Lower Colorado River
Multi-Species Conservation Program

Balancing Resource Use and Conservation

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

2013–2014 Annual Report

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

October 2014

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Lower Colorado River Multi-Species Conservation Program

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ACRONYMS AND ABBREVIATIONS

AGFD	Arizona Game and Fish Department
AICc	corrected Akaike's information criterion
BIO-WEST	BIO-WEST, Inc.
cm	centimeter(s)
CPM	catch per minute
CPUE	catch per unit effort
CRI	Colorado River inflow
FL	fork length
g	gram(s)
km	kilometer(s)
mL	milliliter(s)
L	liter(s)
LCR MSCP	Lower Colorado River Multi-Species Conservation Program
LMWG	Lake Mead Interagency Work Group
m	meter(s)
mm	millimeter(s)
MS-222	tricaine methanesulfonate
msl	mean sea level
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

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EXECUTIVE SUMMARY

In 1996, the Southern Nevada Water Authority (SNWA) and Colorado River Commission of Nevada, in cooperation with the Nevada Department of Wildlife (NDOW), Arizona Game and Fish Department, National Park Service, Bureau of Reclamation (Reclamation), and U.S. Fish and Wildlife Service initiated a study to develop information about the Lake Mead razorback sucker (*Xyrauchen texanus*) population. BIO-WEST, Inc. (BIO-WEST), under contract with the SNWA, designed the study and had primary responsibility for conducting the research. In 2005, Reclamation (under the Lower Colorado River Multi-species Program [LCR MSCP]) became the principal funding agency, and the study became primarily a long-term monitoring study in 2007. In 2012, Reclamation 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, Reclamation 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 18th year (2013–14) of the long-term monitoring study are provided herein, while investigations in the juvenile razorback sucker study are included in Shattuck and Albrecht (2014), and investigations from the Colorado River inflow (CRI) area are included in Albrecht et al. (2014).

During the 18th field season, 22 sonic-tagged fish were monitored, resulting in 152 active contacts and 46,511 passive contacts from 10 submersible ultrasonic receivers. These individuals were representative of several different tagging events, including the following: 2011 (n = 8), 2012 (n = 2), and 2014 (n = 12). During the 2014 tagging event, 11 of the 12 sonic-tagged individuals were captured in concurrent trammel netting efforts, including 1 wild individual originally captured and tagged at the CRI area. 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 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.

Eighty-five razorback suckers were captured using trammel netting—8 from Las Vegas Bay, 22 from Echo Bay, and 55 from the Virgin River/Muddy River inflow area—during the 2014 spawning period. Interestingly, two recaptured razorback sucker x flannelmouth sucker hybrids were collected at the Virgin River/Muddy River inflow area during 2014. This is the second time that hybrids have been captured during the long-term monitoring study. The razorback sucker x flannelmouth sucker hybrid individuals were keyed by visual inspection according to descriptions for meristic counts and measurements in Hubbs and Miller (1953). Of the 85 total razorback suckers collected in 2014, 27 new,

unmarked, wild razorback suckers were captured at the Virgin River/Muddy River inflow area, a highlight of the 18th field season that suggests the continued importance of the Virgin River/Muddy River inflow area of Lake Mead for razorback sucker production and recruitment. For the fifth consecutive study year, trammel netting capture rates in the Virgin River/Muddy River inflow area eclipsed those in other, more extensively studied, long-term monitoring study areas.

Average annual growth during this field season, as determined from 37 recaptured fish analyzed, was 13.6 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 (e.g., Lake Mohave [Minckley 1983] and the Green River [Tyus 1987] have lower annual growth rates [2–5 millimeters per year]), suggesting the Lake Mead razorback sucker populations are able to maintain a fairly strong cohort of young, fast-growing fish). Additionally, fin ray sections were removed from 35 razorback suckers for age determination which, when combined with the 435 fish aged during previous field seasons, brings the total number of fish aged during the long-term study to 470. Age determination techniques have shown near-annual recruitment in Lake Mead and associated recruitment pulses during relatively high, stable lake elevations; however, based on data collected from 2007 to 2014, 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 again documented in all study areas in 2014, with a combined total of 872 larval individuals collected and released. Additionally, BIO-WEST worked collaboratively with NDOW biologists in a continued effort to collect additional Lake Mead larval razorback suckers for future research use and genetic analyses. In part, larval razorback sucker abundance was used to help define spawning sites during the 2013–14 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 2014 and into 2015, this report reiterates the need to further investigate conditions that promote recruitment patterns of razorback suckers in Lake Mead. General research for the 2014–15 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 are Colorado pikeminnow [*Ptychocheilus Lucius*], bonytail chub [*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 razorback suckers have been greatly reduced (Minckley et al. 1991). 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, which replaced warm, riverine environments (Holden and Stalnaker 1975; Joseph et al. 1977; Wick et al. 1982; Minckley et al. 1991). Competition and predation from nonnative 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 apparently recruited during the first few years of reservoir formation. The population of long-lived adults then disappeared 40–50 years following reservoir creation and the initial recruitment period (Minckley 1983). The largest reservoir population, estimated at 75,000 individuals in the 1980s, occurred in Lake Mohave, Arizona and Nevada, but it had declined to less than 3,000 individuals by 2001 (Marsh et al. 2003). Mueller (2005, 2006) reported the wild Lake Mohave razorback sucker population to be near 500 individuals, while the most recent 2014 estimate of wild Lake Mohave razorback suckers was not reported, as too few wild fish were captured (Marsh & Associates, LLC 2014). Interestingly, young, wild fish continue to be captured in Lake Mead, underscoring the uniqueness and natural complexity of this 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). Predation by bass (*Micropterus* spp.), common carp (*Cyprinus carpio*), channel catfish (*Ictalurus punctatus*), sunfish (*Lepomis* spp.), and other nonnative species appears to be the principal reason for lack of razorback sucker recruitment (Minckley et al. 1991; Marsh et al. 2003; Carpenter and Mueller 2008; Schooley et al. 2008a). However, because of the intensive stocking program and the remaining 2,525 repatriate 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 2014).

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 (AGFD) 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 a considerable 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 to 1996, 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 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 their campgrounds; the Colorado River Commission of Nevada; the AGFD; and the USFWS.

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

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

In 1998, Reclamation agreed to contribute additional financial support 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 the areas to be studied and extending the study period into the year 2000.

Additional study objectives added to fulfill Reclamation's needs included the following:

- 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, Reclamation (under the 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 request, BIO-WEST developed a monitoring protocol that helped raise data collection efficiency levels while striving to maintain the amount of information that would be gained studying various razorback sucker life stages during future monitoring and research efforts on Lake Mead (Albrecht et al. 2006a). In 2007, the project became primarily a monitoring study. In 2008, Reclamation and the SNWA established another cooperative agreement, extending monitoring efforts and following monitoring protocols developed by Albrecht et al. (2006a) through 2011. Finally, in 2012, Reclamation provided funding to maintain long-term monitoring efforts in its current form.

Efforts associated with the long-term monitoring have served as a foundation to expand the understanding of razorback suckers at the Colorado River inflow (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 of Lake Mead. More specifically, the following tasks are being conducted at these long-term monitoring study areas in Lake Mead:

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

This annual report presents the results of the 18th field season (February 2014 – April 2014 netting data, July 2013 – June 2014 sonic telemetry data) in accordance with the results reported by Albrecht et al. (2008a, 2010b, 2013a, 2013b), Kegerries et al. (2009), Shattuck et al. (2011), and other past annual reports. This report presents results from the 2013–14 long-term monitoring study, and other information from previous reports is included as applicable.

STUDY AREAS

All Lake Mead long-term monitoring activities conducted during the 2013–14 study year occurred at study areas used during efforts from 1996 to 2013 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; 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 Wash is the portion of the channel with stream-like characteristics. In recent years, this section has become a broad, shallow area that is generally inaccessible by boat.

- Las Vegas Bay begins where the flooded portion of the channel widens and the current velocity is reduced. Las Vegas Bay can have a flowing (lotic) and nonflowing (lentic) portion. The flowing portion is typically short (200–400 meters [m]) and transitory between Las Vegas Wash proper and Las Vegas Bay.

Because lake elevation affects what is called the “wash” or “bay,” 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)

- Nonflowing portion (usually has turbid water but very little, if any, current)

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

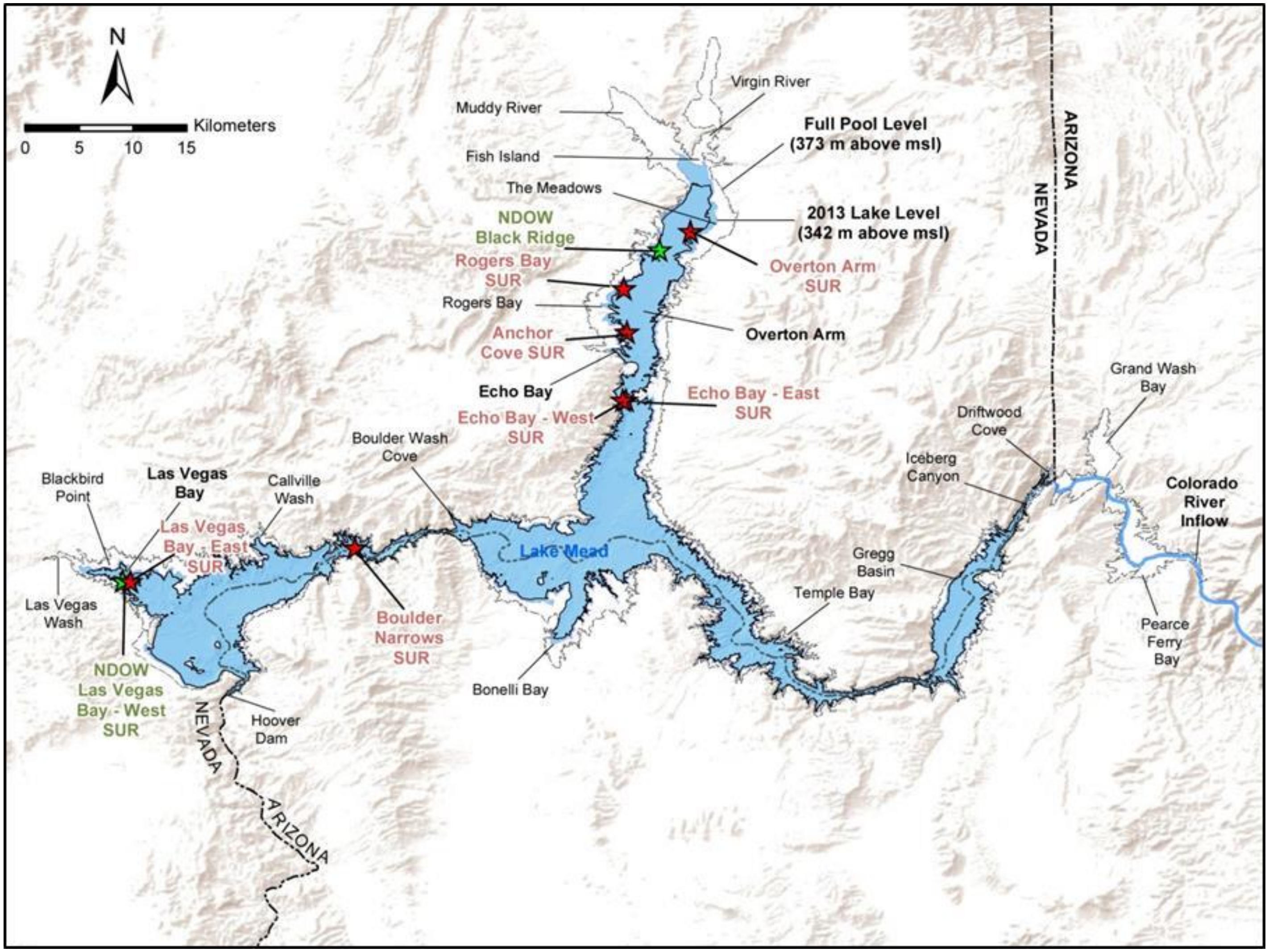

Figure 1.—Lake Mead general study areas.
The locations of long-term monitoring submersible ultrasonic receivers are denoted by red stars (units maintained by BIO-WEST) or green stars (units maintained by the NDOW).

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; depending on lake elevation, this area may or may not be an actual island)

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

METHODS

Lake Elevation

Month-end (1996–2015) and daily lake elevations for the 2013–14 field season (July 1, 2013 – June 30, 2014) were measured in meters above mean sea level (msl) and obtained from Reclamation's Lower Colorado Regional Office Web site (Reclamation 2014).

Sonic Telemetry

Sonic telemetry data for the long-term monitoring study were collected from July 1, 2013, to June 30, 2014, for seamless continuity with past reports and to capture movement throughout the year. During the intensive field season associated with the spawning period (February – May), sonic-tagged fish were located weekly (or sometimes daily) depending on the field schedule and weekly project goals. During the remainder of the year (June – January), sonic-tagged fish were typically located monthly.

Sonic Tagging

In response to recommendations in Albrecht et al. (2013a, 2013b) to use wild fish for replacement of sonic-tagged fish within the long-term study areas, select wild razorback suckers captured at the study areas during the 2013–14 field season were surgically implanted with sonic transmitters. Ten wild razorback suckers were captured and tagged from the study areas (two from Las Vegas Bay, four from Echo Bay, and four from the Virgin River/Muddy River inflow area), and one hatchery-reared razorback sucker from the Lake Mead Fish Hatchery was tagged and released in Las Vegas Bay to supplement lower catch rates observed. Details regarding these fish are included in the "Sonic Telemetry and Trammel Netting" sections of the results. Sonotronics Model CT-05-48-I (48-month) transmitters were used for all fish surgically implanted in 2014. The 48-month tags had a water weight of 12 grams (g) and measured 79 millimeters (mm) long by 15.6 mm in diameter. Transmitter frequencies ranged from 70–80 kilohertz, each with their own unique code to readily distinguish individual fish.

The following surgical protocol was established from procedures developed by Valdez and Nilson (1982), Kaeding et al. (1990), and Valdez and Trinca (1995) for humpback chubs; Tyus (1988) for Colorado pikeminnows; and Valdez and Masslich (1989) for Colorado pikeminnows and razorback suckers (Albrecht et al. 2008a, 2010a, 2013a; Kegerries and Albrecht 2011, 2013a, 2013b; Shattuck et al. 2011; Shattuck and Albrecht 2014). A transmitter air weight to fish weight of 2 percent (%) (Bidgood 1980; Marty and Summerfelt 1990) was used as a guideline to ensure that the tags were not too large for the fish being tagged. Surgery was performed on shore, on boat, or at the hatchery and typically involved a surgeon and an assistant. The assistant recorded data, captured photographs, and monitored fish respiration. BIO-WEST biologists conducted the surgeries, demonstrated current surgical practices, and provided instruction on updated tagging methodologies to other field biologists. Prior to surgery, each fish was placed in a live well containing fresh lake or hatchery water. All surgical instruments were cold sterilized with iodine and 95% ethanol and allowed to air dry on a disposable sterile cloth. Razorback suckers were initially anesthetized in 40 liters (L) of water with a 50-milliliter $(mL)/L^{-1}$ clove oil/ethanol mixture (Bunt et al. 1999). After anesthesia was induced, total length (TL), fork length (FL), standard length (SL), and weight of each fish were recorded. Fish were then placed dorsal-side down on a padded surgical cradle for support during surgery. The head and gills were submerged in 20 L of water with a maintenance concentration of 25 mL/L^{-1} clove oil/ethanol anesthetic (Bunt et al. 1999). Following fish introduction to the maintenance anesthetic, the surgeon made an approximate 2-centimeter (cm) incision on the left side, posterior to the left pelvic girdle. A PIT tag was placed into the incision, followed by the transmitter, which was pushed to rest between the pelvic girdle and urogenital pore. The incision was closed with 2–4 sutures using a 3-0 Maxon absorbable poliglecaprone 25 monofilament suture with an attached PS-1 reverse-cutting, curved needle. Surgery times typically ranged from 2–5 minutes per fish.

After surgical procedures were completed, the fish were allowed to recover and were closely monitored until equilibrium was maintained. Once fully recovered, tagged fish were released at their original point of capture, or in the case of a hatchery-reared individual, released near other sonic-tagged individuals and were re-examined for signs of stress. Tracking ensued immediately following release and continued intensively for the next 24–48 hours.

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 were at times located in 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 fully represent the use of a particular area in its entirety. 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, 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 (SUR) were deployed in various locations throughout Lake Mead. The advantage to using SURs is their ability to record continuous sonic telemetry data both day and night. With an approximate 9-month battery life and the ability to passively detect transmitters, SURs save valuable field time while collecting additional sonic telemetry data. Most importantly, the SUR facilitates an understanding of large-scale razorback sucker movements during the monthly tracking events. Ten SURs were utilized during the 2013–14 field season (see figure 1). Two SURs deployed by BIO-WEST during the 2010–13 field seasons remained stationed in the same general locations as did two SURs set by the NDOW for a Lake Mead striped bass (*Morone saxatilis*) sonic telemetry study that was conducted during 2011–12 (Shattuck et al. 2011; Albrecht et al. 2013a, 2013b; D. Herndon 2011, personal communication). Additionally, six SURs were deployed as part of the concurrent juvenile razorback sucker study to increase the effectiveness of monitoring newly implanted sonic-tagged juveniles 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 ten SURs were set at the following locations (figure 1): across from Sand Island at the southwestern extent of Las Vegas Bay (NDOW), at the northwestern extent of Sand Island (BIO-WEST), 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), on the eastern 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), at the northern extent of Rogers Bay and south of Blue Point Bay (BIO-WEST, partial seasonal coverage through February 26, 2014, only), 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 of the eastern side of the Overton Arm near Glory Hole. 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 and downloaded 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 analysis, a minimum of two records were required within 5 minutes of one another for a record to be reported as a positive identification.

Adult Sampling

Trammel Netting

The primary gear used to sample adult fish were trammel nets 91.4 m long by 1.8 m deep with an internal panel of 2.54-cm mesh and external panels of 30.48-cm mesh. In a few cases, when by-catch was anticipated to be onerous, we used trammel nets 45.7 m long by 1.2 m deep with internal panels of 2.54-cm mesh and external panels of 30.48-cm mesh. Nets were generally set with one end near shore in 1.5–9.0 m of water, with the net stretched out perpendicular to shore into deeper areas. All trammel nets were set in late afternoon (just before sundown) and pulled the next morning (shortly after sunrise), with a full-size net comprising 1 net-night and a shorter net comprising a half net-night for analytical purposes. Netting locations were selected based on locations of sonic-tagged fish, the location or presence of concentrated larval fish, and knowledge of previous adult razorback sucker capture locations. To avoid handling stress on native suckers, trammel netting was typically only conducted when surface water temperatures were less than 20 degrees Celsius (°C) (Hunt et al. 2012).

All fish were removed from nets and were held in 94.6-L live wells filled with lake water. Native suckers were isolated from other fish species and held in aerated live wells. All but the first five common carp and first five gizzard shad were enumerated and returned to the lake, while other species (including five common carp and five gizzard shad) were identified, measured for TL, weighed, and released at the capture location. Razorback suckers, flannelmouth suckers (*Catostomus latipinnis*), or suspected razorback sucker x flannelmouth sucker hybrids were scanned for PIT tags, PIT tagged if they were not recaptured fish, measured (for TL, SL, and FL), 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, or lack of ripeness) were labeled as juvenile. Individuals that were sexually defined were labeled according to their sex. Suspected razorback sucker x flannelmouth sucker 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. As requested by the Lake Mead Interagency Work Group (LMWG), genetic material was also removed from some of the razorback suckers. Genetic samples consisted of a small section (0.5 square centimeter) of fin ray material that was obtained from the caudal fin, preserved in 95% genetics-grade ethanol, and delivered to Reclamation biologists. After all necessary information was collected, fish were released unharmed at the point of capture.

Growth

Razorback sucker annual growth information was gathered from recaptured individuals in trammel netting collections. Recaptured individuals were only measured once during the spawning season, to avoid handling stress, and only used for annual growth analysis if approximately one sampling year had passed between capture occasions. When applicable, recently stocked individuals were excluded from the dataset and analyses to account for discrepancies in environmental conditions (e.g., hatchery-reared or pond-reared individuals recently stocked into a wild environment) and to allow for the yearly cycles of gonadal and somatic growth. Annual growth for razorback suckers was calculated for each individual using the difference in TL (mm) between capture periods. If the data were available, mean annual growth was calculated separately for appropriate stocked and wild individuals. Furthermore, in addition to the general 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).

Remote PIT Tag Antennas

In experimental efforts conducted cooperatively with Reclamation during the 2014 reproductive period, razorback suckers previously tagged with 134-kilohertz

PIT tags were sampled for using a series of six remote PIT tag antennas. Two separate sampling events occurred: one during March 31 – April 3, 2014, at the Virgin River/Muddy River inflow area (n = 6), and one during April 7–10, 2014, at the Virgin River/Muddy River inflow area (n = 3) and at Echo Bay (n = 3). Antennas were deployed nearshore within a suspected spawning area (as pinpointed using sonic telemetry, trammel netting, and larval capture data) at depths ranging from 1–3 m, and data loggers were concealed on shore. Time deployed and location information were recorded for each antennae, and data were processed by Reclamation as total and unique contacts by individual.

Larval Sampling

The primary larval sampling method on Lake Mohave followed that developed by Burke (1995) and other researchers. The procedure uses the positive phototactic response of larval razorback suckers to capture them. After sundown, two to four "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 to four 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, 4–12 sites were sampled on each night 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.

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 aggregate at the CRI area (Albrecht et al. 2010c) of Lake Mead. This same general approach was also used at the long-term monitoring study areas in 2014.

Age Determination

A nonlethal 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 2014 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 razorback sucker x flannelmouth sucker hybrids) for age determination when appropriate.

During the 2014 field season, previously unaged, wild razorback suckers, flannelmouth suckers, and razorback sucker x flannelmouth sucker 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, 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 sample was surgically collected using custom-made bone snips originally developed by BIO-WEST. These surgical tools consist 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 use, and the resulting incisions were packed with antibiotic ointment to minimize post-surgical bacterial infections and promote rapid healing. All native suckers undergoing fin ray extraction techniques were immediately placed in a recovery bath of fresh lake water containing slime-coat protectant and sodium chloride. 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 when 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 our fin ray aging technique, refer to Albrecht and Holden (2005), Albrecht et al. (2006b, 2008a), and other annual Lake Mead razorback sucker reports.

Population and Survival Estimation

Population Estimation

To assess the population of razorback suckers in Lake Mead, the program MARK (Cooch and White 2013) was utilized to produce an estimate from mark-recapture data spanning from 2012 through 2014. This timespan was selected to maintain consistency with past estimates in which 3-year datasets were used. In all, 36 capture occasions (based on weekly sampling efforts during 2012–14) 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]). In an effort to maintain comparability between population estimates produced annually, this general model was selected, as it was most similar to those used in the past; therefore, no other models were produced for this report (Shattuck et al. 2011; Albrecht et al. 2013a, 2013b). 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 (attachment 2). The subsequent results from these two model iterations were then compared according to their corrected Akaike's information criterion (AICc) values, and each estimate was fitted with 95% confidence bounds. Additionally, a weighted average of the two estimates was produced as recommended for closed models with parameters that include a multiset of distinct permutations (Cooch and White 2013). No formal goodness-of-fit test was performed, as the use of individual heterogeneity in the model does not allow for it (Cooch and White 2013).

In an effort to maintain consistency within the capture occasion data across the four study areas from 2012 through 2014, and in an effort to meet the assumption that all razorback sucker individuals are equally likely to be captured, capture occasions from the CRI area were used only when long-term monitoring efforts were concurrent (i.e., sampling was conducted at both long-term monitoring and CRI study areas at the same time). As the closed capture model assumes there is no immigration, emigration, mortality, or natality, the 3-year dataset helps to limit these demographic variables. That is, given the survival rates (approaching 0.70) seen in Lake Mead razorback suckers as presented below (see table 6), and given the relative paucity of juvenile individuals captured during trammel netting efforts in Lake Mead (less than 8% of the overall catch) (Shattuck et al. 2011; Albrecht et al. 2013a; Kegerries and Albrecht 2013a, 2013b), the dataset consists of a population that is largely closed, demographically speaking. Furthermore, stocked fish were not used in any of the population estimates unless they had survived a minimum of 1 year in Lake Mead (i.e., the time between the initial stocking event and recapture). It was assumed that an adult, stocked fish that had survived 1 year in Lake Mead was able to avoid predation and contribute progeny to the population (Albrecht and Holden 2005; Modde et al. 2005). Furthermore, given that sampling occurred only during the reproductive period for razorback suckers in Lake Mead, and given that sampling was only conducted for relatively short periods of time (12–14 weeks, annually), it is assumed that behavioral and temporal variation between capture occasions is limited, as is part of the assumptions in a demographically closed model with heterogeneity (Cooch and White 2013).

Movement of razorback suckers between the long-term monitoring study areas of Echo Bay and the Virgin River/Muddy River inflow area has been well documented (Albrecht et al. 2007, 2008a, 2008b, 2010b, 2013a, 2013b; Kegerries et al. 2009; Shattuck et al. 2011); thus, the use of data between these study areas helps to account for closure in the model assumptions. As noted in both stocked and wild razorback sucker individuals, movement has been observed between all study areas within Lake Mead (i.e., the CRI area, Las Vegas Bay, Echo Bay, and the Virgin River/Muddy River inflow area) (Kegerries and Albrecht 2011, 2013a, 2013b; Shattuck et al. 2011; Albrecht et al. 2013a, 2013b), creating a need to assess the population at the larger, lake-wide scale. Population estimates for individual study areas were not included for this report because of the demonstrated connectivity of the lake and the documented interactions between spawning aggregates, further violating model assumptions. However, despite best efforts to meet model assumptions and limit closure violations, post-hoc testing of closure within the dataset using the program CloseTest (Stanley and Burnham 1999) produced low p-values (χ^2 = 39.78, df = 40, P = 0.48), suggesting that the population is not fully closed within the dataset. Although model assumptions appear not to be completely met, the consistency of the population estimate produced in this annual report, and those in recent past, at a minimum, holds value in monitoring changes within the population from year to year. Nonetheless, caution should be exercised with this estimate beyond its novel use herein.

Survival Estimation

An estimate of the annual apparent survival (φ, the probability of surviving from one year to the next year) rate of razorback suckers in Lake Mead was calculated in the program MARK from the entire mark-recapture study period spanning from 1996 through 2014. 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 [1996–2014] and CRI areas [2010–14]) for adult razorback suckers. A total of 19 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 3). The annual survival estimate models produced in the program MARK were compared according to the AICc values, and the model carrying the most AICc weight was tested for goodness-of-fit ($\hat{c}$) using a logistic regression within the program MARK (Cooch and White 2013).

In goodness-of-fit testing, the model carrying the most AICc weight (attachment 3) produced an estimated $\hat{c}$ value of 1.19 (standard error [SE] = 0.00) in logistic regression, where values ≤ 3 are found to be relatively safe (Lebreton et al. 1992 *in* 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 1996–2014 (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). As in the population estimate, 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 (1996–2014), 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 subbasins (Roberts and Moretti 1989; Bestgen et al. 2009; Zelasko et al. 2011) and that of Lake Mohave (Kesner et al. 2012).

RESULTS

Lake Elevation

Similar to the lake elevation trends seen during the past decade (figure 2), lake elevations during the 2013–14 field season declined overall (figure 3). Starting at a lake elevation of 337 m above msl at the end of July 2013, lake elevations remained relatively static until rising gradually to a peak elevation of approximately 338 m above msl at the beginning of February 2014 (figure 3). In 2014, lake elevations decreased steadily during the spawning months of February through April to a final elevation of approximately 333 m above msl at the end of April (figure 3). This drop equates to an approximate 5 m of change during the 2014 spawning months, averaging nearly 1.25 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. Following the peak spawning months (i.e., February, March, and April), lake elevation continued to decline through the remainder of the 2013–14 field season, reaching some of the lowest lake elevations observed during the course of this study (figure 2).

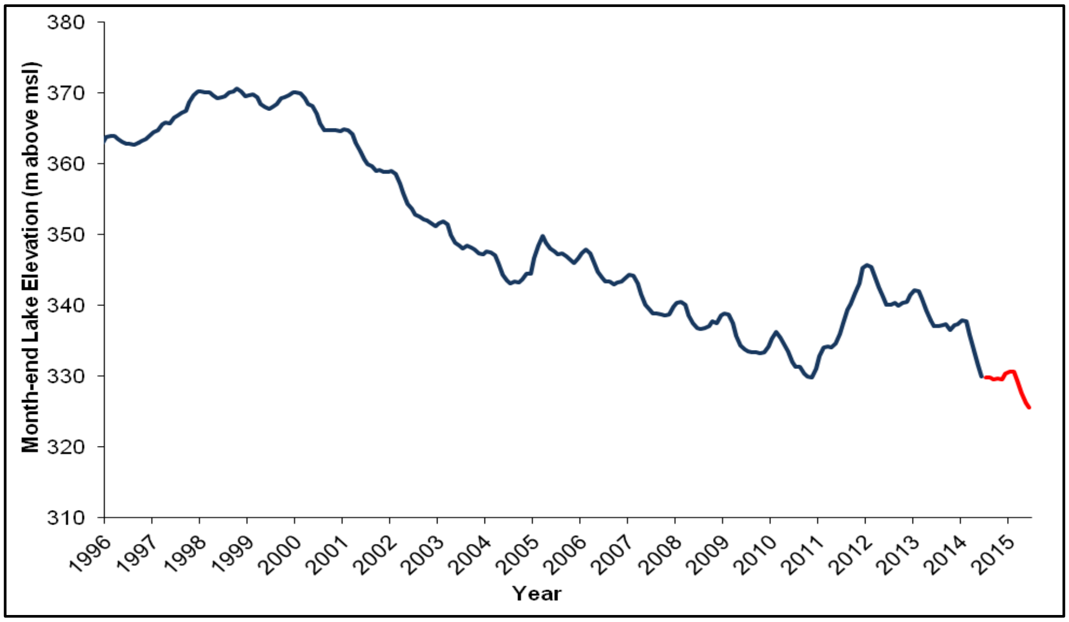

Figure 2.—Lake Mead month-end lake elevations, January 1996 – June 2014, with projected lake elevations for the July 2014 – June 2015 study year (Reclamation 2014).

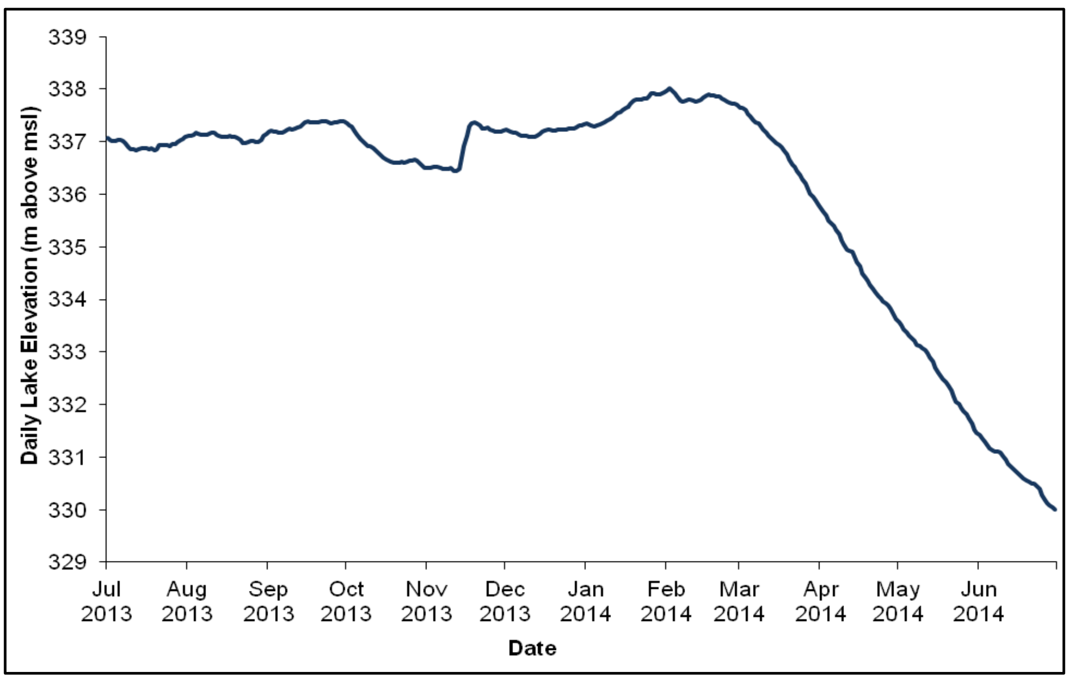

Figure 3.—Lake Mead daily lake elevations, July 1, 2013 – June 30, 2014 (Reclamation 2014).

Sonic Telemetry

Over the course of this study (1997–2014), 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. Additionally, 40 juvenile razorback suckers (1 wild, 3 pond reared, and 36 hatchery reared) have been equipped with sonic transmitters for the purposes of juvenile research throughout long-term monitoring study areas (2012–14 [Albrecht et al. 2013a; Shattuck and Albrecht 2014; Shattuck and Albrecht unpublished]), and 38 adult razorback suckers (2 wild, 27 pond reared, and 9 hatchery reared [Albrecht et al. 2010c, 2014; Kegerries and Albrecht 2011, 2013a, 2013b]) have been equipped with sonic transmitters and released at the CRI area and lower Grand Canyon (2010–14). A complete description of recent sonic telemetry efforts in juvenile research and studies at the CRI area can be found in Shattuck and Albrecht (2014) and Albrecht et al. (2014). During the long-term monitoring 2013–14 field season, 152 active contacts were made with 21 individual sonic-tagged razorback suckers (table 1 and figures 4–6), including one individual originally tagged in 2012 as a juvenile in Las Vegas Bay and another individual originally tagged in 2014 at the CRI area. The 10 SURs (see figure 1) in aggregate contacted 21 sonic-tagged razorback sucker individuals a total of 46,511 times, including 2 individuals originally tagged in 2012 as juveniles in Las Vegas Bay and 1 individual originally tagged in 2014 at the CRI area. The NDOW Black Ridge SUR was contacted the most often, with 19,849 contacts, while the Glory Hole SUR contacted the highest number of individuals at 12. The number of SURs and the number of contacts helped to define the movement of sonic-tagged individuals and aided in accounting for individual, hard 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 near the Virgin River/Muddy River inflow. During the 2013–14 field season, this group of fish was contacted most frequently; each individual was contacted at least once for a total of 71 active sonic telemetry contacts and 37,590 passive contacts made via 8 different SURs (table 1 and figures 4–7). For the most part, each of the two groups of fish released in 2011 remained at its respective release localities for the 2013–14 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 33 times, while individuals stocked into the Virgin River/Muddy River inflow area were actively contacted in that area a total of 37 times (figures 4, 6, and 7). Though no individuals were initially stocked into Echo Bay in 2011, one individual originating from the Virgin River/Muddy River inflow area was actively contacted once in Echo Bay

Table 1.—Tagging and stocking information, location and date of last contact, and status of sonic-tagged razorback suckers in Lake Mead, July 2013 – June 2014

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
2011									
FDLB	1/4/2011	334	564	F	LB	LB-E	2/15/2014	6 (6,369)	Active
FDLB	1/4/2011	3545	556	F	LB	LB	9/23/2013	1 (0)	Active
FDLB	1/4/2011	3584	519	M	LB	LB-W	6/23/2014	14 (6,228)	Active
FDLB	1/4/2011	3775	516	M	LB	LB-W	6/21/2014	12 (219)	Active
FDLB	1/4/2011	448	502	M	OA	OA-W	6/30/2014	12 (5,721)	Active
FDLB	1/4/2011	555	504	M	OA	OA-W	6/22/2014	6 (1,759)	Active
FDLB	1/4/2011	3578	541	F	OA	OA-W	6/30/2014	10 (13,831)	Active
FDLB	1/4/2011	3667	552	F	OA	OA	3/12/2014	10 (3,463)	Active
2012									
LB	2/28/2012	222	425	I	LB	LB-W	6/19/2014	11 (1,299)	Active
CPD	4/23/2012	337	390	I	LW	LB	5/16/2012	0 (0)	Unknown
CPD	4/23/2012	368	345	I	LW	OA-W	4/29/2013	0 (0)	Unknown
CPD	4/23/2012	452	340	I	LB	OA-W	11/16/2013	0 (10)	Active
2014									
CI	2/25/2014	468	592	M	CI	AC	6/30/2014	2 (342)	Active
EB	2/6/2014	586	656	F	EB	AC	6/16/2014	4 (170)	Active
EB	2/12/2014	3375	598	M	EB	EB	4/16/2014	7 (114)	Active
EB	2/12/2014	3447	581	M	EB	AC	4/2/2014	4 (22)	Active
EB	2/12/2014	4656	637	M	EB	GH	6/17/2014	6 (400)	Active
LB	2/11/2014	3488	626	M	LB	LB-W	6/23/2014	7 (5,521)	Active
LB	3/11/2014	3566	536	M	LB	LB	4/14/2014	3 (6)	Active
CPD	3/16/2014	4778	479	M	LB	LB-W	6/13/2014	6 (246)	Active
OA	2/5/2014	578	520	M	OA	GH	6/25/2014	6 (296)	Active
OA	2/26/2014	3337	589	M	OA	AC	6/25/2014	5 (237)	Active
OA	3/6/2014	3374	582	M	OA	AC	6/18/2014	4 (130)	Active
OA	3/6/2014	3478	562	M	OA	GH	5/15/2014	4 (128)	Active

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

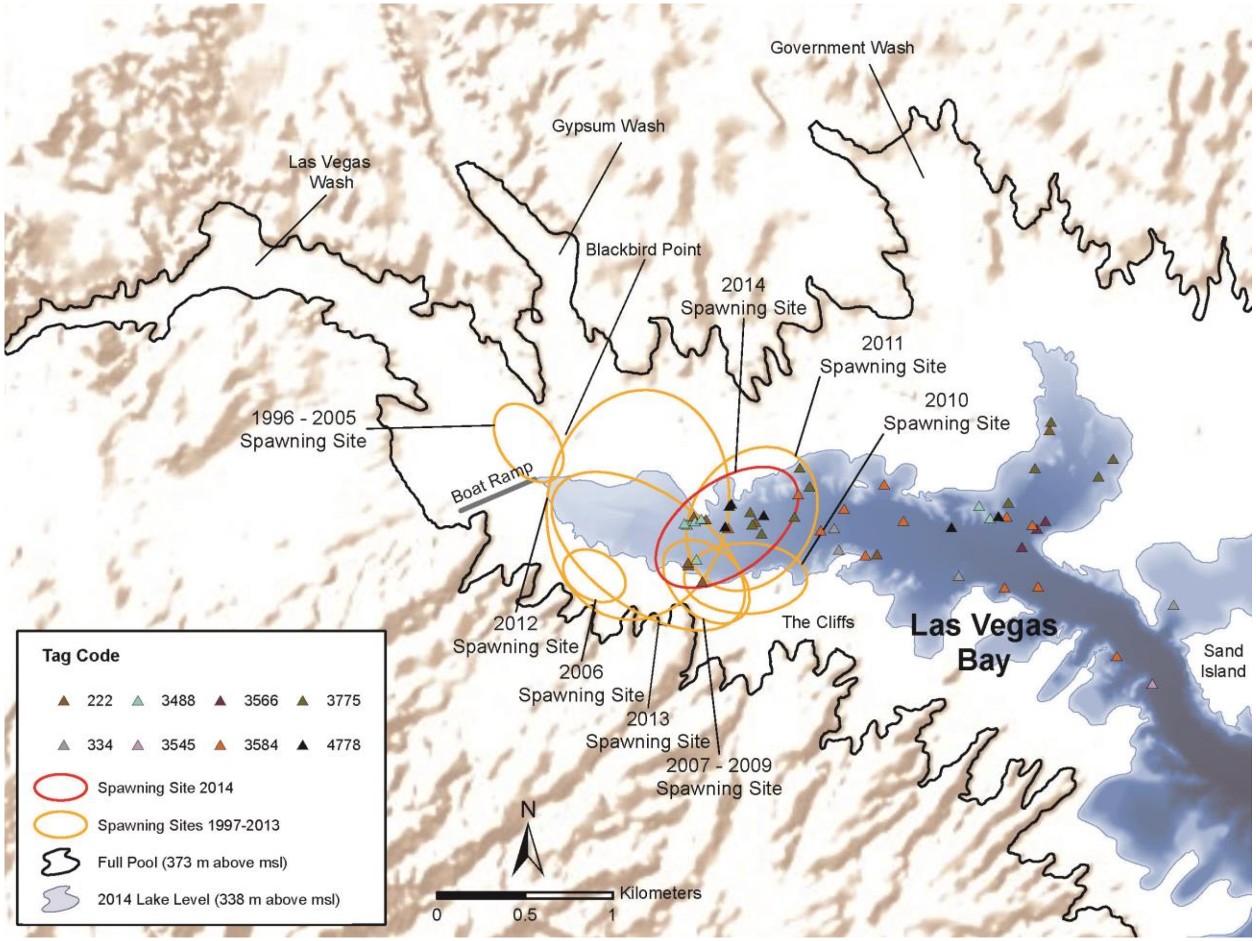

Figure 4.—Distribution of sonic-tagged razorback suckers located through active sonic telemetry in Las Vegas Bay, July 2013 – June 2014.

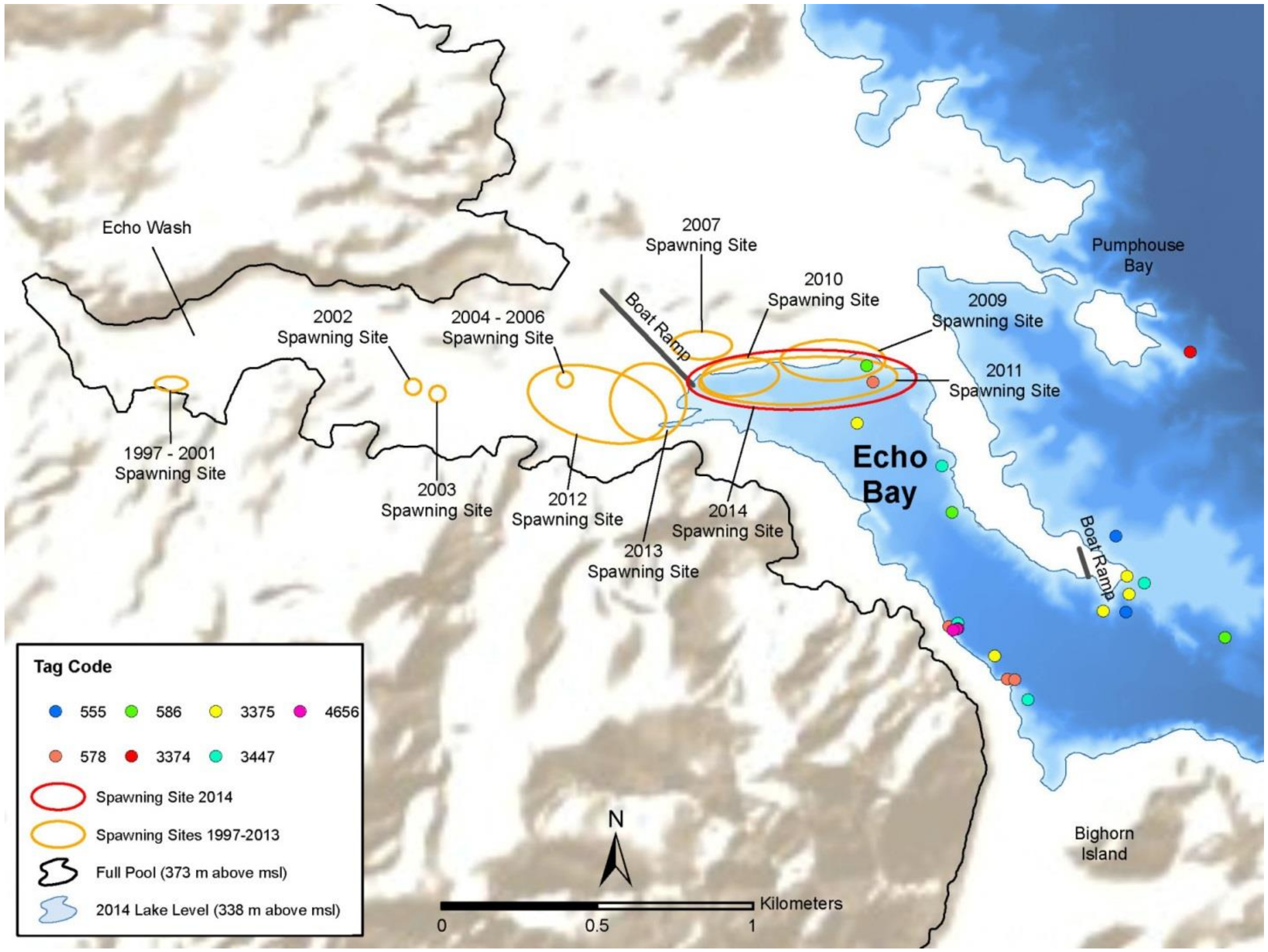

Figure 5.—Distribution of sonic-tagged razorback suckers located through active sonic telemetry in Echo Bay, July 2013 – June 2014.

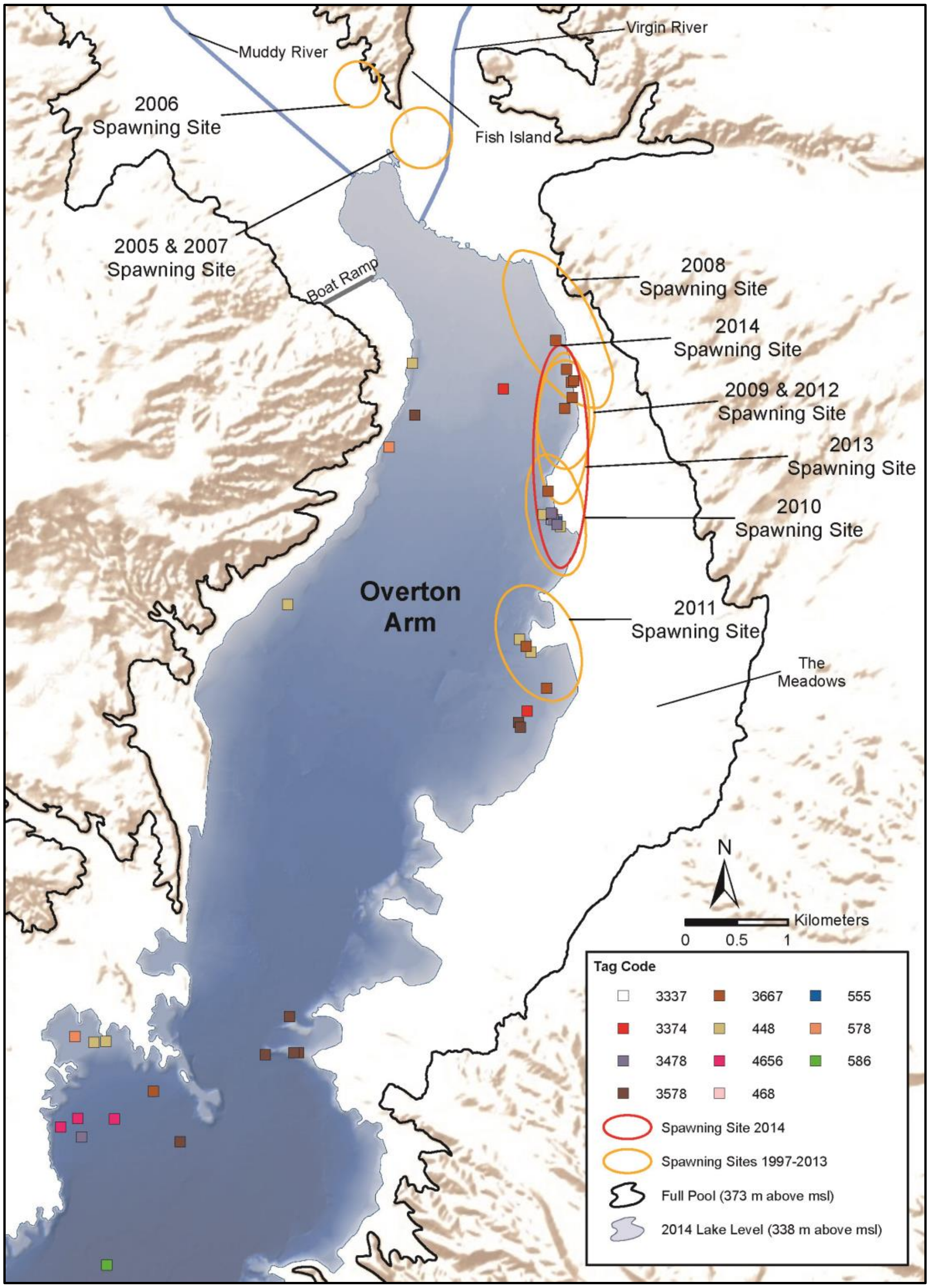

Figure 6.—Distribution of sonic-tagged razorback suckers located through active sonic telemetry at the Virgin River/Muddy River inflow area, July 2013 – June 2014.

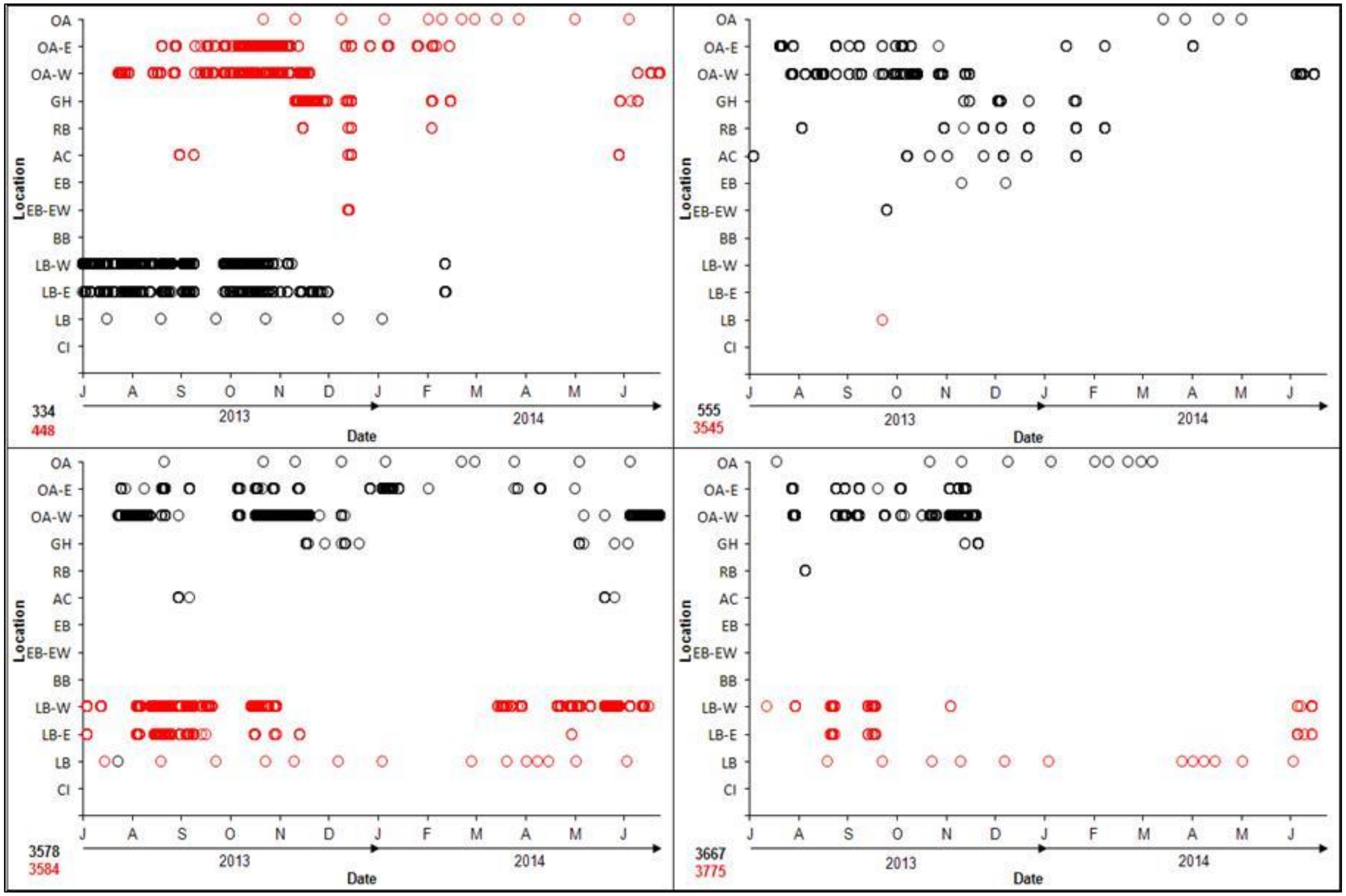

Figure 7.—Movement derived from active and passive sonic telemetry in Lake Mead for razorback suckers sonic tagged in 2011 and July 2013 – June 2014.
Location abbreviations are as follows: CI = Colorado River inflow, LB = Las Vegas Bay area, LB-E = Las Vegas Bay-East SUR, LB-W = NDOW Las Vegas Bay-West SUR, BB = Boulder Narrows SUR, EB-EW = Echo Bay-East SUR and Echo Bay-West SUR, EB = Echo Bay area, AC = Anchor Cove SUR, RB = Rogers Bay SUR, GH = Glory Hole SUR, OA-W = NDOW Black Ridge SUR, OA-E = Overton Arm SUR, and OA = Virgin River/Muddy River inflow area.

during the 2013–14 field season (see figures 5 and 7). 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 = 19,483) and the NDOW Las Vegas Bay-West SUR (n = 11,399) (figures 1 and 7). Numerous contacts were also made at the Overton Arm SUR (n = 3,470), the Glory Hole SUR (n = 1,553), the Las Vegas Bay-East SUR (n = 1,417), the Rogers Bay SUR (n = 138), the Anchor Cove SUR (n = 105), and the Echo Bay-East SUR (n = 25) (figures 1 and 7). No contacts were made with the Boulder Narrows or Echo Bay-West SURs (see figures 1 and 7).

During the 2013–14 field season, four sonic-tagged fish in Las Vegas Bay (codes 334, 3545, 3584, and 3775) used habitats ranging in depth from 2.7 to 21.1 m with an average depth of 9.6 m (± 1.7 SE) at point of contact. Throughout much of the year, individuals from the 2011 tagging event in Las Vegas Bay were often found occupying deeper, mid-channel areas of Las Vegas Bay from the area of Sand Island through the area of Government Wash Cove and west to the area near the Cliffs (see figures 4 and 7). Conversely, individuals were found at shallower locations further to the west during the reproductive season and were often found closer to one another (see figures 4 and 7).

In Echo Bay, one sonic-tagged individual from the 2011 tagging event (code 555) was contacted once at the mouth of Echo Bay at a depth of 14.3 m. Contact with this individual was made in November and December 2013, and no other contacts were made with fish tagged in 2011 in Echo Bay proper during the 2013–14 field season (see figures 5 and 7). This same individual was also contacted at the Virgin River/Muddy River inflow area throughout the year along with three other fish tagged in 2011. In the Virgin River/Muddy River inflow area, four individuals (codes 448, 555, 3578, and 3667) tagged during 2011 used habitats ranging from 4.0 to 37.4 m deep with an average depth of 12.1 m (± 1.6 SE) at point of contact. 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 from the Meadows area of the Overton Arm to Three Corner Hole (see figures 6 and 7). However, in the periods prior to and following the reproductive season, these individuals were contacted in deeper habitat and further south and appeared to move greater distances throughout the Overton Arm, often congregating in the area of Stewarts Bay (see figures 6 and 7).

Similar to movement patterns seen in the past (e.g., Shattuck et al. 2011; Albrecht et al. 2013a, 2013b), the movement of one individual (code 555) tagged in 2011 further supports and characterizes the connection between the areas of the Virgin River/Muddy River inflow area and Echo Bay (see figures 5–7). This individual has exhibited a strong seasonal movement pattern since it was stocked, often spending February through March in Echo Bay near reproductive activity before moving back to the Virgin River/Muddy River inflow area, where this individual again associated with other reproductively active individuals throughout the rest of the spawning season (Shattuck et al. 2011; Albrecht et al.

2013a, 2013b). Throughout the remainder of the year, this fish appears to use habitat in areas of the greater Overton Arm similar to those described in previous years – a pattern that may play an important role in seasonal population dynamics – a potentially important concept that has been addressed in past reports (Albrecht et al. 2008b, 2010b, 2013a, 2013b; Shattuck et al. 2011).

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 2013–14 field season, one 2012 sonic-tagged fish (code 222) was contacted 11 times in active sonic telemetry efforts and 1,299 times via two separate SURs (see table 1 and figure 4). Additionally, one other 2012 sonic-tagged fish (code 452) was contacted 10 times via one SUR; however, no active contacts were made with this individual (see table 1 and figure 8). Like other year-classes of sonic-tagged razorback suckers, the individual actively contacted (code 222) was found throughout the mid-channel areas of Las Vegas Bay from the area of Sand Island through the area of Government Wash Cove (figures 4 and 8). However, this individual was frequently found at shallower locations further to the west during the reproductive season and was often found in close proximity to other sonic-tagged adult razorback suckers (see figures 4 and 8). During the 2013–14 field season, this sonic-tagged individual (code 222) was contacted in habitats ranging from 1.7 to 4.0 m deep with an average depth of 2.0 m (± 0.6 SE) at point of contact.

This individual from the 2012 tagging event was actively contacted solely in Las Vegas Bay during the 2013–14 field season. Although it was often contacted toward the mouth of Las Vegas Bay by both the NDOW Las Vegas Bay-West (n = 1,248) and Las Vegas Bay-East (n = 51) SURs, it has remained in the area since it was tagged and released in 2012. On the contrary, one individual (code 452) that was contacted infrequently during the juvenile razorback sucker pilot study in 2012 (Albrecht et al. 2013a) was contacted a total of 10 times by the NDOW Black Ridge SUR between October and November 2013. Interestingly, during the 2012–13 field season, contacts were made with yet another individual (code 368) from the 2012 tagging event in much the same fashion. However, these contacts were viewed with some skepticism because they did not meet the quality control criteria for analyzing SUR data (i.e., successive contacts inside of the set 2-minute mark) (Albrecht et al. 2013b).

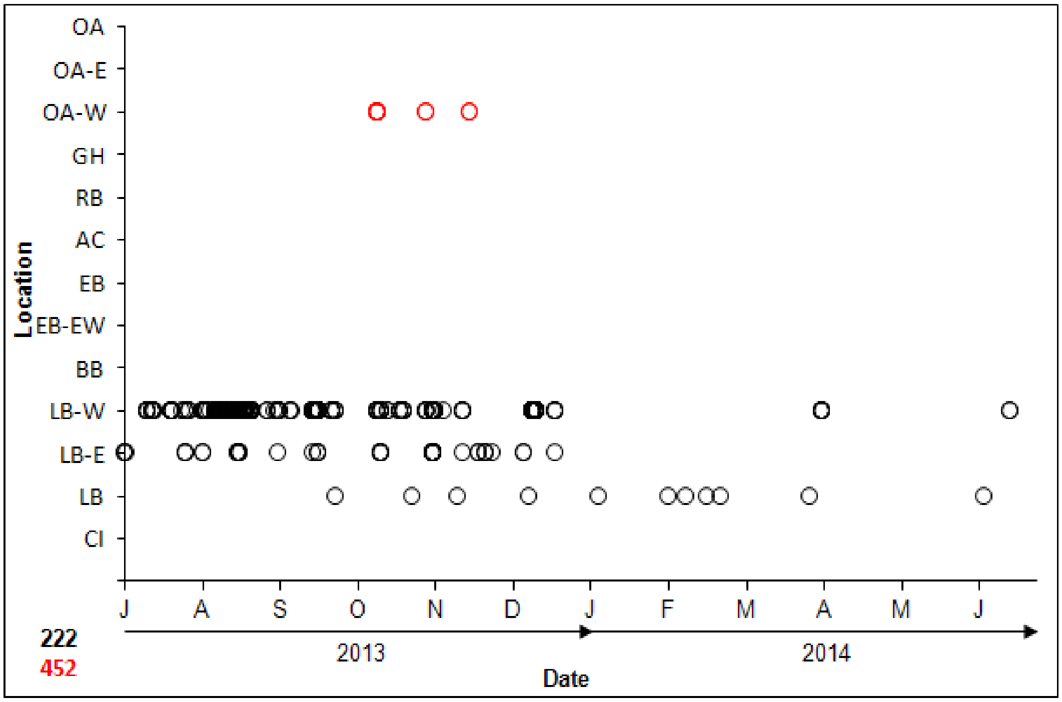

Figure 8.—Movement derived from active and passive sonic telemetry in Lake Mead for razorback suckers sonic tagged in 2012 and July 2013 – June 2014. Location abbreviations are as follows: CI = Colorado River inflow, LB = Las Vegas Bay area, LB-E = Las Vegas Bay-East SUR, LB-W = NDOW Las Vegas Bay-West SUR, BB = Boulder Narrows SUR, EB-EW = Echo Bay-East SUR and Echo Bay-West SUR, EB = Echo Bay area, AC = Anchor Cove SUR, RB = Rogers Bay SUR, GH = Glory Hole SUR, OA-W = NDOW Black Ridge SUR, OA-E = Overton Arm SUR, and OA = Virgin River/Muddy River inflow area.

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) (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 (table 1). Furthermore, concurrent tagging efforts were conducted at the CRI area during 2014, and one wild origin razorback sucker sonic tagged at the CRI area was 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. Additional details about this individual can be found in the companion report on investigations at the CRI area (Albrecht et al. 2014).

During the 2013–14 field season, 12 individuals from this tagging event (including the individual from the CRI area) were contacted at least twice for a total of 58 active sonic telemetry contacts. These same 12 individuals were also passively contacted 7,612 times via 8 different SURs (see table 1 and figures 4, 5, 6, and 9). The majority of contacts were made at the NDOW Las Vegas Bay-West SUR (n = 4,523) and the Las Vegas Bay-East SUR (n = 1,250) (figures 1 and 9). Contacts were also made on the Glory Hole SUR (n = 656), the Overton Arm SUR (n = 358), the NDOW Black Ridge SUR (n = 356), the Rogers Bay SUR (n = 274), the Anchor Cove SUR (n = 184), and the Echo Bay-East SUR (n = 11) (figures 1 and 9). No contacts were made with the Boulder Narrows or Echo Bay-West SURs (see figures 1 and 9).

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 three individuals from the 2014 tagging event were actively contacted in that area 16 times (see figures 4 and 9). During the 2013–14 field season, these three fish (codes 3488, 3566, and 4778) used habitats ranging in depth from 2.7 to 21.1 m with an average depth of 9.6 m (± 1.7 SE) at point of contact in Las Vegas Bay. Throughout much of the year, individuals from the 2014 tagging event in Las Vegas Bay were often found occupying deeper, mid-channel areas of Las Vegas Bay from the area of Sand Island through the area of Government Wash Cove and west to the area near the Cliffs (see figures 4 and 9). Conversely, individuals were found at shallower locations further to the west during the reproductive season and were often found closer to one another (see figures 4 and 9).

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, often moving back and forth between the two long-term monitoring study areas (figures 4, 5, 6, and 9). From the 2014 tagging event, four individuals tagged in Echo Bay (codes 586, 3375, 3447, and 4656), two individuals tagged at the Virgin River/Muddy River inflow area (codes 578 and 3374), and one individual tagged at the CRI area (code 468) were contacted in Echo Bay 24 times. Individuals from the 2014 tagging event contacted in Echo Bay used habitats ranging from 4.0 to 37.4 m deep with an average depth of 11.8 m (± 1.6 SE) at point of contact. During the reproductive season, individuals remained nearshore within Echo Bay proper along the northern and southern shorelines before venturing further into the Overton Arm with the conclusion of the spawning season (see figure 5). Individuals appeared to primarily use the western side of the Overton Arm as they moved through the areas of Pumphouse Bay, Anchor Cove, Rogers Bay, and Stewarts Bay (see figures 5, 6, and 9).

Similar to Echo Bay, four wild individuals tagged at the Virgin River/Muddy River inflow area (codes 578, 3337, 3374, and 3478), two wild individuals tagged in Echo Bay (codes 586 and 4656), and one individual tagged at the CRI area (code 468) were contacted at the Virgin River/Muddy River inflow area 18 times. The seven individuals contacted at the Virgin River/Muddy River inflow area

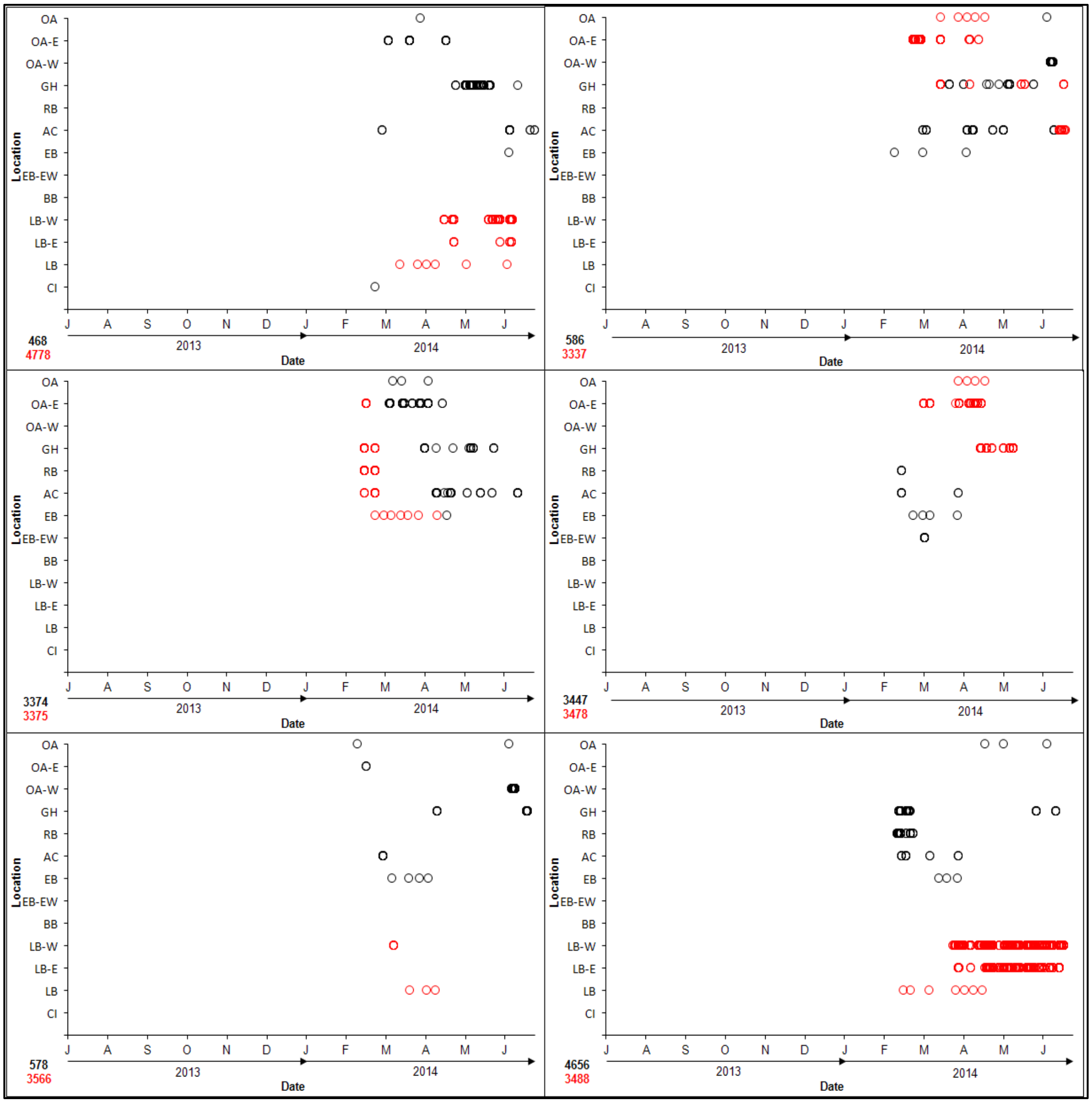

Figure 9.—Movement derived from active and passive sonic telemetry in Lake Mead for razorback suckers sonic tagged in 2014 and July 2013 – June 2014.
Location abbreviations are as follows: CI = Colorado River inflow, LB = Las Vegas Bay area, LB-E = Las Vegas Bay-East SUR, LB-W = NDOW Las Vegas Bay-West SUR, BB = Boulder Narrows SUR, EB-EW = Echo Bay-East SUR and Echo Bay-West SUR, EB = Echo Bay area, AC = Anchor Cove SUR, RB = Rogers Bay SUR, GH = Glory Hole SUR, OA-W = NDOW Black Ridge SUR, OA-E = Overton Arm SUR, and OA = Virgin River/Muddy River inflow area.

from the 2014 tagging event used habitats ranging from 1.5 to 19.4 m deep with an average depth of 7.8 m (± 1.7 SE) at point of contact. During the reproductive season, these individuals remained in shallow areas close to the Virgin River/Muddy River inflow area and along the eastern shoreline from the Meadows area of the Overton Arm to Three Corner Hole (see figures 6 and 9).

Much like individuals from previous tagging events, as the spawning season came to a close, individuals moved into deeper habitat further south toward the area of Stewarts Bay and Echo Bay (see figures 5, 6, and 9).

Although lake-wide movements of sonic-tagged individuals have been observed in the past, the movements of the wild individual from the 2014 tagging event at the CRI area spanned much of Lake Mead within a relatively short period of time. Active contact was last made with this individual on February 26, 2014, at the inflow of the Colorado River near North Beach before it was first contacted by the Anchor Cove SUR 5 days later on March 3, 2014 (Albrecht et al. 2014). This individual was subsequently contacted by the Overton Arm-East SUR and the Glory Hole SUR before being actively captured in trammel netting efforts at the Virgin River/Muddy River inflow area on March 20, 2014 (see figures 5, 6, and 9). At the close of the 2013–14 field season, this individual remained in the area of Anchor Cove on June 10, 2014.

Adult Sampling

Trammel Netting

Trammel netting was conducted from February 3 through April 18, 2014, for a total of 70 net-nights (table 2). Netting locations were dictated by historical knowledge of the system, the capture of multiple razorback suckers, the presence of sonic-tagged fish, or high concentrations of razorback sucker larvae in a particular area. Las Vegas Bay trammel netting was primarily conducted near the Las Vegas Wash inflow on the northern and southern shorelines extending downstream (easterly) toward the entrance of the bay and in the same general vicinity as the 2006 and 2007–09 spawning areas (figure 10). The primary Echo Bay sampling area was located at the west end of the bay, off the northern shoreline (figure 11). Finally, sampling of the Virgin River/Muddy River inflow area occurred along the eastern shoreline and toward the northern end of the Overton Arm, approximately 1–2 km south of the Virgin River inflow area (figure 12).

Table 2.—Trammel netting effort (net-nights) on Lake Mead, February 2014 – April 2014

Month	Las Vegas Bay[a]	Echo Bay	Virgin River/Muddy River inflow area	Total
February	6.5	9	7	22.5
March	12	9	7	28
April	5.5	8	6	19.5
Total	**24**	**26**	**20**	**70**

[a] Indicative of use of shorter, 45.7-m trammel net, calculated at 0.5 net-night each in effort to maintain consistency with past long-term monitoring reports.

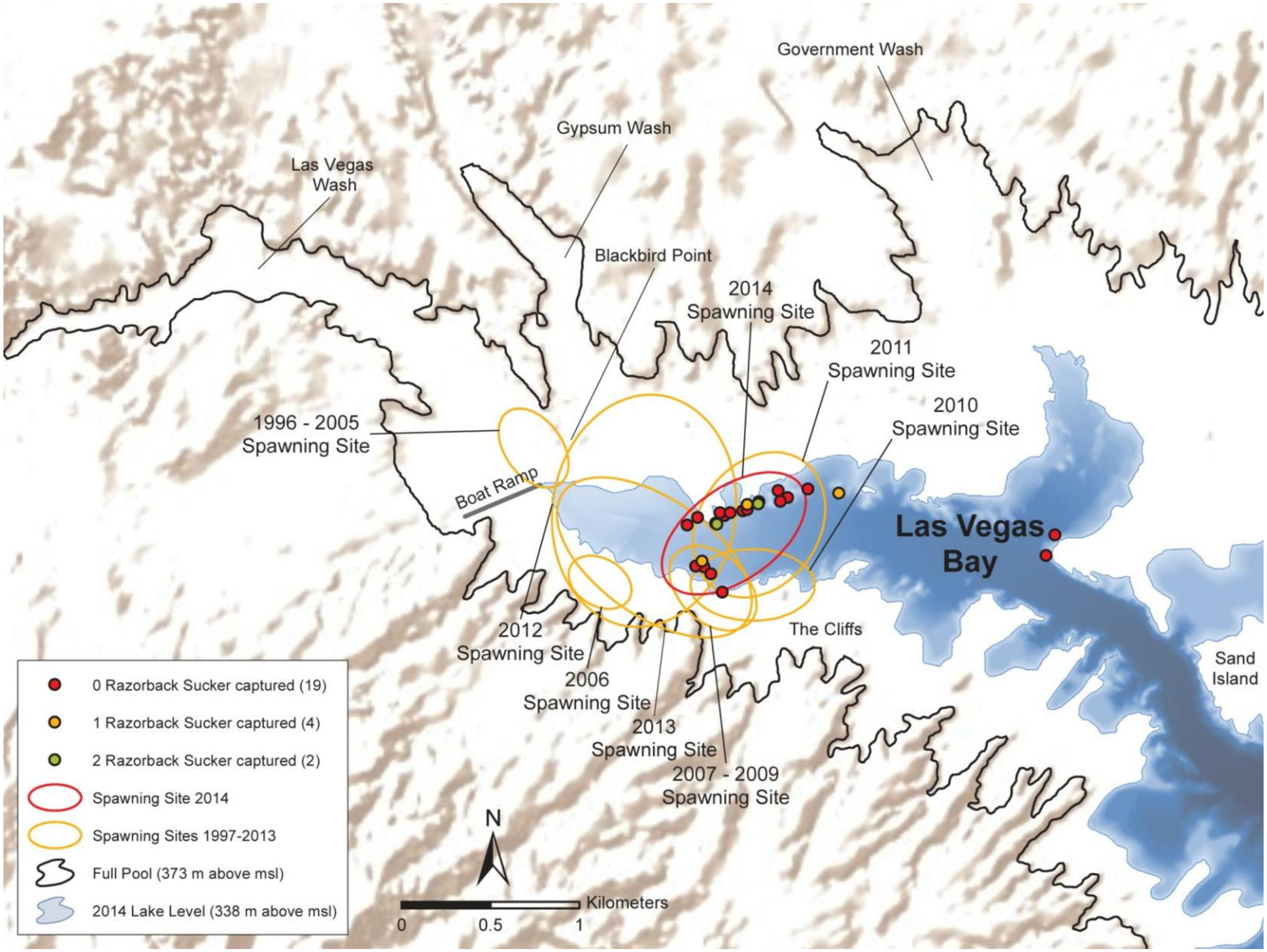

Figure 10.—Locations of trammel netting and numbers of razorback suckers captured in Las Vegas Bay, February 2014 – April 2014.

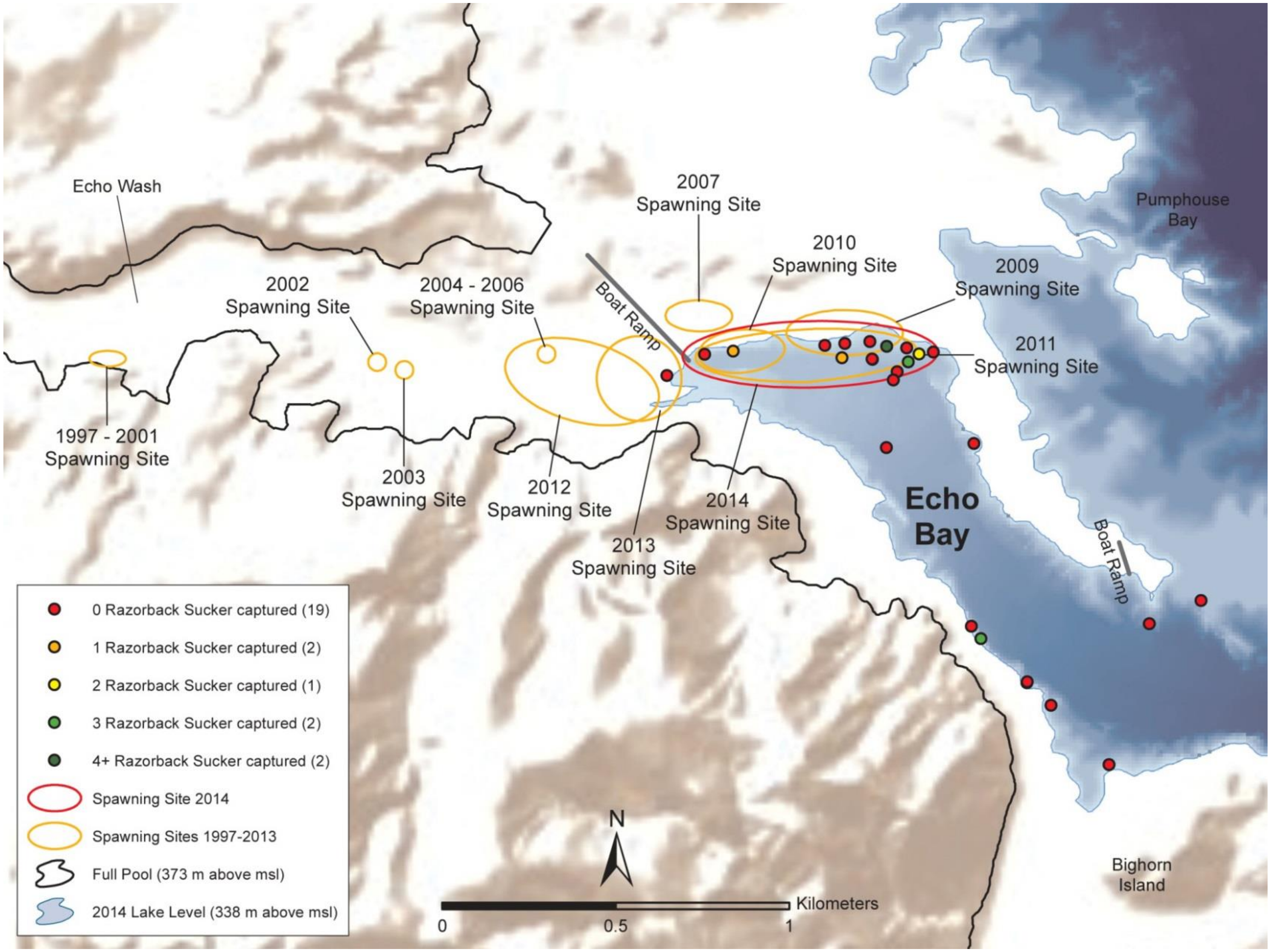

Figure 11.—Locations of trammel netting and numbers of razorback suckers captured in Echo Bay, February 2014 – April 2014.

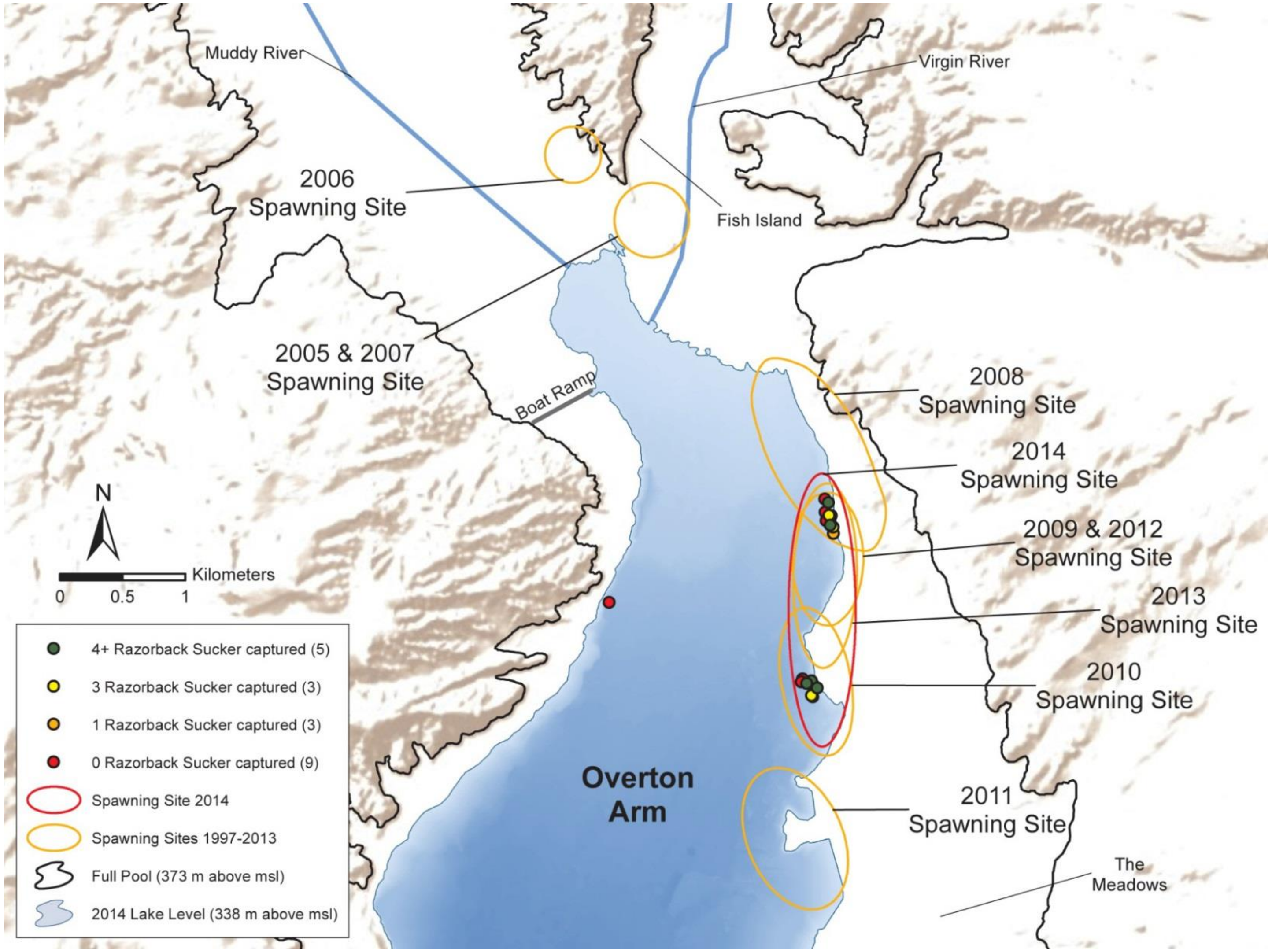

Figure 12.—Locations of trammel netting and numbers of razorback suckers captured at the Virgin River/Muddy River inflow area, February 2014 – April 2014.

The first male razorback sucker expressing milt was captured on February 12, 2014, from Echo Bay, and the first female razorback sucker expressing eggs was captured on February 26, 2014, from the Virgin River/Muddy River inflow area (table 3).

For netting efforts during 2014, combined captures from all of the Lake Mead long-term monitoring consisted of 47% females and 53% males. Sex ratios (females to males) for 2014 were determined to be 3:1 (6 females, 2 males) at Las Vegas Bay, 1:1.4 (9 females, 13 males) at Echo Bay, and 1:1.2 (25 females, 30 males) at the Virgin River/Muddy River inflow area. Although recapture rates varied between study areas, across Lake Mead long-term monitoring study areas, there were 45 recaptures out of 85 total razorback sucker captures (52.9%) in 2014.

At Las Vegas Bay, three recaptures and five new, wild fish were captured (37.5% recaptured razorback suckers), while at Echo Bay, 14 of the 22 (63.6%) razorback suckers caught were recaptures, and 28 of the 55 (50.9%) razorback suckers caught at the Virgin River/Muddy River inflow area were recaptures (table 3). All recaptured fish were found to be of wild origin (previously captured during earlier study years), with the exception of one recaptured individual recaptured in Echo Bay that was originally stocked into Echo Bay from Floyd Lamb Park in 1998 (Holden et al. 1999).

Eight adult razorback suckers were captured in 24 net-nights at Las Vegas Bay during the 2014 spawning period (table 3). Similar to captures seen in past years (Albrecht et al. 2010b, 2013a, 2013b; Shattuck et al. 2011), these fish were captured along the southwestern portion of Las Vegas Bay near the Las Vegas Wash inflow (see figure 10). The razorback sucker catch-per-unit-effort (CPUE) from trammel netting at the Las Vegas Bay area was 0.33 fish/net-night during 2014 (figure 13). This rate is lower than CPUE rates from 2009–11; however, the 2014 CPUE rate is higher than that observed during the 2012 and 2013 spawning seasons and falls within other CPUE values observed from Las Vegas Bay throughout the course of this study (Shattuck et al. 2011; Albrecht et al. 2013a, 2013b). For the third consecutive year, overall captures were relatively low in Las Vegas Bay, with only eight adult razorback suckers captured in 2014. Nonetheless, this improves upon the four fish captured during the 2013 spawning season (Albrecht et al. 2013b) and the two fish captured during the 2012 spawning season (Albrecht et al. 2013a). It should be noted that the lowest CPUE values observed in Las Vegas Bay were 0.04 fish/net-night during the 2003–04 field season (figure 13) (Welker and Holden 2004).

At Echo Bay, nets were focused on areas of frequent sonic-tagged fish contacts toward the west end of the bay and along the northern shoreline near the old boat ramp (see figure 11). Efforts throughout the spawning season were most successful in an area characterized by larger substrates (e.g., gravel, cobble, and boulder) north of the marina structure. In these efforts, 22 adult razorback suckers were

Table 3.—Location, tagging, and size information for razorback suckers captured in Lake Mead, February – April 2014

Date	Capture location[a]	PIT tag[b]	Sonic tag	Date captured[c]	Recapture?	TL[d]	FL[e]	SL[f]	Wt[g]	Sex[h]
2/5/2014	OA	384.1B7969CC18	578	2/5/2014	NO	520	480	439	1,738	M
2/6/2014	EB	384.1B7969EADE	586	2/6/2014	NO	656	611	561	3,190	F
2/11/2014	LB	3D9.1C2C841383	3488	2/13/2009	YES	626	568	543	3,586	M
2/12/2014	EB	3D9.257C60BE38		2/22/2011	YES	535	494	452	1,726	M
2/12/2014	EB	384.1B7969E02A		2/22/2012	YES	572	525	492	2,220	M
2/12/2014	EB	384.1B7969D8C7	3447	2/12/2014	NO	581	533	497	2,212	M
2/12/2014	EB	3D9.1C2C8406B7		2/25/2009	YES	581	535	505	2,438	M
2/12/2014	EB	384.1B7969D3BE	3375	2/12/2014	NO	598	555	513	2,144	M
2/12/2014	EB	384.1B7969D60C		2/22/2012	YES	603	561	520	2,202	M
2/12/2014	EB	3D9.1C2C83D7FC		3/10/2010	YES	605	556	522	2,670	M
2/12/2014	EB	532615681C/ 384.1B7969D655		2/2/2007	YES	629	591	544	2,720	M
2/12/2014	EB	384.1B7969DE0B	4656	2/12/2014	NO	637	583	541	2,814	M
2/26/2014	OA	3DD.003BA2FA93		2/26/2014	NO	570	523	490	2,202	F
2/26/2014	OA	3D9.1C2C8408E1	3337	3/15/2011	YES	589	540	502	2,048	M
2/26/2014	OA	3D9.1C2C7EF17C		3/11/2009	YES	611	575	496	2,848	F
2/26/2014	OA	384.1B7969DEEA		4/10/2013	YES	612	564	525	2,588	F
2/26/2014	OA	384.1B7969E7AA		3/21/2013	YES	617	566	538	2,522	F
2/26/2014	OA	3DD.003BA2FAA2		2/26/2014	NO	626	581	542	3,054	F
2/26/2014	OA	3D9.1C2D2672A1		3/1/2011	YES	644	588	548	2,444	F
2/27/2014	EB	53313C1A11/ 3DD.003BA2FA86		3/19/2008	YES	583	536	500	2,208	M
2/27/2014	EB	53437D5852/ 3DD.003BA2FA96		4/1/2008	YES	595	555	508	2,498	M
2/27/2014	EB	1F4A217303/ 3DD.003BA2FAA1		11/24/1998	YES	703	641	608	3,662	F
3/4/2014	LB	3DD.003BA2FA75		3/4/2014	NO	576	536	505	2,288	F
3/4/2014	LB	3D9.1C2C841AF7		3/3/2009	YES	651	608	564	2,588	F
3/6/2014	OA	3DD.003BA2FA80		3/6/2014	NO	521	480	446	1,618	M
3/6/2014	OA	3D9.1C2C84072C	3478	2/21/2013	YES	562	520	481	2,010	M
3/6/2014	OA	3D9.1C2C84147F	3374	2/16/2012	YES	582	536	502	2,150	M
3/6/2014	OA	3DD.003BA2FA7F		3/6/2014	NO	591	550	511	2,392	F
3/6/2014	OA	3DD.003BA2FA66		3/6/2014	NO	591	552	514	2,332	F
3/6/2014	OA	3DD.003BA2FA7E		3/6/2014	NO	628	579	534	2,608	F
3/6/2014	OA	3D9.1C2D269008		3/15/2011	YES	631	586	550	3,288	F
3/6/2014	OA	3DD.003BA2FA89		3/6/2014	NO	657	611	569	2,548	F
3/11/2014	LB	3DD.003BA2FA7C	3566	3/11/2014	NO	536	498	465	1,708	M
3/11/2014	LB	3DD.003BA2FAAE		3/11/2014	NO	649	625	565	2,598	F

Table 3.—Location, tagging, and size information for razorback suckers captured in Lake Mead, February – April 2014

Date	Capture location[a]	PIT tag[b]	Sonic tag	Date captured[c]	Recapture?	TL[d]	FL[e]	SL[f]	Wt[g]	Sex[h]
3/12/2014	EB	3D9.257C629ACA		2/3/2010	YES	545	499	463	1,776	M
3/12/2014	EB	3DD.003BA2FABB		3/12/2014	NO	554	521	492	2,156	F
3/12/2014	EB	3DD.003BA2FAA8		3/12/2014	NO	594	555	518	2,288	F
3/12/2014	EB	5325646B16/ 3DD.003BA2FA8C		2/14/2007	YES	604	558	518	2,298	M
3/12/2014	EB	532F161F08/ 3D9.1C2C840DF7		2/20/2013	YES	635	581	525	3,438	F
3/12/2014	EB	384.1B7969D618		3/7/2012	YES	664	618	574	3,298	F
3/16/2014	LB	3DD.003BA2F9AE/ 3D9.1C2C8417E8	4778	3/16/2014	NO	479	440	399	1,235	M
3/20/2014	OA	3D9.257C6093E8		2/3/2010	YES	526	479	446	1,726	M
3/20/2014	OA	3DD.003BA2FABF		3/20/2014	NO	531	489	442	1,488	M
3/20/2014	OA	3DD.003BA2FAAF		3/20/2014	NO	532	488	452	1,524	M
3/20/2014	OA	3DD.003BA2FA77		3/20/2014	NO	549	511	463	1,624	M
3/20/2014	OA	384.1B7969D3E6		3/13/2012	YES	552	511	469	1,720	M
3/20/2014	OA	3D9.1C2D25C0FF		2/17/2010	YES	557	513	471	1,524	M
3/20/2014	OA	384.1B7969ECFB		3/21/2013	YES	557	513	477	2,168	M
3/20/2014	OA	3D9.257C60CC21		2/9/2010	YES	561	488	478	1,682	M
3/20/2014	OA	384.1B7969E0DF		3/20/2014	NO	561	515	472	1,696	M
3/20/2014	OA	3D9.1C2C7F4A82		3/1/2011	YES	562	518	477	1,810	M
3/20/2014	OA	3D9.1C2D25D183		2/17/2010	YES	564	523	482	1,682	M
3/20/2014	OA	384.1B7969ED6E		3/20/2014	NO	567	521	484	1,892	M
3/20/2014	OA	384.1B7969D8F2		3/20/2014	NO	569	522	473	1,712	M
3/20/2014	OA	384.1B7969ED87		3/20/2014	NO	574	535	483	1,854	M
3/20/2014	OA	533342342B/ 384.1B7969D885		4/1/2008	YES	578	539	498	1,988	M
3/20/2014	OA	384.1B7969E0B2		3/5/2013	YES	579	532	487	1,948	M
3/20/2014	OA	384.1B7969E26C		3/21/2013	YES	589	542	502	2,148	M
3/20/2014	OA	384.1B7969D4C6		3/20/2014	NO	592	542	494	1,992	M
3/20/2014	OA	3DD.003BA2FA78		3/20/2014	NO	593	550	503	2,094	F
3/20/2014	OA	384.1B7969E15C		3/20/2014	NO	614	565	519	2,386	F
3/20/2014	OA	3DD.003BA2FA5F		3/20/2014	NO	621	566	513	2,422	F
3/20/2014	OA	384.1B7969DEEA		4/10/2013	YES	621	573	525	2,638	F
3/20/2014	OA	3DD.003BA2FA73		3/20/2014	NO	624	569	521	2,528	F
3/20/2014	OA	3DD.003BA2FA7A		3/20/2014	NO	627	581	528	2,734	F
3/20/2014	OA	3D9.257C60B636		2/1/2011	YES	631	581	537	2,960	F
3/20/2014	OA	384.1B7969DA5E		3/20/2014	NO	637	588	535	2,210	F
3/20/2014	OA	3D9.257C619794		2/22/2011	YES	646	593	546	2,748	F

Table 3.—Location, tagging, and size information for razorback suckers captured in Lake Mead, February – April 2014

Date	Capture location[a]	PIT tag[b]	Sonic tag	Date captured[c]	Recapture?	TL[d]	FL[e]	SL[f]	Wt[g]	Sex[h]
3/20/2014	OA	3D9.1C2D265F36	468	3/21/2012	YES	Quick release[i]				M
3/25/2014	EB	3DD.003BA2FABA		3/25/2014	NO	594	546	511	2,238	F
3/25/2014	EB	3DD.003BA2FA6D		3/25/2014	NO	630	583	551	2,894	F
3/25/2014	EB	532F161F08/ 3D9.1C2C840DF7		2/29/2008	YES	Quick release[i]				F
3/27/2014	LB	3DD.003BA2FA79		3/27/2014	NO	525	482	449	1,612	F
3/27/2014	LB	3DD.003BA2FAAA		3/27/2014	NO	567	530	491	1,888	F
4/3/2014	OA	384.1B7969ECFB		3/21/2013	YES	556	510	457	1,888	M
4/3/2014	OA	3DD.003BA2FA95		4/3/2014	NO	572	525	473	1,692	F
4/3/2014	OA	384.1B7969D849		3/15/2012	YES	601	553	492	2,278	F
4/3/2014	OA	3DD.003BA2FAC1		4/3/2014	NO	615	576	515	2,248	F
4/3/2014	OA	3D9.1C2C84072C	3478	2/21/2013	YES	Quick release[i]				M
4/3/2014	OA	384.1B7969DEEA		4/10/2013	YES	Quick release[i]				F
4/10/2014	OA	3D9.1C2C843DBF		4/7/2011	YES	562	519	473	1,968	M
4/10/2014	OA	3DD.003BA2FA9C		4/10/2014	NO	651	589	543	3,198	F
4/10/2014	OA	3D9.1C2D265F36	468	3/21/2012	YES	Quick release[i]				M
4/15/2014	LB	3DD.003BA2FAAE		3/11/2014	YES	Quick release[i]				F
4/16/2014	OA	3DD.003BA2FA88		4/16/2014	NO	504	470	434	1,388	M

[a] OA = Overton Arm (Virgin River/Muddy River inflow area), EB = Echo Bay, and LB = Las Vegas Bay.
[b] Two PIT tag numbers may be present in older, recaptured individuals that were marked originally with an older style PIT tag (e.g., 400 kilohertz) and recently tagged again with a new, 12.5-mm, 134.2-kilohertz style PIT tag.
[c] Date originally stocked or originally captured.
[d] Total length in millimeters.
[e] Fork length in millimeters.
[f] Standard length in millimeters.
[g] Weight in grams.
[h] F = female, M = male, U = unidentified, and I = immature (sex not determined).
[i] No measurements were taken due to the proximity of the date of capture to the date of recapture; individual was released immediately to avoid unnecessary stress.

captured in 26 net-nights during the 2014 spawning season (see tables 2 and 3 and figure 13). The number of adults captured was similar to recent study years, as was the lack of juvenile individuals captured (Shattuck et al. 2011; Albrecht et al. 2013a, 2013b). No juvenile fish were captured from Echo Bay during the 2014 spawning period, marking the seventh year without juvenile captures in this area. However, the 2014 razorback sucker CPUE for trammel netting at Echo Bay was 0.85 fish/net-night, which falls at the uppermost end of the range of catch rates (0.12–0.85 fish/net-night) observed during previous field seasons, and represents a value that has not been achieved within Echo Bay since 1997 (figure 13).

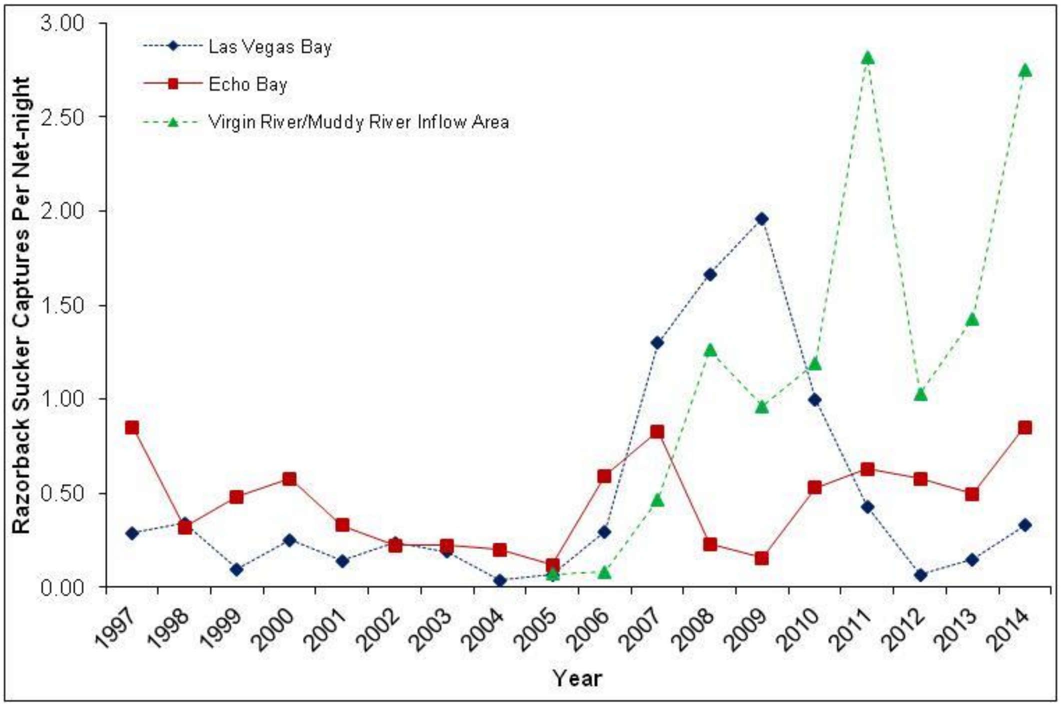

Figure 13.—Trammel netting CPUE (net-night) of razorback suckers at long-term monitoring study areas in Lake Mead, 1996 – 2014.
Sampling at the Virgin River/Muddy River inflow area was initiated during the 2004–05 study year.

Similarly, trammel netting during the 2013–14 field season successfully captured numerous razorback suckers at the Virgin River/Muddy River inflow area (see figure 12). A total of 20 net-nights resulted in the capture of 55 adult razorback suckers, yielding the highest CPUE rates and total number of razorback suckers for any of the long-term monitoring study areas during the 2013–14 field season (see table 3 and figure 13). Most of the fish captured at the Virgin River/Muddy River inflow area were taken over gravel and cobble substrates along the eastern shoreline and near past spawning areas (see figure 12). The razorback sucker CPUE for trammel netting at the Virgin River/Muddy River inflow area was 2.75 fish/net-night (see figure 13), which represents the second highest CPUE value obtained during the course of research and monitoring effort to date (see figure 13). Furthermore, this was the fifth consecutive year that the Virgin River/Muddy River inflow area CPUE exceeded the CPUE values in Las Vegas Bay and Echo Bay (see figure 13). The overall Lake Mead CPUE for 2014 (1.21 fish/net-night) increased from that of 2013 (0.70 fish/net-night) as well as that from 2012 (0.57 fish/net-night). In addition, the 2014 Lake Mead CPUE was higher than the historical average CPUE (0.63 fish/net-night) for the combined long-term monitoring study areas (see figure 13).

Interesting movement data were obtained from some of the recaptured fish in 2014. Although the majority of fish were recaptured within the same general location as their original capture locations, a few individuals demonstrated movement between study areas. This included four razorback suckers of wild origins that were originally captured and PIT tagged near the Virgin River/Muddy River inflow area, which were then recaptured in Echo Bay during the 2014 spawning season. Conversely, two other PIT-tagged fish (also of wild origin) were documented to have moved from Echo Bay to the Virgin River/Muddy River inflow area. Even more striking was the movement of a wild fish originally captured and PIT tagged at the CRI area in 2012, and subsequently captured in 2014 at the CRI area, when it was implanted with a sonic tag. This particular individual was then captured approximately 3 weeks later, during the 2014 spawning season, at the Virgin River/Muddy River inflow along with 28 other ripe fish over gravel/cobble substrates.

In addition to capturing razorback suckers at the Virgin River/Muddy River inflow area during the 2014 spawning period, 14 total flannelmouth suckers and two razorback sucker x flannelmouth sucker hybrids were also captured. Nine of the 14 flannelmouth suckers were wild, unmarked individuals, and select fin ray sections were obtained for aging purposes. The 2014 CPUE for nonrazorback suckers, native Catostomids (including the two hybrid individuals) in the Virgin River/Muddy River inflow area was 0.80 fish/net-night (Virgin River/Muddy River inflow area CPUE: 2011 = 0.05 fish/net-night, 2012 = 0.06 fish/net-night, 2013 = 0.11 fish/net-night). Although flannelmouth suckers have been captured at the Virgin River/Muddy River inflow area in relatively low numbers since 2010, the documented razorback sucker x flannelmouth sucker hybrids within the long-term monitoring study areas during the 2013 and 2014 spawning seasons are unique. In the past, 17 razorback sucker x flannelmouth sucker hybrid individuals have been documented at the CRI area from 2010 to 2013 [Kegerries and Albrecht 2013a, 2013b]), but only 2 individuals have been captured during long-term monitoring. As such, both of the 2014 razorback sucker x flannelmouth sucker hybrids were recaptured individuals, originally identified during the 2013 spawning period from the Virgin River/Muddy River inflow area (Albrecht et al. 2013b).

Growth

Although 45 razorback suckers were recaptured during the 2014 field season (3 from Las Vegas Bay, 14 from Echo Bay, and 28 from the Virgin River/Muddy River inflow area), annual growth analyses were performed using only data from 37 of these individuals (table 4). All recaptures were not included in the analyses because some individuals were captured more than once during the 2014 field season. The difference in TL between capture periods was used to determine mean annual growth (table 4). One stocked fish and 36 wild fish were used to calculate growth information for 2014. The combined mean annual growth of all razorback suckers recaptured from all long-term monitoring study areas during 2014 was 13.64 mm/year (table 4), which is somewhat similar to the reported growth rate for the past 3 years (ranging from 14.8 to 24.7 mm/year) (Shattuck

Table 4.—Lake Mead razorback sucker growth histories for recaptured fish, February – April 2014

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]	Days between captures	Annual growth (mm/day)[g]
Las Vegas Bay										
Wild fish										
3D9.1C2C841AF7	3/3/2009	LB	340	F	3/4/2014	LB	651	311	1,827	62.13
									Mean annual growth	**N/A[h]**
Echo Bay										
Wild fish										
384.1B7969E02A	2/22/2012	EB	548	M	2/12/2014	EB	572	24	721	12.15
384.1B7969D60C	2/22/2012	EB	589	M	2/12/2014	EB	603	14	721	7.09
532615681C/ 384.1B7969D655	2/8/2007	EB	609	M	2/12/2014	EB	629	20	2,561	2.85
3D9.1C2C83D7FC	3/10/2010	EB	535	M	2/12/2014	EB	605	70	1,435	17.80
3D9.1C2C8406B7	2/25/2009	OA	549	M	2/12/2014	EB	581	32	1,813	6.44
3D9.257C60BE38	2/22/2011	OA	509	M	2/12/2014	EB	535	26	1,086	8.74
53313C1A11/ 3DD.003BA2FA86	3/19/2008	EB	532	M	2/27/2014	EB	583	51	2,171	8.57
384.1B7969D618	3/7/2012	EB	663	F	3/12/2014	EB	664	1	735	0.50
5325646B16/ 3DD.003BA2FA8C	2/14/2007	EB	501	M	3/12/2014	EB	604	103	2,583	14.55
532F161F08/ 3D9.1C2C840DF7	2/29/2008	EB	635	F	3/12/2014	EB	635	0	2,203	0.00
3D9.257C629ACA	2/3/2010	OA	455	M	3/12/2014	EB	545	90	1,498	21.93
									Mean annual growth	**9.15 ± 2.10 SE**
Stocked fish										
1F4A217303/ 3DD.003BA2FAA1	11/24/1998	EB	614	F	2/27/2014	EB	703	89	5,574	5.83
									Mean annual growth	**N/A[h]**
Virgin River/Muddy River inflow area										
Wild fish										
384.1B7969DEEA	4/10/2013	OA	598	F	2/26/2014	OA	612	14	322	15.87
384.1B7969E7AA	3/21/2013	OA	617	F	2/26/2014	OA	605	12	342	12.81
3D9.1C2C7EF17C	3/11/2009	OA	585	F	2/26/2014	OA	611	26	1,813	5.23
3D9.1C2C8408E1	3/15/2011	OA	551	M	2/26/2014	OA	589	38	1,079	12.85
3D9.1C2D2672A1	3/1/2011	OA	599	F	2/26/2014	OA	644	45	1,093	15.03

Table 4.—Lake Mead razorback sucker growth histories for recaptured fish, February – April 2014

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]	Days between captures	Annual growth (mm/day)[g]
53437D5852/ 3DD.003BA2FA96	4/1/2008	OA	535	M	2/27/2014	EB	595	60	2,158	10.15
3D9.1C2C84072C	2/21/2013	OA	549	M	3/6/2014	OA	562	13	378	12.55
3D9.1C2D269008	3/15/2011	OA	577	F	3/6/2014	OA	631	54	1,087	18.13
3D9.1C2C84147F	2/16/2012	EB	559	M	3/6/2014	OA	582	23	749	11.21
384.1B7969D3E6	3/13/2012	OA	521	M	3/20/2014	OA	552	31	737	15.35
384.1B7969E0B2	3/5/2013	OA	567	M	3/20/2014	OA	579	12	380	11.53
384.1B7969E26C	3/21/2013	OA	578	M	3/20/2014	OA	589	11	364	11.03
384.1B7969ECFB	3/21/2013	OA	551	M	3/20/2014	OA	557	6	364	6.02
3D9.1C2C7F4A82	3/1/2011	OA	518	M	3/20/2014	OA	562	44	1,115	14.40
3D9.1C2D25C0FF	2/17/2010	OA	470	M	3/20/2014	OA	557	87	1,492	21.28
3D9.1C2D25D183	2/17/2010	OA	494	M	3/20/2014	OA	564	70	1,492	17.12
3D9.257C6093E8	2/3/2010	OA	441	M	3/20/2014	OA	526	85	1,506	20.60
3D9.257C60B636	2/1/2011	OA	572	F	3/20/2014	OA	631	59	1,143	18.84
3D9.257C60CC21	2/9/2010	OA	471	M	3/20/2014	OA	561	90	1,500	21.90
3D9.257C619794	2/22/2011	OA	585	F	3/20/2014	OA	646	61	1,122	19.84
533342342B/ 384.1B7969D885	4/1/2008	OA	514	M	3/20/2014	OA	578	64	2,179	10.72
3D9.1C2D265F36	3/21/2012	CI	571	M	3/20/2014	OA	592	21	706	10.86
384.1B7969D849	3/15/2012	OA	574	F	4/3/2014	OA	601	27	749	13.16
3D9.1C2C843DBF	4/7/2011	EB	533	M	4/10/2014	OA	562	29	1,099	9.63
Mean annual growth										**14.01 ± 0.93 SE**
Long-term monitoring										
Mean annual growth of all wild fish										**13.86 ± 1.68 SE**
Mean annual growth of all stocked fish										**N/A[i]**
Mean annual growth of all fish										**13.64 ± 1.64 SE**

[a] Two PIT tag numbers may be present in older, recaptured individuals that were marked originally with an older style PIT tag (e.g., 400kHz) and recently tagged again with a new, 12.5-mm, 134.2-kilohertz style PIT tag.
[b] Date originally stocked or originally captured.
[c] LB = Las Vegas Bay, EB = Echo Bay, OA = Overton Arm (Virgin River/Muddy River inflow area), and CI = Colorado River inflow area.
[d] F = female, and M = male.
[e] Date of most recent recapture.
[f] Difference in total length from date of stocking to date of most recent recapture.
[g] Annual growth was calculated as the difference in TL from date of stocking to date of most recent recapture divided by the number of days between captures and multiplied by 365.
[i] Mean could not be calculated from growth of one individual.

et al. 2011; Albrecht et al. 2013a, 2013b). The mean annual growth of wild fish captured in Lake Mead in 2014 was 13.86 mm/year, while the mean annual growth of stocked fish in 2014 was not calculated due to lack of stocked fish recaptures (table 4).

Remote PIT Tag Antennas

Nine contacts were made among two of the six antennas set near the 2014 spawning location at the Virgin River/Muddy River inflow area during March 31 – April 3, 2014. Of the nine contacts, six unique individual razorback suckers that have been previously captured in long-term monitoring efforts were contacted. All of the contacted individuals were of wild origin, and the two females and four males ranged in age from 9 to 24 years. All but one individual were fish that were originally captured at the Virgin River/Muddy River inflow area. The one individual not originating from the Virgin River/Muddy River inflow area was a 24-year-old male that had been originally captured in 1992 in Echo Bay. This individual was subsequently recaptured in long-term monitoring efforts four times but never outside of Echo Bay. Because antennas were deployed during long-term monitoring trammel netting efforts in 2014, individuals contacted by antennas were also captured in trammel nets. During the March 31 – April 3, 2014, deployment of antennas, one night of netting (April 2–3, 2014) conducted in the same area captured two of the contacted razorback suckers. However, an additional four razorback sucker individuals and two flannelmouth sucker individuals were captured in trammel nets that were undetected by antennas. Two of the razorback suckers and one of the flannelmouth suckers were new, wild individuals without PIT tags, while the other two razorback suckers and one flannelmouth sucker were recaptured individuals that went undetected. The lack of detection of these individuals was likely due to the difference between the limited reach of the antennas and the 91.4-m length of the trammel nets.

During April 7–10, 2014, no contacts were made on any of the three antennas set near the 2014 spawning location at Echo Bay. However, during this same timeframe, a total of 102 contacts were made among all 3 antennas set near the 2014 spawning location at the Virgin River/Muddy River inflow area. Of the 102 contacts, 16 unique individual razorback suckers, 1 unique individual flannelmouth sucker, and 1 unique razorback sucker x flannelmouth sucker hybrid that have been previously captured in long-term monitoring efforts were contacted. All but 1 of the contacted razorback sucker individuals was of wild origin, and the 3 females and 12 males ranged in age from 8 to 16 years. The one individual not of wild origin was an immature, sonic-tagged, juvenile razorback sucker from the Lake Mead Fish Hatchery that was stocked in 2013 as part of juvenile razorback sucker research efforts. This individual was last contacted 2.5 km away via sonic telemetry on July 24, 2013, and has never been captured in netting efforts. All of the razorback suckers, flannelmouth suckers, and razorback sucker x flannelmouth sucker hybrid individuals contacted were originally captured at the Virgin River/Muddy River inflow area, with the exception of one razorback sucker individual originally captured at Echo Bay in 2012. This individual has never been captured outside of Echo Bay. The flannelmouth sucker individual contacted was one of the individuals captured in 2014, and the razorback sucker x flannelmouth sucker hybrid was one of two hybrid individuals that had ever been captured in long-term monitoring efforts. During the April 7–10, 2014, deployment of antennas, 1 night of netting (April 9–10, 2014) conducted in the same area captured one of the contacted flannelmouth suckers. Although, trammel netting efforts failed to capture any of the 16 unique razorback sucker individuals contacted by antennas, trammel nets captured one new, wild individual and two recaptured individuals. Additionally, trammel nets captured two new, wild flannelmouth suckers and a recaptured razorback sucker x flannelmouth sucker hybrid individual.

Larval Sampling

Larval razorback sucker sampling in long-term monitoring was initiated on February 3, 2014, and larvae were first collected on February 10, 2014, at Las Vegas Bay over a variety of substrates (figure 14). Larval razorback suckers were collected throughout the western portions of Las Vegas Bay and at times within the flowing portions of Las Vegas Wash near the wash/lake interface (figure 14). The collection of larval razorback suckers occurred at temperatures between 17 and 23 °C, and positive collections were often in conjunction with sonic-tagged fish or in areas where previous adult razorback suckers were captured via trammel netting (see figures 4, 10, 14, and 15). Las Vegas Bay yielded a total of 538 larval fish captured within 1,260 minutes of sampling, providing an overall catch-per-minute (CPM) value of 0.427 (figure 16). The 2014 razorback sucker larvae CPM rate at Las Vegas Bay is one of the higher overall CPM values observed at this study area since 2007 and the highest larval CPM value observed from long-term monitoring study areas in 2014 (figure 16).

In Echo Bay, the first razorback sucker larvae were captured on March 11, 2014, along the northern shoreline, with positive larval collections made over gravel and cobble substrates at temperatures ranging 14–19 °C (see figures 15 and 17). The collection of 119 larval razorback suckers within 1,320 minutes at Echo Bay resulted in a CPM value of 0.090 (figure 16). This value represents an improvement over the 40 total larvae (0.019 CPM) reported by Albrecht et al. (2013b) (figure 16). The 2014 larval collection efforts in Echo Bay returned the lowest total number of larval razorback suckers and the lowest CPM values amongst long-term monitoring. Furthermore, for the second time during this study, CPM values (and total numbers of larvae) were lower in Echo Bay than those at the Virgin River/Muddy River inflow area (Albrecht et al. 2013b). Despite low overall numbers relative to other study areas in 2014, the 2014 Echo Bay larval razorback sucker captures and CPM values fall well within the range of past values observed for this particular study area (figure 16). More

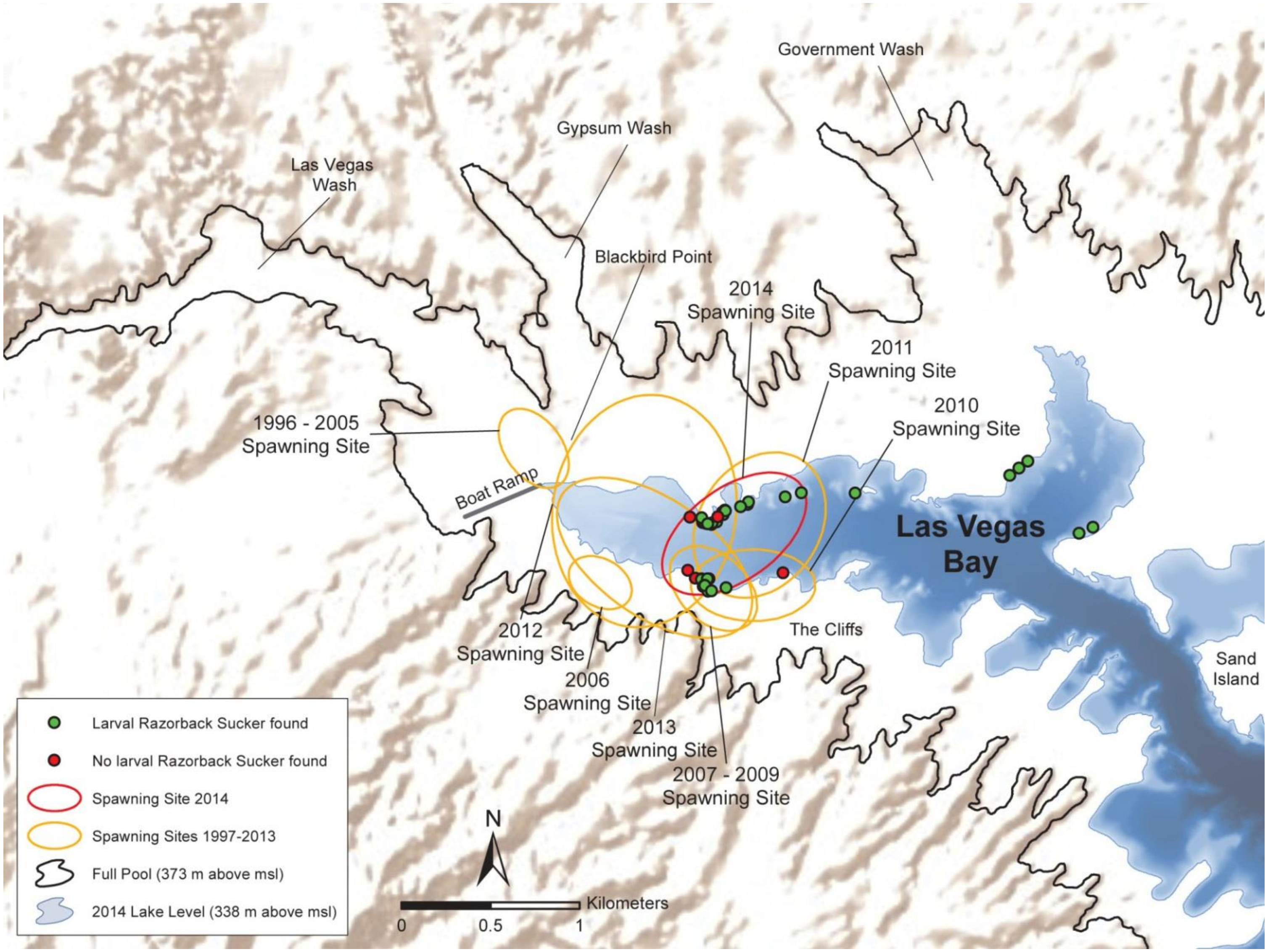

Figure 14.—Locations of larval razorback sucker sampling and captures in Las Vegas Bay, February 2014 – April 2014.

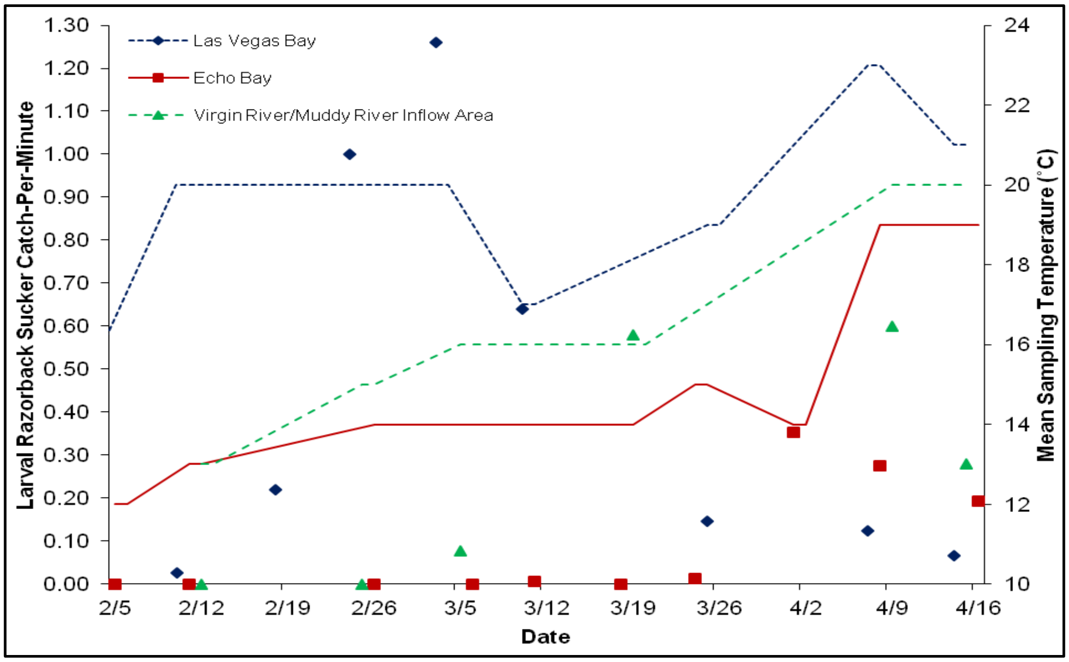

Figure 15.—Larval razorback sucker CPM rates (points) at long-term monitoring study sites in Lake Mead with associated temperature data at time of sampling (lines), February 2014 – April 2014.

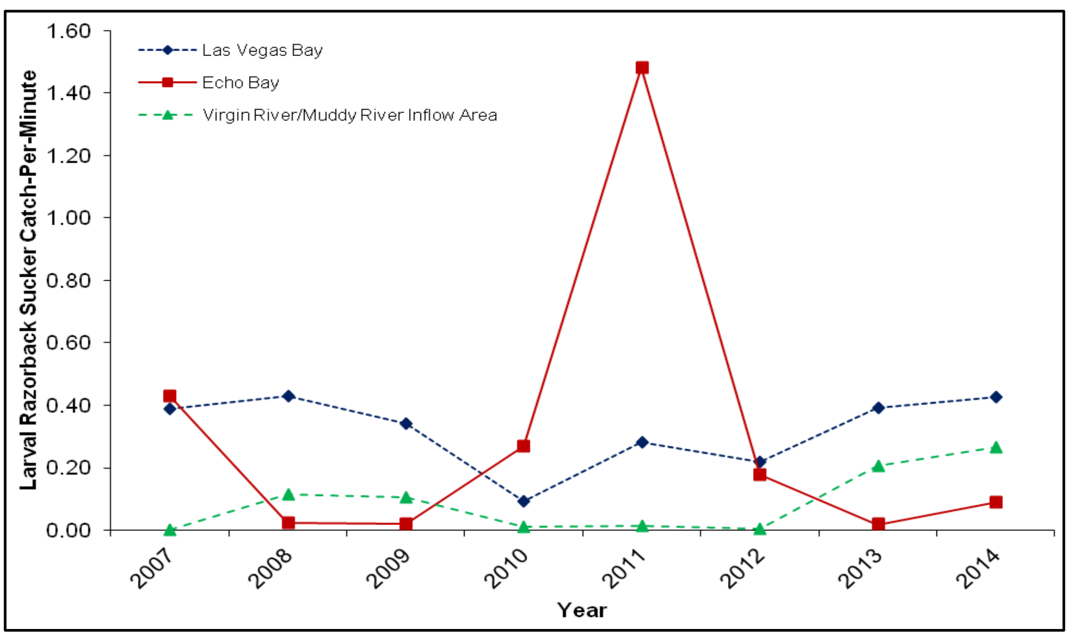

Figure 16.—Larval razorback sucker CPM rates at long-term monitoring study areas in Lake Mead, 2007–14.

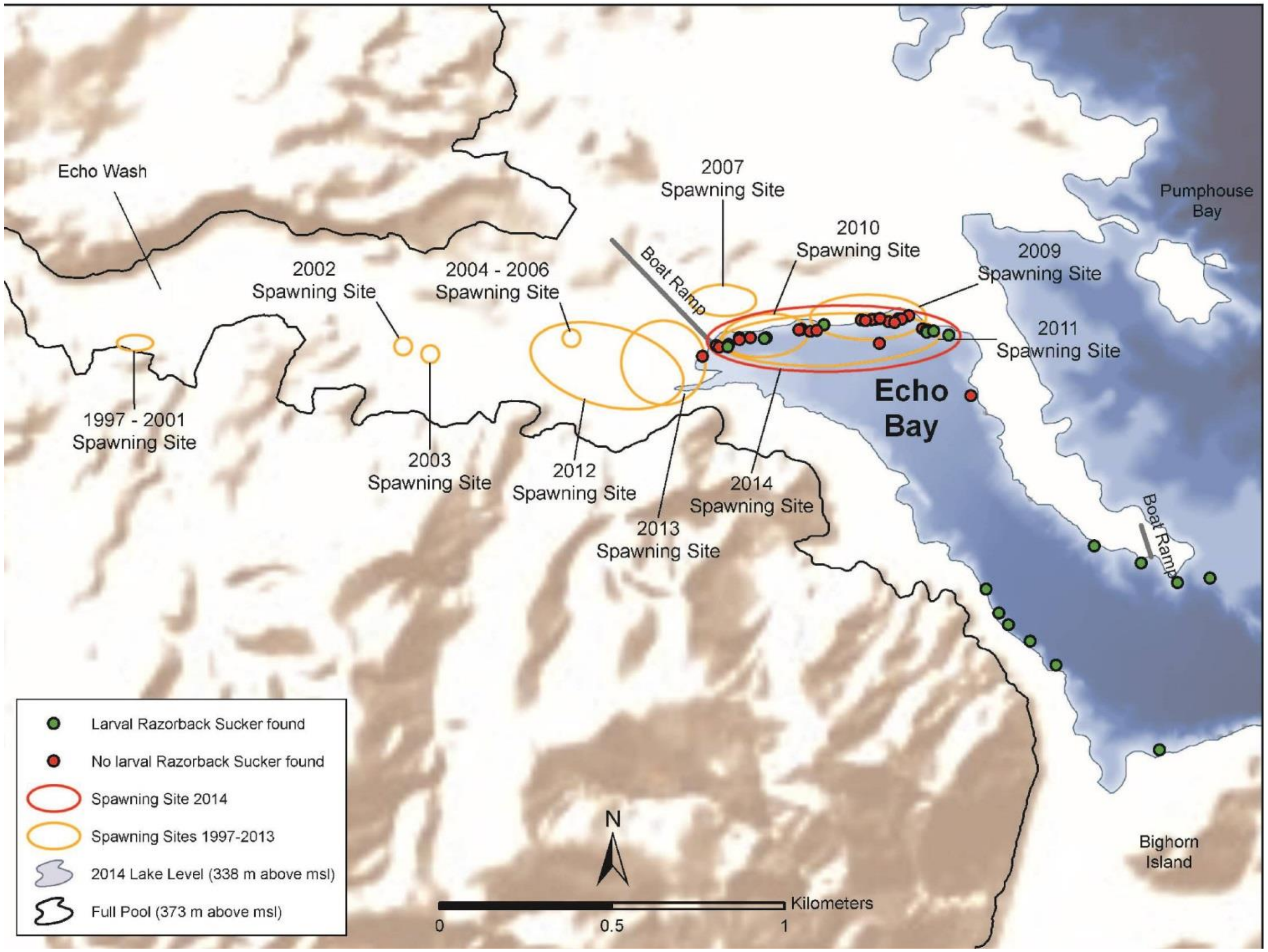

Figure 17.—Locations of larval razorback sucker sampling and captures in Echo Bay, February 2014 – April 2014.

More importantly, these values confirm spawning success at Echo Bay and underscore the importance of this historical spawning location for Lake Mead razorback suckers.

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 2014 were captured on March 5, 2014, over a variety of substrate types and at temperatures ranging from 15 to 20 °C (see figure 15). Larval collections occurred approximately 1–2 km south of the Virgin River/Muddy River inflow area along the eastern shoreline of the Overton Arm (figures 1 and 18). 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 table 4 and figures 6, 12, and 18). Larval razorback suckers were again found in numbers disproportionate to the abundance of adult captures at the Virgin River/Muddy River inflow area; however, this observation has been seen in past sampling for this long-term monitoring study area (Shattuck et al. 2011; Albrecht et al. 2013a, 2013b). Despite this disparity, and for the second consecutive time, both the total number and overall larval razorback sucker CPM values from this relatively new study area were higher than those same metrics observed in Echo Bay. Similarly, for the first time during this study, initial larval captures at the Virgin River/Muddy River inflow area occurred prior to initial larval captures at Echo Bay, possibly a function of Echo Bay remaining cooler for longer during 2014 compared to the Virgin River/Muddy River inflow area (see figure 15). Larval captures in the Virgin River/Muddy River inflow area in 2014 totaled 215 larval razorback suckers captured within 810 minutes of sampling, resulting in a CPM of 0.205. This larval CPM rate was the highest larval razorback sucker catch rate observed from this spawning location to date (see figure 16).

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 historic spawning sites and have continued to find suitable habitat for reproduction. Though relatively few adult razorback suckers were captured in Las Vegas Bay during the 2013–14 field season, the majority of adult fish were found near the western extent of Las Vegas Bay (see figures 4 and 10).

This area was also the primary location for the collection of larval individuals; however, it is noted that larval razorback suckers were captured immediately adjacent to the Las Vegas Wash inflow area and periodically within areas of flow at the wash/lake interface. These collections suggest that at least some of the

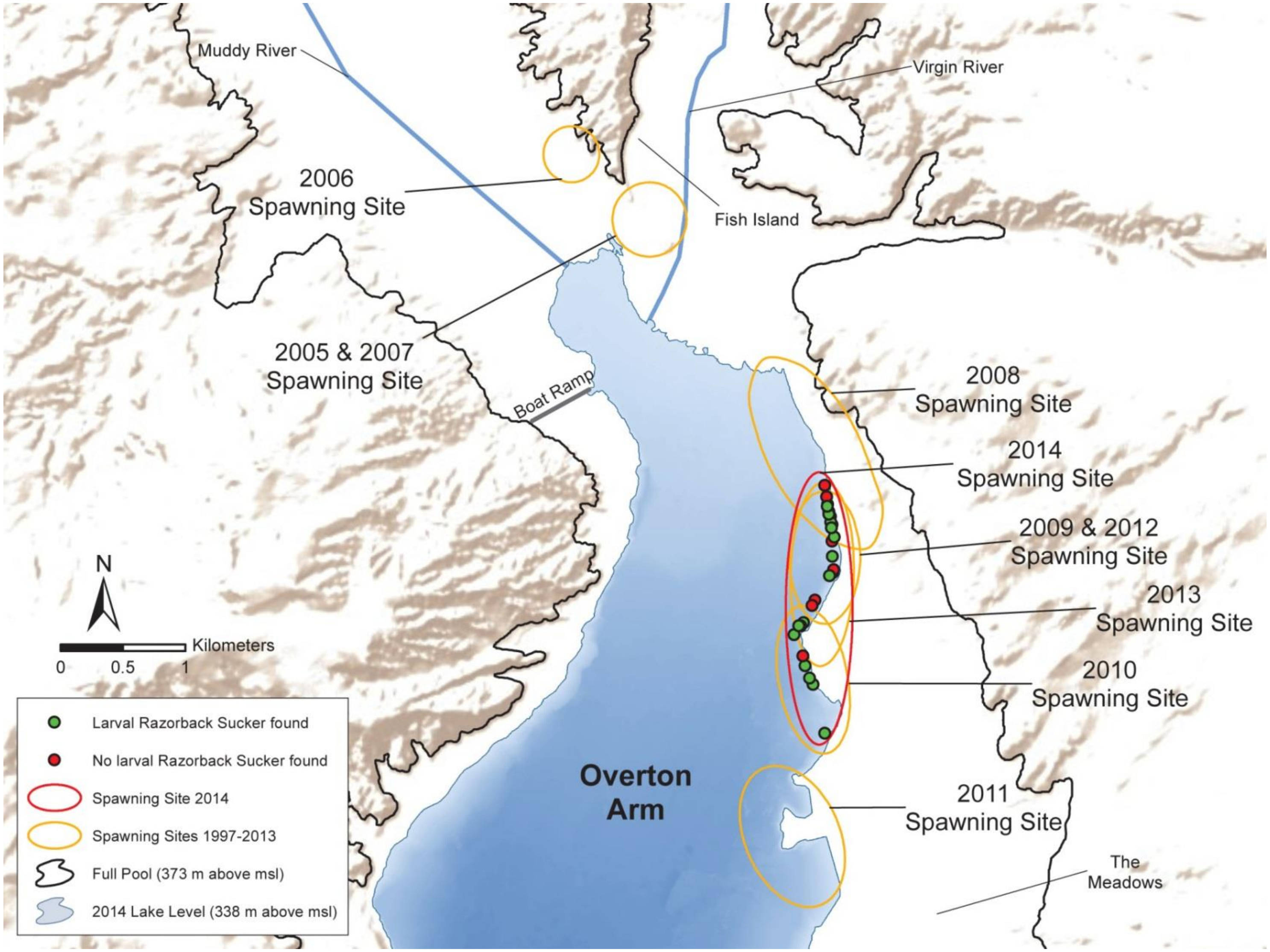

Figure 18.—Locations of larval razorback sucker sampling and captures at the Virgin River/Muddy River inflow area, February 2014 – April 2014.

2014 reproduction likely occurred upstream in the lotic portions of the wash. Furthermore, collection of larval razorback suckers occurred in the southern portion of Government Wash Cove, suggesting that there may have been additional, secondary spawning areas within Las Vegas Bay during 2014. The primary spawning area of the 2013–14 field season was located east of the Las Vegas Wash inflow area along both shorelines of the bay and near the wash/lake interface (see figure 14). For the past 8 years, the primary razorback sucker spawning site has been in the same general vicinity, although it has shifted with fluctuating lake elevations (see figure 14). Similar to the 2011–12 and 2012–13 field seasons, sonic-tagged razorback suckers were observed using Las Vegas Bay in its entirety during the 2013–14 field season. Spawning activity occurred primarily along the western shorelines immediately adjacent to Las Vegas Wash where the majority of larval individuals were collected (see figure 14). Despite a low trammel netting CPUE (relative to the other monitoring study areas in 2014), successful spawning of razorback suckers was confirmed within Las Vegas Bay.

As described in past annual reports (Welker and Holden 2003, 2004; Albrecht et al. 2005, 2006b, 2013a, 2013b; Shattuck et al. 2011), receding lake elevations have resulted in eastward shifts of the primary Echo Bay spawning site. The primary Echo Bay spawning site for the 2013–14 field season overlapped with the spawning sites determined for the 2009–11 spawning seasons (see figure 17); however, the 2013–14 primary spawning area in Echo Bay was less defined and was located over a broader spatial area (compared to some of the past study years primary spawning locations). Trammel netting collections of sexually mature and reproductively ready razorback suckers, as well as routine use of this area by sonic-tagged individuals (see figures 5 and 11), helped confirm the importance of this area for reproductive activities. Larval razorback sucker collections occurred along the far western and northern shorelines of Echo Bay immediately adjacent to the old boat ramp and as far as 0.7 km easterly along the northern shoreline (see figure 17).

Of the three long-term monitoring study areas in Lake Mead, the Virgin River/Muddy River inflow area has typically been 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 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. However, during the 2012–13 (Albrecht et al. 2013b) and again during the 2013–14 field seasons, record numbers of larval razorback suckers were collected at the Virgin River/ Muddy River inflow area, and the spawning site designation was similar to the general areas observed during the 2009–10 and 2012–13 spawning seasons (see figure 18). The collection of numerous reproductively ready, adult razorback suckers in 2014 signified that spawning was likely occurring over a fairly broad area in the Overton Arm (see figure 12), which is further indicated by frequent usage of the area by sonic-tagged individuals (see figure 6). Additionally, the relatively large number of larval razorback suckers (for this particular long-term monitoring study area) collected in the immediate area of captured adults and sonic-tagged adults further defined the primary spawning site designation (see figure 18). The 2014 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 18).

Age Determination

To date, a definitive age has been determined for 470 razorback suckers from long-term monitoring study areas in Lake Mead (not including 28 individuals aged from the CRI area to date [Albrecht et al. 2014]). In 2014, ages were obtained from 35 razorback suckers captured in trammel nets at long-term monitoring study areas, while one individual was aged from the CRI area (attachment 1 and figure 19) (Albrecht et al. 2014). The single CRI area individual was unique; it was the smallest wild razorback sucker captured during the 2014 field season (429 mm TL; sexually immature), and it was aged at 3 years old, making it one of the more youthful fish aged from Lake Mead to date. Conversely, the youngest razorback sucker aged from the long-term monitoring study areas in 2014 was a 5-year-old, sexually mature individual from Las Vegas Bay (attachment 1). The majority of fish aged from the long-term monitoring study areas (91.7%, n = 33) ranged from 6 to 12 years old (2002–08 year-classes), while the oldest razorback sucker aged during 2014 long-term monitoring was a 15-year-old female (1999 year-class) with a TL of 703 mm (attachment 1).

To date, all fish aged have undergone back-calculation techniques, assigning them to year-classes (spanning approximately 1966–2011) (attachment 1). Prior to the last seven field seasons, the majority of aged fish were spawned during high lake elevations between 1978–1989 and 1997–1999 (figure 19). However, more recent data clearly show Lake Mead razorback sucker recruitment occurring beyond 1999, coinciding with a steady decline of lake elevations during more recent study years (Holden et al. 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; Kegerries et al. 2009; Shattuck et al. 2011). Based on the cumulative dataset, the largest number of individuals (326) were spawned from 2001 to 2006. Within that period, 102 individuals (including those from the CRI area) were aged from the 2005 year-class alone, which indicates a pulse of natural recruitment for razorback suckers in Lake Mead. It also appears that some level of recruitment is possible in Lake Mead regardless of lake elevation, as natural recruitment has occurred at long-term monitoring study

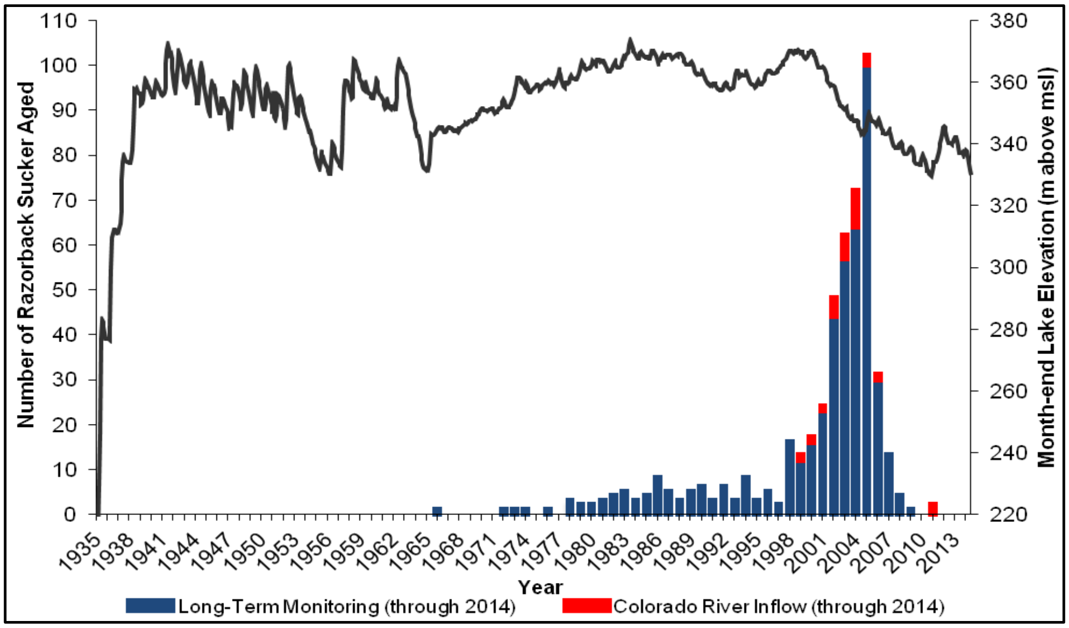

Figure 19.—Cumulative number of razorback suckers back-calculated to year spawned for individuals aged with corresponding Lake Mead month-end lake elevations, January 1935 – June 2014.
Blue bars denote individuals aged in long-term monitoring efforts, 1999–2014, and red bars denote individuals aged in efforts at the CRI area, 2010–14 (Albrecht et al. 2014).

areas nearly every year through at least 2009, with wild recruitment positively documented though 2011 with individuals included from the CRI area (see figure 19). 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).

Furthermore, ages were determined from 4 of the 14 flannelmouth suckers captured at the Virgin River/Muddy River inflow area in 2014 that ranged from 3 to 5 years (2009–11 year-classes, 254–471 mm TL). Both of the razorback sucker x flannelmouth sucker hybrids captured from long-term monitoring study areas in 2014 were recaptures that had been aged previously (2005 and 2006 year-classes) (Albrecht et al. 2013b).

Population and Survival Estimation

Population Estimation

Using mark-recapture data spanning 2012–14 (36 capture occasions), the lake-wide estimate, which included data from all long-term monitoring study areas as well as the CRI area, produced a weighted average estimate of 589 individuals with 95% confidence bounds of 370–808 (table 5). In a model comparison according to AICc weights and model likelihoods for estimates produced in the program MARK, capture probabilities in the model carrying the most AICc weight ranged from 0.01–0.09 (table 5 and attachment 2). This number closely follows that from the lake-wide estimate produced during the 2012–13 field season in which it was calculated that there were 597 individuals (95% confidence bounds of 474–776) (Albrecht et al. 2013b).

Table 5.—Lake-wide population estimate for razorback suckers in Lake Mead produced in the program MARK using mark-recapture data, 2012–14

Model[a]	Estimated number of individuals (95% confidence limits)	Capture events	Standard errror	Capture probability
Lake-wide				
$\pi(.)\rho(t)N(.)$	589.72 (423.06 – 872.56)	36	111.52	0.01 – 0.09
$\pi(.)\rho(.)N(.)$	459.95 (371.19 – 807.79)	36	55.18	0.01
Weighted average				
Derived *N*	588.73 (369.66 – 807.79)		111.77	

[a] π = Probability that the individual occurs in the mixture, (.) = parameter consistent through time, ρ = capture probability, (*t*) = parameter variable through time, and *N* = abundance estimate.

Survival Estimation

A total of 543 individuals were included in the dataset spanning 1996–2014, ranging in size from 451 to 756 mm TL, with a mean TL of 582 mm (± 2.5 SE). Using these data, a weighted average of annual apparent survival was calculated at a rate of 0.68 with 95% confidence bounds of 0.25–0.94 (table 6). Model comparison in the program MARK found the model that carried the most AICc weight ranged in recapture probabilities year to year from 0.05–0.45 (table 6 and attachment 3).

DISCUSSION AND CONCLUSIONS

Long-term monitoring information collected during the 2013–14 field season (18th field season) has expanded our knowledge of spawning behavior, habitat use, recruitment patterns, growth, and the demographics of razorback sucker population(s) in Lake Mead. Information has also been gained regarding the nature of stocked and wild fish interactions, population abundance, adult survival rates, and razorback sucker responses to changing lake elevations. Sonic telemetry, trammel netting, and larval collection data 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

Table 6.—Annual apparent survival rate estimate for razorback sucker in Lake Mead produced in the program MARK using adult (> 450 mm TL) mark-recapture data, 1996–2014

Model[a]	Annual apparent survival rate estimate (95% confidence limits)	Capture events	Standard error	Recapture probability
Cormack-Jolly-Seber				
$\phi(.)p(t)$	0.77 (0.73–0.80)	19	0.02	0.05–0.45
$\phi(t)p(t)$	0.16 (0.04–0.48)	19	0.11	0.06–1.00
$\phi(t)p(.)$	0.33 (0.07–0.77)	19	0.22	0.20
$\phi(.)p(.)$	0.76 (0.72–0.80)	19	0.02	0.20
Weighted average				
Derived ϕ	0.68 (0.25–0.94)		0.03	

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

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 2013–14 field season (see 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 levels declined during the 2014 spawning season, razorback suckers reused some of their historical spawning locations (see figures 14, 17, and 18). 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 2014 spawning period that were tagged during previous field seasons. More on this subject is discussed below in the "Adult Sampling and Spawning Site Observations" section.

Sonic Telemetry

Sonic telemetry was a vital tool during the 2013–14 field season, helping to define spawning sites, place trammel nets and other gear types, and document lake-wide movement. Contact was made with all 8 fish from the 2011 long-term monitoring tagging event, 2 fish from the 2012 juvenile tagging event, and 12 fish from the 2014 tagging event, including 1 individual originating from the CRI area. The individuals that were sonic tagged in 2011 remained exceedingly important during the 2013–14 field season, as there were no individuals contacted from previous tagging years (e.g., 2008 and 2010) and individuals tagged in 2014 were captured and tagged concurrently with trammel netting efforts during the reproductive season. As the 48-month batteries of these 2011 sonic transmitters approach the end of their life expectancies, the 2014 tagging event individuals will help maintain sampling consistency through time and provide clarification regarding the differences between wild and stocked fish.

Interestingly, the patterns of movement by wild, sonic-tagged individuals in 2014 mirrored those observed in the past for pond- and hatchery-reared individuals (Albrecht et al. 2008b, 2010b, 2013a, 2013b; Shattuck et al. 2011). Though not particularly striking, it is encouraging to see similar seasonal movement behaviors in both wild and stocked individuals; however, the exact role that areas such as Echo Bay or the Virgin River/Muddy River inflow play in a seasonal context remains somewhat unclear. Nonetheless, should innate differences between wild and stocked individuals exist, the opportunity to observe differences between cohorts throughout Lake Mead concurrently could help better explain sonic telemetry data collected through recent years. During 2014, wild fish helped define spawning site locations in each of the long-term monitoring study areas and helped improve trammel netting efforts and capture rates (see figure 13). Furthermore, wild sonic-tagged razorback suckers helped increase the number of passive contacts made with SURs during the 2013–14 field season (see figures 4, 5, 6, and 9) and helped define movements to spawning site locations within the context of historic low lake elevations.

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 quiescence and movement into summer foraging areas. Having the ability to monitor areas unfrequented by regular sonic surveillance aided in documenting razorback sucker movement between long-term monitoring study areas and helped account for individuals that have gone undetected for relatively long expanses of time. A small increase in the use of SURs from the 2012–13 field season to the 2013–14 field season, and a more strategic placement of existing units, appears to have aided in the efficiency of monitoring of locations outside of the established long-term monitoring study areas and has helped describe new locations seasonally frequented by razorback suckers (see table 1 and figures 7–9). Although the number of SURs deployed during the 2013–14 field season did not increase drastically from the 2012–13 to the 2013–14 field season, the number of passive contacts was increased six-fold (see table 1) (Albrecht et al. 2013b). 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.

Sonic-tagged individuals from the Virgin River/Muddy River inflow area helped illustrate the seasonal importance of areas in the Overton Arm during periods outside of the spawning season. During the 2013–14 field season, a clear pattern of contacts was formed, as adult sonic-tagged razorback suckers frequented the Stewarts Bay area and were regularly contacted by the NDOW Black Ridge SUR along the western shoreline near Salt Bay from May through September (see figures 7–9). The area of Stewarts Bay has been of noted importance in the past, with individuals perhaps drawn to this location for the abundance of bathymetric heterogeneity, as numerous submerged, shallow contours lie adjacent to deeper habitat. Additionally, it has been noted in the past that sometimes only one sonic-tagged individual is needed to help locate other wild razorback suckers (Shattuck et al. 2011; Albrecht et al. 2013a, 2013b).

However, from October through April, it appears that razorback suckers congregate near the Virgin River/Muddy River inflow area (see figures 6 and 8). After reproductive activity, individuals appear to move further south, and these fish clearly rely on deeper habitat in and along the western shoreline of the Overton Arm from May through September (see figures 6 and 8). Often the movements of these individuals spanned distances greater than 20 km during May through September (see figures 7–9); this is similar to a pattern of movement seen in Las Vegas Bay, although distances between those contacts did not exceed 3 km (see figures 4 and 8). During the 2013–14 field season, interbasin movement between the CRI area and the Overton Arm was observed for a single fish (code 468), underscoring the idea that connectivity exists throughout Lake Mead. This individual, among others (Albrecht et al. 2010c, 2013a, 2013b; Shattuck et al. 2011), has helped further demonstrate that these long-distance movements are not uncommon, particularly when considering that an individual may move between basins in less than 1 week (see figure 9).

In addition to seasonal patterns of movement, sonic-tagged individuals throughout all long-term monitoring study areas were contacted in habitat almost twice as deep during May – September (14.7 m [± 2.3 SE]) when compared to depths at point of contact during October – April (7.2 m [± 0.7 SE]). The variability of available depths in Las Vegas Bay may be an important factor in providing desirable habitat throughout the year (i.e., shallow habitat with available cover during spawning, deep habitat with thermal refuge, and often cover being present during warmer months) and may explain why sonic-tagged individuals are not often contacted outside of Las Vegas Bay proper (see figure 4). This pattern may also explain why sonic-tagged razorback suckers are found only seasonally in Echo Bay and why longer-distance movements are seen in the Overton Arm (see figures 5 and 6). Echo Bay may lack the depth variability to provide year-round habitat and the bathymetry of the Virgin River/Muddy River inflow area, and the Overton Arm appears to have a lower gradient, requiring longer-distance movements to locate seasonally desirable habitat (see figures 5 and 6). Thus, the collection of long-term movement data of sonic-tagged individuals is important in assessing temporal changes in habitat, and further helping to anticipate changes in spawning and recruitment success, given Lake Mead's regularly fluctuating lake levels. Similar results were found during the 2012–13 field season and through juvenile razorback sucker research (Albrecht et al. 2013b; Shattuck and Albrecht 2014).

The sonic telemetry portions of this monitoring study have also lent useful insight to 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 appear to continue in variability (see 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 (see figures 4–6), and sonic-tagged fish have been a key component in closely following those fluctuations.

Though new, wild razorback suckers were captured quite consistently alongside sonic-tagged individuals, sonic-tagged fish were rarely captured. Despite being consistently targeted during trammel netting in 2014, only two individuals with current sonic tags were captured (codes 468 and 3478) (see table 3). This observation has been discussed in recent past reports (Shattuck et al. 2011; Albrecht et al. 2013a). This potential caveat in capture efficiency of trammel netting underscores the elusiveness of razorback suckers and potentially supports the existence of more razorback suckers in Lake Mead than capture rates and population estimates may suggest.

Adult Sampling and Spawning Site Observations

In summary, 1,100 total captures have helped identify 655 unique individual razorback suckers at long-term monitoring study areas during this 18-year study (1996–2014) by multiple agencies (BIO-WEST, NDOW, and USFWS), not including 107 captures of 68 unique individuals from the CRI area (Albrecht et al. 2014), 48 captures of 48 unique individuals from the juvenile razorback sucker research (Shattuck and Albrecht 2014), or 94 captures of 88 unique individuals from 1990–95 (Holden et al. 1997). Trammel netting results in 2014 documented the continued presence of wild, adult razorback suckers, the majority of which were captured in the Virgin River/Muddy River inflow area (65%, n = 55). 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; Kegerries et al. 2009; Shattuck et al. 2011). The Lake Mead population still appears to be relatively young, though fewer individuals 7 years old or younger were captured in 2014 compared with 2011 and 2012 (attachment 1). Additionally, nine razorback sucker year-classes were identified in 2014, spanning 1999–2009 (attachment 1 and figure 19). It also appears that the strong year-class from the 2004–05 field season remains as an excellent recruitment year-class for Lake Mead razorback suckers, a finding made in past reports (Kegerries et al. 2009; Albrecht et al. 2010a, 2010b, 2010c, 2013a, 2013b; 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. Though no juvenile razorback suckers were captured in long-term monitoring efforts during the 2013–14 field season, 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. Since 1996, there has been a total of 90 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 define juvenile razorback sucker habitat use (Shattuck and Albrecht 2014).

The relatively large number of razorback sucker captures in 2014 can be considered a success; however, the lower catch rates at Las Vegas Bay warrant discussion (see figure 13). Because lake levels were at a 5-year high at the beginning of 2012 (see 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's 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, 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. This was exacerbated in 2014 with shallow, turbid, and at times flowing conditions associated with the expanding wash delta where sonic-tagged fish often frequented. Thus, it is likely that the nets may not have been as efficient as in past efforts (Kegerries et al. 2009; Shattuck et al. 2011). Another factor that may have led to lower capture rates in 2013 and 2014 was the overwhelming abundance of nonnative fish in our gear, specifically gizzard shad.

Though nets may not have been effective for bottom fishing, mid-water captures contained enough gizzard shad to hypothetically load the nets and render them unavailable to capture other fishes. However, the presence of numerous nonnative fishes is not new to Lake Mead, though certainly the abundance of particular species has fluctuated greatly (e.g., shad [*Dorosoma* spp]. production) (D. Herndon 2013, personal communication). While netting must remain the mainstay of long-term monitoring in Lake Mead (in order to track recruitment and follow a population that is mostly wild and largely unmarked), use of remote PIT tag antennas (particularly at Las Vegas Bay when conditions warrant) may prove useful, particularly so, given the results observed in the experimental use in 2014 at Echo Bay and the Virgin River/Muddy River inflow area.

The limited use of remote PIT tag antennas in 2014 proved to be successful in documenting previously captured native catostomids primarily at the Virgin River/Muddy River inflow area. As mentioned previously, past trammel netting efforts have often been difficult due to environmental conditions (Albrecht et al. 2013a, 2013b); however, it appears that numerous individuals can be contacted via antenna that would otherwise go undetected in more traditional sampling. The 111 contacts (22 razorback suckers, 1 flannelmouth sucker, and 1 razorback sucker x flannelmouth sucker hybrid) overlapped very little with concurrent trammel netting efforts. Conversely, six razorback suckers, three flannelmouth suckers, and one razorback sucker x flannelmouth sucker hybrid were captured in trammel nets and were undetected by antennas due to either being outside of an antenna's range or by an individual not having been previously PIT tagged. Nonetheless, the combination of the two sampling methods proved to be complementary. When used in combination with sonic-tagged fish, trammel netting, and larval sampling techniques, the use of antennas could further our understanding of razorback sucker demographics and recruitment patterns particularly in areas that do not allow for effective sampling (e.g., the Las Vegas Wash and areas with dense inundated cover). Remote PIT tag antennas should be thought of as an additional tool to help understand razorback sucker populations in Lake Mead and should not replace the current suite of monitoring methodologies that have been developed to capture unmarked wild razorback suckers. With typically one-half of the fish captured from Lake Mead being new, wild, unmarked fish, current and traditional monitoring methods will continue to be necessary to understand and track Lake Mead razorback suckers especially as lake elevations decline and environmental conditions inevitably change.

Despite continued changes in lake elevations (see figure 2) and subsequent changes in associated habitat and biota, successful razorback sucker spawning is still occurring in Lake Mead; it was documented at all of the long-term monitoring study areas in 2014. The 2014 primary spawning sites shifted slightly and were somewhat broader in spatial extent compared with previous year's spawning sites. In general, spawning sites in 2014 appeared to align with spawning sites designated under similar lake level elevations during past study years (Albrecht et al. 2006b, 2007, 2008a, 2010b, 2013a, 2013b; Kegerries et al.

2009; Shattuck et al. 2011). In Las Vegas Bay and the Virgin River/Muddy River inflow area, the 2014 spawning sites overlapped those designated in many of the past study years (see figures 14 and 18) (Albrecht et al. 2006b, 2007, 2008a, 2010b, 2013a, 2013b; Kegerries et al. 2009; Shattuck et al. 2011), while at Echo Bay, the 2014 primary spawning site was more narrowly defined, overlapping the spawning sites of 2009–11 (see figure 17) (Kegerries et al. 2009; Albrecht et al. 2010b; Shattuck et al. 2011). The difference in spawning site overlap at the Virgin River/Muddy River inflow area may be due to the nature of that particular study area, given that the Overton Arm bathymetry is more gradual and may exhibit greater changes in inundation, over a greater area, as lake levels increase and decrease. However, in Las Vegas Bay in 2014, spawning occurred within a fairly large spatial extent as well, one that covered most of the area adjacent to the wash inflow/lake interface –yet, by nature, Las Vegas Bay was fairly constricted in spatial extent wetted due to steeper and more restricted topography particularly at lower lake elevations such as those experienced in 2014. 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 leads 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).

As indicated above, the 2014 spawning site in Las Vegas Bay was more broadly defined as has been the case in previous years (Shattuck et al. 2011; Albrecht et al. 2013a, 2013b). Although a number of sonic-tagged individuals frequented the suspected spawning site, relatively few sexually mature adults were collected (n = 8). 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, we 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. The disparity in locations of larval and adult fish could be due to larval drift caused by high winds or water currents from Las Vegas Wash. Equally likely is that, due to diminished lake elevations, the spatial area available to spawning razorback suckers was reduced in 2014, given the rather constricted nature of Las Vegas Bay. As such, it would be expected that larval production, drift, and wind dispersal might result in more evenly distributed larval captures in a more confined area, such as was observed at Las Vegas Bay this year. Anecdotally, the warmer water from Las Vegas Wash may play a significant 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. Similar species have been found to have multiple runs of fish, often with older and larger fish spawning before their younger and smaller conspecifics (Perkins and Scoppettone 2000).

The primary 2014 spawning site in Echo Bay was identified by a combination of larval fish collections (see figure 17), adult fish collections (see figure 11), 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 also expanded their activity to include most of the northern shoreline of Echo Bay. Additionally, in 2014, Echo Bay again contributed a substantial percentage (approximately 26%) of adult razorback suckers to the overall catch, many of which were relatively large ($\bar{x}$ = 605 mm TL and also the study area with the overall largest fish of the season at 703 mm TL) and relatively old ($\bar{x}$ =10 years and oldest fish of the season at 15 years) individuals (attachment 1). These 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 and attachment 1).

Similar to Echo Bay, the spawning site at the Virgin River/Muddy River inflow area in 2014 was defined based on a combination of larval collection data (see figure 18), adult collections (figure 12), and sonic-tagged fish locations (see figure 6). Sonic-tagged fish were contacted frequently within designated spawning areas 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). Unlike years past when razorback sucker larval collections were scant, larval catch rates in the 2014 primary spawning site were a record high for the Virgin River/Muddy River inflow area, which 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 second consecutive year (Albrecht et al. 2013b).

As documented in previous reports (e.g., Shattuck et al. 2011, Albrecht et al. 2013a, 2013b), 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 to 2013, 14 individuals moved between the two long-term monitoring study areas, while one wild individual tagged at the Virgin River/

Muddy River inflow area moved to Echo Bay and then onto the CRI area (Kegerries et al. 2009; Kegerries and Albrecht 2013a, 2013b). 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 2014, an additional six razorback suckers moved between the Virgin River/Muddy River inflow area and Echo Bay (either direction) and, perhaps even more striking, was documentation of a single, wild individual captured and implanted with a sonic tag earlier in the 2014 season at the CRI area. Ultimately, the CRI area individual was recaptured at the Virgin River/Muddy River inflow area along with 28 other razorback suckers in spawning condition during the 2014 spawning season. This information helps define the rather 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 broader and more diverse than previously thought. The size of this population also appears larger than previously reported, and the documentation of continued recruitment in this area of the lake makes continued investigation of this area imperative.

Data from 2014 suggest that the Virgin River/Muddy River inflow area spawning aggregate is one of the largest in Lake Mead (see figure 13). Nearly 65% of the razorback suckers captured in 2014 came from the Virgin River/Muddy River inflow area, with mainly wild individuals being captured (and approximately one-half of which were new, wild, unmarked fish that were for the first time captured 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 18 field seasons (and no doubt will continue to do so). Biologically, the relatively new influx of gizzard shad and quagga mussels 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 2014 spawning period. Results from the 2013–14 field season were characterized by all-time high capture rates of larval fish at the Virgin River/Muddy River inflow area, strong capture rates of larval fish at Las Vegas Bay, and average capture rates of larval fish at Echo Bay (see figure 16) (Albrecht et al. 2008a, 2010b, 2013a, 2013b; Kegerries et al. 2009; Shattuck et al. 2011). However, given that some level of natural razorback sucker recruitment has occurred nearly every year in Lake Mead since the late 1960s, regardless of lake elevation (see figure 19), there is reason to be hopeful for the success of the 2014 year-class.

In 2014, and for the second consecutive year (Albrecht et al. 2013b), Las Vegas Bay experienced a relatively high larval catch rate (see figure 16). Interestingly, this near-high catch rate occurred despite relatively low captures of reproductively ready adult razorback suckers. Although the majority of larval razorback sucker collections occurred along the westernmost extent of Las Vegas Bay, several larval razorback suckers were collected within flowing conditions imparted by Las Vegas Wash at the wash/lake interface (see figure 14). These collections, albeit somewhat anecdotal, suggest that razorback suckers likely spawned upstream within the Las Vegas Wash proper. Past studies have shown intermittent usage of Las Vegas Wash by adult razorback suckers (Shattuck et al. 2011; Albrecht et al. 2013a) as well as reproductive activity through direct capture of larval individuals well upstream in Las Vegas Wash (Albrecht et al. 2013b). 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 and timing of reproductive activity in Las Vegas Wash proper.

Larval sampling in Echo Bay resulted in the lowest larval catch rate observed among the long-term monitoring study areas in 2014, but this rate was well within the range of larval catch rates observed in this study area since 2006 (see figure 16). The low number of larval razorback suckers captured at this study area was somewhat disappointing given the abundance of adult captures during 2014 trammel netting efforts (see figure 13). Although comparable conditions may have caused declines in the number of larval captures in past field seasons (e.g., declining lake elevations and anthropogenic disturbances during 2006–07 and 2007–08 [Albrecht et al. 2008a, 2010b]), larval abundances are expected to rebound as they have in the past. As anthropogenic development and activity in Echo Bay appear to be on the decline, it is likely that less anthropogenic disturbance may benefit larval razorback sucker production despite declining lake elevations. Furthermore, though larval catch rates were low in Echo Bay (relative to other long-term monitoring study areas), it is clear that razorback suckers aggregated at this long-term monitoring study area spawned successfully once again.

Larval catch rates in the Virgin River/Muddy River inflow area were at an all-time high for the second consecutive year during 2014, where CPM rates also exceeded those observed at Echo Bay (see figure 16). Typically, larval razorback sucker catch rates at the Virgin River/Muddy River inflow area have been the lowest of the long-term monitoring study areas (Albrecht et al. 2010b, 2013a, 2013b; Shattuck et al. 2011). In the past, low 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 study 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 Overton Arm due to the gradual bathymetry in this area of Lake Mead. With declines in lake elevation and the potential for more rapid desiccation of spawning habitats in the Overton Arm, elevated larval catch rates in 2014 were perhaps even more indicative of a strong and sizable reproductive effort and underscore the importance of this spawning location for Lake Mead razorback suckers.

As in past field seasons, BIO-WEST teamed with biologists from the NDOW and Reclamation to collect additional larval razorback suckers for future LMWG needs. These fish are being held and reared by the NDOW, and BIO-WEST continues to work with the NDOW, Reclamation, and the LMWG to develop uses and strategies for these valuable fish (Albrecht et al. 2009). Finally, 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 ongoing juvenile razorback sucker studies (Albrecht et al. 2013a; Shattuck and Albrecht 2014), 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.

Aspects 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 sucker), 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 multiyear 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 levels 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 levels. 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) showed 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 Albrech (2014) reported 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, multiyear 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 given a sizable nonnative 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 (see 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, an environmental variable that has also proven to significantly reduce nonnative 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 between 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).

Albrecht et al. (2007, 2008a, 2008b) hypothesized 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 levels 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 sediment (turbidity) that enters 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 2014 show that pulses in razorback sucker recruitment are possible at both low (e.g., 2002–06) and high (e.g., 1978–1985 and 1998–1999) lake elevations, habitat characteristics―such as cover in the form of turbidity and/or vegetation, 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 a minimum, suggest a relatively positive future for this rare species in Lake Mead.

Growth and Aging

Through 2014, 470 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). The strength of the 2003 and 2005 year-classes has been documented by Kegerries et al. (2009) and Albrecht et al. (2010b) (see figure 19) and is further evident as nearly 92% of the fish aged in 2014 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 the 1960s. Aging of the Lake Mead razorback sucker population remains paramount for tracking continued natural recruitment. Further evidence of a younger, quick-growing population is the relatively high growth rate (nearly 14 mm/year in 2014) in Lake Mead. In contrast, other populations of razorback suckers throughout the Colorado River basin (e.g., Lake Mohave [Minckley 1983] and the Green River [Tyus 1987]) have lower annual growth rates (2–5 mm/year).

Population and Survival Estimation

The lake-wide population estimate produced in the program MARK for the period of 2012–14 yielded a similar abundance to that estimated for the 2011–13 period with the model that carried the greatest AICc weight (Albrecht et al. 2013a, 2013b). Though the 2013 population estimate was slightly higher than the 2014 estimate (see table 5), they were essentially the same (a difference of seven individuals) and with similar confidence bounds (2013 = 474–776, and 2014 = 423–873). Similarly, the weighted average remained relatively close to estimates created in previous years (see table 5). Though effort has remained relatively consistent throughout the past 5 years, there are particular assumptions in a closed population model that may not have been fully met – an aspect that has been discussed in the past (Albrecht et al. 2008a, 2013a; Shattuck et al. 2011). As presented in the "Methods" section, post-hoc testing of the dataset in CloseTest suggested that the population may not be fully closed, and as stated in past reports, some model assumptions may be in violation. However, the assumption of natality and mortality were thought to have been somewhat mitigated by using only 3 years of data for each report's estimate. Razorback suckers are a long-lived, slow-growing species. Turnover in the adult population likely occurs at a slow rate, which helps increase the probability of survival between sampling occasions (Minckley 1983). Additionally, by combining study areas that have demonstrated connectivity, or by constructing a combined dataset, immigration and emigration are accounted for, and those assumptions are somewhat mitigated. That is, the combined lake-wide population estimate includes efforts from the CRI area as well as study areas in long-term monitoring because of confirmed fish movement throughout Lake Mead. Given recent findings in the Colorado River within the lower Grand Canyon, a greater degree of individual immigration and emigration may be occurring at Lake Mead than previously estimated (Kegerries and Albrecht 2013a, 2013b; Albrecht et al. 2014). Continued monitoring will likely provide a greater understanding of population dynamics, and additional data will improve our ability to detect significant correlations between population estimates through time. Adjustments to future analyses that account for more demographic variation may help to increase our overall understanding of the population. Although aspects of monitoring may be lost with less comparative ability, a more reliable and informative estimate may better describe finite demographic processes within the population (e.g., recruitment).

Although a survival estimate was produced for long-term monitoring study areas in the past (Albrecht et al. 2013a), the apparent annual survival rate reported for 2014 includes a larger span of data (1996–2014) and is more consistent with survival rates calculated for other razorback sucker populations (e.g., Schooley et al. 2008b; Zelasko et al. 2011; Kesner et al. 2012). For adult razorback suckers > 450 mm TL and located in the long-term monitoring study areas, the lake-wide apparent annual survival rate for 2014 was 0.68 (95% confidence bounds of 0.25–0.94). This rate 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 < 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 > 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 size of individuals especially given the amount of observed wild razorback sucker recruitment throughout the 18-year, long-term monitoring study.

Conclusions

The 2013–14 field season was exceptional in that all 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, including conditions similar to those observed in 2014. 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 Lake Mead razorback suckers 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.

2014–15 WORK PLAN (LONG-TERM MONITORING)

Specific Objectives for the 19th 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 spawning populations to evaluate whether any further shifts in spawning site selection occur; (3) continuing investigations of the Virgin River/Muddy River inflow area spawning site to evaluate and understand razorback sucker use of this area; and (4) potentially identifying new spawning sites by tracking sonic-tagged fish and utilizing experimental 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 populations of razorback suckers in Lake Mead, documenting the exchange of fish between study areas (including fish moving between the long-term monitoring study areas, the CRI area, and 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), and reviewed by Albrecht et al. (2008b). Following past field seasons, all data will be incorporated into the long-term Lake Mead razorback sucker database currently maintained by BIO-WEST.

2. Produce a comprehensive report. Considering that it has been more than 5 years since the last comprehensive report (Albrecht 2008b), it is suggested that a similar effort be conducted in the near future to encompass and summarize 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 data analysis and development of contemporary, long-term trends regarding razorback sucker status in Lake Mead.

3. Continue to lend support to the LMWG. In short, this effort will also help to more easily achieve the overall goals and objectives under the LCR MSCP that are related to conservation of razorback (and flannelmouth) sucker(s), as well as the goals of Reclamation's Upper Colorado Region and the interest of many collaborators, in the interaction of razorback suckers between Lake Mead and the lower Grand Canyon.

4. Continue to coordinate and work jointly with the other razorback sucker investigations occurring on Lake Mead, including those researching the juvenile life stage and crews working within the CRI area and lower Grand Canyon areas, when applicable. In 2010, efforts were undertaken to document the presence or absence of razorback suckers at the CRI area. 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. 2014). Not only were wild fish documented using this new study area, but sonic telemetry efforts in this portion of Lake Mead have helped locate sonic-tagged fish originating from the long-term monitoring study areas and helped document sonic-tagged individuals utilizing the Colorado River proper and moving into the lower Grand Canyon (Kegerries and Albrecht 2013a, 2013b; Albrecht et al. 2014). Thus, the potential exists for continued, perhaps increased, exchange of sonic-tagged razorback suckers (and other native suckers) among different areas of Lake Mead. It will be important to ascertain whether any of the PIT-tagged fish captured during long-term monitoring trammel netting efforts are recaptured at the CRI area 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

through the first study year better defined seasonal movements of juvenile individuals and documented 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 for more holistically understanding 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 nonnative 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 through juvenile razorback sucker research. Additional efforts pertaining to the early life stages of Lake Mead razorback suckers are currently underway and should continue. Results from the first year of the juvenile study are reported by Shattuck and Albrecht (2014).

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. Use of wild fish will undoubtedly allow for comparisons between data collected from stocked, pond-reared razorback suckers. Pond-reared razorback suckers have been utilized exclusively in recent years for sonic tagging and long-term monitoring purposes, and there remain questions as to whether stocked individuals are truly indicative of habitat use and spawning preferences, as well as other components, important to the wild razorback sucker population within Lake Mead. Use of wild fish for telemetry efforts was also recommended by Albrecht et al. (2013a, 2013b), but at that time, sufficient numbers of active, sonic-tagged fish remained. As noted above, wild fish were implanted during 2014, and for now, it is suggested that additional wild razorback suckers be implanted with new sonic transmitters on an as-needed basis. Doing so will ensure that future monitoring capabilities are as cost efficient and effective and as scientifically similar and comparable to all other monitoring conducted since Albrecht et al. (2006b) outlined the current long-term monitoring strategies for Lake Mead razorback suckers.

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ATTACHMENT 1

Razorback Sucker Aging Data

Table 1-1.—Ages determined from razorback sucker pectoral fin ray sections collected in Lake Mead, 1998–2014

Date collected	Total length (mm[a])	Age	Presumptive year spawned
Las Vegas Bay			
5/10/1998	588	10[b]	1987
12/14/1999	539	13	1986
12/14/1999	606	17+	1979 – 1982
12/14/1999	705	19+	1977 – 1980
1/8/2000	650	18+	1978 – 1981
2/27/2000	628	17+	1979 – 1982
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 – 1993
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 – 1991
3/25/2002	583	22 – 24	1977 – 1979
3/25/2002	545	20[b]	1982
3/25/2002	576	20	1982
5/7/2002	641	15	1986
6/7/2002	407	6	1995
6/7/2002	619	20[b]	1982
6/7/2002	642	20[b]	1982
12/3/2002	354	4	1998
12/6/2002	400	4	1998
12/6/2002	376	4	1998
12/19/2002	395	4	1998
1/7/2003	665	16	1986
1/22/2003	394	4	1998
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[b]	1982
4/17/2003	618	10	1992
4/22/2003	650	20 – 22	1980 – 1982
5/4/2003	415	3+[c]	1999

Table 1-1.—Ages determined from razorback sucker pectoral fin ray sections collected in Lake Mead, 1998–2014

Date collected	Total length (mm[a])	Age	Presumptive year spawned
3/16/2004	370	5	1998
2/22/2005	529	6	1998
2/22/2005	546	6	1998
3/29/2005	656	16	1989
1/26/2006	740	15	1991
2/21/2006	621	23	1983
3/23/2006	461	5	2001
3/23/2006	718	16	1990
3/31/2006	635	7	1999
3/31/2006	605	6	2000
4/4/2006	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
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

Table 1-1.—Ages determined from razorback sucker pectoral fin ray sections collected in Lake Mead, 1998–2014

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

Table 1-1.—Ages determined from razorback sucker pectoral fin ray sections collected in Lake Mead, 1998–2014

Date collected	Total length (mm[a])	Age	Presumptive year spawned
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
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[d]	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, 1998–2014

Date collected	Total length (mm[a])	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
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 – 1988
1/27/2000	557	13	1986
1/27/2000	710	19+	1979 – 1981
2/9/2001	641	13	1988
2/24/2001	577	18+	1980 – 1982
2/24/2001	570	8	1992
2/24/2001	576	15	1986
2/24/2001	553	18	1983
12/18/2001	672	13	1988
2/27/2002	610	18 – 20	1982 – 1984
3/26/2002	623	16	1986
4/2/2002	617	35+	1966 – 1968
4/17/2002	583	20[b]	1982
5/2/2002	568	18 – 19	1983 – 1984
11/18/2002	551	13	1989
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

Table 1-1.—Ages determined from razorback sucker pectoral fin ray sections collected in Lake Mead, 1998–2014

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

Table 1-1.—Ages determined from razorback sucker pectoral fin ray sections collected in Lake Mead, 1998–2014

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

Table 1-1.—Ages determined from razorback sucker pectoral fin ray sections collected in Lake Mead, 1998–2014

Date collected	Total length (mm[a])	Age	Presumptive year spawned
3/25/2014	630	9	2005
Virgin River/Muddy River inflow area			
2/23/2005	608	6	1998
2/22/2006	687	33[f]	1973
2/22/2007	452	4	2003
2/22/2007	542	5	2002
2/22/2007	476	5	2002
2/22/2007	459	4	2003
2/22/2007	494	5	2002
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[g]	2006
3/26/2008	345	3	2005
3/26/2008	541	7	2001
3/26/2008	521	7	2001
3/26/2008	665	18	1990
4/1/2008	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

Table 1-1.—Ages determined from razorback sucker pectoral fin ray sections collected in Lake Mead, 1998–2014

Date collected	Total length (mm[a])	Age	Presumptive year spawned
4/1/2008	559	10	1998
4/22/2008	533	6	2002
4/22/2008	504	6	2002
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
2/9/2010	471	6	2004
2/17/2010	494	6	2004
2/17/2010	470	7	2003
2/17/2010	479	7	2003

Table 1-1.—Ages determined from razorback sucker pectoral fin ray sections collected in Lake Mead, 1998–2014

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

Table 1-1.—Ages determined from razorback sucker pectoral fin ray sections collected in Lake Mead, 1998–2014

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

Table 1-1.—Ages determined from razorback sucker pectoral fin ray sections collected in Lake Mead, 1998–2014

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

Table 1-1.—Ages determined from razorback sucker pectoral fin ray sections collected in Lake Mead, 1998–2014

Date collected	Total length (mm[a])	Age	Presumptive year spawned
3/21/2013	570	9	2004
3/21/2013	578	9	2004
3/21/2013	577	10	2003
3/21/2013	621	14	1999
3/21/2013	639	9	2004
3/27/2013	539	8	2005
3/27/2013	580	10	2003
4/3/2013	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
4/3/2014	572	6	2008
4/3/2014	615	7	2007
4/10/2014	651	7	2007

Table 1-1.—Ages determined from razorback sucker pectoral fin ray sections collected in Lake Mead, 1998–2014

Date collected	Total length (mm[a])	Age	Presumptive year spawned
4/16/2014	504	6	2008
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[d]	11	2001
3/6/2012	573	6	2006
3/6/2012	572	7	2005
3/8/2012	557	8	2004
3/20/2012	630	10	2002
3/20/2012	548	8	2004
3/21/2012	571	9	2003
3/28/2012	572	8	2004
4/3/2012	602	9	2003
4/24/2012	555[e]	9	2003
3/5/2013	215	2	2011
5/14/2014	429	3	2011

[a] mm=millimeters.

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

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

[d] Fish stocked from Floyd Lamb Park ponds; sonic tagged.

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

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

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

ATTACHMENT 2

Razorback Sucker Population Estimate – Model Selection Summary

Table 2-1.—Model selection summary of population estimates for razorback suckers in Lake Mead produced in the program MARK using mark-recapture data, 2012–14

Model[a]	AICc[b]	DELTA AICc[c]	AICc weight[d]	Model likelihood[e]	Number of parameters[f]	Deviance[g]
Lake-wide						
$\pi(.)\rho(t)N(.)$	273.0878	0.0000	0.9924	1.0000	4	446.0600
$\pi(.)\rho(.)N(.)$	282.8178	9.7300	0.0077	0.0077	2	459.7942

[a] π = probability that the individual occurs in the mixture, (.) = parameter consistent through time, ρ = capture probability, (*t*) = parameter variable through time, and *N* = abundance estimate.
[b] Adjusted Akaike's information criterion (AICc) adjusted for small sample size bias.
[c] AICc minus the minimum AICc.
[d] Ratio of delta AICc relative to the entire set of candidate models.
[e] Ratio of AICc weight relative to the AICc weight of best model.
[f] Number of parameters.
[g] Log-likelihood of model minus log-likelihood of the saturated model (Zelasko et al. 2011).

ATTACHMENT 3

Razorback Sucker Apparent Survival Rate Estimate –
Model Selection Summary

Table 3-1.—Cormack-Jolly-Seber model selection summary of annual apparent survival rate estimates for razorback suckers in Lake Mead produced in the program MARK using adult (greater than 450 total length) annual mark-recapture data, 1996–2014

Model[a]	AICc[b]	Delta AICc[c]	AICc weight[d]	Model likelihood[e]	NUMBER OF parameters[f]	Deviance[g]
Cormack-Jolly-Seber						
$\phi(.)p(t)$	1471.8703	0.0000	0.86881	1.0000	19	392.5248
$\phi(t)p(t)$	1474.6512	3.7809	0.13119	0.1510	35	361.5951
$\phi(t)p(.)$	1498.5630	26.6927	0.00000	0.0000	19	419.2175
$\phi(.)p(.)$	1503.7816	31.9113	0.00000	0.0000	2	459.5497

[a] φ = survival, (.) = parameter consistent through time, ρ = recapture probability, and (*t*) = parameter variable through time.
[b] Adjusted Akaike's information criterion (AICc) adjusted for small sample size bias.
[c] AICc minus the minimum AICc.
[d] Ratio of delta AICc relative to the entire set of candidate models.
[e] Ratio of AICc weight relative to the AICc weight of best model.
[f] Number of parameters.
[g] Log-likelihood of model minus log-likelihood of the saturated model (Zelasko et al. 2011).