Lower Colorado River Multi-Species Conservation Program

Balancing Resource Use and Conservation

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

2014–2015 Annual Report

July 2017

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Lower Colorado River Multi-Species Conservation Program

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ACRONYMS AND ABBREVIATIONS

AIC_c	Akaike's information criterion adjusted for small sample size
ANOVA	analysis of variance
BIO-WEST	BIO-WEST, Inc.
cm	centimeter(s)
CPM	catch per minute
CPUE	catch per unit effort
CRI	Colorado River inflow area of Lake Mead
FL	fork length
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
>	greater than
<	less than
≤	less than or equal to
%	percent
±	plus or minus
=	equal to
Δ	difference or change in quantity

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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 study 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. Following success of the 2012 pilot study, the LCR MSCP provided funding for a full, separate study of the movement and habitat use of juvenile razorback suckers in Lake Mead. Information and observations from the 19th season (2014–15) 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. (2015), and investigations from the Colorado River inflow area of Lake Mead are included in Albrecht et al. (2014a) and Kegerries et al. (2015).

During the 19th field season, 20 sonic-tagged fish were detected by active and/or passive telemetry, resulting in 105 active contacts and 21,329 passive contacts from 7 submersible ultrasonic receivers. These individuals were representative of several different tagging events, including the following: 2011 (n = 7), 2012 (n = 2), and 2014 (n = 11). 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 22 razorback suckers—2 from Las Vegas Bay, 1 from Echo Bay, and 19 from the Virgin River/Muddy River inflow area—during the 2015 spawning period. Most notably, a juvenile (221 millimeter total length) razorback sucker was captured during the spawning season at the Virgin River/Muddy River inflow area. This individual was present near the 2015 spawning location. Ten flannelmouth suckers (*Catostomus latipinnis*) were captured in 2015: four were captured in Echo Bay, and six were captured at the Virgin River/Muddy River inflow area. Additionally, one recaptured razorback sucker x flannelmouth sucker hybrid (hybrid) was collected at the Virgin River/Muddy River inflow area during 2015. This is the third time that hybrids have been captured during the long-term monitoring study. The razorback sucker x flannelmouth sucker hybrid individual was keyed by visual

inspection according to descriptions for meristic counts and measurements in Hubbs and Miller (1953). A highlight of the 19th field season was the capture of eight new, unmarked razorback suckers at the Virgin River/Muddy River inflow area of Lake Mead. For the fifth consecutive study year, trammel-netting capture rates in the Virgin River/Muddy River inflow area eclipsed those in other long-term monitoring study areas and have demonstrated the importance of this spawning location.

Average annual growth during this field season, as determined from 10 recaptured fish, was 26.6 millimeters per year. Growth rates of Lake Mead razorback suckers continue to be higher overall than those recorded from other populations within the Colorado River Basin, suggesting the Lake Mead razorback sucker populations are able to naturally maintain a fairly strong cohort of young, fast-growing fish, whereas Lake Mohave (Minckley 1983) and the Green River (Tyus 1987) have lower annual growth rates (2–5 millimeters per year total length), which is suggestive of older, slow-growing fish. Additionally, fin ray sections were removed from eight razorback suckers for age determination which, when combined with the 470 fish aged during previous field seasons, brings the total number of fish aged during the long-term study to 478. Age determination techniques have shown near-annual recruitment in Lake Mead and associated recruitment pulses during relatively high, stable lake elevations; furthermore, based on data collected from 2007 to 2015, strong pulses in recruitment have also been observed to coincide 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 2015, with a combined total of 339 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. In part, larval razorback sucker abundance was used to help define spawning sites during the 2014–15 field season. Primary spawning sites were identified in all long-term monitoring study areas. Spawning sites moved with the corresponding lake elevation, and locations were similar to those found in 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 2015 and into 2016, this report reiterates the need to further investigate conditions that promote recruitment patterns of razorback suckers in Lake Mead. General research for the 2015–16 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 include Colorado pikeminnow [*Ptychocheilus lucius*], bonytail [*Gila elegans*], and humpback chub [*Gila cypha*]) of the Colorado River Basin presently considered endangered by the U.S. Department of the Interior (U.S. Fish and Wildlife Service [USFWS 1991]). Historically widespread and common throughout the larger rivers of the basin, the distribution and abundance of the long-lived razorback sucker is 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 has been 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 disappeared in the 40–50 years following reservoir creation (Minckley 1983). The largest reservoir population was estimated at 75,000 individuals in the 1980s and occurred in Lake Mohave (Arizona and Nevada) but 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 2015 estimate of wild Lake Mohave razorback suckers was not reported, as no wild fish were captured (Marsh & Associates, LLC 2015). Within Lake Mead, however, wild fish are regularly captured, thereby emphasizing the uniqueness and natural complexity of this reservoir's razorback sucker population.

For context, 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 periodic stocking of captive-reared fish (Marsh et al. 2003, 2005; Marsh & Associates, LLC 2015). Predation by 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). However, because of the intensive stocking program and the remaining 2,230 repatriated individuals in the system, Lake Mohave maintains importance for the conservation of the species particularly from a genetic perspective (Dowling et al. 2012a, 2012b; Marsh & Associates, LLC 2015).

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 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 limited 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 the captures of these wild fish, the NDOW, over time, has stocked a limited number of adult and juvenile (sexually immature individuals, as defined in Albrecht et al. 2013a) razorback suckers into Lake Mead. To the best of our knowledge, all of these stocked fish were implanted with passive integrated transponder (PIT) tags prior to release, allowing for positive identification of stocked versus wild captured fish. The collection of razorback suckers during the 1990s raised questions regarding the size, demographics, and status of the Lake Mead population. In 1996, the Southern Nevada Water Authority (SNWA), in cooperation with the NDOW, initiated a study to attempt to answer some of these questions. BIO-WEST, Inc. (BIO-WEST) was contracted to design and conduct the study with collaboration from the SNWA and NDOW. Other cooperating agencies included the Bureau of Reclamation (Reclamation), which provided funding, storage facilities, and technical support; the National Park Service, which graciously provided residence facilities in 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 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 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 at a reduced level of effort (approximately one-half) compared to 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 19th field season (February – April 2015 netting data and July 2014 – June 2015 sonic telemetry data) in accordance with the results reported most recently by Albrecht et al. (2014b) as well as in other past annual reports. This report presents results for work completed during the 2014–15 long-term monitoring study, and other information from previous reports is included when pertinent.

STUDY AREAS

All Lake Mead long-term monitoring activities conducted during the 2014–15 study year occurred at study areas used during efforts from 1996 to 2015 and included Echo Bay, Las Vegas Bay, and the Virgin River/Muddy River inflow area (figure 1) (Holden et al. 1997, 1999, 2000a, 2000b, 2001; Abate et al. 2002; Welker and Holden 2003, 2004; Albrecht and Holden 2005; Albrecht et al. 2006a, 2006b, 2007, 2008a, 2008b, 2010a, 2010b, 2013a, 2013b, 2014b; Kegerries et al. 2009; Shattuck et al. 2011).

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)

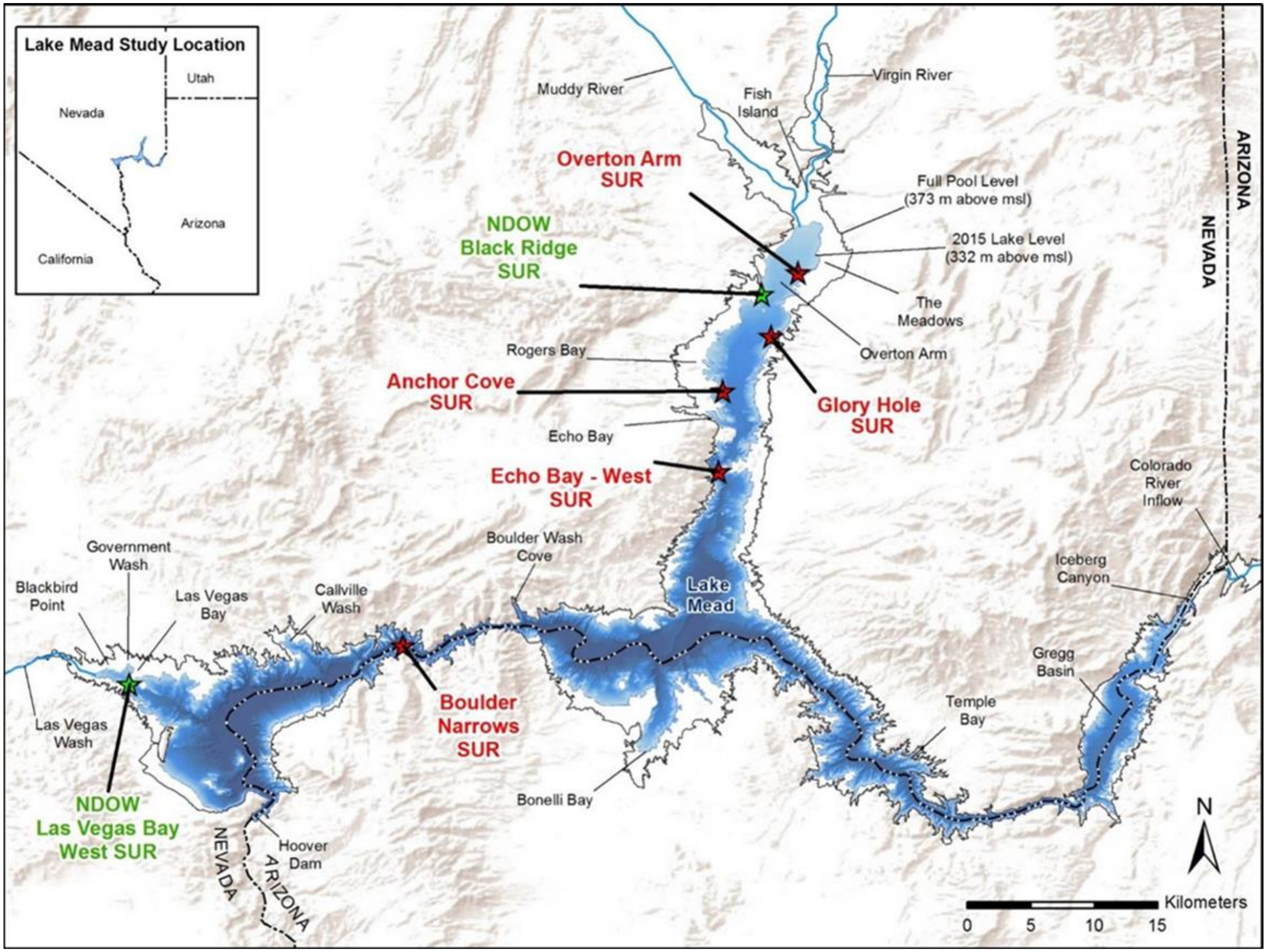


Figure 1.—Long-term monitoring study areas within Lake Mead are shown, and geographic landmarks within the lake are noted.
Locations of long-term monitoring submersible ultrasonic receivers are denoted by red stars (units maintained by BIO-WEST) or green stars (units maintained by the NDOW).

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 (2000–15) and daily lake elevations for the 2014–15 field season (July 1, 2014 – June 30, 2015) were measured in meters above mean sea level (msl) and obtained from Reclamation's Lower Colorado Regional Office Web site (Reclamation 2015). Projected values also described below are taken from Reclamation's regularly updated 2-year study.

Sonic Telemetry

Sonic telemetry data for the long-term monitoring study was collected from July 1, 2014, to June 30, 2015, for continuity with past reports and to capture movement throughout the year. During the intensive field season (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 located monthly.

Sonic Tagging

No razorback suckers were sonic tagged as part of the 2014–15 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. 2014b).

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. Also, the effectiveness of a sonic telemetry signal is 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 inaccessible by boat (e.g., shallow peripheral habitats and flowing portions of inflow areas), the range of observed movements may not always fully represent the use of a particular area. 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 presence. 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 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 their approximate 9-month battery life. Most importantly, the SUR facilitates an understanding of large-scale razorback sucker movements during the monthly tracking events. Seven SURs were deployed during the 2014–15 field season (see figure 1) as part of this long-term monitoring effort. These SURs were also utilized for the concurrent juvenile razorback sucker study to increase the effectiveness of monitoring newly implanted sonic-tagged juveniles released in long-term monitoring study areas. Information from the SURs was shared between BIO-WEST and the NDOW, which provided a larger area of surveillance for monitoring lake-wide movement of razorback suckers.

The seven SURs were set at the following locations (see figure 1): across from Sand Island at the southwestern extent of Las Vegas Bay (NDOW), on the southern shore across from Rotary Cove in the narrows of Boulder Canyon (BIO-WEST), on the western shore south of Echo Bay at the constriction point near Ramshead Island (BIO-WEST), north of Echo Bay off the northern shore of Anchor Cove (BIO-WEST), off of Black Ridge on the southeastern edge of Fire Bay (NDOW), off of the southwestern shore of the Meadows across from

Salt Bay on the eastern side of the Overton Arm, and finally off the eastern shore of Glory Hole Bay. Each SUR was programmed to detect implanted, active sonic transmitter frequencies using Sonotronics's SURsoft software. The semibuoyant SURs were deployed using round weights along a lead of vinyl-coated steel cable secured to the SUR and a concealed spot on shore and 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). To avoid any false-positive contacts due to environmental "noise" in data analyses, 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 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. The nets were generally set with one end near shore in less than 10 m of water, with the net stretched out 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), thereby active for one full net-night. 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. Las Vegas Bay trammel netting was primarily conducted within and near Government Wash cove, in close proximity to sonic-tagged razorback suckers detected nearby. The primary Echo Bay sampling area was well dispersed among the western shore of the bay, the eastern shore near to the boat ramp, and off the northern shoreline. Finally, sampling of the Virgin River/Muddy River inflow area occurred primarily along the eastern shoreline in the northern extent of the Overton Arm, approximately 1–2 km south of the Virgin River inflow often dependent on sonic-tagged individuals. To avoid handling stress on native razorback suckers, trammel netting was typically conducted only when surface water temperatures were less than 20 degrees Celsius (°C) (Hunt et al. 2012).

All fish were removed from the nets and were 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 was collected. For non-lethal aging purposes, 0.5-cm-long fin ray sections were collected from the pectoral fin. As requested by the Lake Mead Interagency Work Group, genetic material was also removed from some of the 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. These samples were delivered to Reclamation biologists for analyses. After all necessary information was collected, the fish were released unharmed at the point of capture.

Given the emerging need and desire to test statistical differences among years, a new metric was initiated for this report (mean number of razorback sucker catch per net-hour) and will become a common measure of effort reported for this study. Using this method of analysis will allow field crews to set short-duration (several hours versus overnight only) net sets when unplanned events occur (i.e., weather, water quality issues, or exploring new areas) and allow field crews to make most of limited sampling opportunities. Furthermore, this new analysis method standardizes catch per unit effort (CPUE) (in the past, net-night could mean a range of times) and allows a greater level of accuracy in reporting. This metric (mean catch per net-hour) is being used for the CRI reports and will allow a more holistic CPUE comparison (mean number of fish/net-hour) for Lake Mead razorback suckers. Sampling units were individual nets fished for a finite amount of time (net-hour). The total time, in hours, was calculated for each net set, and the number of razorback suckers was divided by hours fished to obtain the fish/net-hour metric. Then, an analysis of variance (ANOVA) was used to test for differences in mean catch per net-hour at each site based on the year sampled. As is common with datasets related to fish catch, the data did violate the assumption of normality inherent to ANOVA. After attempting procedures to normalize catch data failed, we decided to proceed with an ANOVA. While ANOVAs are still commonly used in situations pertaining to non-normally distributed catch data (Isely and Grabowski *in* Guy and Brown 2007), we acknowledge there are non-parametric alternatives, and we will utilize those approaches in future years.

Growth

Razorback sucker annual growth information was gathered from recaptured individuals in trammel netting collections across all years of study, 1997–2015. The annual growth for razorback suckers was calculated for each individual using the difference in TL (mm) between capture periods. Capture periods ranged from over 10 years to as little as 2 weeks. Annual growth data were split into groups based on whether they were wild- or stocked-origin razorback suckers. Data distributions from these two groups were normalized prior to analyses using a common base-10 logarithm approach. A linear model was fitted to each set of annual growth data against the TL of the individual in order to assess any difference in growth or growth rates between these two groups. Statistical significance and the r^2 value for each linear regression are reported, and an ANOVA was used to test for differences between the two groups (wild or stocked) of data.

Recaptured individuals from the 2015 season were only measured once during the spawning season, to avoid handling stress, and only used for annual growth analyses independent of time between capture occasions. If the data were available, mean annual growth was calculated separately for appropriate stocked and wild individuals. 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 2015 season are reported.

Finally, to further determine if fish origin (wild or stocked) was related to growth or size of the fish, a von Bertalanffy growth curve, as detailed in Isely and Grabowski (2007), was fitted to age-at-size data from fish obtained during trammel netting collections. A total of 463 unique razorback suckers from long-term sites were used for this analysis. TL (mm) at age data was graphed, separated by wild or stocked origin. A non-linear regression was fit to these data using parameters determined from TL at age data to show how an average individual within the system of Lake Mead would grow into its adult years. This method was included in order to portray the average length at age for razorback suckers within this system and the growth path they typically take, and to visually assess how different stocked fish and wild individuals may grow, in order to help determine how well stocked individuals may be integrating into the system upon their release.

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, four to eight sites were sampled on each night sampling was attempted. 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 for the 2007–2015 study period.

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 also used at the long-term monitoring study areas in 2015.

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 2015 long-term monitoring efforts involved collecting fin ray sections from razorback suckers for aging purposes. Samples were also obtained from other native catostomids (i.e., flannelmouth suckers and hybrids) for age determination when appropriate.

During the 2015 field season, previously unaged, wild razorback suckers, flannelmouth suckers, and hybrids captured via trammel netting were anesthetized, and a single approximately 0.64-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, PIT tagged, and a fin ray sample was surgically collected using custom-made bone snips originally developed by BIO-WEST. This surgical tool consists of a matched pair of finely sharpened chisels welded to a set of wire-stripping pliers. The 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, 2014a), 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, the program MARK (Cooch and White 2013) was utilized in an attempt to produce an estimate from mark-recapture data spanning from 2013 through 2015. 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 capture occasions (based on weekly sampling efforts during 2013–14 and biweekly sampling in 2015) were included in a full-likelihood closed-capture model with two mixtures and simple individual heterogeneity (i.e., with π as the mixture parameter and p as a single encounter parameter [Cooch and White 2013]). For the full-likelihood closed-capture model with mixture and heterogeneity, two model iterations were run in which the encounter parameter (p) was either held constant (.) or variable (t) through time (Albrecht et al. 2014b). Otis et al. 1978 (*in* Cooch and White

2013) recommend recapture rates between 20–30% within a shorter time period (i.e., 1 year or less) to achieve a reliable population estimate. Results from program MARK produced unrealistic estimated 95% confidence bounds (standard error [SE]) likely due to low recapture rates (12%). As such, a population estimate is not provided in this report.

Survival Estimates

An estimate of the annual apparent survival (φ, the probability of surviving from one year to the next year) of razorback suckers in Lake Mead was calculated in program MARK from the entire mark-recapture study period spanning from 1996 through 2015. A Cormack-Jolly-Seber live recapture model (Cormack 1964; Jolly 1965; Seber 1965) was used to obtain a lake-wide annual apparent survival estimate (combined long-term monitoring sites [1996–2015] and CRI [2010–2015]) for adult razorback suckers. A total of 20 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 that of Marsh et al. (2005). Models for apparent survival and recapture (ρ, the probability of being recaptured from one year to the next year) were used in the Cormack-Jolly-Seber survival estimator so that the parameters (φ and ρ) were held either constant (.) or variable through time (t), producing a combination of four model iterations (attachment 2). The annual survival estimate models produced in program MARK were compared according to Akaike's information criterion adjusted for small sample size (AIC_c) values. 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 2) produced an estimated $\hat{c}$ value of 3.5 (SE = 0.2) in logistic regression. Cooch and White 2013 suggest that when the $\hat{c}$ value is > 1, estimates from models with fewer parameters carry a higher AIC_c weights. Furthermore, no consensus for adjusting the models is agreed on at this time; hence, the model with the highest AIC_c is reported within (Cooch and White 2013). Subsequently, each estimate was fitted with 95% confidence bounds, and a weighted average of the four estimates was produced (Cooch and White 2013).

Annual apparent survival estimates the probability of an individual being alive and available for capture from one time period to another – in this case, from year to year during 1996–2015 (Zelasko et al. 2011; Cooch and White 2013). In Lake Mead, razorback suckers smaller than 450 mm TL that have been captured are generally immature fish that are less than 4 years old. In order to be comparable to other razorback sucker populations in the upper and lower basin, annual apparent survival was calculated for adult razorback suckers greater than 450 mm TL (Zelasko et al. 2011; Albrecht et al. 2013a, 2014a). Stocked razorback suckers were not included in the estimate unless they had survived a minimum of 1 year in Lake Mead. The annual survival estimate, spanning the majority of study at Lake Mead (1996–2015), provides some ability to compare annual apparent survival rates of Lake Mead razorback suckers to those of other prominent razorback sucker populations such as that of the upper Colorado River sub-basins (Roberts and Moretti 1989; Bestgen et al. 2009; Zelasko et al. 2011) and that of Lake Mohave (Kesner et al. 2012; Marsh & Associates, LLC 2015).

RESULTS

Lake Elevation

Observed lake elevations for the past 15 years (figure 2) have generally been in decline. Lake elevations continued to decline during the 2014–15 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 nearly 332 m msl at the beginning of February 2015 (figure 3). In 2015, lake elevations decreased steadily during the spawning months of February through May to a final elevation of approximately 328 m msl at the end of May (figure 3). Water elevations dropped approximately 4 m during the 2015 spawning months, averaging 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 was observed during these months. Water level drops have caused vast areas to dry, particularly in coves of the Virgin River/Muddy River inflow area. Following the peak spawning months (i.e., February, March, and April), lake elevations continued to decline through the remainder of the 2014–15 field season, reaching the lowest lake elevations observed since Hoover Dam's construction in 1935.

Sonic Telemetry

Over the course of this study (1997–2015), 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. (2014a), and Kegerries et al. (2015).

During the long-term monitoring 2014–15 field season, a total of 20 unique fish were detected using a combination of active and/or passive telemetry methods. A total of 105 active contacts were made with 17 individual sonic-tagged razorback suckers (table 1; figures 4–6), including 1 individual originally tagged in 2014 at the CRI and last detected in Anchor Cove. The seven SURs (see figure 1) in aggregate contacted 16 sonic-tagged razorback suckers a total of 27,829 times.

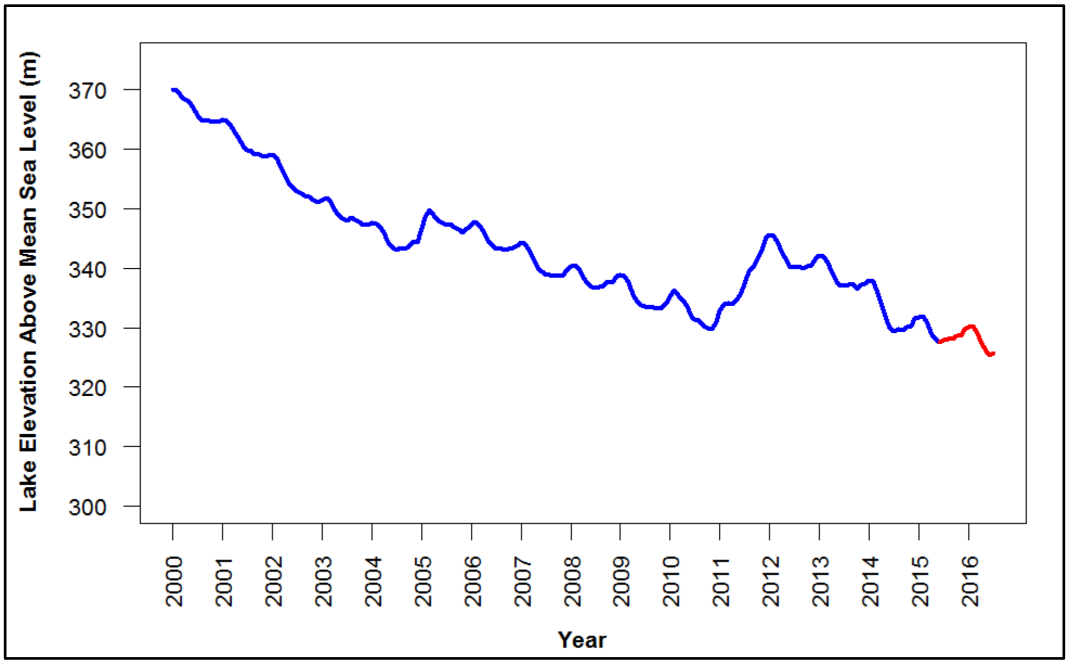


Figure 2.—Lake Mead month-end lake elevations, January 2000 – June 2015, with projected lake elevations for the July 2015 – June 2016 study year (Reclamation 2015).

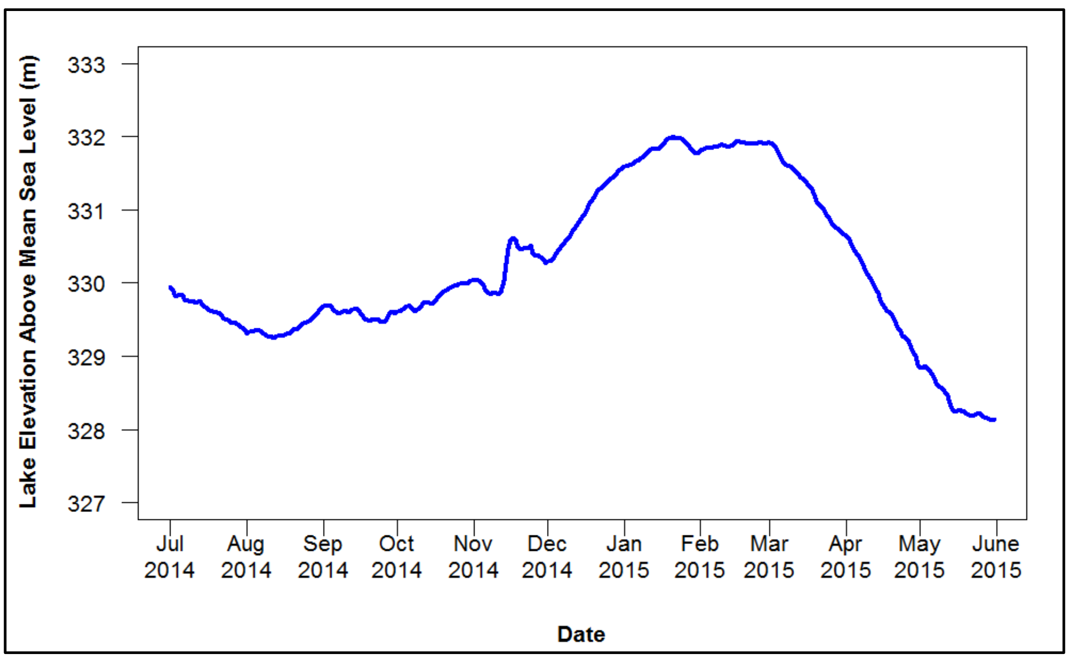


Figure 3.—Lake Mead daily lake elevations, July 1, 2014 – June 30, 2015 (Reclamation 2015).

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)	Unknown
FDLB	1/4/2011	3545	556	F	LB	LB	7/15/2014	1 (0)	Active
FDLB	1/4/2011	3584	519	M	LB	LB	6/23/2014	0 (157)	Active
FDLB	1/4/2011	3775	516	M	LB	LB	6/23/2015	6 (612)	Active
FDLB	1/4/2011	448	502	M	OA	AC	6/23/2015	10 (2,050)	Active
FDLB	1/4/2011	555	504	M	OA	AC	6/26/2015	0 (503)	Active
FDLB	1/4/2011	3578	541	F	OA	OA	6/16/2015	6 (5,830)	Active
FDLB	1/4/2011	3667	552	F	OA	OA	2/17/2015	8 (0)	Active
2012									
LB	2/28/2012	222	425	I	LB	LB	12/8/2014	3 (119)	Active
CPD	4/23/2012	337	390	I	LW	LB	5/16/2012	0 (0)	Unknown
CPD	4/23/2012	368	345	I	LW	LB	3/14/2015	0 (2)	Active
CPD	4/23/2012	452	340	I	LB	OA-W	11/16/2013	0 (0)	Unknown
2014									
CRI	2/25/2014	468	592	M	CRI	LB	2/2/2015	3 (1,571)	Active
EB	2/6/2014	586	656	F	EB	AC	6/24/2015	5 (5,002)	Active
EB	2/12/2014	3375	598	M	EB	EB	5/6/2015	11 (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	1 (188)	Active
LB	2/11/2014	3488	626	M	LB	LB	6/15/2015	12 (1,063)	Active
LB	3/11/2014	3566	536	M	LB	LB	6/15/2015	6 (0)	Active
CPD	3/16/2014	4778	479	M	LB	LB	4/27/2015	8 (200)	Active
OA	2/5/2014	578	520	M	OA	EB	6/16/2015	9 (1,023)	Active
OA	2/26/2014	3337	589	M	OA	AC	5/4/2015	6 (426)	Active
OA	3/6/2014	3374	582	M	OA	AC	6/22/2015	5 (2,118)	Active
OA	3/6/2014	3478	562	M	OA	GH	5/15/2014	0 (0)	Unknown
CRI	2/18/2014	3547	574	M	CRI	OA	2/17/2015	5 (465)	Active

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

[b] F = female, M = male, and I = immature.

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

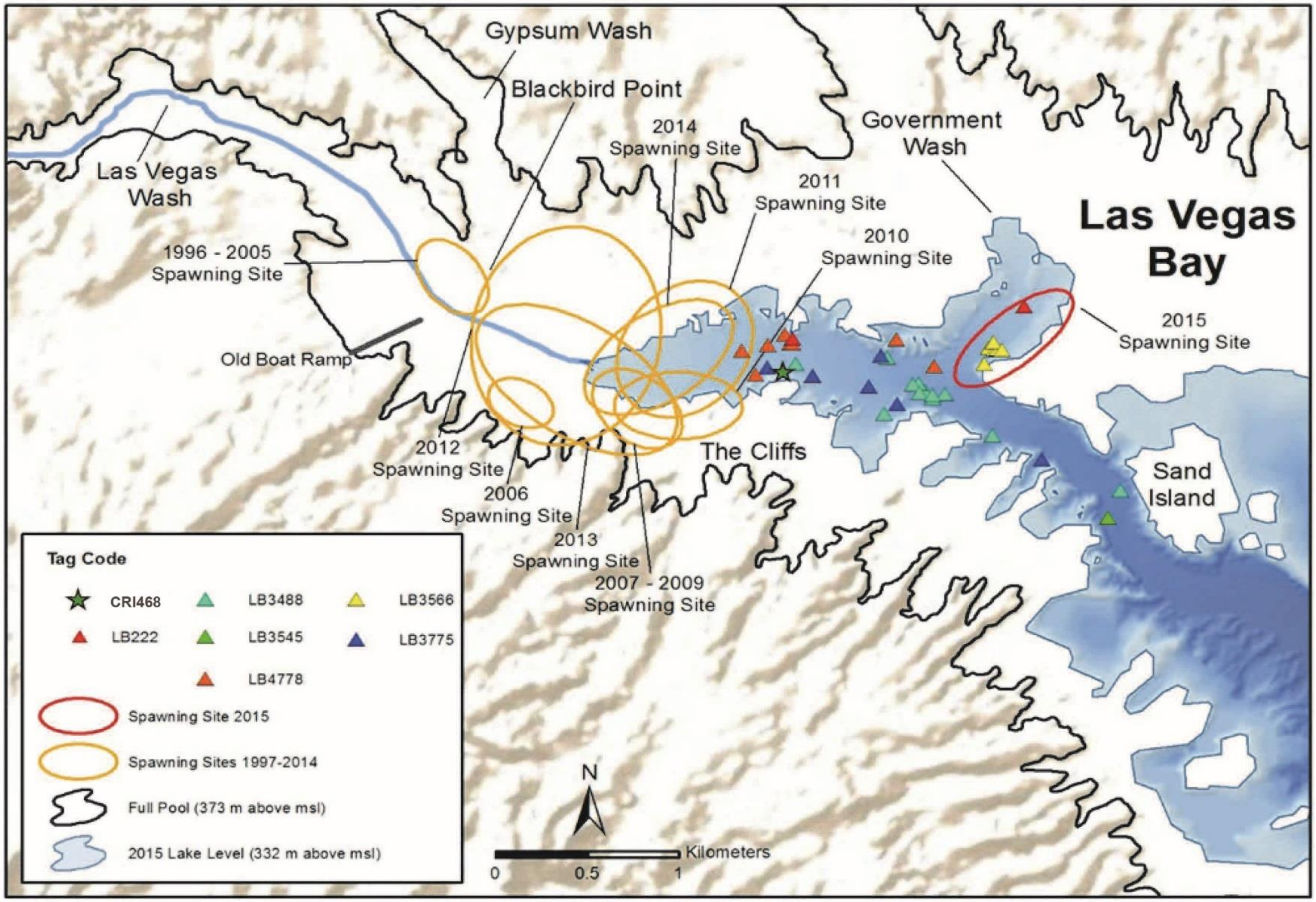


Figure 4.—Distribution of sonic-tagged razorback suckers located through active sonic telemetry in Las Vegas Bay, July 2014 – June 2015.
Symbols for each tag code are unique to their original tagging location, which is noted on the map as the tag code (e.g., CRI468 was originally tagged near the CRI).

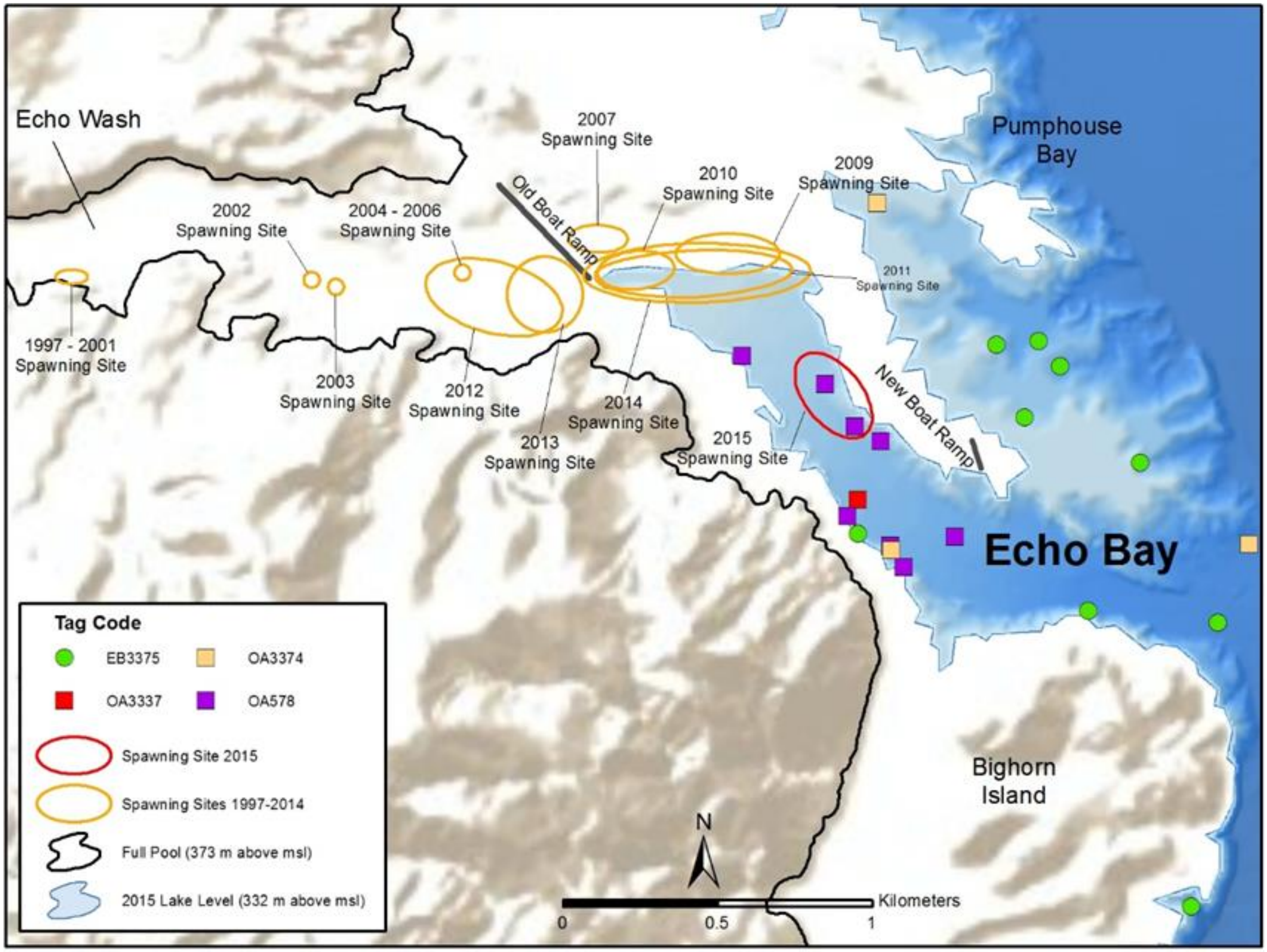


Figure 5.—Distribution of sonic-tagged razorback suckers located through active sonic telemetry in Echo Bay, July 2014 – June 2015.
Symbols for each tag code are unique to their original tagging location, which is noted on the map as the tag code (e.g., fish OA578 was originally tagged near the Virgin River/Muddy River inflow area).

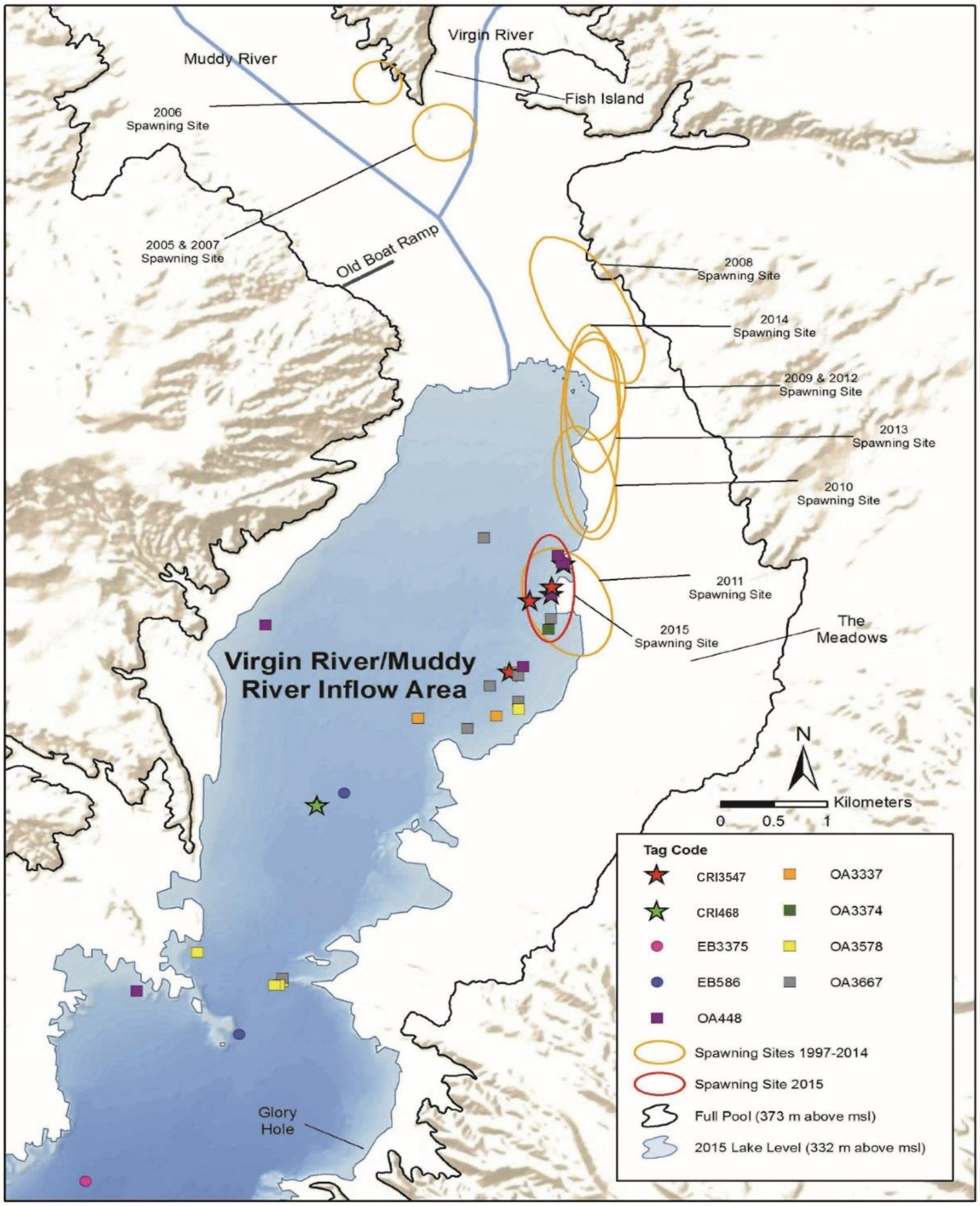


Figure 6.—Distribution of sonic-tagged razorback suckers located through active sonic telemetry near the Virgin River/Muddy River inflow area, July 2014 – June 2015.
Symbols for each tag code are unique to their original tagging location, which is noted on the map as the tag code (e.g., fish EB586 was originally tagged within Echo Bay).

The NDOW Black Ridge SUR contacted razorback suckers most often, with 21,832 contacts, with the Glory Hole SUR, NDOW Black Ridge SUR, and the Las Vegas Bay SUR all contacting 10 individuals. The number of SURs and the number of contacts helped to define movement, particularly long-distance movements of sonic-tagged individuals, and aided in accounting for difficult-to-locate sonic-tagged fish.

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 2014–15 field season, 7 out of 8 fish were contacted a total of 9,183 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 2014–15 field season (i.e., tagged individuals were contacted at the same study area where they were initially released). Individuals from the 2011 tagging event that were stocked into Las Vegas Bay were actively contacted in that area 7 times, while individuals stocked at the Virgin River/Muddy River inflow area were actively contacted in that area a total of 24 times (see table 1; figures 4 and 6). Though no individuals were initially stocked into Echo Bay in 2011, two individuals originating from the Virgin River/Muddy River inflow area were contacted nearby at Anchor Cove during the 2014–15 field season (see table 1). Individuals from the 2011 tagging event were contacted most often by SURs placed throughout Lake Mead, with the majority of contacts made at the NDOW Black Ridge SUR (n = 8,222) and the NDOW Las Vegas Bay SUR (n = 769) (see figure 1; table 1). Numerous contacts were also made at the Glory Hole SUR (n = 60) and the Anchor Cove SUR (n = 105). No contacts were made with the Boulder Narrows or Echo Bay SURs (see figure 1 for SUR locations).

During the 2014–15 field season, two of four sonic-tagged fish were detected using active telemetry in Las Vegas Bay (fish codes 3545 and 3775). These fish were both relatively close to the most prominent spawning location in Las Vegas Bay (see figure 4). Sonic-tagged fish 3584 was not detected via active telemetry, but was detected passively on SURs, and sonic-tagged fish 334 has not been detected since last spawning season (see table 1). At the Virgin River/Muddy River inflow area, one sonic-tagged individual from the 2011 tagging event (fish code 555) was contacted 503 times by the NDOW Black Ridge SUR and the Anchor Cove SUR, but it was not detected via active telemetry. Three other tagged individuals (fish codes 448, 3578, and 3667) were all contacted in close proximity to the observed 2015 spawning location (see figure 6). During the reproductive season, these individuals remained primarily in shallow areas close to the Virgin River/Muddy River inflow area and along the eastern shoreline near the Meadows (see figure 6). However, in the periods prior to and following the reproductive season, these individuals were contacted in deeper, offshore habitats and further south (see figure 6).

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. During the 2014–15 field season, two of the four fish were encountered using active and passive telemetry. One 2012 sonic-tagged fish (fish code 222) was the most active, similar to last year, and was contacted 3 times in active sonic telemetry efforts and 119 times with 1 SUR in Las Vegas Bay (see table 1; figure 4). Like other year-classes of sonic-tagged razorback suckers, the individual actively contacted (fish code 222) was found throughout Las Vegas Bay from the area of Government Wash cove (see figure 4) to the shorelines around the Las Vegas Wash. When this individual was found, it was often in close proximity to other sonic-tagged adult razorback suckers (see figure 4). It was not encountered during the 2015 spawning season but was continuously encountered by passive gear until its most recent encounter by active gear on December 8, 2014. Additionally, one other 2012 sonic-tagged fish (fish code 368) was contacted twice via one SUR; however, no active contacts were made with this individual (see table 1). These SUR contacts were made in close proximity to the original release location.

The status of the two sonic tagged razorback suckers that were not encountered during 2014–15 sampling efforts is unknown. The amount of time since last detection is extensive, especially given all four of these tags were much smaller (shorter battery), which indicates the tag's battery has 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 the 2014 field season, and two wild razorback suckers that were sonic tagged at the CRI were subsequently contacted in 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). Furthermore, fish code 468 was also found in the Las Vegas Bay. Additional details about these individuals can be found in the companion report on razorback sucker investigations at the CRI (Albrecht et al. 2014a; Kegerries et al. 2015).

During the 2014–15 field season, 11 of 13 individuals from the 2014 tagging event (including 2 individuals from the CRI) were contacted at least once for a total of 71 active sonic telemetry contacts. Nine of those 11 individuals were also passively contacted 12,056 times via five different SURs (see table 1). The majority of contacts were made at the NDOW Black Ridge SUR (*n* = 8,441) and the Las Vegas Bay SUR (*n* = 1,551) (see figure 1). Contacts were also made on the Glory Hole SUR (*n* = 508), the Anchor Cove SUR (*n* = 1,546), and the Overton Arm SUR (*n* = 10) (see figure 1). No contacts were made with the Boulder Narrows or Echo Bay SURs (see figure 1).

In 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 3 individuals from the 2014 tagging event were actively contacted in that area 26 times (see figure 4). During the 2014–15 field season, these three individuals (fish codes 3488, 3566, and 4778) from the 2014 tagging event in Las Vegas Bay were often found occupying deeper, mid-channel areas of Las Vegas Bay near Sand Island toward Government Wash cove and west to the area near the Cliffs (see figure 4). These individuals were also found at shallower locations further to the west along shorelines and within Government Wash cove during the reproductive season (see figure 4).

In contrast, the 2014 individuals tagged and released in Echo Bay and the Virgin River/Muddy River inflow area 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, two individuals tagged at the Virgin River/Muddy River inflow area, fish codes 3337 and 3374, were contacted in Echo Bay once and three times, respectively. During the 2015 spawning season however, sonic-tagged fish 3337 remained near the Virgin River/Muddy River inflow area spawning location and remained in the vicinity with the conclusion of the spawning season (see figure 6). Individual 3374 was contacted within Echo Bay prior to the spawning season, but was contacted in early January 2015 in close proximity to the Virgin River/Muddy River inflow area spawning location, and then returned to Echo Bay in March (see figure 6). These movements show the importance of the long-term monitoring sites to razorback sucker viability.

Although lake-wide movements of sonic-tagged individuals have been observed in the past, the movements of the wild individuals from the 2014 tagging event at the CRI spanned much of Lake Mead within a relatively short period of time. Active contact was last made with sonic-tagged fish 468 on February 2, 2015, within Las Vegas Bay. Unfortunately, this fish was then poached in early March 2015 near Las Vegas Bay. Prior to this, this individual was contacted by the NDOW Black Ridge SUR, Anchor Cove SUR, and the Glory Hole SUR in October 2014 before being detected by the Las Vegas Bay SUR only a month later (see figures 4 and 6). In 2014, this individual exhibited long movement patterns, from the CRI to Anchor Cove in less than 5 days, thereby demonstrating the immense movement capabilities of these fish. Individual 3547 moved from the CRI in spring 2014 and was detected throughout the 2014–15 study period near the Virgin River/Muddy River inflow area (see figure 6).

Distance and Submersible Ultrasonic Receiver Data Timing

For the 2014–15 long-term monitoring year, the number of SUR detections for all sonic-tagged fish were compiled for all seven SURs to determine when fish in the lake are most active. SURs exhibited generally short outages during the study period, often associated with battery failure. The NDOW Black Ridge SUR was stolen in January and subsequently had a longer outage that extended through the 2015 spawning season. Fish were detected more often following the 2014 spawning period as they redistributed in the lake until September, at which point the hot temperatures likely caused the fish to move into deeper water where they were unavailable for SUR detection (figure 7). Prior to the 2015 spawning season, immense movement was detected, which likely indicates staging may have been taking place as the fish prepared to spawn. Figure 7 shows that during the February to May spawning period, sonic-tagged fish were detected by SURs far fewer times than the rest of the year, indicating that they are remaining fairly sedentary while spawning.

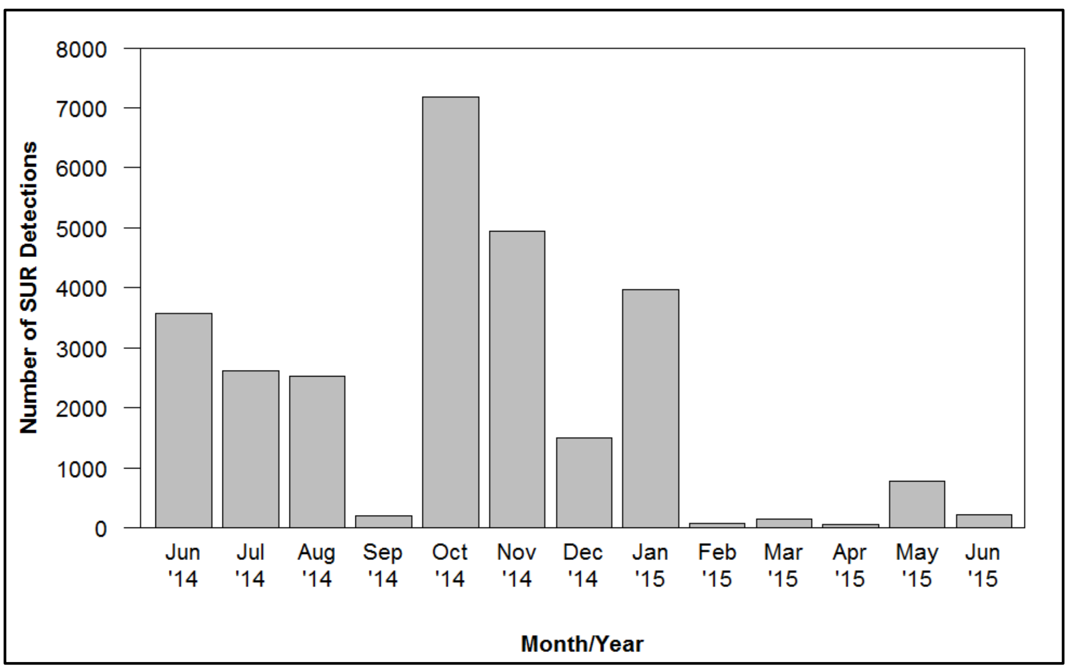


Figure 7.—Number of SUR detections between mid-June 2014 and mid-June 2015 from seven passive sonic telemetry SURs in Lake Mead for sonic-tagged razorback suckers.

The combined telemetry data from active and passive detection methods were used to determine the distance traveled from last contact and were graphed to show how far the majority of fish were moving during the study period (figure 8). All fish were combined for this analysis, but only the maximum per-day distance observed for each fish was used. This was done, for example, because fish code 448 was detected 82 times by 1 SUR in June 2014. The Glory Hole SUR and NDOW Black Ridge SUR are separated by approximately 3,000 m, while the Anchor Cove and NDOW Black Ridge SURs are approximately 8,000 m apart. During the study period, fish were often detected in the same location and only occasionally traveled more than a couple kilometers. Only one fish was responsible for distances greater than 13,000 m. This fish was found by the Glory Hole SUR in October 2014, then again 70 km south in Las Vegas Bay, where it was detected multiple times through late December 2014. Two days after this late December detection in Las Vegas Bay, it was detected by the NDOW Black Ridge SUR. Two weeks after that, it was again found in Las Vegas Bay where it appears to have remained for the 2015 spawning season, thereby suggesting some portion of the population may spawn in multiple areas. The average distance moved during the spawning period was 2,685 m, while non-spawning movements during the rest of the year averaged 4,374 m.

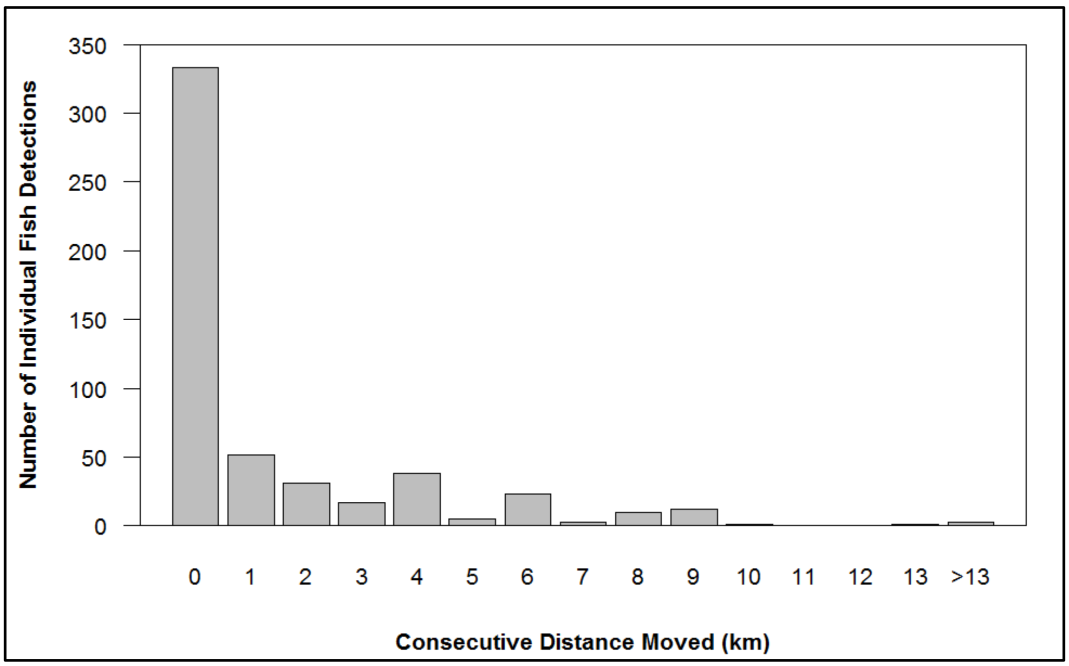


Figure 8.—Number of times a consecutive distance traveled from the previous detection was recorded by 20 individual sonic-tagged fish using active and passive telemetry data from the 2014–15 long-term monitoring study.

Adult Sampling

Trammel Netting

Trammel-netting surveys were conducted from February 3 through April 29, 2015, and consisted of 38 net-nights totaling 560.23 net-hours (table 2; figures 9–11). These efforts resulted in the capture of 18 unique razorback suckers, 10 flannelmouth suckers, and 1 hybrid. The first male razorback sucker expressing milt was captured on February 17, 2015, in Las Vegas Bay, and the first female razorback sucker expressing eggs was captured on February 18, 2015, from the Virgin River/Muddy River inflow area (table 3).

Table 2.—Trammel-netting efforts (net-nights) and trammel-netting effort (net-hours) on Lake Mead, February – April 2015

Month	Las Vegas Bay	Echo Bay	Virgin River/ Muddy River inflow area	Total
February	4	4	4	12
March	6	4	6	16
April	2	6	2	10
Total net-nights	**12**	**14**	**12**	**38**
Total net-hours	**169.53**	**202.23**	**188.47**	**560.23**

All combined netting locations within Lake Mead resulted in capturing a similar sex ratio of individuals compared to past studies (Albrecht et. al 2014b). Approximately 42% of these fish were female, and 58% were male. Both individuals that were captured in Las Vegas Bay were males, and nine male razorback suckers were captured near the Virgin River/Muddy River inflow area (table 3; figures 9 and 11). One adult female razorback sucker was captured in Echo Bay (table 3; figure 10). Most notable was the capture of a single juvenile razorback sucker (221 mm TL) near the Virgin River/Muddy River inflow area in March 2015. This juvenile highlights the ability of currently used trammel-net gear to capture young razorback suckers but underscores the rarity of the event. Within the three long-term monitoring sites, 12 fish were recaptures and 10 were new wild fish. Both fish captured within Las Vegas Bay were new individuals. One fish captured during the 2015 netting season was a sonic-tagged stocked fish, originally released near the Virgin River/Muddy River inflow area in May 2013.

Two razorback suckers were captured in Las Vegas Bay over 12 net-nights, for a mean catch rate of 0.17 razorback sucker per net-night. The 2015 mean catch rate is less than the 2014 mean catch rate (0.33 fish/net-night) but higher than the

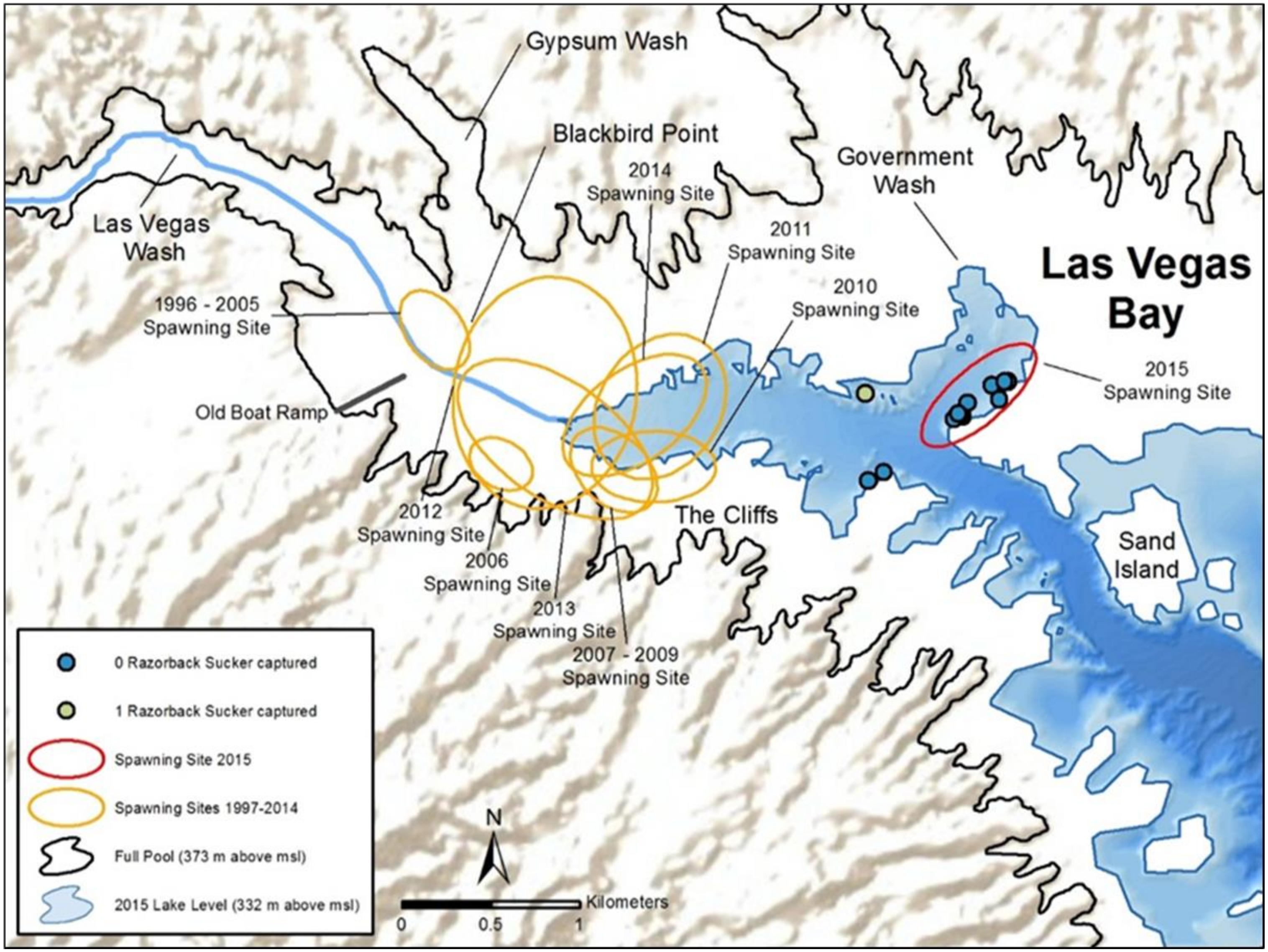


Figure 9.—Locations of trammel netting and numbers of razorback suckers captured in Las Vegas Bay, February – April 2015.

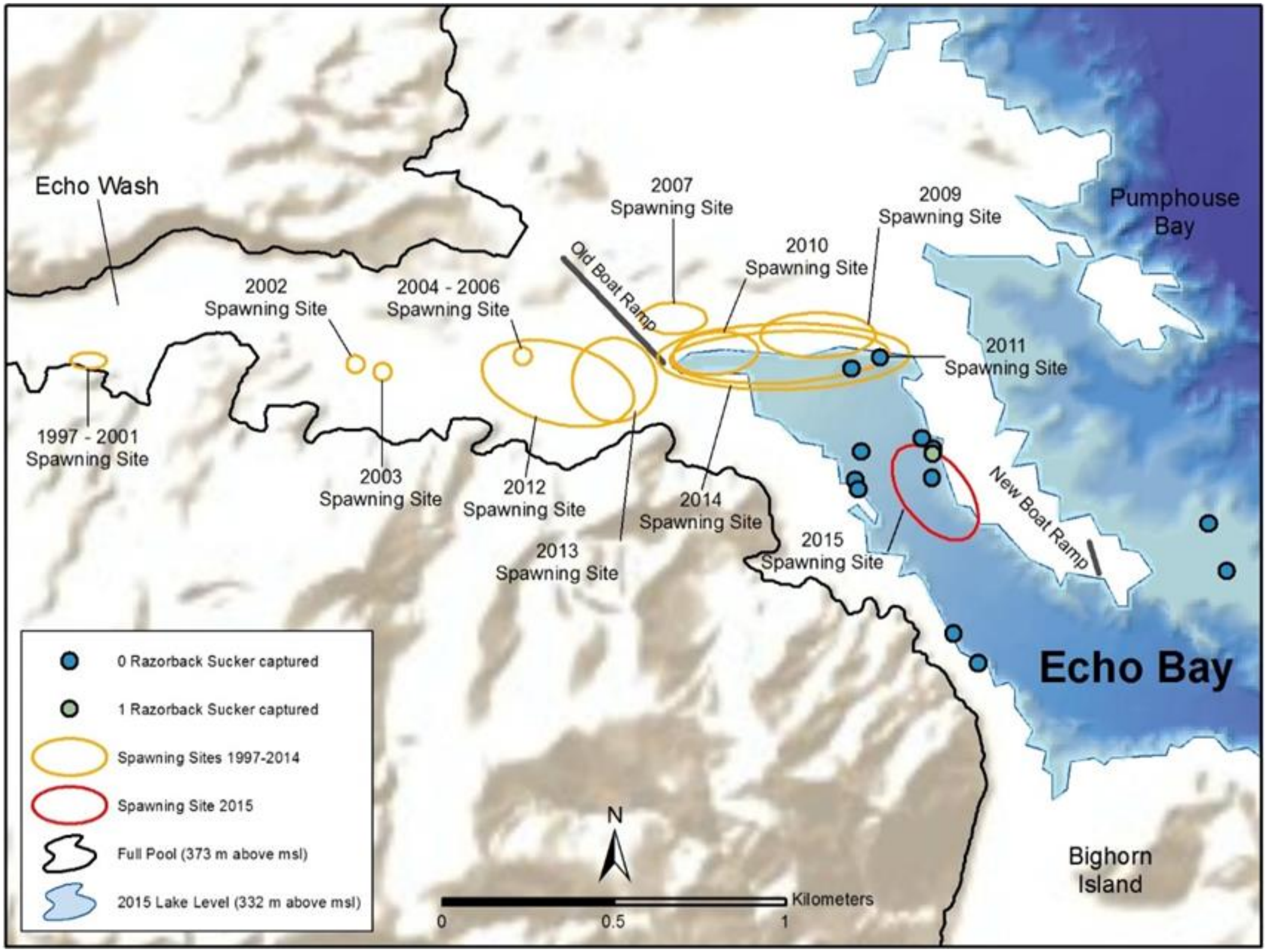


Figure 10.—Locations of trammel netting and numbers of razorback suckers captured in Echo Bay, February – April 2015.

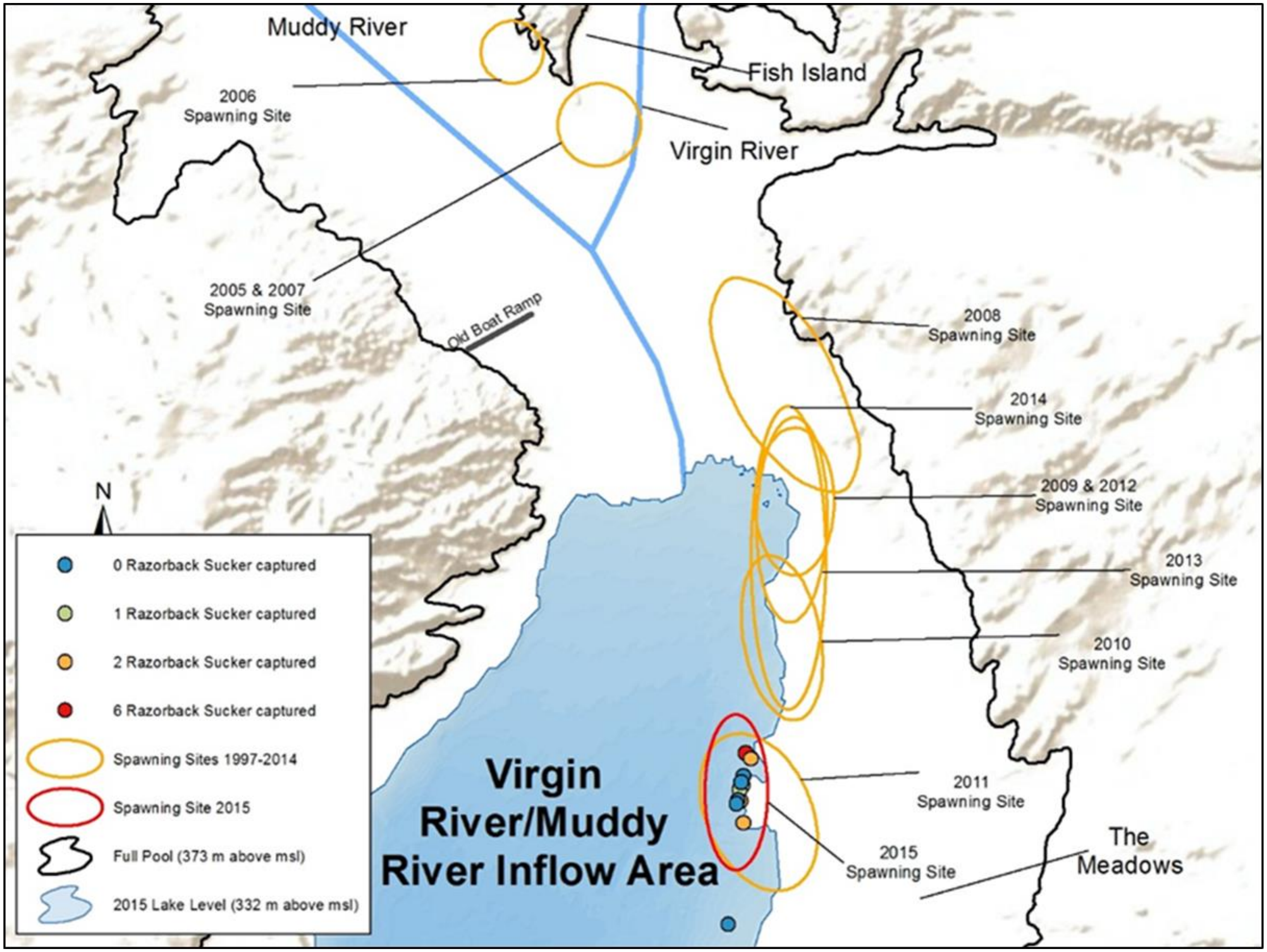


Figure 11.—Locations of trammel netting and numbers of razorback suckers captured at the Virgin River/Muddy River inflow area, February – April 2015.

Table 3.—Capture location, tagging, and size information for razorback suckers captured between February 3 – April 28, 2015

Date	Capture location[a]	Date tagged or stocked[b]	Sonic tag	PIT tag	Recapture?	TL (mm)	FL (mm)	SL (mm)	WT[c]	Sex[d]
2/3/2015	OA	2/1/2011		3D9.1C2D27580E	Y	651	606	564	3,018	F
2/3/2015	OA	2/3/2015		3DD.003BC89EB4	N	638	599	551	2,946	F
2/4/2015	OA	2/1/2011		3D9.1C2D27580E	Y	651	606	564	3,018	F
2/4/2015	OA	2/4/2015		3DD.003BC89EB4	N	638	599	551	2,946	F
2/17/2015	LB	2/17/2015		3DD.003BC89F03	N	468	430	401	1,012	M
2/18/2015	OA	2/22/2011		3D9.257C5F4F54	Y	626	590	549	2,622	F
2/18/2015	OA	2/4/2015		3DD.003BC89EB4	Y	Quick release[e] (captured on 2/4/15)				F
2/18/2015	OA	2/18/2015		3DD.003BC89EF4	N	650	604	571	2,852	F
3/4/2015	OA	3/8/2007		5325506C6C	Y	561	518	481	1,868	M
3/4/2015	OA	2/22/2011		3D9.1C2D278BC3	Y	573	535	498	1,818	M
3/4/2015	OA	5/7/2013		384.1B7969CCA6	Y	515	473	445	1,608	M
3/4/2015	OA	3/6/2014		3DD.003BA2FA80	Y	535	500	464	1,668	M
3/4/2015	OA	2/18/2015		3D9.257C5F4F54	Y	Quick release (captured on 2/18/15)				F
3/4/2015	OA	3/4/2015		3DD.003BC89EBC	N	558	512	473	1,778	M
3/4/2015	OA	3/4/2015		3DD.003BC89EDE	N	586	540	500	1904	M
3/4/2015	OA	3/4/2015		3DD.003BC89F0D	N	221	207	184	102	I
3/4/2015	OA	2/21/2013	3478	3D9.1C2C84072C	Y	570	522	491	1,948	M
3/18/2015	OA	3/18/2015		3DD.003BC89EDC	N	644	600	556	3,380	F
3/31/2015	OA	4/4/2012		384.1B7969E475	Y	575	533	492	1,878	M
3/31/2015	OA	3/31/2015		3DD.003BC89EB2	N	560	518	474	1,764	M
4/14/2015	EB	3/1/2012		3D9.1C2C840ECD	Y	622	573	532	2,768	F
4/28/2015	LB	4/28/2015		3DD.003BC89EBB	N	547	507	466	1,562	M

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

mean catch rate for the 2012–13 season (0.07 fish/net-night). However, the 2015 mean catch rate falls on the lower end of the range of mean catch rates over the 1997–14 time period (0.04–1.96 fish/net-night; figure 12a). One razorback sucker was captured in Echo Bay area during 14 net-nights (0.07 fish/net-night) despite the use of sonic-tagged individuals to direct netting placements and a similar number of net-nights (see table 2). The 2015 catch rate is the lowest mean catch rate ever recorded in the Echo Bay area. Mean catch rates in previous field seasons ranged from 0.12–0.85 fish/net-night (figure 12a).

Trammel netting at the Virgin River/Muddy River inflow area resulted in the capture of 19 adult razorback suckers from 12 net-nights, yielding the highest mean catch rate of 2015 (1.58 fish/net-night) (see table 3; figure 12a). The overall Lake Mead mean catch rate for 2015 was 0.61 fish/net-night, which marks a decrease from 2014, but appears similar to the long-term monitoring efforts average catch rate of 0.58 fish/net-night.

Trammel netting also yields important movement data when fish are recaptured in different locations and provides important information on other native species present throughout Lake Mead. Past studies suggest 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). This year, all fish were recaptured in the same location in which they were originally tagged. In addition to capturing razorback suckers, 10 flannelmouth suckers (0.26 fish/net-night) were captured during the 2015 season. These 10 fish captures were distributed among sampling areas with 4 from Echo Bay and 6 from the Virgin River/Muddy River inflow area. Furthermore, one hybrid was captured from the Virgin River/Muddy River inflow area (0.02 fish/net-night).

Using the new metric to calculate fishing effort, the 2015 razorback sucker mean catch per net-hour in Las Vegas Bay was 0.012 mean number of fish/net-hour (± [SE] 0.008, n = 12), the Echo Bay mean number of fish/net-hour equaled 0.005 (± SE 0.005, n = 14), and the Virgin River/Muddy River inflow area mean number of fish/net-hour was 0.090 (± SE 0.032, n = 12) (figure 12b). Mean catch rates have varied over the past 10 years at each of the long-term monitoring sites.

In Las Vegas Bay, a statistical difference was detected (ANOVA, F = 8.19, $P < 0.0001$). Post-hoc pair-wise comparisons showed 2008 (fish/net-hour = 0.118 [± SE 0.037]) and 2009 (fish/net-hour = 0.134 [± SE 0.032]) are different from 2005 (fish/net-hour = 0.004 [± SE 0.002]). In Echo Bay, a statistical difference was also detected (ANOVA, F = 2.51, P = 0.0065); post-hoc pair-wise comparisons showed that 2005 (fish/net-hour = 0.007 [± SE 0.004]) was different from 2007(fish/net-hour = 0.055 [± SE 0.010]) and 2014 (fish/net-hour = 0.061 [± SE 0.024]). Lastly, a statistical difference was detected at the

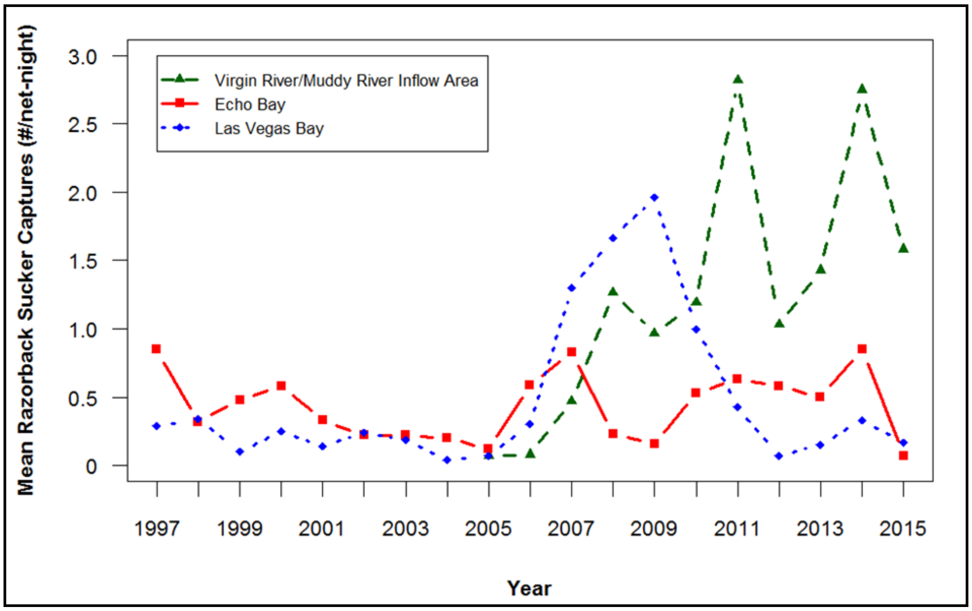


Figure 12a.—Trammel-netting mean CPUE (net-night) of razorback suckers at long-term monitoring study areas in Lake Mead, 1996–2015.
Sampling at the Virgin River/Muddy River inflow area was initiated during the 2004–05 study year.

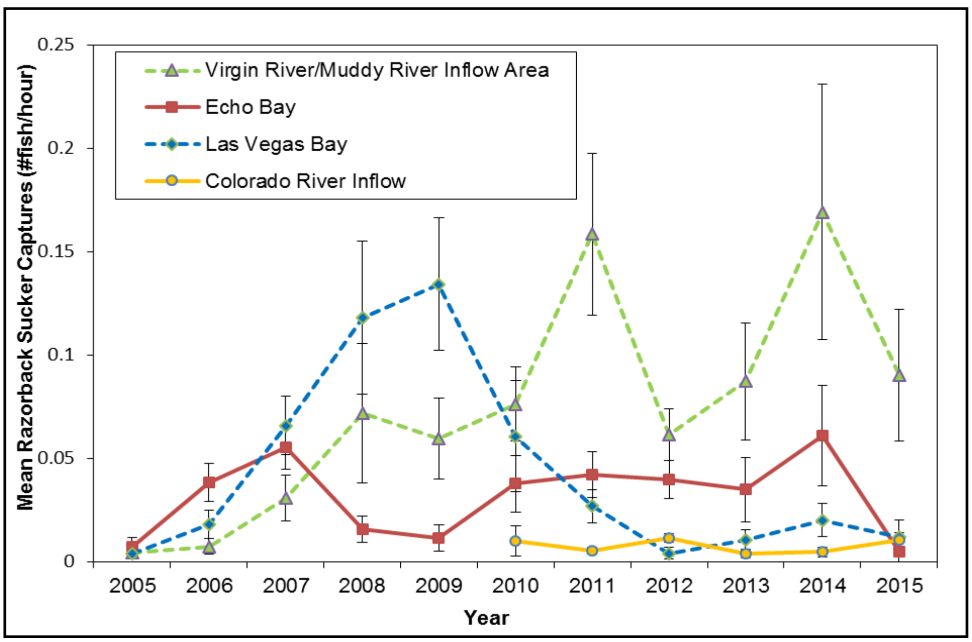


Figure 12b.—Trammel-netting mean CPUE (net-hours) with associated SE of razorback suckers at long-term monitoring and CRI study areas in Lake Mead, 2005–15.
Sampling at the CRI was initiated during the 2010 study year. Trammel netting at the Virgin River/Muddy River inflow area resulted in the capture of 19 adults from 12 net-nights, yielding the highest mean catch rate of 2015 (1.58 fish/net-night) (see table 3; figure 12a). The overall Lake Mead mean catch rate for 2015 was 0.61 fish/net-night, which marks a decrease from 2014, but it appears similar to the long-term monitoring efforts average catch rate of 0.58 fish/net-night.

Virgin River/Muddy River inflow area (ANOVA, F = 4.96, P < 0.0001). Post-hoc pair-wise comparisons showed that 2011(fish/net-hour = 0.158 [± SE 0.039]) and 2014 (fish/net-hour = 0.169 [± SE 0.062]) were different from 2005 (fish/net-hour = 0.004 [± SE 0.003]), 2006 (fish/net-hour = 0.007 [± SE 0.004]), and 2007 (fish/net-hour = 0.031 [± SE 0.011]) (see figure 12b).

Growth

At total of 463 individual razorback suckers from Lake Mead were used for this analysis. Of this total, 441 wild captured razorback suckers were used, while the remaining 22 were stocked-origin fish. No difference was found in the yearly growth rate (mm per year) of individual razorback suckers (figure 13; P = 0.853). Linear regression of each group (wild/stocked) fit well, as indicated by R^2 values (wild = 0.32, stocked = 0.55), and both were significant (wild P = 2.2e-16, stocked P = 2.04e-11). Assumptions of normality and constant variance were met for this analysis.

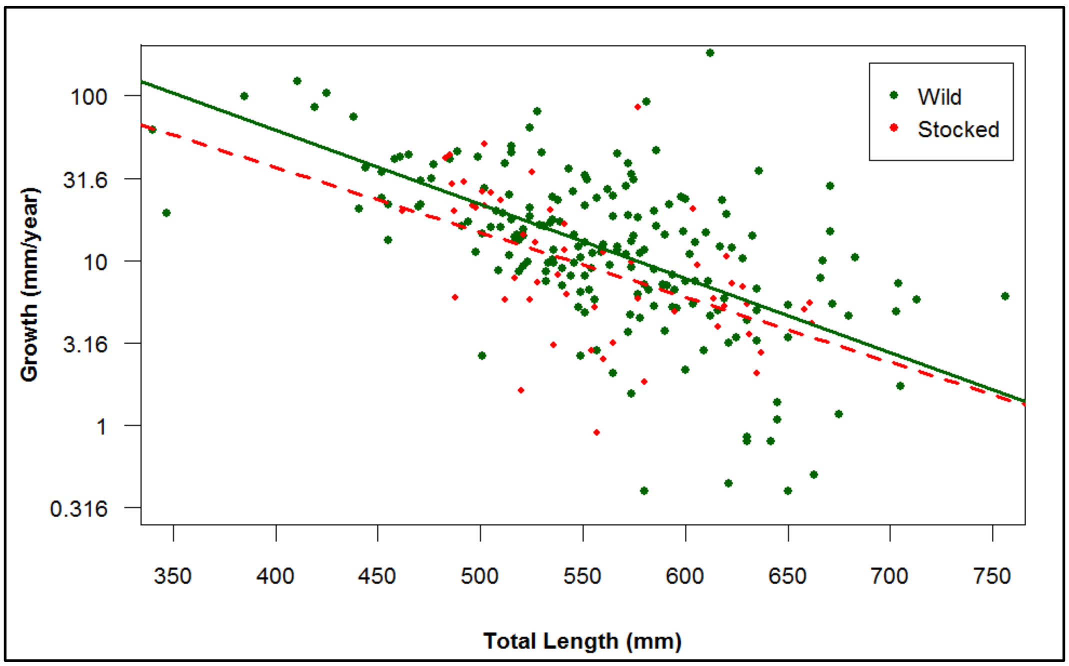


Figure 13.—Growth rates for wild and stocked-origin razorback suckers, log-normalized, graphed against the TL of fish at capture, and fitted with a linear regression line.

Residual plots indicated only very slight heteroscedasticity due to the presence of a few outliers (< 5) in each group and was therefore not considered to be an issue. Known ages of fish were graphed against TL and separated by wild or stocked status. As known, razorback suckers grow quickly in early life stages and grow to similar sizes regardless of stocked versus wild status to an estimated maximum size of 625 mm (figure 14). Furthermore, most fish captured as part of annual

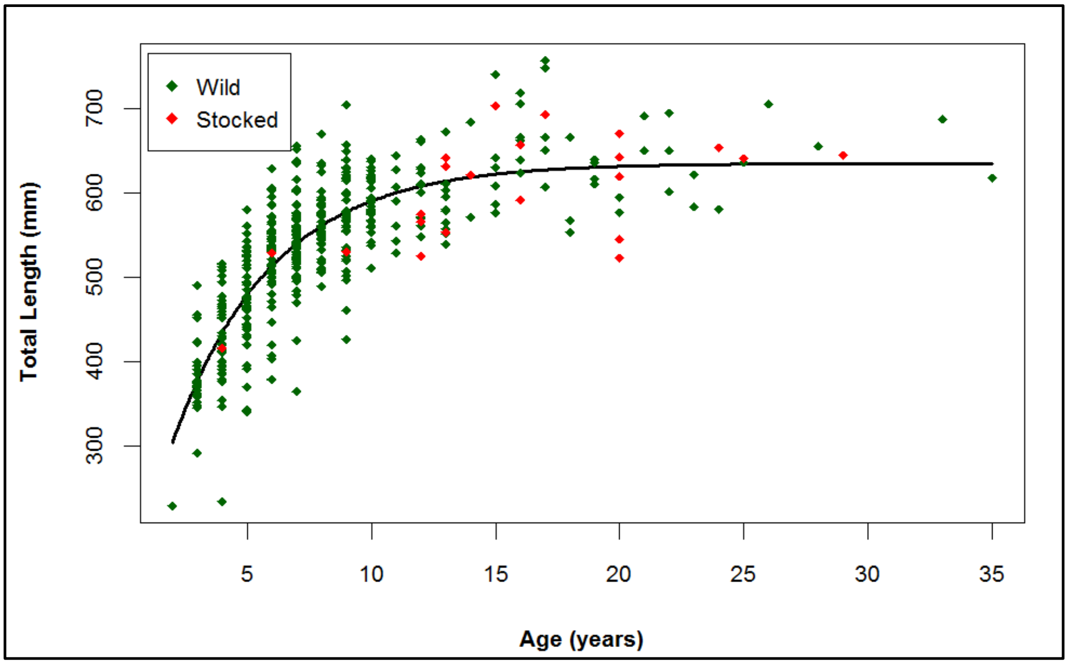


Figure 14.—TL at age estimates were graphed for 463 aged razorback suckers and fitted with a non-linear von Bertalanffy growth curve to demonstrate growth similarities between wild- and stocked-origin fish.

trammel-netting efforts are younger fish (< 10 years). In concert, this combined analysis shows there is no difference in growth rates or overall growth patterns between wild and stocked populations of fish.

Annual growth rates for razorback suckers were calculated using nine wild, recaptured fish despite recapturing more than nine razorback suckers in 2015 (table 4). The nine fish were selected because approximately 1 year had passed from their previous capture to this season's recapture date, which allowed for a more accurate long-term growth measurement. Razorback sucker annual growth ranged from 8.03 mm TL to 152.36 mm TL, with a mean annual growth rate of 27.95 mm TL (± SE = 15.57) (table 4). One fish was recaptured in Echo Bay, while the remaining eight were recaptured at the Virgin River/Muddy River inflow area (table 4).

Larval Sampling

Larval razorback sucker sampling in long-term monitoring was initiated on February 2, 3, and 4 in 2015, at Las Vegas Bay, the Virgin River/Muddy River inflow area, and Echo Bay, respectively. Larvae were first collected on February 16, 2015, in Las Vegas Bay over primarily silt substrates (figure 15). Larval razorback suckers were collected over primarily sand and gravel substrates, the remainder of the spawning period across the northern portions of

Table 4.—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	Annual growth (mm/year)[g]
Echo Bay										
Wild fish										
3D9.1C2C840ECD	3/1/2012	EB	585	F	4/14/2015	EB	622	37	3.12	11.86
Mean annual growth					**N/A[h]**					
Virgin River/Muddy River inflow area										
Wild fish										
3D9.1C2D27580E	2/1/2011	OA	586	F	2/4/2015	OA	651	65	4.01	16.21
3D9.257C5F4F54	2/22/2011	OA	580	F	2/18/2015	OA	626	46	3.99	11.52
384.1B7969CCA6	5/7/2013	OA	237	M	3/4/2015	OA	515	278	1.82	152.36
3D9.1C2C84072C	2/21/2013	OA	549	M	3/4/2015	OA	570	21	2.03	10.34
3D9.1C2D278BC3	2/22/2011	OA	517	M	3/4/2015	OA	573	56	4.03	13.90
3DD.003BA2FA80	3/6/2014	OA	521	M	3/4/2015	OA	535	14	0.99	14.08
5325506C6C	3/8/2007	OA	455	M	3/4/2015	OA	561	106	7.99	13.26
384.1B7969E475	4/4/2012	OA	551	M	3/31/2015	OA	575	24	2.99	8.03
Mean annual growth									**27.95 ± 15.57[i]**	

[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] F = female, and M = male.
[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.
[i] SE = standard error.

Las Vegas Bay, and in close proximity to what remains of the Government Wash cove (figure 15). The collection of larval razorback suckers occurred at temperatures between 14–24 °C (figure 16). Positive collections were often in close proximity to sonic-tagged fish encounters or in areas where previous adult razorback suckers were captured via trammel netting (see figure 4). Las Vegas Bay yielded a total of 104 larvae captured within 550 minutes of sampling, for a mean catch rate of 0.217 catch per minute (CPM) (figure 15). The 2015 razorback sucker larvae CPM at Las Vegas Bay is lower than in 2014 (CPM = 0.427), but within the range observed from 2007 to present (0.093–0.430 CPM) (figure 17).

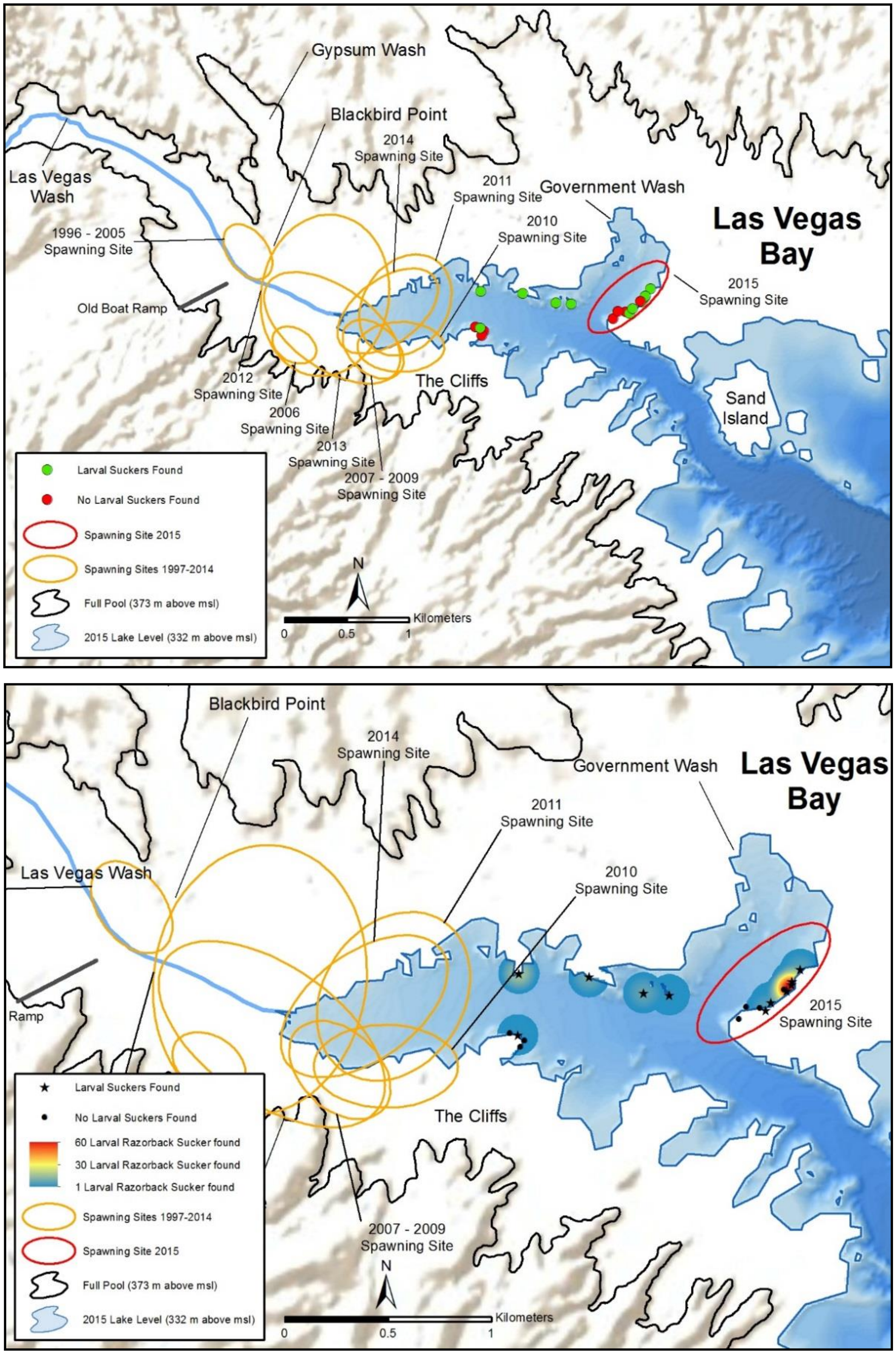


Figure 15.—Locations of larval razorback sucker sampling and capture numbers in Las Vegas Bay, February – April 2015.

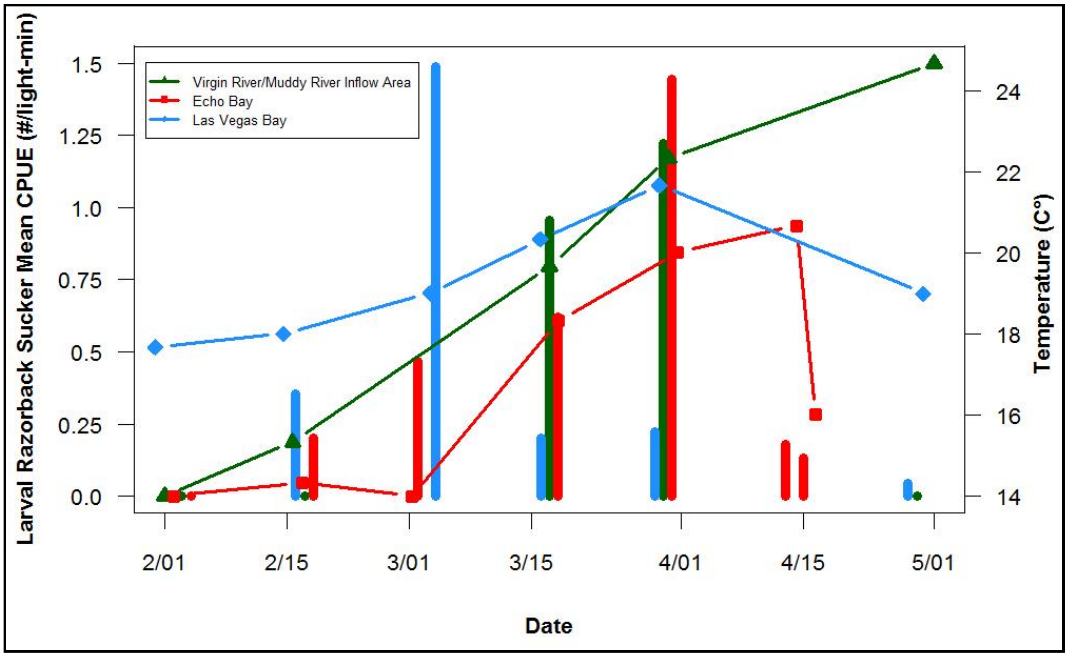


Figure 16.—Larval razorback sucker mean CPM rates (bars) observed at long-term monitoring study areas in Lake Mead with associated temperature data at time of sampling (points), February – April 2015.

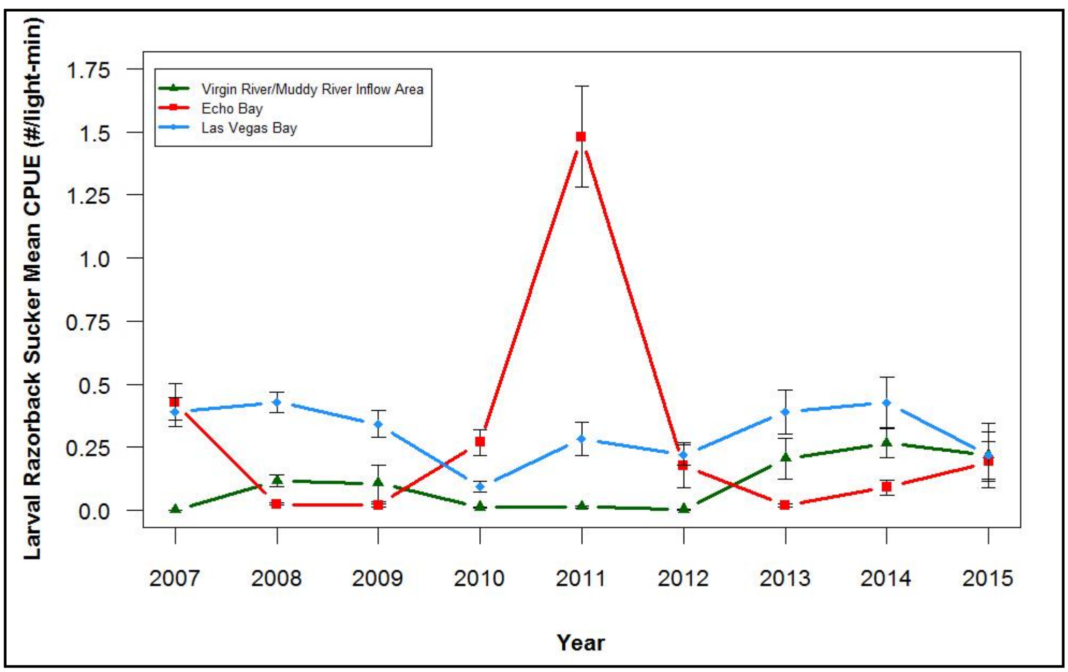


Figure 17.—Larval razorback sucker mean catch per light-minute rates at long-term monitoring study areas in Lake Mead, 2007–15 with associated SE.

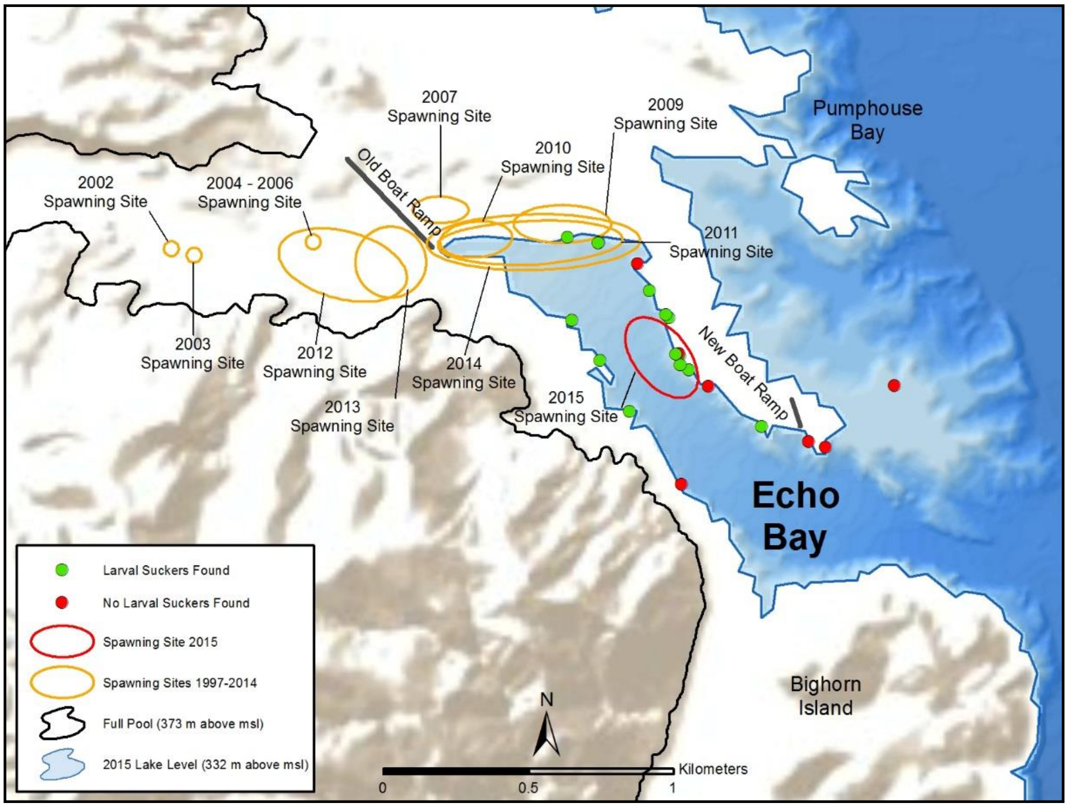
In Echo Bay, the first razorback sucker larvae were captured on February 18, 2015, earlier than last year's first larval encounter on March 11, 2014. Positive larval collections were made primarily over gravel, sand, and occasional cobble substrates at temperatures ranging 14–21 °C (figures 16 and 18). The collection of 137 larval razorback suckers within 630 minutes at Echo Bay resulted in a mean value of 0.193 CPM (see figure 16). Most importantly, these values confirm spawning success at Echo Bay and underscore the importance of this historical spawning location for Lake Mead razorback suckers.

At the Virgin River/Muddy River inflow area, the first razorback sucker larvae of the 2015 sampling season were captured on March 17, 2015, over a variety of substrate types and at temperatures ranging from 20–23 °C (see figure 16). Larval collections occurred approximately 1–2 km south of the Virgin River/ Muddy River inflow area along the eastern shoreline (figure 19). Larval razorback sucker captures occurred in the same vicinity as trammel-netting efforts for adult razorback sucker captures and near areas routinely frequented by sonic-tagged individuals (see figures 11 and 19). In the Virgin River/Muddy River inflow area in 2015, 98 larval razorback suckers were captured within 550 minutes of sampling, resulting in a mean catch rate of 0.218 CPM. This catch rate was almost identical to the Echo Bay spawning location.

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 sucker individuals have returned to general, historic spawning sites and have continued to find suitable habitat for reproduction. Razorback suckers were captured in Las Vegas Bay during the 2014–15 field season, with the majority of adult fish found in close proximity to Government Wash cove (see figure 9).

This area was also the primary location for the collection of larval razorback suckers; however, it is noted that larval razorback suckers were captured on the northern and southern shorelines near the Las Vegas Wash inflow area. These collections continue to suggest that at least some of the 2015 reproduction likely occurred upstream in the lotic portions of the wash (as noted in past annual reports). Furthermore, collection of larval razorback suckers occurred toward Government Wash cove, suggesting that there may have been additional, secondary spawning areas within Las Vegas Bay during 2015. The primary spawning area of the 2014–15 field season was located east of the Las Vegas Wash inflow area, primarily within Government Wash cove, and along both shorelines of the bay (see figure 15). For the past 9 years, the primary



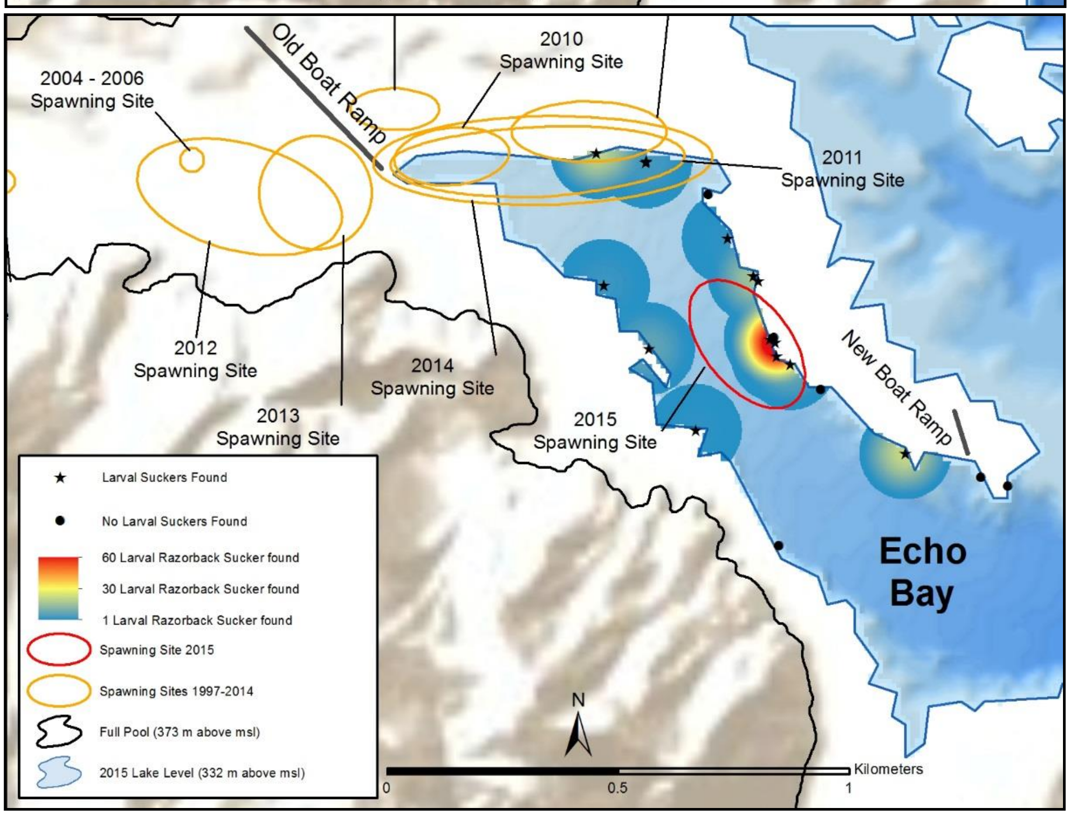


Figure 18.—Locations of larval razorback sucker sampling and capture numbers in Echo Bay, February – April 2015.

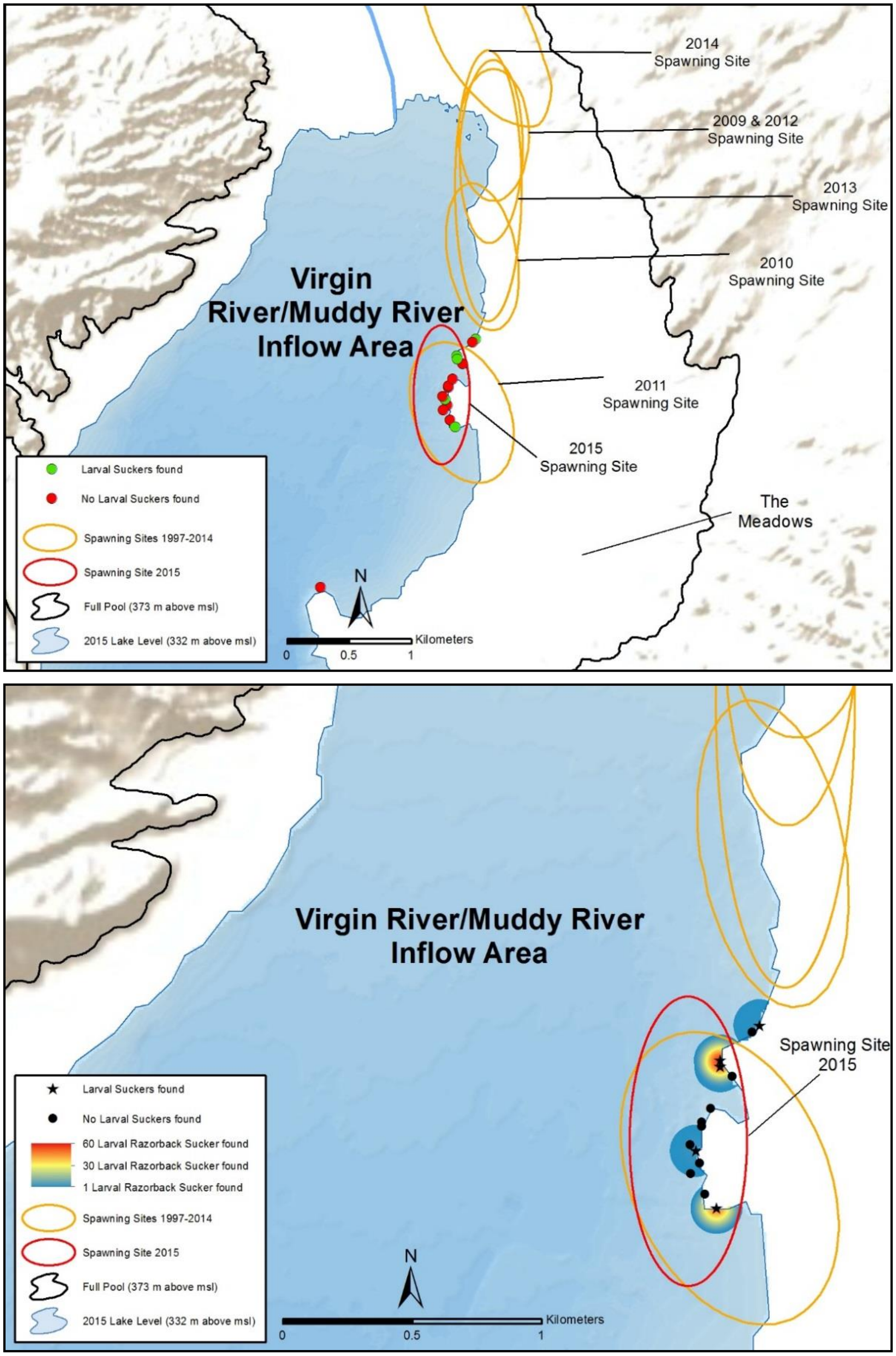


Figure 19.—Locations of larval razorback sucker sampling and captures at the Virgin River/Muddy River inflow area, February – April 2015.

razorback sucker spawning site has been in the same general vicinity, although it has shifted with fluctuating lake elevations (see figure 15). Similar to the 2011–2012, 2012–13 and 2013–14 field seasons, sonic-tagged razorback suckers were observed successfully using Las Vegas Bay in its entirety during the 2014–15 spawning season.

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 the 2013–14 field season, the 2014–15 primary spawning area in Echo Bay was not well defined, as only a single individual was captured toward the end of the spawning period. Despite low adult capture numbers, larval razorback sucker collections occurred broadly throughout all shorelines of Echo Bay in 2015 but were most densely concentrated on the northeastern shoreline (see figure 18).

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). In the past, environmental conditions seem to have driven the success or failure of larval razorback sucker captures despite numerous captures of sexually mature adults in the area. Furthermore, while the Las Vegas Bay and Echo Bay spawning sites have shifted somewhat predictably with lake elevation, the Virgin River/Muddy River inflow area has not followed this generalized trend. The collection of numerous reproductively ready adult razorback suckers in 2015 signified that spawning was likely occurring on a kilometer section of shoreline south of the Virgin River (see figure 11), which is further indicated by frequent usage of the area by sonic-tagged individuals (see figure 6). Additionally, the capture of larval razorback suckers in the immediate area of captured adults and sonic-tagged adults further defined the primary spawning site designation (see figure 19). The 2015 spawning site in the Virgin River/Muddy River inflow area was located approximately 1–2 km south of the Virgin River inflow/delta along the eastern shoreline of the Overton Arm and spanned over a kilometer in length of shoreline utilized for reproductive activity (see figure 19).

Age Determination

To date, a definitive age has been determined for 478 razorback suckers from long-term monitoring study areas in Lake Mead (not including 33 individuals aged from the CRI [Albrecht et al. 2014a]). In 2015, ages were obtained from eight razorback suckers captured in trammel nets at long-term monitoring study areas, while five individuals were aged from the CRI (attachment 1; see figure 19) (Albrecht et al. 2014a). The youngest razorback sucker aged in 2015 from the long-term monitoring study areas was a 5-year-old, sexually mature, 468 mm TL male from Las Vegas Bay (attachment 1). The oldest razorback sucker aged during 2015 long-term monitoring was a 10-year-old male (2005 year-class) with a TL of 581 mm (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 20). However, recent data show Lake Mead razorback sucker recruitment readily occurred beyond 2000, coinciding with a steady decline of lake elevations (figures 2 and 20). The cumulative dataset shows the largest number of individuals (360) were spawned from 2000 to 2011. Within this period, 103 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 (figure 20).

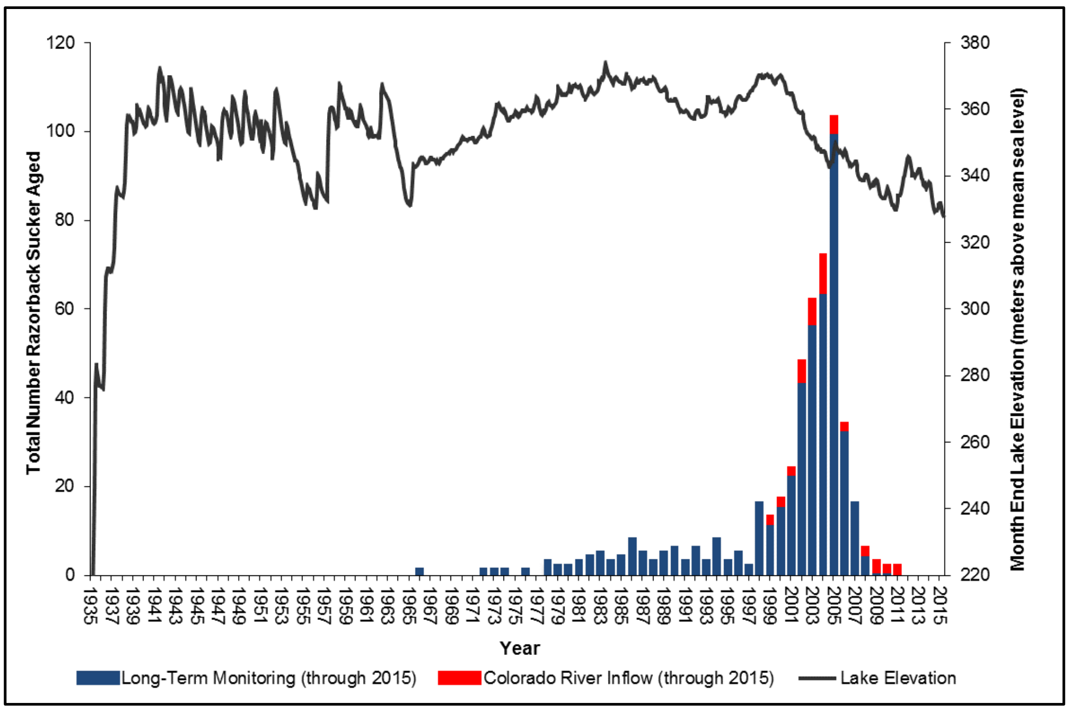


Figure 20.—Cumulative number of razorback suckers back-calculated to year spawned for individuals aged with corresponding Lake Mead month-end lake elevations, January 1935 – June 2015.
Blue bars denote individuals aged in long-term monitoring efforts, 1999–2015; red bars denote individuals aged in efforts at the CRI, 2010–2015 (Albrecht et al. 2014b).

Based on past experience, it typically takes 3–4 years for young razorback suckers to become readily susceptible to the sampling gear used in long-term monitoring efforts, and it is anticipated that fish spawned and recruited from 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, 2014b).

Furthermore, an age was determined from 1 of the 10 flannelmouth suckers captured at long-term monitoring sites. This individual was captured at the Virgin River/Muddy River inflow area and was an individual spawned during 2010 (495 mm TL). One 11-year-old hybrid (558 mm TL) was recaptured at long-term monitoring areas, originally captured in 2013.

Survival Estimation

A total of 560 individuals was included in the dataset spanning 1996–2015, ranging in size from 451 to 756 mm TL, with a mean TL of 582 mm (± SE = 2.5). Using these data, a model averaged of annual apparent survival was calculated at a rate of 0.80 with 95% confidence bounds of 0.45–0.95 (table 5) and was similar to the 2014 estimate (Albrecht et al. 2014b). 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 5; attachment 2).

Table 5.—Annual apparent survival rate estimate for razorback suckers in Lake Mead produced in the program MARK using adult (> 450 mm TL) mark-recapture data, 1996–2015

Model[a]	Annual apparent survival rate estimate (95% confidence bounds)	Capture events	SE	Recapture probability
Cormack-Jolly-Seber Model				
$\phi(.)p(t)$	0.77 (0.73–0.81)	20	0.02	0.05–0.44
$\phi(t)p(t)$	0.17 (0.04–0.48)	20	0.11	0.07–1.00
Model averaged				
Derived ϕ	0.80 (0.45–0.95)		0.12	

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

DISCUSSION AND CONCLUSIONS

Long-term monitoring information collected during the 2014–15 field season (19th field season) has expanded our knowledge of spawning behavior, year-round movement, recruitment patterns, growth, and the demographics of the razorback sucker population 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 response 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 2014–15 field season (figure 2) and can be characterized by declining elevations, desiccation of littoral habitats and spawning areas, and overall dry conditions. In the past, changes in Lake Mead surface elevations have resulted in the movement of suspected, primary razorback sucker spawning sites. As lake elevations declined during the 2015 spawning season, razorback suckers reused historical spawning locations in the Virgin River/Muddy River inflow area but primarily utilized completely new areas in Echo Bay and Las Vegas Bay (figures 15, 18, and 19). 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 2015 spawning period that were tagged during previous field seasons in nearby areas. Continued monitoring to inform the relative importance of each monitoring location, the shifts in spawning site use, and the yearly recruitment will be important as the Colorado River drainage continues to suffer from unprecedented drought conditions. More on this subject is discussed below, in the "Adult Sampling and Spawning Site Observations" section.

Sonic Telemetry

Sonic telemetry continues to be a vital tool in helping to define spawning sites, place trammel nets and other gear types, and document lake-wide movement. Contact was made with 7 of 8 fish from the 2011 long-term monitoring tagging event, 2 of 4 fish from the 2012 juvenile tagging event, and 11 of 13 fish from the

2014 tagging event, including 2 individuals originating from the CRI. The individuals that were sonic tagged in 2011 continued to provide valuable and fortuitous information during the 2014–15 field season, as it was unlikely these fish would be detected due to the expiration of the 48-month battery life in the tag. However, these fish were detected quite readily and underscore the importance of continuing tagging at long-term monitoring sites.

The patterns of movement by wild sonic-tagged individuals in 2014 mirrored those observed in the past for pond- and hatchery-reared individuals stocked in the past (Albrecht et al. 2008b, 2010b, 2013a, 2013b; Shattuck et al. 2011). Though not particularly surprising, it is encouraging to see similar seasonal movement behaviors in both wild and stocked individuals, further demonstrating that stocked individuals seem to integrate well into the overall population. A comprehensive analyses of the size of home ranges between groups, movement patterns observed throughout the year, and habitats used would help determine if innate differences exist between wild and stocked individuals if conducted using multiple years of data. During 2015, wild sonic-tagged razorback suckers helped define spawning site locations in each of the long-term monitoring study areas and helped to guide trammel-netting efforts, similar to the benefits observed in previous study years.

The use of SURs has become an increasingly helpful tool for assessing the timing of returning individuals to spawning sites as well as the timing of post-reproductive movement into summer foraging and resting areas during the late summer months. Having the ability to monitor areas unfrequented by regular sonic surveillance aided in documenting long-distance razorback sucker movement among long-term monitoring study areas and helped account for individuals that have gone undetected for relatively long expanses of time. A small decrease in the use of SURs from the 2013–14 field season to the present, along with a more strategic placement of existing units, appears to have maintained a fairly high level of efficiency in monitoring of locations outside of the established long-term monitoring study areas and has helped to describe seasonally driven movements and movement distances of razorback suckers (figures 7 and 8). Perhaps most interesting, some individuals are detected by either passive or active telemetry but not both (see table 1). This could indicate several possibilities such as (1) some razorback suckers exhibit very small home ranges and never reach a SUR, (2) some individuals are only mobile during times when active telemetry is not taking place or rarely takes place (i.e., night), or (3) there are other important areas of Lake Mead that hold small populations of razorback suckers, and contacting one was a unique event. The possibility that any of the above (or unmentioned possibilities) could be true shows there is much research and monitoring that can be done on this unique species. The sonic telemetry data collected over successive seasons and years has helped to identify areas of importance within Lake Mead not only during reproductive activity but also during periods of environmental stress (e.g., warm summers and cool winters) and during periods of environmental change (e.g., fluctuating lake elevations and high-flow events). By collecting data over a lake-wide scale, as in the use of SURs, movement and habitat association information may be better understood, ultimately lending insight as to why recruitment continues to occur within Lake Mead razorback suckers despite what appears 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 (figure 2), 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 in location interannually (figures 4–6), and sonic-tagged fish have been a key component in the ability to closely follow those fluctuations. Furthermore, these sonic telemetry portions of these studies have shown timing of movement. Demonstrating that movement by razorback suckers is almost non-existent during spawning but highly active before and after spawning. In general, it seems that sonic-tagged razorback suckers decrease movement in the late summer months (figure 7), which may show that fish are occupying refuge habitats during these months. 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 2015, only one individual with a current sonic tag was captured (sonic tagged fish 3478) (see table 3). This observation has been discussed in recent past reports (Shattuck et al. 2011; Albrecht et al. 2013a, 2014b).

Adult Sampling and Spawning Site Observations

In summary, 1,118 razorback sucker captures have helped identify 665 unique individual razorback suckers at long-term monitoring study areas during this 19-year study (1996–2015) by multiple agencies (BIO-WEST, the NDOW, and the USFWS), not including 94 captures of 88 unique individuals from 1990–95 (Holden et al. 1997). Trammel-netting results in 2015 documented the continued presence of wild adult razorback suckers, the majority of which were captured in the Virgin River/Muddy River inflow area (86%, $n = 19$). The presence of numerous new, wild fish in the Virgin River/Muddy River inflow area follows results noted in past reports in which high numbers of younger fish (≤ 7 years of age) have been observed (Albrecht et al. 2008a, 2013a, 2013b, 2014b; Kegerries et al. 2009; Shattuck et al. 2011). The Lake Mead population still appears to be relatively young, though fewer individuals ≤ 7 years old were captured in 2015 compared with 2011 and 2012 (attachment 1), likely because fish recruited during high recruitment years of the early 2000s have exceeded 7 years old. It is also possible that because of the reduced effort during this season, we were not able to capture enough fish to describe these younger age classes. The strong year-class from the 2004–05 field season remains as an excellent recruitment year-class for Lake Mead razorback suckers (Kegerries et al. 2009; Albrecht et al. 2010a, 2010b, 2010c, 2013a, 2013b, 2014b; Shattuck et al. 2011). The capture of these younger fish demonstrates that natural recruitment of razorback suckers has continued at Lake Mead despite changing lake elevations, indicating this may not be a primary recruitment driver. The capture of one juvenile razorback sucker at the Virgin River/Muddy River inflow area during the 2014–15 field season and the number of young individuals captured at or near spawning habitat during the spawning period from 2008–12 directly demonstrates a relatively high abundance of young razorback suckers in Lake Mead, particularly when coupled with the aging information obtained in recent years. Capture of juveniles is important in demonstrating that currently trammel gear is capable of catching young, small-bodied razorback suckers, but it is a rare event for currently unknown reasons. 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 individuals were captured from long-term monitoring study areas. Fortuitously, a specific study targeting this rare life stage is currently in progress and should help further define juvenile razorback sucker habitat use (Shattuck and Albrecht 2014; Kegerries et al. 2015).

The number of razorback sucker captures in 2015 are encouraging; however, the lower mean catch rates at Las Vegas Bay and Echo Bay (figure 12a) warrant discussion. Because lake elevations were at a 5-year high at the beginning of 2012 (figure 2), a large expanse of shallow habitat, which in past years had been inaccessible to razorback suckers, was newly inundated. The availability of this habitat coincided closely with the razorback sucker reproductive season in 2012, and the habitat was used frequently by sonic-tagged individuals (Albrecht et al. 2013a). Though lake elevations began to decline again at the start of the 2013 and 2014 spawning seasons, much of this inundated habitat was still being used by sonic-tagged razorback suckers as well as by new, wild fish (Albrecht et al. 2013b). However, much like the netting difficulties experienced in 2012 and 2013, the heavy cover these fish were associating with also made net placement difficult in 2014 and 2015, particularly coupled with the expansion of the wash delta and abundance of shallow conditions near the wash/lake interface in 2014. Not only was the heavy, inundated cover likely providing structural protection for razorback suckers using this habitat, it often prevented consistent net placement and made it nearly impossible for the trammel net to rest on the bottom. In 2015, as lake elevations continued to drop, more fish were detected by active telemetry in the slightly deeper, less vegetated waters of Government Wash cove; therefore, netting efforts were more focused there. As receding waters left shallow, flatter areas desiccated, much of the remaining habitat had sharper dropoffs from the bank, which possibly made adequate net sets more difficult. Thus, it is likely that the nets may be less efficient than those used in past efforts (Kegerries et al. 2009; Shattuck et al. 2011). Another factor that may have led to lower capture rates in 2015 was the overwhelming abundance of non-native fishes in the gear, specifically gizzard shad (*Dorosoma cepedianum*) (similar to past years). Though nets may not have been effective for bottom fishing, midwater captures contained enough gizzard shad to hypothetically load the nets and render them unavailable to capture other fishes. However, the presence of numerous non-native fishes is not new to Lake Mead, though certainly the abundance of this particular species has fluctuated greatly (e.g., shad production [D. Herndon 2011, personal communication]).

Despite continued changes in lake elevations (figure 2) 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 2015. The 2015 primary spawning sites shifted in tandem with lake elevations but were more focused in spatial extent compared with the previous year's spawning sites. In general, spawning sites in 2015 were in completely new areas of Las Vegas Bay and Echo Bay and overlapped only with the 2011 spawning site at the Virgin River/Muddy River inflow area. At the Virgin River/Muddy River inflow area, the change in site from 2012–14 years is a direct adjustment by fish caused by changes in lake elevation, given that the northern portion of the Overton Arm bathymetry is more gradual and exhibits far greater changes in desiccated lakebed. The Las Vegas Bay spawning site was fairly constricted in spatial extent due to steeper and more restricted topography, particularly at lower lake elevations. It has been noted that spawning sites in the Virgin River/Muddy River inflow area move further in location interannually than at any other long-term monitoring study area (see figure 6) and that sonic-tagged fish have closely followed those fluctuations (Albrecht et al. 2013b). These dynamics and complexities at Las Vegas Bay and the Virgin River/Muddy River inflow area 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, particularly 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. Finally, the continued reproductive activity proximal to historic spawning sites strengthens the idea that many razorback suckers return to the same spawning sites year after year (Tyus and Karp 1990).

The 2015 spawning site in Las Vegas Bay was in a different location than it has been in previous years (Shattuck et al. 2011; Albrecht et al. 2013a, 2013b, 2014b). Although a number of sonic-tagged individuals frequented the suspected spawning site within Government Wash cove, few sexually mature adults were collected (n = 2). 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. In 2012, it was suspected that the northern shore of Las Vegas Bay might be used as a spawning site, although the southern shore produced the only sexually active adult in Las Vegas Bay, as well as numerous larvae. Similarly, in 2013, three sexually mature adults were captured off the southern shore at the western extent of Las Vegas Bay; however, one individual was found in Government

Wash cove, and larval razorback suckers were collected throughout the western extent of the bay. This year, it is likely that due to diminished lake elevations, the spatial area available to spawning razorback suckers has been further reduced, given the rather constricted nature of Las Vegas Bay. For this reason, Government Wash cove may now have similar conditions along its shoreline, as did spawning locations nearer to Las Vegas Wash in past years. Anecdotally, the warmer water from Las Vegas Wash may play a role in cueing sexually ready razorback suckers to spawn earlier than at other study areas in Lake Mead and may promote more broadly distributed spawning. The warmer water within Las Vegas Bay may suggest that an earlier sampling protocol be implemented to better gauge the start of the spawning year and provide a more accurate assessment of the individuals that are frequenting the area.

The primary 2015 spawning site in Echo Bay was identified by a combination of larval fish collections (see figure 18), adult fish collections (see figure 10), and sonic-tagged fish locations (see figure 5). In recent years, the Echo Bay spawning sites had been on the northern side of the bay and appeared to follow receding lake elevations. As such, razorback suckers in Echo Bay appeared to not only follow historic trends and return to the spawning site locations of years past, but the primary activity included much of the northeastern shoreline of Echo Bay. Echo Bay contributed few adult razorback suckers to the overall catch despite frequent contacts during the spawning season via active telemetry. Again, the sonic-tagged fish helped define the Echo Bay spawning site and indicated that Lake Mead razorback suckers can survive for substantial periods of time despite many potential stressors and causes of mortality (see table 3; attachment 1).

Similar to Echo Bay, the spawning site at the Virgin River/Muddy River inflow area in 2015 was defined based on a combination of larval collection data (see figure 19), adult collections (see figure 11), and sonic-tagged fish locations (see figure 6). Sonic-tagged fish were contacted frequently within and near the designated spawning area at the Virgin River/Muddy River inflow area (see figure 6), and the placement of trammel nets near these sonic-tagged fish yielded high densities of adult razorback suckers exhibiting reproductive readiness (e.g., colored and tuberculated individuals freely giving milt or eggs). Razorback sucker larval collections at the Virgin River/Muddy River inflow area spawning site were relatively high and almost identical to the other two long-term monitoring sites. This further aided in the identification of the spawning location for this long-term monitoring study area and confirms similar observations of high larval abundance in this study area for the third consecutive year (Albrecht et al. 2013b, 2014b).

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. In long-term monitoring capture data from 1996–2013, 14 individuals moved between the

2 long-term monitoring study areas, while 1 wild individual tagged at the Virgin River/Muddy River inflow area moved to Echo Bay and then to the CRI (Kegerries et al. 2009; Kegerries and Albrecht 2013a, 2013b; Albrecht et al. 2014b). 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 2015, several razorback suckers moved between the Virgin River/Muddy River inflow area and Echo Bay (in either direction). Perhaps even more striking was documentation of two wild individuals captured and implanted with a sonic tag in the 2014 season at the CRI, immigrating to the Virgin River/Muddy River inflow area presumably to spawn (as documented through active and passive sonic telemetry) within the 2015 spawning site. Furthermore, one of these individuals continued to migrate a long distance from the Virgin River/Muddy River inflow area to the Las Vegas Bay and back again within several days, but it cannot be stated with certainty where spawning actually occurred. Given this fish was a mature male, it is possible it spawned in multiple locations. This combined information helps define the connected nature of the various spawning aggregates of razorback suckers throughout Lake Mead. Based on data collected since 2005, it appears that the northern Lake Mead razorback sucker population's use of spawning habitat is broad and can be quite diverse.

Data from 2015, along with past years, indicate the Virgin River/Muddy River inflow area spawning aggregate is one of the largest (or most active) in Lake Mead (see figure 13). Nearly 86% of the razorback suckers captured in 2015 came from the Virgin River/Muddy River inflow area. Mainly wild individuals were captured, and approximately one-half were new, wild, unmarked fish that were captured for the first time this season (see table 3). The broad use of spawning habitats throughout the northern portion of Lake Mead is extremely important in terms of the overall status of Lake Mead razorback suckers, suggesting that the total numbers of fish inhabiting the lake may be higher than previously thought. However, the three primary, long-term monitoring study areas at Lake Mead have changed dramatically over the last 19 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 apparent reduction of common carp captures 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.

Larval Sampling

Larval razorback suckers were again captured at each of the previously documented spawning sites in Lake Mead (i.e., Las Vegas Bay, Echo Bay, and the Virgin River/Muddy River inflow area) during the 2015 spawning period. Results from the 2014–15 field season were characterized by nearly equal CPM rates of larval fish at each site (figure 16) (Albrecht et al. 2008a, 2010b, 2013a, 2013b; Kegerries et al. 2009; Shattuck et al. 2011). 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 (figure 20), there is little reason to be pessimistic about the success of the 2015 year-class despite the historically low lake elevations.

In 2015, and for the third consecutive year (Albrecht et al. 2013b, 2014b), Las Vegas Bay experienced a relatively high larval mean catch rate (see figure 16; 0.217 larval mean CPM). Mean larval catch rates varied between 0.093 in 2010 to a high of 0.430 in 2008. Interestingly, this elevated catch rate occurred despite catching almost no reproductively ready adult razorback suckers. This could suggest that adult spawning occurred in Las Vegas Bay before the netting season started. This pattern appears to have occurred for several years (Albrecht et al. 2013a, 2014b; Shattuck et al. 2011). Warm-water inputs from Las Vegas Wash are what may be driving an earlier spawning que for razorback suckers compared to other long-term monitoring sites. Although the majority of larval razorback sucker collections occurred within Government Wash cove, several larval razorback suckers were collected near the flowing conditions imparted by Las Vegas Wash at the wash/lake interface on the north and south shorelines (see figure 17). These collections stress the importance of the moving water environment and additions of sediment and nutrients made by flowing water at long-term monitoring sites. Past studies have shown 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 though 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.

Larval sampling in Echo Bay resulted in higher catch rates in 2015, above the range of larval catch rates observed in this study area from 2012–14 (see figure 16). The high number of larval razorback suckers captured at this study area was surprising given that relatively few fish were detected via active telemetry, and that only one individual was captured during trammel netting. As anthropogenic development and activity in Echo Bay appear to be on the decline, it is possible that less anthropogenic disturbance is benefitting larval razorback sucker production. Future studies focused on the drivers behind spawning success should be undertaken at this site.

Mean larval catch rates in the Virgin River/Muddy River inflow area were at an all-time high for the third consecutive year during 2015, where CPM rates were also equivalent to Echo Bay (see figure 16). 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; Shattuck et al. 2011; Albrecht et al. 2013a, 2013b, 2014b); however, the sharp, upward trend of the last 3 years appears unique. 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 and relativity long fetch in this area of Lake Mead. With declines in lake elevation and the potential for more rapid desiccation of spawning habitats at the Virgin River/Muddy River inflow area, elevated mean larval catch rates in 2015 were perhaps indicative of a strong and sizable reproductive effort, underscoring the importance of this spawning location for Lake Mead razorback suckers.

Future collection of detailed physiochemical and limnological data, as well as larval fish capture data through the long-term monitoring efforts (as described in this and past reports) and the ongoing juvenile razorback sucker studies (Albrecht et al. 2013a; Shattuck and Albrecht 2014; Kegerries et al. 2015), will be important in helping to understand differences in larval fish production, which in turn and placed in context, 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 additions (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.

Drivers of Lake Mead Recruitment

The continued pulses of new captures of 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 unexpected initiation of Lake Mead razorback sucker recruitment has been attributed to changes in the management of the lake. 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 habitat 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.

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 other Lake Mead or Lake Mohave coves they evaluated. Shattuck and Albrecht (2014) and Kegerries et al. (2015) report similar observations, with seasonally elevated turbidity values being observed for the Virgin River/Muddy River inflow area and Las Vegas Bay during recent juvenile razorback sucker sampling efforts at all three long-term monitoring locations. Furthermore, it has been accepted for years that turbidity plays a role in the susceptibility of young razorback suckers to predation (Johnson and Hines 1999). This information led to the hypothesis that low, annual fluctuations and large, multi-year lake elevation changes that 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. Findings regarding juvenile razorback suckers by Shattuck and Albrecht (2014) are some of the first to quantify the use of cover by this rare life stage and underscore the importance of cover, turbidity, and complex habitats to juvenile razorback suckers in Lake Mead, particularly relevant considering a sizable non-native fish presence. This is especially interesting, given the possibility that some catostomid fishes may not spawn every year (Geen et al. 1966; Perkins and Scoppettone 2000).

Data collected during recent spawning periods suggest that turbidity may be much more important for razorback sucker recruitment in Lake Mead than previously thought, at least under conditions imposed by low lake elevations (Albrecht et al. 2008b). Inflow habitats have been noted to 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 (figure 19) (Shattuck et al. 2011). Razorback sucker aging data show that, along with the strong recruitment in 2002 and 2003, very substantial recruitment continued from 2004 to 2006. Since lake elevations declined during this period, it is hypothesized that a majority of shoreline cover in the form of inundated vegetation was lost and that razorback sucker recruitment may have been successful during this time due to the availability of cover in the form of turbidity. Turbidity is an environmental variable that has also proven to significantly reduce non-native predation of similar Colorado River fishes (D. Ward 2012, personal communication; Knecht and Ward 2012). Additionally, high-flow events that bring woody debris and fine sediments into Lake Mead may play an important role in providing cover and nutrients. Both turbidity and vegetative cover are likely important recruitment factors 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 comparisons among years or lake elevations can be made in the future. Steps toward this end have been recently initiated at Lake Mead (Shattuck and Albrecht 2014; Kegerries et al. 2015).

Albrecht et al. (2007, 2008a, 2008b) hypothesize that turbidity is an important factor allowing for continued razorback sucker recruitment under low lake elevations on Lake Mead; however, turbidity appears to be equally important in the transitional increase of lake elevation. It seems logical that deltas associated with Lake Mead inflows begin to expand during low-water years, and riverine and wave action on the exposed sediment of the deltas and barren shorelines could contribute to increased cover in the form of turbidity, either directly (by deposition of smaller, suspended particles) or indirectly (through increased nutrient loading and wind-driven mixing). Additionally, high-flow disturbances that provide large influxes of sediment and woody debris would, in turn, provide increased cover in the form of turbidity as lake elevations increase. In fact, this has been observed during the course of recent studies. As the deltas expand due to dropping lake elevations and hydrological forces of flowing water at the inflows, more and more sediment could be eroded. As stated previously, this may in turn increase the amount of suspended sediment (turbidity) that occurs at Lake Mead at the inflows, which would provide cover for early life stages of razorback suckers. Hence, cover in the form of turbidity increases, ultimately leading to increased recruitment. 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., 1978–85 and 1998–99) lake elevations, habitat characteristics— such as cover in the form of turbidity and/or vegetation, similar to that found in Lake Mead—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.

Growth and Aging

Through 2015, 478 razorback suckers from long-term monitoring study areas have been aged from approximately 2 to 36 years. Lake Mead has had an increasing number of young, wild razorback suckers (7–9 years old) that have been captured and tagged, characterizing the recent recruitment in Lake Mead (Albrecht et al. 2008b) that occurred in the early 2000s. The strength of the 2003 and 2005 year-classes has been documented by Kegerries et al. (2009) and Albrecht et al. (2010b) (figure 20) and is further evident as most fish aged in 2015 were 6–12 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. This is the first year in which there has been confirmed similar, indistinguishable growth between stock and wild individuals. This suggests that in at least aspects of growth (i.e., growth rate and maximum size), stocked fish integrate into the Lake Mead population very well.

Population and Survival Estimation

The lake-wide population estimates produced in program MARK for 2013–15 used identical methods as the previous reporting years; however, useful results were not able to be obtained and were therefore not included in this report. Limited recaptures (or re-encounters) of adult razorback suckers severely limited the ability to estimate the population size. These unusable results are likely driven by the change in sampling methodology during the 2015 field season (biweekly sampling versus weekly sampling and the overall lack of captures/recaptures). The decline in effort resulted in less captures in 2015 compared to previous years from fewer opportunities for individuals to be captured/recaptured at the long-term monitoring sites. A much higher re-encounter rate of tagged razorback suckers of around 20–30% within a potentially shorter amount of time (i.e., 1 year or less) would be ideal to properly achieve a useful population estimate (Cooch and White 2013). It could be possible to obtain a population estimate in the future, should it be deemed necessary, by (1) netting during an intensive week to 2-week long period when its most likely razorback suckers could be caught (attachment 3), (2) the use of PIT tag antennas in conjunction with the currently used netting protocol, and/or (3) a combination of the two.

Although an apparent survival estimate was produced for long-term monitoring study areas in the past (Albrecht et al. 2013a, 2014b), the apparent annual survival rate reported for 2015 includes a larger span of data (1996–2015) and 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). The weighted average of lake-wide annual apparent survival calculated a rate of 0.80 (95% confidence bounds of 0.45–0.95) for adult razorback suckers greater than 450 mm TL in the four combined study areas of Lake Mead, which is similar to other populations of adult individuals. 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, those less than 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 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 19 years of long-term monitoring study.

Conclusions

The 2014–15 field season was exceptional in that all of the long-term monitoring objectives were met. Multiple life stages of razorback suckers were captured, sampled, and surveyed using a wide variety of methodologies in a 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), particular interest remains in the 2011 year-class of razorback suckers, which appears to have been subjected to conditions similar to those experienced by the relatively strong 2005 year-class (see figure 19). With the capture of larval fish at all known spawning sites in 2014, the status of the Lake Mead razorback sucker remains optimistic. It is noted that 2014 CPUE values for both larval sampling and trammel netting either exceeded or remain within the range of values previously reported during long-term monitoring efforts to date. This context underscores the importance of maintaining long-term monitoring and continuing to build long-term datasets for tracking and understanding this unique population. Without such monitoring, this type of continued insight would not be possible, and the dedication and foresight by all collaborators to date, and toward this end, should and will continue to be applauded, for and on behalf of this species. 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. 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.

2015–2016 WORK PLAN (LONG-TERM MONITORING)

Specific Objectives for the 20th 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 in 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 February during the onset of typical long-term monitoring, it is recommended that initiating sampling efforts at that study site be at least 1 month earlier (starting in January) than has typically been done, as doing so may help to alleviate the relatively lower catch rates of razorback sucker life stages in this warmer water study location that has been observed in recent years. 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 (attachment 3). Furthermore, the use of 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, increased netting efforts would be preferred. Finally, and following 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 7 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 the contemporary conservation status of razorback suckers in Lake Mead.

3. Continue to lend support to the Lake Mead Interagency Work Group. In short, 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 the juvenile life stage and crews working 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, ripe adult and larval razorback suckers, these efforts have resulted in the documentation of a spawning aggregate near the Colorado River/Lake

Mead interface and identified the possibility of spawning occurring within the lower Grand Canyon (Kegerries and Albrecht 2013b; Albrecht et al. 2014a; 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. 2014a). Thus, the potential exists for continued, perhaps increased, exchange of sonic-tagged razorback suckers (and other native suckers) between 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). Furthermore, in 2013, a full-scale study focusing on the movement and habitat associations of juvenile razorback suckers was initiated. The results thus far better define seasonal movements of juvenile individuals and document some of the habitat associations that may allow for the survival and subsequent natural recruitment that makes the Lake Mead population somewhat unique throughout the Colorado River Basin. To date, this study provides one of the only existing collections of physicochemical data for Lake Mead, specific to razorback suckers, which may provide insight into the adult population demographics with regard to recruitment patterns based on seasonal and annual environmental conditions. 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 the non-native fish pressures and habitat modifications that are common throughout the historical range of this species. Albrecht et al. (2013a) present the initial developments in achieving this goal though juvenile razorback sucker research. Additional efforts pertaining to the early life stages of Lake Mead razorback suckers are currently underway and would be recommended to continue. Results from the juvenile study are most recently reported by Shattuck and Albrecht (2014) and Kegerries et al. (2015).

6. Sonic tag wild-caught razorback suckers from Lake Mead if/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, as doing so will ensure that future monitoring capabilities remain as cost efficient and effective, and as scientifically similar and comparable, to all other monitoring conducted on Lake Mead since Albrecht et al. (2006b).

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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, 1998–2015

Date collected	Total length (millimeters)	Age	Presumptive year spawned
Las Vegas Bay			
5/10/1998	588	10[a]	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[a]	1982
3/25/2002	576	20	1982
5/7/2002	641	15	1986
6/7/2002	407	6	1995
6/7/2002	619	20[a]	1982
6/7/2002	642	20[a]	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, 1998–2015

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	21[a]	1982
4/17/2003	618	10	1992
4/22/2003	650	20–22	1980–82
5/4/2003	415	3+[b]	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, 1998–2015

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, 1998–2015

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, 1998–2015

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[f]	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, 1998–2015

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, 1998–2015

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, 1998–2015

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[e]	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, 1998–2015

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[c]	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, 1998–2015

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[d]	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, 1998–2015

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, 1998–2015

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, 1998–2015

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, 1998–2015

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, 1998–2015

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, 1998–2015

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, 1998–2015

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[f]	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, 1998–2015

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[d]	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*) Annual Apparent Survival Rate Estimate – Model Selection Summary

Table 2-1.—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 (greater than 450 millimeters total length) annual mark-recapture data, 1996–2015

Model[a]	**AIC_c**[b]	**ΔAIC_c**[c]	**AIC_c weight**[d]	**Model likelihood**[e]	**Number of parameters**	**Deviance**[f]
Cormack-Jolly-Seber						
$\phi(.)p(t)$	1576.2732	0.0000	0.60436	1.0000	20	417.4866
$\phi(t)p(t)$	1577.1205	0.8473	0.39564	0.6546	37	381.6214
$\phi(t)p(.)$	1601.5613	25.2881	0.00000	0.0000	20	442.7748
$\phi(.)p(.)$	1619.3977	43.1245	0.00000	0.0000	2	497.7141

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

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

[c] AIC_c minus the minimum AIC_c.

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

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

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

ATTACHMENT 3

Razorback Sucker (*Xyrauchen texanus*) Catch per Net-Hour at Long-Term Monitoring Sites During the February – April Sampling Season

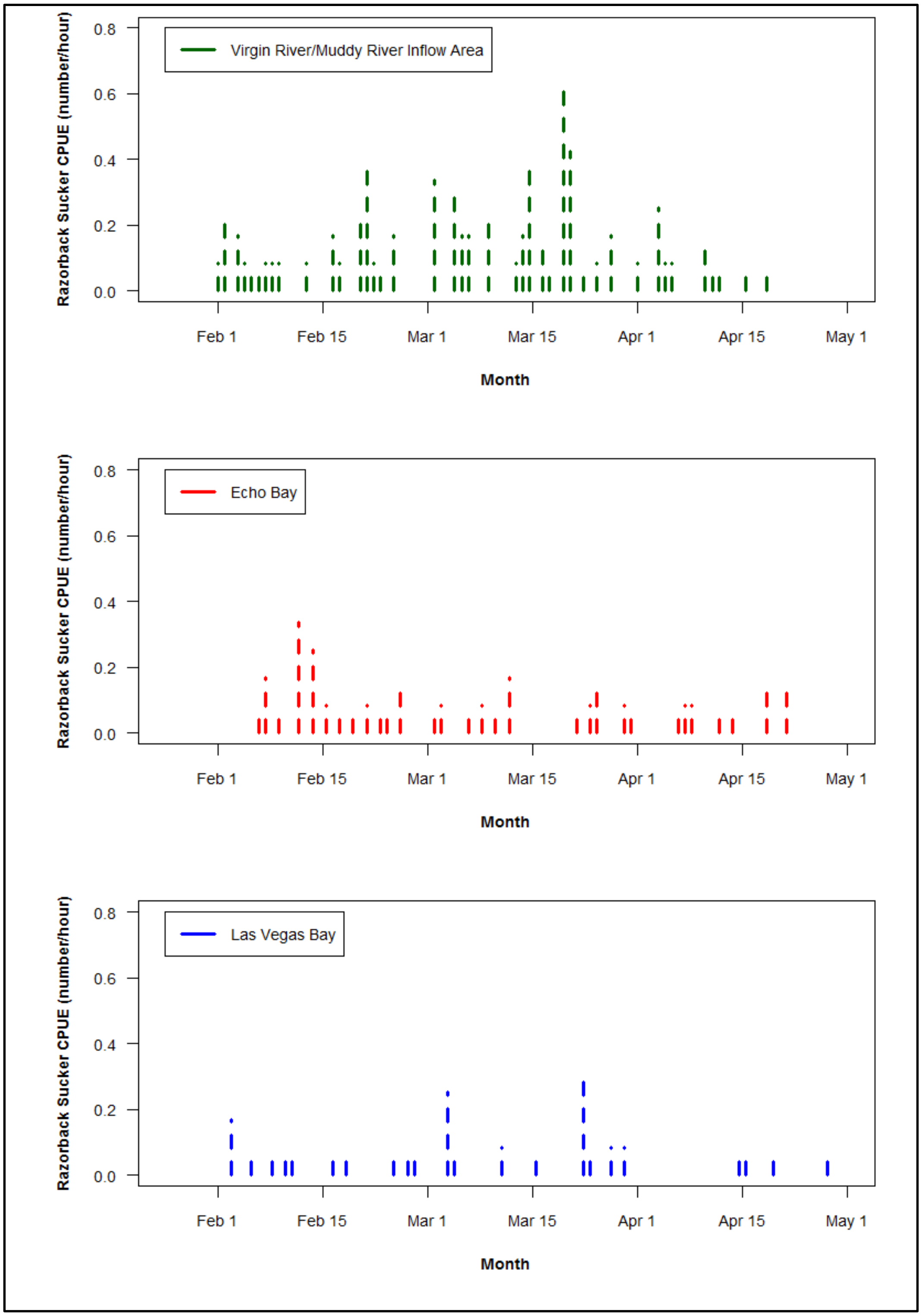

Figure 3-1.—Razorback sucker catch per unit effort (net-hours) for individual nets at each long-term monitoring site is shown based on the date each net was pulled from Lake Mead.