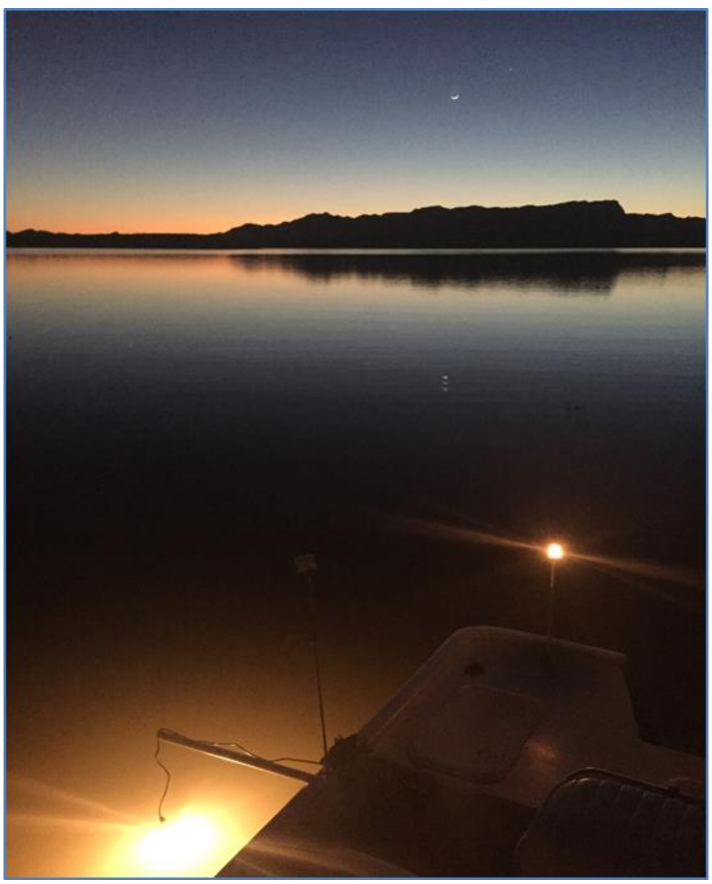
Lower Colorado River Multi-Species Conservation Program

Balancing Resource Use and Conservation

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

2015–2016 Annual Report



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July 2017

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Lower Colorado River Multi-Species Conservation Program

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

2015–2016 Annual Report

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ACRONYMS AND ABBREVIATIONS

AIC_c	Akaike's information criterion adjusted for small sample size
ANOVA	analysis of variance
BIO-WEST	BIO-WEST, Inc.
CJS	Cormack-Jolly-Seber
cm	centimeter(s)
CPUE	catch per unit effort
CRI	Colorado River inflow area of Lake Mead
FL	fork length
HSD	Tukey's honestly significant difference
hybrid	razorback sucker x flannelmouth sucker hybrid
km	kilometer(s)
LCR MSCP	Lower Colorado River Multi-Species Conservation Program
m	meter(s)
mm	millimeter(s)
MS-222	tricaine methanesulfonate
msl	mean sea level
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, and the U.S. Fish and Wildlife Service, initiated a study to develop information about the Lake Mead razorback sucker (*Xyrauchen texanus*) population. BIO-WEST, Inc., under contract with the Southern Nevada Water Authority, designed the study and had primary responsibility for conducting the research. In 2005, the Lower Colorado River Multi-Species Conservation Program became the principal funding agency, and the study became primarily a long-term monitoring effort in 2007. In 2012, the program provided funding to continue long-term monitoring efforts as well as funding to initiate a pilot study for juvenile razorback suckers in Lake Mead. Information and observations from the 20th season (2015–16) of the long-term monitoring study are provided herein, investigations from the juvenile razorback sucker study are included in Shattuck and Albrecht (2014) and Kegerries et al. (2016), and investigations from the Colorado River inflow area of Lake Mead are included in Kegerries et al. (2015).

During the 20th field season, 10 sonic-tagged fish were detected by active and/or passive telemetry, resulting in 83 active contacts and 11,539 passive contacts by 5 submersible ultrasonic receivers. These fish represented two different sonic-tagging events (2011 [n = 3] and 2014 [n = 7]). By using data gathered from sonic-tagged fish in conjunction with trammel netting and larval sampling data, information regarding 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 annual spawning site information, sonic-tagged fish provided habitat association data in lake-wide movement patterns and seasonal movement patterns within long-term monitoring study areas.

Trammel netting resulted in the capture of 67 razorback suckers—4 from Las Vegas Bay, 35 from Echo Bay, and 28 from the Virgin River/Muddy River inflow area—during the 2016 spawning period. Nineteen flannelmouth suckers (*Catostomus latipinnis*) were captured in 2016: 13 were captured in Echo Bay, and six were captured at the Virgin River/Muddy River inflow area. Additionally, two recaptured razorback sucker x flannelmouth sucker hybrids (hybrids) were collected at the Virgin River/Muddy River inflow area during 2016. This is the fourth time that hybrids have been captured during the long-term monitoring study. A highlight of the 20th field season was the capture of 28 new, wild razorback suckers at long-term monitoring sites in Lake Mead.

Average annual growth during this field season, as determined from 30 recaptured fish, was 18.6 millimeters per year. The 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 31 razorback suckers for age determination which, when combined with the 478 fish aged during previous field seasons, brings the total number of fish aged during the long-term monitoring study to 509. Razorback sucker aging has been used to document near-annual recruitment in Lake Mead and associated recruitment pulses during relatively high, stable lake elevations; furthermore, based on data collected from 2007 to 2016, strong pulses in recruitment have coincided with low, declining lake elevations and high-flow events in the Virgin River (2004–05 and 2010–11).

Larval razorback suckers were documented in all study areas in 2016, with 1,167 total larval individuals collected and released. Additionally, BIO-WEST, Inc., worked collaboratively with the Nevada Department of Wildlife and Bureau of Reclamation biologists in a continued effort to collect additional Lake Mead larval razorback suckers for genetic analyses. Larval razorback sucker abundance was used to help define spawning sites during the 2015–16 field season. Primary spawning sites were identified in all long-term monitoring study areas. Spawning sites moved in correspondence with lake elevations, and locations were somewhat similar to those found during previous years with similar conditions. An overall abundance of spawning activity (i.e., adult captures and larval collections) was noted in all three of the long-term monitoring study areas.

Given the potential for continuing lake level fluctuations during the remainder of 2016 and into 2017, this report reiterates the need to further investigate conditions that promote recruitment patterns of razorback suckers in Lake Mead. General research for the 2016–17 field season includes three main objectives: (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 as needed.

INTRODUCTION

The razorback sucker (*Xyrauchen texanus*) is one of four endemic, "big-river" fish species (the others being 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 suckers are now greatly reduced (Minckley et al. 1991) principally due to anthropogenic causes. One of the major factors causing the decline of razorback suckers and other big-river fishes was the construction of main stem dams and the resulting cool tailwaters and reservoir habitats that 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 adult population then functionally disappeared in the 40–50 years following reservoir creation (Minckley 1983), but it has since rebounded in some areas.

The largest reservoir population was estimated at 75,000 individuals in the 1980s and occurred in Lake Mohave (Arizona and Nevada), but it had declined to less than 3,000 individuals by 2001 (Marsh et al. 2003). Mueller (2005, 2006) 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 (Marsh & Associates, LLC 2016). 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. However, the Lake Mohave population today is largely supported by routine stocking of captive-reared fish (Marsh et al. 2003, 2005; Marsh & Associates, LLC 2016). 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 the lack of razorback sucker recruitment (Minckley et al. 1991; Marsh et al. 2003; Carpenter and Mueller 2008; Schooley et al. 2008a). Based on 2014 and 2015 remote passive integrated transponder (PIT) scanning, the Lake Mohave repatriate population for 2014 was estimated at 3,572 individuals (95% confidence bound of 3,341–3,818) (Wisenall et al. 2016), which maintains the importance of the lake for the conservation of the species from a genetic perspective (Dowling et al. 2012a, 2012b).

Lake Mead was formed in 1935 when Hoover Dam was closed. Razorback suckers were relatively common in the lake throughout the 1950s and 1960s, apparently from reproduction soon after the lake 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 when 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 razorback suckers from Lake Mead (Sjoberg 1995). This may have been partially due to changes in the agencies' lake sampling programs; however, there was an observed decline from the more than 30 razorback suckers collected during sport fish surveys in the 1970s.

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 1990–96, 61 wild razorback suckers were collected: 34 from the Blackbird Point area of Las Vegas Bay and 27 from Echo Bay in the Overton Arm (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 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 its campgrounds; the Colorado River Commission of Nevada; the Arizona Game and Fish Department; and the USFWS.

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

- Estimate the population size of razorback suckers in Lake Mead

- Characterize habitat use and life history characteristics of the Lake Mead population

- Characterize the use and habitat of known spawning sites

In 1998, Reclamation agreed to contribute additional financial support to the project to facilitate fulfillment of Provision #10 of the Reasonable and Prudent Alternatives generated by the USFWS's Final Biological and Conference Opinion on Lower Colorado River Operations and Maintenance-Lake Mead to Southerly

International Boundary (USFWS 1997). That year, a cooperative agreement between Reclamation and the SNWA was established, specifying Las Vegas Bay and Echo Bay as the areas to be studied and extending the study period into 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 the two established study areas
- Enhance the sampling efforts for juvenile razorback suckers at both established study areas

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 lake for potential stocking options and locations was added to the project as a response to a growing number of larval fish that had been and were slated to eventually be repatriated to Lake Mead. Also in 2005, the Lower Colorado River Multi-Species Conservation Program (LCR MSCP) became the primary funding agency 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 by studying various razorback sucker life stages during future monitoring and research efforts on Lake Mead (Albrecht et al. 2006a). In 2007, the project became primarily a monitoring study. In 2008, the LCR MSCP and SNWA established another cooperative agreement, extending monitoring efforts and following monitoring protocols developed by Albrecht et al. (2006a) through 2011. In 2012, the LCR MSCP provided funding to maintain long-term monitoring efforts through 2014. Finally, in 2015, the program continued long-term monitoring efforts but at a reduced level of effort (approximately one-half compared with previous years), which 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 of Lake Mead (CRI), in the lower Grand Canyon, and with regard to the juvenile life stage. 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. 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 daily and/or 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 razorback sucker recruitment in Lake Mead

This annual report presents the results of the 20th field season (January – April 2016 netting data and July 2015 – June 2016 sonic telemetry data) in accordance with the results reported most recently by Mohn et al. (2015). Other information from previous reports is included when pertinent.

STUDY AREAS

All Lake Mead long-term monitoring activities conducted during the 2015–16 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;

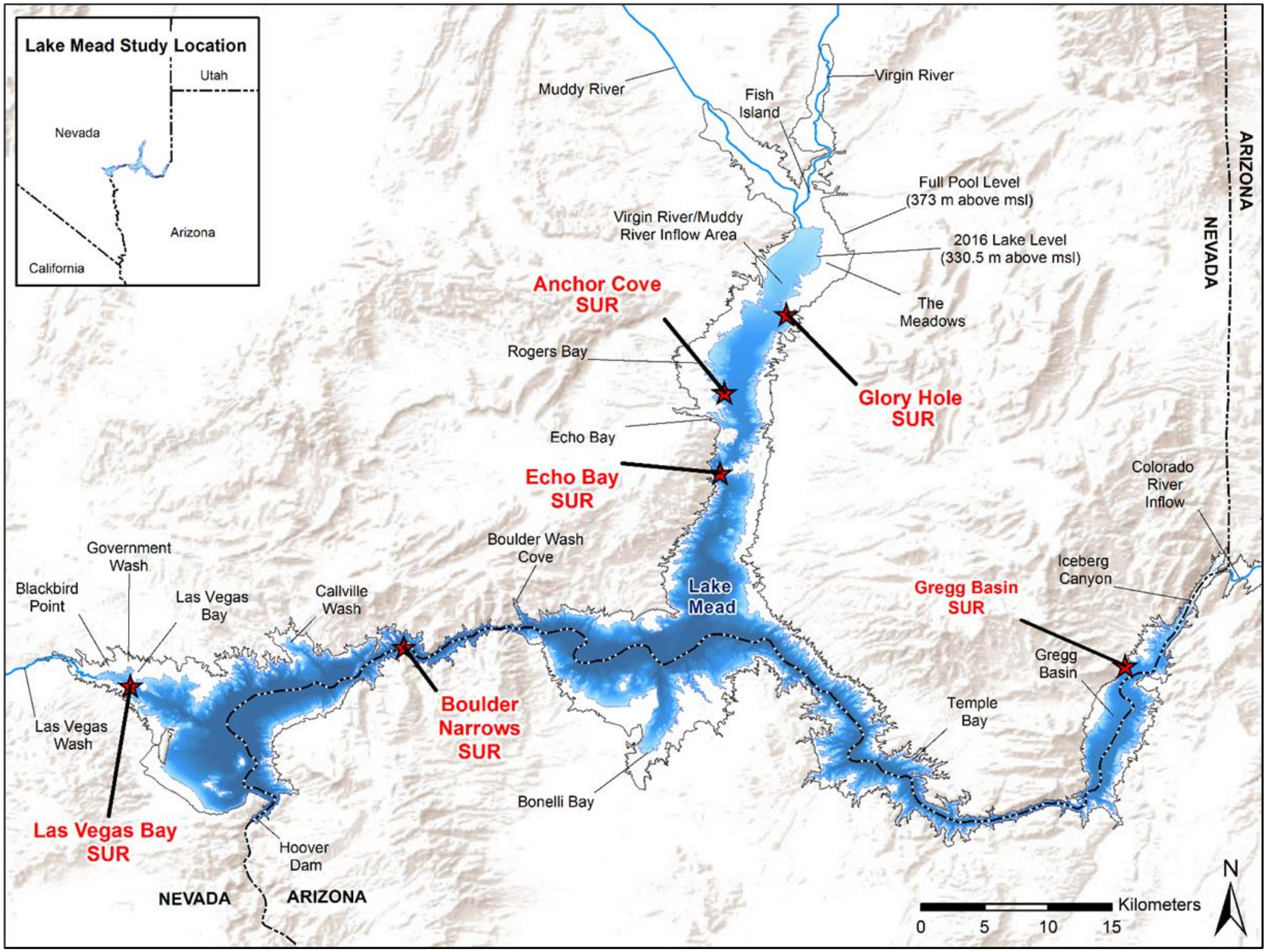

Figure 1.—Long-term monitoring study areas within Lake Mead, along with geographic landmarks.
Red stars indicate locations of long-term monitoring submersible ultrasonic receivers.

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).

Most areas of Lake Mead, including the Overton Arm, Boulder Basin, and Virgin 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 Bay and Las Vegas Wash in which the study was conducted were given in Holden et al. (2000b). The following definitions are still accurate for various portions of the wash:

- Las Vegas Bay begins where the flooded portion of the channel widens and the current velocity is reduced. It 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 proper and Las Vegas Bay.

- 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.

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

Throughout this report, three portions of Las Vegas Bay may be referred to using the following terms:

- Flowing portion (the area closest to, or within, Las Vegas Wash)

- Non-flowing portion (usually has turbid water but very little current)

- Las Vegas Bay (the majority of the bay that is not immediately influenced by Las Vegas Wash and is lentic in nature)

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 Muddy River confluence and Virgin River confluence with Lake Mead at the upper end of the Overton Arm)

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

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

METHODS

Lake Elevation

Month-end (2000–16) and daily lake elevations for the 2015–16 field season (July 1, 2015 – June 30, 2016) were measured in meters above mean sea level (msl) 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 2016).

Sonic Telemetry

Sonic telemetry data for the long-term monitoring study were collected from July 1, 2015, to June 30, 2016, to capture movement throughout the study period. During the intensive field season (at least every other week, February – May), sonic-tagged fish were located during each sampling trip, or sometimes daily, depending on the field schedule and project goals. During the remainder of the year (June – January), sonic-tagged fish were typically searched for on a monthly basis.

Sonic Tagging

No razorback suckers were sonic tagged as part of the 2015–16 study year at long-term monitoring sites; therefore, readers are encouraged to review past reports for sonic-tagging protocols used for Lake Mead razorback suckers (Albrecht and Holden 2005; Albrecht et al. 2014a).

Active Sonic Telemetry

Active sonic-tagged fish 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 and flowing portions of inflow areas), the range of observed movements may not always fully represent razorback sucker use of those particular areas. Active tracking consisted of listening underwater for coded sonic tags using a Sonotronics USR-08 model of ultrasonic receiver and DH4 hydrophone. The hydrophone was lowered just below the water's surface and rotated 360 degrees to detect sonic-tagged fish. Once detected, the position of the sonic-tagged fish was pinpointed by lowering the gain (sensitivity) of the receiver and moving in the direction of the fish until the signal was heard in all directions with the same intensity. Once pinpointed, the fish's tag number, Global Positioning System location, and depth were recorded. In all cases, when sonic-tagged fish were located within shallow habitats or within inflow riverine portions of Lake Mead (e.g., Las Vegas Wash and 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 SUR's advantage is the ability to continuously record sonic telemetry data over its approximate 9-month battery life. Most importantly, the SUR facilitates an understanding of large-scale razorback sucker movements during monthly tracking events. Seven SURs were deployed during the 2015–16 field season (see figure 1) as part of this long-term monitoring effort. Unfortunately, two SURs were either stolen or vandalized by the general public despite the researcher's best efforts to conceal their locations. Information from the SURs was shared between BIO-WEST and the NDOW, as appropriate, and helped provide a larger area of surveillance for monitoring lake-wide movements of razorback suckers.

The five SURs were set at the following locations (see figure 1): off the Cliffs southeast of Government Wash cove in Las Vegas Bay (NDOW), on the western shore south of Echo Bay at the constriction point near Ramshead Island (Reclamation), north of Echo Bay off the northern shore of Anchor Cove (Reclamation), off the eastern shore near Glory Hole (Reclamation), and finally on the southern shore near the Boulder Narrows (BIO-WEST). Unfortunately, several SURs were either stolen or damaged by the general public, thereby damaging the continuity of data collection. However, several SURs have since been replaced and are recording large-scale movements of sonic-tagged razorback suckers. 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 a concealed spot on shore. The SURs were allowed to sink to the lake bottom. The SURs were inspected frequently by pulling them up 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 898–902 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

The primary gear used to sample adult fish were trammel nets that measured 91.4 m long by 1.8 m deep with an internal panel of 2.54-centimeter (cm) mesh and external panels of 30.48-cm mesh. 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 (adult or juvenile), and/or high concentrations of razorback sucker larvae. To avoid inflicting handling stress on native razorback suckers, 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 lake water. Native suckers were isolated from other fish species and held in aerated live wells. The first five non-native fish of each species were measured (total length [TL] and fork length [FL] – both in millimeters [mm]), weighed (grams), and released at the capture location. The remaining non-native species were enumerated and returned to the lake. Razorback suckers, flannelmouth suckers (*Catostomus latipinnis*), or suspected razorback sucker x flannelmouth sucker hybrids (hybrids) were scanned for PIT tags, PIT tagged if they were not recaptured fish, measured (for TL, FL, and standard length [SL]), weighed, and assessed for sexual maturity, overall health, and reproductive readiness. 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. Individuals that were sexually defined were labeled according to their sex. 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 analyses. 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 approximate 0.5-cm section of caudal fin and preserving the sample in 95% genetics-grade ethanol. After all necessary information was collected, the fish were released unharmed at the point of capture. All genetic samples were delivered to Reclamation biologists for analyses following the field season.

Catch per unit effort (CPUE) for razorback sucker captures via trammel netting was calculated as the mean number of fish captured per net-hour fished. All statistical analyses were performed using the programs Statistix 8.1 and R version 3.1.2. An analysis of variance (ANOVA) was used to test for yearly differences in mean CPUE for each sampling site following recommendations of Hubert and Fabrizio 2007. 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. Given the residuals were found to be not normally distributed ($P \leq 0.05$), the data were transformed [Ln(CPUE+1)]. Hereafter, all mention of CPUE in the context of adult trammel netting captures are natural log-normalized data. When ANOVA detected significant differences of less than or equal to an alpha value of 0.05, a Tukey's honestly significant difference (HSD) test was used to examine all possible pair-wise comparisons

Remote Passive Integrated Transponder Scanning

In tandem with trammel-netting efforts, occasionally remote PIT tag antennas were deployed to detect previously PIT-tagged fish occupying the same areas in which 2016 netting efforts took place. Submersible scanners were deployed near overnight trammel net sets and retrieved the following day. Information recorded for scanning data included general location description, Global Positioning System location, date, and start and end scanning time.

Growth

Razorback sucker annual growth information was gathered from recaptured individuals previously tagged during trammel-netting collections between 1996 and 2015. The annual growth for razorback suckers was calculated for each individual using the difference in TL (mm) between capture periods. Recaptured individuals from the 2016 season were only measured once during the spawning season to avoid handling stress, and they were only used for annual growth analyses independent of time between capture occasions. An analysis in a previous study (Mohn et. al 2015) showed razorback suckers have no statistical difference in growth depending on whether they are wild or stocked; therefore, all fish were combined by sample site. In addition to the long-term monitoring growth calculation, annual growth was calculated for fish recaptured from individual long-term monitoring study areas (i.e., Las Vegas Bay, Echo Bay, and the Virgin River/Muddy River inflow area). All data specific to the 2016 season are reported.

Larval Sampling

The primary larval sampling method followed that developed by Burke (1995) and other Lake Mohave researchers. The procedure uses the positive phototactic response of larval razorback suckers to capture them. After sundown, two crappie 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. The procedure was repeated for 15 minutes at each location. Typically, two to five sites were sampled each night sampling was attempted. At each site location data, start and end time, depth, 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. 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 night throughout the 2007–16 study period. The results were graphed using a kernel density function in which the shape of the curve depends on the density of localized data points in a given area. The area under each curve on the graph is standardized to equal a value of 1.0.

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). This same general approach was used at the long-term monitoring study areas in 2016.

Age Determination

A non-lethal 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 2016 long-term monitoring efforts involved collecting fin ray sections from razorback suckers for aging purposes. Samples were also obtained from hybrids for age determination.

During the 2016 field season, previously unaged, wild razorback suckers and hybrids 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 with a lake-water bath 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 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 connecting membrane between fin rays was cut using a scalpel blade, and the section was placed in a labeled envelope for drying. All surgical equipment was sterilized before each use, and the resulting incisions were packed with antibiotic ointment to minimize postsurgical bacterial infections and promote rapid healing. All native razorback suckers undergoing fin ray extraction techniques were immediately placed in a recovery bath of fresh lake water containing slime-coat protectant and NaCl. They were allowed to recover and were released as soon as they regained equilibrium. Vigilant monitoring was conducted during all phases of the procedure.

In the laboratory, fin ray segments were embedded in thermoplastic epoxy resin and heat cured. This technique allowed the fin rays to be perpendicularly sectioned using a Buhler isomet low-speed saw. Resultant sections were then mounted on microscope slides, sanded, polished, and examined under a stereo-zoom microscope. Each sectioned fin ray was aged independently by at least 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, 2008a, 2010a), and other annual Lake Mead razorback sucker reports. Information for all razorback suckers aged since 1998 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 2014 through 2016. This timespan was selected to maintain consistency with past estimates in which 3-year datasets were used. These razorback suckers are essentially a small remnant population of a once larger Colorado River population, and recruitment in the Lake Mead system is assumed to be relatively low. Given this, it was presumed that, over a 3-year time scale, closed population model assumptions would not be violated significantly by bias associated with recruitment. Thirty-four capture occasions (based on weekly sampling efforts during 2014 and biweekly sampling in 2015–16) 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). Additionally, this approach was repeated with the inclusion of remote PIT tag scanner data that were opportunistically deployed simultaneously with trammel-netting efforts. These efforts were an attempt to increase "recapture" rates of previously marked individuals. Otis et al. 1978 (*in* Cooch and White 2013) recommends recapture rates between 20 and 30% to achieve a reliable population estimate. A population model for both "netting only" and "netting and PIT scanner" models were derived using program MARK and reported within. The model with highest ranking (lowest Akaike's information criterion adjusted for small sample size [AIC_c] weight) is reported within. No model averaging was conducted this year because one model (*Mt*) carried all the AIC_c 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 from the entire mark-recapture study period spanning from 1996 through 2016. A Cormack-Jolly-Seber (CJS) live recapture model (Cormack 1964; Jolly 1965; Seber 1965) was used to obtain a lake-wide estimate (combined data from long-term monitoring sites [1996–2016] and the CRI [2010–16]). Twenty-one 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 CJS 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 AIC_c values in which the best fitting models have the lowest AIC_c scores. The saturated model ($\phi[t]p[t]$) was then tested for goodness-of-fit by estimating the over-dispersion parameter ($\hat{c}$) using median $\hat{c}$ within program MARK (Cooch and White 2013). In goodness-of-fit testing, the saturated model (attachment 3) produced an estimated $\hat{c}$ value of 3.3 (standard error [SE] = 0.2) in logistic regression. Weighted average estimates for φ and p were calculated along with 95% confidence bounds (Cooch and White 2013).

In Lake Mead, razorback suckers smaller than 450 mm TL are generally immature fish less than 4 years old. To be comparable with other razorback sucker populations in the Upper and Lower Colorado River Basin, 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 study at Lake Mead (1996–2016), facilitates comparison of survival for Lake Mead razorback suckers with that of 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).

Transition Estimates

Program MARK (Cooch and White 2013) was used with RMark (Laake 2013) to create a set of multi-state models using mark-recapture data. These models are extensions of CJS models that can be used to estimate not only survival and recapture probabilities but also transition probabilities. A smaller dataset was used compared to the above survival analysis because it was the year the Virgin River/Muddy River inflow area was added as a sample site, and it would also provide a high number of tagged individuals. Twelve years of data were used for 12 capture events (2005–16) for 712 razorback suckers captured during the spawning season. In this case, transition probabilities were explored for individuals moving among sites during the spawning season. Additionally, PIT-tag detections from deployed scanners were used to increase the number of fish "recaptures" during those spawning periods. The models created were null models for survival, recapture probability, and transition variables as well as models where site was allowed to vary. We chose to purely focus on site and its effect on transitional probabilities for this analysis, as we assumed survival and capture probability remained constant through time. A table of AIC_c values and weights was obtained as described above, and transition estimates, along with 95% confidence bounds, were taken from the top-performing model. Goodness-of-fit testing was attempted using a variety of methods but ultimately was unsuccessful. Given this dataset is a shortened version of the survival dataset (above), we would expect similar median $\hat{c}$ values. The results were not model-averaged for two reasons: (1) the top-performing model carried 90% of the AIC_c weight and (2) models between 4 and 7 ΔAIC_c units from the top-performing model had considerably less support (Burnham and Anderson 2004).

RESULTS

Lake Elevation

For the past 16 years (figure 2), lake elevations have generally declined. Lake elevations continued to decline during the 2015–16 field season (figure 3). However, lake elevations remained relatively static between July and the end of December, until rising gradually to a peak elevation of 330.5 m msl at the beginning of February 2016 (figure 3). In 2016, lake elevations decreased steadily during the spawning months of February through May to a final elevation of approximately 327 m msl at the end of May (figure 3). Lake elevations dropped approximately 3 m during the 2016 spawning months, or approximately 1 m of lake elevation decline per month. 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 were observed during these months. Lake elevation drops have caused vast areas to dry, particularly in the Virgin River/Muddy River inflow area coves and formerly shallow areas of Echo Bay.

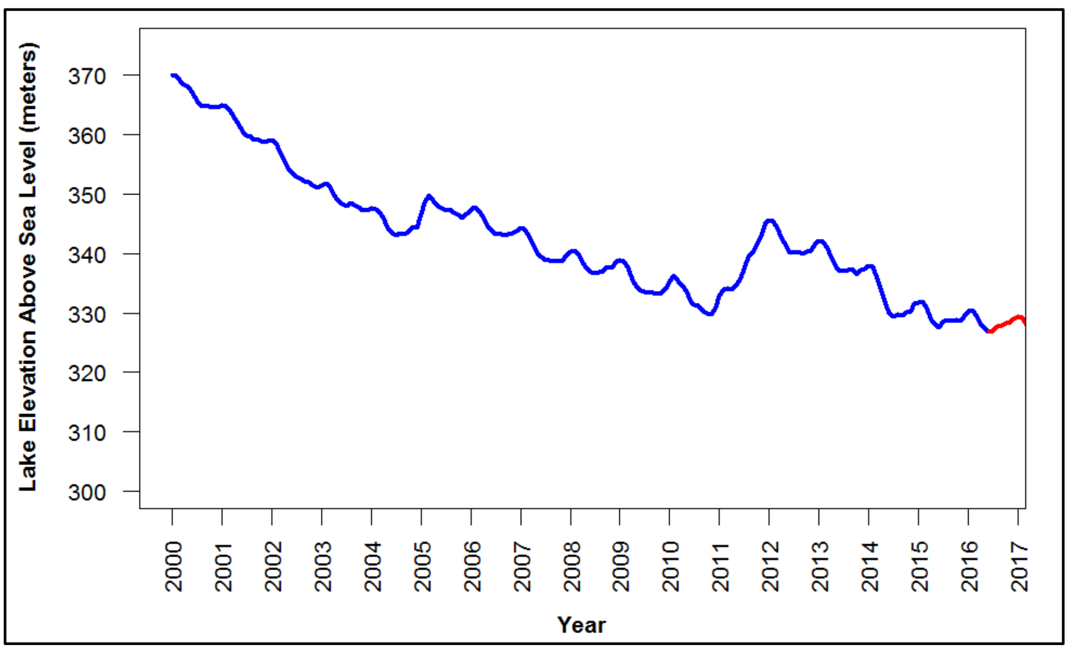

Figure 2.—Lake Mead month-end lake elevations, January 2000 – June 2016, with projected lake elevations for the July 2016 – June 2017 study year (Reclamation 2016).

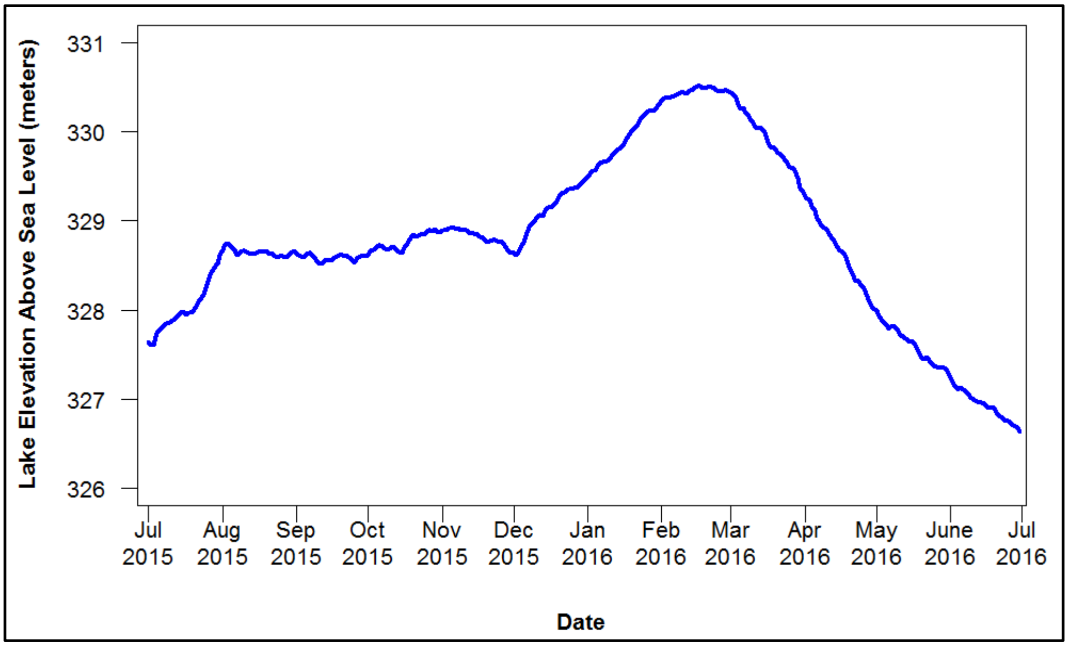

Figure 3.—Lake Mead daily lake elevations, July 1, 2015 – June 30, 2016 (Reclamation 2016).

Following the peak spawning months (i.e., February, March, and April), lake elevations continued to decline through the remainder of the 2015–16 field season, reaching the lowest lake elevations observed since Hoover Dam's construction in 1935.

Sonic Telemetry

Over the course of this study (1997–2016), 93 adult razorback suckers (48 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. A complete description of recent sonic telemetry efforts specific to juvenile research and studies at the CRI can be found in Shattuck and Albrecht (2014), Albrecht et al. (2014b), and Kegerries et al. (2016).

During the long-term monitoring 2015–16 field season, 10 unique fish were detected using active and/or passive telemetry methods. Eighty-three total active contacts were made with 10 individual sonic-tagged razorback suckers (table 1; figures 4–6). The five SURs mentioned above, plus another deployed at the CRI (see figure 1), contacted 8 of 10 sonic-tagged razorback suckers a total of 11,539 times. The Anchor Cove SUR contacted razorback suckers most often (9,998 contacts), while the Boulder Narrows SUR contacted no fish. The number of SURs and the number of contacts typically are used to define movement,

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

Capture location[a]	Date tagged	Tag 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-E	2/15/2014	0 (0)	Expired
FDLB	1/4/2011	3545	556	F	LB	LB	7/15/2014	0 (0)	Expired
FDLB	1/4/2011	3584	519	M	LB	LB	6/23/2014	0 (0)	Expired
FDLB	1/4/2011	3775	516	M	LB	LB	1/15/2016	1 (646)	Unknown
FDLB	1/4/2011	448	502	M	OA	OA	6/14/2016	7 (90)	Active
FDLB	1/4/2011	555	504	M	OA	OA	2/16/2016	1 (105)	Active
FDLB	1/4/2011	3578	541	F	OA	OA	6/16/2015	0 (0)	Expired
FDLB	1/4/2011	3667	552	F	OA	OA	2/17/2015	0 (0)	Expired
2012									
LB	2/28/2012	222	425	I	LB	LB	12/8/2014	0 (0)	Expired
CPD	4/23/2012	337	390	I	LW	LB	5/16/2012	0 (0)	Expired
CPD	4/23/2012	368	345	I	LW	LB	3/14/2015	0 (0)	Expired
CPD	4/23/2012	452	340	I	LB	OA-W	11/16/2013	0 (0)	Expired
2014									
EB	2/6/2014	586	656	F	EB	AC	4/2/2016	7 (377)	Active
EB	2/12/2014	3375	598	M	EB	EB	4/4/2016	10 (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)	Unknown
LB	2/11/2014	3488	626	M	LB	LB	6/13/2016	13 (0)	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	6/13/2016	11 (47)	Active
OA	2/5/2014	578	520	M	OA	EB	3/30/2016	13 (277)	Active
OA	2/26/2014	3337	589	M	OA	AC	2/16/2016	10 (8,926)	Active
OA	3/6/2014	3374	582	M	OA	EB	6/14/2016	10 (1,071)	Active
OA	3/6/2014	3478	562	M	OA	GH	5/15/2014	0 (0)	Unknown

[a] AC = Anchor Cove, CPD = Center Pond, EB = Echo Bay, FDLB = Floyd Lamb Park, GH = Glory Hole SUR, LB = Las Vegas Bay, LB-E = Las Vegas Bay SUR, LW = Las Vegas Wash, OA = Overton Arm (Virgin River/Muddy River inflow area), and OA-W = NDOW Blackridge SUR.

[b] F = female, I = immature (sex not determined), and M = male.

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

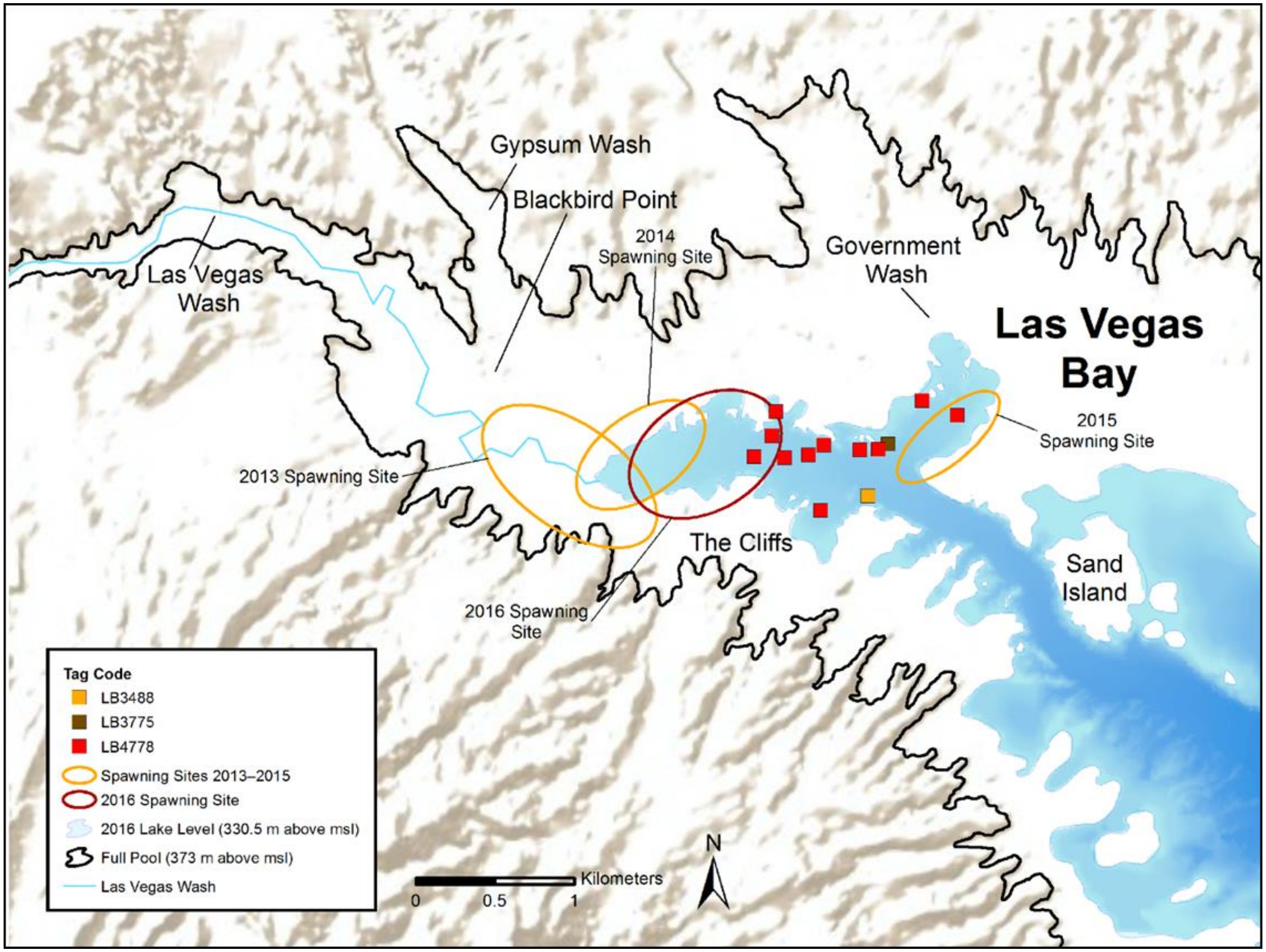

Figure 4.—Distribution of sonic-tagged razorback suckers located through active sonic telemetry in Las Vegas Bay, July 2015 – June 2016.
Symbols for each tag code are unique to their original tagging location, which is noted on the map as the tag code (e.g., LB4778 was originally tagged within Las Vegas Bay).

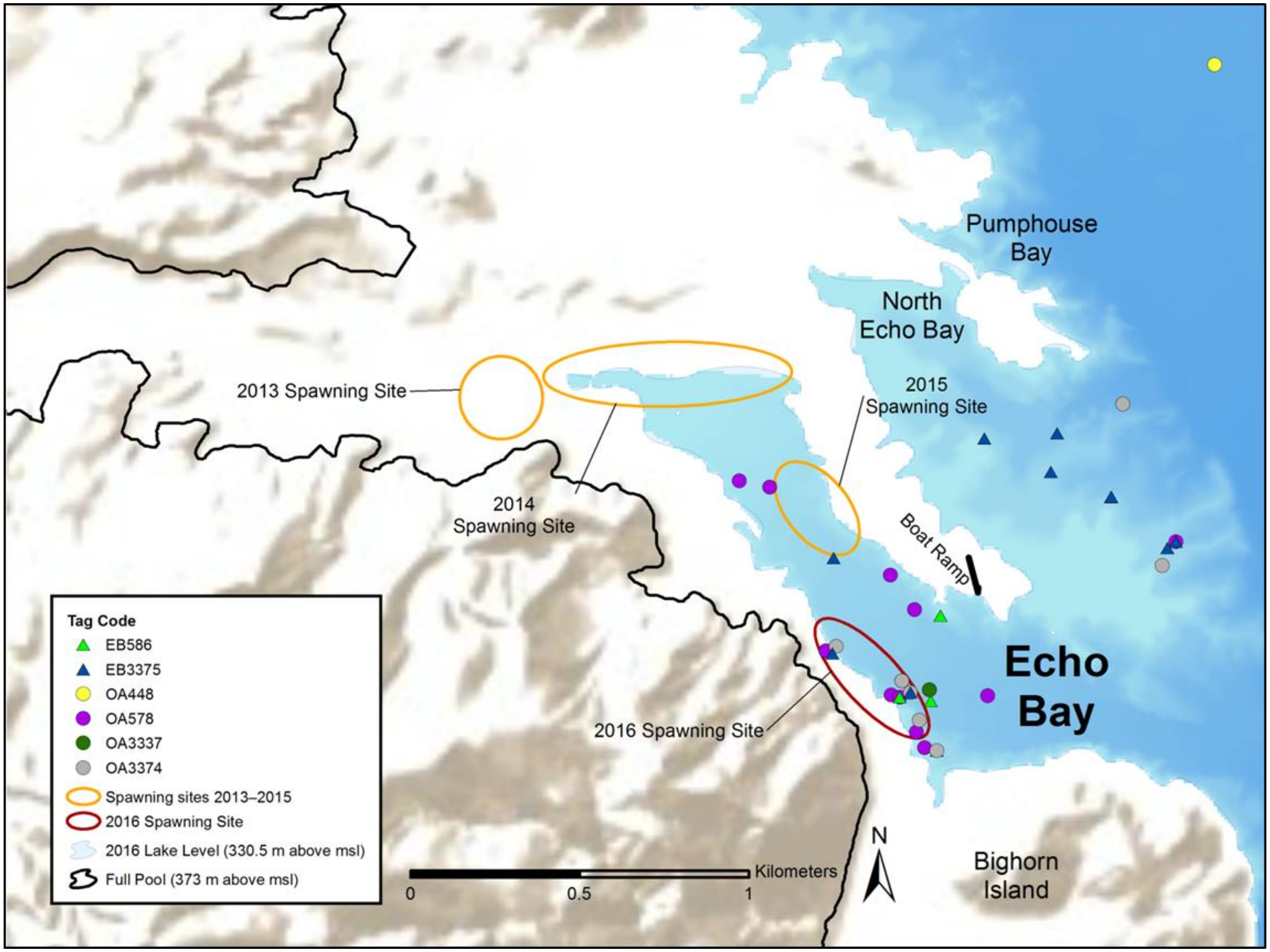

Figure 5.—Distribution of sonic-tagged razorback suckers located through active sonic telemetry in Echo Bay, July 2015 – June 2016.
Symbols for each tag code are unique to their original tagging location, which is noted on the map as the tag code (e.g., fish OA578 was originally tagged near the Virgin River/Muddy River inflow area).

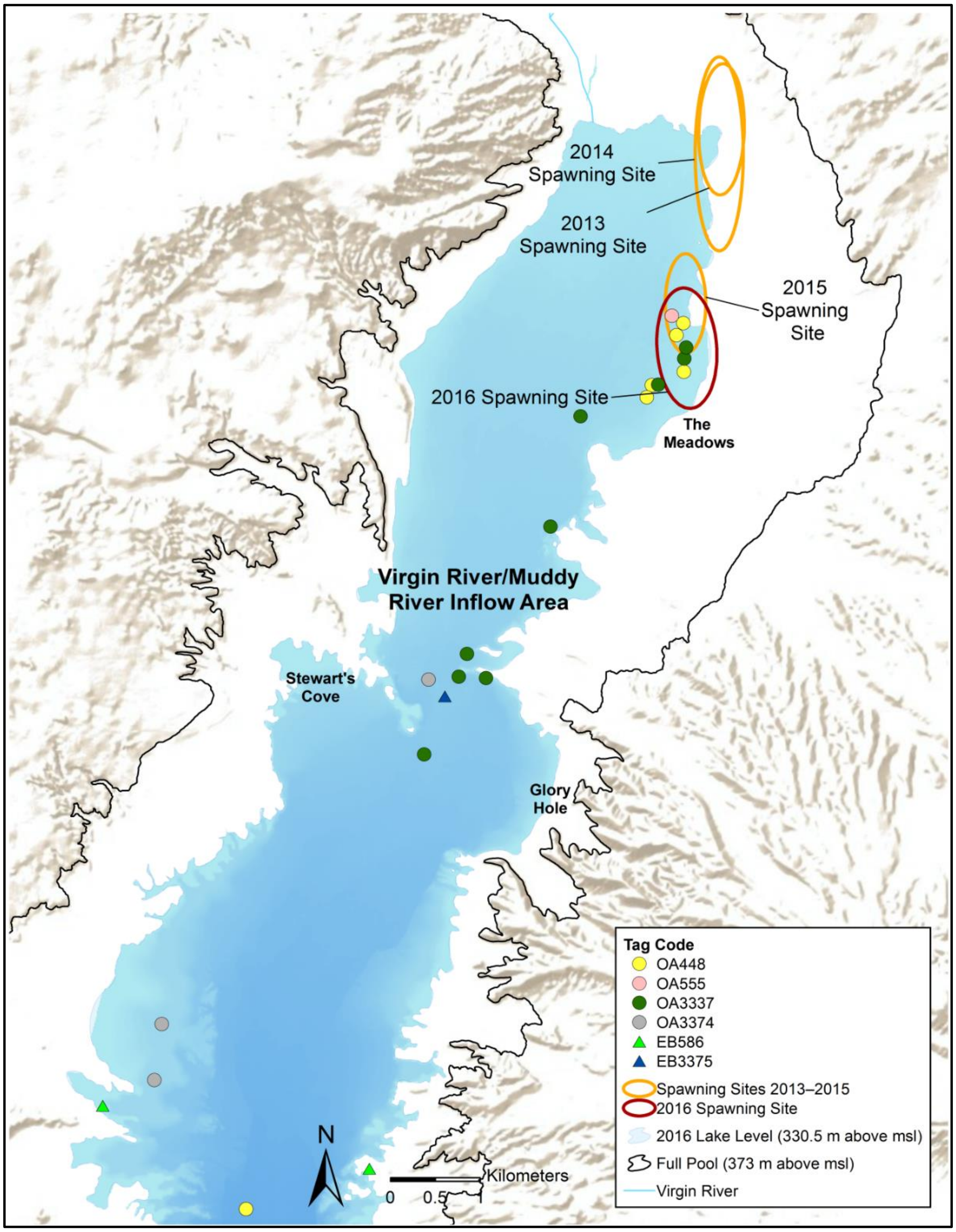

Figure 6.—Distribution of sonic-tagged razorback suckers located through active sonic telemetry near the Virgin River/Muddy River inflow area, July 2015 – June 2016.

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).

particularly long-distance movements of sonic-tagged individuals, and aide in accounting for difficult-to-locate sonic-tagged fish. We found fish that moved between Echo Bay and the Virgin River/Muddy River inflow area but none that moved from these sites to Las Vegas Bay in 2016.

Fish Sonic Tagged in 2011

Eight razorback suckers from Floyd Lamb Park were sonic tagged in Lake Mead in January 2011. Four individuals were released in Las Vegas Bay, and four individuals were released in the Virgin River/Muddy River inflow area. During the 2015–16 field season, 3 out of 8 fish were contacted a total of 850 times (see table 1) using a combination of active and passive methods. For the most part, fish released in 2011 remained at their respective release localities for the 2015–16 field season (i.e., tagged individuals were contacted at the same study area where they were initially released). The one individual from the 2011 tagging event that was stocked into Las Vegas Bay was actively contacted in that area only once (mid-January). Once spawning season began, this fish was not contacted again. The two individuals detected at the Virgin River/Muddy River inflow area were actively contacted in that area eight times (see table 1; figures 4 and 6). Though no individuals from this year-class were initially stocked into Echo Bay, one sonic-tagged individual (code 448) from the Virgin River/Muddy River inflow area was contacted near Anchor Cove during the 2015–16 field season (see table 1). Individuals from the 2011 tagging event were contacted most often by SURs placed throughout Lake Mead; the majority of contacts made by the Glory Hole SUR (n = 165; see figure 1; table 1). No contacts were made by the Boulder Narrows or Echo Bay SURs.

Sonic tags implanted in 2011 are likely to now be expired, considering that the 4-year expected battery life has ended.

Fish Sonic Tagged in 2012

Four sonic-tagged juvenile razorback suckers were implanted and released into Lake Mead in February and April 2012: three pond-reared individuals from Center Pond at the Overton Wildlife Management Area and one wild individual caught in Las Vegas Bay (see table 1). In the time since these individuals were tagged, they have likely grown and matured and are presumed to have integrated with the adult razorback sucker population.

No contacts were made with any of these individuals in 2016. The amount of time since last detection is extensive, and given all four of these tags were smaller (shorter battery life), the batteries have likely expired.

Fish Sonic Tagged in 2014

Following recommendations made in Albrecht et al. (2013a, 2013b), a select 10 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). 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). Furthermore, concurrent tagging efforts were conducted at the CRI during 2014 field season, and two wild razorback suckers that were sonic tagged at the CRI were subsequently contacted with active sonic telemetry twice during long-term monitoring efforts in the area from Echo Bay to the Virgin River/Muddy River inflow area (fish codes 468 and 3547).

During the 2015–16 field season, 7 of 11 individuals from the 2014 tagging event were contacted at least once for a total of 74 active sonic telemetry contacts. Five of those 11 individuals were also passively contacted 10,698 times via three different SURs (see table 1). The contacts were made at the Glory Hole SUR (n = 9,833), Anchor Cove SUR (n = 479), and the Las Vegas Bay SUR (n = 47) (see figure 1). No contacts were made with the Boulder Narrows or Echo Bay SURs (see figure 1).

During past tagging events, fish implanted with sonic transmitters and released into a particular locality of Lake Mead often remained within the general release area. This was the pattern seen in Las Vegas Bay, where 2 individuals from the 2014 tagging event were actively contacted in that area 24 times. During the 2015–16 field season, one individual (fish 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 cove and Las Vegas Wash. Fish code 3488 was contacted nearly every month in the same location and is now considered deceased (see figure 4).

In contrast, the individuals tagged and released in Echo Bay and the Virgin River/Muddy River inflow area in 2014 exhibited a greater frequency of movement outside of their respective release locations, occasionally moving back and forth between the two long-term monitoring study areas (see figures 5 and 6). From the 2014 tagging event, three individuals tagged at the Virgin River/Muddy River inflow area—fish codes 3337, 578, and 3374—were contacted in Echo Bay, particularly during the spawning season. Fish code 3374 was contacted once at the Virgin River/Muddy River inflow area in March, but it returned to Echo Bay soon after (see figure 6). These movements indicate that Echo Bay was preferred over the Virgin River/Muddy River inflow area for spawning in 2016 when compared with 2015 and show the importance of all three long-term monitoring sites to razorback sucker viability. Additional evidence for this can be found in sections below.

Adult Sampling

Trammel Netting

Trammel-netting surveys were conducted from January 12 through April 20, 2016, and consisted of 108 net sets totaling 1,731.87 total net-hours (table 2; figures 7–9). This effort and number of net sets includes efforts of Reclamation biologists and the joint efforts of BIO-WEST, Reclamation, and the NDOW during March 21–25, 2016. During these efforts, 67 razorback suckers (representing 61 unique individuals), 13 flannelmouth suckers, and two hybrids were captured. The first male razorback sucker expressing milt was captured on February 8, 2016, in Las Vegas Bay, and the first female razorback sucker expressing eggs was captured on February 10, 2016, in Echo Bay (see table 3).

Table 2.—Trammel-netting efforts (number of nets and net-hours) on Lake Mead, January – April 2016

Month	Las Vegas Bay	Echo Bay	Virgin River/ Muddy River inflow area	Total
January	8	11	6	25
February	8	11	8	27
March	5	20	22	47
April	3	4	2	9
Total number of nets	**24**	**46**	**38**	**108**
Total net-hours	**372.15**	**725.87**	**633.85**	**1,731.87**

Efforts in all combined netting locations within Lake Mead resulted in capturing a similar sex ratio of individuals compared with past studies (Albrecht et. al 2014b). Approximately 52% of these fish were female, and 48% were male. Four individuals were captured in Las Vegas Bay, two of which were female and two of which were male. A combined 14 male and 14 female razorback suckers were captured near the Virgin River/Muddy River inflow area (table 3; figures 7 and 9). Thirty-five razorback suckers were captured in Echo Bay, composed of 19 females and 16 males (table 3; figure 8). No juvenile fish were captured during the 2016 field efforts. Within the three long-term monitoring sites, 39 fish were recaptures, and 28 were newly captured wild fish. Four fish captured during the 2016 netting season were sonic-tagged, stocked fish. One was a wild fish sonic tagged near the Virgin River/Muddy River inflow area in May 2014, and three were stocked fish. All were sonic tagged in 2014 as part of the juvenile razorback sucker habitat association project. These individuals appeared to have

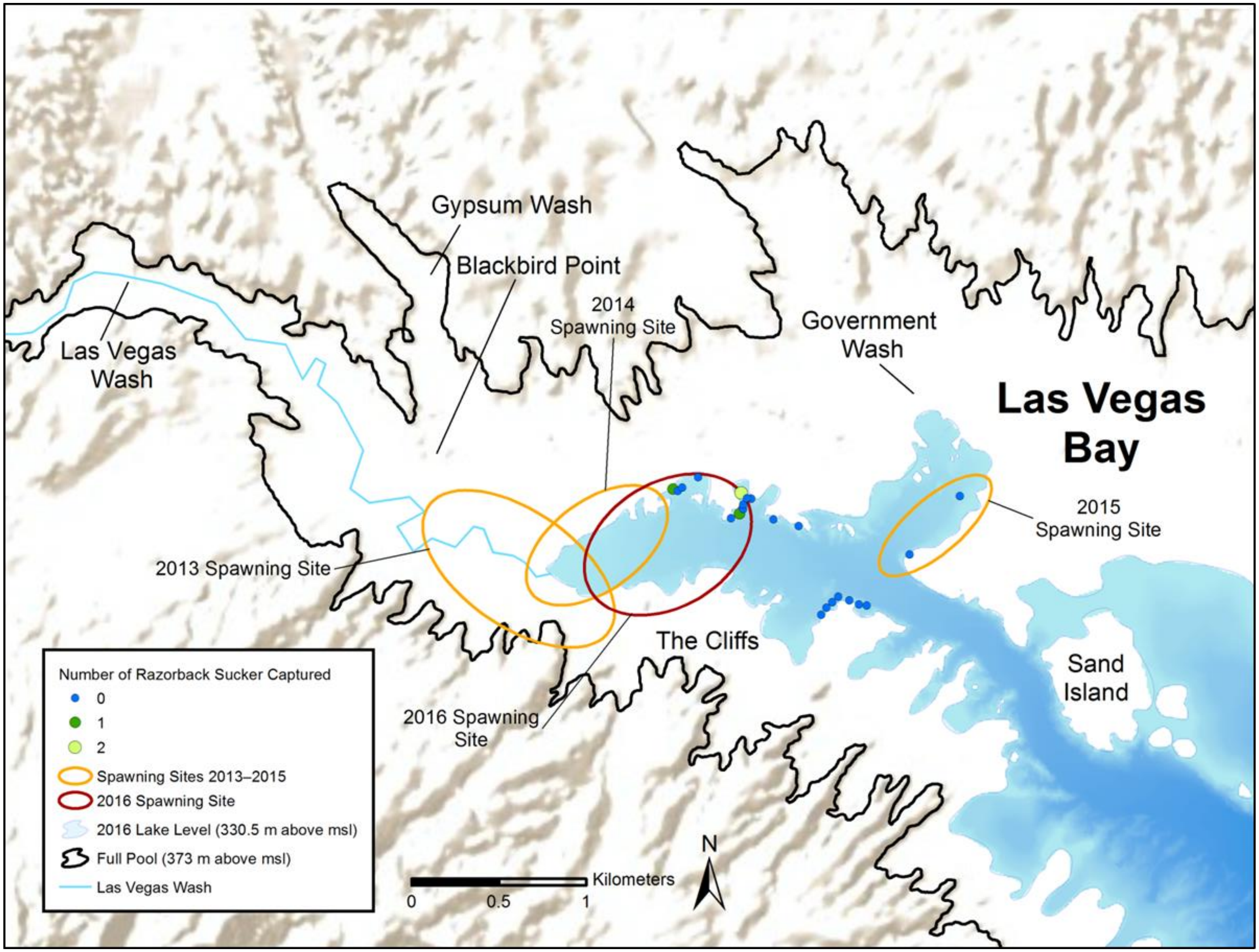

Figure 7.—Locations of trammel netting and numbers of razorback suckers captured in Las Vegas Bay, February – April 2016.

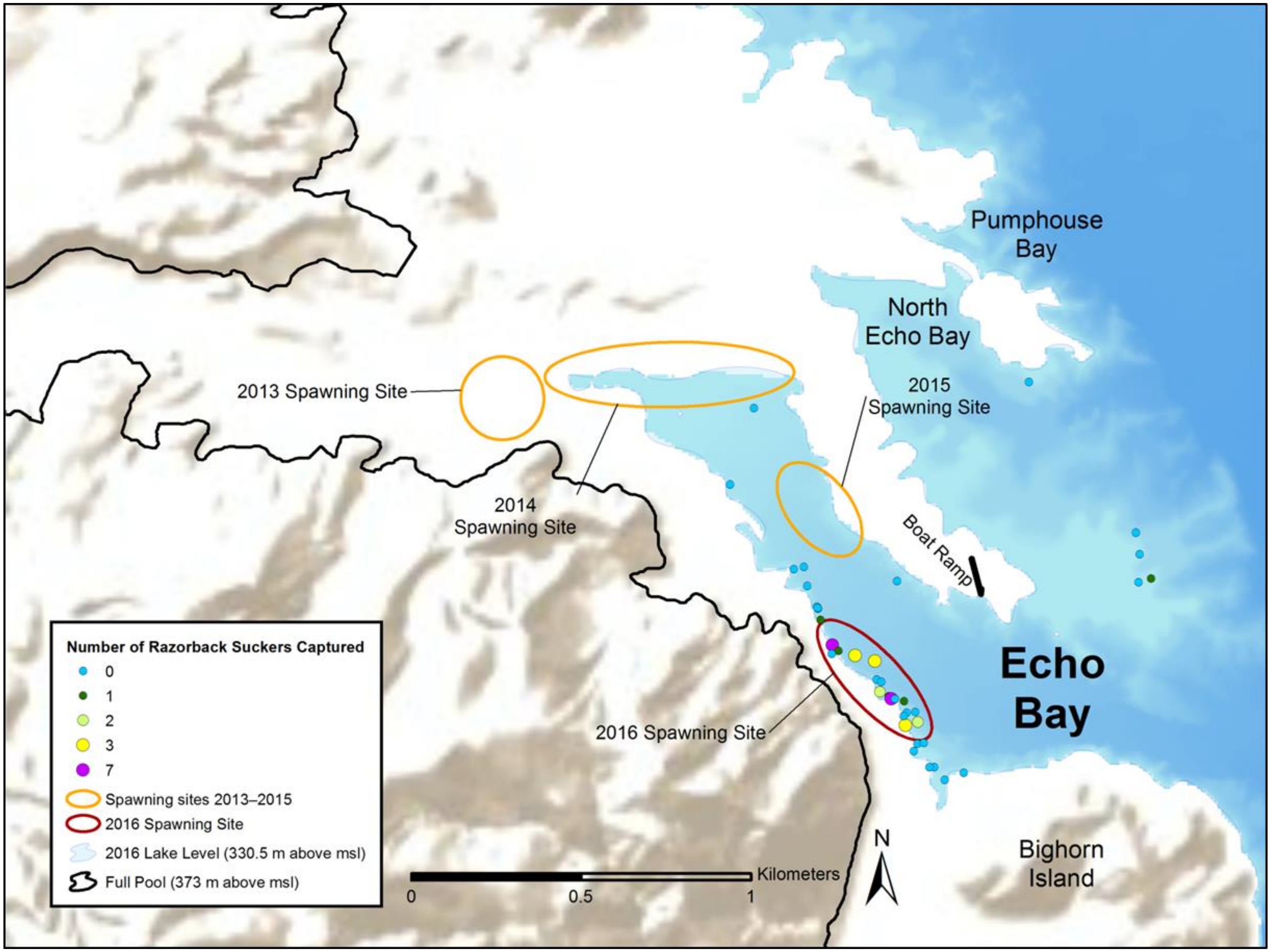

Figure 8.—Locations of trammel netting and numbers of razorback suckers captured in Echo Bay, February – April 2016.

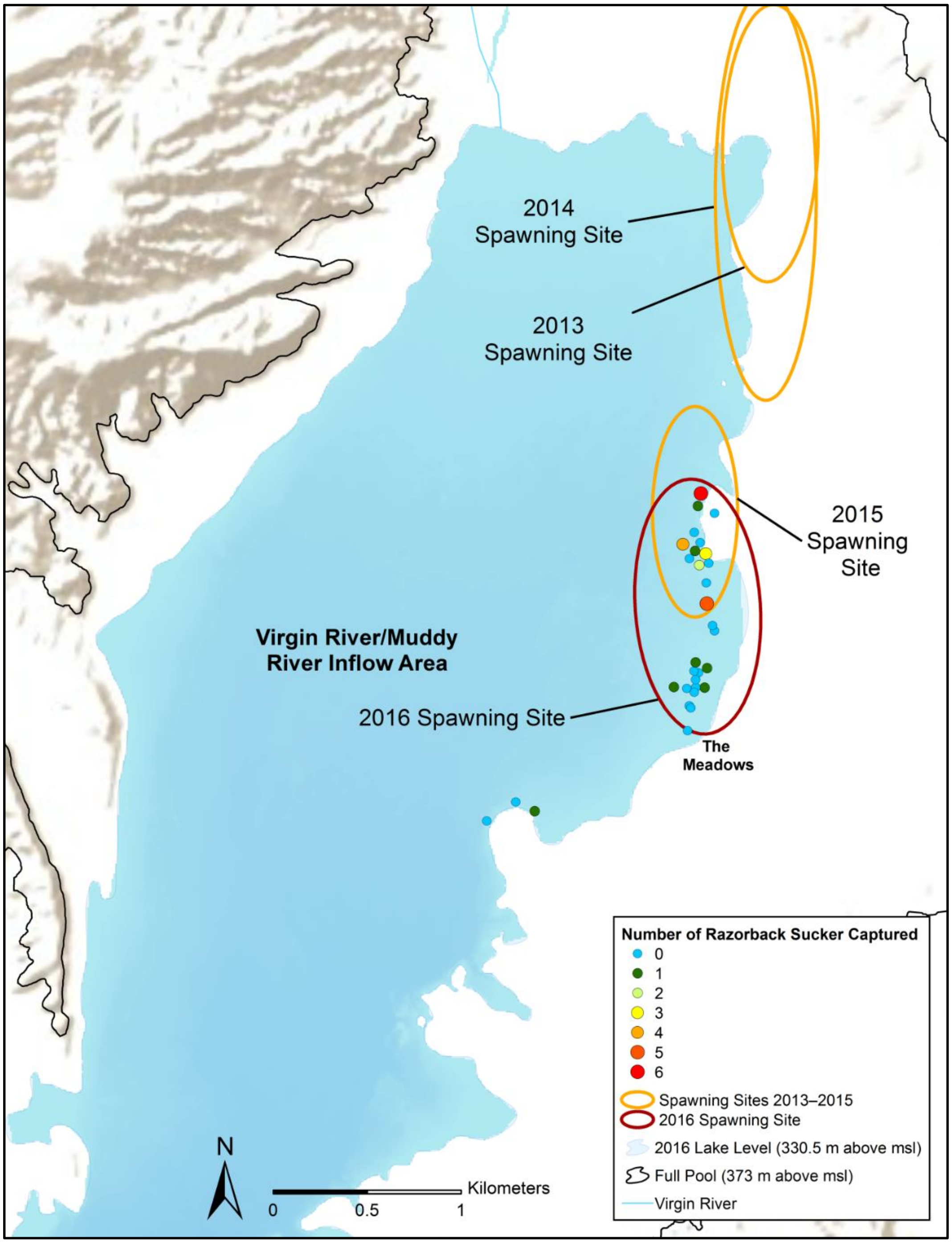

Figure 9.—Locations of trammel netting and numbers of razorback suckers captured at the Virgin River/Muddy River inflow area, February – April 2016.

Table 3.—Capture location, tagging, and size information for razorback suckers captured between February 9 and April 21, 2016

Date	Capture location[a]	Date tagged or stocked[b]	Sonic tag	PIT tag	Recapture?	TL (mm)	FL (mm)	SL (mm)	WT[c]	Sex[d]	Origin
2/09/2016	LB	2/09/2016		3DD.003BCB9359	N	569	521	481	2,192	M	Wild
2/11/2016	EB	2/02/2007		384.1B7969D655	Y	643	588	552	2,760	M	Wild
2/11/2016	EB	4/10/2013		384.1B7969DEEA	Y	632	590	545	2,888	F	Wild
2/11/2016	EB	2/07/2013		3D9.1C2D260916	Y	582	537	503	2,444	M	Wild
2/11/2016	EB	1/11/2007		53256C725A	Y	667	619	576	3,168	F	Wild
2/16/2016	OA	2/16/2016		3DD.003BA74927	N	455	423	385	1,140	M	Wild
2/16/2016	OA	5/08/2013	3016	384.1B7969CCA6	Y	545	505	464	1,950	M	Stocked
2/16/2016	OA	2/16/2016		3DD.003BA7492E	N	555	510	472	1,980	M	Wild
2/16/2016	OA	2/16/2016		3DD.003BA7687E	N	635	585	543	3,040	F	Wild
2/16/2016	OA	3/21/2013		384.1B7969DB68	Y	660	610	605	3,115	F	Wild
2/16/2016	OA	3/06/2014		3DD.003BA2FA7F	Y	615	570	522	2,680	F	Wild
2/17/2016	OA	2/17/2016		3DD.003BA74901	N	545	500	460	1,770	M	Wild
2/17/2016	OA	3/13/2012		384.1B7969D59B	Y	Quick release[e]				F	Wild
2/17/2016	OA	2/08/2012		3D9.1C2D262764	Y	655	610	565	2,950	F	Wild
2/23/2016	EB	3/28/2012		384.1B7969EBE1	Y	625	584	545	2,962	F	Wild
2/24/2016	OA	2/24/2016		3DD.003BCB937C	N	471	430	394	1,184	M	Wild
2/24/2016	OA	2/24/2016		3DD.003BCB9380	N	559	515	480	2,120	M	Wild
2/24/2016	OA	2/24/2016		3DD.003BCB938B	N	647	598	561	2,918	F	Wild
2/24/2016	OA	2/24/2016		3DD.003BCB9395	N	635	586	552	3,112	F	Wild
2/24/2016	OA	2/01/2011		3D9.1C2C2F86BA	Y	654	604	569	3,184	F	Wild
3/08/2016	EB	2/05/2014	578	384.1B7969CC18	Y	544	503	472	1,864	M	Stocked
3/08/2016	EB	5/06/2014	3020	3DD.003BA2FA91	Y	497	460	423	1,262	F	Stocked
3/08/2016	EB	5/06/2014	3027	3DD.003BA2FA94	Y	463	428	394	1,094	I	Stocked
3/08/2016	EB	3/08/2016		3DD.003BCB9388	N	612	567	534	2,330	F	Wild
3/08/2016	EB	3/08/2016		3DD.003BCB93B7	N	650	605	564	3,100	F	Wild
3/08/2016	EB	2/07/2013		3D9.1C2C840A3C	Y	652	609	571	3,028	F	Wild
3/08/2016	EB	3/01/2012		3D9.1C2C840ECD	Y	627	584	548	3,072	F	Wild
3/08/2016	EB	2/16/2016		3DD.003BCB93CA	Y	Quick release[e]				M	Wild
3/09/2016	LB	2/16/2015		3D9.1C2D6978DA	Y	606	573	531	2,268	F	Stocked
3/22/2016	EB	5/06/2014	3027	3DD.003BA2FA94	Y	461	423	393	1,108	F	Stocked
3/22/2016	OA	3/22/2016		3DD.003BCB9392	N	541	496	444	1,672	M	Wild
3/22/2016	EB	3/22/2016		3DD.003BCB93A5	N	570	529	497	1,898	M	Wild
3/22/2016	EB	3/22/2016		3DD.003BCB93BF	N	545	497	461	1,608	M	Wild
3/22/2016	EB	3/22/2016		3DD.003BCB93C7	N	476	437	404	1,154	M	Wild
3/22/2016	EB	3/22/2016		3DD.003BCB93DC	N	634	592	554	2,398	F	Wild
3/22/2016	EB	3/22/2016		3DD.003BCB93CC	N	545	497	456	1,520	M	Wild
3/22/2016	EB	3/24/2009		3D9.1C2C840D17	Y	597	550	518	2,138	M	Wild
3/22/2016	EB	2/16/2012		3D9.1C2C84147F	Y	596	545	503	2,180	M	Wild
3/22/2016	EB	3/01/2011		3D9.1C2C844E09	Y	634	586	551	2,888	F	Wild

Table 3.—Capture location, tagging, and size information for razorback suckers captured between February 9 and April 21, 2016

Date	Capture location[a]	Date tagged or stocked[b]	Sonic tag	PIT tag	Recapture?	TL (mm)	FL (mm)	SL (mm)	WT[c]	Sex[d]	Origin
3/22/2016	EB	3/01/2011		3D9.1C2D279A4D	Y	620	576	538	2,664	F	Wild
3/22/2016	EB	2/22/2011		3D9.257C60BE38	Y	536	493	458	1,598	M	Wild
3/22/2016	EB	2/09/2010		3D9.257C60E67A	Y	553	513	481	1,818	M	Wild
3/22/2016	EB	2/09/2010		3D9.257C633584	Y	604	569	530	2,290	F	Wild
3/22/2016	EB	2/27/2014		53437D5852	Y	604	559	523	2,485	M	Wild
3/23/2016	OA	2/06/2015		3DD.003BA63967	Y	509	480	442	1,380	M	Stocked
3/23/2016	OA	3/23/2016		3DD.003BCB938E	N	577	524	486	2,068	M	Wild
3/23/2016	OA	3/23/2016		3DD.003BCB9392	N	541	496	444	1,672	M	Wild
3/23/2016	OA	3/27/2013		384.1B7969E2F4	Y	595	545	515	2,295	F	Wild
3/24/2016	OA	2/06/2015		3D9.1C2D694CD2	Y	450	420	383	1,392	F	Stocked
3/24/2016	OA	3/24/2016		3DD.003BA62D53	N	565	526	471	1,850	M	Wild
3/24/2016	OA	3/24/2016		3DD.003BA62D5C	N	582	539	486	1,920	M	Wild
3/24/2016	OA	3/24/2016		3DD.003BA74917	N	562	525	483	1,885	M	Wild
3/24/2016	OA	3/24/2016		3DD.003BA76885	N	490	451	412	1,230	M	Wild
3/24/2016	OA	3/27/2013		384.1B7969E2F4	Y	605	573	522	2,240	F	Wild
3/24/2016	OA	3/14/2013		384.1B7969E3C7	Y	626	580	527	2,290	F	Wild
3/24/2016	OA	2/09/2010		3D9.257C60CC21	Y	571	510	485	1,730	M	Wild
3/24/2016	OA	4/03/2014		3DD.003BA2FAC1	Y	635	600	565	2,555	F	Wild
4/05/2016	EB	4/05/2016		3DD.003BCB938F	N	648	600	556	2,640	F	Wild
4/05/2016	EB	4/05/2016		3DD.003BCB939F	N	650	608	564	2,540	F	Wild
4/05/2016	EB	4/05/2016		3DD.003BCB93A7	N	618	580	539	2,718	F	Wild
4/05/2016	EB	4/05/2016		3DD.003BCB93C6	N	591	546	510	2,308	F	Wild
4/05/2016	EB	2/02/2007		384.1B7969D655	Y	Quick release[e]				M	Wild
4/05/2016	EB	2/09/2010		3D9.257C633584	Y	Quick release[e]				F	Wild
4/19/2016	LB	4/19/2016		3DD.003BCB93BA	N	599	561	520	2,408	F	Wild
4/19/2016	LB	2/09/2016		3DD.003BCB9359	Y	Quick release[h]				M	Wild
4/21/2016	EB	4/21/2016		3DD.003BCB9334	N	463	425	392	1,070	M	Wild
4/21/2016	EB	4/21/2016		3DD.003BCB935C	N	561	521	478	1,650	M	Wild

[a] EB = Echo Bay, LB = Las Vegas Bay, and OA = Overton Arm (Virgin River/Muddy River inflow area).
[b] Date originally stocked or originally captured.
[c] Weight (g).
[d] F = female, I = immature (sex not determined), and M = male.
[e] No measurements taken due to proximity of date of capture to date of recapture, individual was released immediately to avoid unnecessary stress.

integrated into the adult spawning population, as they were captured alongside spawning adult suckers, at least two of which were females expressing gametes.

Trammel-netting efforts in Las Vegas Bay were focused on the northwest shore of the bay outside of Las Vegas Wash as well as in Government Wash cove and off the south shore across from Government Wash cove (see figure 7). Four adult razorback suckers were captured in the northwest corner of the bay as a result of 24 net sets. This effort yielded the lowest mean CPUE of 2016 at 0.0104 (± SE = 0.0064, untransformed) (figure 10). Trammel netting efforts in Echo Bay primarily focused on the western shore across from the boat ramp, which resulted in the capture of 35 adult razorback suckers from 46 net-nights (see figure 8; tables 2–3). Echo Bay had the highest mean CPUE at 0.0440 (± SE = 0.0129). This was similar to the Virgin River/Muddy River inflow area, which resulted in the capture of 28 adult razorback suckers from 38 net-nights and yielded a mean CPUE of 0.0415 (± SE = 0.0125) (see figure 9; tables 2–3). Sampling of the Virgin River/Muddy River inflow area occurred primarily along the eastern shoreline in the northern extent of the Overton Arm over gravel bars or adjacent silt areas. This occurred approximately 1–2 km south of the Virgin River/Muddy River inflow area and was often dependent on the presence of sonic-tagged individuals (see figure 9). The overall Lake Mead mean CPUE for 2016 was 0.0173 (± SE = 0.0034), which is a small increase over 2015's CPUE (0.0150 [± SE = 0.0035]).

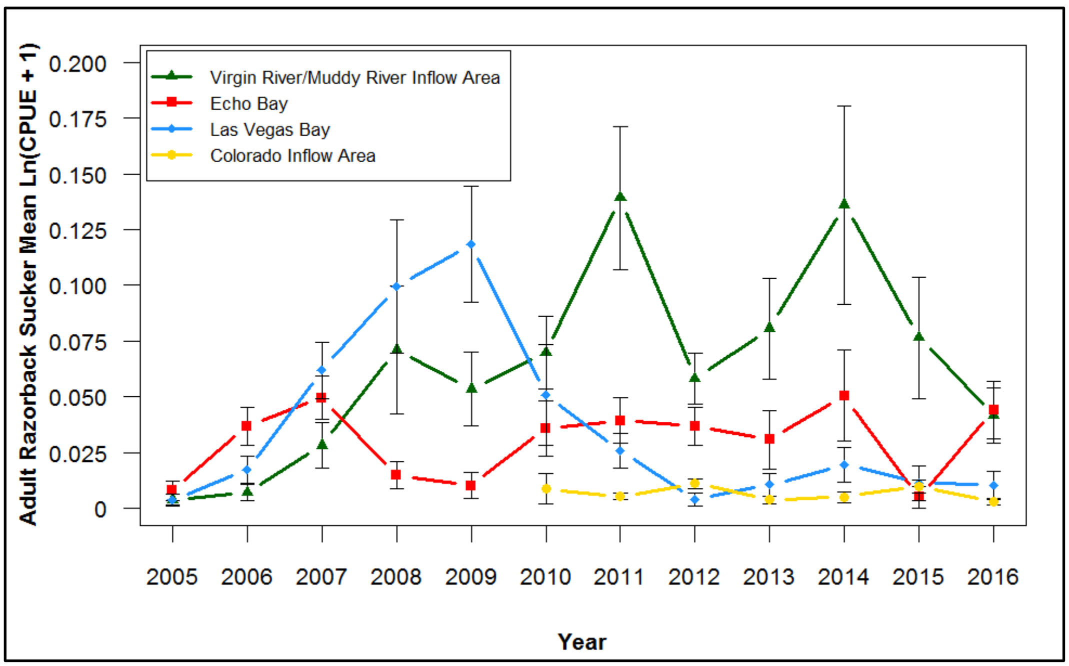

Figure 10.—Trammel netting mean CPUE (Ln[#fish/hr+1]) with associated SE of razorback suckers at long-term monitoring and CRI study areas in Lake Mead, 2005–16.
Sampling at the Virgin River/Muddy River inflow area was initiated during the 2004–05 study year. Sampling at the CRI was initiated during the 2010 study year.

In Echo Bay, there was a statistical difference in the yearly CPUE mean values (ANOVA, $F_{11,381} = 2.22$, $p = 0.0128$). However, no homogenous groups could be assigned using a Tukey HSD all-pairwise comparisons test. A statistical difference was detected at the Virgin River/Muddy River inflow area (ANOVA, $F_{11,306} = 5.24$, $P < 0.0001$) between sample means. Post-hoc pair-wise comparisons showed that the CPUEs in 2011 and 2014 were significantly greater than the CPUE for razorback suckers in 2005–07 and 2016. Lastly, a statistical difference was detected among yearly mean CPUE values (ANOVA, $F_{11,333} = 8.65$, $P < 0.0001$) in Las Vegas Bay. Post-hoc pair-wise comparisons showed that 2009 was a significantly better year for razorback sucker captures, as very few suckers were captured in 2005 and 2012. Compared with other years, very few razorback suckers were captured in 2016 at this site.

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 (e.g., moving from the Virgin River/Muddy River inflow area to Las Vegas Bay) (Albrecht et. al 2014b). Movement was documented this year, as 14 wild adult razorback suckers were captured at different sites than those in which they were originally PIT tagged. Twelve fish moved from the Virgin River/Muddy River inflow area to Echo Bay. One fish, originally tagged in Echo Bay in 2012, was recaptured at the Virgin River/Muddy River inflow area in 2014 and also recaptured in Echo Bay in 2016. The last fish moved from the Virgin River/Muddy River inflow area to the CRI.

In addition to capturing razorback suckers, 19 (13 unique fish and 6 recaptures) flannelmouth suckers were captured during the 2016 season at a CPUE of 0.0033 (± SE = 0.0005). Flannelmouth sucker captures were distributed among sampling areas, with 13 from Echo Bay and 6 from the Virgin River/Muddy River inflow area. Two of the flannelmouth suckers recaptured in Echo Bay were originally tagged at the CRI. For the first time, to our knowledge, two hybrids were captured in Echo Bay (CPUE of 0.0030 [±SE = 0.0010]), both of which were originally tagged at the Virgin River/Muddy River inflow area, again demonstrating the connectivity of at least this portion of the lake.

Non-Native Fishes

Sixteen non-native fish species have been documented in Lake Mead since 2005. Of these 16 species, the most abundant species captured in 2016 was gizzard shad (*Dorosoma cepedianum*) (untransformed CPUE of 0.4288 [± SE = 0.0313]) (figure 11). The second most abundant non-native species captured in 2016 was common carp with a CPUE of 0.2251 [± SE = 0.0155]) (figure 11). The next five most abundant species included channel catfish with a CPUE of 0.1042 (± SE = 0.0110), striped bass (*Morone saxatilis*) with a CPUE of

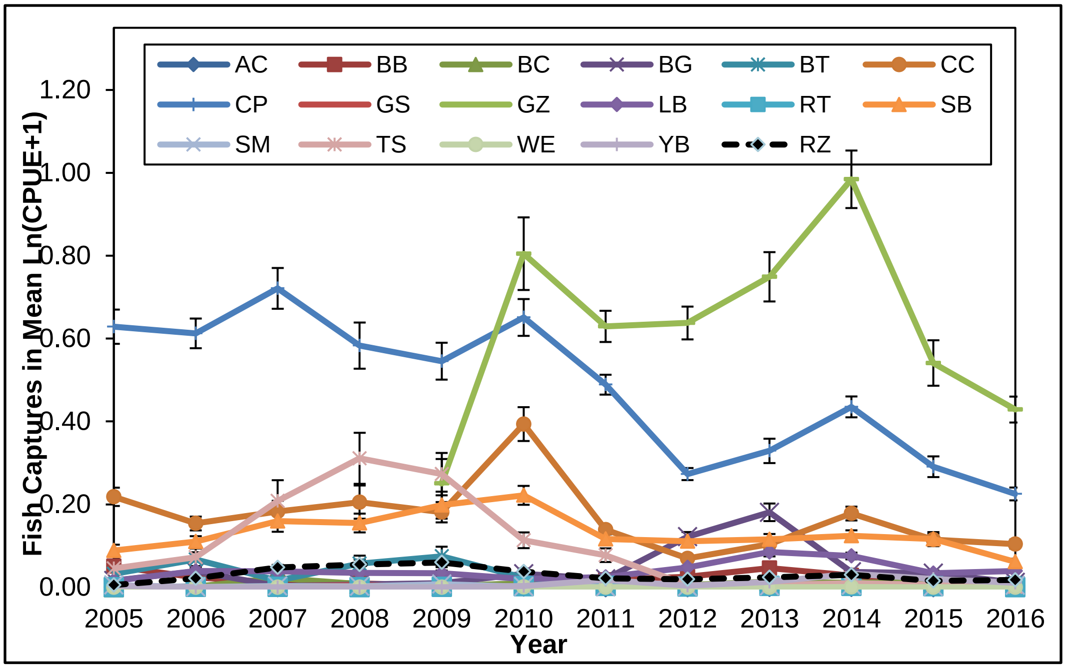

Figure 11.—Trammel netting mean CPUE (Ln[#fish/hr+1]) with associated SE of non-native species at long-term monitoring study areas in Lake Mead, 2005–16. Species included are: AC = sailfin armored catfish (*Pterygoplichthys* sp.), BB = black bullhead (

0.0612 (± SE = 0.0077), largemouth bass (*Micropterus salmoides*) with a CPUE of 0.0389 (± SE = 0.0039), black crappie (*Pomoxis nigromaculatus*) with a CPUE of 0.0128 (± SE = 0.0036), and bluegill (*Lepomis macrochirus*) with a CPUE of 0.0111 (± SE = 0.0020) (see figure 11).

Additional Efforts

In addition to fish captured via trammel netting, the use of remote PIT tag scanners allowed for the detection of 21 individual razorback suckers and 1 flannelmouth sucker (table 4). Sampling comprised 1,043 hours with 60 scanners at Las Vegas Bay, Echo Bay, and the Virgin River/Muddy River inflow area, for a catch rate of 0.02 fish per scanning hour. The PIT tag scanners were placed, on average, at a depth of 1.6 meters. One individual was contacted in Las Vegas Bay, an area where there has been difficulty recapturing fish in the last several years, and it has been at large for 1,059 days. In Echo Bay four individuals were located that had not been contacted in a range of

Table 4.—Remote PIT tag scanner detections with locations and last contact of each individual fish detected in 2016

Remote PIT tag detections	Date	Location[a]	Date of last capture	Original tagging location[a]	Days at large	Origin
Razorback suckers						
384.1B7969EADE	1/20/16	EB	2/6/14	EB	713	Wild
3D9.1C2C83D7FC	1/20/16	EB	2/12/14	EB	707	Wild
3D9.1C2C83CA43	1/21/16	LB	2/26/13	LB	1,059	Wild
3D9.1C2D6974B7	2/16/16	OA	2/6/15	OA	375	Stocked
3DD.003BA2FA7F	2/16/16	OA	3/6/14	OA	712	Wild
384.1B7969E2F4	2/17/16	OA	3/27/13	OA	1,057	Wild
3D9.1C2C841C6D	2/17/16	OA	3/7/12	EB	1,442	Wild
3DD.003BA2FA80	2/17/16	OA	3/4/15	OA	350	Wild
384.1B7969D27B	2/17/16	OA	3/15/12	OA	1,434	Wild
3D9.257C60C637	2/17/16	OA	3/15/11	OA	1,800	Wild
384.1B7969ED6E	2/17/16	OA	3/20/14	OA	699	Wild
3D9.1C2C83E2AA	2/17/16	OA	4/11/12	OA	1,407	Wild
384.1B796EE6E9	2/17/16	OA	2/6/15	OA	376	Stocked
3DD.003BA2FA77	2/17/16	OA	3/20/14	OA	699	Wild
3D9.1C2D69655F	2/17/16	OA	2/6/15	OA	376	Stocked
3D9.1C2C841581	3/23/16	OA	3/15/11	OA	1,835	Wild
3D9.257C608715	3/23/16	OA	2/1/11	OA	1,877	Wild
3DD.003BA2FA73	3/23/16	OA	3/20/14	OA	734	Wild
3DD.003BA639B1	3/23/16	OA	2/6/15	OA	411	Stocked
3DD.003BC89EDE	3/23/16	OA	3/4/15	OA	385	Wild
384.1B7969EE45	3/24/16	OA	2/14/13	EB	1,134	Wild
Flannelmouth suckers						
3DD.003BC89EC5	1/20/16	EB	1/14/16	EB	6	Wild

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

707–1,442 days. Additionally, one recently captured flannelmouth sucker was detected in Echo Bay. Lastly, 18 unique razorback suckers were contacted via PIT antenna at the Virgin River/Muddy River inflow area. Two of these fish had not been contacted in more than 5 years (see table 4).

Additional trammel netting was conducted in the Overton Arm (Echo Bay and Virgin River/Muddy River inflow area) the week of March 21–25, 2016. Cooperative efforts of the NDOW and Reclamation increased net-hours for the 2015–16 season (see table 2). During this week, the group captured more razorback suckers than in all other weeks in 2016 and 2015 (week 511, figure 12A). However, the mean razorback sucker CPUE for any single week in the last two sampling seasons was not significantly different (ANOVA, $F_{17,92} = 0.81$, $P = 0.6726$) when comparing the weekly CPUE during 2015–16 (figure 12B).

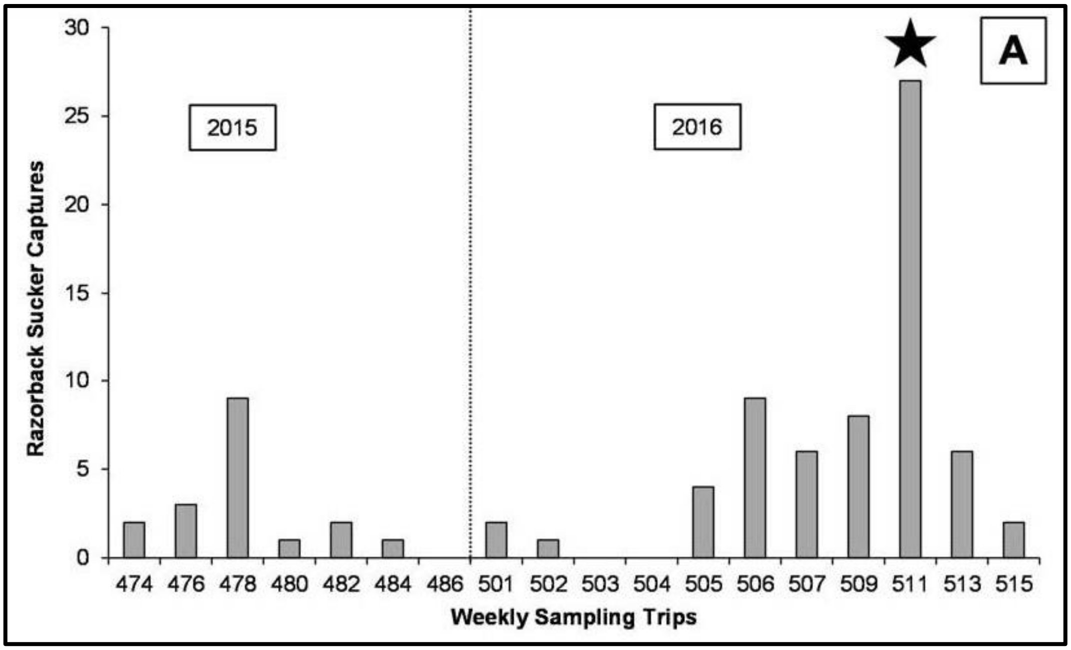

Figure 12A.—Razorback sucker captures per week in both 2015 (February 3 – April 29, 2015 [390.70 net-hours]) and 2016 (January 12 – April 20, 2016 [1,359.72 net-hours]).
The star highlights the week in which additional effort took place.

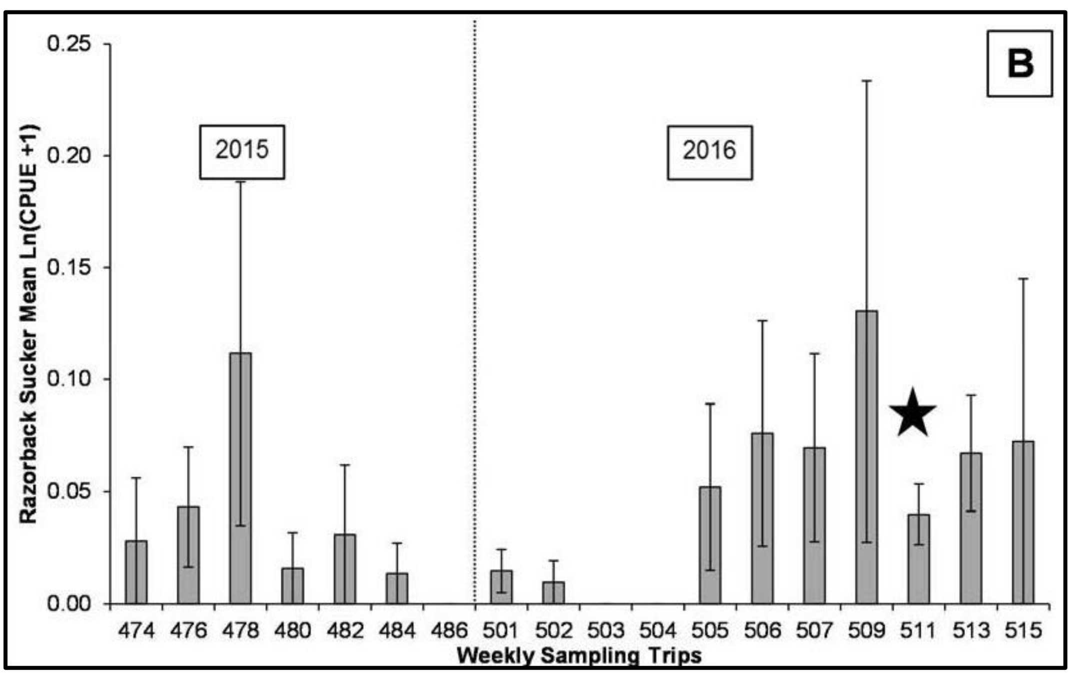

Figure 12B.—Razorback sucker mean CPUE (Ln[CPUE+1]) with associated SE.

Growth

The annual growth rates for razorback suckers were calculated using 28 recaptured, wild, and stocked fish caught in 2016 (table 5). The 28 fish were selected because more than 1 year had passed from their previous capture to this season's recapture date, which allowed for a more accurate long-term growth measurement. Wild and stocked fish were combined (but status noted) because no significant differences in growth were detected between them after analyzing data since 1996 (Mohn et al. 2015). Razorback sucker annual growth at Echo Bay ranged from -5.84 to 112.43 mm TL, with a mean annual growth rate of 21.33 mm TL (± SE = 7.43; table 5). Razorback sucker annual growth in the Virgin River/Muddy River inflow area was similar, with a range of -6.22 to 110.87 mm TL and a mean annual growth rate of 19.67 mm TL (± SE = 10.24, table 5). Variations in measurements (particularly negative values) were likely attributed to field measurement errors and were excluded from this analysis. One fish was recaptured in Las Vegas Bay that had grown 11.31 mm per year (table 5).

Larval Sampling

Larval Captures

Larval razorback sucker sampling in long-term monitoring sites was initiated on January 11, 12, and 13, 2016, at Las Vegas Bay, the Virgin River/Muddy River inflow area, and Echo Bay, respectively. Larvae were first collected on January 21, 2016, in Las Vegas Bay over primarily sand and gravel substrates (figure 13). Larval razorback suckers were collected over primarily gravel, cobble, and sand substrates during the remainder of the spawning period across the western portions of Las Vegas Bay on both the north and south shores near Las Vegas Wash (figure 13). The collection of larval razorback suckers occurred at temperatures between 12 and 24 °C (figure 14). Positive collections were often near sonic-tagged fish encounters or in areas where other adult razorback suckers were captured via trammel netting (see figure 7). Las Vegas Bay yielded a total of 367 larvae captured during 1,050 minutes of sampling for a mean catch rate of 0.350 (± SE = 0.136). The 2016 razorback sucker larvae CPUE at Las Vegas Bay was higher than in 2015 (CPUE of 0.217), and it was in the upper portion of the range observed from 2007 to present (0.093–0.430 CPUE) (figure 15).

In Echo Bay, the first razorback sucker larvae were captured on March 21, 2016, later than last year's first larval encounter (February 18, 2015). Larval collections were made primarily over gravel and sand and occasionally over cobble substrates at temperatures ranging from 11 to 21 °C (figures 14 and 16). The larval highest concentration was on the western shore of Echo Bay, with some (likely wind-blown) larvae found on the eastern shore near the boat ramp. The collection of 737 larval razorback suckers within 1,260 minutes at Echo Bay resulted in a mean value of 0.585 CPUE [± SE = 0.283] (figure 15). Most importantly, these values

Table 5.—Lake Mead razorback sucker growth histories for recaptured fish, February – April 2015

PIT tag number[a]	Capture date[b]	Capture location[c]	Capture TL (mm)	Sex[d]	Recapture date[e]	Recapture location[c]	Recapture TL (mm)	Tl change (mm)[f]	Years between captures	Origin	Annual growth (mm/year)[g]
Echo Bay											
384.1B7969D655	2/02/2007	EB	609	M	2/11/2016	EB	643	34	9.03	Wild	3.77
384.1B7969DEEA	4/10/2013	OA	598	F	2/11/2016	EB	632	34	2.84	Wild	11.97
3D9.1C2D260916	2/07/2013	EB	579	M	2/11/2016	EB	582	3	3.01	Wild	1.00
53256C725A	1/11/2007	EB	535	F	2/11/2016	EB	667	132	9.09	Wild	14.52
384.1B7969EBE1	3/28/2012	OA	573	F	2/23/2016	EB	625	52	3.91	Wild	13.30
384.1B7969CC18	2/05/2014	OA	520	M	3/08/2016	EB	544	24	2.09	Stocked	11.50
3DD.003BA2FA91	5/06/2014	EB	290	F	3/08/2016	EB	497	207	1.84	Stocked	112.43
3DD.003BA2FA94	5/06/2014	EB	300	I	3/08/2016	EB	463	163	1.84	Stocked	88.53
3D9.1C2C840ECD	3/01/2012	EB	585	F	3/08/2016	EB	627	42	4.02	Wild	10.44
3D9.1C2C840D17	3/24/2009	OA	572	M	3/22/2016	EB	597	25	7.00	Wild	3.57
3D9.1C2C84147F	2/16/2012	EB	559	M	3/22/2016	EB	596	37	4.10	Wild	9.03
3D9.1C2C844E09	3/01/2011	OA	553	F	3/22/2016	EB	634	81	5.06	Wild	16.00
3D9.1C2D279A4D	3/01/2011	OA	560	F	3/22/2016	EB	620	60	5.06	Wild	11.85
3D9.257C60BE38	2/22/2011	OA	509	M	3/22/2016	EB	536	27	5.08	Wild	5.31
3D9.257C60E67A	2/09/2010	OA	464	M	3/22/2016	EB	553	89	6.12	Wild	14.55
3D9.257C633584	2/09/2010	OA	444	F	3/22/2016	EB	604	160	6.12	Wild	26.15
53437D5852	4/01/2008	OA	535	M	3/22/2016	EB	604	69	7.98	Wild	8.65
Mean annual growth											**21.33 ± SE 7.43**

Table 5.—Lake Mead razorback sucker growth histories for recaptured fish, February – April 2015

PIT tag number[a]	Capture date[b]	Capture location[c]	Capture TL (mm)	Sex[d]	Recapture date[e]	Recapture location[c]	Recapture TL (mm)	Tl change (mm)[f]	Years between captures	Origin	Annual growth (mm/year)[g]
Virgin River/Muddy River inflow area											
384.1B7969CCA6	5/08/2013	OA	237	M	2/16/2016	OA	545	308	2.78	Stocked	110.87
384.1B7969DB68	3/21/2013	OA	616	F	2/16/2016	OA	660	44	2.91	Wild	15.12
3DD.003BA2FA7F	3/06/2014	OA	591	F	2/16/2016	OA	615	24	1.95	Wild	12.30
3D9.1C2D262764	2/08/2012	OA	623	F	2/17/2016	OA	655	32	4.03	Wild	7.95
3D9.1C2C2F86BA	2/01/2011	OA	601	F	2/24/2016	OA	654	53	5.07	Wild	10.46
384.1B7969E2F4	3/27/2013	OA	580	F	3/23/2016	OA	595	15	2.99	Wild	5.01
3D9.1C2D694CD2	2/06/2015	OA	450	F	3/24/2016	OA	450	0	1.13	Stocked	0.00
384.1B7969E3C7	3/14/2013	OA	600	F	3/24/2016	OA	626	26	3.03	Wild	8.58
3D9.257C60CC21	2/09/2010	OA	471	M	3/24/2016	OA	571	100	6.12	Wild	16.33
3DD.003BA2FAC1	4/03/2014	OA	615	F	3/24/2016	OA	635	20	1.98	Wild	10.12
Mean annual growth											**19.67 ± SE 10.24**
Las Vegas Bay											
3D9.1C2D6978DA	2/16/2015	LB	594	F	3/09/2016	LB	606	12	1.06	Stocked	11.32
Mean annual growth											**N/A[h]**

[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 kHz) and recently tagged again with a new 12.5-mm, 134.2-kHz PIT tag.
[b] Date originally stocked or originally captured.
[c] EB = Echo Bay, and OA = Overton Arm (Virgin River/Muddy River inflow area).
[d] M = male, and F = female.
[e] Date of most recent recapture.
[f] Difference in TL from date of stocking to date of most recent recapture.
[g] Annual growth was calculated as the difference in TL from the date of stocking to the date of most recent recapture divided by the number of days between captures and multiplied by 365.
[h] Mean could not be calculated from growth of one individual.

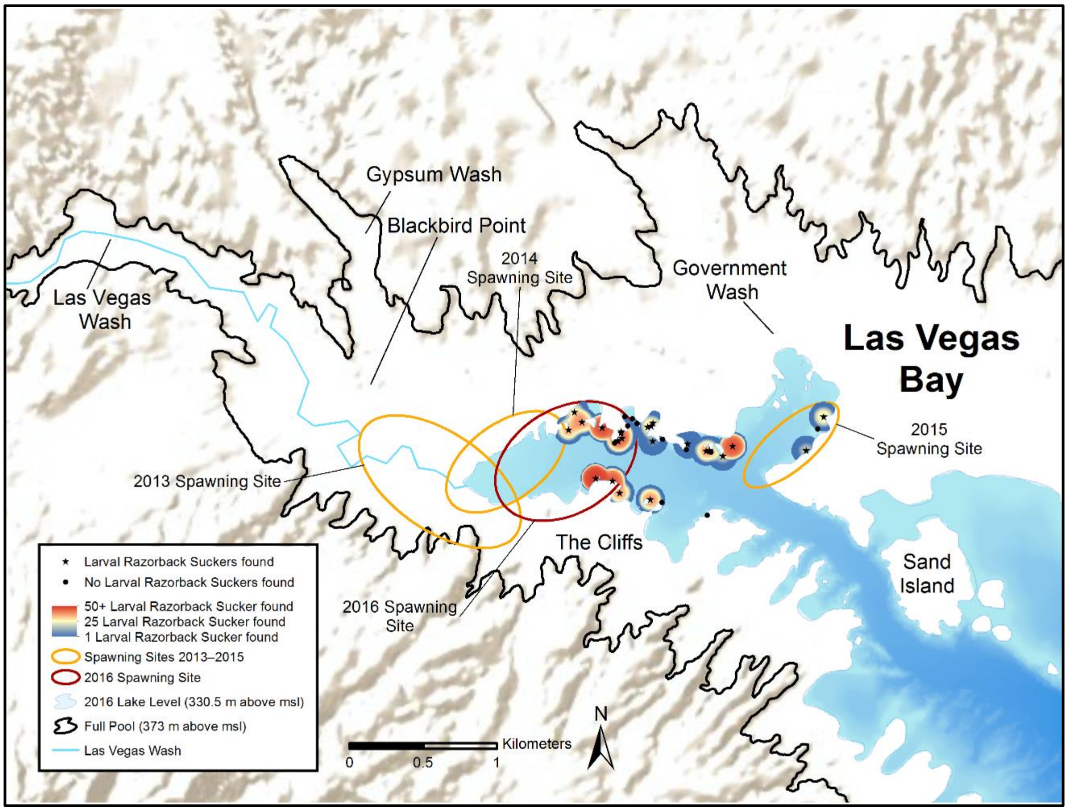

Figure 13.—Locations of larval razorback sucker sampling efforts and capture numbers in Las Vegas Bay, January – April 2016.

confirm spawning success at Echo Bay, underscore the importance of this historical spawning location for Lake Mead razorback suckers, and perhaps indicate a resurgence of use by razorback suckers this year.

At the Virgin River/Muddy River inflow area, the first razorback sucker larvae of the sampling season were captured on March 22, 2016, over a variety of substrate types and at temperatures ranging from 10 to 24 °C (figure 14). Larval collections occurred approximately 1–2 km south of the Virgin River/Muddy River inflow area along the eastern shoreline (figure 17). Larval razorback sucker captures occurred in the same vicinity as trammel-netting efforts for adults and near areas somewhat frequented by sonic-tagged individuals (figures 9 and 17). In the Virgin River/Muddy River inflow area in 2016, 63 larval razorback suckers were captured in 825 minutes of sampling, resulting in a mean catch rate of 0.058 CPUE [± SE = 0.012]. This catch rate is the lowest of the three spawning areas; however, it still falls within the historical trend of this site (figure 15).

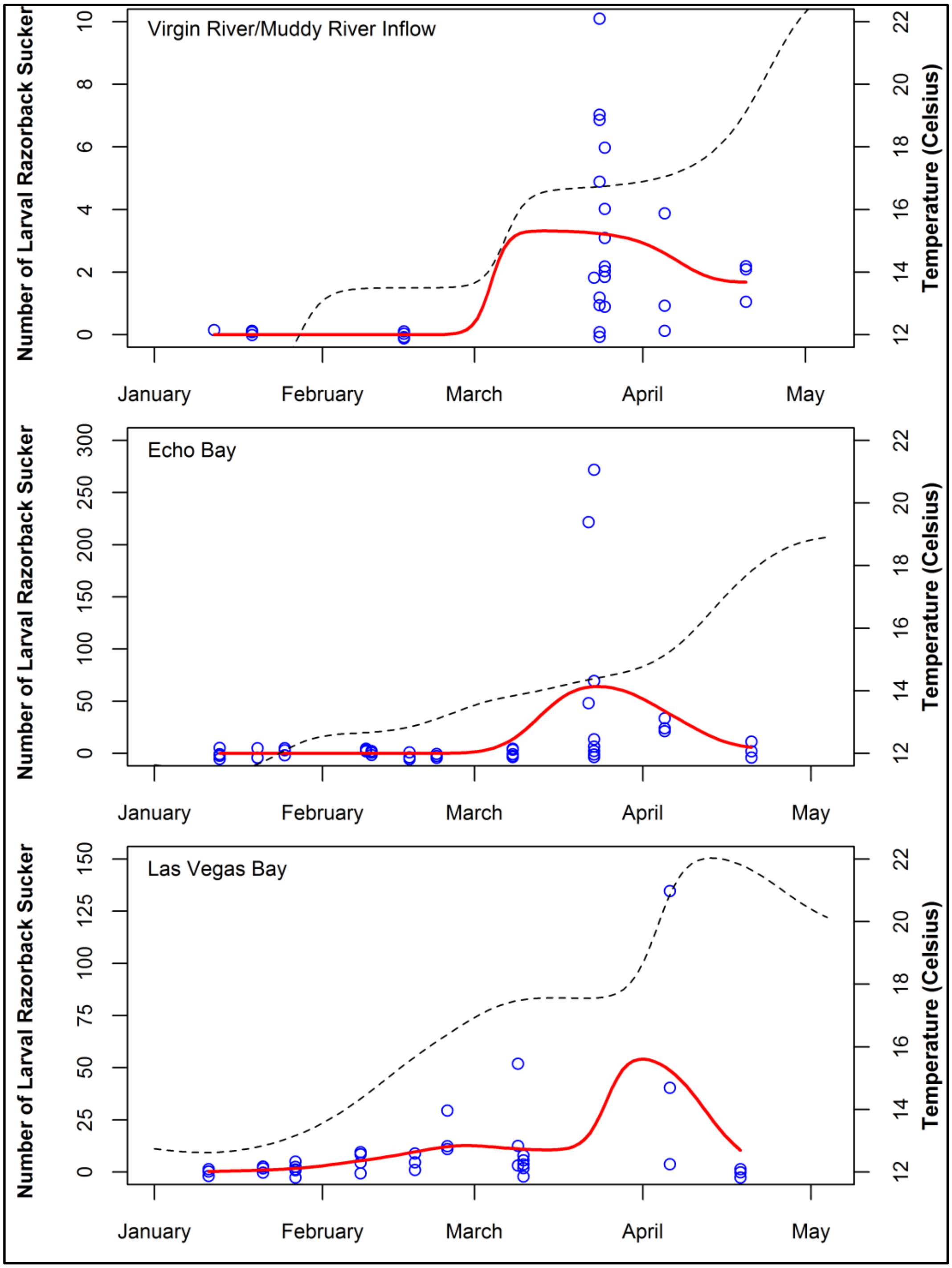

Figure 14.—Individual larval razorback sucker catch numbers (blue dots) obtained at long-term monitoring study areas in Lake Mead, February – April 2016, with a kernel regression line in red.
Associated temperature data at the time of sampling are shown as a dashed kernel density regression line.

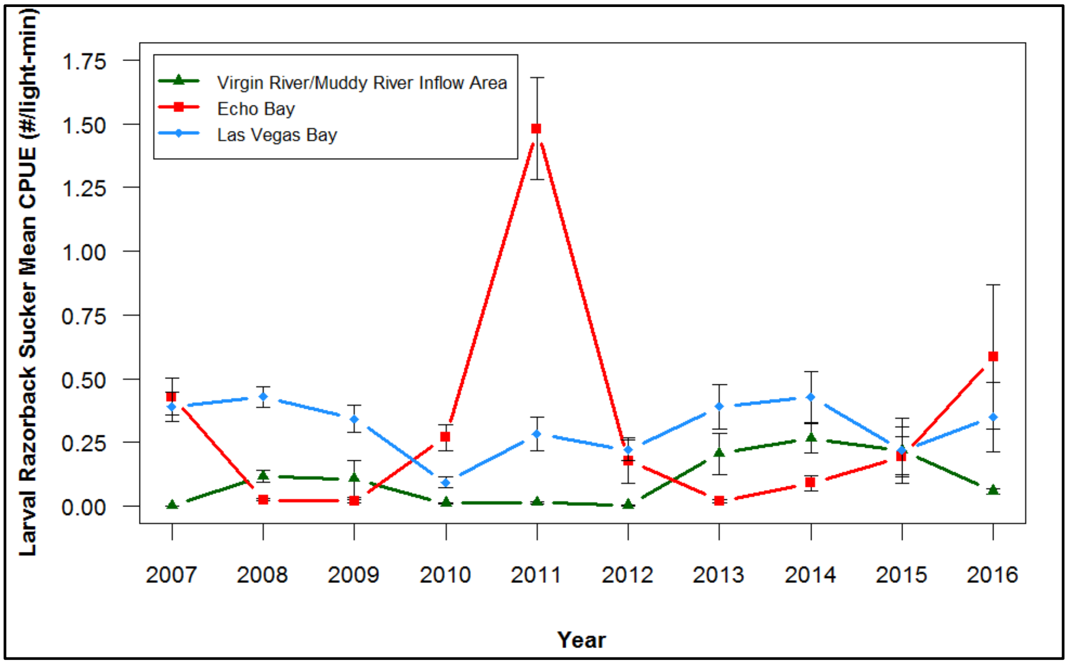

Figure15.—Larval razorback sucker mean catch per light-minute rates at long-term monitoring study areas in Lake Mead, 2007–16, with associated SE.

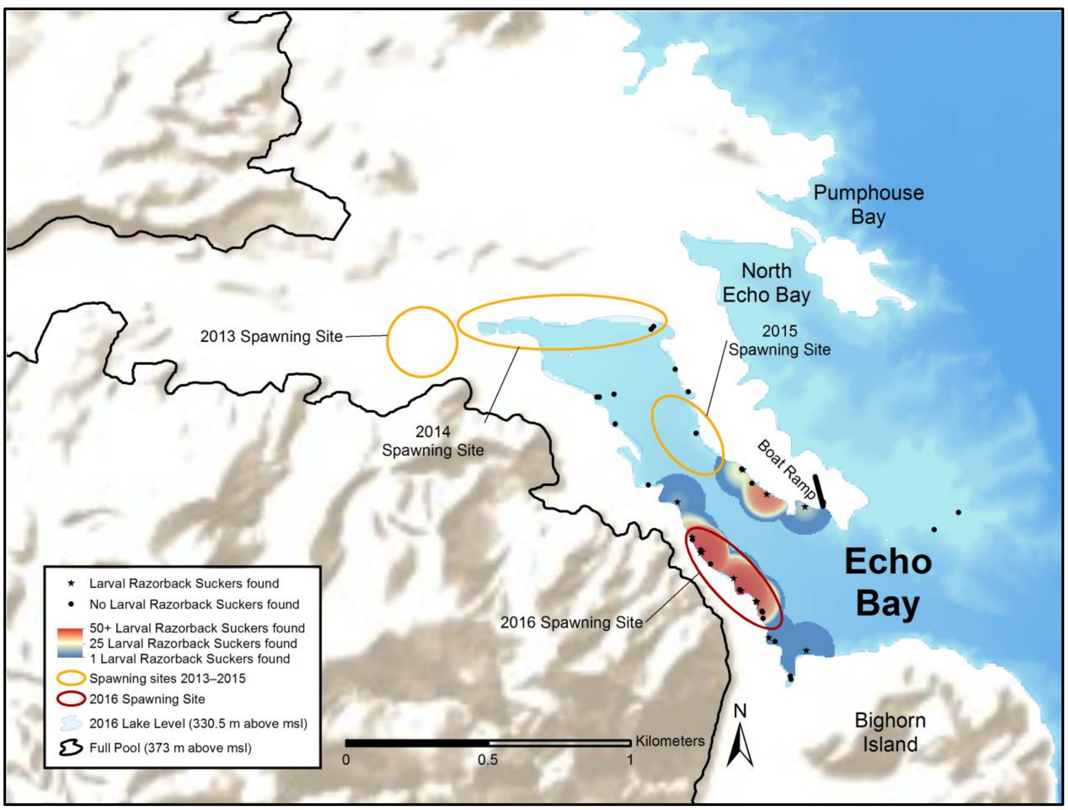

Figure 16.—Locations of larval razorback sucker sampling and capture numbers in Echo Bay, January – April 2016.

Spawning Site Identification and Observations

For the past decade, fluctuating lake 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. 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 2015–16 field season; the few that were caught were adult fish found near Las Vegas Wash (see figure 7). This area was also the primary location for the collection of larval razorback suckers, which were captured on the northern and southern shorelines near the Las Vegas Wash inflow area.

As described in past annual reports (Welker and Holden 2003, 2004; Albrecht et al. 2005, 2006b, 2013a, 2013b, 2014b; Shattuck et al. 2011), receding lake elevations have resulted in eastward shifts of the primary Echo Bay spawning site. In contrast to 2014–15, when a primary spawning area in Echo Bay was not well defined (few adult captures, few sonic contacts, and a lack of consistent larval captures), the 2016 spawning site was well defined and located off the southern shore across from the boat ramp. This was evident by the concentrated and consistent sonic-tagged fish present, increased adult captures, and larval captures in that area (see figures 5, 8, and 16).

Of the three long-term monitoring study areas in Lake Mead, the Virgin River/ Muddy River inflow area has typically been one of the least productive with regard to larval razorback sucker collections (Albrecht et al. 2007, 2008a, 2010b, 2013a, 2013b; Kegerries et al. 2009; Shattuck et al. 2011), and 2016 was no exception. In the past, environmental conditions seemed to drive the success or failure of larval razorback sucker captures despite numerous captures of sexually mature adults in the area. The collection of numerous reproductively ready adult razorback suckers in 2016 signified that spawning was likely occurring on a kilometer-long section of shoreline south of the Virgin River (see figure 9), which is further supported by frequent usage of the area by sonic-tagged individuals (see figure 6). Additionally, the few captures of larval razorback suckers in the immediate area of captured adults and sonic-tagged adults further helped define the primary spawning site designation (figure 17).

Age Determination

To date, a definitive age has been determined for 509 razorback suckers from long-term monitoring study areas in Lake Mead (not including 35 individuals

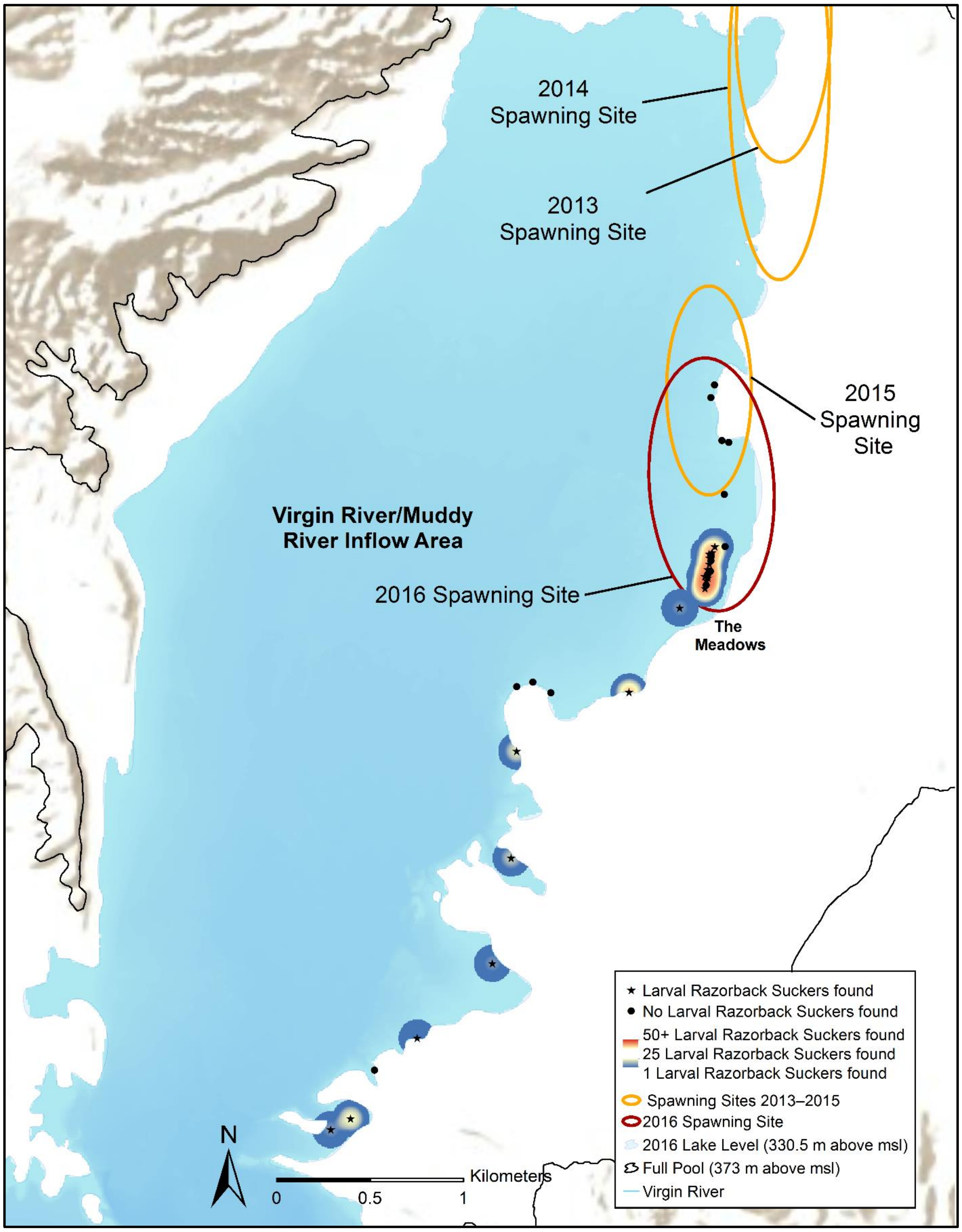

Figure 17.—Locations of larval razorback sucker sampling and captures at the Virgin River/Muddy River inflow area, January – April 2016.

aged from the CRI [Kegerries et al. 2015]). In 2016, ages were obtained from 31 razorback suckers captured in trammel nets at long-term monitoring study areas, while two individuals were aged from the CRI (attachment 1). The youngest razorback sucker aged in 2016 from the long-term monitoring study areas was a 5-year-old (2011 year-class), sexually mature, 455 mm TL male from the Virgin River/Muddy River inflow area (attachment 1). This fish was the first of its age class. The oldest razorback sucker aged during 2016 long-term monitoring was a 14-year-old male (2002 year-class) with a TL of 647 mm also from the Virgin River/Muddy River inflow area (attachment 1).

To date, all aged fish have undergone back-calculation techniques, assigning them to year-classes (spanning 1966–2011) (attachment 1). Prior to 2000, the majority of aged fish were spawned during high lake elevations while the lake was relatively stable around full pool (figure 18). However, recent data show that Lake Mead razorback sucker recruitment readily occurred beyond 2000, which coincided with a steady decline of lake elevations (figures 2 and 18).

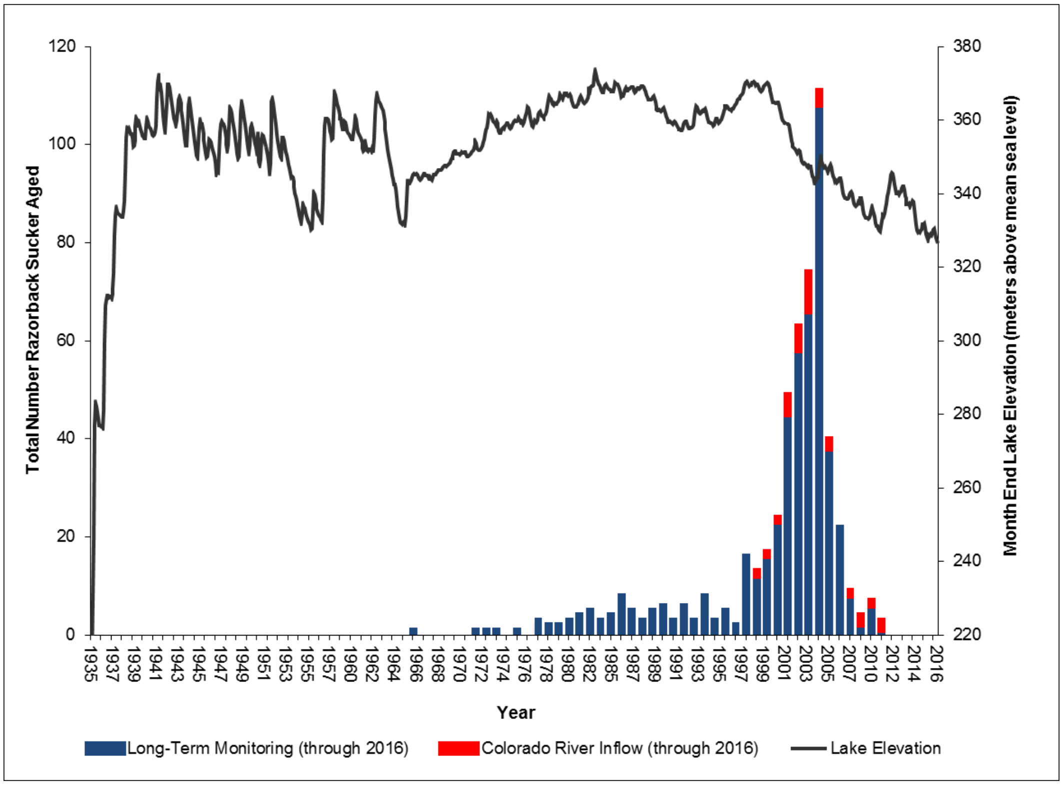

Figure 18.—Cumulative number of razorback suckers back-calculated to year spawned for individuals aged with corresponding Lake Mead month-end lake elevations, January 1935 – June 2016.
Blue bars denote individuals aged during long-term monitoring efforts, 1999–2016; red bars denote individuals aged during efforts at the CRI, 2010–16 (Albrecht et al. 2014b).

The cumulative dataset shows that most individuals (394) were spawned from 2000 to 2011. Within this period, 111 individuals (including 3 from the CRI) were aged from the 2005 year-class alone, which indicates a pulse of natural recruitment for razorback suckers in Lake Mead during a period of decreasing lake elevation. It is evident that some level of recruitment is possible in Lake Mead regardless of lake elevation, as natural recruitment has occurred at long-term monitoring study areas nearly every year, with wild recruitment positively documented though 2011 at all study sites (see figure 18).

Based on past experience, it typically takes 4–5 years for young razorback suckers to reach a size that is readily susceptible to the sampling gear used in long-term monitoring efforts, and it is anticipated that fish spawned and recruited in 2012 and 2013 will become susceptible to sampling gear 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).

Population and Survival Estimation

Population Estimates

Top models for lake-wide population estimates included time-varying capture probability (*Mt*) (attachment 2). Using data from 2014 to 2016, the population model for netting of razorback suckers at the four combined sampling sites was estimated at 418 (SE = 58) and bound with a 95% confidence bound of 327 through 559 (table 6). Remote PIT tag scanners contributed 21 additional contacts, of which 11 were unique individual razorback suckers that were not captured during netting efforts from 2014 to 2016. This increased the recapture rate from 48.7% (without remote PIT tag scanner) to 55.5% (with remote PIT tag scanner). The resulting population model (netting and remote PIT tag scanner combined) for razorback suckers at the four combined sampling sites was estimated at 374 (SE = 46) and bound with a 95% confidence bound of 302 through 484 (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.

Survival Estimates

The top model assumed that survival did not change, but the probability of recapture was allowed to vary with time. The dataset spanning 1996–2016 included 603 individuals ranging in size from 450 to 756 mm TL, with a mean TL of 582 mm (SE = 1.9). Using these data, a model average of annual apparent survival was calculated at a rate of 0.71 with 95% confidence bounds of 0.28–0.94 (table 7), which was similar to the 2015 estimate (Mohn et al. 2015). Model comparison in program MARK found the model that carried the most AIC_c weight ranged in recapture probabilities year to year from 0.05–0.44 (table 7; attachment 3).

Table 6.—Lake-wide population estimates for Lake Mead razorback suckers using mark-recapture data from 2014 to 2016 from program MARK

Model	Population estimate (95% confidence bounds)	Capture events	Standard error
Lake-wide netting only population estimate			
Mt	418 (327–559)	34	58
Lake-wide netting and remote pit scanner population estimate			
Mt	374 (302–484)	34	46

Table 7.—Annual apparent survival rate estimate for razorback suckers in Lake Mead produced in the program MARK using adult (> 450 mm TL) mark-recapture data, 1996–2016

Model	Annual apparent survival rate estimate (95% confidence bounds)	Capture events	Standard error	Recapture probability
Cormack-Jolly-Seber				
$\phi(.)p(t)$	0.77 (0.74–0.81)	21	0.02	0.05–0.44
Model average (derived ϕ)	0.71 (0.28–0.94)	21	0.03	NA[a]

[a] Recapture probabilities were unable to be calculated for the model-averaged estimate and are listed as not available (NA) because the recapture probability ranged from 0.0–1.0.

Transition Estimates

A total of 712 individual fish captures of razorback suckers were used from the time period spanning 2005–16. The top model varied survival by site and allowed fish to transition among sites (table 8). Lake-wide survival estimates generated from this analysis were similar to the above survival estimates and, therefore, are not reported. There was little support that recapture probability differed among sites (mean: 13.8%, range: 11.3–16.8%), evidenced by the site variable not being in the top-ranked model and greater than 4 ΔAIC_c units from the top model (table 8). Transition probabilities varied greatly among sites (table 9). No fish from the Virgin River/Muddy River inflow area or the CRI has moved to or from Las Vegas Bay, and no fish has moved from Echo Bay to the CRI (this analysis excludes sonic-tagged fish). The greatest movement estimates were between Echo Bay and the Virgin River/Muddy River inflow area at 8.10 and 9.05%, respectively.

Table 8.—Multi-state models ranked according to AIC_c
(ΔAIC_c is difference in AIC_c between each model and the best model.)

Model	AIC_c	ΔAIC_c	AIC_c weight	Number of parameters	Deviance
Φ (site), *p* (.), Ψ (site:site)	1664.80	0	0.90	17	601.00
Φ (site), *p* (site), Ψ (site:site)	1669.12	4.32	0.10	20	599.03
Φ (site), *p* (.), Ψ (.)	1694.46	29.66	0	6	653.31
Φ (.), *p* (.), Ψ (site:site)	1706.57	41.77	0	14	649.01
Φ (.), *p* (.), Ψ (.)	1741.04	76.24	0	3	705.96

[a] *φ* = survival, *ρ* = recapture probability, (.) = parameter consistent through time, and Ψ = transition between states.

Table 9.—Estimated percentage of razorback suckers moving between four Lake Mead study sites with 95% confidence bounds using mark-recapture data from 2005 to 2016

	Recapture site			
Initial site	Las Vegas Bay	Echo Bay	Overton Arm	CRI
Las Vegas Bay	–	1.1 (0.16–7.71)	0	0
Echo Bay	2.3 (0.58–8.83)	–	8.1 (3.78–16.54)	0.95 (0.12–7.04)
Overton Arm	0	9.05 (5.76–13.9)	–	0.44 (0.05–3.95)
CRI	0	0	2.34 (0.31–14.3)	–

DISCUSSION AND CONCLUSIONS

Long-term monitoring information collected during the 2015–16 field season (20th field season) added to our knowledge of razorback sucker spawning behavior, year-round movement, movement among sites, growth, and the population demographics in Lake Mead. Information has also been gained regarding the nature of stocked and wild fish interactions, population abundance, adult survival rates, and razorback sucker responses to changing lake 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 help demonstrate near-annual recruitment and continued production of new, wild razorback suckers in Lake Mead. To our knowledge, these processes have not been documented to this degree, for this species, anywhere else in the Colorado River Basin within the recent past.

Lake Elevation

Lake elevations at Lake Mead steadily declined through the 2015–16 field season and can be characterized by the quick desiccation of littoral habitats and spawning areas that began during the spawning season and continued throughout summer and fall. Lake elevations resulted in the obvious need for fish to move spawning sites, given that yearly drops in lake elevations often exceed 3 m, thereby drying previously utilized areas. Changes were observed at all three spawning sites in the form of location, fish numbers, and larval captures, all of which are discussed in the "Adult Sampling and Spawning Site Observations" section below. Continued monitoring to inform the relative importance of each monitoring location, the shifts in spawning site use, and variations in yearly recruitment will be important as Lake Mead continues to suffer from declining lake elevations (Reclamation 2016).

Sonic Telemetry

Sonic telemetry continues to be a vital tool in helping to define spawning sites, place trammel nets and PIT scanners, and document lake-wide movement. During this field season, 10 fish were regularly detected. The individuals that were sonic tagged in 2011 continued to provide valuable information during this field season. This is the second year in which we were surprised to detect these fish, as it was even more unlikely they would be detected due to the anticipated expiration of the tags' 4-year battery life. We do not expect to locate these fish during the 2016–17 field season, which makes the need to tag several more wild fish at each monitoring site paramount.

Similar seasonal movement behaviors of both wild and stocked individuals demonstrated that stocked individuals seem to integrate well into the overall population. During 2016, wild sonic-tagged razorback suckers helped define spawning site locations and guide trammel-netting efforts, similar to the benefits observed during previous study years. Sonic telemetry results were somewhat unique during 2016 at each of the sites. All sonic-tagged fish in Las Vegas Bay disappeared during the spawning season and returned soon after, which indicates that the defined spawning area may have been in Las Vegas Wash rather than within the bay itself. For the past 9 years, the primary razorback sucker spawning site has been in the same general vicinity, although it has shifted with fluctuating lake elevations. Sonic-tagged razorback suckers were not routinely observed in Las Vegas Bay until April 5, 2016, after we assumed spawning had ended, further suggesting that spawning took place largely within Las Vegas Wash. While fish could also have moved to spawn elsewhere in the lake, larval and trammel-netting results indicated a high likelihood that the wash was the primary spawning area. Several sonic-tagged fish from the Virgin River/Muddy River inflow area were also observed to have moved into Echo Bay during the season presumably in order to spawn. Trammel-netting results also indicated this happening, but few fish originally captured in Echo Bay moved in the opposite direction to spawn. In concert with the other aspects of this monitoring effort, sonic tagging and tracking have an important role and provide an idea of what razorback suckers in Lake Mead are doing throughout the year.

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 the late summer. The ability to monitor areas unfrequented by regular sonic surveillance aided with documenting long-distance razorback sucker movements among long-term monitoring study areas and helped account for individuals that were undetected for relatively long expanses of time. Within the past few years, we have focused on strategically placing existing units to maintain a high level of efficiency. It is perhaps most interesting that some individuals are detected by either passive or active telemetry but not always both due to the possibility that (1) some sonic-tagged fish exhibit small home ranges and never reach an SUR, (2) some individuals are only mobile during times when active telemetry is not taking place or rarely takes place (i.e., night), or (3) there are other important areas of Lake Mead that may hold small populations that are not regularly examined for sonic-tagged razorback suckers. The possibility that any of the above (or other unmentioned possibilities) could be true shows that there is much more to learn from research and monitoring of 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., warm summers and cool winters) and change (e.g., fluctuating lake elevations and high-flow events). By collecting data over a lake-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 despite what appears, from a human perspective, to be increasingly harsh conditions.

The sonic telemetry portions of this monitoring study have also lent useful insight into other systems where razorback suckers are present and have provided an effective model to follow (e.g., use of sonic telemetry in the study of razorback suckers in Lake Powell [Francis et al. 2013]). As lake elevations continue to vary, it will be necessary to monitor changes in movement and habitat use to help identify important areas of Lake Mead throughout the year. Spawning sites continue to move location interannually, and sonic-tagged fish have been a key component in the ability to closely follow those fluctuations. Though new, wild razorback suckers were captured quite consistently alongside sonic-tagged individuals, sonic-tagged fish were rarely captured. Despite being consistently targeted during trammel netting in 2016, only one individual with an active sonic tag was captured (fish code 578). Three individuals originally stocked as juveniles were caught alongside wild adults in both Echo Bay and the Virgin River/Muddy River inflow area, underscoring the probable integration of stocked, sonic-tagged fish into the Lake Mead population.

Adult Sampling and Spawning Site Observations

In summary, 1,185 razorback sucker captures have helped identify 695 unique individual razorback suckers at long-term monitoring study areas during this 20-year study (1996–2016) by multiple agencies (BIO-WEST, the NDOW, and the USFWS). These do not include 94 captures of 88 unique individuals from 1990–95 (Holden et al. 1997), prior to the long-term monitoring era. Trammel-netting results in 2016 documented the continued presence of wild adult razorback suckers, the slight majority of which were captured in Echo Bay (52%, $n = 35$). The capture of numerous new, wild fish in all monitoring sites follows the results noted in past reports in which high numbers of younger fish (≤ 7 years of age; Albrecht et al. 2008a, 2013a, 2013b, 2014a; Kegerries et al. 2009; Shattuck et al. 2011; Mohn et al. 2015) have been observed. The Lake Mead population appears to be relatively young, although fewer individuals that were ≤ 7 years old were captured in 2016 compared with 2011 and 2012, likely because fish recruited the early 2000s, a period of high recruitment, are now > 7 years old. Far more fish captured were in the 10–12 year old range, signaling that the 2004–05 field season remains one of the peak years for Lake Mead razorback sucker recruitment (Kegerries et al. 2009; Albrecht et al. 2010a, 2010b, 2010c, 2013a, 2013b, 2014a; Shattuck et al. 2011). The capture of juvenile razorback suckers remains a rare event. Since 1996, there has been a total of 91 wild, juvenile (≤ 450 mm TL and sexually immature) (Albrecht et al. 2013a) razorback suckers captured in Lake Mead, and all but 2 of these individuals were captured from long-term monitoring study areas. The capture of these younger fish demonstrates that natural recruitment of razorback suckers has continued at Lake Mead despite declining lake elevations, indicating this may not be a primary recruitment driver.

Despite continued changes in lake elevations and subsequent changes in associated habitat and biota, successful razorback sucker spawning is still occurring in Lake Mead. Successful spawning was documented at all of the long-term monitoring study areas in 2016, with some areas appearing to be better than others. It has been widely demonstrated that individuals migrate to specific areas as they return for reproductive activity (Tyus and Karp 1990; Mueller et al. 2000), a finding that is supported by the recapture of fish at the long-term monitoring study areas during the 2016 spawning period that were tagged during previous field seasons in nearby areas. The 2016 primary spawning sites shifted in tandem with lake elevations and appeared to be equally focused in spatial extent compared with the previous year's spawning sites. These continuing shifts in location, lead to questions as to where some of these fish may spawn from year to year (Albrecht et al. 2013b) and makes each season of long-term monitoring important and challenging for field crews. This logic also underscores the importance of maintaining active sonic-tagged fish to help in identifying annual habitat use by razorback suckers in Lake Mead and will be particularly important next year as several more sonic tag batteries will likely expire. The continued reproductive activity proximal to historic spawning sites strengthens the idea that many razorback suckers return to similar spawning sites year after year (Tyus and Karp 1990).

The 2016 spawning site in Las Vegas Bay was difficult to locate. As mentioned above, no sonic-tagged fish were detected in January when fish are expected to begin spawning due to the warmer water in this bay. Furthermore, no fish were detected until May when spawning had likely ended. Boulder Basin was extensively tracked several times during the spawning period (January to April), but no fish were found. A SUR was placed within Las Vegas Wash for 2 months, but also did not detect any fish, suggesting that other methods such as PIT antennas and increased netting efforts could be valuable in the future for this locale. In past field seasons, a progressively less-definitive spawning site location was observed in Las Vegas Bay, bringing into question the potential drivers determining location and abundance of reproductive activity within the bay. It is likely that due to diminished lake elevations, the spatial area available to spawning razorback suckers has been further reduced given the constricted topography of Las Vegas Bay. Las Vegas Bay experienced a relatively high larval mean catch rate (0.350 [± SE = 0.136]), which falls on the upper end of the range of values seen at this site (0.093 in 2010 to a high of 0.430 in 2008). Interestingly, this comparatively high catch rate occurred despite catching almost no reproductively ready adult razorback suckers. Only a few adult razorback suckers were captured directly adjacent to the wash inflow. Given that netting began in January due to the revised protocol in place this season, we do not think these low catch rates are simply due to spawning occurring before netting efforts were initiated. However, we do suggest that the earlier start helped understand this early spawning dynamic particularly through earlier larval capture events. The majority of larvae were captured in eddy pools on either side of the wash inflow and became less abundant on both north and south sides of the bay as sampling moved away from the wash. Past studies have shown at least intermittent usage of Las Vegas Wash by adult razorback suckers (e.g., Shattuck et al. 2011; Albrecht et al. 2013a) as well as reproductive activity through direct capture of larval individuals well upstream in Las Vegas Wash (Albrecht et al. 2013b). To date, no focused investigation regarding the importance of Las Vegas Wash has been undertaken. These reproductive confirmations, in conjunction with the consistently early collections of larval razorback suckers near the Las Vegas Wash inflow (Shattuck et al. 2011; Albrecht et al. 2013a, 2013b), may warrant further investigation to determine the potential extent, timing of reproductive activity, and the relative contribution of larvae to Las Vegas Bay from Las Vegas Wash proper.

The primary 2016 spawning site in Echo Bay was identified by a combination of sonic-tagged fish locations, larval fish collections, and adult fish collections. In recent years, the Echo Bay spawning sites had been on the northern side of the bay and followed receding lake elevations. Razorback suckers in Echo Bay, however, bucked historic trends and spawned on the western side of the bay in constrained patches of gravel. The majority of the western side is steep cliffs, but spring lake elevations made this small area a prime spawning location due to the shallow presence of gravel substrates. Echo Bay contributed the majority of adult razorback suckers to the overall catch, 10 of which were originally tagged in the Virgin River/Muddy River inflow area. Four sonic-tagged fish, originally tagged in the Virgin River/Muddy River inflow area, were also contacted in Echo Bay further indicating a year of exchange between the two sites. The high number of larval razorback suckers captured in Echo Bay was not surprising given that we caught the highest number of fish at this location, and detected the most sonic-tagged individuals. Future analyses focused on the drivers behind spawning success at this location in particular should be undertaken from a comprehensive, long-term perspective given the amount of data now available.

The spawning site at the Virgin River/Muddy River inflow area in 2016 was defined based on a combination of primarily larval and adult captures but also was helped by some sonic-tagged fish detected in close proximity. The sonic-tagged fish found were contacted within and near the designated spawning area at the Virgin River/Muddy River inflow area, and the placement of trammel nets near these sonic-tagged fish yielded fairly high densities of adult razorback suckers exhibiting reproductive readiness (e.g., colored and/or tuberculated individuals freely giving milt or eggs). Razorback sucker larval collections at the Virgin River/Muddy River inflow area spawning site were relatively low compared to the last 3 years but fall within the historical context for this site. Typically, mean larval razorback sucker catch rates at the Virgin River/Muddy River inflow area have been the lowest of the long-term monitoring study areas (Albrecht et al. 2010b, 2013a, 2013b, 2014a; Shattuck et al. 2011), and this year was no exception. In the past, low mean larval capture rates at the Virgin River/Muddy River inflow area were thought to be related to high winds and associated wave action common to this topographically open monitoring area (Albrecht et al. 2010b, 2013a; Shattuck et al. 2011). The effects of wind-related dispersal of larval razorback suckers were also believed to have aided in the movement and distribution of larvae in both Lake Mead and Lake Mohave (Bozek et al. 1990; Albrecht et al. 2010b, 2013a; Shattuck et al. 2011). Similarly, in Oregon’s Upper Klamath Lake, high winds were shown to be a likely cause of mortality and dispersal from rearing grounds in larval catostomids (Cooperman et al. 2010). Additionally, lake elevation declines are also most pronounced in the northern portion of the Overton Arm due to the gradual bathymetry in this area of Lake Mead. Keeping this in mind, while the observed reproductive effort is lower this year than in previous years, it is likely we are not able to truly capture peak numbers of larvae in the Overton Arm.

Given that some level of natural razorback sucker recruitment has occurred nearly every year in Lake Mead since the late 1960s, regardless of lake elevation (see figure 18), there is little reason to be pessimistic about the success of the 2016 year-class despite the historically low lake elevations. Data from 2016, along with past years, indicates that the Echo Bay and Virgin River/Muddy River inflow area spawning aggregates are two of the largest (or most active) in Lake Mead (see figure 10). As documented in previous reports (e.g., Shattuck et al. 2011; Albrecht et al. 2013a, 2013b, 2014b), razorback suckers often utilize both the Virgin River/Muddy River inflow area and Echo Bay during the spawning period. Past monitoring efforts in the northernmost portions of Lake Mead, near the Virgin River/Muddy River inflow area, have provided evidence that this spawning aggregate is an extension of the Echo Bay spawning population (Albrecht et al. 2008b). In this report, we further explored this through the use of long-term data in program MARK multi-state models to show an approximate 10% probability of exchange of individuals on a yearly basis. The three primary, long-term monitoring study areas at Lake Mead have changed dramatically over the last 20 field seasons (and no doubt will continue to do so). Biologically, the relatively new influx of gizzard shad and quagga mussels (*Dreissena bugensis*) and the continued presence of non-native species at the known spawning sites may be important factors to track and understand in terms of their potential impacts on razorback sucker recruitment success. Likewise, it will be essential to track physicochemical and biological changes over time to better understand and document continued razorback sucker recruitment success. This will be important in helping to understand differences in larval fish production, which should provide additional information pertaining to the natural razorback sucker recruitment observed in Lake Mead. Recruitment in Lake Mead appears to be limited to areas with flowing water (Las Vegas Wash and the Muddy and Virgin Rivers) or occasional rain events at washes (Echo Bay Wash). Future studies that focus on why these areas are so productive would be highly beneficial to the Lake Mead razorback sucker population and would help guide recovery/management efforts for this species. Given we now have 20 years of data, long-term drivers of larval and recruitment success can be explored in more detail.

Growth and Aging

Through 2016, 513 razorback suckers from long-term monitoring study areas have been aged from approximately 2 to 36 years. Lake Mead had a large number of young, wild razorback suckers (7–9 years old) that were captured and tagged 2–3 years ago, characterizing the recent recruitment in Lake Mead (Albrecht et al. 2008b) that occurred in the mid-2000s. The strength of the 2003 and 2005 year-classes has been documented by Kegerries et al. (2009) and Albrecht et al. (2010b) (see figure 18) and is further evident as most fish aged in 2016 were 9–12 years. This pulse of young fish indicates that successful spawning and recruitment are indeed occurring at low lake elevations and that razorback sucker recruitment has occurred in Lake Mead nearly every year since at least the 1960s. Aging of the Lake Mead razorback sucker population remains paramount for tracking continued natural recruitment and elucidating the drivers behind recruitment success.

Population, Survival, and Transition Estimation

The lake-wide population estimates produced in program MARK for 2014–16 used identical methods as in previous reporting years. We obtained useful estimates for this year, but as is common with low-density organisms, limited recaptures of adult razorback suckers caused large confidence bounds. These results were benefitted by an intensive, interagency sampling week in the Virgin River/Muddy River inflow area and Echo Bay. This effort approximately doubled capture numbers compared with 2015, which in turn helped to provide usable population abundance estimates. Additionally, the use of PIT tag scanners increased the numbers of recaptures this year, and it would be useful to deploy them more extensively alongside trammel nets in upcoming years. Furthermore, they may be helpful for gaining insight into trap shyness (some razorback suckers may learn to avoid nets) and the length of time some razorback suckers may remain at large. It is important to continue using all methods for achieving high capture/recapture rates for monitoring population size and stability.

The apparent annual survival rate reported for 2016 remains consistent with survival rates calculated for other razorback sucker populations (e.g., Schooley et al. 2008b; Zelasko et al. 2011; and Kesner et al. 2012). 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 with smaller razorback suckers (< 450 mm TL). Rates between 0.03 and 0.29 have been commonly reported, with lower rates calculated for smaller individuals (Schooley et al. 2008b; Zelasko et al. 2011; Kesner et al. 2012). Although an annual apparent survival estimate (0.71) was calculated only for razorback suckers larger than 450 mm TL in Lake Mead at this time, as more data are obtained, it would be interesting to investigate a Lake Mead rate for the smaller-sized individuals, especially given the amount of observed wild razorback sucker recruitment throughout the 20 years of study.

All data for transition estimates were taken from captured and recaptured razorback suckers during the spawning period, indicating that estimated transitional movement among spawning sites likely indicates some level of genetic exchange between the four areas. Within Lake Mead, overall genetic diversity is higher than in upstream populations but comparatively lower than populations in its downstream neighbor, Lake Mohave (Dowling et. al 2012a, 2012b). Given the life span and estimated movement percentages among sites in Lake Mead, it is possible these groups could be considered one "metapopulation" of razorback suckers.

Drivers of Lake Mead Recruitment

The continued pulses of newly captured, young razorback suckers at all Lake Mead long-term monitoring study areas in recent years support the concept that the only known, sustainable, naturally recruiting, and largely wild population of razorback suckers remains at Lake Mead (Albrecht et al. 2006b). This does not ignore ongoing research in Upper Colorado River Basin rivers or Lake Powell, which suggests there may be some level of new recruitment taking place in recent years (T. Francis 2016, personal communication). This unexpected initiation of Lake Mead razorback sucker recruitment has been attributed to changes in the management of Lake Mead. From the 1930s to 1963, Lake Mead was either filling (a time when initial recruitment likely occurred and created the original lake population of razorback suckers) or it was operated with a sizable annual fluctuation. The lake was drawn down approximately 30.5 m in the mid-1960s as Lake Powell filled, and since that time, it has been operated with relatively small annual fluctuations but relatively large multi-year fluctuations. It has been suspected that the drawdown of Lake Mead (for the filling of Lake Powell and a subsequent drawdown in the 1990s) allowed terrestrial vegetation to become well established around the shoreline. This vegetation was then inundated as lake elevations rose, but (with small annual fluctuations) the vegetation remained intact for many years and provided cover in coves and other habitats that young razorback suckers may inhabit. Furthermore, complex habitat conditions, particularly related to vegetation and turbidity (an additional form of cover) near the inflow areas apparently resulted in continued recruitment. 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 lake elevations. Lake elevations reached their highest levels from 1978 to 1987 when the maximum amount of intact inundated vegetation probably existed in the lake.

It has been accepted for years that turbidity plays a role in the susceptibility of young razorback suckers to predation (Johnson and Hines 1999; Ward et. al 2016). Golden and Holden (2003) show that cover, in terms of turbidity and vegetation, is more abundant in Echo Bay and Las Vegas Bay than in the other Lake Mead or Lake Mohave coves they evaluated. Albrecht et al. (2013b), Shattuck and Albrecht. (2014), and Kegerries et al. (2015) report similar observations, and seasonally elevated turbidity values were observed for the Virgin River/ Muddy River inflow area and Las Vegas Bay. Inflow habitats 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); thus, it is not surprising that a pulse of recruitment that coincides with lake condition and water year has been observed at some of the inflow areas in Lake Mead (Shattuck et al. 2011). This pulse of recruitment is best illustrated in the similarities between 2005 and 2011 with regard to flood-related cover influxes and lake elevation increases via the Virgin and Colorado Rivers (Shattuck et al. 2011). Additionally, high-flow events that bring woody debris and fine sediments into Lake Mead may play an important role in providing more cover and nutrients. Razorback sucker aging data show that, along with the strong recruitment in 2002 and 2003, substantial recruitment continued from 2004 to 2006. This information led to the hypothesis that low, annual fluctuations and large, multi-year lake elevation changes promote the growth of vegetation around the lake. The inundation of that vegetation and turbid conditions (compared with other locations within the Lower Colorado River Basin) are likely major reasons for continued razorback sucker recruitment in Lake Mead. Shattuck and Albrecht (2014) are some of 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 continues to show a dense and predatory fish community, but it also shows yearly recruitment. Both turbidity and vegetative cover are likely important recruitment factors for this reason and should be considered for future investigation and monitoring, particularly with regard to early life stages of razorback suckers. These parameters must be measured consistently so that future comparisons among years or lake elevations can be made. Steps toward this end have been recently initiated at Lake Mead (Albrecht et al. 2013; Shattuck and Albrecht 2014; Kegerries et al. 2015). Because data obtained from 2007 to 2015 show that pulses in razorback sucker recruitment are possible at both low (e.g., 2002–06) and high (e.g., 1978–1985 and 1998–1999) lake elevations, habitat characteristics—such as cover in the form of turbidity and/or vegetation—are potential keys to understanding (and perhaps enhancing) the sustainability of the species throughout the Colorado River Basin and, at minimum, suggest a relatively positive future for this rare species in Lake Mead.

Conclusions

All long-term monitoring objectives for the 2015–16 field season were met. Multiple life stages of razorback suckers were captured, sampled, and surveyed using a wide variety of methodologies in a consistently dynamic environment. Although it is unclear how environmental conditions will affect future recruitment and population size, optimism remains regarding this unique population. 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. As reported by Shattuck et al. (2011), the 2011 year-class of razorback suckers is particularly interesting, as it appears to have been subjected to conditions similar to those experienced by the strong 2005 year-class. With the capture of larval fish at all known spawning sites in 2016, the status of the Lake Mead razorback suckers remains optimistic. This context underscores the importance of maintaining long-term monitoring and continuing to build long-term datasets for tracking and understanding this unique population. When viewed cumulatively, information contained in this annual report indicates that the Lake Mead razorback sucker population appears generally young, resilient, and self-sustaining. This alone demonstrates the uniqueness of the Lake Mead razorback sucker population and provides a positive outlook for an endangered species. Lake Mead presents an unequaled opportunity to discover mechanisms for how to perhaps promote recruitment in locations throughout the Colorado River Basin and to study even the rarest life stages of this species, especially given how long term this dataset has become. Hence, the need for future research and monitoring to understand how and why razorback suckers are able to naturally maintain a population despite ongoing physicochemical and biological change is underscored.

2016–2017 Work Plan (Long-Term Monitoring)

Specific Objectives for the 21st Field Season

1. Continue data collection, including tracking the active, sonic-tagged, pond-reared, and wild razorback suckers in hopes of (1) continuing to document natural, wild razorback sucker recruitment in Lake Mead, (2) following known and historical spawning aggregates to evaluate whether any further shifts in spawning site selection occur, and (3) potentially identifying new spawning sites by tracking sonic-tagged fish and utilizing remote PIT tag antennas as appropriate.

   Continue long-term monitoring efforts, including larval sampling, trammel netting, and fin ray collection and aging techniques, with particular emphasis on PIT tagging and aging any new, wild, juvenile, and adult razorback suckers. Data stemming from continued monitoring will further assist us with understanding the size and habitat use of the population of razorback suckers in Lake Mead, documenting the exchange of fish among study areas (including fish moving among the long-term monitoring study areas, the CRI, and the lower Grand Canyon), identifying problems or habitat shifts associated with the known spawning aggregates, and elucidating recruitment patterns of the razorback sucker population in Lake Mead. Methods should follow those outlined in Albrecht et al. (2006a), updated in Albrecht et al. (2007, 2008a), reviewed by Albrecht et al. (2008b), and most recently reported herein. Given the noted presence of larval razorback suckers in Las Vegas Bay in January, it is recommended that initiating sampling efforts at that study site remain at least 1 month earlier than has typically been done (starting in January, as was done during this reporting year), as doing so may help alleviate the relatively lower catch rates of razorback sucker life stages in this warmer water study location and help to understand the role of Las Vegas Wash to razorback sucker recruitment, as suggested in this and other past annual reports. In addition, and if/as possible, more sampling coverage would be recommended, similar to and following past study years (Albrecht et al. 2006a), which would help to better inform population estimates by providing an increased opportunity for capture/recaptures of razorback suckers in Lake Mead. Options might include increased netting efforts during pertinent times of the year (spawning) when razorback suckers will be easiest to catch. This would include a higher netting effort during times when BIO-WEST netting efforts have been most successful. Also, as shown herein, a multi-agency sampling effort to increase trammel-netting captures would also help contribute captures/recaptures for population estimation. Such an effort was successful in 2015 and 2016 and is recommended again, particularly if additional funding or crew time is not possible during other portions of the spawning season. Furthermore, implementing PIT tag antennas to re-encounter fishes not often captured in nets may prove useful in obtaining a population estimate, although, given the goals to track natural recruitment and with the abundance of wild, unmarked fish, increased netting efforts would be preferred. Finally, as with past field seasons, all data will be incorporated into the long-term Lake Mead razorback sucker database currently maintained by BIO-WEST and supplied to Reclamation annually as requested.

2. Produce a comprehensive report. Considering that the last comprehensive report (Albrecht 2008b) was conducted over 8 years ago, it is suggested that a similar effort be conducted in the near future to encompass and summarize longer-term trend data developed over this time period from a broader and more holistic perspective than is possible though annual reporting. This comprehensive effort could provide substantial insight into the overall trajectory and contemporary conservation status of razorback suckers in Lake Mead. Albrecht et al. (2008b) covered data spanning 1996–2007, approximately a decade of data. We are quickly approaching another 10-year data span, and an update, similar to Albrecht et al. (2008b) is strongly recommended after the 2017 study year to help provide a pathway for Lake Mead razorback suckers, moving forward.

3. Continue to lend support to the Lake Mead Interagency Work Group. This effort will also help the LCR MSCP more easily achieve its overall goals and objectives related to the conservation of razorback and flannelmouth suckers. Also, continue to document the interaction of razorback suckers between Lake Mead and the lower Grand Canyon to simultaneously support the interest and goals of other collaborators (including, but not limited to, Reclamation's Upper Colorado Region).

4. Continue to coordinate and work jointly with other Lake Mead razorback sucker investigators, including those researching within the CRI and lower Grand Canyon areas when applicable. In 2010, efforts were undertaken to document the presence or absence of razorback suckers at the CRI. Through the capture of wild larval and wild, ripe adult razorback suckers, these efforts have resulted in the documentation of a spawning aggregate near the CRI and identified spawning occurring within the lower Grand Canyon (Kegerries and Albrecht 2013a; Albrecht et al. 2014b; Kegerries et al. 2015). Not only were wild fish documented using this new study area, but sonic telemetry efforts in this portion of Lake Mead have located sonic-tagged fish originating from the long-term monitoring study areas and documented sonic-tagged individuals utilizing the Colorado River proper and moving into the lower Grand Canyon (Kegerries and Albrecht 2013a, 2013b; Albrecht et al. 2014b). Thus, the potential exists for continued, perhaps increased, exchange of sonic-tagged razorback suckers (and other native suckers) among different areas of Lake Mead. It will be important to ascertain whether any of the PIT-tagged fish captured during long-term monitoring trammel-netting efforts are recaptured at the CRI or in the lower Grand Canyon (or vice versa). Coordination and collaboration between field crews will continue, as necessary, to achieve the best and most efficient research and monitoring system possible to more holistically understand Lake Mead razorback suckers despite study-specific goals or locations.

5. Continue to search for avenues to investigate the physicochemical and biological factors that allow continued Lake Mead razorback sucker recruitment. This research item was originally posed by Albrecht et al. (2008b) and is now contained within the current Lake Mead razorback sucker management plan (Albrecht et al. 2009). Ultimately, it is important to investigate and try to understand why Lake Mead razorback suckers are recruiting despite non-native fish pressures and habitat modifications that are common throughout the historical range of this species.

6. Sonic tag wild-caught razorback suckers from Lake Mead, as needed, to maintain effective, efficient, long-term monitoring efforts and gain additional information pertaining to this unique, wild population. As noted above, wild fish were implanted during 2014; for now, it is suggested that additional wild razorback suckers be implanted with new sonic transmitters on an as-needed basis. This will ensure that future monitoring capabilities remain as cost efficient and effective, and as scientifically similar to and comparable with all other monitoring conducted on Lake Mead since Albrecht et al. (2006b).

7. Given the last several years' findings in Las Vegas Bay and the potential use of Las Vegas Wash by Lake Mead razorback suckers, we suggest considering additional sampling area within Las Vegas Wash proper, as it is ever more apparent that razorback suckers may be utilizing this location as a primary spawning location.

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ATTACHMENT 1

Razorback Sucker (*Xyrauchen texanus*) Aging Data

Table 1-1.—Ages determined from razorback sucker pectoral fin ray sections collected in Lake Mead, 1998–2016

Date collected	Total length (millimeters)	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
1/8/2000	650	18+	1978–81
2/27/2000	628	17+	1979–82
1/9/2001	378	6	1994
2/7/2001	543	11	1989
2/22/2001	585	13	1987
12/1/2001	576	8–10	1991–93
12/1/2001	694	22	1979
12/1/2001	553	10	1991
2/2/2002	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
5/7/2002	641	15	1986
6/7/2002	407	6	1995
6/7/2002	619	20[b]	1982
6/7/2002	642	20[b]	1982
12/3/2002	354	4	1998
12/6/2002	400	4	1998
12/6/2002	376	4	1998
12/19/2002	395	4	1998
1/7/2003	665	16	1986
1/22/2003	394	4	1998

Table 1-1.—Ages determined from razorback sucker pectoral fin ray sections collected in Lake Mead, 1998–2016

Date collected	Total length (millimeters)	Age	Presumptive year spawned
2/5/2003	385	4	1998
2/18/2003	443	5	1997
3/4/2003	635	19	1983
3/20/2003	420	4	1998
4/8/2003	638	21b	1982
4/17/2003	618	10	1992
4/22/2003	650	20–22	1980–82
5/4/2003	415	3+[c]	1999
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
4/4/2006	629	6	2000
4/25/2006	452	4	2002
4/25/2006	463	4	2002
1/30/2007	514	5	2002
2/6/2007	519	5	2002
2/6/2007	574	8	1999
2/13/2007	526	5	2002
2/16/2007	530	5	2002
2/20/2007	534	6	2001
2/21/2007	358	3	2004
2/21/2007	511	5	2002

Table 1-1.—Ages determined from razorback sucker pectoral fin ray sections collected in Lake Mead, 1998–2016

Date collected	Total length (millimeters)	Age	Presumptive year spawned
2/27/2007	645	13	1994
2/27/2007	586	15	1992
2/27/2007	603	13	1994
2/27/2007	650	17	1990
3/6/2007	515	4	2003
3/6/2007	611	13	1994
3/6/2007	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
4/9/2007	644	11	1996
2/12/2008	425	5	2003
2/12/2008	390	3	2005
2/12/2008	490	3	2005
2/12/2008	430	4	2004
2/12/2008	379	4	2004
2/12/2008	399	4	2004
2/12/2008	430	4	2004
2/12/2008	413	4	2004
2/12/2008	554	9	1999
2/12/2008	426	9	1999
2/18/2008	385	3	2005
2/25/2008	605	6	2002
2/25/2008	655	36	1972
4/3/2008	468	4	2004
4/3/2008	619	7	2001
4/3/2008	640	10	1998
4/3/2008	560	11	1997

Table 1-1.—Ages determined from razorback sucker pectoral fin ray sections collected in Lake Mead, 1998–2016

Date collected	Total length (millimeters)	Age	Presumptive year spawned
4/8/2008	423	3	2005
4/8/2008	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
3/3/2009	416	4	2005
3/3/2009	565	8	2001
3/3/2009	431	5	2004
3/3/2009	340	5	2004
3/3/2009	539	8	2001
3/3/2009	521	8	2001
3/3/2009	419	6	2003
3/3/2009	535	6	2003

Table 1-1.—Ages determined from razorback sucker pectoral fin ray sections collected in Lake Mead, 1998–2016

Date collected	Total length (millimeters)	Age	Presumptive year spawned
3/3/2009	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
4/6/2009	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
2/2/2010	531	5	2005
2/2/2010	391	5	2005
2/2/2010	342	5	2005
2/11/2010	351	3	2007
3/3/2010	485	5	2005
3/3/2010	553	6	2004
3/3/2010	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
2/8/2011	587	8	2003
2/10/2011	574	12[g]	1999
3/3/2011	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

Table 1-1.—Ages determined from razorback sucker pectoral fin ray sections collected in Lake Mead, 1998–2016

Date collected	Total length (millimeters)	Age	Presumptive year spawned
3/29/2011	346	4	2007
3/29/2011	376	3	2008
2/5/2013	510	10	2003
2/19/2013	512	7	2006
2/26/2013	500	7	2006
4/16/2013	561	8	2005
3/4/2014	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
Echo Bay			
1/22/1998	381	5	1993
1/9/2000	527	13	1987
1/9/2000	550	13	1987
1/9/2000	553	13	1987
1/9/2000	599	12–14	1986–88
1/27/2000	557	13	1986
1/27/2000	710	19+	1979–81
2/9/2001	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
5/2/2002	568	18–19	1983–84
11/18/2002	551	13	1989

Table 1-1.—Ages determined from razorback sucker pectoral fin ray sections collected in Lake Mead, 1998–2016

Date collected	Total length (millimeters)	Age	Presumptive year spawned
12/4/2002	705	26	1976
1/21/2003	591	16	1986
2/3/2003	655	27–29	1974
2/3/2003	580	13	1989
4/2/2003	639	19–20	1982
4/2/2003	580	23–25	1978
4/23/2003	584	10	1992
5/6/2003	507	9+	1993
5/6/2003	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
4/6/2004	755	17	1985
3/2/2005	608	15	1990
3/2/2005	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
2/1/2007	637	7	2000
2/8/2007	609	12	1995
2/14/2007	501	4	2003
3/2/2007	590	11	1996
3/9/2007	660	12	1995
3/16/2007	691	21	1986

Table 1-1.—Ages determined from razorback sucker pectoral fin ray sections collected in Lake Mead, 1998–2016

Date collected	Total length (millimeters)	Age	Presumptive year spawned
3/28/2007	564	13	1994
2/28/2008	640	25	1983
2/29/2008	635	8	2000
3/5/2008	653	24	1984
3/19/2008	532	6	2002
3/19/2008	510	7	2001
2/20/2009	602	7	2002
2/26/2009	662	16	1993
2/18/2010	520	7	2003
2/25/2010	465	5	2005
3/10/2010	535	7	2003
3/10/2010	530	9[f]	2001
3/24/2010	451	4	2006
3/24/2010	465	5	2005
3/24/2010	466	5	2005
4/8/2010	470	5	2005
4/8/2010	540	8	2002
4/22/2010	538	7	2003
4/22/2010	489	8	2002
4/22/2010	460	9	2001
2/9/2011	529	7	2004
2/9/2011	524	7	2004
2/24/2011	555	7	2004
3/2/2011	513	6	2005
4/7/2011	533	7	2004
4/7/2011	522	7	2004
4/19/2011	537	6	2005
4/19/2011	540	7	2004
4/19/2011	515	6	2005

Table 1-1.—Ages determined from razorback sucker pectoral fin ray sections collected in Lake Mead, 1998–2016

Date collected	Total length (millimeters)	Age	Presumptive year spawned
2/9/2012	619	10	2002
2/9/2012	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
3/1/2012	585	7	2005
3/7/2012	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
2/7/2013	670	8	2005
2/7/2013	579	10	2003
2/7/2013	655	7	2006
2/14/2013	692	17	1996
2/27/2014	703	15	1999
3/12/2014	554	8	2006
3/13/2014	594	10	2004
3/25/2014	594	8	2006
3/25/2014	630	9	2005
Virgin River/Muddy River inflow area			
2/23/2005	608	6	1998
2/22/2006	687	33[d]	1973
2/22/2007	452	4	2003
2/22/2007	542	5	2002
2/22/2007	476	5	2002
2/22/2007	459	4	2003
2/22/2007	494	5	2002

Table 1-1.—Ages determined from razorback sucker pectoral fin ray sections collected in Lake Mead, 1998–2016

Date collected	Total length (millimeters)	Age	Presumptive year spawned
3/1/2007	477	5	2002
3/1/2007	512	4	2003
3/8/2007	463	5	2002
3/8/2007	455	4	2003
3/15/2007	516	4	2003
4/3/2007	508	4	2003
4/11/2007	498	7	2000
2/27/2008	465	4	2004
2/27/2008	670	20	1988
3/25/2008	530	6	2002
3/25/2008	271	2[e]	2006
3/26/2008	541	7	2001
3/26/2008	521	7	2001
3/26/2008	665	18	1990
4/1/2008	229	2	2006
4/1/2008	370	3	2005
4/1/2008	360	3	2005
4/1/2008	385	4	2004
4/1/2008	514	5	2003
4/1/2008	536	5	2003
4/1/2008	514	6	2002
4/1/2008	548	6	2002
4/1/2008	518	7	2001
4/1/2008	530	7	2001
4/1/2008	494	8	2000
4/1/2008	535	9	1999
4/1/2008	559	10	1998
4/22/2008	533	6	2002
4/22/2008	504	6	2002

Table 1-1.—Ages determined from razorback sucker pectoral fin ray sections collected in Lake Mead, 1998–2016

Date collected	Total length (millimeters)	Age	Presumptive year spawned
2/4/2009	496	9	2000
2/12/2009	553	10	1999
2/12/2009	505	8	2001
2/19/2009	464	5	2004
2/25/2009	549	7	2002
3/11/2009	585	8	2001
3/11/2009	552	8	2001
3/24/2009	366	3	2006
3/24/2009	572	9	2000
4/8/2009	348	3	2006
4/8/2009	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
2/3/2010	455	3	2007
2/3/2010	475	5	2005
2/3/2010	441	5	2005
2/3/2010	495	7	2003
2/3/2010	532	8	2002
2/9/2010	491	5	2005
2/9/2010	444	5	2005
2/9/2010	500	5	2005
2/9/2010	464	6	2004

Table 1-1.—Ages determined from razorback sucker pectoral fin ray sections collected in Lake Mead, 1998–2016

Date collected	Total length (millimeters)	Age	Presumptive year spawned
2/9/2010	471	6	2004
2/17/2010	494	6	2004
2/17/2010	470	7	2003
2/17/2010	479	7	2003
2/17/2010	425	7	2003
2/17/2010	483	7	2003
2/24/2010	234	4	2006
3/17/2010	477	4	2006
3/17/2010	465	5	2005
3/17/2010	485	5	2005
3/17/2010	499	6	2004
3/17/2010	491	6	2004
3/17/2010	600	9	2001
3/18/2010	452	5	2005
3/18/2010	473	5	2005
3/24/2010	485	5	2005
2/1/2011	601	7	2004
2/1/2011	571	6	2005
2/1/2011	556	7	2004
2/1/2011	586	6	2005
2/1/2011	506	8	2003
2/1/2011	572	8	2003
2/1/2011	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

Table 1-1.—Ages determined from razorback sucker pectoral fin ray sections collected in Lake Mead, 1998–2016

Date collected	Total length (millimeters)	Age	Presumptive year spawned
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
3/1/2011	510	10	2001
3/1/2011	573	9	2002
3/1/2011	518	8	2003
3/1/2011	538	6	2005
3/1/2011	532	9	2002
3/1/2011	553	6	2005
3/1/2011	595	6	2005
3/1/2011	563	6	2005
3/1/2011	555	6	2005
3/1/2011	483	7	2004
3/1/2011	599	9	2002
3/1/2011	560	5	2006
3/9/2011	556	7	2004
3/9/2011	534	6	2005
3/9/2011	549	7	2004
3/9/2011	494	4	2007
3/9/2011	505	6	2005
3/15/2011	575	8	2003
3/15/2011	551	8	2003
3/15/2011	515	7	2004

Table 1-1.—Ages determined from razorback sucker pectoral fin ray sections collected in Lake Mead, 1998–2016

Date collected	Total length (millimeters)	Age	Presumptive year spawned
3/15/2011	558	8	2003
3/15/2011	576	8	2003
3/15/2011	587	8	2003
3/15/2011	572	7	2004
3/15/2011	575	10	2001
3/15/2011	551	7	2004
3/15/2011	561	7	2004
3/15/2011	566	9	2002
3/15/2011	542	6	2005
3/15/2011	577	8	2003
4/5/2011	521	7	2004
4/5/2011	495	6	2005
4/12/2011	572	8	2003
1/31/2012	604	7	2005
1/31/2012	570	7	2005
2/1/2012	525	12	2000
2/7/2012	525	9	2003
2/8/2012	536	7	2005
2/8/2012	501	9	2003
2/8/2012	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

Table 1-1.—Ages determined from razorback sucker pectoral fin ray sections collected in Lake Mead, 1998–2016

Date collected	Total length (millimeters)	Age	Presumptive year spawned
3/15/2012	576	10	2002
3/15/2012	574	10	2002
3/21/2012	559	7	2005
3/28/2012	575	8	2004
4/4/2012	551	6	2006
4/4/2012	575	7	2005
4/11/2012	535	9	2003
2/6/2013	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
3/5/2013	567	10	2003
3/5/2013	537	10	2003
3/5/2013	621	10	2003
3/5/2013	558	8	2005
3/5/2013	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

Table 1-1.—Ages determined from razorback sucker pectoral fin ray sections collected in Lake Mead, 1998–2016

Date collected	Total length (millimeters)	Age	Presumptive year spawned
3/21/2013	639	9	2004
3/27/2013	539	8	2005
3/27/2013	580	10	2003
4/3/2013	554	8	2005
4/3/2013	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
3/6/2014	657	9	2005
3/6/2014	521	9	2005
3/6/2014	591	8	2006
3/6/2014	591	9	2005
3/6/2014	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

Table 1-1.—Ages determined from razorback sucker pectoral fin ray sections collected in Lake Mead, 1998–2016

Date collected	Total length (millimeters)	Age	Presumptive year spawned
4/3/2014	572	6	2008
4/3/2014	615	7	2007
4/10/2014	651	7	2007
4/16/2014	504	6	2008
2/4/2015	638	9	2006
2/18/2015	650	9	2006
3/4/2015	558	8	2007
3/4/2015	586	8	2007
3/18/2015	644	9	2006
3/31/2015	560	8	2007
Colorado River inflow area			
4/20/2010	563	6	2004
4/20/2010	508	6	2004
4/20/2010	568	11	1999
2/8/2011	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
3/1/2012	546	8	2004
3/1/2012	559	9	2003
3/6/2012	535[g]	11	2001
3/6/2012	573	6	2006
3/6/2012	572	7	2005
3/8/2012	557	8	2004

Table 1-1.—Ages determined from razorback sucker pectoral fin ray sections collected in Lake Mead, 1998–2016

Date collected	Total length (millimeters)	Age	Presumptive year spawned
3/20/2012	630	10	2002
3/20/2012	548	8	2004
3/21/2012	571	9	2003
3/28/2012	572	8	2004
4/3/2012	602	9	2003
4/24/2012	555[e]	9	2003
3/5/2013	215	2	2011
5/14/2014	429	3	2011
2/24/2015	581	10	2005
2/26/2015	634	7	2008
3/3/2015	624	5	2010
3/17/2015	572	6	2009
3/18/2015	595	6	2009

[a] Fish stocked from Echo Bay larval fish captured in 1999 and raised at the Nevada Department of Wildlife Lake Mead Fish Hatchery.
[b] Fish stocked from Floyd Lamb Park ponds (1982 Dexter National Fish Hatchery cohort placed in Floyd Lamb Park ponds in 1984).
[c] Fish was aged at 33 years of age, ± 2 years.
[d] Fish was a mortality; it was found dead in a net.
[e] Fish stocked from Floyd Lamb Park ponds (from an unknown 2001–03 cohort stocking event).
[f] Fish stocked from Floyd Lamb Park ponds, sonic tagged.

ATTACHMENT 2

Razorback Sucker (*Xyrauchen texanus*) Population Estimate (2014–2016) – Model Selection Summary

Table 2-1.—Model selection summary information for closed-capture populations of razorback suckers in Lake Mead using 34 mark-recapture netting-only capture occasions data from 2014–2016 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	85.5273	0.0000	1.00000	1.0000	33	213.3012
Mb	224.5464	139.0191	0.00000	0.0000	3	412.7362
Mo	225.3179	139.7906	0.00000	0.0000	2	415.5099

[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).

Table 2-2.—Model selection summary information for closed-capture populations of razorback suckers in Lake Mead using 34 mark-recapture netting-only capture occasions and 5 remote passive integrated transponder tag scanner capture occasions data from 2014–16 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	124.7638	0.0000	1.00000	1.0000	33	236.4184
Mo	285.1297	160.3659	0.00000	0.0000	2	459.1946
Mb	286.2582	161.4944	0.00000	0.0000	3	458.3210

[a] Otis et al. 1978 abundance models (Cooch and White 2013).
[b] Akaike's information criterion adjusted for small sample size bias.
[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, 1996–2016

Model[a]	AIC_c[b]	ΔAIC_c[c]	AIC_c weight[d]	Model likelihood[e]	Number of parameters	Deviance[f]
Cormack-Jolly-Seber						
$\phi(.)p(t)$	1779.2055	0.0000	0.89312	1.0000	21	457.4885
$\phi(t)p(t)$	1783.4515	4.2460	0.10688	0.1197	39	422.8169
$\phi(t)p(.)$	1812.5415	33.3360	0.00000	0.0000	21	490.8245
$\phi(.)p(.)$	1823.9954	44.7899	0.00000	0.0000	2	541.4510

[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).