Lower Colorado River
Multi-Species Conservation Program

Balancing Resource Use and Conservation

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

2012–2013 Annual Report

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

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Lower Colorado River Multi-Species Conservation Program

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2012–2013 Annual Report

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ACRONYMS AND ABBREVIATIONS

AGFD	Arizona Game and Fish Department
AIC_c	Akaike's Information Criterion
BIO-WEST	BIO-WEST, Inc.
cm	centimeter(s)
cm^2	square centimeters
CPM	catch per minute
CPUE	catch per unit effort
CRI	Colorado River inflow area
FL	fork length
kHz	kilohertz
km	kilometer(s)
LCR MSCP	Lower Colorado River Multi-Species Conservation Program
LMWG	Lake Mead Interagency Work Group
m	meter(s)
mm	millimeter(s)
msl	mean sea level
NDOW	Nevada Department of Wildlife
NPS	National Park Service
OWMA	Overton Wildlife Management Area
PIT	passive integrated transponder
Reclamation	Bureau of Reclamation
SE	standard error
SL	standard length
SNWA	Southern Nevada Water Authority
SUR	submersible ultrasonic receivers
TL	total length
USFWS	U.S. Fish and Wildlife Service

Symbols

°C	degrees Celsius
%	percent

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EXECUTIVE SUMMARY

In 1996, the Southern Nevada Water Authority (SNWA) and the Colorado River Commission of Nevada, in cooperation with the Nevada Department of Wildlife (NDOW), initiated a study to develop information about the Lake Mead razorback sucker (*Xyrauchen texanus*) population. BIO-WEST, Inc. (BIO-WEST), under contract with the Southern Nevada Water Authority (SNWA), designed the study and had the primary responsibility of conducting the research. In 2005, the Bureau of Reclamation (Reclamation) became the principal funding agency, and the study became primarily a long-term monitoring study in 2007. In 2012, Reclamation (Lower Colorado River Multi-Species Conservation Program [LCR MSCP]) provided funding to continue long-term monitoring efforts as well as funding to initiate a pilot study for juvenile razorback sucker in Lake Mead (Albrecht et al. 2013). Following the success of the 2012 pilot study, Reclamation (LCR MSCP) provided funding for a full, separate study of juvenile razorback sucker and their habitat use in Lake Mead via sonic telemetry. As such, information and observations from the 17th year (2012–2013) of the long-term monitoring study are provided herein, while information gathered and obtained during the juvenile razorback sucker study are included in a companion report that will be available in spring 2014. Furthermore, readers interested in the 2013 study results from the Colorado River inflow area (CRI) should consult Kegerries and Albrecht (2013a), which provides concurrent information on those efforts.

During the 17th field season, the habitat use and movements of 10 sonic-tagged fish were monitored, which resulted in 127 total active contacts. One of these fish was from the 2010 tagging event at the CRI, eight fish were from the 2011 tagging event, and one fish was from the 2012 juvenile tagging event. 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. Along with spawning site information, sonic-tagged fish provided valuable data on movement patterns within and between Las Vegas Bay, the Muddy River/Virgin River inflow area, Echo Bay, the CRI, and areas of Lake Mead not regularly monitored (i.e., the Virgin Basin). Sonic-tagged fish continued to provide invaluable data regarding the movement patterns and habitat use of razorback sucker in Lake Mead and aided field crews that monitored the study areas.

Trammel netting captured 60 razorback suckers—4 from Las Vegas Bay, 16 from Echo Bay, and 40 from the Muddy River/Virgin River inflow area—during the 2013 spawning period. Interestingly, one razorback sucker *x* flannelmouth sucker hybrid was collected at the Muddy River/Virgin River inflow area; a first occurrence during the long-term monitoring study. The hybrid individual was keyed by visual inspection according to descriptions for meristic counts and measurements in Hubbs and Miller (1953). Of the 60 total razorback suckers collected, 25 were recaptured fish. The capture of 28 new wild razorback suckers at the Muddy River/Virgin River inflow area, a highlight of the 17th field season, suggests the continued importance of the Muddy River/Virgin River inflow area of Lake Mead for razorback sucker production and recruitment.

Average annual growth during this field season, as determined from 22 recaptured fish, was 14.8 millimeters per year. Growth rates of Lake Mead razorback sucker continue to be substantially higher overall than those recorded from other populations within the Colorado River basin (Minckley 1983; Tyus 1987), suggesting the Lake Mead razorback sucker populations are able to maintain a fairly strong cohort of young, fast-growing fish.

Fin ray sections were removed from 37 razorback suckers for age determination during the 17th field season which, when combined with the 395 fish aged during previous field seasons, brings the total number of fish aged during the study to 432. Of particular interest is the continued documentation of recent (2000–2008) recruitment (Shattuck et al. 2011; Albrecht et al. 2013). Age determination techniques continue to show that recruitment pulses in Lake Mead are associated with relatively high, stable lake elevations. However, based on data collected from 2007 to 2013, we have also observed strong pulses in recruitment that coincide with low, declining lake elevation trends and a large, high-flow event in the Virgin River in 2004–2005. Data collected to date indicate that Lake Mead razorback sucker recruitment occurs nearly every year. This report reiterates the need to further our understanding of conditions that promote the unique recruitment pattern of razorback sucker in Lake Mead and highlights the necessity of sonic-tagged individuals in helping to define movement and habitat use.

Larval razorback sucker were again documented in all study locations in 2013 and, in addition to the efforts and findings reported above, BIO-WEST worked collaboratively with NDOW biologists in a continued effort to collect additional Lake Mead larval razorback sucker for future use. These fish will allow for increased razorback sucker presence in Lake Mead, additional research opportunities to test hypotheses concerning lake levels and cover, and may contribute to our understanding of recruitment patterns during future field seasons.

During the 2012–2013 field season, primary spawning sites were identified in all long-term monitoring areas. Spawning sites moved with the corresponding water surface elevation, and locations were similar to those found in other 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 areas. Additionally, spawning near the Muddy River/Virgin River inflow area was again successfully documented in 2013. For the fourth consecutive time, trammel netting capture rates in the Muddy River/Virgin River inflow area eclipsed those in other, more extensively studied long-term sites.

Given the potential for continuing lake level fluctuations during the remainder of 2013 and in 2014, general research for the 2013–2014 field season includes three main objectives: (1) continuing to monitor razorback sucker at the three main study areas, (2) continuing to age individual razorback sucker from Lake Mead, (3) and maintaining sonic-tagged fish presence as needed.

INTRODUCTION

The razorback sucker (*Xyrauchen texanus*) is one of four endemic, large-river fish species (the others are Colorado pikeminnow [*Ptychocheilus Lucius*], bonytail [*Gila elegans*], and humpback chub [*Gila cypha*]) of the Colorado River basin presently considered endangered by the U.S. Department of the Interior (U.S. Fish and Wildlife Service [USFWS] 1991). Historically widespread and common throughout the larger rivers of the basin (Minckley et al. 1991), the distribution and abundance of razorback sucker have been greatly reduced. One of the major factors causing the decline of razorback sucker and other large-river fish has been the construction of main stem dams and the resultant cool tailwaters and reservoir habitats that replaced a warm, riverine environment (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 sucker 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 2013 estimate of wild Lake Mohave razorback sucker was not reported, as apparently no wild fish were captured (Marsh and Associates 2013). Interestingly, wild fish continue to be captured in Lake Mead, and the unique ability of Lake Mead razorback sucker to naturally recruit has spurred a number of questions. Though recent studies sought to better define the genetic variability of the two closely related Lake Mohave and Lake Mead populations, it was reaffirmed that the Lake Mohave population is not significantly different (mitochondrial DNA and microsatellites) than that of Lake Mead (Dowling et al. 2012a, 2012b). Though the Lake Mohave population has maintained a higher degree of genetic variation through stocking, consistent with that of an expanding population (Dowling et al. 2012a, 2012b), it has coincidentally been the Lake Mead population that exhibits actual and natural population expansion (Albrecht et al. 2010a). These findings underscore the uniqueness and natural complexity of the razorback sucker population in Lake Mead.

For context, adult razorback sucker 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 non-native species appears to be the principal reason for the lack of razorback sucker recruitment (e.g., Minckley et al. 1991; Marsh et al. 2003; Carpenter and Mueller 2008; Schooley et al. 2008). However, through an intensive stocking program and the remaining 1,854 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 and Associates 2013).

Lake Mead was formed in 1935 when Hoover Dam was closed, and razorback sucker 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 sucker 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 sucker were still found in two areas of Lake Mead (Las Vegas Bay and Echo Bay), 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, NDOW, over time, has stocked a limited number of juvenile (sexually immature individuals, as defined in Albrecht et al. 2013) razorback sucker into Lake Mead. Fortunately, and 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. No formal razorback sucker stocking program exists for Lake Mead. Collection of razorback sucker in the 1990s raised many questions about the Lake Mead fish: How large is the population? Are the Las Vegas Bay and Echo Bay groups separate populations? Does razorback sucker recruitment occur in the lake? How old are the fish in Lake Mead, and are the Las Vegas Bay and Echo Bay groups different in age structure? In 1996, the Southern Nevada Water Authority (SNWA), in cooperation with 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 SNWA and NDOW. Other cooperating agencies included the Bureau of Reclamation (Reclamation), which provided funding, storage facilities, and technical support; the National Park Service (NPS), which 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 sucker in Lake Mead

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

- Characterize use and habitat of known spawning sites

In 1998, Reclamation agreed to contribute additional financial support to the project to facilitate fulfillment of Provision #10 of the Reasonable and Prudent Alternatives generated by the USFWS's Final Biological and Conference Opinion on Lower Colorado River Operations and Maintenance – Lake Mead to Southerly International Boundary (USFWS 1997). In July 1998, a Cooperative Agreement between Reclamation and SNWA was completed, specifying the areas to be studied and extending the study period into 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 sucker at both established study sites

If potential new populations were located by finding larval razorback sucker, trammel netting would be used to capture adults, and sonic tagging would be used to evaluate the general range and habitat use of the newly discovered population. In 2002, Reclamation and SNWA completed 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 became the primary funding agency and requested that a monitoring protocol be established to ensure the success and continuity of the long-term, growing database maintained by BIO-WEST that stems from Lake Mead collections made during this more than decade-long course of studies. In response, 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 SNWA completed another Cooperative Agreement, extending monitoring efforts and following monitoring protocols developed by Albrecht et al. (2006a) through 2011.

In 2012, the Lower Colorado River Multi-Species Program (LCR MSCP) provided funding to maintain long-term monitoring efforts. Furthermore, following the completion of the juvenile razorback sucker pilot study, the LCR MSCP provided funding for further investigation of juvenile razorback sucker sonic telemetry and habitat use in Lake Mead at the beginning of 2013. The goal of the juvenile studies is to gain a better understanding of why Lake Mead razorback sucker are able to demonstrate consistent, natural recruitment. Lake Mead currently provides a unique opportunity to study this life stage in a wild form, as it is perhaps one of the last locations where wild fish continue to recruit naturally and where wild juvenile razorback sucker are routinely captured (Albrecht et al. 2010a, 2010b, 2013; Shattuck et al. 2011). Readers interested in the juvenile study efforts should review Albrecht et al. (2013) and the stand-alone juvenile razorback sucker report, which is slated to be completed in early 2014.

It should be noted that during 2010–2013, efforts were also expanded to determine the presence or absence of razorback sucker in the CRI of Lake Mead using study methodologies developed and honed during the past 17 years of razorback sucker investigations on Lake Mead. Similar to the juvenile-specific research described above, the CRI efforts are not reported herein. The results are reported in a stand-alone document that serves as a companion to this report. Readers interested in the CRI investigations should review those documents (i.e., Albrecht et al. 2010c; Kegerries and Albrecht 2011, 2013a, 2013b).

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. More specifically, the following tasks are being conducted:

- Locating and capturing larval, juvenile, and adult razorback sucker

- Identifying annual spawning site locations within the study areas

- Marking captured juvenile and adult razorback sucker for individual identification (to be accomplished only when no pre-existing means of identification are present)

- Monitoring movements and/or movement patterns of adult razorback sucker within the study areas and identifying the general habitat types in which these fish are found

- Recording biological data (e.g., sex, total length [TL], and weight) and examining and documenting the general health and condition of captured adult razorback sucker
- Providing mean daily and/or mean annual growth rates for recaptured razorback sucker
- 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, striving to understand razorback sucker recruitment in Lake Mead

This annual report presents the results of the 17th field season (February 2013–April 2013 long-term monitoring data, July 2012–June 2013 sonic telemetry data) in accordance with the results reported by Albrecht et al. (2008a), Kegerries et al. (2009), Albrecht et al. (2010b), Shattuck et al. (2011), Albrecht et al. (2013), and other past annual reports. This report presents results from the 2012–2013 long-term monitoring study, and other information from previous reports is included as applicable.

SUMMARY OF EARLIER MONITORING RESULTS, 1996–2012

Since the Lake Mead razorback sucker study began in 1996, netting efforts conducted by multiple agencies (BIO-WEST, NDOW, and USFWS) have resulted in 787 captures of wild individuals (including 44 from the CRI from 2002 to 2013 [Kegerries and Albrecht 2013a]) and 265 captures of stocked individuals (including 45 from the CRI from 2002 to 2013 [Kegerries and Albrecht 2013a]). Within these captures, 511 unique wild razorback sucker (including 26 from the CRI from 2002 to 2013) were caught and PIT tagged, and an additional 163 unique individuals (including 32 from the CRI from 2002 to 2013 [Kegerries and Albrecht 2013a]) were stocked for various purposes from 1996 through 2012 (Albrecht et al. 2013). These totals do not include individuals captured during the 2012–2013 long-term monitoring field season or the concurrent juvenile razorback sucker study. The totals for unique PIT-tagged individual razorback sucker among long-term monitoring sites include 267 individuals in Las Vegas Bay, 143 individuals in Echo Bay, and 204 individuals at the Muddy River/Virgin

River inflow area. Through this capture and recapture data, a greater understanding of life history processes specific to Lake Mead (e.g., growth, movement patterns, and population size) has been attained.

In long-term monitoring efforts during the span of 1996–2012, the female to male sex ratio of all unique wild razorback sucker was 1:1.3 (165 females, 207 males); while in the span of 2002–2013, the female to male sex ratio of all unique wild razorback sucker at the CRI was 1:1.1 (12 females, 13 males). Additionally, since 1996, there have been a total of 89 wild juvenile razorback suckers captured, and all but 1 individual was captured from long-term monitoring locations. Interestingly, between 1997 and 1998, six juvenile razorback suckers were captured in Echo Bay, indicating that relatively recent, natural recruitment had occurred within the Lake Mead population. Twelve additional wild juvenile razorback sucker were captured in the Blackbird Point area of Las Vegas Bay through 2006. From 2007 to 2012, an additional 70 juvenile razorback suckers were captured in Lake Mead, indicating continued, natural recruitment.

Beginning in 1999, small sections of pectoral fin rays were removed from wild razorback sucker for age determination. Through 2012, 395 razorback suckers captured from long-term monitoring sites have been aged (not including 25 razorback suckers aged from the CRI [Kegerries and Albrecht 2013a]) (Albrecht et al. 2013). Adult fish collected have ranged in age from approximately 4 to 36 years, and juvenile fish have ranged in age from 2 to 4 years. We have hypothesized that the initiation of recruitment observed in the Lake Mead razorback sucker population has been a function of lake level fluctuations, which promotes both turbid conditions and growth of shoreline vegetation (Golden and Holden 2003). The inundated vegetation likely serves as protective cover that, along with turbidity, allows young razorback sucker to avoid predation by nonnative fishes. Recent non-native introductions, such as quagga mussels (*Dreissena rostriformis bugensis*) and gizzard shad (*Dorosoma cepedianum*), could also affect the razorback sucker population in Lake Mead, but the nature of these new potential stressors remains unknown.

During the last decade, fluctuating lake elevations in Lake Mead have affected razorback sucker spawning at nearly all sampling sites. For example, at Echo Bay from 1997 to 2001, aggregations of sonic-tagged adults, visual observation of spawning behaviors, and larval concentrations indicated that spawning was occurring at the westernmost extent of Echo Bay along the southern shore. Specifically, it appeared that adult razorback suckers were spawning at the base of a 15-meter (m) tall cliff. By the end of the May 2001 spawning season, this spawning site was dry. As lake levels further declined during the next several years and sites from previous years were left dry, the Echo Bay population continued to utilize new spawning sites up or down Echo Bay Wash depending on lake level.

At Las Vegas Bay during the first 9 years of this study, most razorback sucker larvae were captured along the western shore and at the tip of Blackbird Point. This seasonal return of individuals and annual reproductive activity suggested that Blackbird Point was an important spawning site. However, as lake levels declined, the depths off the western shore of Blackbird Point changed dramatically. At higher lake elevations in the late 1990s, the spawning site was thought to be near a depth of 24 m. By 2003, the spawning depth was closer to 6 m, and by the end of 2004, the area was completely desiccated. As a result, spawning was not observed at the Blackbird Point spawning area during the 2003–2004 field season, and only four larval razorback sucker were captured during that entire season at Las Vegas Bay, a site that once harbored the largest razorback sucker population in Lake Mead. Though the Blackbird Point spawning area was again accessible in 2005, as Lake Mead elevations rose more than 6 m during the spawning period (January – April), subsequent years of declining lake levels effectively cut off razorback sucker individuals from utilizing this specific area. In response to lowered lake elevations in 2006–2012, the spawning aggregate at Las Vegas Bay shifted spawning sites from Blackbird Point to the southwestern shoreline of Las Vegas Bay. As lake levels decreased further, spawning aggregates continued to retreat up or down the bay, much like the spawning aggregate in the Echo Bay spawning area, where the local population adjusted spawning sites in accordance with lake elevation. In 2011, lake elevations increased overall in response to above-average snowmelt runoff. Similar to the adjustment of spawning sites observed during declining lake elevations, razorback sucker throughout Lake Mead shifted spawning site locations in response to increased lake levels and once again utilized the large, littoral habitat that had been re-inundated. Continued observation of razorback sucker use of littoral, inundated vegetative cover was also common in 2012.

During 2003–2004, larval sampling was conducted at the Muddy River/Virgin River inflow area and throughout the Overton Arm of Lake Mead. Despite having habitat characteristics similar to Echo Bay and Las Vegas Bay (in terms of turbidity, vegetation, and gravel shorelines), no larval razorback sucker were captured in the Overton Arm (north of Echo Bay). However, after following movements of a single sonic-tagged fish in 2005, adult and larval sampling were reinitiated at the Muddy River/Virgin River inflow area. The result was the documentation of spawning activities in this area of Lake Mead. Since 2006, razorback sucker have been documented spawning successfully near the Muddy River/Virgin River inflow area (specific spawning location dependent on lake elevation), and in the last several years, juvenile and adult captures in this relatively new spawning area have rivaled and/or surpassed those in Las Vegas Bay and Echo Bay (depending on year and life stage of interest) (Albrecht et al. 2010b, 2013; Shattuck et al. 2011).

During the first 6 years of the Lake Mead razorback sucker study, 42 wild fish were equipped with internal or external sonic tags. Approximately half of these tags, implanted in 1997 and 1998, had a 12-month battery life, and the other half had a 48-month battery life. Sonic telemetry revealed a seasonal habitat-use pattern within the lake. At Las Vegas Bay, fish concentrated near Blackbird Point during the spawning period, but moved farther out into the main portions of the bay during the nonspawning period (June – November), mainly into habitat on the northern shore of Las Vegas Bay between Blackbird Point and Black Island. A similar pattern was seen at Echo Bay. Fish left the Echo Bay spawning area and regularly used Rogers Bay, Blue Point Bay, and other locations north of Echo Bay along the western shore of the Overton Arm. In January 2003 (7th field season), four razorback sucker (two in Echo Bay and two in Las Vegas Bay) were captured during standard trammel netting and implanted with 48-month sonic tags. Though the majority of these individuals were last contacted in 2003 (8th field season), one remaining fish from the 2003 sonic-tagging effort was contacted several times during the early part of the 2004–2005 field season, offering movement and habitat use information for subsequent field seasons.

In 2004, a decline in larval fish abundance was observed, spurring questions about where the Las Vegas Bay population was spawning, if at all. Welker and Holden (2004) proposed tagging six razorback sucker from Floyd Lamb Park as an experiment, hoping that these fish would integrate with the wild population in Las Vegas Bay and help identify new spawning areas. Hence, six fish from Floyd Lamb Park were tagged with 48-month tags during the 2004–2005 field season, and sonic surveillance of these individuals produced interesting results. Though contact with the four fish introduced into Las Vegas Bay was lost within 1 month due to tag failure, the two fish introduced into Echo Bay appeared to integrate with the wild population and were followed throughout the 2004–2005 field season. One of the Echo Bay individuals spent the majority of the field season in the westernmost end of Echo Bay, while the other individual moved from Echo Bay to the Overton Arm of Lake Mead. To compensate for sonic tag failure during the early 2004–2005 field season, 10 additional sonic-tagged fish from Floyd Lamb State Park were stocked into Lake Mead later in 2005. Similarly, one of these individuals moved from Echo Bay (stocking location) to the Overton Arm and then to Las Vegas Bay (Albrecht et al. 2006b, 2007, 2008a). As sonic tags from the 2005 event approached their longevity threshold (48 months), the decision was made to tag and release 12 additional fish from Floyd Lamb Park with 48-month tags (four at each long-term study area) in Lake Mead in December 2008. This group of fish has provided extensive movement and habitat use data, which continue to be gathered to date. Five individuals were contacted in 2010, and two individuals were contacted through 2011. Similarly, in 2011, eight additional Floyd Lamb Park razorback sucker were implanted with 48-month tags and released (four into Las Vegas Bay and four into Echo Bay) in an effort to maintain sonic-tagged fish presence at the long-term monitoring sites. In 2012, in an effort to increase the understanding of the movement and habitat associations of wild juvenile razorback sucker, four wild-caught individuals less than 450 millimeters (mm) TL were sought for implantation with either a 9- or 12-month tag based on their weight. Only one wild individual was captured in Las Vegas Bay and subsequently implanted with a 12-month tag, while the remaining three individuals were supplemented from Center Pond at the Overton Wildlife Management Area (OWMA) and implanted with 9-month and 12-month tags. In all of the above cases, sonic-tagged fish from Floyd Lamb Park and Center Pond were stocked into the Nevada portions of Lake Mead in cooperation with NDOW. Many of these sonic-tagged fish continue to provide field crews with invaluable information about razorback sucker spawning areas, which allows us to increase monitoring efficiency at long-term monitoring sites (Shattuck et al. 2011; Albrecht et al. 2013).

STUDY AREAS

All Lake Mead long-term monitoring activities conducted in 2013 occurred at the locations studied during efforts from 1996 to 2012 and included Echo Bay, Las Vegas Bay, and the Muddy River/Virgin 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, 2013; Kegerries et al. 2009; Shattuck et al. 2011).

Most areas of the lake, 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 Muddy River/Virgin 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 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:

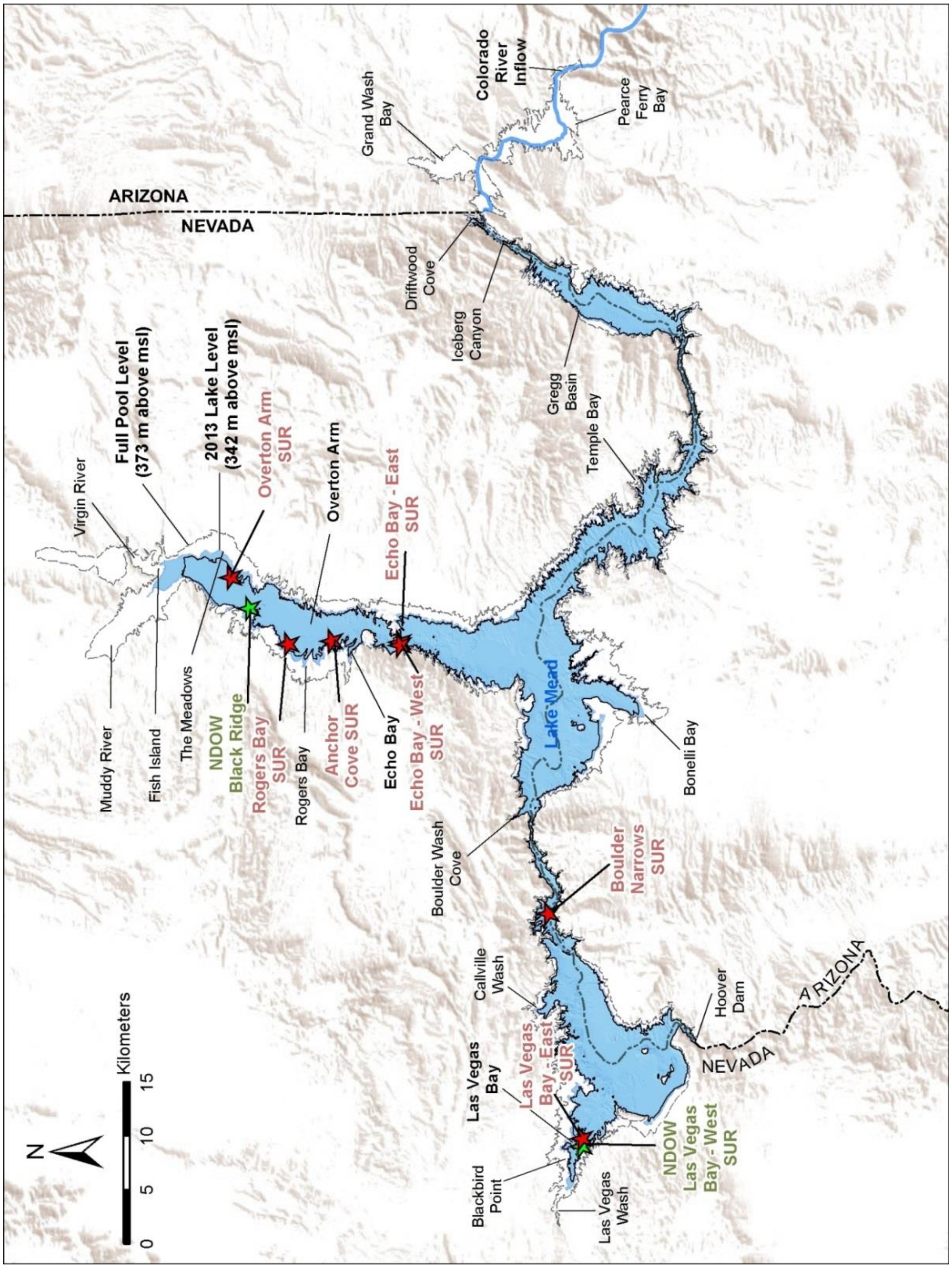

Figure 1.—Lake Mead general study areas.
Locations of long-term monitoring submersible ultrasonic receivers are denoted by red stars (units maintained by BIO-WEST, Inc.) or green stars (units maintained by the Nevada Department of Wildlife).

- 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)

Additionally, the location of wild adult and larval razorback sucker 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):

- Muddy River/Virgin 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 lake elevations for the 2013 field season (July 1, 2012 – June 30, 2013) were measured in meters above mean sea level (msl) and obtained from Reclamation's Lower Colorado Regional Office Web site (Reclamation 2013).

Sonic Telemetry

Overall, the sonic telemetry data collected during this study have provided valuable information on razorback sucker spawning, movement patterns, and shifts in habitat use and spawning site selection. These data have also demonstrated that tracking hatchery-reared, sonic-tagged razorback sucker preceding spawning activity can be a highly effective method for locating new spawning areas and monitoring known spawning sites used by wild razorback sucker populations. Hence, monitoring sonic-tagged fish can increase the efficiency of field efforts.

Sonic Tagging

No sonic tagging occurred specifically for the purposes of the long-term monitoring efforts in 2013, as tags implanted into adult fish from past study years continue to remain active. Readers are encouraged to reference other past annual reports for detailed descriptions of tagging methodologies (Shattuck et al. 2011; Albrecht et al. 2013; Kegerries and Albrecht 2013a, 2013b).

Active Sonic Telemetry

Sonic telemetry data for the long-term monitoring study were collected from July 1, 2012, to June 30, 2013, 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. Fish searches were largely conducted along shorelines with listening points spaced approximately 0.8 kilometer (km) apart 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, Sonotronics, personal communication; personal experiences of the authors). Additionally, because sonic-tagged razorback sucker were at times located in areas of Lake Mead inaccessible by boat (e.g., shallow peripheral habitats, 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 or earlier model of ultrasonic receiver and a DH4 hydrophone. The hydrophone was lowered just below the water's surface and rotated 360 degrees to detect sonic-tagged fish presence. Once detected, the position of the sonic-tagged fish was pinpointed by 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. Nine SURs were utilized during the 2012–2013 field season. Two SURs deployed by BIO-WEST during the 2010–2011 and 2011–2012 field seasons remained stationed in the same general locations as did two SURs set by NDOW for a concurrent Lake Mead striped bass (*Morone saxatilis*) sonic telemetry study during 2011– 2012 (Shattuck et al. 2011; Albrecht et al. 2013; D. Herndon, NDOW, personal communication). Additionally, five 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 NDOW, which provided a larger area of surveillance for monitoring lakewide movement of razorback sucker.

The nine SURs were set at the following locations (figure 1): one across from Sand Island at the southwestern extent of Las Vegas Bay (NDOW), one at the northwestern extent of Sand Island (BIO-WEST), one on the southern shore across from Rotary Cove in the narrows of Boulder Canyon (BIO-WEST), two south of Echo Bay at the constriction point near Ramshead Island on the western and eastern shore (BIO-WEST), one north of Echo Bay off the northern shore of Anchor Cove (BIO-WEST), one at the northern extent of Rogers Bay and south of Bluepoint Cove (BIO-WEST), one off of Black Ridge on the southeastern edge of Fire Bay (NDOW), and one off of the southwestern shore of the Meadows across from Salt Bay on the eastern side of the Overton Arm. Each SUR was programmed to detect implanted, active sonic tag frequencies using Sonotronics's SURsoft software. The semibuoyant SURs were then suspended from an anchor (e.g., rock, anchor, and block) using approximately 0.5 m of rope. A lead of vinyl-coated steel cable was secured to the anchor as the SUR was deployed. The cable was allowed to sink to the lake bottom, secured on shore, and concealed. 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 was 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 91.4 m long by 1.8 m deep trammel nets with an internal panel of 2.54-centimeter (cm) mesh and external panels of 30.48 cm mesh. Nets were generally set with one end near shore in 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 single net comprising one 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).

Fish were removed from nets, and live fish were held in 94.6-liter coolers filled with lake water. Native suckers were isolated from other fish species and held in aerated live wells. Suspected razorback sucker *x* flannelmouth sucker hybrids were keyed based on descriptions and meristic counts provided in Hubbs and Miller (1953). All but the first five common carp (*Cyprinus carpio*) 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 sucker, flannelmouth sucker, or suspected razorback sucker *x* flannelmouth sucker hybrids were scanned for PIT tags, PIT tagged if they were not recaptured fish, measured (TL, standard length [SL], and fork length [FL]), weighed, and assessed for sexual maturity and reproductive readiness. Individuals that were not sexually defined and did not exhibit sexual maturity (e.g., lack of nuptial tubercles, lack of color, and lack of ripeness) were labeled as juvenile. Individuals that were sexually defined were labeled as their respective sex. 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 bit (0.5 cm^2) of skin material that was obtained from the caudal fin, preserved in 95 percent (%) nondenatured ethanol, and delivered to Reclamation biologists. After all necessary information was collected, fish were released at the point of capture unharmed.

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. Stocked individuals were excluded from the dataset and analyses to account for discrepancies in environmental conditions (e.g., a hatchery-/pond-reared individual recently stocked into a wild environment) and to allow for the yearly cycles of gonadal and somatic growth. Annual growth for razorback sucker 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 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 sites (i.e., Las Vegas Bay, Echo Bay, and the Muddy River/Virgin River inflow area).

Larval Sampling

The primary larval sampling method followed that developed by Burke (1995) and other researchers on Lake Mohave. The procedure uses the positive phototactic response of larval razorback sucker 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 in water 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 sucker 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, and 4–12 sites were customarily 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.

Based on successes of utilizing larval light traps at the CRI (Kegerries and Albrecht 2013a, 2013b), larval light traps were also deployed on an experimental basis during the 2013 spawning season. The intent was to help increase efforts to collect razorback sucker larvae in locations not conducive to the methods described in the previous paragraph (e.g., areas of flowing water, dense stand of inundated vegetation) as well as to overcome the vast sampling areas common to the long-term monitoring sites in recent years. These traps were set out either overnight or for several hours after sunset and were deployed by tying a lead rope to the vegetation near shore in suspected spawning areas. A 15.24 cm, 8-hour white light stick was inserted into the trap and allowed to float freely, and light traps were collected after the desired deployment time. At the time of collection, the catch bowls were checked for the presence of larval fish, and all larval fish present were identified visually in the field to species, enumerated, and returned to the lake. Data were recorded separately and are reported separately herein so as to maintain long-term continuity with past larval collections and allow for direct comparisons with past annual reports.

Spawning Site Identification and Observations

We have 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 being 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 sucker. Captured fish are then evaluated for signs of ripeness 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 Muddy River/Virgin River inflow area in the Overton Arm of Lake Mead. This same general approach was also used at the long-term monitoring locations in 2013.

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 2013 long-term monitoring efforts involved collecting fin ray sections from razorback sucker for aging purposes. Samples were also obtained from other native catostomids (i.e., flannelmouth sucker and razorback sucker *x* flannelmouth sucker hybrid) for age determination when appropriate.

During the 2013 field season, select native catostomids captured (i.e., previously unaged, wild razorback sucker, flannelmouth sucker, razorback sucker *x* flannelmouth sucker hybrid) 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, NaCl, and slime-coat protectant to reduce surgery-related stresses, speed recovery, and avoid accidental injury to fish during surgical procedures. During the surgery, standard processing was simultaneously conducted (i.e., weighing, measuring, PIT tagging, and photographing), and a sample was surgically collected using custom-made bone snips originally developed by BIO-WEST. This surgical tool consists of a matched pair of finely sharpened chisels welded to a set of wire-stripping pliers. The connecting membrane between fin rays was cut using a scalpel blade, and the section was placed in a labeled envelope for drying. All surgical equipment was sterilized before use, and subsequent wounds 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 NaCl, allowed to recover, and released as soon as they regained equilibrium and appeared recovered from the anesthesia. Vigilant monitoring was conducted during all phases of the procedure.

In the laboratory, fin ray segments were embedded in thermoplastic epoxy resin and heat cured. This technique allowed the fin rays to be perpendicularly sectioned using a Buhler isomet low-speed saw. Resultant sections were then mounted on microscope slides, sanded, polished, and examined under a stereo-zoom microscope. Each sectioned fin ray was aged independently by at least three readers. Sections were then reviewed by the readers in instances where the assigned age was not agreed upon. If age discrepancies remained after the second reading, all three readers collectively assigned an age. For further information regarding the development of our fin ray aging technique, please refer to Albrecht and Holden (2005), Albrecht et al. (2006b), Albrecht et al. (2008a), and other annual Lake Mead razorback sucker reports. Ages for Lake Mead razorback suckers determined in 2013 were cataloged with past samples spanning from 1998 to 2012 and are included in attachment 1.

Population Estimation

To assess the population of razorback sucker in Lake Mead, the program MARK (MARK [Cooch and White 2013]) was utilized to produce an estimate from mark-recapture data spanning from 2011 through 2013. This most recent timespan was selected to help ensure the likelihood that there would be no mortality or natality in the population (demographically) for the purposes of meeting model assumptions (Cooch and White 2013). That is, given the high survivability seen in Lake Mead razorback sucker in past studies (Albrecht et al. 2013), and given the relative paucity of individuals 3 years old and younger (Shattuck et al. 2011; Albrecht et al. 2013; Kegerries and Albrecht 2013a), the dataset maintains a demographically closed population. 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., time between initial capture 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).

Additionally, movement of razorback sucker between the long-term monitoring sites of Echo Bay and the Muddy River/Virgin River inflow area has been well documented (Albrecht et al. 2007, 2008a, 2008b, 2010b, 2013; Kegerries et al. 2009; Shattuck et al. 2011), and the use of data between these sites helps maintain a level of closure for model assumptions. While wild razorback sucker have been localized between captures, stocked razorback suckers have moved between all study locations within Lake Mead (i.e., the CRI, Las Vegas Bay, Echo Bay, and the Muddy River/Virgin River inflow area) (Kegerries and Albrecht 2011, 2013b; Shattuck et al. 2011; Albrecht et al. 2013), leading to the necessity to assess the population at a number of different scales.

Thus, three population estimates were produced in a tiered approach to meet assumptions for a closed population (one without immigration or emigration): a combined Echo Bay and Muddy River/Virgin River inflow area estimate, a combined estimate for all long-term monitoring sites (i.e., Las Vegas Bay, Echo Bay, the Muddy River/Virgin River inflow area), and a combined lakewide estimate incorporating data from the CRI with those from all long-term monitoring sites. Each estimate incorporates a greater area to maintain the assumption that no immigration or emigration occurs in the population while broadening the reality that movement across the greater Lake Mead area is possible.

For each individual estimate, models produced in MARK were tested and ranked by relative goodness of fit value (according to the corrected Akaike's Information Criterion [AICc] values [Cooch and White 2013]) to produce the most precise and informative estimate. The population model with the highest ranked AICc value is reported herein along with the estimate and 95% confidence bounds. Contrary to past reports (e.g., Shattuck et al. 2011; Albrecht et al. 2013), a sole population estimate for Las Vegas Bay was not calculated in this report, as there were no recaptured fish during the 2011–2013 sampling period. Las Vegas Bay captures, however, were included in the combined long-term monitoring estimate as well as the combined lakewide estimate. For the combined lakewide estimate, 37 capture events were used, where capture events from the CRI were used only when long-term monitoring efforts were concurrent (i.e., sampling was conducted at both long-term monitoring and CRI areas at the same time). This model design helps maintain consistency in effort across the lake from 2011 through 2013. Similarly, 37 capture events were used in the combined long-term monitoring estimate and for the combined Echo Bay and Muddy River/Virgin River inflow area estimate.

RESULTS

Lake Elevation

Similar to the lake elevation trends seen during the past decade (excluding 2011), lake elevations during the 2012–2013 field season declined overall (figures 2 and 3). Starting at a lake elevation of 340 m above msl at the end of July 2012, lake elevations remained relatively static until rising gradually to a peak elevation of 342 m above msl at the end of January 2013 (figure 3). In 2013, lake elevations decreased steadily during the spawning months of February, March, and April to a final elevation of 339 m above msl at the end of April (figure 3). This drop equates to an approximate total of 3 m of change during the 2013 spawning months or nearly 1 m of lake elevation decline per month on average. Field biologists observed noticeable drying of littoral spawning areas and the loss of expanses of recently inundated terrestrial vegetation within all of the long-term monitoring sites during these months. Following the peak spawning months (i.e., February, March, and April), lake elevation continued to decline through the remainder of the 2012–2013 field season, nearing elevations seen in 2009 with a projected forecast of elevations similar to those in 2010 (figure 2).

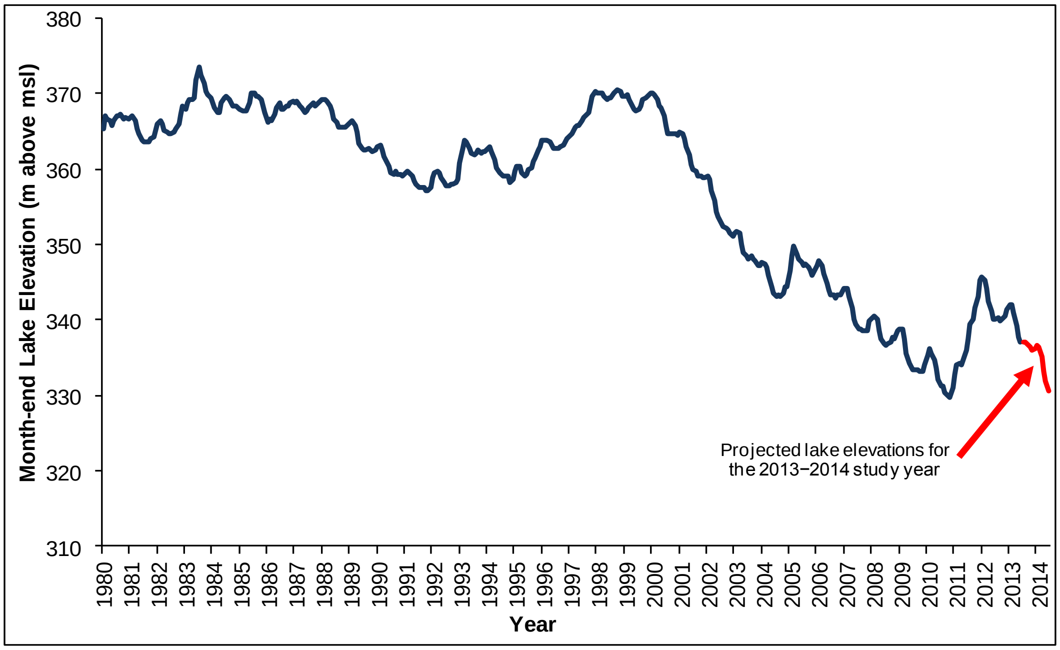

Figure 2.—Historical Lake Mead month-end lake elevations in meters above mean sea level from January 1980 through June 2013 and projected lake elevations for the July 2013 – June 2014 study year (Reclamation 2013).

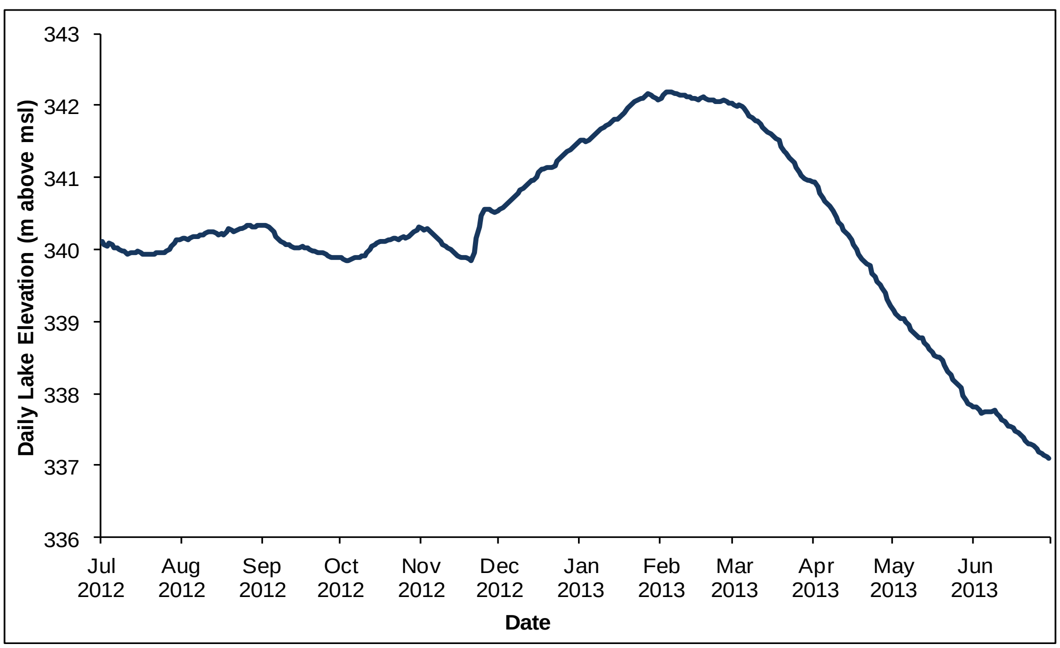

Figure 3.—Lake Mead daily lake elevations in meters above mean sea level from July 1, 2012 through June 30, 2013 (Reclamation 2013).

Sonic Telemetry

Over the course of this study (1997–2013), 86 fish (39 wild and 47 hatchery-reared) have been equipped with sonic transmitters for the purposes of long-term monitoring and/or research at Las Vegas Bay, Echo Bay, and the Muddy River/Virgin River inflow area. Included in the total of sonic-tagged individuals are the one wild and three hatchery-reared juveniles tagged in 2012. Additionally, a number of individuals have been equipped with sonic transmitters and released at the CRI. A complete description of sonic telemetry efforts at the CRI can be found in the Kegerries and Albrecht (2013a) companion report. During the long-term monitoring 2012–2013 field season, 127 active contacts were made with 10 individual sonic-tagged razorback suckers (table 1, figures 4–6), including 1 individual originally tagged in 2012 as a juvenile in Las Vegas Bay. The nine SURs (see figure 1) in aggregate contacted 10 sonic-tagged razorback sucker individuals a total of 7,224 times, helping to define movement of sonic-tagged individuals and aid in accounting for hard to locate, individual sonic-tagged fish.

Fish Sonic Tagged in 2008

Twelve sonic-tagged fish were stocked in Lake Mead in December 2008, four at each of the three primary spawning sites (Las Vegas Bay, Echo Bay, and the Muddy River/Virgin River inflow area) (Kegerries et al. 2009). No contacts were made with any of these individuals during the 2012–2013 field season, and their statuses are unknown (table 1). Though these fish have been valuable to field crew efficiency and effectiveness in capturing razorback sucker for nearly 5 years, it is likely that the battery life of their implanted tags has expired, as noted in previous reports (Albrecht et al. 2010b; Shattuck et al. 2011).

Fish Sonic Tagged in 2010

Eight sonic-tagged fish were stocked in Lake Mead in February 2010, four at the CRI and four in Gregg Basin near Scanlon Bay (Albrecht et al. 2010c). After last being contacted at the CRI in August 2011 (Kegerries and Albrecht 2013a, 2013b), one individual (code 357) was contacted in Las Vegas Bay in April 2012 (Albrecht et al. 2013). Since April 2012, this individual remained in the Las Vegas Bay area and was contacted 77 times (including 68 contacts made by SURs) during the 2012–2013 field season. Contacts made with this individual spanned across Las Vegas Bay, from the Las Vegas Wash inflow eastward to Sand Island (table 1, figures 4 and 7). During the 2012–2013 field season, this sonic-tagged fish used habitats ranging from 1.83 m to 24.38 m deep, with an average depth of 11.89 m (± 2.83 standard error [SE]) at point of contact. This individual frequently associated with the general cover types of inundated

Table 1.—Lake Mead razorback sucker tagging and stocking information, location and date of last contact, and status of sonic-tagged fish gathered during the July 2012 – June 2013 field season

Capture location[1]	Date tagged	Tag code	Total length (mm) at tagging	Sex[2]	Stocking location[1]	Last location[1]	Date of last location	Contacts made: Active (passive)	Current tag status
2008									
FDLB	12/2/2008	365	496	M	EB	EB	11/9/2010	0 (0)	Unknown
FDLB	12/2/2008	376	198	M	EB	EB	8/25/2010	0 (0)	Unknown
FDLB	12/2/2008	678	492	M	EB	VB	5/8/2012	0 (0)	Unknown
FDLB	12/2/2008	3386	193	F	EB	OA	2/3/2009	0 (0)	Unknown
FDLB	12/3/2008	377	479	M	LB	LB	10/12/2011	0 (0)	Unknown
FDLB	12/3/2008	465	520	F	LB	CRI	5/26/2010	0 (0)	Unknown
FDLB	12/3/2008	677	529	F	LB	LB	9/13/2011	0 (0)	Unknown
FDLB	12/3/2008	3355	483	M	LB	CRI	8/17/2011	0 (0)	Unknown
FDLB	12/2/2008	345	515	M	OA	LB	11/7/2012	0 (0)	Unknown
FDLB	12/2/2008	366	479	M	OA	OA	3/10/2009	0 (0)	Unknown
FDLB	12/2/2008	488	534	F	OA	OA	6/23/2009	0 (0)	Unknown
FDLB	12/2/2008	3354	506	F	OA	OA	8/16/2011	0 (0)	Unknown
2010									
FDLB	2/23/2010	357	490	M	GB	LB	5/20/2013	9 (68)	Active
2011									
FDLB	1/4/2011	334	564	F	LB	LB	6/27/2013	21 (2,657)	Active
FDLB	1/4/2011	3545	556	F	LB	LB	4/3/2013	2 (0)	Active
FDLB	1/4/2011	3584	519	M	LB	LB	6/25/2013	17 (1,719)	Active
FDLB	1/4/2011	3775	516	M	LB	LB	6/9/2013	8 (62)	Active
FDLB	1/4/2011	448	502	M	OA	OA	6/20/2013	16 (834)	Active
FDLB	1/4/2011	555	504	M	OA	OA	6/20/2013	16 (423)	Active
FDLB	1/4/2011	3578	541	F	OA	OA	6/20/2013	6 (487)	Active
FDLB	1/4/2011	3667	552	F	OA	OA	6/20/2013	10 (251)	Active
2012									
LB	2/28/2012	222	425	I	LB	LB	6/24/2013	22 (723)	Active
CPD	4/23/2010	337	390	I	LW	LB	5/16/2012	0 (0)	Unknown
CPD	4/23/2010	368	345	I	LW	OA	4/29/2013	0 (0)	Unknown
CPD	4/23/2010	452	340	I	LB	LB	4/24/2012	0 (0)	Unknown

[1] FDLB = Floyd Lamb Park, EB = Echo Bay, VB = Virgin Basin, OA = Overton Arm (Muddy River/Virgin River inflow area), LB = Las Vegas Bay, CRI = Colorado River inflow area, GB = Gregg Basin near Scanlon Bay, CPD = Center Pond, and LW = Las Vegas Wash.

[2] F = Female, M = Male, I = Immature.

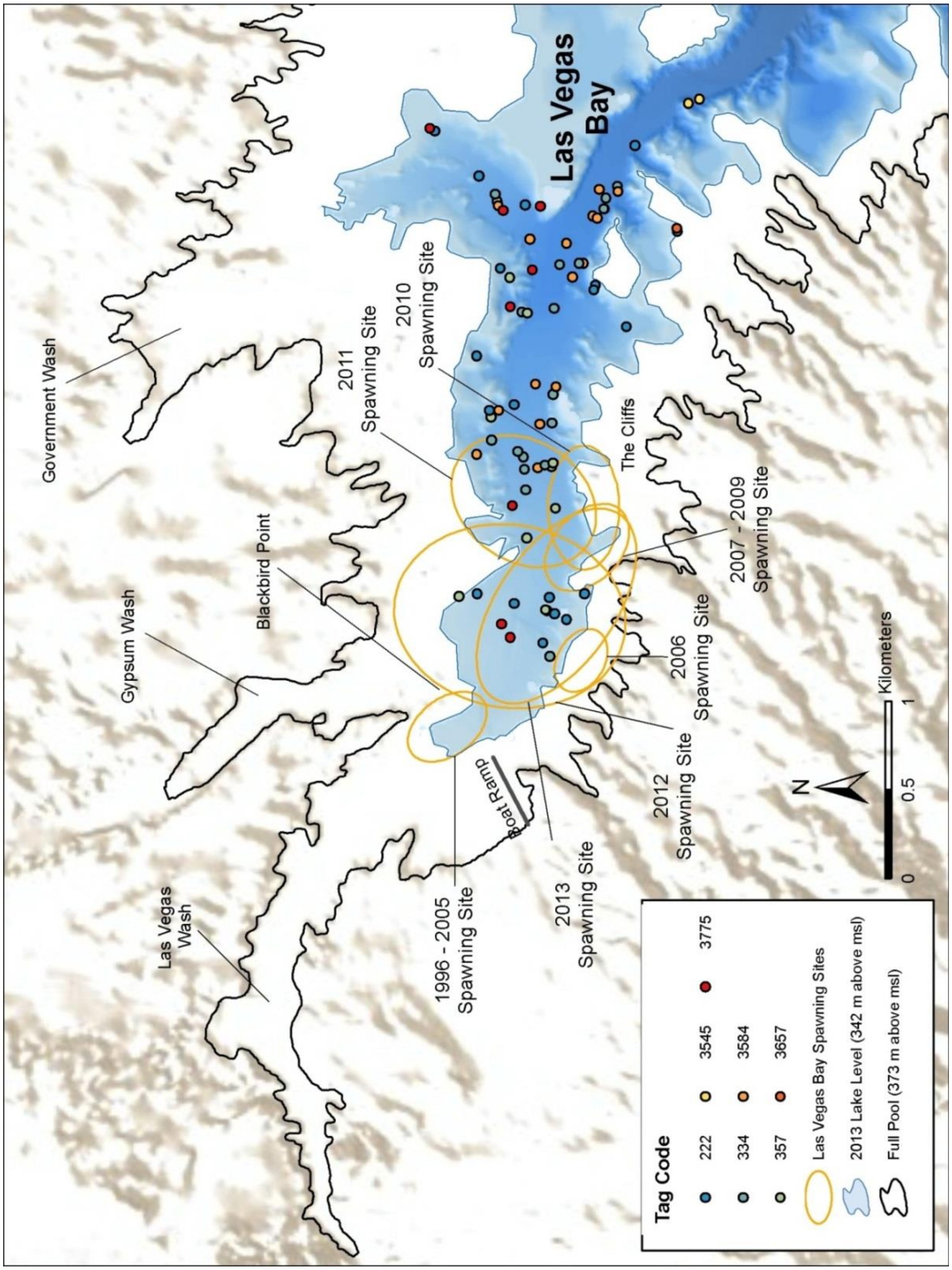

Figure 4.—Distribution of sonic-tagged fish located through active sonic telemetry in Las Vegas Bay during the July 2012 – June 2013 field season.

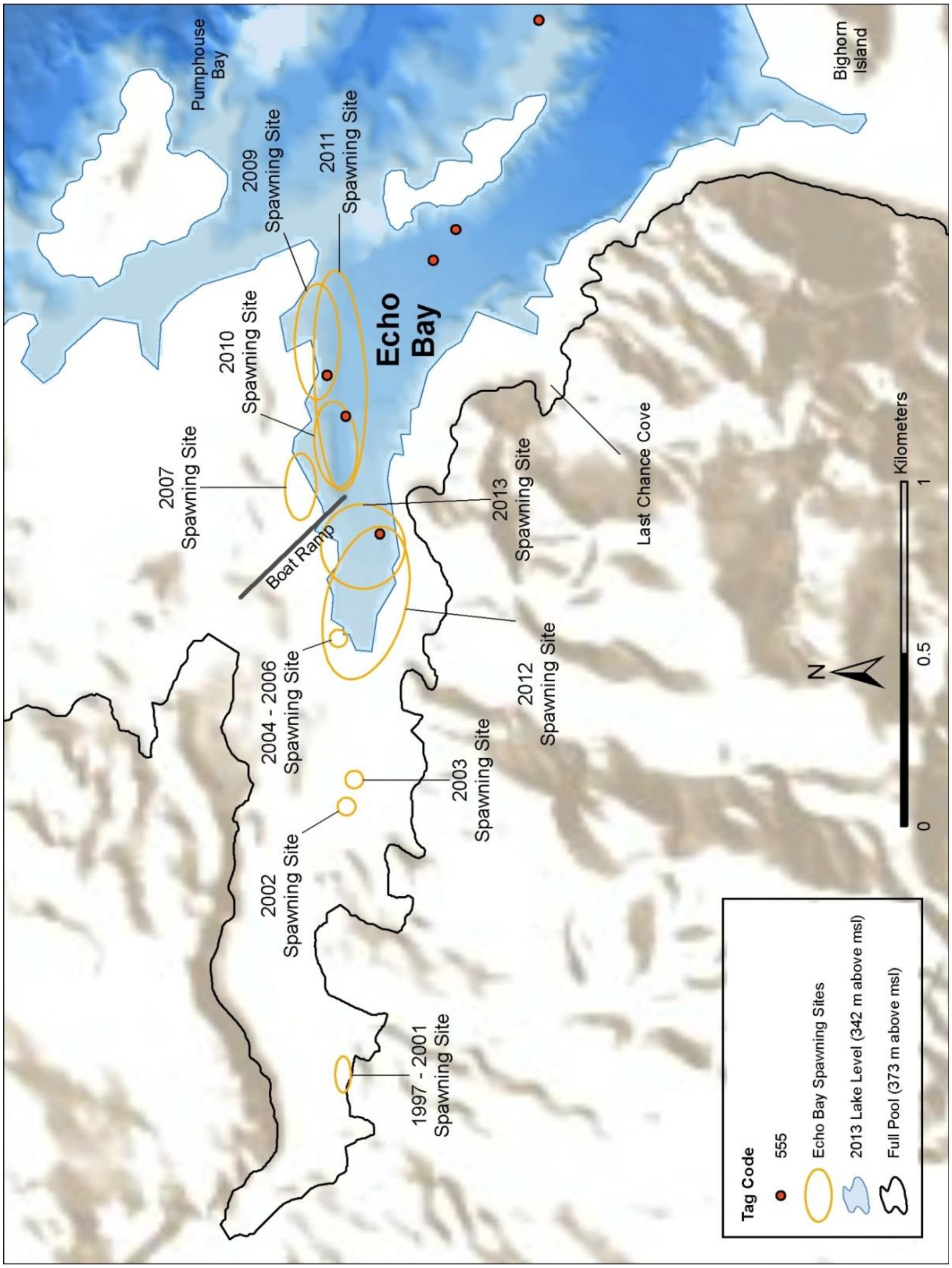

Figure 5.—Distribution of sonic-tagged fish located through active sonic telemetry in Echo Bay during the July 2012 – June 2013 field season.

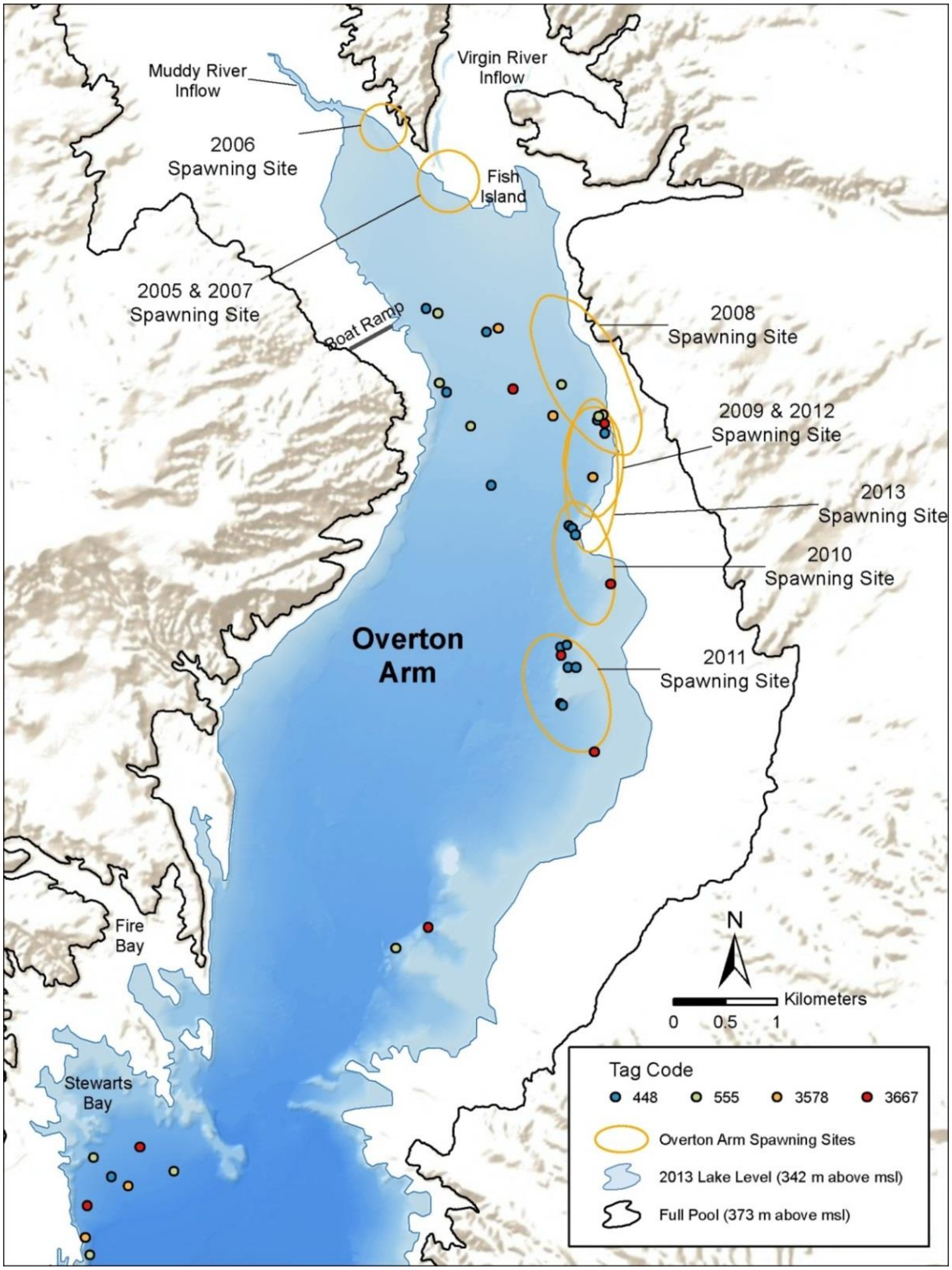

Figure 6.—Distribution of sonic-tagged fish located through active sonic telemetry in the Muddy River/Virgin River inflow area during the July 2012 – June 2013 field season.

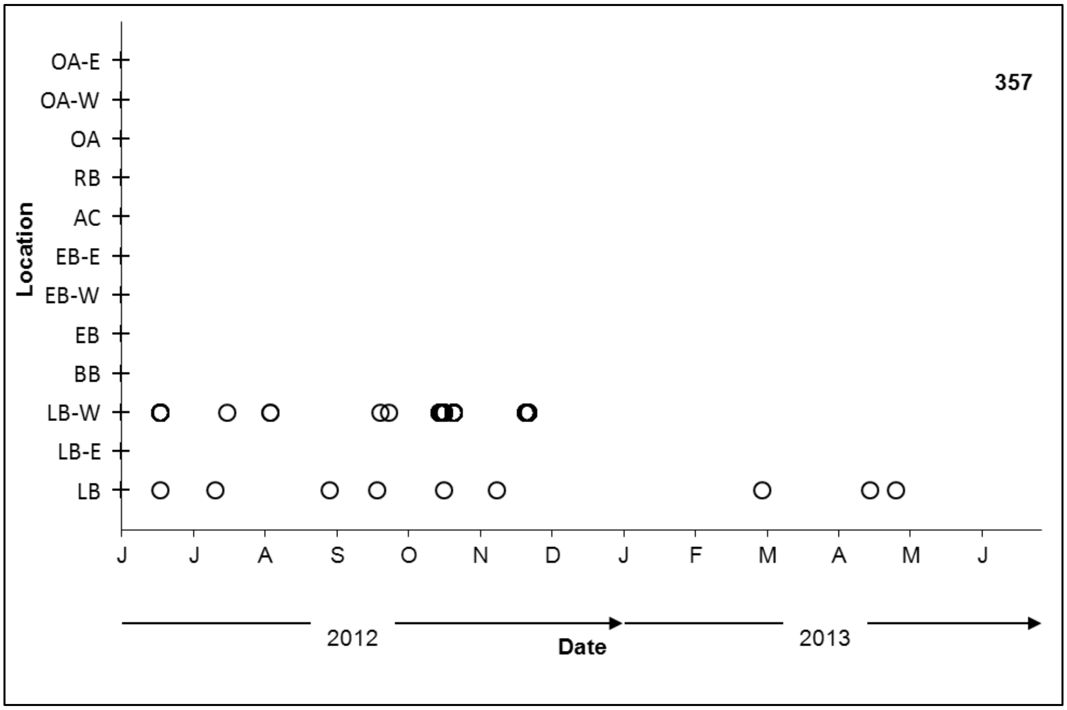

Figure 7.—Movement derived from active and passive sonic telemetry during the July 2012 – June 2013 field season for long-term monitoring of individuals sonic tagged in 2010 at Lake Mead.
Location abbreviations are as follows: LB = Las Vegas Bay area, LB-E = Las Vegas Bay-East SUR, LB-W = NDOW Las Vegas Bay-West SUR, BB = Boulder Narrows SUR, EB = Echo Bay area, EB-W = Echo Bay-West SUR, EB-E = Echo Bay-East SUR, AC = Anchor Cove SUR, RB = Rogers Bay SUR, OA = Muddy River/Virgin River inflow area, OA-W = NDOW Black Ridge SUR, and OA-E = Overton Arm SUR.

vegetation and turbidity and was often found in shallow habitat during the months preceding the spawning season through the end of the spawning season. This pattern of habitat use was often seen during earlier study years (Albrecht et al. 2008b).

This individual (code 357) was most often contacted within lentic portions of the lake, though contacts made adjacent to lotic habitat in the Las Vegas Wash may suggest that razorback sucker continue to utilize this shallow, flowing habitat more than our recorded contacts show. Although the wash is typically difficult to track or sample by boat, a similar pattern of movement and association with lotic habitat has been observed during previous years where individuals were noted to congregate toward the western end of Las Vegas Bay into Las Vegas Wash (Albrecht et al. 2008b, 2010b, 2013; Shattuck et al. 2011).

Fish Sonic Tagged in 2011

Eight razorback suckers were sonic tagged in Lake Mead in January 2011. Four individuals were released in Las Vegas Bay, and four individuals were released near the Muddy River/Virgin River inflow. During the 2012–2013 field season, this group of fish was contacted most frequently; each individual was contacted at least twice for a total of 96 active sonic telemetry contacts and 6,433 passive contacts made via 5 different SURs (table 1, figures 4–6 and 8). For the most part, each of the two groups of fish stocked in 2011 remained at its respective release localities for the 2012–2013 field season (i.e., tagged individuals were contacted at the same site they were initially stocked into). Individuals from the 2011 tagging event that were stocked into Las Vegas Bay were actively contacted in that area 48 times, while individuals stocked into the Muddy River/Virgin River inflow area were actively contacted in that area a total of 42 times (figures 4, 6, and 8). Though no individuals were initially stocked into Echo Bay, one individual originating from the Muddy River/Virgin River inflow area was actively contacted six times in Echo Bay (figures 5 and 8). Individuals from the 2011 tagging event were contacted most often by SURs placed throughout Lake Mead with 4,436 contacts at the NDOW Las Vegas Bay-West and Las Vegas Bay-East SURs, five contacts at the Echo Bay-West SUR, and 1,990 contacts at the Rogers Bay, NDOW Black Ridge, and Overton Arm SURs (figures 1 and 8). No contacts were made with the Boulder Narrows, Echo Bay-East, or Anchor Cove SURs.

During the 2012–2013 field season, four sonic-tagged fish in Las Vegas Bay (codes 334, 3545, 3584, and 3775) used habitats ranging in depth from 1.83 to 34.44 m with an average depth of 18.49 m (± 1.39 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 (figure 4). Conversely, individuals were found at shallower locations further to the west during the reproductive season and were often found closer to one another (figure 4).

In Echo Bay, one sonic-tagged individual from the 2011 tagging event (code 555) used habitats 1.83–15.85 m deep with an average depth of 8.99 m (± 1.89 SE). Contacts with this fish occurred across Echo Bay proper, where this individual was contacted once in October 2012 and throughout most of February 2013 during observed active razorback sucker spawning (figure 5). This same individual was also contacted at the Muddy River/Virgin River inflow area throughout the year along with three other fish tagged in 2011. In the Muddy River/Virgin River inflow area, four individuals (codes 448, 555, 3578, and 3667) tagged during 2011 used habitats ranging from 2.13 to 67.36 m deep with an average depth of 11.34 m (± 1.76 SE) at point of contact. During the reproductive season, these individuals remained primarily in shallow areas close to the Muddy River/Virgin River inflow area and along the eastern shoreline from the Meadows area of the Overton Arm to Three Corner Hole. However, in the periods prior to and following the reproductive season, these individuals were contacted in deeper habitat and further south in the Overton Arm (e.g., Stewarts Bay) (figure 6).

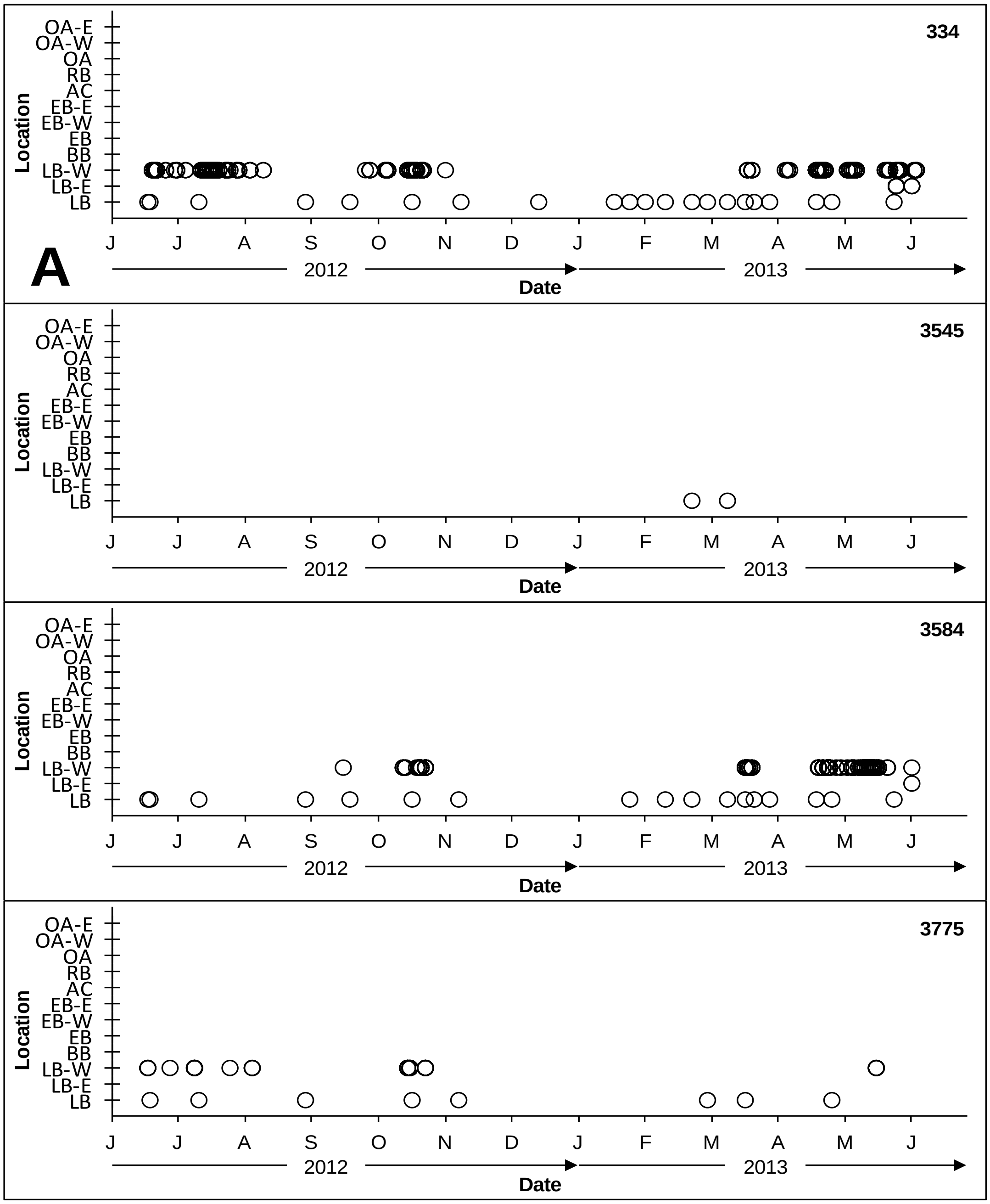

Figure 8.—Movement derived from active and passive sonic telemetry during the July 2012 – June 2013 field season for long-term monitoring of individuals sonic tagged in 2011 (A = LB stocked and B = OA stocked) at Lake Mead.
Location abbreviations are as follows: LB = Las Vegas Bay area, LB-E = Las Vegas Bay-East SUR, LB-W = NDOW Las Vegas Bay-West SUR, BB = Boulder Narrows SUR, EB = Echo Bay area, EB-W = Echo Bay-West SUR, EB-E = Echo Bay-East SUR, AC = Anchor Cove SUR, RB = Rogers Bay SUR, OA = Muddy River/Virgin River inflow area, OA-W = NDOW Black Ridge SUR, and OA-E = Overton Arm SUR.

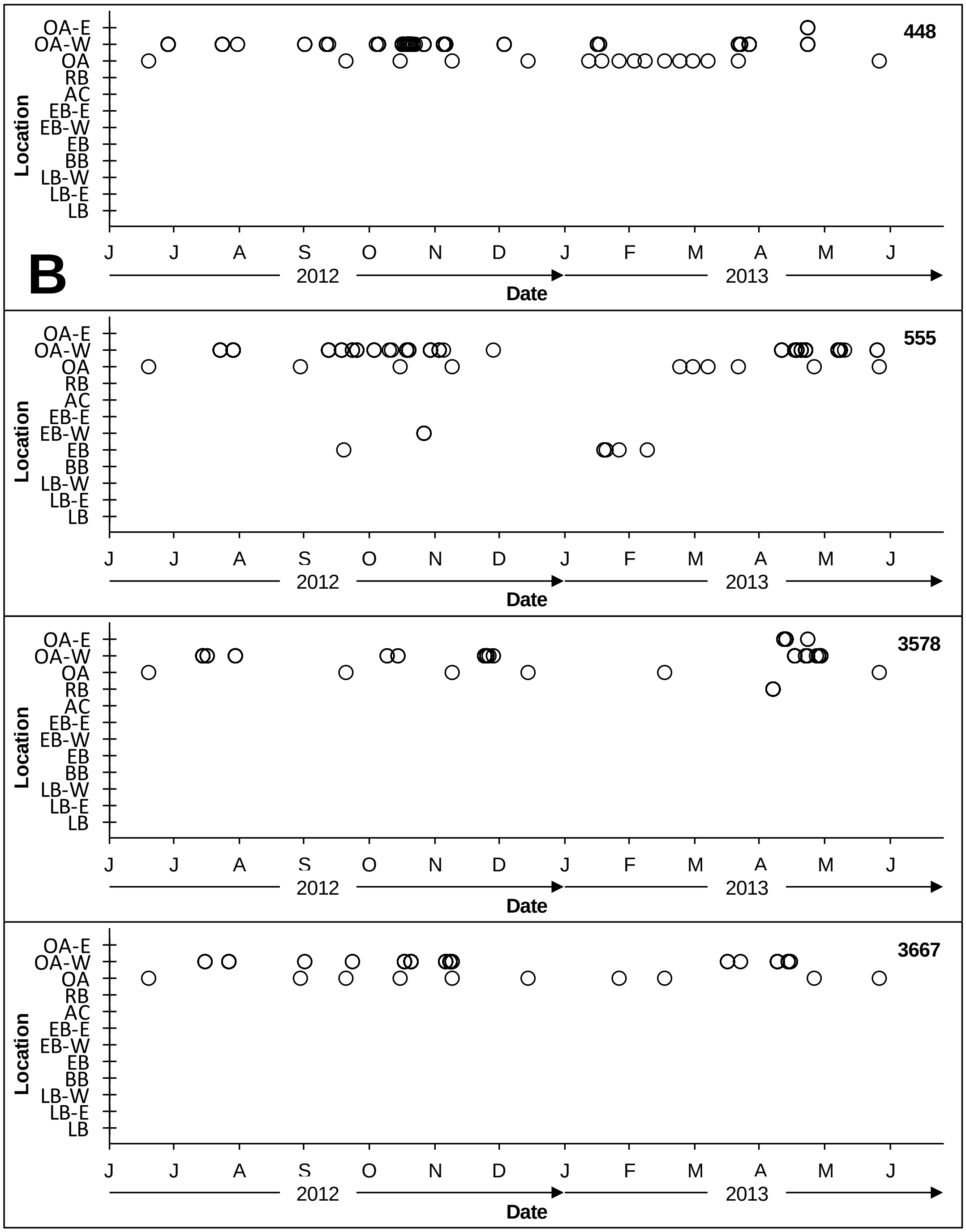

Figure 8 (continued.)

Similar to movement patterns seen in the past (Shattuck et al. 2011; Albrecht et al. 2013), the movement of one individual (code 555) tagged in 2011 further supports and characterizes the connection between the areas of the Muddy River/Virgin River inflow area and Echo Bay (figures 5 and 6). 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

Muddy River/Virgin River inflow area where this individual again associates with other reproductively active individuals throughout the rest of the year (Shattuck et al. 2011; Albrecht et al. 2013). 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, 2013; Shattuck et al. 2011).

Because there were fewer individuals tagged in other years (e.g., 2008, 2010) that were contacted during the reproductive season, the individuals that were sonic tagged in 2011 remained exceedingly important during the 2012–2013 field season. The individuals tagged in 2011 helped define locations of spawning sites in Echo Bay and at the Muddy River/Virgin River inflow area and aided in trammel netting efforts at both locations (figures 5 and 6), which had some of the higher capture rates at Lake Mead this season. Furthermore, the individuals sonic tagged in 2011 helped document areas that may have a seasonal importance outside of the reproductive season, particularly in Las Vegas Bay and at the Muddy River/Virgin River inflow area (figures 4 and 6). As the 48-month battery life of these sonic tags begins to approach, it will be necessary to replace this cohort of sonic-tagged razorback sucker to maintain sampling consistency through time.

Fish Sonic Tagged in 2012

Four sonic-tagged juvenile razorback suckers were stocked in Lake Mead in February and April 2012: three pond-reared individuals from Center Pond at the OWMA and one wild individual caught in Las Vegas Bay (table 1). The wild individual caught in Las Vegas Bay during the 2011–2012 field season (code 222) was a larger, yet immature fish (425 mm TL at tagging [table 1]) that provided an immense amount of data pertaining to the juvenile pilot study. However, as this fish likely grew and matured during winter 2012 and spring 2013, we presumed it integrated with the wild adult razorback sucker population in this location. During the 2012–2013 field season, this sonic-tagged fish was contacted 745 times (including 723 contacts made by SURs); much like other year-classes of sonic-tagged razorback suckers, this individual was contacted throughout Las Vegas Bay and was frequently contacted near other adult sonic-tagged razorback sucker (table 1, figures 4 and 9). During the 2012–2013 field season, one sonic-tagged individual (code 222) used habitats ranging from 1.22 m to 37.80 m deep with an average depth of 11.16 m (± 2.34 SE) at point of contact. Additionally, this individual was found associating with the general cover types of inundated vegetation and turbidity near the Las Vegas Wash inflow as well as within Government Wash Cove, displaying a seasonal shift from shallow habitat in the spring to deeper habitat during the summer (figure 4).

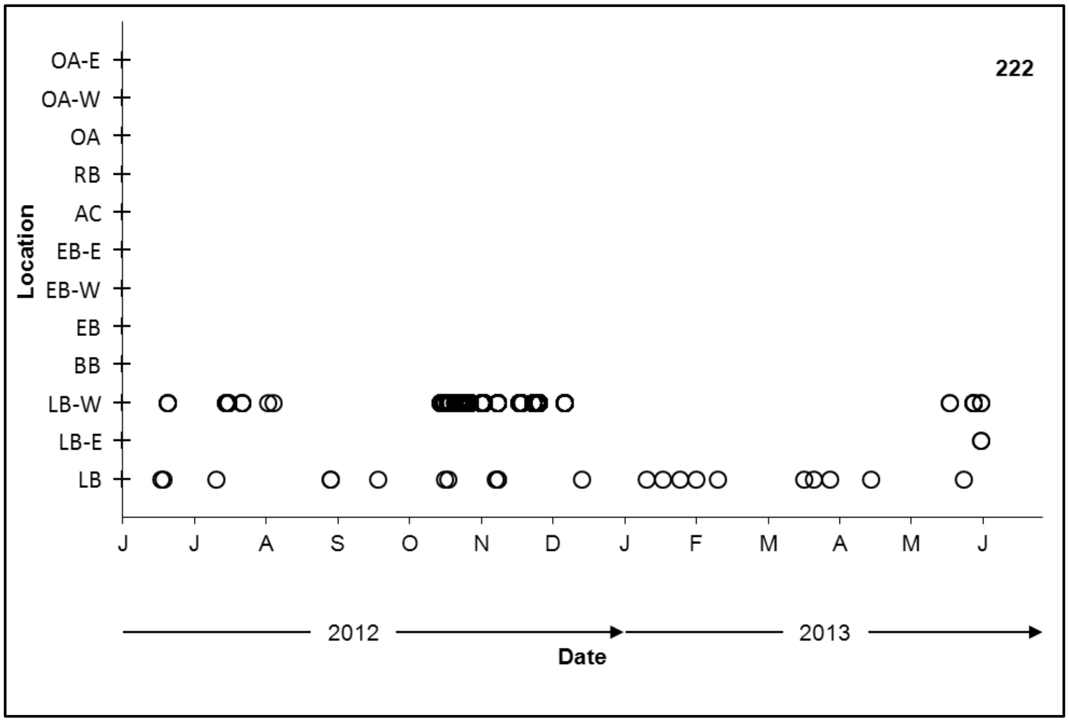

Figure 9.—Movement derived from active and passive sonic telemetry during the July 2012 – June 2013 field season for long-term monitoring of individuals sonic tagged in 2012 at Lake Mead.
Location abbreviations are as follows: LB = Las Vegas Bay area, LB-E = Las Vegas Bay-East SUR, LB-W = NDOW Las Vegas Bay-West SUR, BB = Boulder Narrows SUR, EB = Echo Bay area, EB-W = Echo Bay-West SUR, EB-E = Echo Bay-East SUR, AC = Anchor Cove SUR, RB = Rogers Bay SUR, OA = Muddy River/Virgin River inflow area, OA-W = NDOW Black Ridge SUR, and OA-E = Overton Arm SUR.

The wild fish from the 2012 tagging event helped define the spawning site location in Las Vegas Bay and was associated with every new, wild adult razorback sucker captured at this long-term monitoring site during the 2012–2013 field season, thus improving trammel netting efforts and capture rates (figure 4). The capture of new, wild adult fish in association with this sonic-tagged individual further illustrates its apparent maturation in 2013.

Interestingly, aside from the wild fish tagged in 2012 (code 222) and contacted throughout the 2012–2013 field season, no other individual had been contacted since May 2012. However, the NDOW Black Ridge SUR made four contacts (two sets of near-consecutive contacts) with an individual tagged in 2012 (code 368) last contacted in Las Vegas Bay on April 24, 2013. This fish was contacted twice on April 25, 2013, and twice on April 29, 2013, at intervals of 11 and 12 minutes, respectively, outside of the set 2-minute mark for successive contacts. These contacts were therefore excluded from the verified dataset in efforts to reduce erroneous contacts by SURs due to noise.

Furthermore, no active contacts were made with this individual, bringing into question the validity of the contacts; thus, these results remain anecdotal in nature and, unfortunately, purely speculative.

Adult Sampling

Trammel Netting

Trammel netting occurred from February 4, 2013, to April 25, 2013, in accordance with recommendations for long-term monitoring of Lake Mead razorback sucker (Albrecht et al. 2006a). 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. Netting was conducted for 86 net-nights, with 26 net-nights spent in Las Vegas Bay, 32 net-nights in Echo Bay, and 28 net-nights in the Muddy River/Virgin River inflow area (table 2). 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 2007–2009 spawning areas (figure 10). The primary sampling area of Echo Bay was located at the west end of the bay behind the main boat ramp and off the northern and southern shorelines (figure 11). Finally, sampling of the Muddy River/Virgin River inflow area occurred near the 2012 spawning area, along the eastern shoreline of the north 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 from February 2013 through April 2013

Month	Las Vegas Bay	Echo Bay	Muddy River/ Virgin River inflow area	Total
February	11	11	9	31
March	8	9	11	28
April	7	12	8	27
Total	**26**	**32**	**28**	**86**

The first male razorback sucker expressing milt was captured on February 5, 2013, from Las Vegas Bay. The first female razorback sucker expressing eggs was captured on February 7, 2013, in Echo Bay (table 3). Across Lake Mead long-term monitoring sites there were 25 recaptures out of 60 total razorback sucker captures (41.7%) in 2013. Recapture rates varied between study areas. At

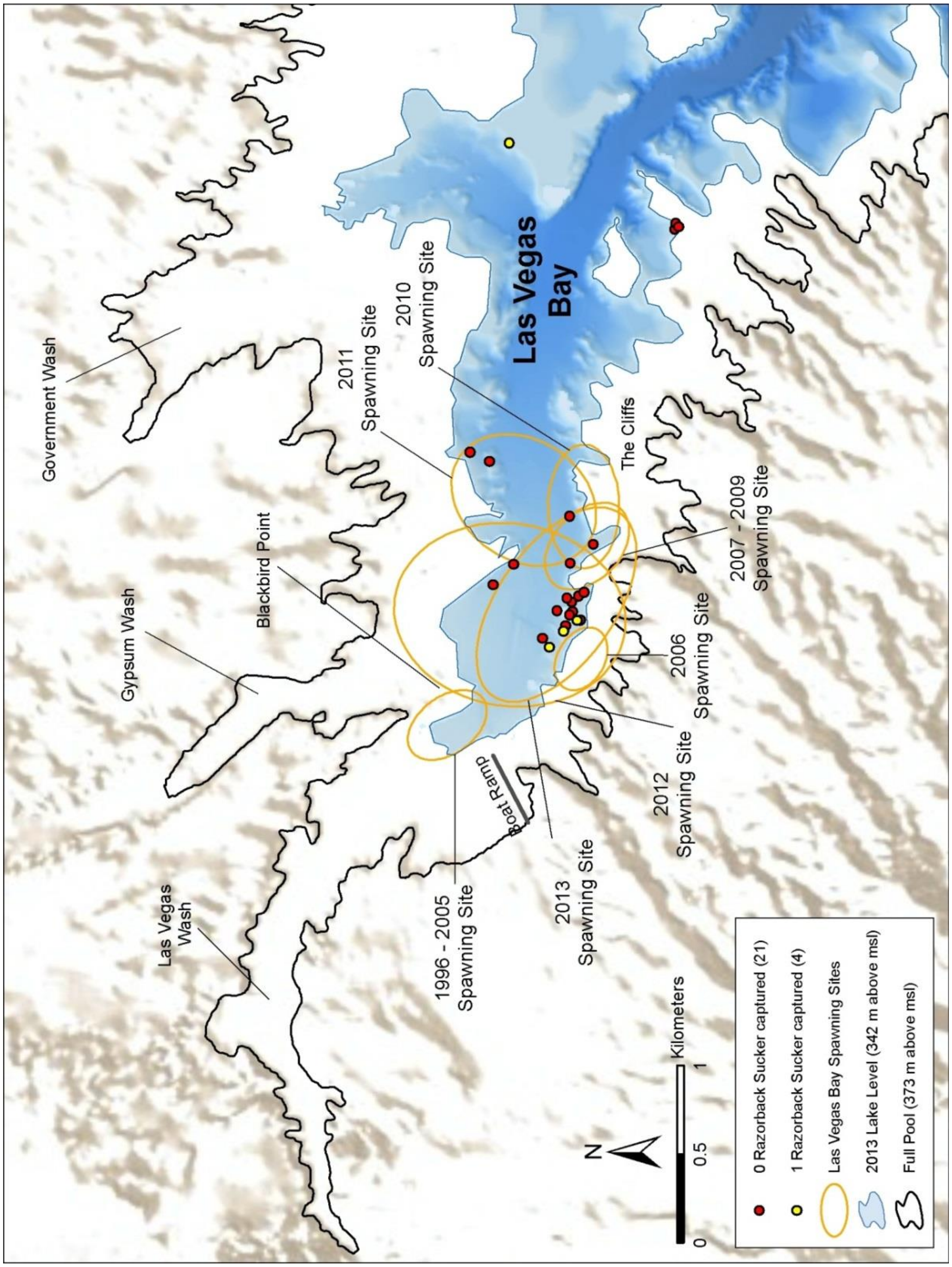

Figure 10.—Locations of trammel netting and numbers of fish captured in Las Vegas Bay, February 2013 – April 2013.

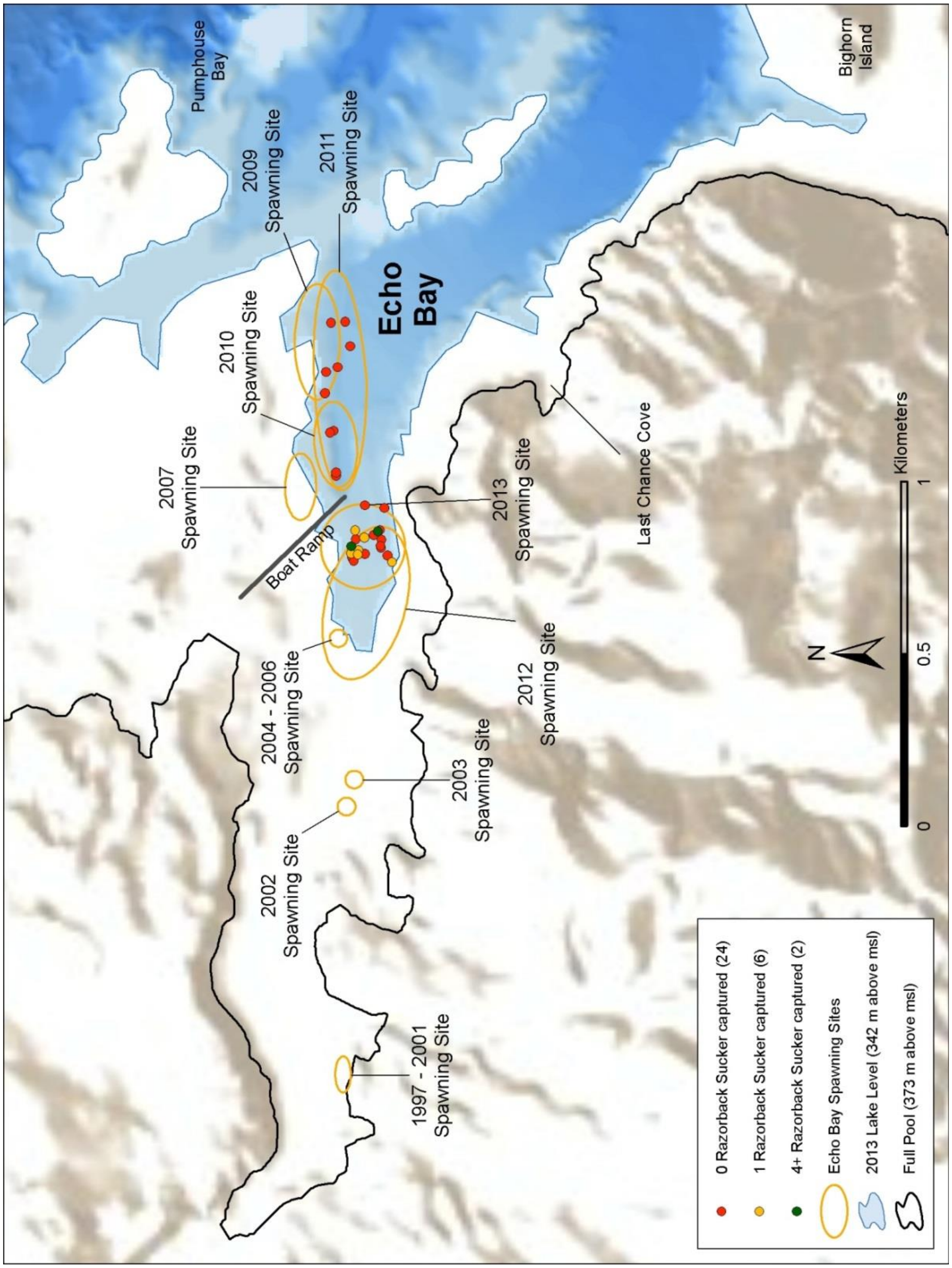

Figure 11.—Locations of trammel netting and numbers of fish captured in Echo Bay, February 2013 – April 2013.

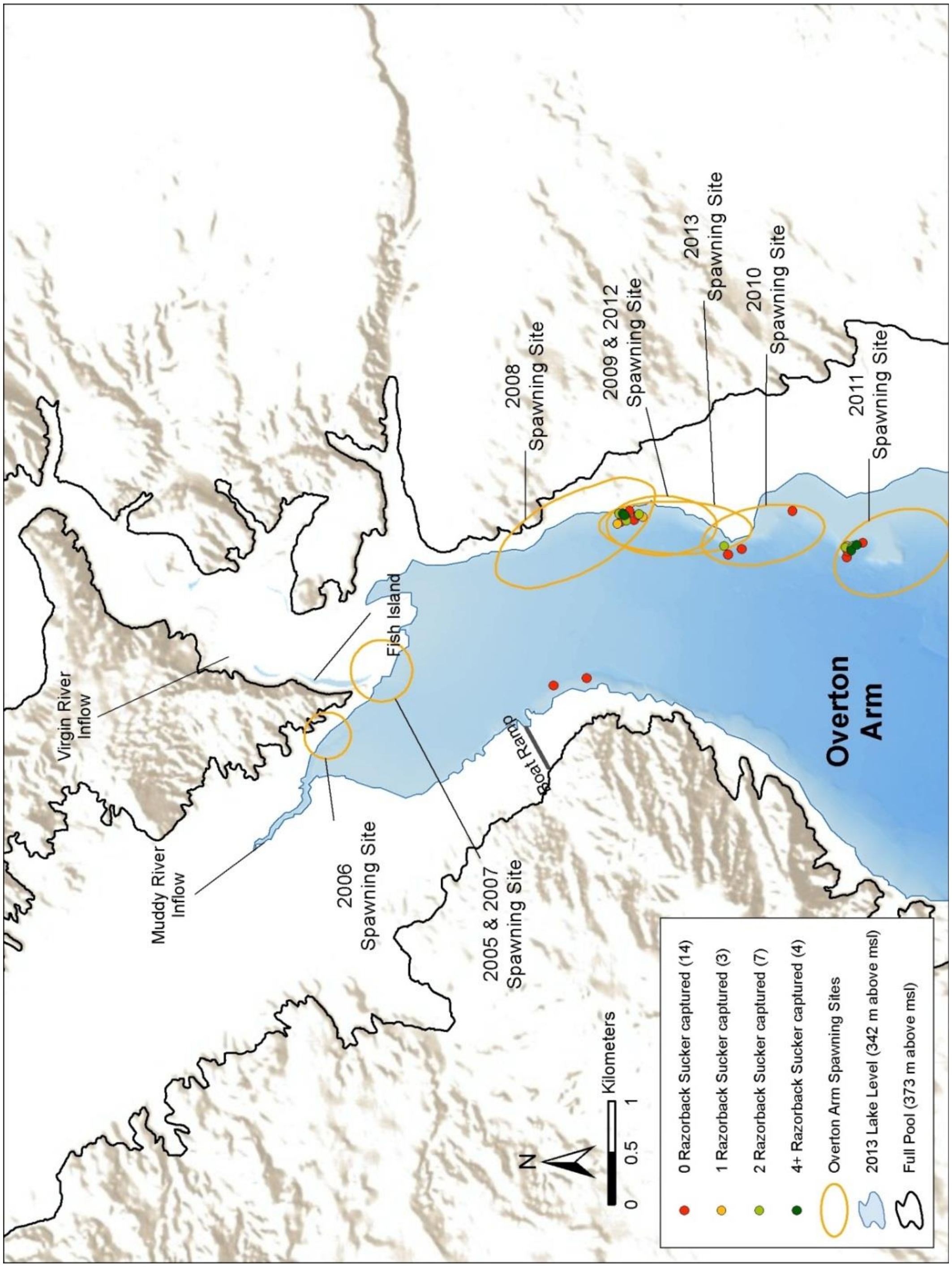

Figure 12.—Locations of trammel netting and numbers of fish captured in the Muddy River/Virgin River inflow area, February 2013 – April 2013.

Table 3.—Location, tagging, and size information for razorback sucker captured in Lake Mead from February 2013 through April 2013

Date	Capture location[1]	PIT tag number	Sonic tag	Date stocked[2]	Recapture?	TL (mm)	FL (mm)	SL (mm)	Weight (grams)	Sex[3]
2/5/2013	LB	3D9.1C2D26949B		2/5/2013	NO	510	472	440	1562	M
2/6/2013	OA	3D9.1C2D267EBC		2/6/2013	NO	519	478	450	1818	M
2/7/2013	EB	5331484E1A/ 3D9.1C2D261259	376	12/2/2008	YES	585	538	485	2088	M
2/7/2013	EB	7F7D16534B/ 3D9.1C2D269A06[h]		3/18/1992	YES	604	550	494	3098	M
2/7/2013	EB	3D9.1C2D273931		2/7/2013	NO	655	613	579	3388	F
2/7/2013	EB	3D9.1C2D260916		2/7/2013	NO	579	530	492	2208	M
2/7/2013	EB	3D9.1C2C7F4DA8		2/1/2006	YES	724	661	601	4000	F
2/7/2013	EB	3D9.1C2C840A3C		2/7/2013	NO	670	618	560	4000	F
2/13/2013	OA	3D9.257C60CC21		2/9/2010	YES	550	512	476	1670	M
2/13/2013	OA	3D9.1C2C7EF17C		3/11/2009	YES	620	575	536	2948	F
2/13/2013	OA	3D9.1C2C83BCE0		2/13/2013	NO	630	578	536	2734	F
2/14/2013	EB	3D9.1C2D273931		2/7/2013	YES	Quick release[4]				F
2/14/2013	EB	3D9.1C2C840A3C		2/7/2013	YES	Quick release				F
2/14/2013	EB	3D9.1C2D260916		2/7/2013	YES	Quick release				M
2/14/2013	EB	53257D1C30/ 3D9.1C2C84510B		2/1/2007	YES	638	594	554	3248	M
2/14/2013	EB	3D9.1C2D25B898		2/9/2011	YES	562	517	478	1906	M
2/14/2013	EB	53257F4D73/ 3D9.1C2D265A48	558	11/29/2005	YES	692	641	598	3904	F
2/14/2013	EB	7F7D4C302B/ 3D9.1C2D268918		2/10/1998	YES	638	586	540	2784	M
2/14/2013	EB	7F7D2B2D5F/ 384.1B7969EE45		4/2/1993	YES	605	553	515	2730	M
2/20/2013	EB	532F161F08/ 3D9.1C2C840DF7		2/29/2008	YES	655	601	596	3618	F
2/21/2013	OA	3D9.1C2C840860		4/19/2011	YES	553	516	474	1660	M
2/21/2013	OA	3D9.1C2C84072C		2/21/2013	NO	549	505	483	1984	M
2/21/2013	OA	3D9.1C2C840DFB		2/21/2013	NO	546	503	478	1192	M
2/21/2013	OA	3D9.1C2C8416AF		2/21/2013	NO	606	555	519	2508	M
2/21/2013	OA	3D9.1C2C83C054		2/21/2013	NO	584	540	506	1938	F
2/21/2013	OA	3D9.257C60EB46		2/9/2013	YES	540	491	460	1676	M
2/21/2013	OA	3D9.1C2D26865F		2/21/2013	NO	544	468	405	1860	M
2/19/2013	LB	3D9.1C2D268D87		2/19/2013	NO	512	480	441	1662	M
2/26/2013	LB	3D9.1C2C83CA43		2/26/2013	NO	500	459	425	1698	M
3/5/2013	OA	3D9.1C2D25F509		3/18/2010	YES	523	485	451	1668	M
3/5/2013	OA	384.1B7969E0B2		3/5/2013	NO	567	524	481	1990	M
3/5/2013	OA	384.1B7969D639		3/5/2013	NO	621	575	555	2640	F
3/5/2013	OA	384.1B7969EFC7		3/5/2013	NO	601	558	518	2554	F

Table 3.—Location, tagging, and size information for razorback sucker captured in Lake Mead from February 2013 through April 2013

Date	Capture location[1]	PIT tag number	Sonic tag	Date stocked[2]	Recapture?	TL (mm)	FL (mm)	SL (mm)	Weight (grams)	Sex[3]
3/5/2013	OA	3D9.1C2C841C24		3/5/2013	NO	537	500	464	1790	M
3/5/2013	OA	3D9.1C2D2617E7		3/5/2013	NO	558	510	475	1938	M
3/6/2013	EB	3D9.1C2C840ECD		3/1/2012	YES	594	548	520	2998	F
3/14/2013	OA	3D9.1C2C83C193		3/1/2011	YES	585	539	504	2098	F
3/14/2013	OA	3D9.1C2D263000		3/14/2013	NO	616	567	530	2464	F
3/14/2013	OA	384.1B7969E3C7		3/14/2013	NO	600	553	516	2238	F
3/14/2013	OA	3D9.1C2D263226		3/9/2011	YES	537	498	456	1496	M
3/21/2013	OA	3D9.257C633584		2/9/2010	YES	558	525	476	1840	F
3/21/2013	OA	384.1B7969E26C		3/21/2013	NO	578	532	488	2104	M
3/21/2013	OA	384.1B7969D7FA		3/21/2013	NO	577	540	500	1928	M
3/21/2013	OA	5334521528/ 384.1B7969E2B7	488	12/2/2008	YES	621	576	530	2998	F
3/21/2013	OA	384.1B7969CB78		3/21/2013	NO	639	593	554	2850	F
3/21/2013	OA	384.1B7969CFBA		3/21/2013	NO	570	527	492	1820	M
3/21/2013	OA	384.1B7969ECFB		3/21/2013	NO	551	513	483	2038	M
3/21/2013	OA	384.1B7969D41E		3/13/2012	YES	625	584	543	2534	F
3/21/2013	OA	384.1B7969DB68		3/21/2013	NO	616	579	535	2550	F
3/21/2013	OA	384.1B7969E7AA		3/21/2013	NO	605	567	523	2308	F
3/21/2013	OA	384.1B7969E306		3/21/2013	NO	629	582	537	2980	F
3/27/2013	OA	3D9.1C2C856C17		3/15/2011	YES	618	570	529	2090	F
3/27/2013	OA	3D9.1C2D268EC1		2/22/2011	YES	550	510	483	1706	M
3/27/2013	OA	384.1B7969E2F4		3/27/2013	NO	580	535	500	2106	F
3/27/2013	OA	384.1B7969EA92		3/27/2013	NO	539	497	459	1592	M
4/3/2013	OA	384.1B7969DF01		4/3/2013	NO	554	510	472	1480	M
4/3/2013	OA	384.1B7969DA02		4/3/2013	NO	542	490	451	1618	M
4/10/2013	OA	384.1B7969DAE6		4/10/2013	NO	560	518	482	1966	M
4/10/2013	OA	384.1B7969DEEA		4/10/2013	NO	598	555	512	2220	F
4/16/2013	LB	3DD.003BA2FA74		4/16/2013	NO	561	515	478	1538	M

[1] EB = Echo Bay, LB = Las Vegas Bay, and OA = Overton Arm (Muddy River/Virgin River inflow area).
[2] Date originally stocked or originally captured.
[3] F = Female, M = Male, U = Unidentified, I = Immature (sex not determined).
[4] 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 [kHz]) and recently tagged again with a new, 12.5-mm, 134.2-kHz style PIT tag.
[i] No measurements taken due to proximity of date of capture to date of recapture; individual was released immediately to avoid unnecessary stress.

Las Vegas Bay, no recaptures were made, and all four of the captures were new, wild fish. At Echo Bay, 13 of the 16 (81.3%) razorback suckers caught were recaptures. Of these 13 recaptures, all but 2 were originally captured as wild, unmarked fish during previous study years. The other two recaptured fish from Echo Bay were sonic-tagged individuals from previous study years (fish 558 was originally stocked into the Muddy River/Virgin River inflow area in 2005, and fish 376 was originally stocked into Echo Bay in 2008), suggesting that sonic-tagged fish can incorporate with the wild population and continue to be healthy for many years post-surgery. At the Muddy River/Virgin River inflow area, 12 of 40 (30.0%) razorback suckers caught in 2013 were recaptures. Of these 12 recaptures, 1 was a wild fish originally tagged in Echo Bay, and 1 was a sonic-tagged fish (code 448) that was originally stocked in 2008. For netting efforts during 2013, combined captures from all of the Lake Mead long-term monitoring consisted of 43% females and 57% males. We note that for the second year in a row, overall captures were relatively low in Las Vegas Bay at only four fish; however, during the 2011–2012 field season, only two razorback suckers were captured (Albrecht et al. 2013). At Las Vegas Bay, all four razorback sucker captured in 2013 were male fish. During this time, the ratio of females to males was 1:1 (8 females, 8 males) at Echo Bay and 1:1.2 (18 females, 22 males) at the Muddy River/Virgin River inflow area.

Four adult razorback suckers were captured at Las Vegas Bay during the 2013 spawning period (table 3). These fish were captured from the back of Las Vegas Bay, along the southwestern portion of the bay and extending out from the Las Vegas Wash inflow, similar to captures seen in past years (Albrecht et al. 2010b, 2013; Shattuck et al. 2011). The razorback sucker catch per unit effort (CPUE) from trammel netting at the Las Vegas Bay area was 0.15 fish/net-night during 2013 (figure 13). This rate is lower than CPUE rates from 2009–2011; however, the 2013 CPUE rate is higher than that observed during the 2011–2012 field season and falls within other CPUE values observed throughout the course of this study (Shattuck et al. 2011; Albrecht et al. 2013). It should be noted that the lowest CPUE values observed in Las Vegas Bay were 0.04 fish/net-night during the 2003–2004 field season (figure 13) (Welker and Holden 2004).

At Echo Bay, when possible, nets were set toward the west end of the bay behind the boat ramp and back toward the inflow of Echo Wash into Echo Bay, focusing on areas where sonic-tagged fish were contacted and, in one instance, where adult razorback sucker were visually observed spawning along the northern shoreline at the back of Echo Bay (figure 11). However, as the spawning season progressed, netting efforts became increasingly constrained by declining lake levels in this historically productive area of Echo Bay (Albrecht et al. 2010b). Efforts throughout the spawning season were focused on both the northern shore of Echo Bay in an area composed of larger substrates (e.g., cobble, boulder) and along the southern shoreline in an area of recently inundated vegetation and appropriate cobble/gravel substrates. Under the conditions described above, 16 adult razorback suckers were captured in 32 net-nights during the 2013 spawning

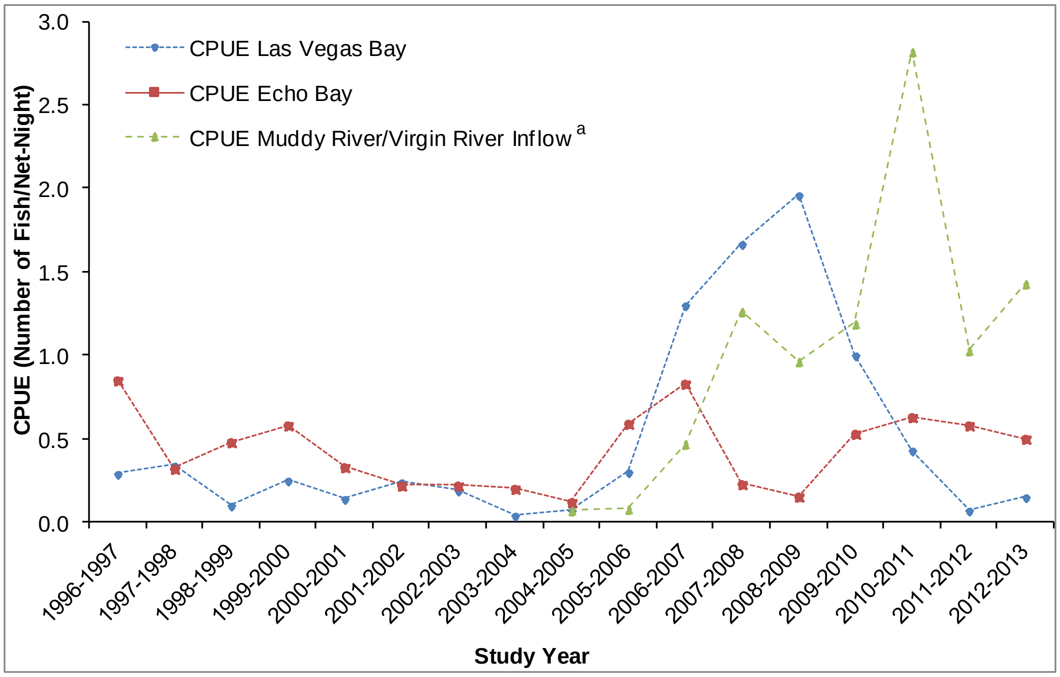

Figure 13.—Trammel netting catch per unit effort in number of fish per net-night for studies on Lake Mead razorback sucker, 1996–2013.
[a] Sampling at the Muddy River/Virgin River inflow area was initiated in 2004–2005.

season (tables 2 and 3, 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. 2013). No juvenile fish were captured from Echo Bay during the 2013 spawning period, marking the sixth year without juvenile captures in this area. The 2013 razorback sucker CPUE for trammel netting at Echo Bay was 0.50 fish/net-night, which falls well within the range of catch rates (0.12–0.85 fish/net-night) observed during previous field seasons (figure 13).

During the 2012–2013 field season, razorback sucker were successfully caught at the Muddy River/Virgin River inflow area once again (figure 12). Trammel netting in 2012–2013 resulted in the capture of 40 adult razorback suckers, yielding the highest CPUE rates and total number of razorback sucker for long-term monitoring sites of the 2012–2013 field season (table 3, figure 13). This is the fourth consecutive year that the Muddy River/Virgin River inflow area CPUE exceeded CPUEs in Las Vegas Bay and Echo Bay (figure 13). Most of the fish captured at the Muddy River/Virgin River inflow area were taken over gravel and small-cobble substrates along the eastern shoreline south of the Virgin River inflow/delta and near the 2009 and 2012 spawning areas (figure 12). The razorback sucker CPUE for trammel netting at the Muddy River/Virgin River inflow area was 1.43 fish/net-night (figure 13), and for the fourth consecutive year, CPUE rates at this site exceeded those of the Las Vegas Bay and Echo Bay study areas (figure 13). The overall Lake Mead CPUE for 2013 (0.70 fish/net-night) increased from 2012 (0.57 fish/net-night) and was also higher than the average, combined (all long-term monitoring sites), historical CPUE of 0.57 fish/net-night.

It should be noted that during the 2013 spawning period, three flannelmouth suckers and one razorback sucker *x* flannelmouth sucker hybrid were captured, all from the Muddy River/Virgin River inflow area. Each of the four suckers was wild, unmarked individuals, and fin ray sections were obtained for aging purposes. The 2013 CPUE for flannelmouth sucker (including one hybrid individual) in the Muddy River/Virgin River inflow area was 0.11 fish/net-night (Muddy River/Virgin River inflow area CPUE: 2011 = 0.05 fish/net-night, 2012 = 0.06 fish/net-night). Flannelmouth sucker have been captured at the Muddy River/Virgin River inflow area in low numbers since 2010. To our knowledge, this marks the first time that a razorback sucker *x* flannelmouth sucker hybrid has been documented within the long-term monitoring sites (17 hybrid individuals were documented at the CRI from 2010 to 2013 [Kegerries and Albrecht 2013a]). This new, wild hybrid (subsequently recaptured two additional times during the 2012–2013 field season) measured 495 mm TL and was documented as a male exhibiting obvious signs of sexual maturity.

Growth

Although 25 razorback suckers were recaptured during the 2013 field season (13 from Echo Bay and 12 from the Muddy River/Virgin river inflow area), annual growth analyses were only performed using data from 22 of these individuals. All recaptures were not included in the analyses because some individuals were captured more than once. The difference in TL between capture periods was used to determine mean annual growth (table 4). Three stocked fish and 19 wild fish were used to calculate growth information for 2013. The combined mean annual growth of all razorback suckers recaptured from all long-term monitoring sites during 2013 was 14.8 mm per year (table 4), slightly lower than the reported growth rate for the past 2 years (Shattuck et al. 2011; Albrecht et al. 2013). Mean annual growth of wild fish captured in Lake Mead in 2013 was 14.8 mm per year, while mean annual growth of stocked fish in 2013 was 15.1 mm per year (table 4).

Larval Sampling

Larval razorback sucker sampling at the three primary spawning sites (Las Vegas Bay, Echo Bay, and the Muddy River/Virgin River inflow area) was initiated on February 4, 2013. With few exceptions, four to eight monitoring sites were sampled nearly weekly during February, March, and April 2013 for each of the three primary spawning sites. Larvae were first collected on February 4, 2013, at

Table 4.—Lake Mead razorback sucker growth histories for fish recaptured from February 2013 through April 2013

PIT tag number(s)	Date stocked[1]	TL (mm)	Last date recaptured	TL (mm)	Total growth (mm)	Days between measurements	Growth/year (mm/365 days)
Echo Bay							
Wild fish							
3D9.1C2C7F4DA8/ 5325515754	2/1/2006	705	2/7/2013	724	19	2,563	2.7
3D9.1C2D269A06/ 7F7D16534B	3/18/1992	549	2/7/2013	604	55	7,631	2.6
3D9.1C2D25B898	2/9/2011	529	2/14/2013	562	33	736	16.4
3D9.1C2C84510B/ 53257D1C30	2/1/2007	637	2/14/2013	638	1	2,205	0.2
384.1B7969EE45/ 7F7D2B2D5F	4/2/1993	574	2/14/2013	605	31	7,258	1.6
3D9.1C2D268918/ 7F7D4C302B	2/10/1998	347	2/14/2013	638	291	5,483	19.4
3D9.1C2C840DF7/ 532F161F08	2/29/2008	635	2/20/2013	655	20	1,818	4.0
3D9.1C2C840ECD	3/1/2012	585	3/6/2013	594	9	370	8.9
Mean annual growth							**7.0 ± 2.6**
Stocked fish							
3D9.1C2D261259/ 5331484E1A	12/2/2008	498	2/7/2013	585	87	1,528	20.8
3D9.1C2D265A48/ 53257F4D73	11/29/2005	662	2/14/2013	692	30	2,634	4.2
Mean annual growth							**12.5 ± 8.3**
Muddy River/Virgin River inflow area							
Wild fish							
3D9.1C2C7EF17C	3/11/2009	585	2/13/2013	620	35	1,435	8.9
3D9.257C60CC21	2/9/2010	471	2/13/2013	550	79	1,100	26.2
3D9.1C2C840860	4/19/2011	540	2/21/2013	553	13	674	7.0
3D9.257C60EB46	2/9/2010	491	2/21/2013	540	49	1,108	16.1
3D9.1C2D25F509	3/18/2010	452	3/5/2013	523	71	1,083	23.9
3D9.1C2C83C193	3/1/2011	538	3/14/2013	585	47	744	23.1
3D9.1C2D263226	3/9/2011	505	3/14/2013	537	32	736	15.9
384.1B7969D41E	3/13/2012	610	3/21/2013	625	15	373	14.7
3D9.257C633584	2/9/2010	444	3/21/2013	558	114	1,136	36.6
3D9.1C2C856C17	3/15/2011	551	3/27/2013	618	67	743	32.9
3D9.1C2D268EC1	2/22/2011	508	3/27/2013	550	42	764	20.1
Mean annual growth							**20.5 ± 2.8**
Stocked fish							
384.1B7969E2B7/ 5334521528	12/2/2008	534	3/21/2013	621	87	1,570	20.2
Mean annual growth							**N/A[2]**
Mean annual growth of all wild fish							**14.8 ± 2.5**
Mean annual growth of all stocked fish							**15.1 ± 5.5**
Mean annual growth of all fish							**14.8 ± 2.2**

[1] The date a fish was stocked into Lake Mead or the date a wild fish was originally captured.
[2] Mean could not be calculated from the growth of one individual.

Las Vegas Bay over a variety of substrates. Temperatures in Las Vegas Bay had already reached 15–17 °C during the initial sampling of this study site. Larval razorback sucker were collected throughout the back portions of Las Vegas Bay and even within the flowing portions of Las Vegas Wash (figure 14). The collection of larval razorback sucker occurred primarily at temperatures between 17–20 °C, and positive collections were often in conjunction with sonic-tagged fish (figures 4 and 14). Las Vegas Bay yielded a total of 505 larval fish captured within 1,290 minutes of sampling, providing an overall catch per minute (CPM) value of 0.391 (table 5). Razorback sucker larvae CPM at Las Vegas Bay in 2013 was higher than that observed in recent years, and it represents one of the higher overall CPM values observed since 2007 (table 6).

Despite visually observing a group of 12–20 reproductively active razorback suckers in spawning aggregate at the western extent of Echo Bay on February 6, 2013, the first razorback sucker larvae from Echo Bay were not captured until March 26, 2013. Positive larval collections were made over gravel/cobble substrates and at temperatures near 16 °C in the southwestern portion of the bay. However, subsequent collections spanned much of the northern shoreline toward the Overton Arm (figure 15). Collection efforts in Echo Bay returned the lowest total number of captures and CPM values for larval razorback sucker of any study area during 2013, and for the first time during our studies, CPM values (and total numbers of larvae) were lower in Echo Bay than at the Muddy River/Virgin River inflow area. The collection of 40 larval razorback suckers resulted in a CPM value of 0.019 (table 5). Despite low overall numbers (table 6), the 2013 Echo Bay larval razorback sucker captures again confirmed spawning success in this historical spawning location and further demonstrate that this location is an important spawning area for Lake Mead razorback sucker.

At the Muddy River/Virgin River inflow area, the first razorback sucker larvae of the season were captured on April 2, 2013, over nearly all substrate types and at temperatures ranging from 17 to 19 °C. Larval collections occurred approximately 3.2 km south of the Muddy River/Virgin River inflow area, along the eastern shoreline of the Overton Arm, near the 2009 and 2012 spawning areas (figures 1 and 16). Larval razorback sucker captures occurred in the same vicinity as multiple adult razorback sucker captures from trammel netting efforts and near areas routinely frequented by sonic-tagged individuals (table 5, figure 16), although larval razorback sucker were still found in numbers disproportionate to the abundance of adult captures in the Overton Arm (as has been typical and relative to values observed at this location to date [Shattuck et al. 2011; Albrecht et al. 2013). Despite this disparity, and for the first time during our studies, both the total number and overall larval razorback sucker CPM value from this relatively new location were higher than those same metrics observed in Echo Bay in 2013. Larval captures in the Muddy River/Virgin River inflow area in 2013 were higher than the majority of previous years' captures and occurred at

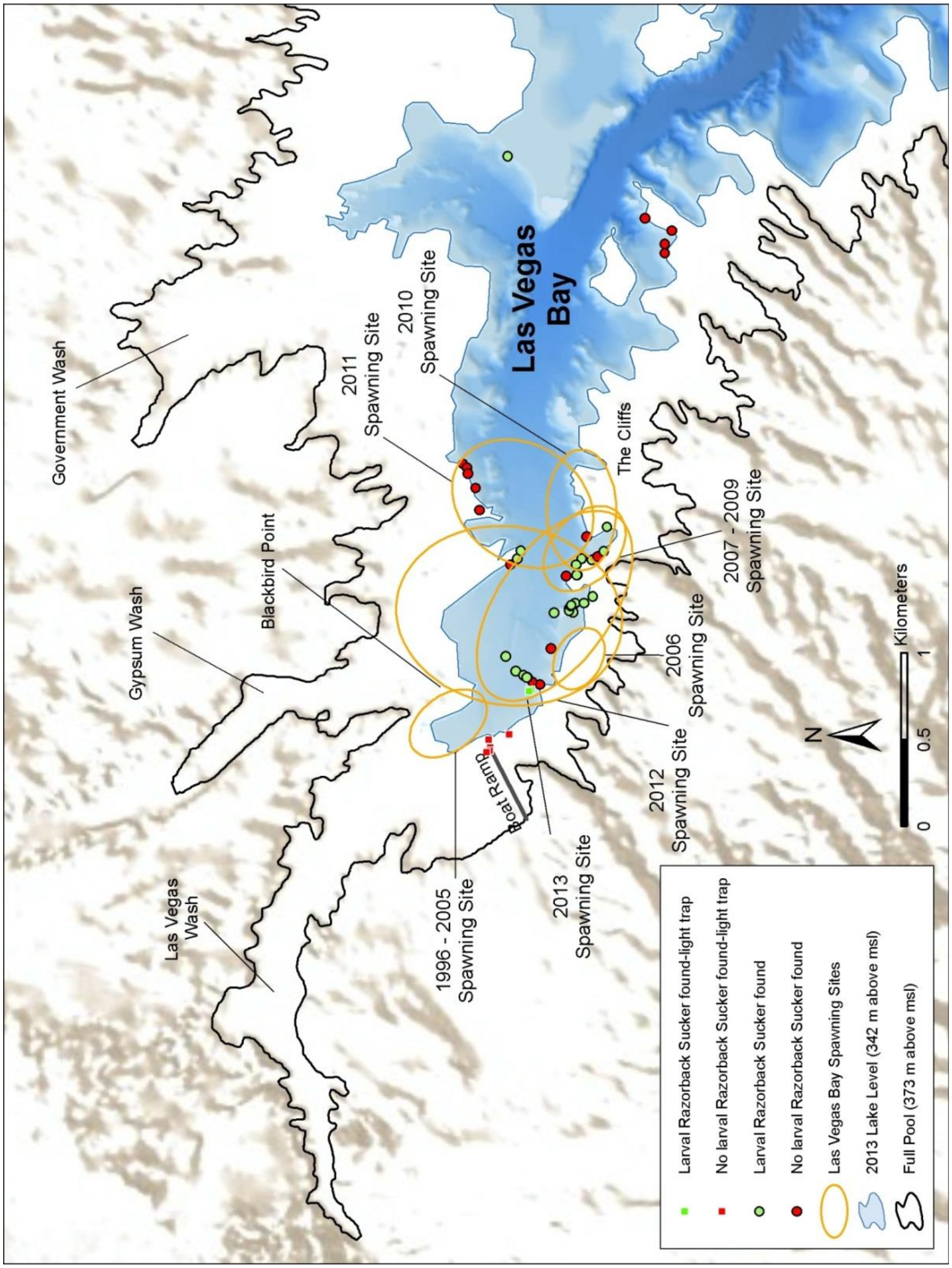

Figure 14.—Locations of larval razorback sucker sampling and captures in Las Vegas Bay, February 2013 – April 2013.

Table 5.—Number of razorback sucker larvae collected at Las Vegas Bay, Echo Bay, and the Muddy River/Virgin River inflow area, February 2013 – April 2013

Date	Las Vegas Bay sampling sites			Echo Bay sampling sites			Muddy River/Virgin River inflow area sampling sites		
	Minutes sampled	Larvae captured	CPM	Minutes sampled	Larvae captured	CPM	Minutes sampled	Larvae captured	CPM
02/04/13	150	10	0.067						
02/05/13							60	0	0.000
02/06/13				90	0	0.000			
02/11/13	150	47	0.313						
02/12/13							120	0	0.000
02/13/13				150	0	0.000			
02/18/13	180	184	1.022						
02/20/13				120	0	0.000			
02/25/13	90	42	0.467						
02/26/13				90	0	0.000			
03/04/13							150	0	0.000
03/05/13				240	0	0.000			
03/13/13				150	0	0.000			
03/18/13	180	129	0.717						
03/19/13				120	0	0.000			
03/20/13							120	0	0.000
03/26/13				180	4	0.022			
03/27/13				180	4	0.022			
04/01/13				180	7	0.039			
04/02/13							150	128	0.853
04/03/13	120	0	0.000						
04/08/13				180	12	0.067			
04/10/13	120	5	0.042						
04/16/13				150	7	0.047			
04/17/13							150	59	0.393
04/18/13	150	88	0.587						
04/22/13	150	0	0.000						
04/24/13				150	4	0.027			
04/29/13							180	4	0.022
04/30/13				180	2	0.011			
Totals	**1,290**	**505**	**0.391**	**2,160**	**40**	**0.019**	**930**	**191**	**0.205**

Table 6.—Larval razorback sucker catch per minute comparisons by long-term monitoring site, 2007–2013

Long-term monitoring site	Larval razorback sucker captures (CPM)						
	2007	2008	2009	2010	2011	2012	2013
Las Vegas Bay	0.390	0.430	0.342	0.093	0.282	0.220	0.391
Echo Bay	0.430	0.024	0.021	0.269	1.482	0.179	0.019
Muddy River/Virgin River inflow area	0.001	0.116	0.107	0.011	0.013	0.004	0.205

temperatures ranging from 16 to 24 °C. In all, 191 larval razorback suckers were captured, resulting in a CPM of 0.205, which is the highest larval razorback sucker catch rate observed from this spawning location to date (tables 5 and 6).

During the 2013 long-term monitoring field season, larval light traps were used on a limited, experimental basis in part due to the success with this methodology at the CRI (Kegerries and Albrecht 2013a, 2013b). Note that these efforts are not included within table 6 in an effort to maintain consistent comparisons with past annual reports. In Las Vegas Bay, larval light traps were deployed in flowing portions of Las Vegas Wash proper (adjacent to the Las Vegas Bay boat ramp and near the wash/lake interface) for a cumulative set time of 107 hours and 51 minutes. Interestingly, light traps set in lotic portions near the wash/lake interface successfully documented four razorback sucker larvae; they were captured approximately 150 m upstream of the Las Vegas Wash inflow area (figure 14) and provide direct evidence of successful razorback sucker spawning and use of the flowing portions of Las Vegas Wash proper in 2013. In Echo Bay, larval light traps were deployed in the furthest western extent of the bay along the northern and southern shorelines for a cumulative set time of 33 hours and 44 minutes (figure 15). No larval razorback sucker were captured during these, albeit limited, efforts (figure 15). Finally, larval light traps were deployed at the Muddy River/Virgin River inflow area for a cumulative set time of 58 hours and 4 minutes. Traps were solely set near the capture area of numerous reproductively ready adults at the northern extent of the 2011 spawning area near the Meadows (figure 16). As with larval light trapping efforts in Echo Bay, no larval razorback suckers were captured at the Muddy River/Virgin River inflow area during these efforts

Spawning Site Identification and Observations

For the past decade, fluctuating lake elevations have influenced habitat conditions in all areas where razorback sucker sampling activities have occurred. As a result

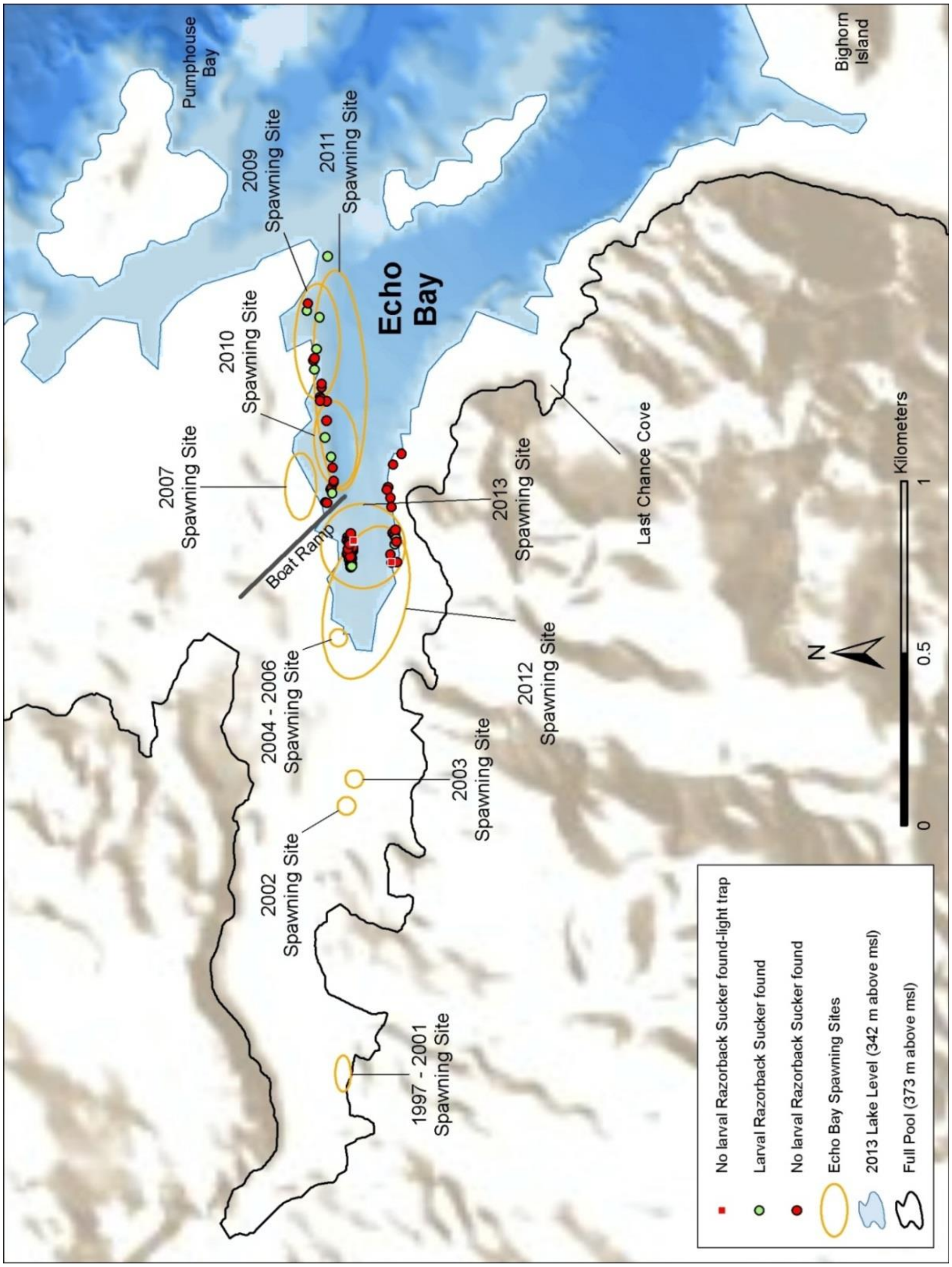

Figure 15.—Locations of larval razorback sucker sampling and captures in Echo Bay at Lake Mead, February 2013 – April 2013.

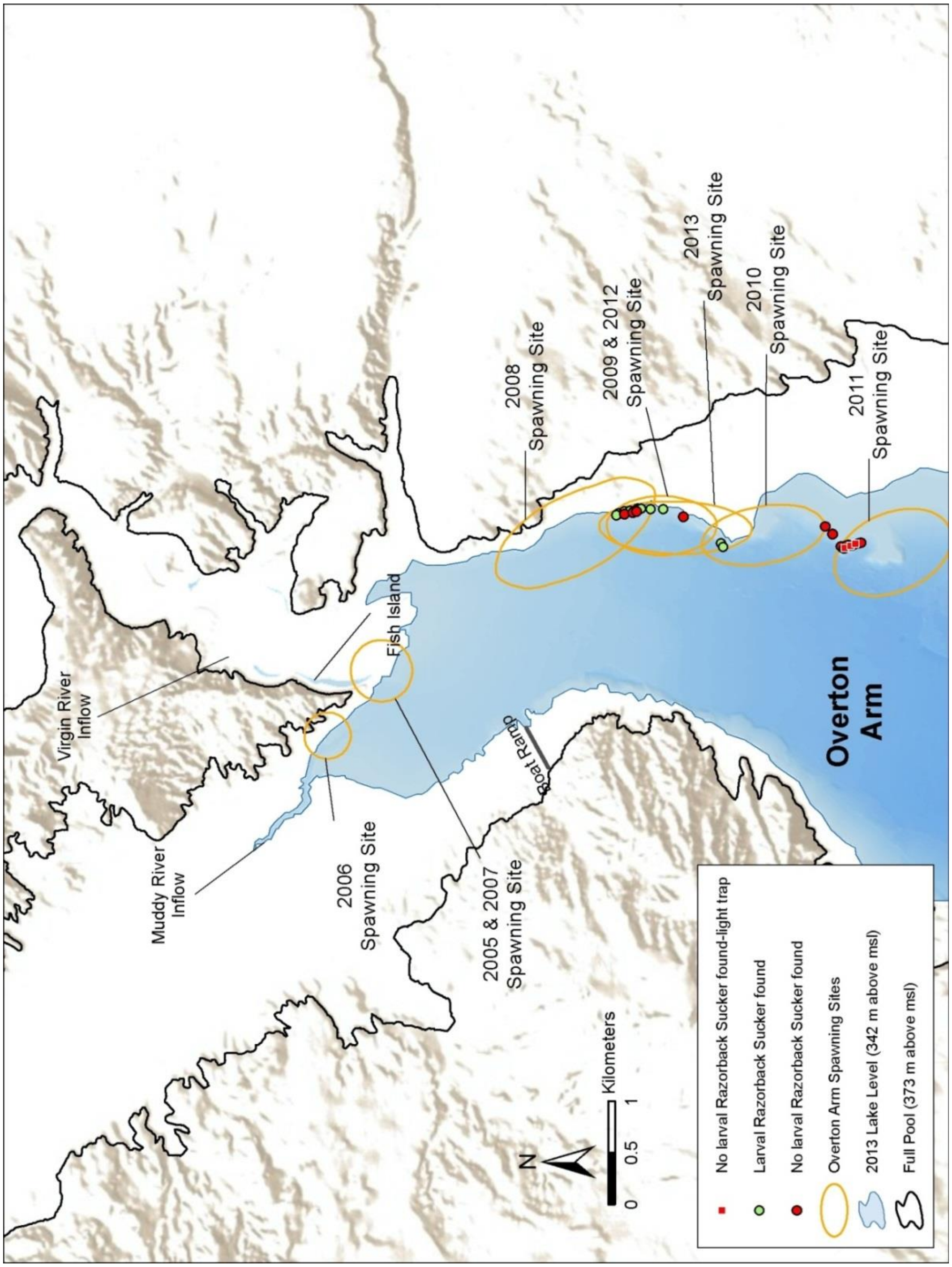

Figure 16.—Locations of larval razorback sucker sampling and captures in the Muddy River/Virgin River inflow area at Lake Mead, February 2013 – April 2013.

of variable lake elevations throughout the last decade, Lake Mead razorback sucker have continually shifted spawning sites to accommodate for varying conditions.

Though few adult razorback suckers were captured in Las Vegas Bay during the 2012–2013 field season, the majority of adult fish were found along the southern edge of western extent of Las Vegas Bay. This area was also the primary location for the collection of larval individuals; however, it is noted that larval razorback sucker were captured upstream of the Las Vegas Wash inflow area in a portion of the Las Vegas Wash near the old Las Vegas Bay boat ramp. The collection of larval razorback sucker in Las Vegas Wash suggests that reproduction may have occurred upstream in the lotic portions of the wash. Furthermore, one sexually mature adult and the collection of larval razorback sucker occurred in the southeastern portion of Government Wash Cove, suggesting that there may have been additional, secondary spawning areas within Las Vegas Bay. The primary 2012–2013 field season spawning area was located 0.5 km southeast of the Las Vegas Wash inflow area along the southwestern shoreline of the bay. For the past 7 years, the primary razorback sucker spawning site has been in the same general vicinity, although it has shifted with fluctuating lake elevations (figure 14). Similar to the 2011–2012 field season, during the 2012–2013 field season, sonic-tagged razorback sucker were observed generally using the entire westernmost portion of Las Vegas Bay. Spawning activity primarily occurred along the western shorelines immediately adjacent to Las Vegas Wash where the majority of larval individuals was collected (figure 14). Despite a low trammel netting CPUE, successful spawning of razorback sucker was confirmed within the back portions of Las Vegas Bay, and razorback sucker habitat use appeared to be closely associated with shoreline habitats near the inflow of Las Vegas Wash.

As described in past annual reports (Welker and Holden 2003, 2004; Albrecht et al. 2005, 2006b; Shattuck et al. 2011), receding lake elevations resulted in eastward shifts of the primary Echo Bay spawning site. The Echo Bay spawning site for the 2012–2013 field season overlapped with the spawning area for the 2011–2012 field season (figure 15); however, the 2012–2013 primary spawning area in Echo Bay was more defined and located further east of the previous year's location. This spawning area definition was due in part to the direct observation of 12–20 reproductively ready razorback suckers in spawning aggregate towards the back of Echo Bay on February 6, 2013. Trammel netting collections of sexually mature and reproductively ready razorback sucker further validated this observation, and one sonic-tagged individual was contacted in the immediate area as well. Although larval razorback sucker collections were not as numerous as those in previous years (Shattuck et al. 2011; Albrecht et al. 2013), all collections occurred along the far western and northern shorelines of Echo Bay immediately adjacent to the boat ramp and as far as 0.6 km east along the northern shoreline (figure 15).

Of the three long-term monitoring sites in Lake Mead, the Muddy River/Virgin River inflow area has typically been the least productive with regard to larval razorback sucker collections (Albrecht et al. 2007, 2008a, 2010b, 2013; 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 Muddy River/Virgin River inflow area has not followed this generalized trend. However, during the 2012–2013 field season, a record number of larval razorback suckers were collected in the Muddy River/Virgin River inflow area and the spawning site designation was similar to that of the 2011–2012 field season (figure 16). The collection of numerous reproductively ready adult razorback suckers in 2013 signified that spawning was likely occurring there, and the overwhelming number of larval razorback sucker collected in the immediate area further defined the primary spawning site designation. The 2013 spawning site in the Muddy River/Virgin River inflow area was located approximately 3.2 km south of the Virgin River inflow/delta along the eastern shoreline of the Overton Arm (figure 16).

Age Determination

To date, a definitive age has been determined for 432 razorback suckers from long-term monitoring sites in Lake Mead (not including 25 individuals aged from the CRI [Kegerries and Albrecht 2013a]). In 2013, ages were obtained from 37 razorback suckers captured in trammel nets at long-term monitoring sites, while 1 individual was aged from the CRI (attachment 1 and figure 17) (Kegerries and Albrecht 2013a). The single CRI individual was unique: it was the smallest wild razorback sucker captured during the 17-year-long Lake Mead study (215 mm TL), and it was aged at 2 years old, making it one of the youngest fish aged to date (Kegerries and Albrecht 2013a). Conversely, the youngest razorback suckers aged from the long-term monitoring locations in 2013 included five individuals aged at 7 years old (2006 year-class), and were all sexually mature and ranged in size from 500 mm to 655 mm (TL) (attachment 1). The majority of fish aged from the long-term monitoring locations (86.8%, n = 33) ranged from 7 to 10 years old (2003–2006 year-classes), while the oldest razorback sucker aged during 2013 was a 17-year-old female (1996 year-class) with a TL of 692 mm (attachment 1).

To date, all fish aged have undergone back-calculation techniques, assigning them to year-classes (spanning approximately 1966–2011) (attachment 1). Until the last seven field seasons, the majority of aged fish were spawned during high lake elevations between 1978–1989 and 1997–1999 (figure 17). However, data to date clearly show Lake Mead razorback sucker recruitment occurring beyond 1999, which coincides with a steady decline of lake elevations during more recent study

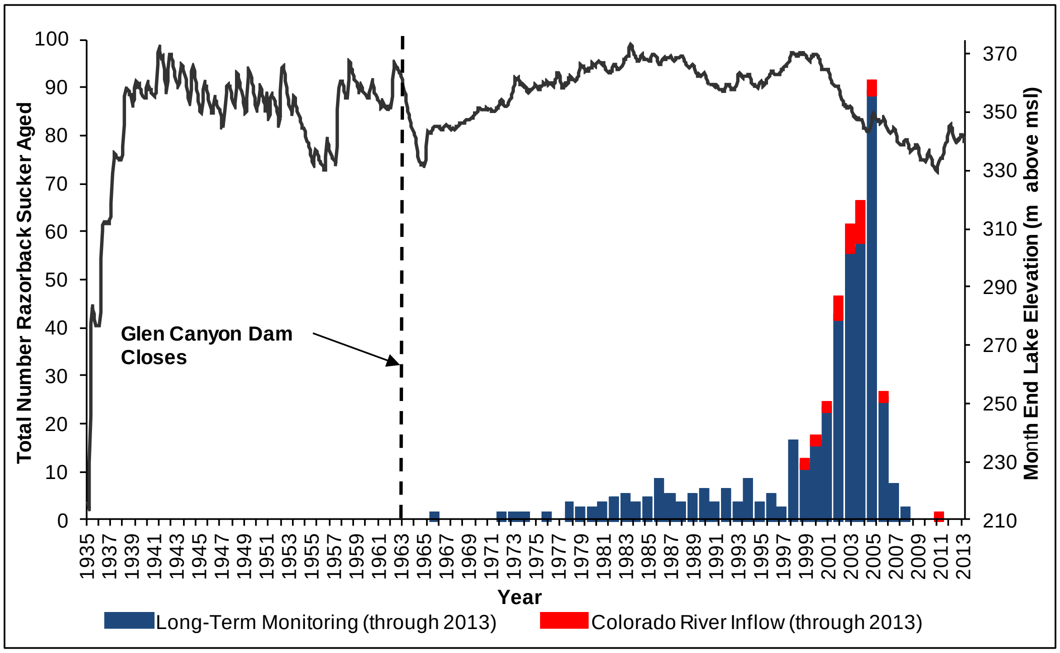

Figure 17.—Cumulative number of razorback suckers back-calculated to year spawned for individuals aged with corresponding Lake Mead month-end lake elevations in meters above mean sea level (msl), January 1935–June 2013. Blue bars denote individuals aged in long-term monitoring efforts, 1999–2013; red bars denote individuals aged in efforts at the Colorado River inflow area, 2010–2013 (Kegerries and Albrecht 2013a).

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, 2013; Kegerries et al. 2009; Shattuck et al. 2011). Based on the cumulative dataset, the largest number of individuals (321) was spawned from 2001 to 2006. Within that period, 91 individuals (including those from the CRI) were aged from the 2005 year-class alone, which exemplifies a pulse of natural recruitment for razorback sucker 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 nearly every year through at least 2008 (figure 17). Wild recruitment has now been positively documented though 2011, and it is anticipated that fish spawned and recruited from 2012 and 2013 will become susceptible to sampling gear in the near future (based on past experience, it typically takes 3–4 years for young razorback sucker to become readily susceptible to our sampling gear at the spawning areas).

Furthermore, ages were determined for three flannelmouth sucker and one razorback sucker *x* flannelmouth sucker hybrid captured at the Virgin River/Muddy River inflow area in 2013. The ages of these native fish consisted of a 2-year-old flannelmouth sucker (258 mm TL), a 6-year-old flannelmouth sucker (484 mm TL), and a 9-year-old individual (511 mm TL). These three flannelmouth suckers represent the year-classes of 2004, 2007, and 2011. A

495-mm TL razorback sucker *x* flannelmouth sucker hybrid was also aged and determined to be 7 years old (2006 year-class). This fish is the first razorback sucker *x* flannelmouth sucker hybrid from a long-term monitoring site that has been captured or aged.

Population Estimation

Using mark-recapture data from the period spanning 2011–2013, the combined Echo Bay and Muddy River/Virgin River inflow area estimate produced approximately 705 individuals with 95% confidence bounds of 491–1,056 (table 7). This estimate had the highest number of individuals as well as the most expansive confidence bounds. Including all new captures from Las Vegas Bay (n = 15), the combined long-term monitoring estimate produced approximately 632 individuals with 95% confidence bounds of 462–900 (table 7). Similarly, the lakewide estimate that included mark-recapture data from all long-term monitoring sites as well as the CRI produced approximately 597 individuals with 95% confidence bounds of 474–776 (table 7). Model ranking according to AICc weights and model likelihoods for estimates produced in MARK can be found in attachment 2.

Table 7.—Population estimates for razorback sucker in Lake Mead produced in the program MARK using mark-recapture data from 2011 to 2013

Estimate	Number of individuals (95% confidence limits)	Capture events	Capture probability
Echo Bay and Muddy River/Virgin River inflow area	705 (491–1,056)	37	0.0069
All long-term monitoring sites	632 (462–900)	37	0.0084
Lakewide	597 (474–776)	37	0.0115

DISCUSSION AND CONCLUSIONS

Long-term monitoring information collected during the 2012–2013 field season (17th field season) has expanded our knowledge of spawning behavior, habitat use, recruitment patterns, growth, and the demographics of razorback sucker populations in Lake Mead. Information has also been gained regarding the nature of stocked and wild fish interactions, population abundance, and razorback sucker response to changing lake elevations. Sonic telemetry, trammel netting, and larval collection data reaffirm the importance of Las Vegas Bay, Echo Bay, and the Muddy River/Virgin River inflow area to spawning razorback sucker in Lake Mead. To date, these data help demonstrate nearly annual recruitment and continued production of new, wild razorback sucker 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 2012–2013 field season (figure 2) and provided conditions similar to those observed during the 2006–2007 and 2007–2008 field seasons (Albrecht et al. 2007, 2008a). Instead of habitat being re-inundated and lake levels increasing, the 2012–2013 spawning period 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 2013 spawning season, razorback sucker reused some of their historical spawning locations (figures 14–16). It has been widely demonstrated that individuals do 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 Echo Bay during the 2013 spawning period that were tagged during previous field seasons. This subject is discussed further in the “Adult Sampling and Spawning Site Observations” section below.

In 2011, dramatic lake elevation increases were observed following a high-flow event in the Virgin River during late 2010 (Shattuck et al. 2011). This increase in discharge may have helped provide conditions for another strong year of razorback sucker recruitment, similar to the recruitment pulse observed in 2004–2005. It is hypothesized that these high-flow events help transport large amounts of nutrients, woody debris, and turbidity into the Muddy River/Virgin River inflow area, and subsequently into the Overton Arm of Lake Mead, possibly increasing available habitat and providing cover-related refuge for adults, juveniles, and larvae. Turbidity can also increase spatially in the Muddy River/Virgin River inflow area during these high flows, providing an additional form of cover for razorback sucker. Additionally, the distribution of such cover can often be increased by the common disturbance and mixing effects of high winds at Lake Mead. Such recruitment responses are not often observable until at least 2–3 years after they occur, as young razorback sucker in Lake Mead have been observed to require this amount of time (at a minimum) to grow and become susceptible to our gear (Albrecht et al. 2008b, 2013; Shattuck et al. 2011).

Sonic Telemetry

Sonic telemetry was a vital tool during the 2012–2013 field season, helping to define spawning sites, place trammel nets, and document lakewide movement.

Contact was maintained with all eight fish from the 2011 long-term monitoring tagging event, one fish from the 2010 CRI tagging event, and one fish from the 2012 juvenile tagging event; however, no individuals from the 2008 tagging event were contacted during the 2012–2013 field season, leaving a need for a new class of razorback sucker implanted with sonic transmitters. As was recommended in 2012 (Albrecht et al. 2013), using three to four wild razorback suckers captured from each long-term monitoring site may provide the best means of replacing these sonic-tagged individuals, while at the same time clarifying a number of questions regarding the differences between wild and stocked fish.

During the 2012–2013 field season, SURs were increasingly helpful tools 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 sites and helped account for individuals that have gone undetected for relatively longer expanses of time. Increases in future usage of SURs could aid in the efficient monitoring of locations outside of the established long-term monitoring areas and help describe new locations frequented by razorback sucker. Additionally, the use of SUR data, in conjunction with active sonic telemetry efforts, has led to a more complete timeline and visual representation of movement patterns throughout Lake Mead (figures 7–9).

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, cool winters) and during periods of environmental change (e.g., fluctuating lake elevations, high-flow events). Often it only takes one sonic-tagged individual to help locate other wild razorback sucker; such has been the case for the past 3 years in Echo Bay (Shattuck et al. 2011; Albrecht et al. 2013). One individual sonic tagged in 2011 and stocked into the Muddy River/Virgin River inflow area (code 555), which has typically been the sole sonic-tagged fish contacted in Echo Bay, has helped define the spawning site location and aided in the capture of additional razorback sucker (figures 5 and 11). This individual, amongst others, has also helped further demonstrate the connectivity between spawning sites throughout the Overton Arm (figures 5 and 6).

Conversely, although a number of adult sonic-tagged fish were regularly contacted in Las Vegas Bay during the 2012–2013 field season, all four wild razorback suckers were captured near one sonic-tagged individual, a wild 2012 sonic-tagged fish (code 222) (figures 4 and 10). As this individual was wild caught and the other sonic-tagged adults were from hatcheries or ponds, a potential lack of understanding of differences inherently found in stocked versus wild fish is highlighted. Having an opportunity to observe wild and stocked sonic-tagged fish throughout Lake Mead concurrently could help explain potential differences found in some of the sonic telemetry data collected through recent years, primarily for stocked sonic-tagged individuals.

Sonic-tagged individuals from the Muddy River/Virgin River inflow area helped illustrate the seasonal importance of areas in the Overton Arm during periods outside of the spawning season. During the 2012–2013 field season, a clear pattern of contacts was formed as adult sonic-tagged razorback sucker 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 (figures 6 and 8). 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. However, from October through April, it appears that razorback sucker congregate near the Muddy River/Virgin River inflow area (figures 6 and 8). Although, 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 (figures 6 and 8). Often the movements of these individuals spanned distances greater than 20 km during May through September (figures 6 and 8); this is similar to a pattern of movement seen in Las Vegas Bay, although distances between those contacts did not exceed 3 km (figures 4 and 8). Though no interbasin movement (e.g., between the CRI, Las Vegas Bay, and the Overton Arm) of sonic-tagged razorback sucker was observed during the 2012–2013 field season, past reports have shown that these long-distance movements are not uncommon and often occur during the summer (Albrecht et al. 2010c, 2013; Shattuck et al. 2011).

In addition to seasonal patterns of movement, sonic-tagged individuals throughout all long-term monitoring sites were contacted in habitat almost twice as deep during May – September (19.73 m ± 1.75 SE) when compared to depths at point of contact during October – April (10.52 m ± 0.99 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 during warmer months) and may explain why sonic-tagged individuals are not often contacted outside of Las Vegas Bay proper (figure 4). This pattern may also explain why sonic-tagged razorback sucker are only seasonally found in Echo Bay and why longer-distance movements are seen in the Overton Arm (figures 5 and 6). Echo Bay lacks the depth variability to provide year-round habitat and the bathymetry of the Muddy River/Virgin River inflow area, and Overton Arm appears to have a lower gradient, requiring longer-distance movements to locate seasonally desirable habitat (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.

The sonic telemetry portions of this monitoring study have also lent useful insight to other systems where razorback sucker are present and have provided an effective model to follow (e.g., use of sonic telemetry in the study of razorback sucker in Lake Powell [Francis et al. 2013]). As lake elevations appear to continue in variability (figure 2), it will be necessary to monitor changes in movement and habitat use to help identify important areas of Lake Mead throughout the year. Spawning sites continue to move in location interannually (figures 4–6), and sonic-tagged fish have been a key component in 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 2013, no individuals with current sonic tags were captured (table 3). This observation has been discussed in recent past reports (Shattuck et al. 2011; Albrecht et al. 2013). This potential caveat in capture efficiency of trammel netting underscores the elusiveness of razorback sucker and potentially supports the existence of more razorback sucker in Lake Mead than capture rates and population estimates suggest.

Adult Sampling and Spawning Site Observations

In summary, 649 unique individual razorback suckers have been identified at long-term monitoring sites during this 17-year study (1996–2013) by multiple agencies (BIO-WEST, NDOW, and USFWS). These unique individuals help comprise the 1,021 total captures in long-term monitoring, with a female to male sex ratio for all captured razorback sucker of 1:1.4 (339 females, 482 males), and a total of 88 captures of wild juvenile razorback sucker. Trammel netting results in 2013 documented the continued presence of wild adult razorback sucker, the majority of which were captured in the Muddy River/Virgin River inflow area (67%, $n = 40$). The presence of numerous new, wild fish in the Muddy River/Virgin River inflow area follows the trend noted in past reports in which high numbers of younger fish (≤ 7 years of age) have been observed (Albrecht et al. 2008a, 2013; 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 2013 compared with 2011 and 2012 (attachment 1). Additionally, eight razorback sucker year-classes were identified in 2013, spanning 1996–2006 (attachment 1 and figure 17). It also appears that the strong year-class from the 2004 to 2005 field season has recruited to the adult population, a finding made in past reports (Kegerries et al. 2009; Albrecht et al. 2010a, 2010b, 2010c, 2013; Shattuck et al. 2011). The capture of these younger fish demonstrates that natural recruitment of razorback sucker has continued at Lake Mead despite changing lake elevations. Though no juvenile razorback sucker were captured in long-term monitoring efforts during the 2012–2013 field season, the number of young individuals captured at or near spawning habitat during the spawning period 2008–2012 demonstrates a relatively high abundance of young razorback sucker in Lake Mead. It is not fully understood why catching juvenile fish has proven difficult and rather stochastic throughout the past 5 years. The difficulties of sampling this younger life stage have been discussed in Albrecht et al. (2006a, 2008b, 2013), and a specific study targeting this life stage is currently in progress and should help define juvenile razorback sucker habitat use (Shattuck et al., in prep.).

The number of razorback sucker captures in 2013 can be considered a success; however, the lower catch rates at many of the long-term monitoring sites are cause for more discussion (figure 13). As lake levels were at a 5-year high at the beginning of 2012 (figure 2), a large portion of shallow habitat unavailable in past years was newly inundated. The availability of this habitat coincided closely with the razorback sucker reproductive season in 2012, and the habitat was used frequently by sonic-tagged individuals (Albrecht et al. 2013). Though lake elevations began to decline again at the start of 2013, much of this inundated habitat was still being used by sonic-tagged razorback sucker as well as by new, wild fish. However, much like the netting difficulties experienced in 2012, the heavy cover these fish were associating with also made net placement difficult in 2013. Not only was the heavy inundated cover likely providing protection for razorback sucker using this habitat, it often prevented consistent net placement and made it nearly impossible for the trammel net to rest on the bottom. Thus, it is likely that the nets were not as efficient as in past efforts, particularly during low and declining lake elevation years (Kegerries et al. 2009; Shattuck et al. 2011). Another factor that may have led to lower capture rates in 2013 was the overwhelming abundance of nonnative fish in our gear, specifically gizzard shad. Though nets may not have been effective for bottom fishing, midwater captures contained enough gizzard shad to hypothetically load the nets and render them unavailable to capture other fishes. However, the immense presence of 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, Nevada Department of Wildlife, personal communication]).

Despite continued changes in lake elevations (figure 2) and subsequent changes in associated habitat and biota, successful razorback sucker spawning is still occurring in Lake Mead; it was documented at all of the long-term monitoring study sites in 2013. The 2013 primary spawning sites shifted only slightly from the previous year's spawning sites and appeared to align closely with sites designated under similar lake-level elevations (Albrecht et al. 2006b, 2007, 2008a, 2010b, 2013; Kegerries et al. 2009; Shattuck et al. 2011). In Las Vegas Bay and Echo Bay, spawning sites overlapped those designated in 2006 and 2012 (figures 14 and 15) (Albrecht et al. 2006b, 2013). However, the designated spawning site at the Muddy River/Virgin River inflow area overlapped the spawning sites of 2009 and 2012 (figure 16) (Kegerries et al. 2009; Albrecht et al. 2013). The difference in spawning site overlap at the Muddy River/Virgin River inflow area may be due to the nature of that particular site since the Overton Arm bathymetry is more gradual and may exhibit greater changes in inundation as lake levels increase and decrease. Additionally, as spawning sites in the Muddy River/Virgin River inflow area move further in location interannually than at any other long-term monitoring area (figure 6), sonic-tagged fish have closely followed those fluctuations. This poses interesting questions as to where some of these fish may spawn from year to year. Regardless, the continued reproductive activity proximal to historic spawning sites strengthens the idea that many razorback sucker return to the same spawning sites year after year (Tyus and Karp 1990).

The 2013 spawning site in Las Vegas Bay was more difficult to define, as has been the case in previous years (Shattuck et al. 2011; Albrecht et al. 2013). Although a number of sonic-tagged individuals frequented the suspected spawning site briefly, few sexually mature adults were collected ($n = 4$). 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 sucker 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. An equally likely scenario is that, in 2013, spawning occurred earlier than expected in Las Vegas Bay. The first larval razorback sucker was collected on February 4, 2013, approximately 2 weeks earlier than in 2011 and near the same time as the first collection in 2012 (Shattuck et al. 2011; Albrecht et al. 2013). Furthermore, this initial collection of larvae occurred nearly 2 months earlier than in the Muddy River/Virgin River inflow area (table 5). It should be noted that we did not initiate larval sampling until February 4, 2013, and larval fish were already present, which also suggests that successful spawning had already occurred. Anecdotally, the warmer water from Las Vegas Wash may play a significant role in cueing sexually ready razorback sucker to spawn earlier than at other lake locations. 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 2013 spawning site in Echo Bay was identified by direct visual observation of razorback sucker displaying spawning behavior. Larval fish collection (figure 15), adult fish collections (figure 11), and sonic-tagged fish locations (figure 5) confirmed this initial observation. In recent years, the Echo Bay spawning sites had been on the northern side of the bay and appeared to follow receding lake elevations; however, lake levels in 2013 resembled those in 2006 (Albrecht et al. 2006b, 2007). As such, razorback sucker in Echo Bay appeared to not only follow historic trends and return to the spawning site of years past but also expand their activity to include most of the western end of the bay. Additionally, in 2013, Echo Bay again contributed a substantial percentage (approximately 27%) of adult razorback sucker to the overall catch, many of which were relatively large ($\bar{x}$ = 630.8 mm TL) and relatively old ($\bar{x}$ = 12.9 years) individuals (attachment 1). These older fish helped define the Echo Bay spawning site and indicated that Lake Mead razorback sucker survive for substantial periods of time despite many potential stressors and causes of mortality (table 3 and attachment 1).

Similar to Echo Bay, the spawning site at the Muddy River/Virgin River inflow area in 2013 was defined based on a combination of larval collection data (figure 16), adult collections (figure 12), and sonic-tagged fish locations (figure 6). Sonic-tagged fish were contacted frequently in the 2009 and 2012 designated spawning area at the Muddy River/Virgin River inflow area (figure 6), and the placement of trammel nets near these sonic-tagged fish yielded high densities of adult razorback sucker exhibiting reproductive readiness (e.g., colored and tuberculated individuals freely giving milt or eggs). Although a number of reproductively ready adults were captured south of the 2013 spawning area near the 2011 spawning area at the Meadows, it is likely that these individuals were moving toward the 2013 spawning area. No larval razorback sucker were captured in the area following this occurrence, and no additional adults were captured in netting efforts in the following weeks. Unlike years past when razorback sucker larval collections were scant, larval catch rates in the 2013 designated spawning site were a record high for the Muddy River/Virgin River inflow area, which further aided in the identification of the spawning location for this long-term monitoring site.

As documented in previous reports (e.g., Shattuck et al. 2011, Albrecht et al. 2013), razorback sucker often utilize both the Muddy River/Virgin 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 sites while one wild individual tagged at the Muddy River/Virgin River inflow area moved to Echo Bay and then onto the CRI (Kegerries et al. 2009; Kegerries and Albrecht 2013b). Past monitoring efforts in the northernmost portions of Lake Mead, near the Muddy River/Virgin River inflow area, have provided evidence that this spawning aggregate is an extension of the Echo Bay spawning population (Albrecht et al. 2008b). 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 number of new recruits in this area of the lake makes continued investigation of this population and area imperative.

Data from 2013 suggest that the Muddy River/Virgin River inflow area spawning aggregate is one of the largest in Lake Mead (table 7, figure 13). Nearly 67% of the razorback sucker captured in 2013 came from the

Muddy River/Virgin River inflow area with new, wild individuals comprising the majority of the fish captured (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 sucker, 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 17 field seasons. 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 physical, chemical, and biological changes over time to better understand and document razorback sucker recruitment success.

Larval Sampling

Larval razorback sucker were again captured at each of the previously documented spawning sites in Lake Mead (i.e., Las Vegas Bay, Echo Bay, and the Muddy River/Virgin River inflow area) during the 2013 spawning period. Results from the 2012–2013 field season were characterized by all-time high capture rates of larval fish at the Muddy River/Virgin River inflow area, near all-time high capture rates of larval fish at Las Vegas Bay, and one of the lowest capture rates of larval fish at Echo Bay (table 6) (Albrecht et al. 2008a, 2010b, 2013; 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 (figure 17), there is reason to be hopeful for the success of the 2013 year-class.

In 2013, Las Vegas Bay experienced the second highest larval catch rate observed since 2006 (table 6). Interestingly, this near-high catch rate follows the near-low catch rate seen in 2012 despite equally low captures of reproductively ready adult razorback suckers (Albrecht et al. 2013). Although the majority of larval collections occurred along the southern shoreline at the westernmost extent of Las Vegas Bay, several larval razorback suckers were collected upstream of the Las Vegas Wash inflow near the Las Vegas Bay boat ramp (figure 14). This collection, albeit somewhat anecdotal due to the trial nature of larval light traps in long-term monitoring study, indicates that razorback suckers likely spawned upstream within the Las Vegas Wash proper. Though past studies have shown intermittent usage of Las Vegas Wash by adult razorback sucker (e.g., Shattuck et al. 2011, Albrecht et al. 2013), it was unclear on whether reproductive activity took place in this riverine environment. This reproductive confirmation, in conjunction with the consistently early collections of larval razorback sucker near the Las Vegas Wash inflow (Shattuck et al. 2011; Albrecht et al. 2013), may warrant further investigation to determine the potential extent and timing of reproductive activity in Las Vegas Wash proper. Additionally, further study of the potential dynamics in Las Vegas Bay could ultimately lead to a better understanding of razorback sucker recruitment and, more specifically, the role inflow areas may play in that regard.

Larval sampling in Echo Bay resulted in the lowest larval catch rate observed at this location since 2006 and the lowest CPM rate among the long-term monitoring sites in 2013 (table 6). The low number of larval razorback sucker captured at this site was disappointing, given the observed reproductive activity of adult razorback sucker and the abundance of captures in early trammel netting efforts (figure 11). 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 2006–2007 and 2007–2008 [Albrecht et al. 2008a, 2010b]), larval abundances are expected to rebound as they have similarly done 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, it is clear that the razorback sucker aggregate at this long-term monitoring site spawned successfully once again.

Larval catch rates in the Muddy River/Virgin River inflow area were at an all-time high during 2013, where CPM rates nearly doubled the past recorded high for this long-term monitoring site (table 6). Typically in past years, larval razorback sucker catch rates at this location have been the lowest of the long-term monitoring areas (Albrecht et al. 2010b; Shattuck et al. 2011); however, in a period of approximately 2 weeks, a relatively high number of larval razorback sucker were captured in the immediate vicinity of numerous captures of reproductively ready razorback sucker adults (figures 12 and 16). One potential explanation for the higher larval CPM values from the Muddy River/Virgin River inflow area in 2013 may be the lack of high winds. In the past, high winds and associated wave action were 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, 2013; 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). Though anecdotal, the relatively calm spring at the Muddy River/Virgin River inflow area in 2013 may have resulted increased larval catch rates possibly due to less dispersal and potentially less mortality under these conditions; however, further research within this area is warranted to help determine the factors that may be limiting sampling efforts and/or observed larval catch rates.

As in past field seasons, BIO-WEST teamed with biologists from NDOW and Reclamation to collect additional larval razorback sucker for future repatriation efforts. These fish are being held and reared by NDOW, and BIO-WEST continues to work with NDOW, Reclamation, and the LMWG to design experimental stocking procedures and monitoring strategies for these valuable fish. Finally, future collection of detailed physiochemical and limnological data could help in understanding differences in larval fish production which, in turn, should provide important and additional data pertaining to Lake Mead razorback sucker recruitment.

Aspects of Lake Mead Recruitment

The continued pulses of new, young razorback sucker captures at all Lake Mead sampling locations in recent years support the concept that the only known, sustainable, and largely wild population of razorback sucker remains at Lake Mead (Albrecht et al. 2006b). This unexpected initiation of Lake Mead razorback sucker recruitment has been attributed to a change in the management of Lake Mead. From the 1930s to 1963, Lake Mead was either filling (a time when initial recruitment likely occurred and created the original lake population of razorback 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 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 sucker may inhabit. Furthermore, 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 sucker 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. Furthermore, it has been accepted for years that turbidity plays a role in the susceptibility of young razorback sucker 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. This is especially interesting, given the possibility that some catostomid fishes may not spawn every year (Geen et al. 1966; Perkins and Scoppettone 2000).

Data collected during recent spawning periods suggest that turbidity may be much more important for razorback sucker recruitment in Lake Mead than previously thought, at least under conditions imposed by low lake elevations (Albrecht et al. 2008b). Inflow habitats have been noted to provide unique conditions that can support large numbers of species and life stages through habitat diversity and associated increases in niche availability (Kaemingk et al. 2007); thus, it is not surprising that a pulse of recruitment that coincides with lake condition and water year has been observed at some of the inflow areas in Lake Mead (Shattuck et al. 2011). This pulse of recruitment is best illustrated in the similarities between 2005 and 2011 with regard to flood-related cover influxes and lake elevation increases via the Virgin and Colorado rivers (figure 17) (Shattuck et al. 2011). The 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, U.S. Geological Survey, personal communication; Knecht and Ward 2012). Additionally, high-flow events that bring woody debris and fine sediments into Lake Mead may play a large 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 sucker. These parameters need to be measured consistently so comparisons between years or lake elevations can be made in the future.

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). 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, we observed this during the course of our 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 and provide cover for early life stages of razorback sucker. Hence, cover in the form of turbidity increases, ultimately leading to increased recruitment. Because data obtained from 2007 to 2013 show that pulses in razorback sucker recruitment are possible at both low (e.g., 2002–2006) 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.

Growth and Aging

Through 2013, 432 razorback suckers from long-term monitoring sites 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) (figure 17) and is further evident as 35% of the fish aged in 2013 were 7–9 years old. 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. Further evidence of a younger, quick-growing population is the relatively high growth rate (14.8 mm per year in 2013) in Lake Mead. In contrast, other populations of razorback sucker 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 per year).

Population Estimation

Population estimates produced in the program MARK for the period of 2011–2013 yielded similar abundances to those estimated for the 2010–2012 period (Albrecht et al. 2013). Though the 2013 population estimate for the combined Echo Bay and Muddy River/Virgin River inflow area (table 7) was slightly higher than the previous year's estimate (589 in 2012), the combined long-term monitoring estimate (table 7) was slightly lower than the previous year's estimate (695 in 2012) (Albrecht et al. 2013). The lakewide estimate (table 7) was essentially the same between the two years (a difference of one individual), and the confidence bounds were much narrower, perhaps suggesting a more reliable estimate. 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 (Albrecht et al. 2008a). 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 sucker are a long-lived, slow-growing species, where 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 sites that have demonstrated connectivity, or by constructing a combined dataset, immigration and emigration are accounted for, and those assumptions are somewhat mitigated. For example, Echo Bay and the Muddy River/Virgin River inflow area were combined due to movement of individuals between those two sites. Furthermore, the combined lakewide population estimate includes efforts from the CRI because of confirmed fish movement between the CRI and long-term monitoring sites. 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.

Conclusions

The 2012–2013 field season was exceptional in that we met all long-term monitoring objectives. Multiple life stages of razorback sucker 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, we remain hopeful and positive 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 2013. As reported by Shattuck et al. (2011), we remain particularly positive regarding the 2011 year-class of razorback sucker, which appears to have been subjected to conditions similar to those experienced by the relatively strong 2005 year-class (figure 17). With capture of larval fish at all known spawning sites in 2013, the status of the Lake Mead razorback sucker remains optimistic. While there is concern for the Las Vegas Bay and Echo Bay spawning aggregates at this time, we remind readers that CPUE values for both larval sampling and trammel netting remain within the range of values previously reported from these locations. This underscores the importance of long-term monitoring and long-term datasets. When this information is coupled with data pertaining to growth, age structure, and population estimates, the population appears generally young, self-sustaining, and perhaps even growing. 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 how to promote this unique trend in locations throughout the Colorado River basin. Hence, we reiterate the need for future research to understand how and why razorback sucker are able to naturally maintain a population despite fluctuating habitat conditions.

2013–2014 Work Plan (Long-Term Monitoring)

Specific Objectives for the 18th Field Season

1. Continue data collection, including tracking the remaining active, sonic-tagged, pond-reared razorback sucker 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 investigation of the Muddy River/Virgin 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.

   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 new, wild, juvenile, and adult razorback sucker. Data stemming from continued monitoring will further assist us with understanding the size and habitat use of the populations of razorback sucker in Lake Mead, documenting the exchange of fish between sites (including fish moving between the long-term sites and the CRI and lower Grand Canyon), identifying problems or habitat shifts associated with the known spawning aggregates, and elucidating recruitment patterns in Lake Mead. Methods will 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 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. This comprehensive effort should 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 the LCR MSCP more easily achieve its overall goals and objectives related to conservation of razorback (and flannelmouth) sucker(s).

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 and lower Grand Canyon areas when/as applicable. In 2010, efforts were undertaken to

document the presence or absence of razorback sucker at the CRI. Through the capture of wild, ripe adult and larval razorback sucker, 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). Not only were wild fish documented using this new study area, but sonic telemetry efforts in this portion of Lake Mead have located sonic-tagged fish originating from the long-term monitoring study areas and documented sonic-tagged individuals utilizing the Colorado River proper and moving into the lower Grand Canyon (Kegerries and Albrecht 2013a, 2013b). Thus, the potential exists for continued, perhaps increased, exchange of sonic-tagged razorback sucker (and other native suckers) between different areas of Lake Mead. Furthermore, it will be important to ascertain whether any of the PIT-tagged fish captured during long-term monitoring trammel netting efforts are recaptured at the CRI (or vice versa). Coordination and collaboration between field crews will continue, as necessary, to achieve the best possible research and monitoring system for more holistically understanding Lake Mead razorback sucker 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 Long-term Management Plan for the Conservation of Razorback Sucker in Lake Mead, Nevada and Arizona (Albrecht et al. 2009). Ultimately, it is important to investigate and try to understand why Lake Mead razorback sucker are recruiting despite the nonnative fish pressures and habitat modifications that are common throughout the historical range of this species. Albrecht et al. (2013) presents the latest developments in achieving this goal and the results of a pilot study conducted in 2012. Additional efforts pertaining to the early life stages of Lake Mead razorback sucker are currently underway, and results will be reported during the upcoming year.

6. Sonic tag wild-caught razorback sucker 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 sucker. 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. This was also a recommendation in Albrecht et al. (2013), but at that time, sufficient numbers of active, sonic-tagged fish remained. As noted above, we

suggest that three to four wild razorback suckers from each long-term monitoring location be implanted with new sonic transmitters during the 2013–2014 field season. This will ensure that we can maintain future efforts that 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 sucker.

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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

Date collected	Total length (mm)	Age	Presumptive year spawned
Las Vegas Bay			
5/10/1998	588	10[a]	1987
12/14/1999	539	13	1986
12/14/1999	606	17+	1979–1982
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[a]	1982
3/25/2002	576	20	1982
5/7/2002	641	15	1986
6/7/2002	407	6	1995
6/7/2002	619	20[a]	1982
6/7/2002	642	20[a]	1982
12/3/2002	354	4	1998
12/6/2002	400	4	1998
12/6/2002	376	4	1998
12/19/2002	395	4	1998
1/7/2003	665	16	1986
1/22/2003	394	4	1998
2/5/2003	385	4	1998
2/18/2003	443	5	1997
3/4/2003	635	19	1983
3/20/2003	420	4	1998
4/8/2003	638	21[a]	1982
4/17/2003	618	10	1992
4/22/2003	650	20–22	1980–1982
5/4/2003	415	3+[b]	1999

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

Date collected	Total length (mm)	Age	Presumptive year spawned
Las Vegas Bay (continued)			
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

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

Date collected	Total length (mm)	Age	Presumptive year spawned
Las Vegas Bay (continued)			
2/12/2008	490	3	2005
2/12/2008	430	4	2004
2/12/2008	379	4	2004
2/12/2008	399	4	2004
2/12/2008	430	4	2004
2/12/2008	413	4	2004
2/12/2008	554	9	1999
2/12/2008	426	9	1999
2/18/2008	385	3	2005
2/25/2008	605	6	2002
2/25/2008	655	36	1972
4/3/2008	468	4	2004
4/3/2008	619	7	2001
4/3/2008	640	10	1998
4/3/2008	560	11	1997
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

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

Date collected	Total length (mm)	Age	Presumptive year spawned
Las Vegas Bay (continued)			
2/24/2009	446	6	2003
3/3/2009	416	4	2005
3/3/2009	565	8	2001
3/3/2009	431	5	2004
3/3/2009	340	5	2004
3/3/2009	539	8	2001
3/3/2009	521	8	2001
3/3/2009	419	6	2003
3/3/2009	535	6	2003
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

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

Date collected	Total length (mm)	Age	Presumptive year spawned
3/24/2011	390	3	2008
3/29/2011	379	6	2005
3/29/2011	346	4	2007
3/29/2011	376	3	2008
2/5/2013	510	10	2003
2/19/2013	512	7	2006
2/26/2013	500	7	2006
4/16/2013	561	8	2005
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[a]	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

Date collected	Total length (mm)	Age	Presumptive year spawned
Echo Bay (continued)			
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[†]	2001

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

Date collected	Total length (mm)	Age	Presumptive year spawned
Echo Bay (continued)			
3/24/2010	451	4	2006
3/24/2010	465	5	2005
3/24/2010	466	5	2005
4/8/2010	470	5	2005
4/8/2010	540	8	2002
4/22/2010	538	7	2003
4/22/2010	489	8	2002
4/22/2010	460	9	2001
2/9/2011	529	7	2004
2/9/2011	524	7	2004
2/24/2011	555	7	2004
3/2/2011	513	6	2005
4/7/2011	533	7	2004
4/7/2011	522	7	2004
4/19/2011	537	6	2005
4/19/2011	540	7	2004
4/19/2011	515	6	2005
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

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

Date collected	Total length (mm)	Age	Presumptive year spawned
Muddy River/Virgin River inflow area			
2/23/2005	608	6	1998
2/22/2006	687	33[c]	1973
2/22/2007	452	4	2003
2/22/2007	542	5	2002
2/22/2007	476	5	2002
2/22/2007	459	4	2003
2/22/2007	494	5	2002
3/1/2007	477	5	2002
3/1/2007	512	4	2003
3/8/2007	463	5	2002
3/8/2007	455	4	2003
3/15/2007	516	4	2003
4/3/2007	508	4	2003
4/11/2007	498	7	2000
2/27/2008	465	4	2004
2/27/2008	670	20	1988
3/25/2008	530	6	2002
3/25/2008	271	2[e]	2006
3/26/2008	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

Date collected	Total length (mm)	Age	Presumptive year spawned
Muddy River/Virgin River inflow area (continued)			
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

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

Date collected	Total length (mm)	Age	Presumptive year spawned
Muddy River/Virgin River inflow area (continued)			
2/17/2010	479	7	2003
2/17/2010	425	7	2003
2/17/2010	483	7	2003
2/24/2010	234	4	2006
3/17/2010	477	4	2006
3/17/2010	465	5	2005
3/17/2010	485	5	2005
3/17/2010	499	6	2004
3/17/2010	491	6	2004
3/17/2010	600	9	2001
3/18/2010	452	5	2005
3/18/2010	473	5	2005
3/24/2010	485	5	2005
2/1/2011	601	7	2004
2/1/2011	571	6	2005
2/1/2011	556	7	2004
2/1/2011	586	6	2005
2/1/2011	506	8	2003
2/1/2011	572	8	2003
2/1/2011	500	6	2005
2/22/2011	501	7	2004
2/22/2011	534	6	2005
2/22/2011	506	6	2005
2/22/2011	508	6	2005
2/22/2011	524	7	2004
2/22/2011	517	8	2003
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

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

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

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

Date collected	Total length (mm)	Age	Presumptive year spawned
Muddy River/Virgin River inflow area (continued)			
2/1/2012	525	12	2000
2/7/2012	525	9	2003
2/8/2012	536	7	2005
2/8/2012	501	9	2003
2/8/2012	623	12	2000
2/21/2012	566	10	2002
2/21/2012	590	10	2002
3/13/2012	555	9	2003
3/13/2012	521	9	2003
3/13/2012	618	9	2003
3/13/2012	610	12	2000
3/14/2012	539	7	2005
3/14/2012	530	9	2003
3/15/2012	546	7	2005
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

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

Date collected	Total length (mm)	Age	Presumptive year spawned
Muddy River/Virgin River inflow area (continued)			
3/21/2013	551	8	2005
3/21/2013	616	10	2003
3/21/2013	605	10	2003
3/21/2013	629	9	2004
3/21/2013	570	9	2004
3/21/2013	578	9	2004
3/21/2013	577	10	2003
3/21/2013	621	14	1999
3/21/2013	639	9	2004
3/27/2013	539	8	2005
3/27/2013	580	10	2003
4/3/2013	554	8	2005
4/3/2013	542	7	2006
4/10/2013	560	10	2003
4/10/2013	598	9	2004
Colorado River inflow area			
4/20/2010	563	6	2004
4/20/2010	508	6	2004
4/20/2010	568	11	1999
2/8/2011	594	8	2003
3/10/2011	659	11	2000
3/24/2011	584	9	2002
3/24/2011	530	7	2004
3/24/2011	545	6	2005
4/19/2011	636	9	2002
4/20/2011	570	10	2001
1/26/2012	602	8	2004
2/21/2012	604	10	2002
3/1/2012	546	8	2004
3/1/2012	559	9	2003
3/6/2012	535[f]	11	2001
3/6/2012	573	6	2006
3/6/2012	572	7	2005
3/8/2012	557	8	2004
3/20/2012	630	10	2002

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

Date collected	Total length (mm)	Age	Presumptive year spawned
Colorado River inflow area (continued)			
3/20/2012	548	8	2004
3/21/2012	571	9	2003
3/28/2012	572	8	2004
4/3/2012	602	9	2003
4/24/2012	555[d]	9	2003
3/5/2013	215	2	2011

[a] Fish stocked from Echo Bay larval fish captured in 1999 and raised at Nevada Department of Wildlife Lake Mead Fish Hatchery.
[b] Fish stocked from Floyd Lamb Park ponds (1982 Dexter National Fish Hatchery cohort placed in Floyd Lamb Park ponds in 1984).
[c] Fish was aged at 33 years, plus or minus 2 years.
[d] Fish stocked from Floyd Lamb Park ponds, sonic tagged.
[e] Fish was a mortality. Found dead in net.
[f] Fish stocked from Floyd Lamb Park ponds (from an unknown 2001–2003 cohort stocking event).

ATTACHMENT 2

Razorback Sucker Population Estimate – Model Selection Summary

Table 2-1.—Model selection summary of population estimates for razorback sucker in Lake Mead produced in the program MARK using mark-recapture data from 2011 to 2013

Model[1]	AICc[2]	Delta AICc[3]	AICc weight[4]	Model likelihood[5]	Number of parameters[6]	Deviance[7]
Echo Bay and Muddy River/Virgin River inflow area						
π(.)ρ(.)N(.)	101.9676	0.0000	0.1828	1.0000	2	313.2550
π(.)ρ(.)N(t)	101.9676	0.0000	0.1828	1.0000	2	313.2550
π(t)ρ(.)N(.)	101.9676	0.0000	0.1828	1.0000	2	313.2550
π(t)ρ(.)N(t)	101.9676	0.0000	0.1828	1.0000	2	313.2550
π(.)ρ(t)N(.)	103.9696	2.0020	0.0672	0.3675	3	313.2550
π(.)ρ(t)N(t)	103.9696	2.0020	0.0672	0.3675	3	313.2550
π(t)ρ(t)N(.)	103.9696	2.0020	0.0672	0.3675	3	313.2550
π(t)ρ(t)N(t)	103.9696	2.0020	0.0672	0.3675	3	313.2550
Long-term monitoring sites						
π(.)ρ(.)N(.)	135.8719	0.0000	0.1828	1.0000	2	320.6557
π(.)ρ(.)N(t)	135.8719	0.0000	0.1828	1.0000	2	320.6557
π(t)ρ(.)N(.)	135.8719	0.0000	0.1828	1.0000	2	320.6557
π(t)ρ(.)N(t)	135.8719	0.0000	0.1828	1.0000	2	320.6557
π(.)ρ(t)N(.)	137.8738	2.0020	0.0672	0.3675	3	320.6557
π(.)ρ(t)N(t)	137.8738	2.0020	0.0672	0.3675	3	320.6557
π(t)ρ(t)N(.)	137.8738	2.0020	0.0672	0.3675	3	320.6557
π(t)ρ(t)N(t)	137.8738	2.0020	0.0672	0.3675	3	320.6557
Lakewide						
π(.)ρ(.)N(.)	200.8315	0.0000	0.1828	1.0000	2	427.0219
π(.)ρ(.)N(t)	200.8315	0.0000	0.1828	1.0000	2	427.0219
π(t)ρ(.)N(.)	200.8315	0.0000	0.1828	1.0000	2	427.0219
π(t)ρ(.)N(t)	200.8315	0.0000	0.1828	1.0000	2	427.0219
π(.)ρ(t)N(.)	202.8330	2.0015	0.0672	0.3675	3	427.0219
π(.)ρ(t)N(t)	202.8330	2.0015	0.0672	0.3675	3	427.0219
π(t)ρ(t)N(.)	202.8330	2.0015	0.0672	0.3675	3	427.0219
π(t)ρ(t)N(t)	202.8330	2.0015	0.0672	0.3675	3	427.0219

[1] *π* = Probability that the individual occurs in the mixture. (.) = Constant, *ρ* = Capture probability, *N* = Abundance estimate, and (*t*) = Time varying.
[2] Adjusted Akaike's Information Criterion (AICc) adjusted for small sample size bias.
[3] AICc minus the minimum AICc.
[4] Ratio of delta AICc relative to entire set of candidate models.
[5] Ratio of AICc weight relative to AICc weight of best model.
[6] Number of parameters.
[7] Log-likelihood of model minus log-likelihood of the saturated model (Zelasko et al. 2011).