 times via 5 different SURs (see table 1). The contacts were made at the

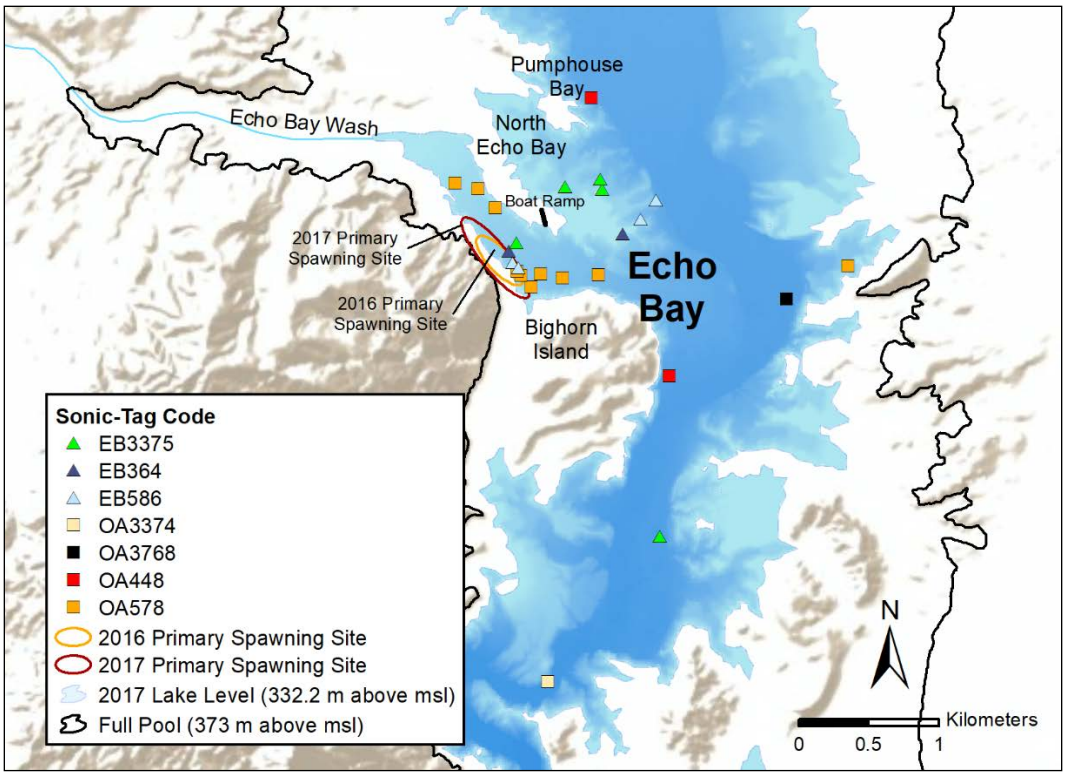

Figure 4.—Distribution of sonic-tagged razorback suckers located through active sonic telemetry in Echo Bay, July 2016 – June 2017.
Symbols for each tag code are unique to their original tagging location, which is noted on the map as the tag code (e.g., fish OA578 was originally tagged near the Virgin River/ Muddy River inflow area).

Stewart's Cove SUR (*n* = 4,132), Echo Bay North SUR (*n* = 1,475), Anchor Cove SUR (*n* = 479), Lime Cove SUR (*n* = 335), and the Echo Bay South SUR (*n* = 81) (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 2016–17 field season (figures 5 and 6). Two individuals (sonic codes 578 and 3374) sonic tagged at the Virgin River/Muddy River inflow area in 2014 were contacted in Echo Bay during the spawning season. During the 2016–17 field season, one individual (sonic code 4778) from the 2014 tagging event in Las Vegas Bay was often found occupying deeper, mid-channel areas of Las Vegas Bay between Government Wash and Las Vegas Wash.

Fish Sonic Tagged in 2017

During the 2017 field season, six wild male razorback suckers captured in trammel nets, two at each study area, were implanted with sonic tags from February to April. All six fish were contacted by either active and/or passive

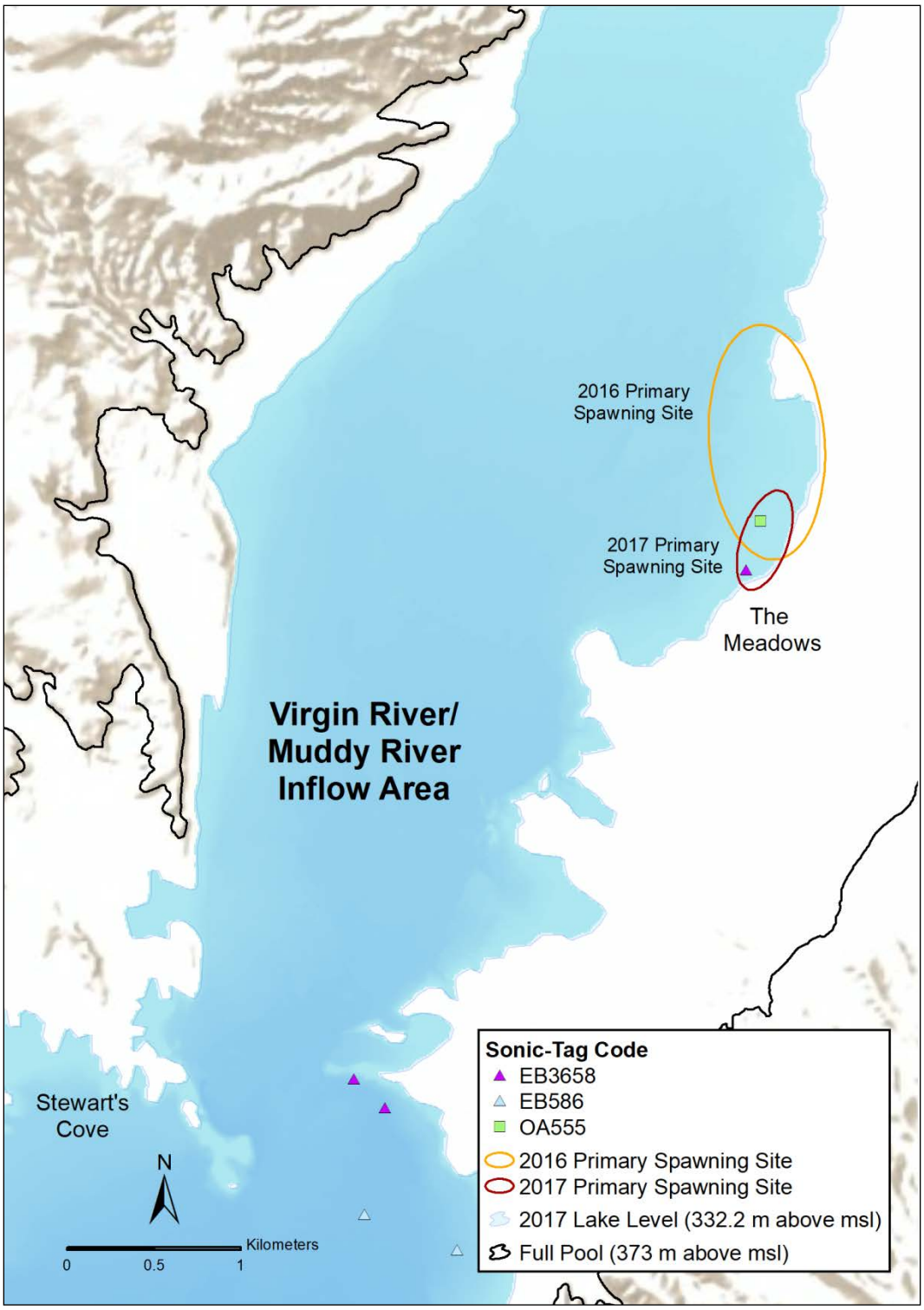

Figure 5.—Distribution of sonic-tagged razorback suckers located through active sonic telemetry near the Virgin River/Muddy River inflow area, July 2016 – June 2017.

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 EB586 was originally tagged within Echo Bay).

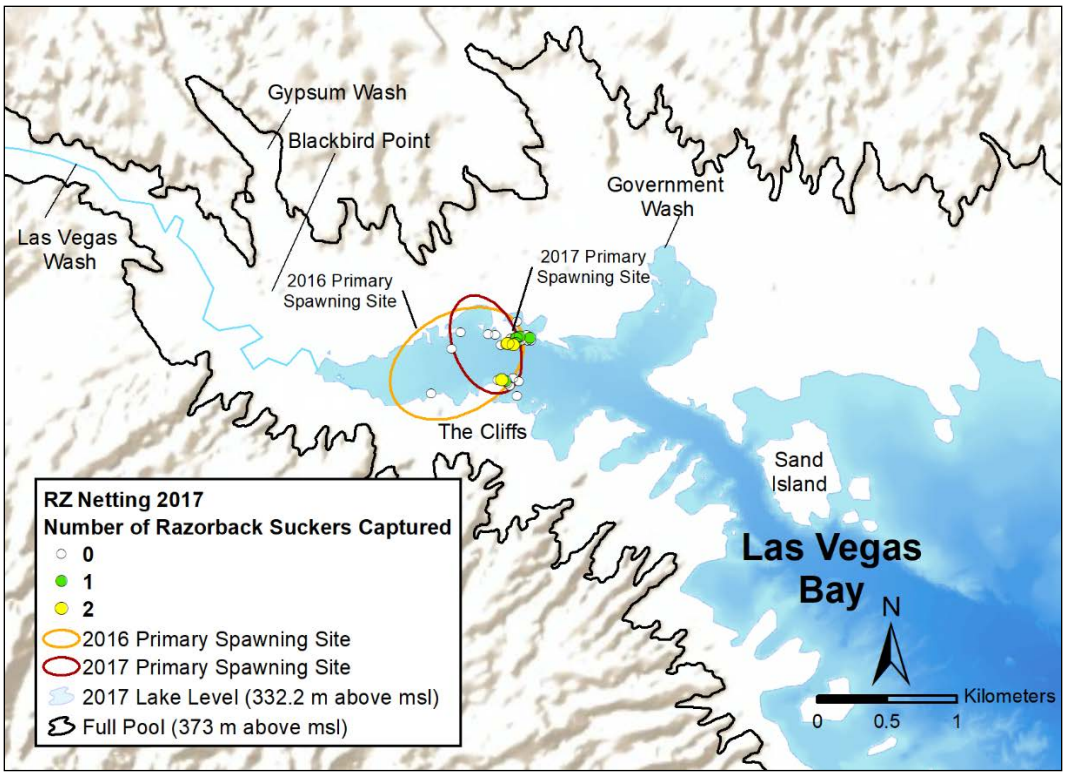

Figure 6.—Locations of trammel netting efforts and numbers of razorback suckers captured in Las Vegas Bay, January – April 2017.

telemetry (see table 1). Five fish were contacted 15 times in aggregate via active tracking methods, while 2 fish were contacted 1,882 times via SURs (see figures 4–6). These fish remained near spawning locations and dispersed into deeper habitats as the spawning period ended (see figure 3). During past tagging events, fish implanted with sonic tags and released into a particular locality of Lake Mead often remained within the general release area. One fish (sonic code 3585) from the 2017 tagging event was observed moving between deeper mid-channel areas near Government Wash west toward the shallow areas adjacent to Las Vegas Wash (see figure 3).

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 2016–17 field season (see figures 5 and 6). Two fish (codes 3658 and 586) that were tagged in Echo Bay in 2017 were last found south of the Virgin River/Muddy River inflow area across from Stewart's Cove (see figure 5).

Adult Sampling

Trammel Netting

Trammel netting surveys were conducted from January 3 to April 19, 2017, and consisted of 99 nets set totaling 1,579.3 total net-hours (table 2; figures 6–8). This effort and the number of net sets includes efforts of Reclamation biologists and joint efforts of BIO-WEST, Reclamation, and the NDOW during March 20–24, 2017. During these trammel netting efforts, a total of 41 razorback suckers were captured (table 3). Additionally, two flannelmouth suckers were captured. The first male razorback sucker expressing milt was captured on January 17, 2017, in Las Vegas Bay, and the first female razorback sucker expressing eggs was captured on February 5, 2017, in Echo Bay.

Table 2.—Trammel netting efforts (number of nets and net-hours) on Lake Mead, January – April 2017

Month	Las Vegas Bay	Echo Bay	Virgin River/Muddy River inflow area	Total
January	19	2	4	25
February	11	11	7	29
March	2	21	15	38
April	1	4	2	7
Total number of nets	**33**	**38**	**28**	**99**
Total net-hours	**545.1**	**574.1**	**460.1**	**1,579.3**

Efforts in all combined netting locations within Lake Mead found that 37% of captured razorback suckers were females, 49% were males, 12% were juveniles, and 2% were of unknown sex. Of 12 individuals captured in Las Vegas Bay, 3 were female, 5 were male, and 4 were wild juvenile fish (table 3; see figure 6). Fourteen adult razorback suckers were captured in Echo Bay, composed of five females and nine males (table 3; figure 7). Razorback suckers captured south of the Virgin River/Muddy River inflow area comprised seven females, six males, one undetermined sex, and one wild juvenile (table 3; figure 8). Within the three long-term monitoring study areas combined, 20 razorback suckers were recaptured, and 21 wild, unmarked fish were captured. One fish captured during the netting season was sonic tagged and stocked in 2011. This individual appeared to have integrated with the adult spawning population, as it was captured alongside other spawning adults. Additionally, one wild razorback sucker, sonic tagged in 2014, was recaptured in Echo Bay.

The combined (Reclamation, the NDOW, and BIO-WEST) 2017 trammel netting efforts in Lake Mead yielded an overall mean CPUE of 0.0248 (± standard error [SE] = 0.0043). Efforts in Las Vegas Bay were focused on the western shore of

Table 3.—Capture location, tagging, and size information for razorback suckers captured, January 3 – April 21, 2017

Date	Capture location[a]	Date tagged or stocked[b]	Sonic code	PIT tag	Recapture	TL (mm)	FL (mm)	SL (mm)	Wt[c]	Sex[d]	Origin
01/04/17	LB	01/04/11	3775	384.1B796EE4DC	Y	584	538	510	2,788	M	Stocked
01/04/17	LB	01/04/17		3DD.003BCB9366	N	361	332	295	484	I	Wild
01/10/17	LB	01/10/17		3DD.003BC89ED3	N	586	542	508	2,508	M	Wild
01/10/17	LB	01/10/17		3DD.003BC89EEE	N	305	282	157	304	I	Wild
01/11/17	LB	01/11/17		3DD.003BCB938D	N	357	295	269	348	I	Wild
01/13/17	OA	02/06/15		3D9.1C2D695D82	Y	597	571		2,100	F	Stocked
01/17/17	LB	02/26/13		3D9.1C2C83CA43	Y	562	538	497	2,722	M	Wild
01/17/17	LB	03/20/14	3585	3DD.003BA2FAAF	Y	549	505	476	1,834	M	Wild
01/27/17	OA	03/05/13		384.1B7969E0B2	Y	593	542		2,300	M	Wild
01/27/17	OA	01/27/17		3D9.2794E27D5A	N	592	540		2,170	M	Wild
01/27/17	OA	01/27/17		3DD.003BA7687D	N	657	607		3,430	F	Wild
02/03/17	LB	02/06/15		3D9.257C602471	Y	596	540	500	2,100	F	Stocked
02/03/17	LB	02/03/17		3DD.003BC89EE7	N	301	278	253	290	I	Wild
02/04/17	OA	02/09/10		3D9.257C633584	Y	605	561	512	2,294	F	Wild
02/04/17	OA	02/04/17		3DD.003BC89F07	N	541	489	453	1,718	F	Wild
02/05/17	EB	04/05/16		3DD.003BCB938F	Y	654	609	561	2,688	F	Wild
02/05/17	EB	04/22/10	364	3D9.257C612FA9	Y	582	551	516	2,223	M	Wild
02/14/17	OA	02/14/17		3D9.2794EA27D6	N	624	585		2,785	F	Wild
02/15/17	EB	02/15/17		3D9.2794EA816F	N	472	435		1,060	M	Wild
02/20/17	OA	03/15/12	6677	384.1B7969D27B	Y	585	544	509	2,298	M	Wild
02/20/17	OA	02/09/10	3768	3D9.257C60EB46	Y	576	513	492	1,978	M	Wild
02/21/17	EB	02/22/11		3D9.257C60BE38	Y	535	494	460	1,728	M	Wild
02/21/17	EB	02/14/17		3D9.2794EA27D6	Y	Quick release					
02/21/17	EB	02/21/17	3658	3DD.003BCB9336	N	628	581	452	2,358	M	Wild
02/21/17	EB	02/12/14	4656	384.1B7969DE0B	Y	646	591	555	2,618	M	Wild
02/21/17	EB	02/21/17		3DD.003BCB9337	N	560	523	499	1,848	M	Wild
02/21/17	EB	02/21/17		3DD.003BCB9317	N	521	475	440	1,428	M	Wild
02/22/17	LB	02/22/17		3DD.003BCB9316	N	586	541	511	1,872	F	Wild
03/02/17	EB	02/14/17		3D9.2794EA27D6	Y	Quick release					
03/02/17	EB	03/02/17		3DD.003BA62D4C	N	664	623	582	3,445	F	Wild
03/03/17	OA	03/03/17		3DD.003BCB9318	N	586	542	505	2,440	U	
03/03/17	OA	04/03/13		384.1B7969DA02	Y	571	525	490	1,970	M	Wild
03/03/17	OA	03/03/17		3D9.025893A7D7	N	642	590	545	2,675	F	Wild
03/03/17	OA	03/03/17		3DD.003BA7688C	N	541	496	451	1,895	M	Wild
03/07/17	LB	02/06/15		3D9.257C602471	Y	Quick Release					
03/08/17	OA	03/01/11		3D9.1C2D262910	Y	641	596	557	3,488	F	Wild
03/09/17	EB	02/16/16		3DD.003BCB93CA	Y	547	505	470	1,708	M	Wild
03/09/17	EB	03/09/17		384.1B79697992	N	642	611	563	3,328	F	Wild
03/09/17	EB	03/22/16		3DD.003BCB93BF	Y	541	508	475	1,798	M	Wild
03/22/17	OA	03/22/17		3DD.003BCB9319	N	319	296	266	350	I	Wild
04/04/17	LB	04/04/17	3577	3DD.003BCB935F	N	564	520	481	1,968	M	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] Wt = weight (grams).
[d] Sex: F = female, I = immature, M = male, and U = undetermined.

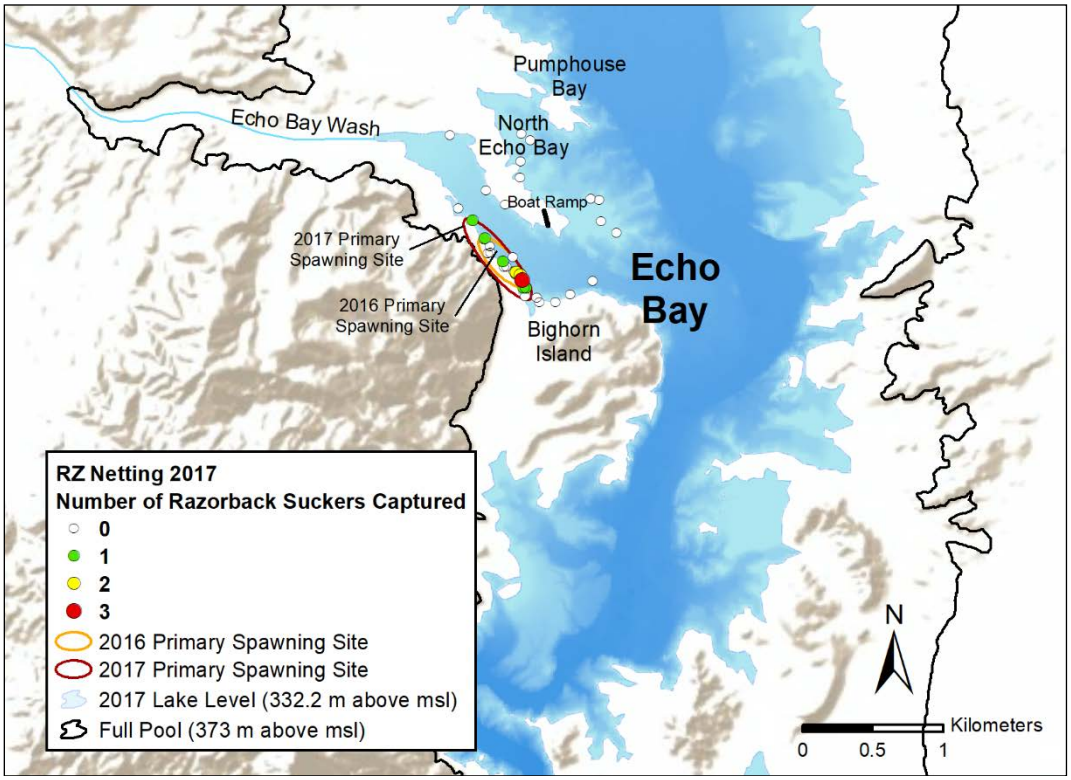

Figure 7.—Locations of trammel netting efforts and numbers of razorback suckers captured in Echo Bay, February – April 2017.

the bay outside of Las Vegas Wash (see figure 6). Twelve razorback suckers were captured as a result of 545.1 net-hours (see tables 2 and 3). This effort yielded a mean CPUE of 0.0221 (± SE = 0.0068) (figure 9). Trammel netting efforts in Echo Bay primarily focused on the western shoreline across from the boat ramp, which resulted in the capture of 14 razorback suckers from 574.1 net-hours (see figure 7; tables 2 and 3). Echo Bay had a mean CPUE of 0.0231 (± SE = 0.00720) (figure 9). Trammel netting within the Virgin River/Muddy River inflow area resulted in the capture of 15 razorback suckers from 460.1 net-hours and yielded a mean CPUE of 0.0303 (± SE = 0.0087) (figure 9; see tables 2 and 3). Sampling of the Virgin River/Muddy River inflow area occurred primarily along the eastern shore over gravel bars, approximately 3 km south of the Virgin River/Muddy River inflow area, and net sets were often dependent on the presence of sonic-tagged individuals (figure 8). In 2017, the mean CPUE at all three long-term monitoring study areas fell within the range of mean CPUE values observed since 2005 and generally remain higher than the same observations at the CRI (figure 9).

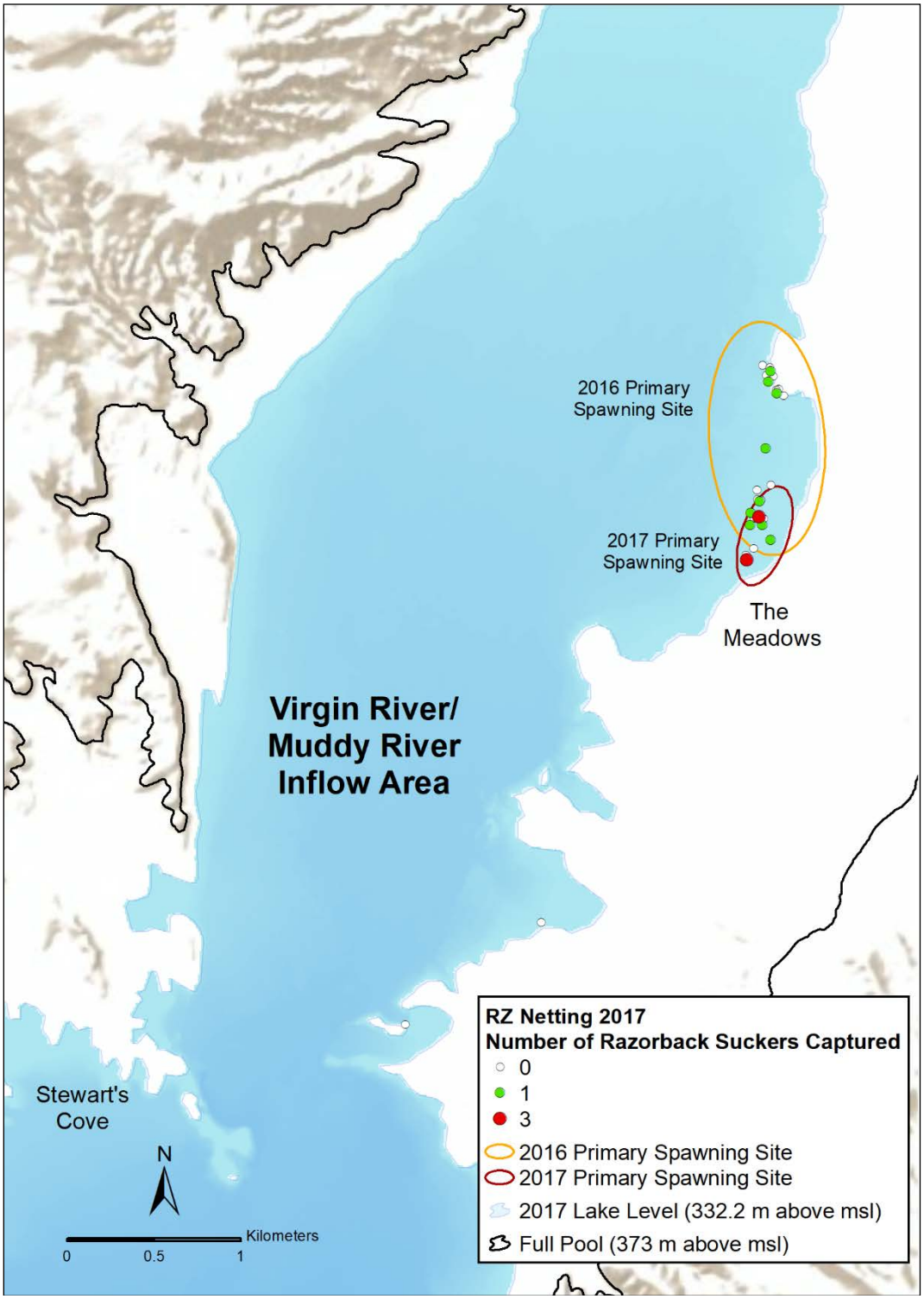

Figure 8.—Locations of trammel netting efforts and numbers of razorback suckers captured at the Virgin River/Muddy River inflow area, February – April 2017.

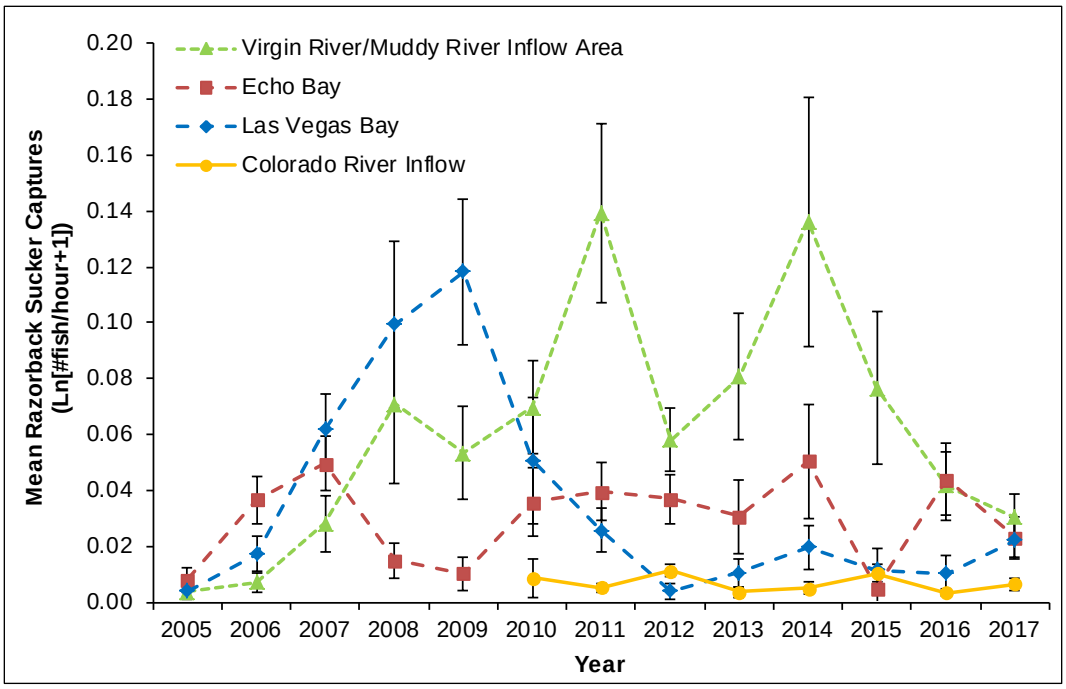

Figure 9.—Trammel netting mean CPUE (Ln[#fish/hr+1]) with associated SE of razorback suckers at long-term monitoring and CRI study areas in Lake Mead, 2005–17.
Sampling at the Virgin River/Muddy River inflow area was initiated during the 2004–05 study year. Sampling at the CRI was initiated during the 2010 study year.

A statistical difference was detected among annual mean CPUE values (ANOVA, $F_{12,365} = 8.50$, $P < 0.0001$) in Las Vegas Bay. Post-hoc pairwise comparisons showed that 2009 had a significantly higher CPUE than 2005 and 2012 (see figure 9). However, the mean annual CPUE of 2017 was not statistically different from other years but has remained low when compared to 2007–10 (see figure 9). In Echo Bay there was a statistical difference in the annual mean CPUE values (ANOVA, $F_{12,418} = 2.18$, $P = 0.0120$), but no statistical differences for the pairwise comparisons in post-hoc testing was observed (see figure 9). With the exception of 2007 and 2014, Echo Bay appears to be to be an important spawning location for razorback suckers (see figure 9). Lastly, a statistical difference was detected at the Virgin River/Muddy River inflow area (ANOVA, $F_{12,333} = 5.29$, $P < 0.0001$) between mean annual CPUE values. Post-hoc pairwise comparisons showed that the mean CPUE values in 2011 and 2014 were significantly higher than the mean CPUE values for razorback suckers in 2005–07, 2016, and 2017 (see figure 9).

Trammel netting yields important movement data when fish are recaptured in different locations and provides important information about other native species present throughout Lake Mead. Past studies suggest that a small percentage of

razorback suckers exhibit long-distance movements (Albrecht et al. 2014a; Mohn et al. 2016). Movement was documented this year, as seven wild adult razorback suckers were captured at different sites than those in which they were originally PIT tagged. Two fish moved from the Virgin River/Muddy River inflow area to Echo Bay. One fish, originally tagged in Echo Bay, was recaptured at the Virgin River/Muddy River inflow area. One fish was tagged at the Virgin River/ Muddy River inflow area and recaptured in Las Vegas Bay. Three fish tagged at long-term monitoring study areas (n = 2 in the Virgin River/Muddy River inflow area, and n = 1 in Echo Bay) were recaptured at the CRI in 2017 (Kegerries et al. *in press*).

Two flannelmouth suckers also were captured in 2017. One new flannelmouth sucker was captured in Echo Bay (mean CPUE 0.0018), and the other was recaptured at the Virgin River/Muddy River inflow area (mean CPUE 0.0016); this individual originally was tagged in Echo Bay in 2016.

Remote Passive Integrated Transponder Scanning

Within the three long-term monitoring study areas, remote PIT scanning efforts were conducted for a total of 2,476.0 hours and resulted in the detection of 70 unique individual razorback suckers. Fifty-eight of the fish contacted were not captured in trammel nets this year (table 4). Additionally, 29 fish have not been captured with trammel nets since 2014 (table 4). Scanners deployed in Las Vegas Bay and Echo Bay detected three unique fish at each of the study areas, during 115.1 and 431.5 hours of scanning, respectively. Finally, PIT scanning provided additional information regarding razorback sucker movement amongst the Overton Arm study areas as five individuals that were originally tagged in Echo Bay were detected at the Virgin River/Muddy River inflow area (table 4).

Growth

Annual growth rates for razorback suckers were calculated using 15 fish recaptured during 2017 (table 5). Razorback sucker annual growth at Echo Bay ranged from 2.97 to 13.68 mm TL, with a mean annual growth rate of 6.90 mm TL (± SE = 2.38) (table 5). Razorback suckers in the Virgin River/Muddy River inflow had an annual growth rate range of 6.66–23.03 mm TL, with a mean annual growth rate of 10.35 mm TL (± SE = 2.22) (table 5). In Las Vegas Bay, annual growth rates ranged from 6.00 to 25.93 mm TL, with a mean annual growth rate of 14.80 mm TL (± SE = 4.23). For fish recaptured during 2017 in the three combined long-term monitoring study areas, the growth rate was 10.61 mm TL (± SE = 1.71) (table 5).

Table 4.—Remote PIT tag scanner detections at long-term monitoring study areas with scanner locations, date of last capture, original tagging location, and days at large of each individual razorback sucker detected in 2017

Remote PIT tag detections	Date scanned	Scanner location[a]	Date of last capture	Original tagging location[a]	Days at large	Origin
3DD.003BA2FAC1	1/13/2017	OA	3/24/2016	OA	295	Wild
384.1B796EE6E9	1/26/2017	OA	2/6/2015	OA	720	Stocked
3DD.003BA2088C	1/27/2017	OA	12/8/2015	OA	416	Wild
384.1B7969D27B	1/28/2017	OA	2/20/2017	OA	23	Wild
3D9.1C2D694E50	1/28/2017	OA	2/6/2015	OA	722	Stocked
3D9.257C60E183	1/28/2017	OA	2/22/2011	OA	2,167	Wild
384.1B7969DA02	1/29/2017	OA	3/3/2017	OA	33	Wild
384.1B7969DF01	1/29/2017	OA	4/3/2013	OA	1,397	Wild
384.1B796EE0D6	1/29/2017	OA	2/1/2012	OA	1,824	Stocked
3D9.1C2C8406B7	1/29/2017	OA	2/12/2014	OA	1,082	Wild
3D9.1C2D26878D	1/29/2017	OA	1/31/2012	EB	1,825	Wild
3DD.003BA639B1	1/29/2017	OA	2/6/2015	OA	723	Stocked
3D9.1C2D2636A6	1/30/2017	OA	4/12/2012	EB	1,754	Wild
3DD.003BA7492E	1/30/2017	OA	2/16/2016	OA	349	Wild
3D9.1C2C8408E1	1/31/2017	OA	2/26/2014	OA	1,070	Wild
3D9.1C2C840DFB	1/31/2017	OA	2/21/2013	OA	1,440	Wild
384.1B796EF3CF	2/1/2017	OA	2/6/2015	OA	726	Stocked
3D9.1C2C83C396	2/1/2017	OA	2/7/2012	OA	1,821	Wild
3D9.1C2D6974B7	2/1/2017	OA	2/6/2015	OA	726	Stocked
3D9.257C6096E1	2/1/2017	OA	3/15/2012	OA	1,784	Stocked
3D9.257C60CC21	2/1/2017	OA	3/24/2016	OA	314	Wild
3D9.257C60EB46	2/1/2017	OA	2/20/2017	OA	19	Wild
3DD.003BC89EB2	2/1/2017	OA	3/31/2015	OA	673	Wild
3DD.003BCB9317	2/1/2017	EB	2/21/2017	EB	20	Wild
3D9.1C2C841878	2/2/2017	OA	3/1/2011	OA	2,165	Wild
3D9.1C2D27580E	2/2/2017	OA	2/4/2015	OA	729	Wild
3D9.1C2D69596A	2/2/2017	OA	2/6/2015	OA	727	Stocked
3D9.1C2C83C054	2/3/2017	OA	2/21/2013	OA	1,443	Wild
3DD.003BA0587B	2/3/2017	OA	Unknown	Unknown	Unknown	Unknown
3DD.003BC89EB4	2/3/2017	OA	2/18/2015	OA	716	Wild
3DD.003BCAA81A	2/3/2017	OA	Unknown	Unknown	Unknown	Unknown
3D9.1C2D268EC1	2/4/2017	OA	3/27/2013	OA	1,410	Wild

Table 4.—Remote PIT tag scanner detections at long-term monitoring study areas with scanner locations, date of last capture, original tagging location, and days at large of each individual razorback sucker detected in 2017

Remote PIT tag detections	Date scanned	Scanner location[a]	Date of last capture	Original tagging location[a]	Days at large	Origin
3DD.003BCB9380	2/4/2017	OA	2/24/2016	OA	346	Wild
3D9.1C2D263000	2/5/2017	OA	3/14/2013	OA	1,424	Wild
3D9.1C2C7F4A82	2/6/2017	OA	3/20/2014	OA	1,054	Wild
3D9.1C2C856C17	2/6/2017	OA	3/27/2013	OA	1,412	Wild
3D9.1C2D2617E7	2/6/2017	OA	3/5/2013	OA	1,434	Wild
3D9.1C2D266829	2/6/2017	OA	3/1/2011	OA	2,169	Wild
3D9.1C2D63A99F	2/6/2017	OA	1/20/2016	OA	383	Stocked
3D9.1C2D695D82	2/6/2017	OA	1/13/2017	OA	24	Stocked
3D9.257C608715	2/6/2017	OA	2/1/2011	OA	2,197	Wild
3D9.257C608F32	2/6/2017	OA	2/17/2010	OA	2,546	Wild
3DD.003BA62D53	2/6/2017	OA	3/24/2016	OA	319	Wild
3D9.1C2C7EF17C	2/7/2017	OA	2/26/2014	OA	1,077	Wild
3D9.1C2C7F47CD	2/7/2017	OA	3/1/2011	OA	2,170	Wild
3D9.1C2C8413A5	2/7/2017	OA	3/15/2011	OA	2,156	Wild
3DD.003BA63971	2/7/2017	OA	2/6/2015	OA	732	Stocked
3DD.003BA76885	2/7/2017	OA	3/24/2016	OA	320	Wild
384.1B7969DA5E	2/8/2017	OA	3/20/2014	OA	1,056	Wild
3D9.1C2C84072C	2/8/2017	OA	3/4/2015	OA	707	Wild
3D9.1C2C8412CB	2/8/2017	OA	2/22/2011	OA	2,178	Wild
3DD.003BA63962	2/8/2017	OA	2/6/2015	OA	733	Stocked
3DD.003BC89EF4	2/8/2017	OA	2/18/2015	OA	721	Wild
384.1B7969DB4E	2/10/2017	OA	3/13/2012	OA	1,795	Wild
3D9.1C2C843FA8	2/11/2017	OA	2/8/2012	OA	1,830	Wild
3D9.1C2D262910	2/12/2017	OA	3/8/2017	OA	24	Wild
3DD.003BCB938B	2/12/2017	OA	2/24/2016	OA	354	Wild
3DD.003BCB9395	2/12/2017	OA	2/24/2016	OA	354	Wild
384.1B7969E7AA	2/14/2017	OA	2/26/2014	OA	1,084	Wild
384.1B7969E475	2/15/2017	OA	3/31/2015	OA	687	Wild

[a] EB = Echo Bay, and OA = Overton Arm (Virgin River/Muddy River inflow area).

Table 5.—Lake Mead razorback sucker growth histories for recaptured fish, January – April 2017

PIT tag number[a]	Date captured[b]	Location captured[c]	Captured TL (mm)	Sex[d]	Date recaptured[e]	Location recaptured[c]	Recaptured TL (mm)	Change in TL (mm)[f]	Days between captures	Origin	Annual growth (mm/yr)[g]
Echo Bay											
384.1B7969DE0B	02/12/14	EB	637	M	02/21/17	EB	646	9	1,105	Wild	2.97
3D9.257C60BE38	02/22/11	OA	509	M	02/21/17	EB	535	26	2,191	Wild	4.33
3D9.257C612FA9	04/22/10	EB	489	M	02/05/17	EB	582	93	2,481	Wild	13.68
3DD.003BCB93CA	02/16/16	EB	540	M	03/09/17	EB	547	7	387	Wild	6.60
Mean annual growth											6.90 (± SE = 2.38)
Virgin River/Muddy River inflow area											
384.1B7969D27B	03/15/12	OA	546	M	02/20/17	OA	585	39	1,803	Wild	7.90
384.1B7969DA02	04/03/13	OA	542	M	03/03/17	OA	571	29	1,430	Wild	7.40
384.1B7969E0B2	03/05/13	OA	567	M	01/27/17	OA	593	26	1,424	Wild	6.66
3D9.1C2D262910	03/01/11	OA	595	F	03/08/17	OA	641	46	2,199	Wild	7.64
3D9.1C2D695D82	02/06/15	OA	582	F	01/13/17	OA	597	15	707	Stocked	7.74
3D9.257C60EB46	02/09/10	OA	491	M	02/20/17	OA	576	85	2,568	Wild	12.08
3D9.257C633584	02/09/10	OA	444	F	02/04/17	OA	605	161	2,552	Wild	23.03
Mean annual growth											10.35 (± SE = 2.22)
Las Vegas Bay											
384.1B796EE4DC	01/04/11	LB	516	M	01/04/17	LB	584	68	2,192	Stocked	11.32
3D9.1C2C83CA43	02/26/13	LB	500	M	01/17/17	LB	562	62	1,421	Wild	15.93
3D9.257C602471	02/06/15	LB	542	F	02/03/17	LB	596	54	760	Stocked	25.93
3DD.003BA2FAAF	03/20/14	OA	532	M	01/17/17	LB	549	17	1,034	Wild	6.00
Mean annual growth											14.80 (± SE = 4.23)
Reservoir-wide mean annual growth											10.61 (± SE = 1.71)

[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).
[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 date of most recent recapture divided by the number of days between captures and multiplied by 365.

Larval Sampling

Larval Captures

Larval razorback sucker sampling in long-term monitoring study areas was initiated on January 12, 2017, in Las Vegas Bay, and on February 3 and 4, 2017, in Echo Bay and the Virgin River/Muddy River inflow area, respectively. Larvae were first collected on February 2, 2017, in Las Vegas Bay and were routinely captured over cobble and gravel substrates near the wash inflow area (figure 10).

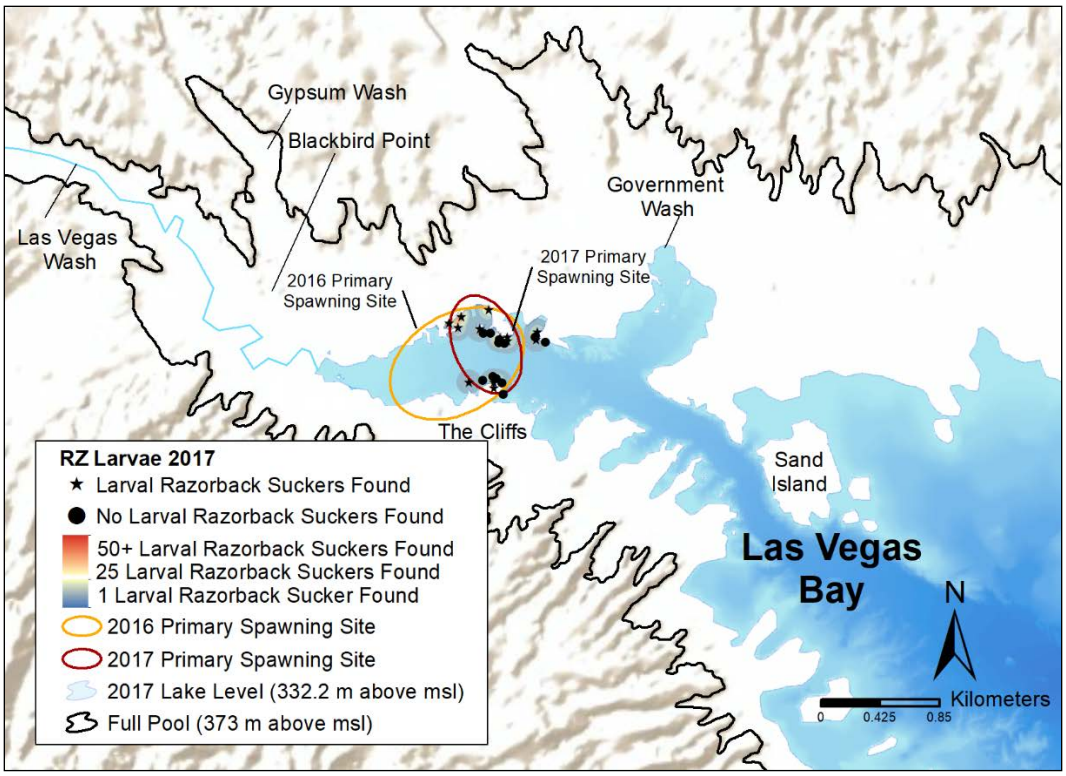

Figure 10.—Locations of larval razorback sucker sampling efforts and capture numbers in Las Vegas Bay, January – April 2017.

The collection of larval razorback suckers occurred at temperatures between 13.3 and 20.6 °C (figure 11). Sampling for larvae was conducted in the western portions of Las Vegas Bay, and the larvae were collected near sonic-tagged fish or in areas where other adult razorback suckers were captured via trammel netting (see figures 3 and 6). Las Vegas Bay yielded 120 total larvae captured during 740 minutes of sampling for a mean CPUE of 0.1480 (± SE = 0.0439). The 2017 razorback sucker larvae mean CPUE at Las Vegas Bay falls within range of the observed mean CPUE from 2007 to present (mean CPUE 0.0811–0.3047) (figure 12).

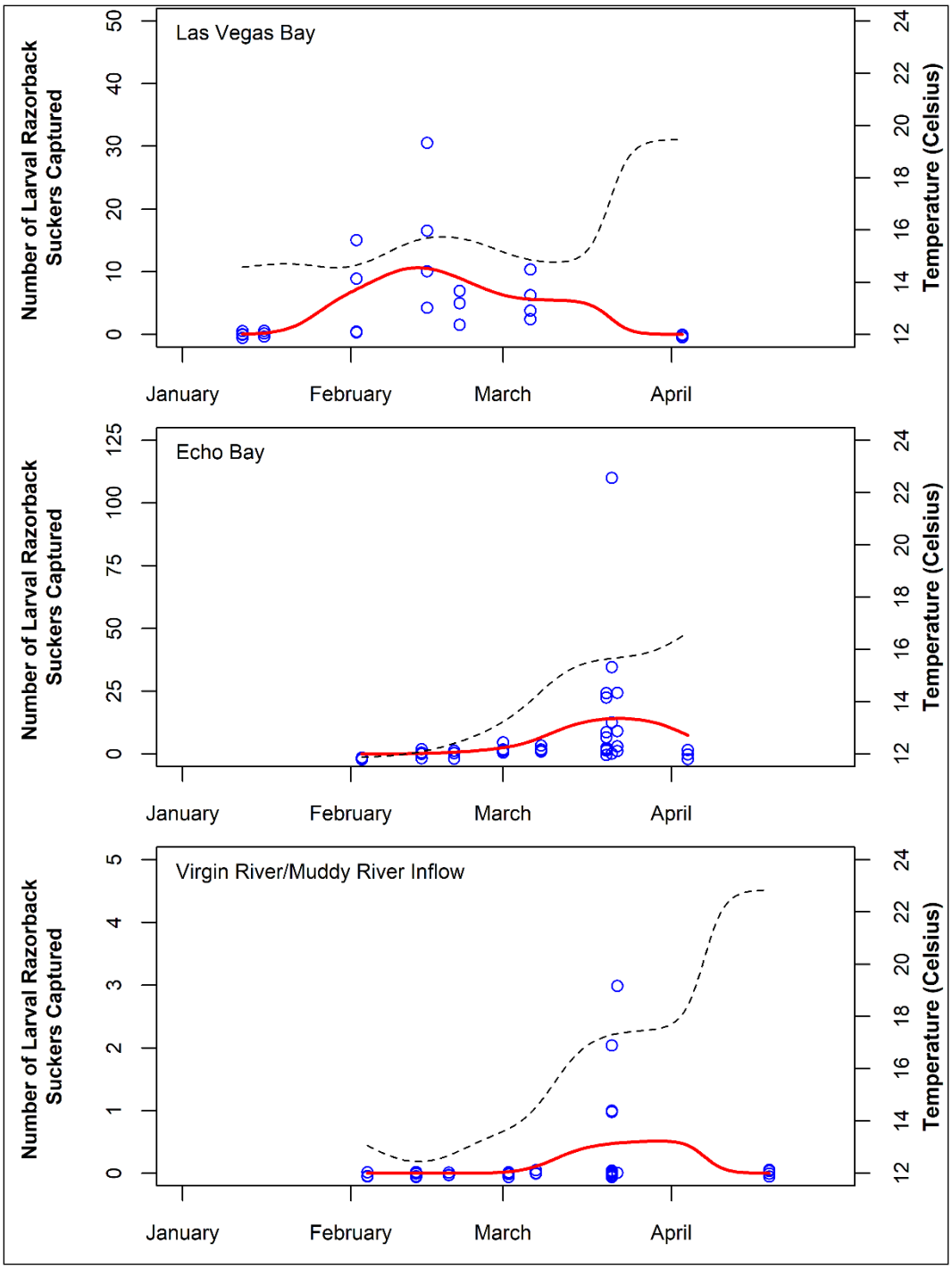

Figure 11.—Individual larval razorback sucker catch numbers (blue dots) obtained at long-term monitoring study areas in Lake Mead, February – April 2017, with a kernel regression line in red.
Associated temperature data at the time of sampling are shown as a dashed kernel density regression line. Please note difference in scales.

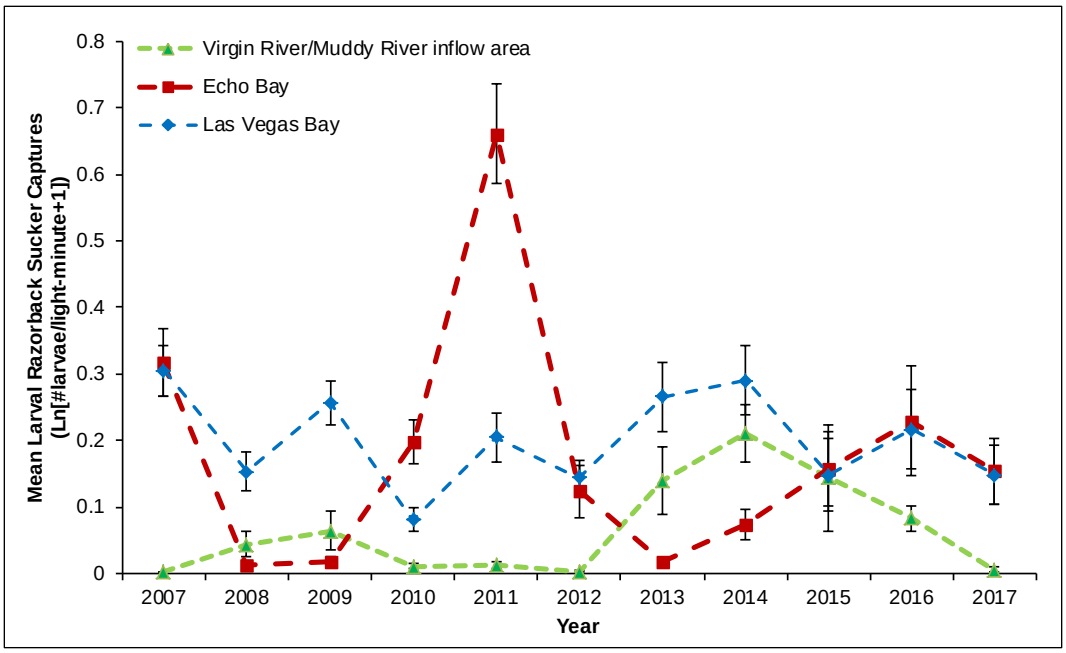

Figure 12.—Larval razorback sucker mean catch per light-minute rates at long-term monitoring study areas in Lake Mead, 2007–17, with associated SE.

In Echo Bay the first razorback sucker larvae were captured on March 1, 2017, earlier than last year's first larval encounter (March 21, 2016) (Mohn et al. 2016). Larval collections were made primarily over gravel and sand, and occasionally over cobble substrates at temperatures ranging from 11.6 to 18.2°C (see figure 11). The highest concentration of larvae was on the southern shoreline of Echo Bay; some larvae also were found on the northern shore near the boat ramp (figure 13). The collection of 275 larval razorback suckers within 1,100 minutes at Echo Bay resulted in a mean CPUE of 0.1537 (± SE = 0.0496) (see figure 12). Most importantly, these values again confirmed spawning success at Echo Bay and underscore the importance of this spawning location for Lake Mead razorback suckers.

At the Virgin River/Muddy River inflow area, the first razorback sucker larvae of the sampling season were captured on March 21, 2017 (similar to last year when larvae were first collected on March 22, 2016), over a variety of substrate types and at temperatures ranging from 11.3 to 23.7 °C (see figure 11). Larval collections occurred approximately 3 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 in 2017, seven larval razorback suckers were captured in 1,060 minutes of sampling, resulting in a mean CPUE of 0.0061 (± SE = 0.0032). However, this catch rate still falls within the observed catch rates and seems typical of this site (mean CPUE ranging from 0.0015 to 0.2110) (see figure 12).

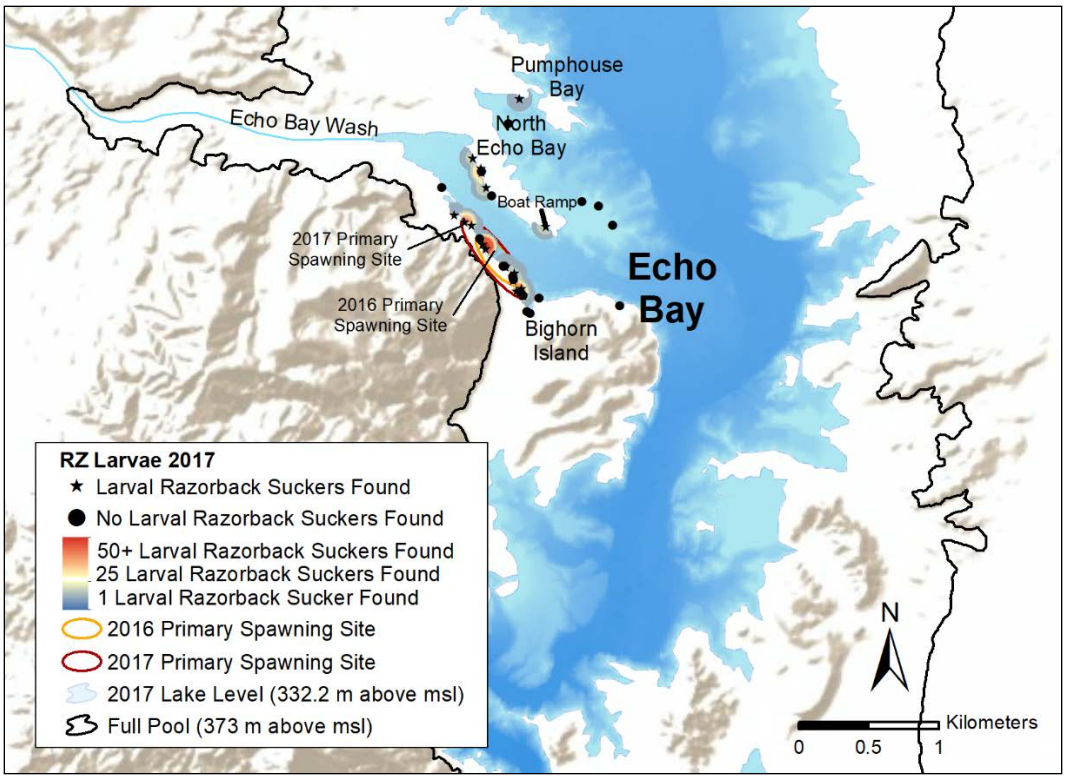

Figure 13.—Locations of larval razorback sucker sampling and capture numbers in Echo Bay, February – April 2017.

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 (Welker and Holden 2003, 2004; Albrecht and Holden 2005; Albrecht et al. 2006a, 2006b, 2007, 2008a, 2008b, 2010a, 2010b, 2013a, 2013b, 2014a; Kegerries et al. 2009; Shattuck et al. 2011; Mohn et al. 2015). Despite this, razorback suckers have returned to general, historic spawning sites and continued to find suitable habitat for reproduction. Razorback suckers were captured in Las Vegas Bay during the 2016–17 field season (table 3); successful trammel netting efforts occurred throughout the spawning season, but most captures occurred in January (see table 3). Additionally, four juvenile razorback suckers were captured just outside of Las Vegas Wash in January (see figure 6). This area was also the primary location for the collection of larval razorback suckers (see figure 10). The 2017 spawning area was similar to the 2016 spawning area, which again demonstrates the importance of this bay for razorback sucker spawning and recruitment (see figure 10; see table 3).

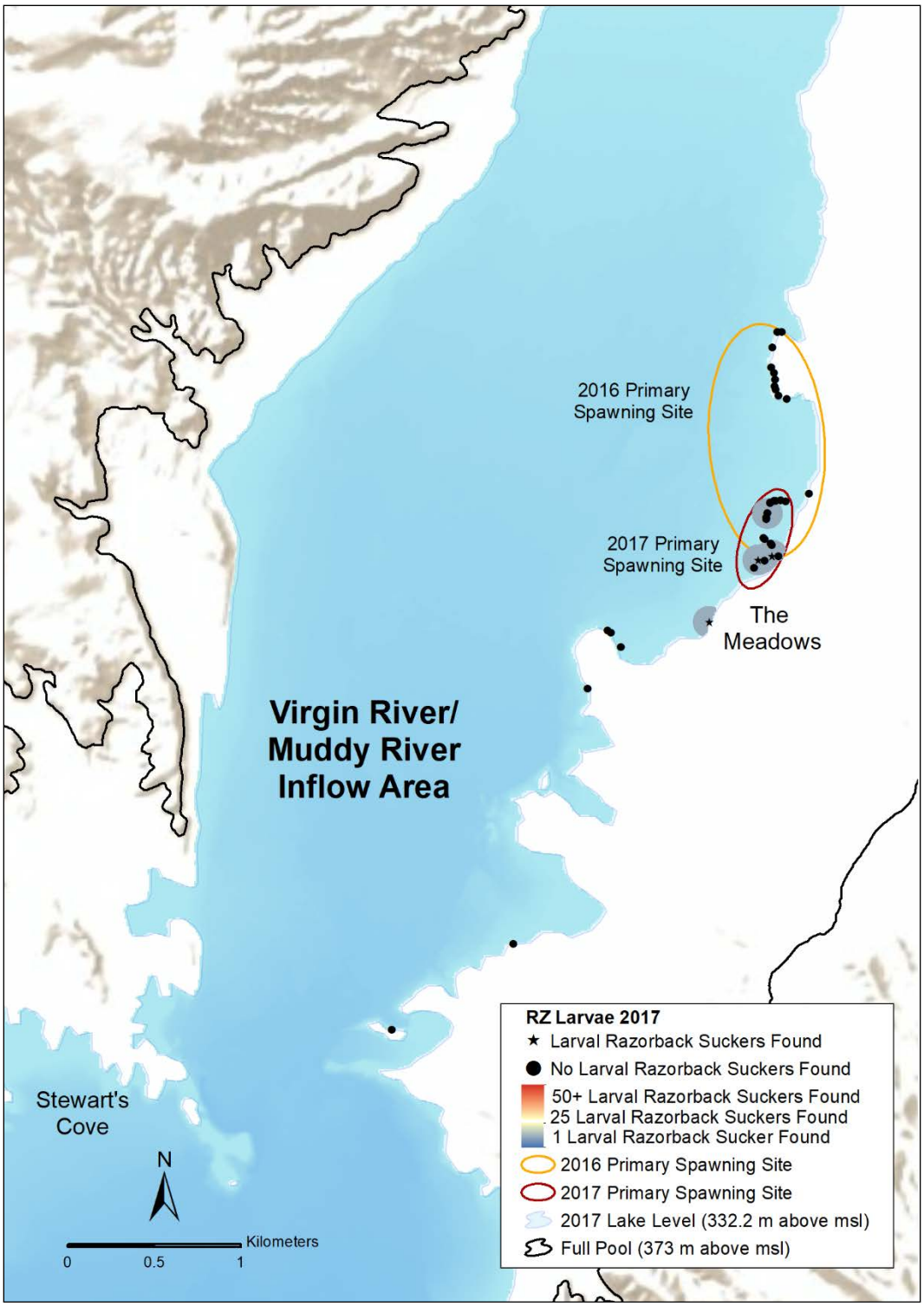

Figure 14.—Locations of larval razorback sucker sampling and captures at the Virgin River/Muddy River inflow area, February – April 2017.

The primary Echo Bay spawning site in 2017 was well defined and located off the southern shore across from the boat ramp, in a location similar to the 2016 primary spawning location (see figures 7 and 13). 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 2017 (see figures 5, 8, and 13).

In 2017, the lowest mean larval CPUE was observed at the Virgin River/Muddy River inflow area as compared to other long-term monitoring study areas (see figure 12). However, the collection of numerous adult, reproductively ready razorback suckers in 2017 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. Sonic-tagged fish contacts in this area were sparse during the spawning season, but fish eventually were detected further south near Glory Hole in March and April (see figure 5). An additional juvenile razorback sucker was captured on March 22, 2017.

Age Determination

To date, a definitive age has been determined for 531 razorback suckers from long-term monitoring study areas in Lake Mead (not including 45 individuals aged from the CRI (Kegerries et al. *in press*). In 2017, ages were obtained from 22 razorback suckers captured in trammel nets at long-term monitoring study areas (attachment 1). Additionally, 12 razorback suckers were aged from the CRI in 2017. The four youngest razorback suckers from the long-term monitoring study areas that were aged in 2017 were 2-year-old (2015 year class), sexually immature, 301–361 mm TL fish from Las Vegas Bay (attachment 1). These fish are the first of their year class and are significant in that they represent the continued wild recruitment trend seen in Lake Mead. The oldest razorback sucker aged during 2017 long-term monitoring was a 12-year-old female from Echo Bay (2005 year class) with a TL of 664 mm (attachment 1).

To date, all aged fish have been assigned a spawned year class spanning 1966–2015 (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 (figures 2 and 15).

The cumulative dataset shows that most individuals (410) were spawned from 2000 to 2011. Within this period, 112 individuals (including 3 from the CRI)

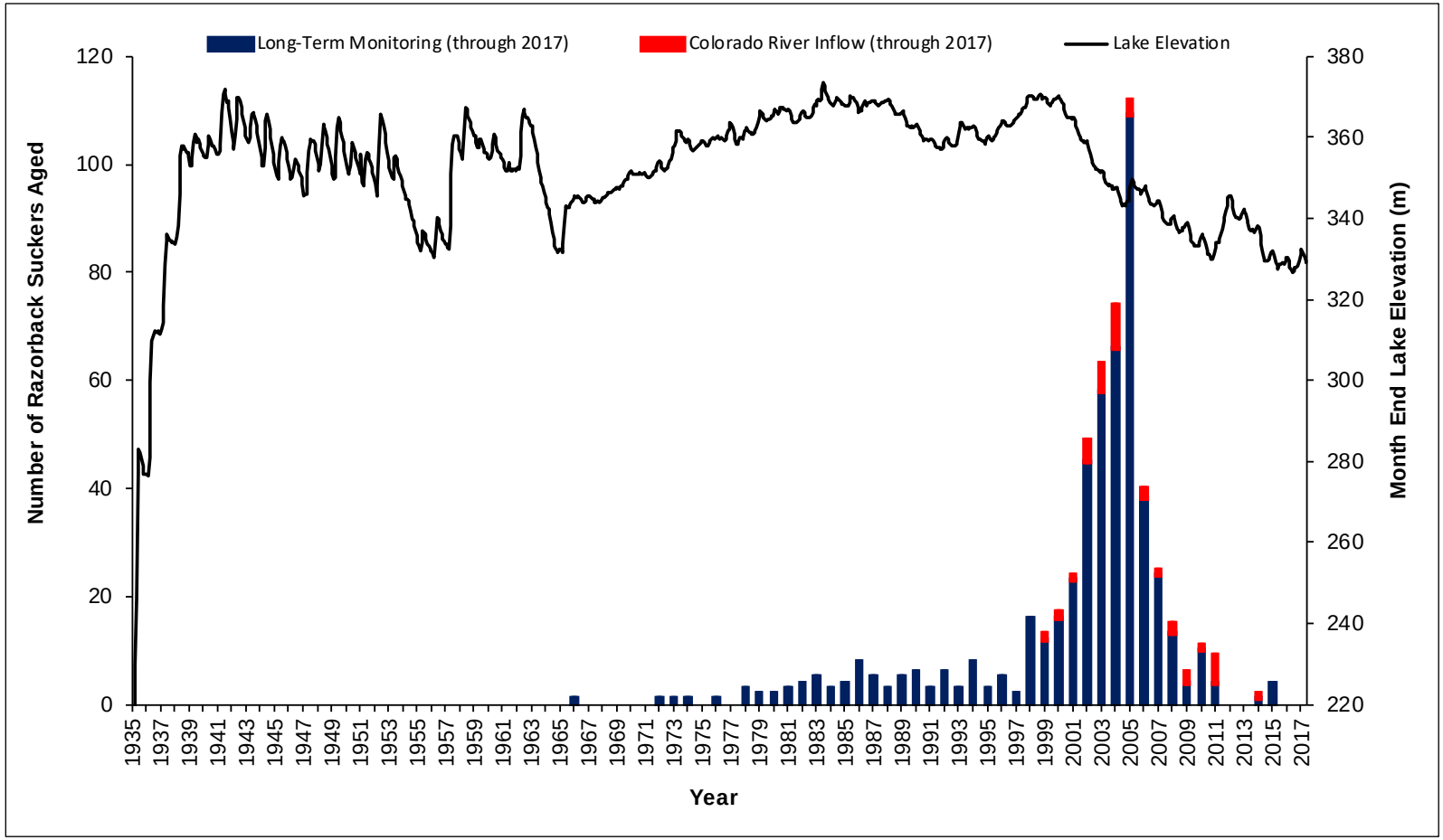

Figure 15.—Cumulative number of razorback suckers back-calculated to year spawned for individuals aged with corresponding Lake Mead month-end lake elevations, January 1935 – June 2017.
Blue bars denote individuals aged during long-term monitoring efforts, 1999–2017; red bars denote individuals aged during efforts at the CRI, 2010–17.

were aged from the 2005 year class alone, which indicates that a pulse of natural recruitment of razorback suckers occurred in Lake Mead during a period of decreasing reservoir elevation. Figure 15 suggests that some level of recruitment is possible in Lake Mead regardless of reservoir elevation, as natural recruitment has occurred almost annually at long-term monitoring study areas; wild recruitment has been documented through 2015 within Lake Mead (see figure 15).

Based on past experience, it typically takes 4–5 years for a young razorback sucker to reach a size that is readily susceptible to the sampling gear used for long-term monitoring efforts, and it is anticipated that fish spawned and recruited in 2013 and 2014 will become susceptible to sampling in the near future. This underscores the importance of long-term and active monitoring to verify continued recruitment of this unique population (Shattuck et al. 2011; Albrecht et al. 2013a, 2014a; Mohn et al. 2015, 2016).

Population and Survival Estimation

Population Estimates

The top model for reservoir-wide population estimates included time-varying capture probability (*Mt*) (attachment 2). Using 32 capture occasions from 2015 to 2017, the population model at the 4 combined sampling sites (long-term monitoring combined with CRI) produced a point estimate of 421 (± SE = 77) with a 95% confidence interval of 305–615 (table 6). Model ranking according to the AIC_c weights and model likelihoods for estimates produced in program MARK can be found in attachment 2.

Table 6.—Reservoir-wide population estimates for Lake Mead razorback suckers using mark-recapture data from 2015 to 2017 from program MARK

Model	Population estimate (95% confidence interval)	Capture events	Standard error
Reservoir-wide population estimate			
Mt	421 (305–615)	32	77

Survival Estimates

Twenty-two annual capture events were used in an annual apparent survival model. In goodness-of-fit testing, the saturated model (attachment 3) produced an estimated $\hat{c}$ value of 1.2 (± SE = 0.01). The top model assumed that survival did not vary through time, but the probability of recapture was allowed to vary through time. The top model carried 91% of the AIC_c weight, and delta AIC_c units from the top-performing model had considerably less support (attachment 3) (Burnham and Anderson 2004; Zelasko et al. 2011; Mohn et al. 2016). The top

model had calculated an annual apparent survival of 0.77 with a 95% confidence interval of 0.74–0.81, and the recapture probabilities year to year ranged from 0.05 to 0.44 (table 7; attachment 4).

Table 7.—Annual apparent survival rate estimate for razorback suckers in Lake Mead produced in program MARK using adult (> 450 mm TL) mark-recapture data, 1996–2017

Model	Annual apparent survival rate estimate (95% confidence interval)	Capture events	SE	Recapture probability
Cormack-Jolly-Seber				
$\phi(.)p(t)$	0.77 (0.74–0.81)	22	0.02	0.05–0.44

Bureau of Reclamation (Lower Colorado River Multi-Species Conservation Program) and Nevada Department of Wildlife Hatchery Stocking Note

Pertinent to long-term monitoring, it should be noted that biologists from Reclamation (LCR MSCP) and the NDOW stocked 168 juvenile razorback suckers on January 12, 2017, as discussed by the Lake Mead Work Group during its fall 2016 meeting. This stocking event was requested by the NDOW to put captured and reared Lake Mead larvae (the result of saving fish for genetics monitoring) back into Lake Mead in order to efficiently use hatchery resources. As such, and in an attempt to determine stocking dispersal patterns within the inflow area of Las Vegas Bay, juvenile fish were released into either Las Vegas Bay or Las Vegas Wash. All fish were PIT tagged, measured, and weighed, and genetics samples were taken from each individual for analysis. Stocked juveniles ranged in size from 103 to 473 mm TL and were from three distinct year classes (2014, 2015, and 2016). Juvenile razorback suckers were split into 2 approximately equal groups by number of individuals (n = 86 in Las Vegas Wash, and n = 82 in Las Vegas Bay) and sizes classes (Las Vegas Wash: 262.2 [± SE = 12.6] mm TL and Las Vegas Bay 263.6 [± SE = 12.4] mm TL) and stocked into the respective locations.

Reclamation deployed five self-contained submersible scanners. Three scanners were located in Las Vegas Wash near the old Las Vegas Bay boat ramp (deployed January 11–17, 2017), and two were located at the delta area of Las Vegas Bay (January 12–17, 2017). The five scanners were deployed for a combined 596.5 hours. Fifty-two unique razorback suckers were contacted during this effort, 50 of which were fish from the juvenile stocking event. The remaining two fish were Floyd Lamb State Park adult razorback suckers that the NDOW released in 2015 into Las Vegas Bay. Four juvenile razorback suckers moved downstream

from Las Vegas Wash to Las Vegas Bay within approximately 10 hours after being stocked. The individuals that moved ranged in size from 140 to 208 mm TL, and all were from the 2016 year class. None of these stocked juvenile razorback suckers were captured during the remainder of BIO-WEST's long-term monitoring trammel netting efforts in 2017. Furthermore, it is unlikely that any of the untagged juvenile razorback suckers captured during long-term monitoring efforts originated from this stocked cohort, as all stocked fish were PIT tagged prior to release, and all but two (one of which was from the Overton Arm) were captured prior to this stocking event.

DISCUSSION AND CONCLUSIONS

Long-term monitoring data collected during the 2016–17 field season (21st 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. Sonic telemetry, trammel netting, and larval collection data continue to reaffirm 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.

Reservoir Elevation

Reservoir elevations fluctuated throughout the 2016–17 field season and could be characterized by a general increase in elevation that inundated littoral habitats and then declined throughout from early March through June 2017. Continued monitoring efforts may be useful in evaluating the relative importance of each monitoring location, shifts in spawning site use, and variations in yearly recruitment as Lake Mead continues to display projected declines in reservoir elevation (Reclamation 2017). 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

Sonic telemetry continues to be a vital tool to help define spawning sites, place trammel nets and PIT scanners, and document reservoir-wide movement. During

this field season, 14 fish were regularly detected within the 3 long-term monitoring study areas. Interestingly, individuals that were sonic tagged in 2011 were contacted in July 2016, and tracking them provided information through January 2017. This was an unexpected event, given the anticipated expiration of the tags' 4-year battery life. Furthermore, sonic tag batteries from 2014 are nearing their anticipated expiration. Additionally, two sonic-tagged fish were recaptured this year, one that was tagged in 2011 (sonic code 3775) and one that was tagged in 2014 (sonic code 4656). In both cases, field crews observed that these tags had expired batteries. Six wild razorback suckers (two at each study area) were tagged in 2017, and they provided valuable information through the remainder of the field season. Sonic-tagged fish remain essential to Lake Mead razorback sucker monitoring efforts, and additional tagging should be considered periodically.

Passive tracking of sonic-tagged fish via SUR is a helpful tool for assessing the timing of returning individuals to spawning sites as well as the timing of post-reproductive movement into foraging and resting areas during summer and fall. The ability to monitor areas remotely, especially during the non-spawning season, aided with documenting long-distance razorback sucker movements 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 a 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 hold small populations. 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 and cold winters) and 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 recruitment continues to occur within the Lake Mead razorback sucker population.

As reservoir elevations continue to fluctuate, monitoring changes in movement and habitat use may help identify important areas for razorback suckers in Lake Mead throughout the year. Furthermore, wild razorback suckers were captured quite consistently alongside sonic-tagged individuals, whereas sonic-tagged fish were rarely captured. Despite being constantly targeted during trammel netting in 2017, only one individual with an active sonic tag was captured (sonic

code 4656). Spawning sites continue to shift location nearly annually, depending on reservoir elevation, and sonic-tagged fish have been a key component in tracking these changes.

Adult Sampling and Spawning Site Observations

In summary, 1,226 razorback sucker captures have identified 716 unique individual razorback suckers at long-term monitoring study areas during this 21-year (1996–2017), multiple-agency study (BIO-WEST, the NDOW, Reclamation, and the USFWS). These data do not include 94 captures of 88 unique individuals from 1990 to 1995 (Holden et al. 1997), which is before long-term monitoring began. Trammel netting in 2017 documented the continued presence of wild razorback suckers. The captures in 2017 were fairly evenly distributed among study areas, with 37% of the catch occurring at the Virgin River/Muddy River inflow area (n = 15), 34% in Echo Bay (n = 14), and 29% in Las Vegas Bay (n = 12), demonstrating the importance of all the long-term monitoring study areas.

More 12-year-old fish were captured in 2017, signaling that the 2005 spawning season remains one of the peak years for razorback sucker recruitment in Lake Mead (Kegerries et al. 2009; Albrecht et al. 2010a, 2010b, 2010c, 2013a, 2013b, 2014a; Shattuck et al. 2011, Mohn et al. 2015, 2016). Additionally, the 2015 year class was documented in 2017 by the capture of four juvenile razorback suckers. These four fish were captured before the NDOW and Reclamation stocked juvenile razorback suckers into Las Vegas Bay and Las Vegas Wash, and all the juveniles stocked this January were PIT tagged to determine the origin of recaptured fish. Since 1997 there have been 95 (approximately 8% of the catch) wild, juvenile (≤ 450 mm TL and sexually immature) razorback suckers captured in Lake Mead, and all but 4 of these individuals were captured from long-term monitoring study areas. Specific studies of younger age-classes could result in new insights into why this species continues to recruit in Lake Mead.

Successful spawning was documented at all of the long-term monitoring study areas in 2017. Razorback suckers have a demonstrated propensity to migrate to specific spawning sites (Tyus and Karp 1990; Mueller et al. 2000); 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 2017 were similar to the spawning sites in 2016, as reservoir elevation was fairly similar between these field seasons (Mohn et al. 2016). 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, which makes it critical to maintain active, sonic-tagged fish to help identify razorback sucker habitat use in Lake Mead, particularly to locate spawning aggregates. However, given that

some level of natural razorback sucker recruitment has occurred nearly every year in Lake Mead since the late 1960s, regardless of reservoir elevation (see figure 15), there is little reason to be pessimistic about the success of the 2017 year class.

Starting and focusing trammel netting efforts in January in Las Vegas Bay yielded more adult and juvenile captures there than the past two field seasons combined (Mohn et al. 2015, 2016). The 2017 primary spawning area in Las Vegas Bay followed patterns similar to those detailed in past reports (Albrecht et al. 2008a, 2013a, 2014a; Kegerries et al. 2009; Shattuck et al. 2011). Additionally, the capture of both juvenile and adult razorback suckers in Las Vegas Bay in 2017 once again demonstrates that this site remains important for the Lake Mead razorback sucker population. Furthermore, in Las Vegas Bay, the capture of an adult male that was originally tagged at the Virgin River/Muddy River inflow area also supports the concept that the razorback sucker population is connected within the reservoir. Sampling Las Vegas Bay starting in early January should be given consideration in 2018.

The primary 2017 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 2017, as in 2016, the spawning site was located on the southern side of the bay, near the mouth of Echo Bay, over patches of cobble and gravel. This relatively shallow littoral area is adjacent to a steep edge where razorback suckers may retreat during daytime hours. This again shows that razorback suckers can find suitable spawning habitat as the reservoir elevation fluctuates.

Data from 2017, along with past years', indicate that the Echo Bay and Virgin River/Muddy River inflow area spawning aggregates are two of the largest, or at least most active, in Lake Mead. As documented in previous reports (e.g., Shattuck et al. 2011; Albrecht et al. 2013a, 2013b, 2014b), razorback suckers often use both Echo Bay and the Virgin River/Muddy River inflow area during the spawning period. The 2017 Virgin River/Muddy River inflow area spawning site was primarily defined based on adult captures but also on larval captures and 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 from larval razorback sucker collections in 2017 at the Virgin River/Muddy River inflow area spawning site were within historical context for this site. Typically, mean larval razorback sucker catch rates at the Virgin River/Muddy River inflow area have been relatively low compared with catch rates at the other long-term monitoring study areas (Albrecht et al. 2010b, 2013a, 2013b, 2014a; Shattuck et al. 2011; Mohn et al. 2015, 2016), and this year was no exception. High winds,

a long fetch, and associated wave action common near the Virgin River/Muddy River inflow area are believed to have aided in the movement and distribution of razorback sucker larvae in Lake Mead (Albrecht et al. 2010b, 2013a; 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).

In 2017, over 99% 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 (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 may be an important factor to track and understand in terms of impacts on razorback sucker recruitment success. Future monitoring could also include tracking the physicochemical characteristics of known spawning areas through time which, when coupled with non-native fish capture information, may lead to a better understanding of razorback sucker recruitment success.

Shore-based PIT scanners deployed at the Virgin River/Muddy River inflow area contacted several individuals that were present on the spawning site but not captured during trammel netting efforts, thus demonstrating the elusiveness of this species. This method, if repeated through time as a consistent, set methodology, might contribute additional knowledge pertaining to movement and spawning behavior previously unknown in Lake Mead, such as the frequency of razorback sucker movements from other long-term monitoring study areas as well as movements from the CRI.

Growth and Aging

The relatively fast mean annual growth rate of 15 recaptured razorback suckers in Lake Mead continues to indicate a fairly youthful population of this species within the reservoir. Growth rates ranged from 6.9 [± SE = 2.4] TL mm/yr in Echo Bay to 14.8 [± SE = 4.2] TL mm/yr in Las Vegas Bay in 2017. These growth rates appear to be lower than those reported in the past (Albrecht et al. 2010b; Shattuck et al. 2011), but they still fall within the observed context of the Lake Mead razorback sucker population. Despite being relatively low this year, Lake Mead growth rates still surpass the growth rates (< 2.0 mm/yr) reported for razorback suckers in Lake Mohave (Pacey and Marsh 1998) and the Green River (McAda and Wydoski 1980; Tyus 1987).

Through 2017, 531 razorback suckers from long-term monitoring study areas have been aged from 2 to 36 years old. One 3-year-old and four 2-year-old juvenile razorback suckers comprise the youngest known year classes in Lake Mead (year-classes 2014 and 2015) to date. The new 2015 year class

documented in this annual report further demonstrates that successful spawning and recruitment continue and provides optimism for future year classes of razorback suckers. Based on previous observations, 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. This observation emphasizes the importance of long-term monitoring to verify continued recruitment of this unique population (Shattuck et al. 2011; Albrecht et al. 2013a, 2014a; Mohn et al. 2015, 2016). As discussed above, more fish from the 2005 year class were captured and aged again this year, showing the strength of that year class (Kegerries et al. 2009; Albrecht et al. 2010b) (see figure 15). 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 an equal probability of being captured; and (3) tags/marks are not lost and are accurately recorded (Cooch and White 2013). The assumption of natality and mortality were thought to have been mitigated by using 3 years of research data for each reported population estimate. The razorback sucker is a long-lived species where turnover in the adult population likely occurs at a slow rate; this 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 model, 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 an equal probability of being captured, PIT scanner data were not used for this year's estimate because over one-half (51%) of the of the razorback suckers captured were unmarked, wild fish that could not be detected by PIT scanning equipment (see table 3). Lastly, tag loss is minimal for bluehead suckers (*Catostomus discobolus*) and Lost River suckers (*Deltistes luxatus*) (Ward and David 2006; Burdick 2011), 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 do occur. Methods used to produce the 2015–17 reservoir-wide population estimate in program MARK were identical to those used for previous reports (Mohn et al. 2015, 2016). Useful estimates were obtained for this year, but as is common with low-density organisms, limited recaptures of adult razorback suckers caused fairly large confidence intervals.

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) (Zelasko et al. 2011; Kesner et al. 2012); however, this rate dramatically declines to 0.03 and 0.29 for smaller razorback suckers (< 450 mm TL) (Schooley et al. 2008b; Zelasko et al. 2011; Kesner et al. 2012). The apparent annual survival rate reported for 2017 remains consistent with rates reported since 2014 in Lake Mead (Albrecht et al. 2014a; Mohn et al. 2015, 2016) 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 0.74–0.81]) was calculated only for razorback suckers larger than 450 mm TL in Lake Mead. As more data are obtained, it would be interesting to investigate a Lake Mead survival rate for the smaller-sized individuals, especially given the amount of wild razorback sucker recruitment observed throughout the study.

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, the reservoir elevation increased during the spawning period (Albrecht and Holden 2005; Shattuck et al. 2011). During this same time, razorback sucker recruitment seems to have increased, as is evident by the increased number of captured individuals from the 2005 year class. The increasing reservoir levels during the spawning season may have given the deposited razorback sucker eggs a chance to hatch before the reservoir receded and dried out the spawning areas, as well as provided cover for juvenile razorback suckers (Welker and Holden 2004; Albrecht and Holden 2005).

It has been accepted for years that turbidity plays a role in the susceptibility of native Colorado River fish to predation (Johnson and Hines 1999; Ward et al. 2016). Additionally, 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 (Golden and Holden 2003). Albrecht et al. (2010a) show 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. 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 (Kaemingk et al. 2007). Additionally, high-flow events that bring woody debris and fine sediments into Lake Mead may play an important role in providing even more cover. Shattuck and Albrecht (2014) were among the first to quantify the use of cover by juvenile razorback suckers and underscore the importance of cover, turbidity, and complex habitats to this life stage in Lake Mead, which is particularly relevant considering the sizable non-native fish presence. Research in Lake Mead continues to show a dense and predatory fish community, but it also shows annual recruitment. 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 key to understanding (and perhaps enhancing) species survival and recruitment throughout the Colorado River Basin and, at a minimum, suggest a relatively positive future for this rare species in Lake Mead.

Currently, recruitment in Lake Mead appears to be near areas with flowing water (Las Vegas Wash, Muddy and Virgin Rivers, and the CRI). However, spawning and recruitment are also occurring in Echo Bay. Echo Bay is unique among these other spawning areas in that it is an intermittent wash that flows and deposits sediments from a large drainage basin during rain events. There are other areas in Lake Mead that appear somewhat similar to Echo Bay, such as Bonelli and perhaps 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 for some part of the year (Shattuck et al. 2011; Albrecht et al. 2012). However, no sampling has been conducted in this area since that discovery. With currently available technology (PIT scanners, reliable sonic tags, and SURs) and a refined approach, perhaps using targeted trammel netting and larval sampling, it may be time to explore these areas in greater detail. Exploring other potential spawning areas throughout Lake Mead was suggested by the Lake Mead Work Group, and it could add to the body of knowledge about razorback sucker habitat associations, refine current population and survival estimates, and further the understanding of growth, habitat use, and movement patterns of this species in Lake Mead.

Conclusions

All long-term monitoring objectives for the 2016–17 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. The continued pulses of newly captured, young razorback suckers at all Lake Mead long-term monitoring study areas in recent years (including 2017) 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 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 capture of larval fish at all known spawning sites in 2017, coupled with the direct capture of age-2 and age-3 wild, juvenile razorback suckers, the status of the species within Lake Mead remains optimistic. This context underscores the importance of maintaining long-term monitoring efforts and continuing to build long-term datasets from tracking this population to 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. 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 – hence the need for future research and monitoring to understand how and why razorback suckers in Lake Mead are able to naturally maintain a population despite ongoing physicochemical and biological change remains a priority for the species.

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ACKNOWLEDGMENTS

This project was funded by the LCR MSCP and was a cooperative effort between BIO-WEST, Reclamation, the SNWA, the NDOW, the Arizona Game and Fish Department, the National Park Service, and the USFWS. Sampling, logistics, and planning strategies were conducted jointly among these groups in various capacities. We sincerely thank the many who volunteered to assist with field work on Lake Mead for their tireless efforts. We thank Jim Stolberg, Nathan Rudd, Becky Blasius, Jeff Lantow, Jeff Anderson, Sharon Leffel, and Sandra Livingston Turner for the thoughtful and constructive comments provided during the review process and the many others who have helped and been involved with this project.

ATTACHMENT 1

Razorback Sucker (*Xyrauchen texanus*) Aging Data

Table 1-1.—Ages determined from razorback sucker pectoral fin ray sections collected in Lake Mead, 1998–2017

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
3/4/2003	635	19	1983
3/20/2003	420	4	1998
4/08/2003	638	21b	1982
4/17/2003	618	10	1992
4/22/2003	650	20–22	1980–82
5/4/2003	415	3+[c]	1999

Table 1-1.—Ages determined from razorback sucker pectoral fin ray sections collected in Lake Mead, 1998–2017

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
4/2/2007	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, 1998–2017

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, 1998–2017

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
3/3/2011	434	4	2007
3/24/2011	411	4	2007
3/24/2011	390	3	2008
3/29/2011	379	6	2005
3/29/2011	346	4	2007
3/29/2011	376	3	2008
2/05/2013	510	10	2003

Table 1-1.—Ages determined from razorback sucker pectoral fin ray sections collected in Lake Mead, 1998–2017

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
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
4/02/2002	617	35+	1966–1968
4/17/2002	583	20	1982
5/02/2002	568	18–19	1983–84

Table 1-1.—Ages determined from razorback sucker pectoral fin ray sections collected in Lake Mead, 1998–2017

Date collected	Total length (mm[a])	Age	Presumptive year spawned
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
2/1/2006	705	16	1990
2/16/2006	601	22	1984
1/11/2007	535	5	2002
1/11/2007	493	5	2002
2/01/2007	637	7	2000
2/08/2007	609	12	1995
2/14/2007	501	4	2003
3/02/2007	590	11	1996
3/09/2007	660	12	1995
3/16/2007	691	21	1986
3/28/2007	564	13	1994
2/28/2008	640	25	1983
2/29/2008	635	8	2000
3/05/2008	653	24	1984
3/19/2008	532	6	2002
3/19/2008	510	7	2001
2/20/2009	602	7	2002

Table 1-1.—Ages determined from razorback sucker pectoral fin ray sections collected in Lake Mead, 1998–2017

Date collected	Total length (mm[a])	Age	Presumptive year spawned
2/26/2009	662	16	1993
2/18/2010	520	7	2003
2/25/2010	465	5	2005
3/10/2010	535	7	2003
3/10/2010	530	9[e]	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
20/9/2011	524	7	2004
2/24/2011	555	7	2004
3/2/2011	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
2/07/2013	670	8	2005
2/07/2013	579	10	2003
2/07/2013	655	7	2006

Table 1-1.—Ages determined from razorback sucker pectoral fin ray sections collected in Lake Mead, 1998–2017

Date collected	Total length (mm[a])	Age	Presumptive year spawned
2/14/2013	692	17	1996
2/27/2014	703	15	1999
3/12/2014	554	8	2006
3/13/2014	594	10	2004
3/25/2014	594	8	2006
3/25/2014	630	9	2005
2/16/2016	540	7	2009
2/18/2016	634	9	2007
2/29/2016	631	9	2007
3/08/2016	544	9	2007
3/08/2016	612	10	2006
3/08/2016	650	12	2004
3/22/2016	476	6	2010
3/22/2016	545	8	2008
3/22/2016	545	9	2007
3/22/2016	570	11	2005
3/22/2016	634	12	2004
4/05/2016	591	10	2006
4/05/2016	648	11	2005
4/05/2016	650	11	2005
4/21/2016	463	6	2010
4/21/2016	561	10	2006
2/15/2017	472	6	2011
2/21/2017	521	9	2008
2/21/2017	646	10	2007
2/21/2017	560	9	2008
2/21/2017	628	8	2009
3/02/2017	664	12	2005
3/09/2017	642	9	2008
Virgin River/Muddy River inflow area			
2/23/2005	608	6	1998
2/22/2006	687	33[f]	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

Table 1-1.—Ages determined from razorback sucker pectoral fin ray sections collected in Lake Mead, 1998–2017

Date collected	Total length (mm[a])	Age	Presumptive year spawned
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[g]	2006
3/26/2008	345	3	2005
3/26/2008	541	7	2001
3/26/2008	521	7	2001
3/26/2008	665	18	1990
4/01/2008	229	2	2006
4/01/2008	370	3	2005
4/01/2008	360	3	2005
4/01/2008	385	4	2004
4/01/2008	514	5	2003
4/01/2008	536	5	2003
4/01/2008	514	6	2002
4/01/2008	548	6	2002
4/01/2008	518	7	2001
4/01/2008	530	7	2001
4/01/2008	494	8	2000
4/01/2008	535	9	1999
4/01/2008	559	10	1998
4/22/2008	533	6	2002
4/22/2008	504	6	2002
2/04/2009	496	9	2000
2/12/2009	553	10	1999
2/12/2009	505	8	2001
2/19/2009	464	5	2004
2/25/2009	549	7	2002
3/11/2009	585	8	2001
3/11/2009	552	8	2001

Table 1-1.—Ages determined from razorback sucker pectoral fin ray sections collected in Lake Mead, 1998–2017

Date collected	Total length (mm[a])	Age	Presumptive year spawned
3/24/2009	366	3	2006
3/24/2009	572	9	2000
4/08/2009	348	3	2006
4/08/2009	291	3	2006
4/15/2009	374	3	2006
4/15/2009	372	3	2006
4/15/2009	390	3	2006
4/15/2009	365	3	2006
4/15/2009	375	3	2006
4/15/2009	399	3	2006
4/15/2009	362	3	2006
4/15/2009	386	4	2005
4/15/2009	390	4	2005
2/03/2010	455	3	2007
2/03/2010	475	5	2005
2/03/2010	441	5	2005
2/03/2010	495	7	2003
2/03/2010	532	8	2002
2/09/2010	491	5	2005
2/09/2010	444	5	2005
2/09/2010	500	5	2005
2/09/2010	464	6	2004
2/09/2010	471	6	2004
2/17/2010	494	6	2004
2/17/2010	470	7	2003
2/17/2010	479	7	2003
2/17/2010	425	7	2003
2/17/2010	483	7	2003
2/24/2010	234	4	2006
3/17/2010	477	4	2006
3/17/2010	465	5	2005
3/17/2010	485	5	2005
3/17/2010	499	6	2004
3/17/2010	491	6	2004
3/17/2010	600	9	2001
3/18/2010	452	5	2005
3/18/2010	473	5	2005

Table 1-1.—Ages determined from razorback sucker pectoral fin ray sections collected in Lake Mead, 1998–2017

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

Table 1-1.—Ages determined from razorback sucker pectoral fin ray sections collected in Lake Mead, 1998–2017

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

Table 1-1.—Ages determined from razorback sucker pectoral fin ray sections collected in Lake Mead, 1998–2017

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

Table 1-1.—Ages determined from razorback sucker pectoral fin ray sections collected in Lake Mead, 1998–2017

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

Table 1-1.—Ages determined from razorback sucker pectoral fin ray sections collected in Lake Mead, 1998–2017

Date collected	Total length (mm[a])	Age	Presumptive year spawned
2/24/2016	647	14	2002
3/22/2016	541	10	2006
3/23/2016	577	9	2007
3/24/2016	490	6	2010
3/24/2016	582	8	2008
3/24/2016	562	9	2007
3/24/2016	565	11	2005
1/27/2017	592	7	2010
1/27/2017	657	7	2010
2/04/2017	541	6	2011
2/14/2017	624	9	2008
3/03/2017	541	8	2009
3/03/2017	642	7	2010
3/03/2017	586	7	2010
3/22/2017	319	3	2014
Colorado River inflow area			
4/20/2010	563	6	2004
4/20/2010	508	6	2004
4/20/2010	568	11	1999
2/08/2011	594	8	2003
3/10/2011	659	11	2000
3/24/2011	584	9	2002
3/24/2011	530	7	2004
3/24/2011	545	6	2005
4/19/2011	636	9	2002
4/20/2011	570	10	2001
1/26/2012	602	8	2004
2/21/2012	604	10	2002
3/01/2012	546	8	2004
3/01/2012	559	9	2003
3/06/2012	535[e]	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

Table 1-1.—Ages determined from razorback sucker pectoral fin ray sections collected in Lake Mead, 1998–2017

Date collected	Total length (mm[a])	Age	Presumptive year spawned
3/28/2012	572	8	2004
4/03/2012	602	9	2003
4/24/2012	555[e]	9	2003
3/05/2013	215	2	2011
5/14/2014	429	3	2011
2/24/2015	581	10	2005
2/26/2015	634	7	2008
3/03/2015	624	5	2010
3/17/2015	572	6	2009
3/18/2015	595	6	2009
1/21/2016	585	9	2007
3/08/2016	604	10	2006
2/14/2017	268	3	2014
2/15/2017	621	6	2011
3/29/2017	602	10	2007
3/08/2017	556	6	2011
3/07/2017	598	11	2006
4/18/2017	401	6	2011

[a] mm = millimeters.
[b] Fish stocked from Echo Bay larval fish captured in 1999 and raised at the Nevada Department of Wildlife's 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 aged at 33 years of age, ± 2 years.
[g] Fish was a mortality, found dead in net.

ATTACHMENT 2

Razorback Sucker (*Xyrauchen texanus*) Population Estimate (2015–2017) – Model Selection Summary

Table 2-1.—Model selection summary information for closed-capture populations of razorback suckers in Lake Mead using 32 mark-recapture netting-only capture occasions data from 2015 to 2017 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	87.3029	0.0000	1.00000	1.0000	33	158.3648
Mb	150.9866	63.6837	0.00000	0.0000	3	280.5584
Mo	154.4977	67.1948	0.00000	0.0000	2	286.0724

[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 3

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

Table 3-1.—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, 1996–2017

Model[a]	AIC_c[b]	ΔAIC_c[c]	AIC_c weight[d]	Model likelihood[e]	Number of parameters	Deviance[f]
Cormack-Jolly-Seber						
$\phi(.)p(t)$	1920.2886	0.0000	0.91244	1.0000	22	508.7650
$\phi(t)p(t)$	1924.9763	4.6877	0.08756	0.0960	41	472.5025
$\phi(t)p(.)$	1953.2094	32.9208	0.00000	0.0000	22	541.6858
$\phi(.)p(.)$	1964.5835	44.2949	0.00000	0.0000	2	594.2353

[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 4

Recapture Probability Estimate of Adult (> 450 Millimeters Total Length) Razorback Suckers (*Xyrauchen texanus*) in Lake Mead, 1996–2017, Produced in Program MARK

Table 4–1.—Recapture probability estimate by year for adult (> 450 millimeters total length) razorback suckers in Lake Mead produced in program MARK (Cormack-Jolly-Seber model) with mark-recapture data, 1996–2017

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