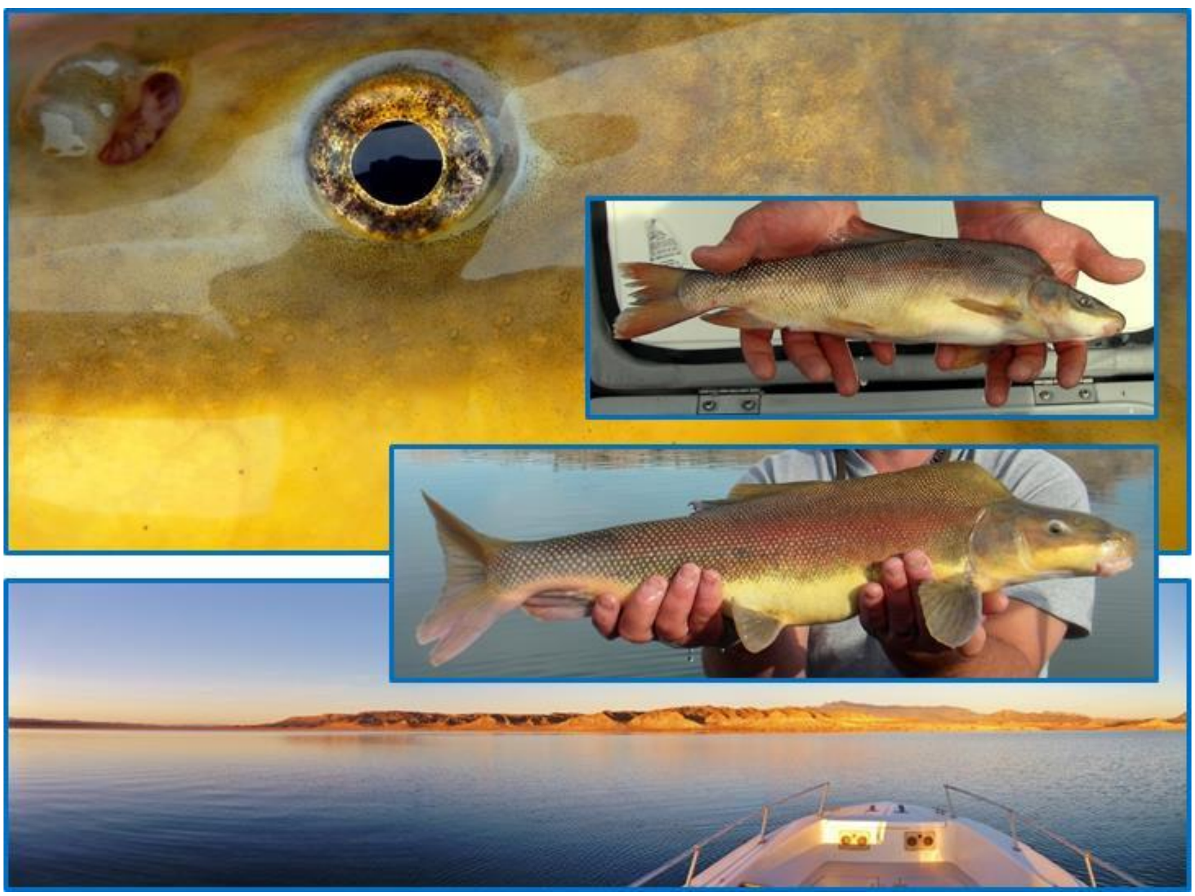
Lower Colorado River Multi-Species Conservation Program

Balancing Resource Use and Conservation

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

2011–2012 Annual Report



February 2013

Lower Colorado River Multi-Species Conservation Program
Steering Committee Members

Federal Participant Group

Bureau of Reclamation
U.S. Fish and Wildlife Service
National Park Service
Bureau of Land Management
Bureau of Indian Affairs
Western Area Power Administration

Arizona Participant Group

Arizona Department of Water Resources
Arizona Electric Power Cooperative, Inc.
Arizona Game and Fish Department
Arizona Power Authority
Central Arizona Water Conservation District
Cibola Valley Irrigation and Drainage District
City of Bullhead City
City of Lake Havasu City
City of Mesa
City of Somerton
City of Yuma
Electrical District No. 3, Pinal County, Arizona
Golden Shores Water Conservation District
Mohave County Water Authority
Mohave Valley Irrigation and Drainage District
Mohave Water Conservation District
North Gila Valley Irrigation and Drainage District
Town of Fredonia
Town of Thatcher
Town of Wickenburg
Salt River Project Agricultural Improvement and Power District
Unit “B” Irrigation and Drainage District
Wellton-Mohawk Irrigation and Drainage District
Yuma County Water Users’ Association
Yuma Irrigation District
Yuma Mesa Irrigation and Drainage District

Other Interested Parties Participant Group

QuadState Local Governments Authority
Desert Wildlife Unlimited

California Participant Group

California Department of Fish and Wildlife
City of Needles
Coachella Valley Water District
Colorado River Board of California
Bard Water District
Imperial Irrigation District
Los Angeles Department of Water and Power
Palo Verde Irrigation District
San Diego County Water Authority
Southern California Edison Company
Southern California Public Power Authority
The Metropolitan Water District of Southern California

Nevada Participant Group

Colorado River Commission of Nevada
Nevada Department of Wildlife
Southern Nevada Water Authority
Colorado River Commission Power Users
Basic Water Company

Native American Participant Group

Hualapai Tribe
Colorado River Indian Tribes
Chemehuevi Indian Tribe

Conservation Participant Group

Ducks Unlimited
Lower Colorado River RC&D Area, Inc.
The Nature Conservancy

Lower Colorado River Multi-Species Conservation Program

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

2011–2012 Annual Report

Prepared by:

Brandon Albrecht, Zachary Shattuck, and Ron J. Rogers
BIO-WEST, Inc.
1063 West 1400 North
Logan, Utah 84321-2291

Lower Colorado River
Multi-Species Conservation Program
Bureau of Reclamation
Lower Colorado Region
Boulder City, Nevada
http://www.lcrmscp.gov

February 2013

Albrecht, B., Z. Shattuck, and R.J. Rogers. 2013. Razorback Sucker (*Xyrauchen texanus*) Studies on Lake Mead, Nevada and Arizona, 2011–2012 Annual Report. Submitted to the Bureau of Reclamation, Boulder City, Nevada, by BIO-WEST, Inc., Logan, Utah.

ACRONYMS AND ABBREVIATIONS

AGFD	Arizona Game and Fish Department
AICc	corrected Akaike's information criterion
BIO-WEST	BIO-WEST, Inc.
CCA	canonical correspondence analysis
CI	confidence interval
CJS	Cormack-Jolly-Seber
cm	centimeter(s)
CPM	catch per minute
CPUE	catch per unit effort
CRI	Colorado River inflow
DO	dissolved oxygen
FL	fork length
ft	foot/feet
ft AMSL	feet above mean sea level
ft^3/s	cubic feet per second
g	gram(s)
GPS	Global Positioning System
in	inch(es)
km	kilometer(s)
LCR MSCP	Lower Colorado River Multi-Species Conservation Program
LMWG	Lake Mead Interagency Work Group
m	meter(s)
mi	mile(s)
mm	millimeter(s)
MS-222	tricaine methanesulfonate
NDOW	Nevada Department of Wildlife
NTU	nephelometric turbidity unit(s)
PCA	principal component analysis
PIT	passive integrated transponder
Reclamation	Bureau of Reclamation
SE	standard error
SL	standard length
SNWA	Southern Nevada Water Authority
SUR	submersible ultrasonic receiver
TDS	total dissolved solids
TL	total length
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey

Symbols

φ	apparent survival
°C	degrees Celsius
°F	degrees Fahrenheit
>	greater than
<	less than
≤	less than or equal to
%	percent
ρ	recapture

CONTENTS

Page

Page

Tables

Figures

Figures

Figure Page

Attachments

Attachment

EXECUTIVE SUMMARY

In 1996, the Southern Nevada Water Authority (SNWA) and Colorado River Commission of Nevada, in cooperation with the Nevada Department of Wildlife (NDOW), initiated a study to develop information about the Lake Mead razorback sucker (*Xyrauchen texanus* [Abbott]) population. BIO-WEST, Inc. (BIO-WEST), under contract with the SNWA, designed the study and had primary responsibility for 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) provided funding to continue long-term monitoring efforts and initiate a pilot study for juvenile razorback suckers in Lake Mead. As such, information and observations from the 16th year (2011–12) of this long-term monitoring study are provided in chapter 1, while information gathered and obtained during the pilot study pertaining to juvenile razorback suckers is included in chapter 2. Readers interested in the 2012 results from the Colorado River inflow (CRI) area should consult Kegerries and Albrecht (2013), which provides information on those efforts and serves as a companion report to this document.

During the 16th field season, the habitat use and movements of 14 sonic-tagged fish were monitored, which resulted in 152 total contacts. Five of these fish were from the 2008 tagging event, one fish was from the 2010 tagging event at the CRI area, and the other eight fish were from the 2011 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 from 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 area, 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 continued for juvenile (sexually immature razorback suckers) and adult fish during the spawning period. Fifty-three razorback suckers—2 from Las Vegas Bay, 18 from Echo Bay, and 33 from the Muddy River/Virgin River inflow area—were captured during the 2012 spawning period. Interestingly, one of the two razorback suckers collected at Las Vegas Bay was another rare, juvenile individual. Of the 53 total razorback suckers collected, 20 were recaptured fish. The capture of 33 new wild razorback suckers at the Muddy River/Virgin River inflow area, a highlight of the 16th field season, suggests the continued importance of the Muddy River/Virgin River inflow area of Lake Mead for razorback sucker production and recruitment.

Pertaining to the juvenile pilot study, a single, wild razorback sucker from Las Vegas Bay was captured and implanted with a sonic tag during long-term monitoring efforts. This particular young fish provided much of the information on where sampling for this life stage was conducted during the 2012 pilot study (chapter 2). In addition, BIO-WEST worked collaboratively with NDOW biologists to implant three additional juvenile fish originating from Center Pond (Overton Wildlife Management Area) with sonic tags. These young fish were also released into Las Vegas Bay in an effort to increase the number of sonic-tagged, juvenile razorback sucker present in Las Vegas Bay for pilot study purposes.

Average annual growth during this field season, as determined from 17 recaptured fish, was 16.8 millimeters/year. Growth rates of Lake Mead razorback suckers 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 35 razorback suckers for age determination during the 16th field season which, when combined with the 360 fish aged during previous field seasons, brings the total number of fish aged during the study to 395. Of particular interest is the continued documentation of recent (2000–2008) recruitment (Shattuck et al. 2011). 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 2012, 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 2004–05. 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 suckers in Lake Mead. Chapter 2 provides more specific information about this as well as an approach for understanding why, how, and where Lake Mead razorback suckers are able to continue to recruit.

Larval razorback suckers were again documented in all study locations in 2012 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 suckers 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 2011–12 field season, primary spawning sites were identified in all long-term monitoring sites. 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 for all three of the long-term monitoring sites. Additionally, spawning near the Muddy River/Virgin River inflow area was again successfully documented in 2012. For the third 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 2012 and in 2013, general research for the 2013 field season includes four main objectives: continuing to monitor razorback suckers at the three main study areas; continuing to age individual razorback suckers from Lake Mead; continuing to study juvenile razorback sucker habitat use throughout the long-term monitoring sites of Lake Mead; and maintaining sonic-tagged fish presence as needed.

General Introduction

The razorback sucker (*Xyrauchen texanus* [Abbott]) is one of four endemic, large-river fish species (the others are Colorado pikeminnow [*Ptychocheilus lucius*], bonytail chub [*Gila elegans*], and humpback chub [*Gila cypha*]) of the Colorado River basin presently considered endangered by the U.S. Department of the Interior (U.S. Fish and Wildlife Service [USFWS] 1991). Historically widespread and common throughout the larger rivers of the basin (Minckley et al. 1991), the razorback sucker's distribution and abundance have been greatly reduced. One of the major factors causing the decline of razorback suckers, and other large-river fishes, 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 suckers persisted in several reservoirs constructed in the Lower Colorado River Basin; however, these populations consisted primarily of adult fish that apparently recruited during the first few years of reservoir formation. The population of long-lived adults then disappeared 40–50 years following reservoir creation and the initial recruitment period (Minckley 1983). The largest reservoir population, estimated at 75,000 individuals in the 1980s, occurred in Lake Mohave, Arizona and Nevada, but it had declined to less than 3,000 individuals by 2001 (Marsh et al. 2003). Mueller (2005, 2006) reported the wild Lake Mohave razorback sucker population to be near 500 individuals, while the most recent 2012 estimate of wild Lake Mohave razorback sucker was not reported, as apparently no wild fish were captured (Marsh and Associates 2012). Interestingly, wild fish continue to be captured in Lake Mead, and the unique ability of Lake Mead razorback suckers 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, one 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 suckers are most evident in Lake Mohave from January to April when they congregate in shallow shoreline areas to spawn, and larvae can be numerous soon after hatching. However, the Lake Mohave population today is largely supported by periodic stocking of captive-reared fish (Marsh et al. 2003, 2005). Predation by bass (*Micropterus* spp.), common carp

(*Cyprinus carpio*), channel catfish (*Ictalurus punctatus*), sunfish (*Lepomis* spp.), and other nonnative species appears to be the principal reason for the lack of razorback sucker recruitment (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 2,577 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 2012).

Lake Mead was formed in 1935 when Hoover Dam was closed, and razorback suckers were relatively common in the lake throughout the 1950s and 1960s, apparently from reproduction soon after the lake was formed. The Lake Mead razorback sucker population appeared to follow the trend of populations in other Lower Colorado River Basin reservoirs. Lake Mead razorback sucker numbers became noticeably reduced in the 1970s, approximately 40 years after closure of the dam (Minckley 1973; McCall 1980; Minckley et al. 1991; Holden 1994; Sjoberg 1995). From 1980 through 1989, neither the Nevada Department of Wildlife (NDOW) nor the Arizona Game and Fish Department (AGFD) collected razorback suckers from Lake Mead (Sjoberg 1995). This may have been partially due to changes in the agencies' lake sampling programs; however, there was a considerable decline from the more than 30 razorback suckers collected during sport fish surveys in the 1970s. These results are not surprising and fit well within the pattern of razorback sucker population declines approximately 40–50 years following reservoir development, as was seen in other Lower Colorado River Basin reservoirs.

After receiving reports in 1990 from local anglers that razorback suckers were still found in two areas of Lake Mead (Las Vegas Bay and Echo Bay), the NDOW initiated limited sampling. From 1990 to 1996, 61 wild razorback suckers were collected – 34 from the Blackbird Point area of Las Vegas Bay and 27 from Echo Bay in the Overton Arm (Holden et al. 1997). Two razorback sucker larvae were collected near Blackbird Point by an NDOW biologist in 1995, confirming suspected spawning in the area. In addition to the captures of these wild fish, the NDOW, over time, has stocked a limited number of juvenile (sexually immature individuals, as defined in the "Methods" section of this document) razorback suckers 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. The collection of razorback suckers 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 the NDOW, initiated a study to attempt to answer some of these questions. BIO-WEST, Inc.

(BIO-WEST) was contracted to design and conduct the study with collaboration from the SNWA and NDOW. Other cooperating agencies included the Bureau of Reclamation (Reclamation), which provided funding, storage facilities, and technical support; the National Park Service, which 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:

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

In 1998, Reclamation agreed to contribute additional financial support for the project to facilitate fulfillment of Provision #10 of the Reasonable and Prudent Alternative 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 the SNWA was completed, specifying the areas to be studied and extending the study period into the year 2000.

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

- Search for new razorback sucker population concentrations via larval light trapping outside the two established study areas
- Enhance the sampling efforts for juvenile razorback suckers at both established study sites

If potential new populations were located by finding larval razorback suckers, trammel netting would be used to capture adults, and sonic tagging would be used to determine the general range and habitat use of the newly discovered population. In 2002, Reclamation and the 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 into 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 phases during future monitoring and research efforts on Lake Mead (Albrecht et al. 2006a). In 2007, the project became primarily a monitoring study. In 2008, Reclamation and the SNWA completed another cooperative agreement, extending monitoring efforts and following monitoring protocols developed by Albrecht et al. (2006a) through 2011.

Most recently in 2012, under the Lower Colorado River Multi-Species Program (LCR MSCP), funding was provided to maintain long-term monitoring efforts for the next few years. In addition, funding was also provided for a pilot study to be conducted in 2012 in an effort to initiate investigations of juvenile razorback suckers in Lake Mead. The general goal of the pilot study is to gain better understanding of this rare life stage and to understand why Lake Mead razorback suckers are able to demonstrate consistent, natural recruitment. Currently, Lake Mead is perhaps one of the last locations where continued, natural, wild recruitment of this species is documented and where wild, juvenile razorback suckers are routinely captured. Furthermore, in recent years, a pulse in natural recruitment has been documented, which provides an increase in juvenile fish captures and a potentially opportune time to initiate sampling efforts for this rare life stage (Albrecht et al. 2010a, 2010b; Shattuck et al. 2011). As such, Lake Mead currently provides an opportunity to study this unique life stage in a wild form. It is hoped that through additional and specific efforts directed toward understanding the habitat use of juveniles, sufficient information can be gleaned to help foster young, wild razorback sucker in other locations within the Colorado River Basin.

The primary goals associated with the most recent funding is to effectively and efficiently monitor the Lake Mead razorback sucker population and initiate efforts to better understand the juvenile life stage of razorback suckers in Lake Mead. More specifically, the following objectives are being addressed:

- Locating and capturing larval, juvenile, and adult razorback suckers
- Identifying annual spawning site locations within the study areas
- Marking captured juvenile and adult razorback suckers 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 suckers within the study areas and identifying the general habitat types in which these fish are found

- Monitoring movements and/or movement patterns of juvenile razorback suckers within the study areas and identifying general habitat types in which these fish are found (see chapter 2)

- Striving to locate recruitment habitat and quantifying its physicochemical properties (see chapter 2)

- Recording biological data (e.g., sex, total length [TL], and weight) and examining and documenting the general health and condition of captured adult razorback suckers

- Providing mean daily and/or mean annual growth rates for recaptured razorback suckers

- Providing a population estimate for the current razorback sucker population(s)

- Characterizing the age structure of the Lake Mead razorback sucker population(s) through appropriate, nonlethal aging techniques

- Determining why razorback sucker recruitment occurs in Lake Mead

This annual report presents the results of the 16th field season (February 2012 – April 2012 long-term monitoring data, July 2011 – June 2012 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), and other past annual reports. The recent 2011–12 long-term monitoring data will be presented within chapter 1 of this document. Other information and data from previous years and reports are included as applicable. More specifically, chapter 1 presents data and findings from the long-term monitoring locations on Lake Mead, which include Las Vegas Bay, Echo Bay, and the Muddy River/Virgin River inflow area (the part of Lake Mead near Fish Island in the northernmost portions of the Overton Arm). Chapter 2 presents the methodology, analysis, and findings pertaining to the 2012 pilot study efforts to better understand wild, juvenile razorback suckers within Lake Mead.

It should be noted that during 2010–12, efforts were expanded to determine the presence or absence of razorback suckers in the CRI area using study methodologies developed and honed during the past 16 years of razorback sucker investigations on Lake Mead. Those efforts are not reported herein; they are reported in a stand-alone document that serves as a companion to this report. Readers interested in the CRI area investigations are encouraged to obtain and read those documents (Albrecht et al. 2010c; Kegerries and Albrecht 2011, 2013).

Chapter 1: Long-Term Monitoring

BACKGROUND AND SUMMARY OF EARLIER MONITORING RESULTS, 1996–2011

Since the Lake Mead razorback sucker study began in 1996, BIO-WEST's netting efforts have resulted in 767 total razorback sucker captures, represented by 436 unique individuals that were captured in long-term monitoring sites and PIT tagged. Through recapture data, a greater understanding of life history processes (e.g., growth, movement patterns, and population size) specific to Lake Mead has been attained. Interestingly, in 1997, four juvenile razorback suckers were captured in Echo Bay, indicating that relatively recent, natural recruitment had occurred within the Lake Mead population. Seventeen additional wild, juvenile razorback suckers were captured in the Blackbird Point area of Las Vegas Bay through 2005. From 2006 to 2011, an additional 80 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 suckers for age determination, and through 2011, a total of 360 razorback suckers had been aged (Shattuck et al. 2011). 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 suckers to avoid predation by nonnative fishes. Recent nonnative 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, redd locations, 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 50-foot (ft) (15.24-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 down the Echo Bay Wash. 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 80 ft (24.39 mm). By 2003, the spawning depth was closer to 20 ft (6.10 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 2003–04 field seasons, and only four larvae razorback suckers 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 20 ft (6.10 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 2006–09, 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 down the bay, much like those 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 suckers throughout Lake Mead shifted spawning site locations in response to increased lake levels and once again utilized the large, littoral habitat that had been reinundated.

During 2003–04, larval sampling was conducted at the Muddy River/Virgin River inflow areas 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 suckers 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 suckers have been documented spawning successfully near the Muddy River/Virgin River inflow area (specific spawning locations are 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).

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 2004–05 field season, offering movement and habitat use information for subsequent field seasons.

In 2004, a drastic 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 suckers 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 during the 2004–05 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 2004–05 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 2004–05 field season, 10 additional sonic-tagged fish 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, the decision was made to tag and release 12 additional fish from Floyd Lamb Park (4 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 continues 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 suckers were implanted 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 all of the above cases, sonic-tagged fish from Floyd Lamb Park were stocked into the Nevada portions of Lake Mead in cooperation with the NDOW. 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).

STUDY AREAS

All Lake Mead long-term monitoring activities conducted in 2012 occurred at the locations studied during efforts from 1996 to 2011 (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; Kegerries et al. 2009; Shattuck et al. 2011). The two most frequently sampled areas historically were Echo Bay and Las Vegas Bay (figure 1-1). More recently, razorback sucker activity was also monitored at the Muddy River/Virgin River inflow area (figure 1-1).

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 the 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 yards [183–366 m]) and transitory between Las Vegas Wash proper and Las Vegas Bay. Because lake elevation affects what is called the "wash" or "bay," the above definitions are used to differentiate the various habitats at the time of sampling.

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

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

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

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

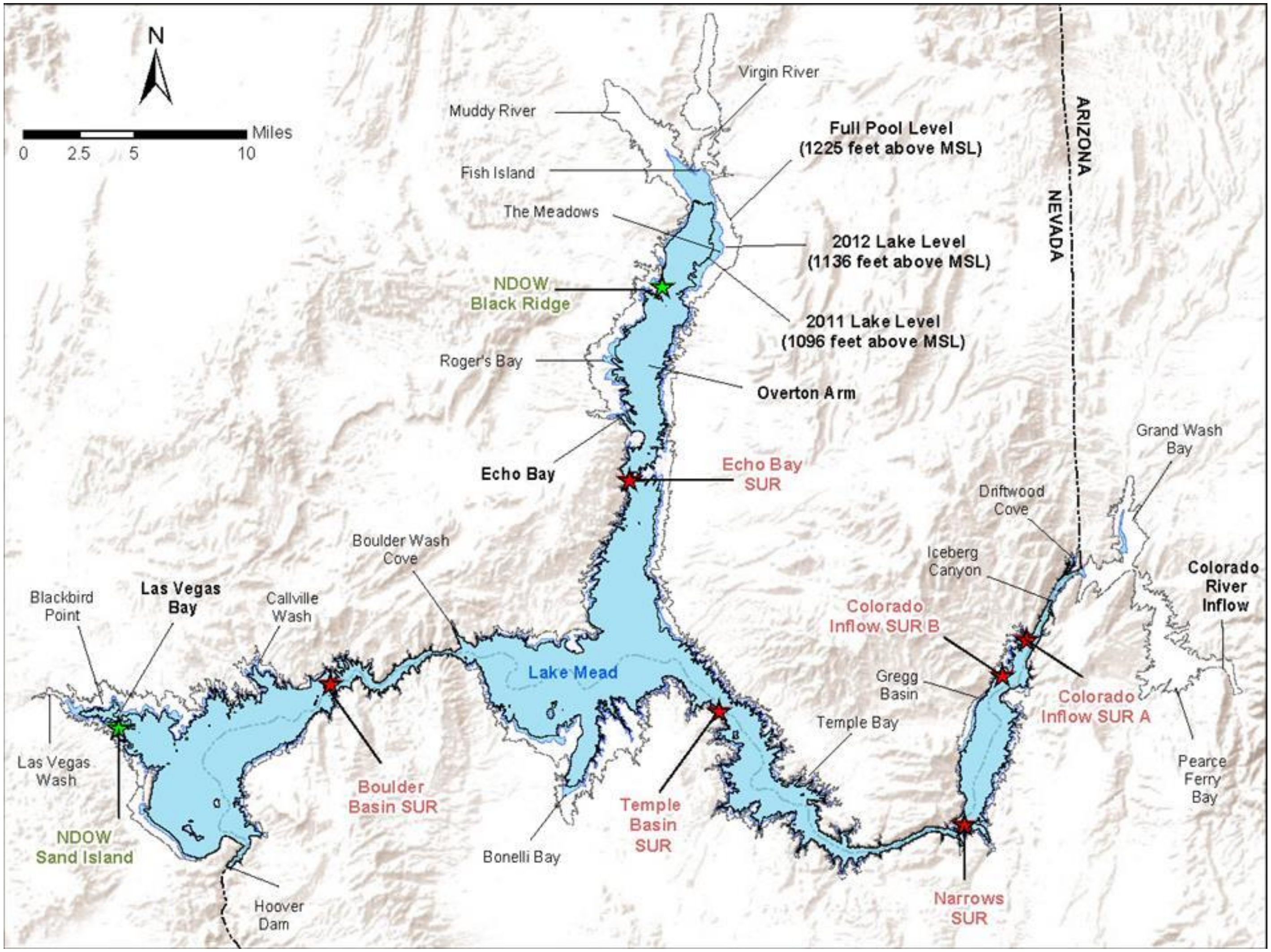


Figure 1-1.—Lake Mead general study areas.
The locations of long-term monitoring submersible ultrasonic receivers are denoted by red stars (units maintained by BIO-WEST) or green stars (units maintained by the NDOW).

Additionally, the location of wild, adult and larval razorback suckers in the northern portion of the Overton Arm necessitates a description of these areas. These location definitions follow those provided in Albrecht and Holden (2005):

- 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 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 2012 field season (July 1, 2011 – June 30, 2012) were measured in feet above mean sea level (ft AMSL) and obtained from Reclamation's Lower Colorado Regional Office Web site (Reclamation 2012). During sampling trips to the study sites, biologists also documented the effect of fluctuating lake levels on razorback sucker habitat with written observations and photographs.

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 suckers 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 for the purposes of the long-term monitoring efforts in 2012. However, it should be noted that tagging efforts were conducted for the juvenile pilot study. As such, readers are encouraged to refer to chapter 2 of this document for a detailed description of this methodology and its results.

Active Sonic Telemetry

Sonic telemetry data for the long-term monitoring study were collected from July 1, 2011, to June 30, 2012, 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 0.5 miles (mi) (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 2010, personal communication; personal experiences of the authors). Additionally, because sonic-tagged razorback suckers were at times located in areas of Lake Mead inaccessible by boat (e.g., shallow, peripheral habitats and flowing portions of inflow areas), the range of observed movements may not fully represent the use of a particular area in its entirety. Active tracking consisted of listening underwater for coded sonic tags using a Sonotronics USR-08 or an earlier model of an ultrasonic receiver and DH4 hydrophone. The hydrophone was lowered into the water 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 (GPS) location, and depth were recorded. In all cases when sonic-tagged fish were located within shallow habitats or within inflow riverine portions of Lake Mead (e.g., Las Vegas Wash or the Virgin River inflow), individual fish locations were recorded at the closest point accessible by boat.

Passive Sonic Telemetry

Along with active tracking methods, submersible ultrasonic receivers (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 allows us to gain an understanding of large-scale razorback sucker movements during summer. Four SURs were utilized during the 2011–12 field season – two deployed by BIO-WEST remained stationed in locations used during the 2010–11 field season (Shattuck et al. 2011), and two were set by the NDOW for a concurrent Lake Mead striped bass (*Morone saxatilis*) telemetry study in areas not already monitored by BIO-WEST SURs (D. Herndon 2011, personal communication). Information from the SURs was shared between BIO-WEST and the NDOW, which provided a larger area of surveillance for monitoring lake-wide movement of razorback sucker.

The SURs were set at the following locations (see figure 1-1): Sand Island at the southeastern extent of Las Vegas Bay (NDOW), Boulder Basin near the narrows of Boulder Canyon (BIO-WEST), south of Echo Bay near Ramshead Island (BIO-WEST), and Black Ridge on the northeastern edge of the Overton Arm (NDOW). 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 (rock, anchor, or block) using approximately 18 inches (in) 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 were required within 5 minutes of one another for a record to be reported as a positive identification.

Adult Sampling

Trammel Netting

The primary gear used to sample adult fish were 300-ft (91.4-m)-long by 6-ft (1.8-m)-deep trammel nets with an internal panel of 1-in (2.54-centimeter [cm]) mesh and external panels of 12-in (30.48-cm) mesh. Nets were generally set with one end near shore in 5–30 ft (1.5–9.1 m) of water, with the net stretched out perpendicular to the 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. 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. As has been the norm on Lake Mead, extreme care was taken to avoid inflicting handling stress on native suckers, and as such, trammel netting was typically only conducted when surface water temperatures were less than 68 degrees Fahrenheit (°F) (20 degrees Celsius [°C]) (e.g., Hunt et al. 2012).

Fish were removed from nets, and live fish were held in 100-quart (94.6-liter) coolers filled with lake water. Razorback and flannelmouth suckers (*Catostomus latipinnis*) were isolated from other fish species and held in aerated live wells. All but the first five common carp and first five gizzard shad were enumerated and returned to the lake, while other species (including five common carp and five gizzard shad) were identified, measured for TL, weighed, and released at the capture location. Razorback 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, or 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 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 square centimeter) of skin material that was obtained from the caudal fin, preserved in 95-percent (%) 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 suckers was calculated for each individual using the difference in TL (mm) between capture periods. If the data were available, mean annual growth was calculated separately for stocked and wild individuals. Furthermore, annual growth was calculated for fish recaptured from individual sites (Las Vegas Bay, Echo Bay, and the Muddy River/Virgin River inflow area) as well as from Lake Mead as a whole.

Larval Sampling

Larval sampling methods followed those developed by Burke (1995) and other researchers on Lake Mohave. The procedure uses the positive phototactic response of larval razorback suckers to capture them. After sundown, two to four 12-volt “crappie” lights were connected to a battery, placed over each side of the boat, and submerged in 4–10 in (10.2–25.4 cm) of water. Two to four field crew members equipped with long-handled aquarium dip nets were stationed to observe the area around the lights. Larval razorback suckers that swam into the lighted area were netted out of the water and placed into a holding bucket. The procedure was repeated for 15 minutes at each location, 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.

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 suckers. 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 Fish Island in the Overton Arm of Lake Mead. This same general approach was also used at the long-term monitoring locations in 2012.

Age Determination

For age determinations, we used a nonlethal technique employing fin ray sections, which was developed in 1999 (Holden et al. 2000a) and refined over subsequent years. As in past years, an emphasis in 2012 long-term monitoring efforts involved collecting fin ray sections from razorback suckers for aging purposes. A sample was also obtained from a single flannelmouth sucker for age determination.

During the 2012 monitoring period, selected suckers captured via trammel netting were anesthetized, and a single (approximately 0.25-in-long) segment of the second left pectoral fin ray was surgically removed. Fish were anesthetized with a lake-water bath containing MS-222, sodium chloride, and a 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. These surgical tools consist of a matched pair of finely sharpened chisels welded to a set of wire-stripping pliers. The connecting membrane between fin rays was cut using a scalpel blade, and the section was placed in a labeled envelope for drying. All surgical equipment was sterilized before use, and 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 sodium chloride, 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 when the assigned age was not agreed upon. If age discrepancies remained after the second reading, all three readers collectively assigned an age. For further information regarding the development of our fin ray aging technique, refer to Albrecht and Holden (2005), Albrecht et al. (2006b, 2008a), and other annual Lake Mead razorback sucker reports. Determined ages for razorback suckers from Lake Mead in 2012 were cataloged with past samples spanning from 1998 to 2011 and are included in attachment 1.

Population and Survival Rate Estimation

Population Estimation

From 1996 through 2011, program CAPTURE (CAPTURE) was used to generate population estimates from mark-recapture data for razorback suckers in Lake Mead. To maintain consistency with past reports, population estimates were calculated in CAPTURE for data spanning 2010–12 (attachment 2). Three models were used in CAPTURE population estimates following methods from past reports for consistency (Albrecht et al. 2008a, 2010b; Kegerries et al. 2009; Shattuck et al. 2011). The null estimator (M_o) is the simplest model that assumes all members are equal in their probability of capture through time and typically provides some of the most reliable estimates for endangered western fishes (R. Ryel 2001, personal communication). Chao M_h and Jackknife (M_h) are good estimators for sparse data; however, these models allow for heterogeneity in capture probability by individuals, and these differences in capture probability are constant through time (Rexstad and Burnham 1992; Cooch and White 2011). The allowance for heterogeneity helps to eliminate underestimation of abundance and overestimation of the probability of capture (Cooch and White 2011). Future reports will include results generated from CAPTURE in an attachment to provide a platform for interannual comparison. In 2012, a population estimate was produced in a more contemporary program, program MARK (MARK), using mark-recapture data from 2010–12. Models produced in MARK are tested and ranked to produce the most precise and informative estimate. Results from MARK are included in addition to those produced in CAPTURE in an effort to increase model selection capability and to test relative model goodness of fit (Cooch and White 2011).

Population estimates were produced for four areas within the lake: Las Vegas Bay, the combined Echo Bay and Muddy River/Virgin River inflow area, and a combined estimate (all long-term monitoring sites). Additionally, a combined estimate incorporating the long-term monitoring sites with the CRI area is included. There were 32 capture events for the Las Vegas Bay estimate, 35 capture events for the Echo Bay and Muddy River/Virgin River combined estimate, 35 capture events for the combined estimate (all long-term monitoring sites), and 41 capture events for the combined long-term monitoring and CRI area estimates. For the combined long-term monitoring and CRI areas, netting efforts from the CRI area were used only when long-term monitoring efforts were taking place simultaneously on the lake to maintain some semblance of consistency in effort across space and time. To date, frequent movement of wild razorback suckers to and from Las Vegas Bay has not been detected (relative to other locations) and, therefore, an estimate is generated for the individual site. Movement of razorback suckers has been documented on numerous occasions in which individuals from Echo Bay moved into the Muddy River/Virgin River inflow area and vice versa as reported in Albrecht et al. (2007, 2008a, 2008b, 2010b); Kegerries et al. (2009); and Shattuck et al. (2011). Therefore, data obtained from 2010 to 2012 from Echo Bay and the Muddy River/Virgin River inflow areas have been combined to provide a single population estimate. The combined estimate (all long-term monitoring sites) attempts to assess how Lake Mead may fluctuate with regard to population abundance at the combined monitoring and research sites. Stocked fish were not used in the population estimates unless they had survived a minimum of 1 year in Lake Mead. 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). Within MARK, the models where ranked according to their relative goodness of fit value (according to the corrected Akaike's information criterion [AICc] values [Cooch and White 2011]) to determine which was the best fit model for the dataset. The population model with the highest ranked AICc value is reported herein.

Survival Rate Estimation

Similar to the population estimation analyses, MARK was used to estimate an apparent survival (φ) rate of razorback suckers in Lake Mead from trammel netting data taken during the spawning season (February–May) from 2010 to 2012. Two models, the Cormack-Jolly-Seber (CJS) live recapture model (Cormack 1964; Jolly 1965; Seber 1965), and the Pradel survival model (Pradel

1996), were used in MARK to calculate apparent survival rates based on 41 capture events for the combined long-term monitoring and CRI areas (Cooch and White 2011).

Apparent survival estimates the probability of an individual being alive and available for capture from one time period to another (Zelasko et al. 2011). Razorback sucker survival rate estimates in Lake Mead were not reported in past reports; thus, this analysis may provide additional information regarding population dynamics for wild razorback suckers in Lake Mead. Additionally, these estimates provide a means to compare Lake Mead razorback sucker apparent survival rates to those of other prominent razorback sucker populations (e.g., the Green River and upper Colorado River subbasins [Zelasko et al. 2011] as well as Lake Mohave [Kesner et al. 2012]). Combined long-term monitoring and CRI area data selection and encounter histories were identical to those used in the population estimate (described above) and were analyzed using an approach similar to that of Zelasko et al. (2011). The predefined models of φ (apparent survival) and ρ (recapture) were used for both the CJS and the Pradel survival estimators. Within MARK, the models where ranked according to their relative goodness of fit value (AICc) [Cooch and White 2011]) to determine which was the best fit model for the dataset. The apparent survival rate estimate with the highest ranked AICc value is reported for both the CJS and Pradel models for comparison purposes.

RESULTS

Lake Elevation

Similar to the lake elevation trends seen in the past decade, (excluding 2011, the 15th field season, which was an above-average flow year in the Colorado River Basin), lake elevations during 2012 (16th field season) declined overall (figure 1-2). From a starting elevation in January 2012 of approximately 1,134 ft (345.6 m) AMSL, lake elevations decreased steadily during the spawning months of February, March, and April to a final elevation of 1,123 ft (342.3 m) AMSL (figure 1-3). This drop equates to a total of 11 ft (3.4 m) of change during the 2012 spawning months, or 3.6 ft (1.1 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.

Sonic Telemetry

Over the course of this study (1997–2012), 86 fish (39 wild and 47 hatchery reared) have been equipped with sonic tags for the purposes of long-term monitoring and/or research at Las Vegas Bay, Echo Bay, and the

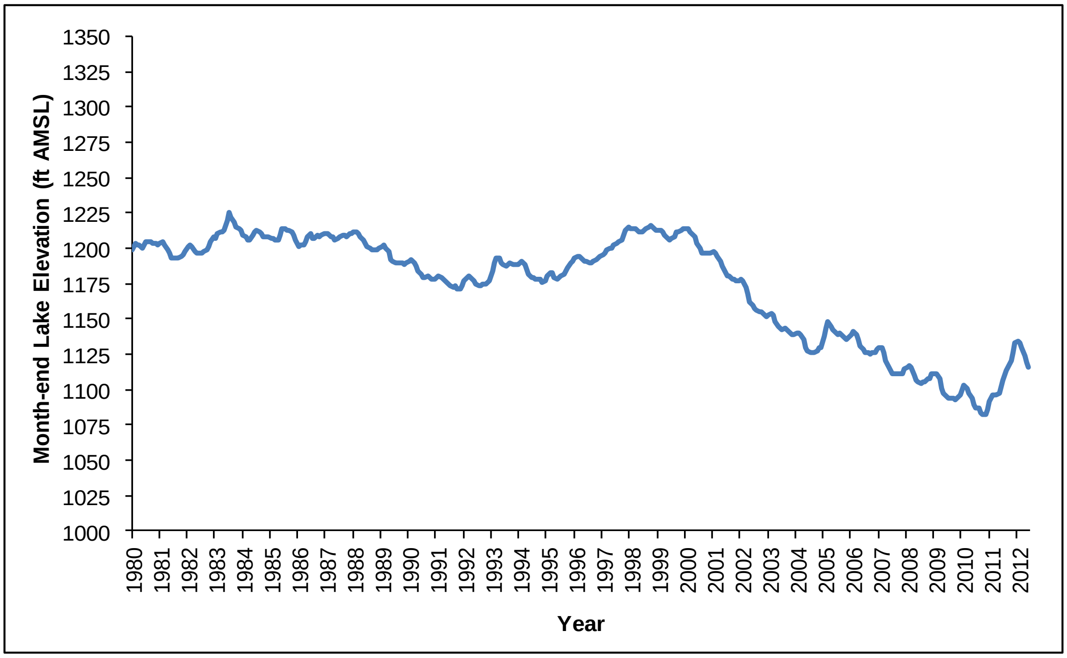


Figure 1-2.—Lake Mead month-end lake elevations in ft AMSL, January 1980 – June 2012 (Reclamation 2012).

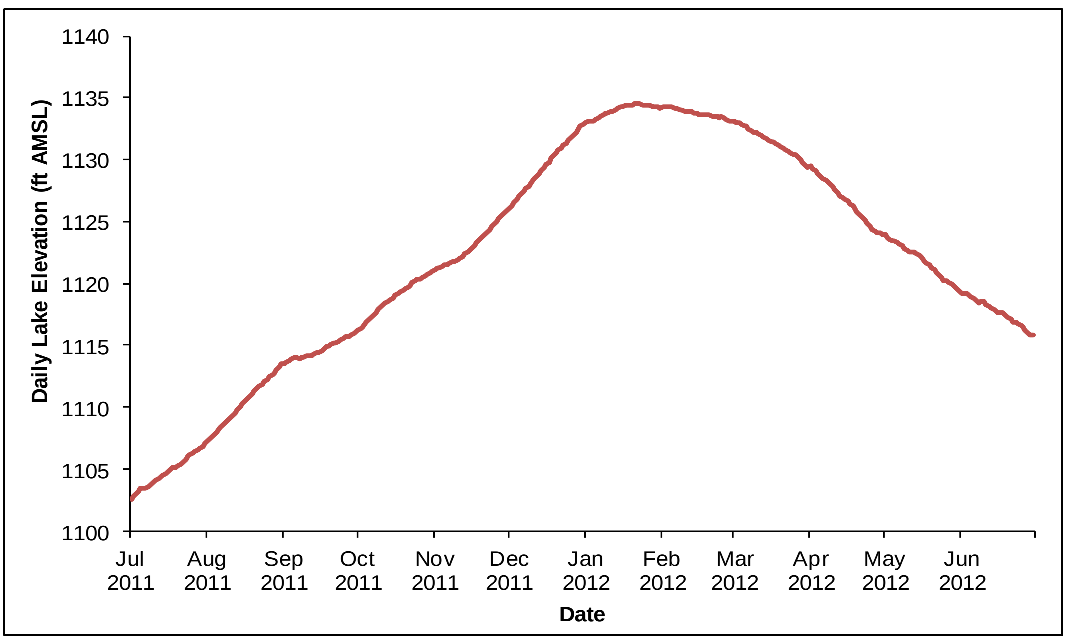


Figure 1-3.—Lake Mead daily lake elevations in ft AMSL, July 1, 2011 – June 30, 2012 (Reclamation 2012).

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 and discussed further in chapter 2 of this report. Additionally, a number of individuals were equipped with sonic tags and released at the CRI area. A complete description can be found in the companion report, Kegerries and Albrecht (2013). During the long-term monitoring 2011–12 field season, 152 total contacts were made with 14 individual sonic-tagged razorback suckers (table 1-1 and figures 1-4 through 1-6), including an individual originally tagged in Las Vegas Bay and contacted solely at the CRI area during the 2011–12 field season (Kegerries and Albrecht 2013). Ten sonic-tagged razorback suckers were contacted by the four SURSs (see figure 1-1) in aggregate a total of 89,425 times, helping to define movement of sonic-tagged individuals and aide in accounting for missing sonic-tagged fish.

Table 1-1.—Lake Mead razorback sucker tagging and stocking information, location and date of last contact, and status of sonic-tagged fish gathered during July 2011–June 2012 monitoring

Capture location[a]	Date tagged	Tag code	TL (millimeters) at tagging	Sex[b]	Stocking location[a]	Last location[a]	Date of last location	Contacts made 2011–12	Current tag status
2008									
FDLB	12/2/2008	365	496	M	EB	EB	2/16/2012	0	Inactive
FDLB	12/2/2008	376	198	M	EB	EB	8/25/2010	0	Unknown
FDLB	12/2/2008	678	492	M	EB	VB	5/8/2012	8	Active
FDLB	12/2/2008	3386	193	F	EB	OA	2/3/2009	0	Unknown
FDLB	12/3/2008	377	479	M	LB	LB	10/12/2011	1	Active
FDLB	12/3/2008	465	520	F	LB	CI	5/26/2010	0	Unknown
FDLB	12/3/2008	677	529	F	LB	LB	9/13/2011	1	Active
FDLB	12/3/2008	3355	483	M	LB	CI	8/17/2011	1	Active
FDLB	12/2/2008	345	515	M	OA	OA	12/7/2008	0	Unknown
FDLB	12/2/2008	366	479	M	OA	OA	3/10/2009	0	Unknown
FDLB	12/2/2008	488	534	F	OA	OA	6/23/2009	0	Unknown
FDLB	12/2/2008	3354	506	F	OA	OA	8/16/2011	1	Active
2010									
FDLB	2/23/2010	357	490	M	GB	LB	6/19/2012	12	Active
2011									
FDLB	1/4/2011	334	564	F	LB	LB	6/18/2012	35	Active
FDLB	1/4/2011	3545	556	F	LB	LB	5/31/2012	15	Active
FDLB	1/4/2011	3584	519	M	LB	LB	6/18/2012	19	Active
FDLB	1/4/2011	3775	516	M	LB	LB	6/18/2012	14	Active
FDLB	1/4/2011	448	502	M	OA	OA	6/20/2012	12	Active
FDLB	1/4/2011	555	504	M	OA	OA	6/20/2012	13	Active
FDLB	1/4/2011	3578	541	F	OA	OA	6/20/2012	10	Active
FDLB	1/4/2011	3667	552	F	OA	OA	4/18/2012	10	Active

[a] FDLB = Floyd Lamb State Park, EB = Echo Bay, VB = Virgin Basin, OA = Overton Arm (Muddy River/Virgin River inflow area), LB = Las Vegas Bay, CI = Colorado River inflow area, and GB = Gregg Basin near Scanlon Bay.
[b] F = female, and M = male.

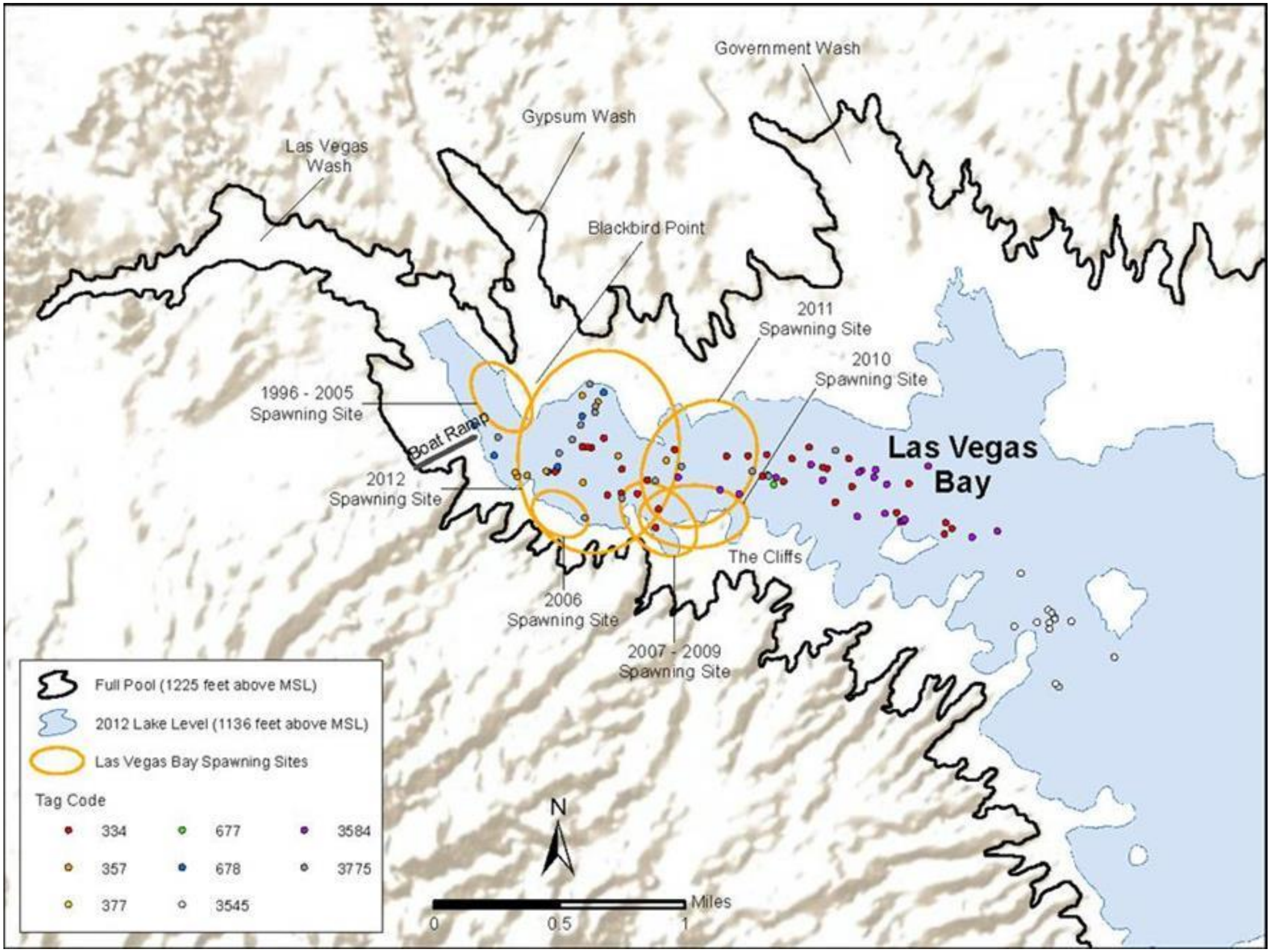


Figure 1-4.—Distribution of sonic-tagged fish located in Las Vegas Bay during the July 2011 – June 2012 Lake Mead field season.

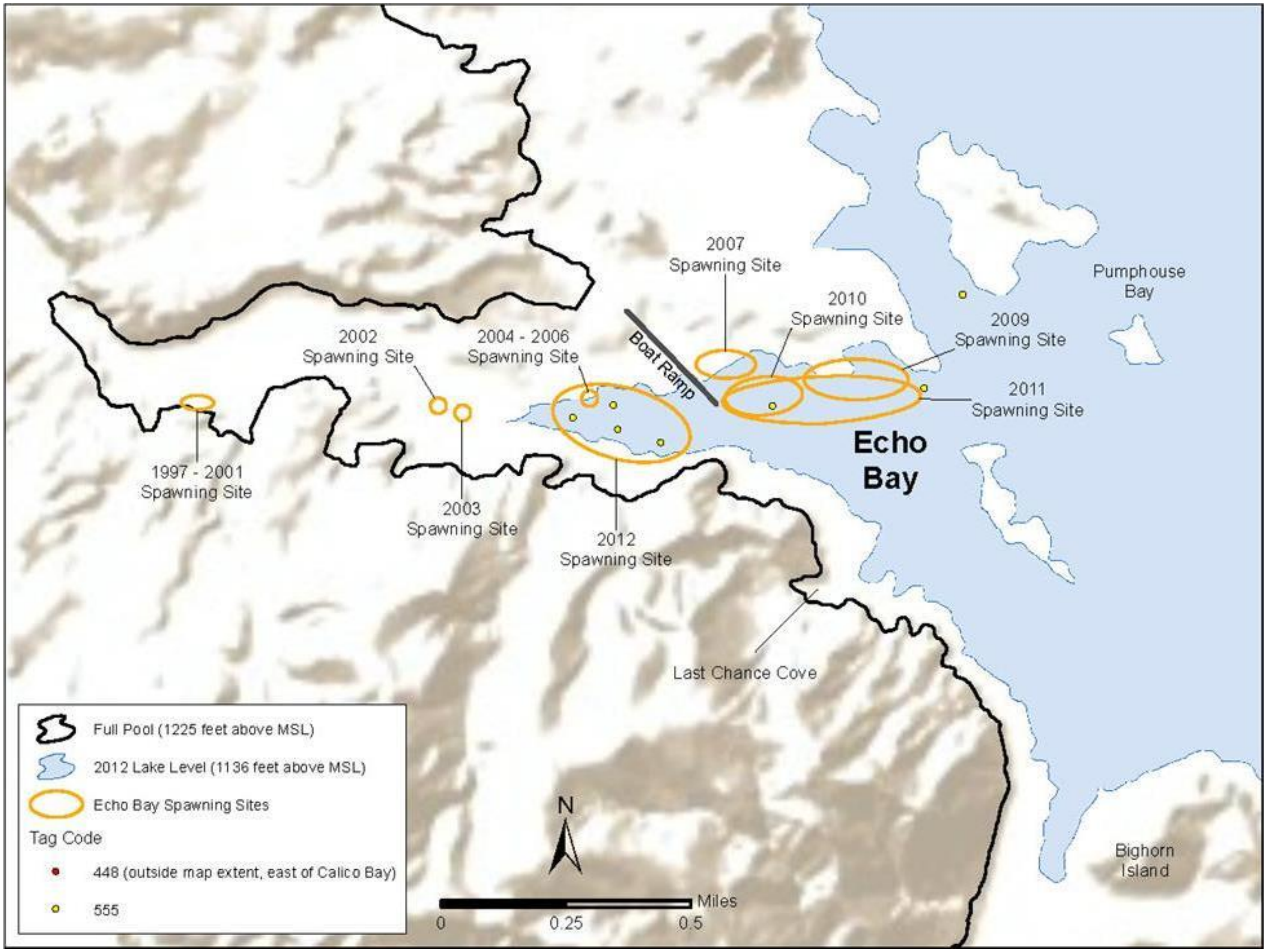


Figure 1-5.—Distribution of sonic-tagged fish located in Echo Bay during the July 2011 – June 2012 Lake Mead field season.

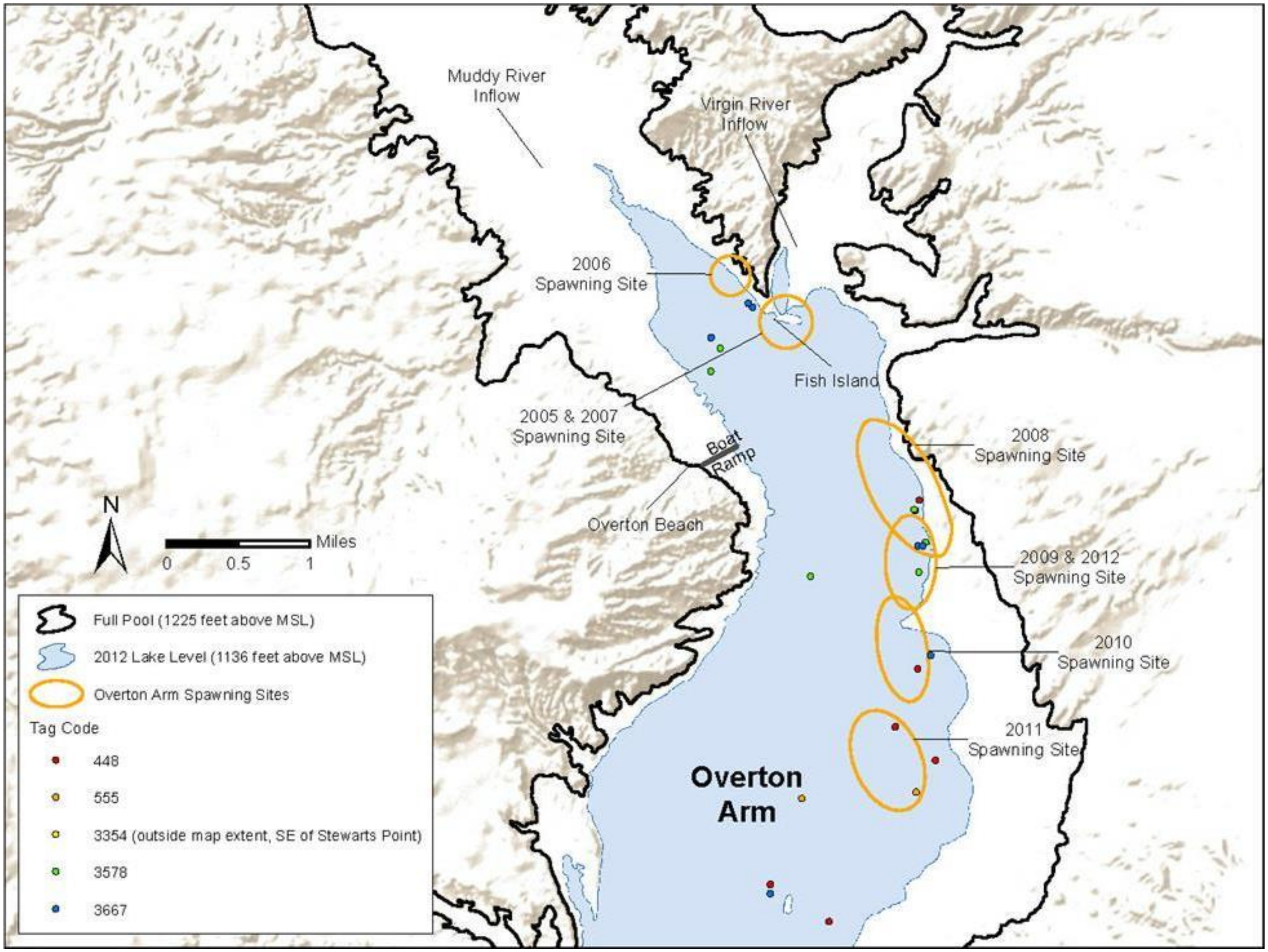


Figure 1-6.—Distribution of sonic-tagged fish located in the Muddy River/Virgin River inflow area during the July 2011 – June 2012 Lake Mead field season.

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). During the 2011–12 field season, 12 contacts (including 9 contacts obtained from the NDOW Sand Island SUR and 1 contact from the CRI area SUR [Kegerries and Albrecht 2013]) were made with 5 of these fish, spanning much of Lake Mead (see table 1-1 and figures 1-4, 1-6, and 1-7). During the 2011–12 field season, contacts for fish stocked in 2008 were made during the February – April razorback sucker spawning season at Lake Mead as well as during summer and fall as individuals moved throughout the lake. Sonic-tagged fish have become an important tool for identifying spawning sites and learning about habitat use during the spawning season (Kegerries and Albrecht 2011; Shattuck et al. 2011). These fish remain valuable to field crew efficiency and effectiveness in capturing razorback suckers. In addition, these sonic-tagged fish have conveyed valuable information with regard to lake-wide movement and spatiotemporal variation in the habitat use and occupancy of areas of the reservoir during months of nonreproductive activity.

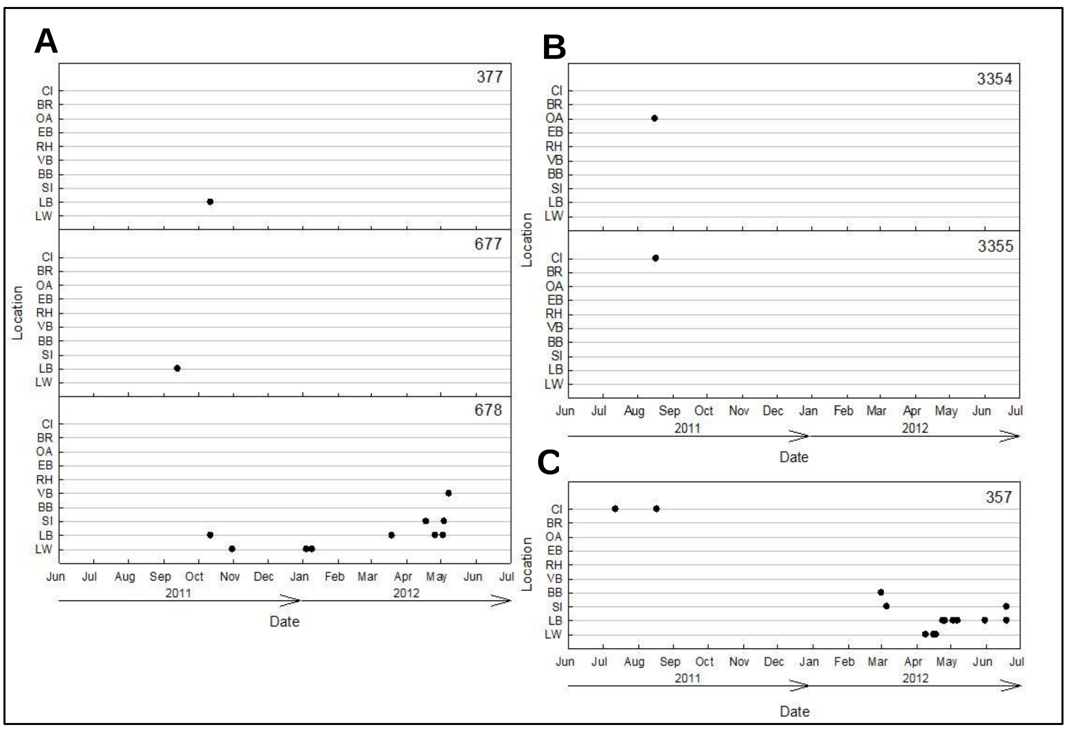


Figure 1-7.—Movement derived from active and passive sonic telemetry during the July 2011 – June 2012 Lake Mead field season for long-term monitoring of individuals sonic tagged in 2008 (A and B) and in 2010 (C).
Location abbreviations are as follows: CI = Colorado River inflow area, BR = NDOW Black Ridge SUR, OA = Muddy River/Virgin River inflow area, EB = Echo Bay area, RH = Echo Bay SUR near Ramshead Island, VB = Virgin Basin area, BB = Boulder Basin SUR, SI = NDOW Sand Island SUR, LB = Las Vegas Bay area, and LW = Las Vegas Wash.

During the 2011–12 field season, the fish stocked in 2008 used habitats ranging from 6.0 to 93.0 ft (1.8–28.3 m) deep, with an average depth of 23.8 ft (7.3 m) at the point of contact. The remaining, active individuals from the 2008 stocking effort were primarily contacted in Las Vegas Bay (see figure 1-4), though one individual was contacted south of the Muddy River/Virgin River inflow area (figure 1-6). All five of the fish from the 2008 tagging event that were contacted during the 2011–12 field season are presumed to be alive and active. Conversely, the statuses of seven individuals from the same tagging event are unknown (see table 1-1). As a number of these fish have not been located recently, it is likely that the battery life of implanted tags has expired, as noted in previous reports (Albrecht et al. 2010b; Shattuck et al. 2011). This assumption continues to maintain merit as one individual (code 365) stocked in 2008 was captured in 2012; the fish was healthy, but the tag was inactive (see table 1-1). However, two individuals thought to have tags that expired in 2010–11 (e.g., codes 677 and 3355) were contacted via sonic telemetry efforts during the 2011–12 field season.

In 2010, it was postulated that some fish from the 2008 tagging event had moved out of the regularly monitored, long-term areas of the lake and into relatively unmonitored areas such as the CRI area or Virgin Basin (Albrecht et al. 2010b). Exploratory tracking efforts in 2011 gave support to this possibility, and tagged individuals were observed in both locations (Kegerries and Albrecht 2011; Shattuck et al. 2011). During the 2011–12 field season, additional individuals were found at the CRI area and in the Bonelli Bay area of the Virgin Basin, further showing that razorback suckers use more portions of Lake Mead than previously thought.

One individual from the 2008 tagging event (code 3354) was stocked in the Muddy River/Virgin River inflow area and remained there until late February 2009 (Albrecht et al. 2010c). After a span of nearly 14 months, this individual was contacted at the CRI area in April 2010, where it remained until October 2010 (Albrecht et al. 2010c; Kegerries and Albrecht 2011). This individual moved out of the area and was briefly found in Echo Bay in November 2010 and was subsequently contacted in the Muddy River/Virgin River inflow area in December 2010 – April 2011 (Shattuck et al. 2011). This individual was contacted once more in the Muddy River/Virgin River inflow area in August 2011 but was not contacted again for the remainder of the 2011–12 field season (see figure 1-7). An additional individual from the 2008 effort was contacted at the CRI area during the 2011–12 field season (code 3355), though the movement from Las Vegas Bay to the CRI area went undetected (figure 1-7). This individual was stocked into Las Vegas Bay in December 2008 and stayed in the area for approximately 8 months. This individual had not been contacted in any portion of Lake Mead since August 2009, until it was contacted in August 2011 near "Lunch Cove" at the CRI area (Kegerries and Albrecht 2013).

Finally, another individual from the 2008 tagging event (code 678) illustrates the potential for lake-wide movement by a stocked razorback sucker. This fish was stocked into Echo Bay where it remained until late April 2010 (Albrecht et al. 2010b). After 4 months without contact, this individual was contacted in Las Vegas Bay in August 2010 (see figure 1-4). This individual remained in the area until it was contacted in May 2011 by the Boulder Basin SUR and then contacted in May 2011 near the southwestern shoreline of Bonelli Bay. After 5 months without contact, this individual was found again in Las Vegas Bay, frequenting Las Vegas Wash and the immediately adjacent area in October 2011. This individual was regularly contacted throughout the reproductive season in Las Vegas Bay; it was last contacted in the area on May 3, 2012. Five days later, this fish was contacted at the southern end of Bonelli Bay (see figure 1-7). The repeated seasonal use of Bonelli Bay and Las Vegas Bay by this individual poses questions as to how razorback suckers may utilize the lake during particular times of the year (e.g., spring spawning and summer foraging). In the past, other portions of Lake Mead have been noted as receiving seasonal use (e.g., Pumphouse Bay, Roger’s Bay, and Stewarts Bay) (Albrecht et al. 2008b, 2010b).

Fish Sonic Tagged in 2010

Eight sonic-tagged fish were stocked in Lake Mead in February 2010, four at the CRI area, and four in Gregg Basin near Scanlon Bay (Albrecht et al. 2010c). During the 2011–12 field season, 1 fish was contacted 39 times (including 27 contacts made by the NDOW Sand Island and Boulder Basin SURs and 2 contacts made at the CRI area); these contacts spanned across Lake Mead (see table 1-1 and figures 1-4 and 1-7). After last being contacted at the CRI area in August 2011 (Kegerries and Albrecht 2013), this individual (code 357) was contacted by two consecutive SURs in March 2012 before being contacted through active sonic telemetry in Las Vegas Bay in April 2012. During the 2011–12 field season, this sonic-tagged fish used habitats ranging from 5.0 to 28.0 ft (1.5 to 8.5 m) deep, with an average depth of 11.6 ft (3.5 m) at point of contact and was found frequently associating with the general cover types of inundated vegetation and turbidity. Further details on contacts made at the CRI area can be found in Kegerries and Albrecht (2013). During the end of the 2011–12 field season, this individual was found frequenting Las Vegas Wash and the immediately adjacent area in the western portions of Las Vegas Bay, a pattern of habitat use that was often seen during earlier study years (Albrecht et al. 2008b).

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 2011–12 field season, this group of fish was contacted most frequently; each individual was contacted at least 10 times for a total of 128 active sonic telemetry contacts and 89,387 passive contacts made via three different SURs (the majority of these SUR contacts [88,374] were from one individual [code 3545] that remained within close range of the NDOW Sand Island SUR from January 2012 through May 2012) (see table 1-1 and figure 1-8). For the most part, each of the two groups of fish stocked in 2001 remained at their respective release localities for the 2011–12 field season (i.e., tagged individuals were contacted at the same site they were initially stocked into). Individuals from the 2011 tagging event were contacted 83 times in Las Vegas Bay, made 88,775 contacts with the NDOW Sand Island SUR (figures 1-4 and 1-8), were contacted 8 times in Echo Bay, made 11 contacts with the SUR near Ramshead Island (figures 1-5 and 1-8), were contacted 37 times in the Muddy River/Virgin River inflow area, and made 601 contacts with the NDOW Black Ridge SUR (figures 1-6 and 1-8). During the 2011–12 field season, four sonic-tagged fish in Las Vegas Bay used habitats ranging in depth from 5.0 to 158.0 ft (1.5 to 48.2 m), with an average depth of 66.1 ft (20.1 m) at point of contact. Individuals were often found occupying deeper, mid-channel areas of Las Vegas Bay from the mouth of Government Wash Cove west to the area near the Cliffs (see figure 1-4). In Echo Bay, two sonic-tagged fish used habitats 5.0–51.0 ft (1.5–15.5 m) in depth, with an average depth of 24.8 ft (7.6 m). The majority of contacts with these fish occurred near the northern and western extents of the bay (see figure 1-4). These same two individuals, along with two others, used habitats in the Muddy River/Virgin River inflow area ranging from 9.0 to 89.0 ft (2.7 to 27.1 m) in depth, averaging 33.9 ft (10.3 m) deep, and primarily were found along the northern and eastern shorelines.

Again, individuals tended to remain in the area in which they were stocked; however, three Muddy River/Virgin River inflow area individuals (codes 448, 555, and 3578) strayed from their stocking area and were contacted in Echo Bay and at the SUR south of Echo Bay near Ramshead Island at various times during the 2011–12 field season (figures 1-5 and 1-8). These individuals further characterize a connection between the areas of the Muddy River/Virgin River inflow and Echo Bay and support patterns of seasonal movement similar to those seen in the past for razorback suckers in the Overton Arm (e.g., 2005, 2008, 2011 [Albrecht et al. 2010b; Shattuck et al. 2011]). The connectivity of habitat between Echo Bay and the Muddy River/Virgin River inflow area may play an important role in seasonal population dynamics and is a caveat that has been addressed in past reports (Shattuck et al. 2011).

Though the individuals sonic tagged in 2011 in Las Vegas Bay primarily remained in that area, movement was observed for two individuals (codes 334 and 3775) between Las Vegas Bay and Las Vegas Wash (figures 1-4 and 1-8). These individuals were contacted in lotic-type habitat in and immediately adjacent to Las Vegas Wash. These contacts may suggest that razorback suckers utilize this shallow, flowing habitat more than our recorded contacts show, as the wash is typically difficult to track or sample by boat. The increase in water surface elevations during the 2011–12 field season may have helped facilitate some of

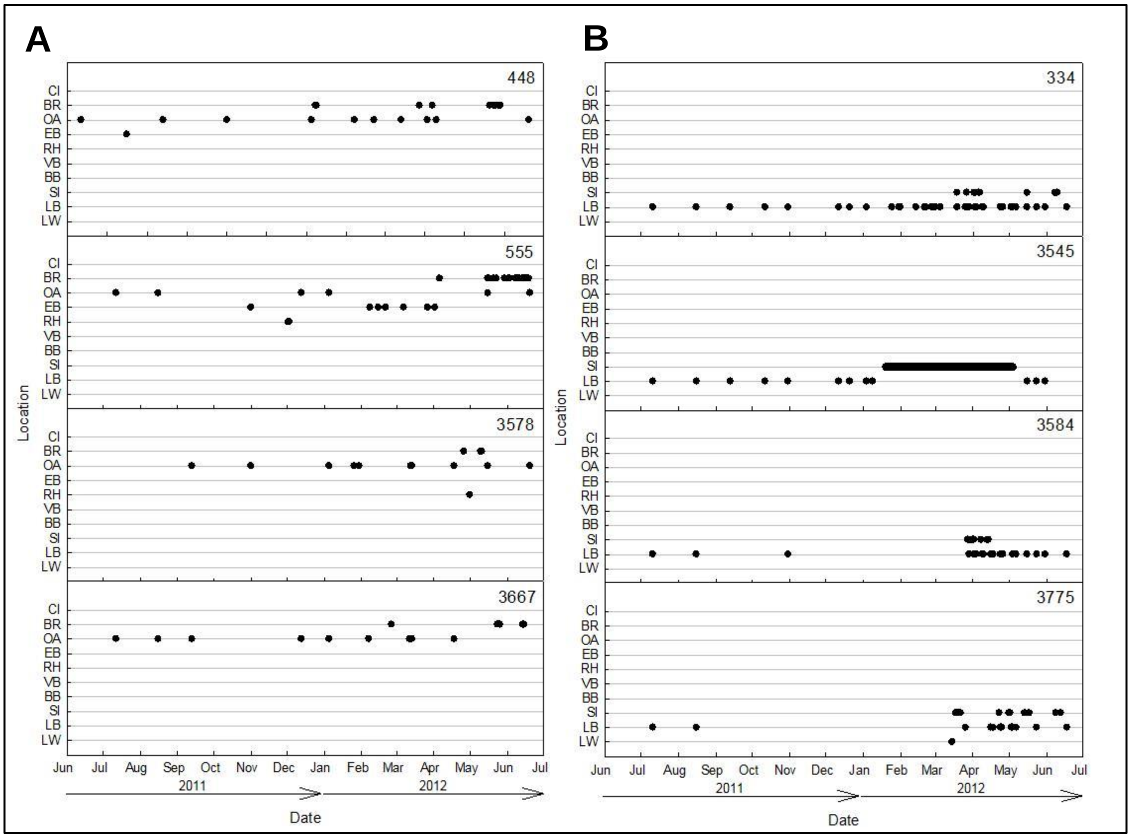


Figure 1-8.—Movement derived from active and passive sonic telemetry during the July 2011 – June 2012 Lake Mead field season for long-term monitoring of individuals sonic tagged in 2011 (A = OA stocked, and B = LB stocked).
Location abbreviations are as follows: CI =Colorado River inflow area, BR = NDOW Black Ridge SUR, OA = Muddy River/Virgin River inflow area, EB = Echo Bay area, RH = Echo Bay SUR near Ramshead Island, VB = Virgin Basin area, BB = Boulder Basin SUR, SI = NDOW Sand Island SUR, LB = Las Vegas Bay area, and LW = Las Vegas Wash.

this movement, though a number of these patterns have been observed during previous years when individuals were noted to congregate toward the western end of Las Vegas Bay into Las Vegas Wash (Albrecht et al. 2008b, 2010b; Shattuck et al. 2011).

As there were generally fewer individuals from other sonic tagging years contacted during the reproductive season (e.g., 2008 and 2010), the individuals sonic tagged in 2011 became exceedingly important during the 2011–12 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, which had some of the higher capture rates seen in netting efforts at Lake Mead this season. Furthermore, the individuals sonic tagged in 2011 helped document areas where sonic-tagged fish were regularly contacted in Las Vegas Bay, helped capture the only juvenile captured during 2012, helped direct larval sampling efforts, and proved razorback sucker use of this area despite sampling difficulties associated with vegetative cover and abundant nonnative fishes (i.e., gizzard shad).

Adult Sampling

Trammel Netting

Trammel netting occurred from January 30 to April 26, 2012, 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 fish larvae in a particular area. Netting was conducted for 93 net-nights during the 16th field season, with 30 net-nights spent in Las Vegas Bay, 31 net-nights in Echo Bay, and 32 net-nights in the Muddy River/Virgin River inflow area (table 1-2). Las Vegas Bay trammel netting was conducted near the Las Vegas Wash inflow on the northern and southern shorelines toward the west end of the bay (figure 1-9). 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 1-10). Finally, sampling of the Muddy River/Virgin River inflow area occurred near the 2009 spawning area, along the eastern shoreline of the north end of the Overton Arm, approximately 1.0 mile (1.6 km) south of the Virgin River inflow area (figure 1-11).

Table 1-2.—Trammel netting effort (net-nights) on Lake Mead during the 16th field season, February 2012 – April 2012

Month	Las Vegas Bay/ Boulder Basin	Echo Bay	Overton Arm	Total
February	16	9	12	37
March	7	10	13	30
April	7	12	7	26
Total	**30**	**31**	**32**	**93**

The first male razorback sucker expressing milt was captured on January 31, 2012, from the Muddy River/Virgin River inflow area. The first female razorback sucker expressing eggs was captured on February 16, 2012, in Echo Bay (table 1-3). Across Lake Mead there were 20 recaptures out of 53 total razorback sucker captures (37.7%) in 2012. Recapture rates varied between study areas. At Las Vegas Bay, one of the two (50.0%) razorback suckers caught was a previously captured fish. At Echo Bay, 8 of the 18 (44.4%) razorback suckers caught were recaptures. Of these eight recaptures, four were wild fish originally

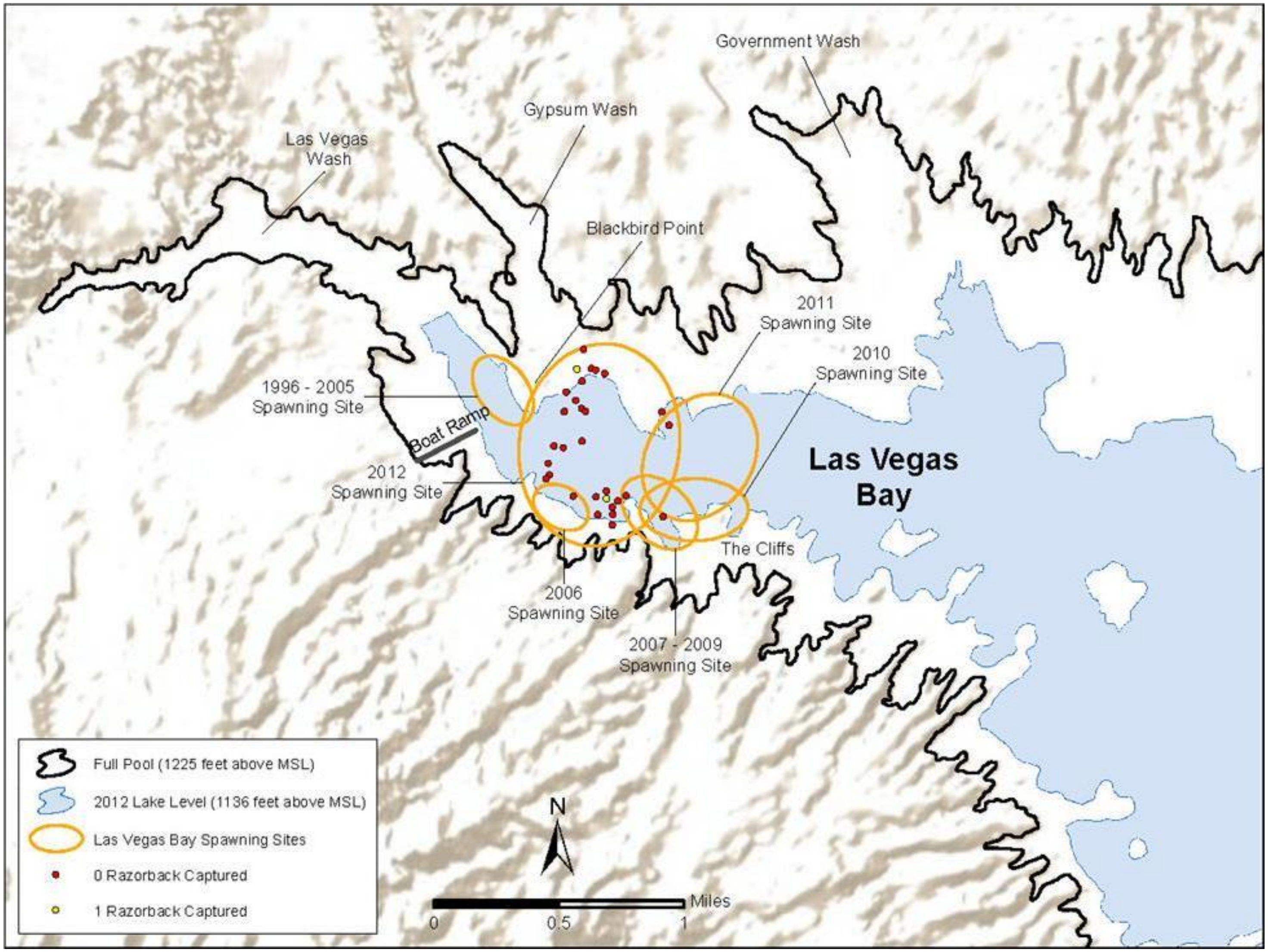


Figure 1-9.—Las Vegas Bay study area showing locations of trammel netting and numbers of fish captured, February 2012 – April 2012.

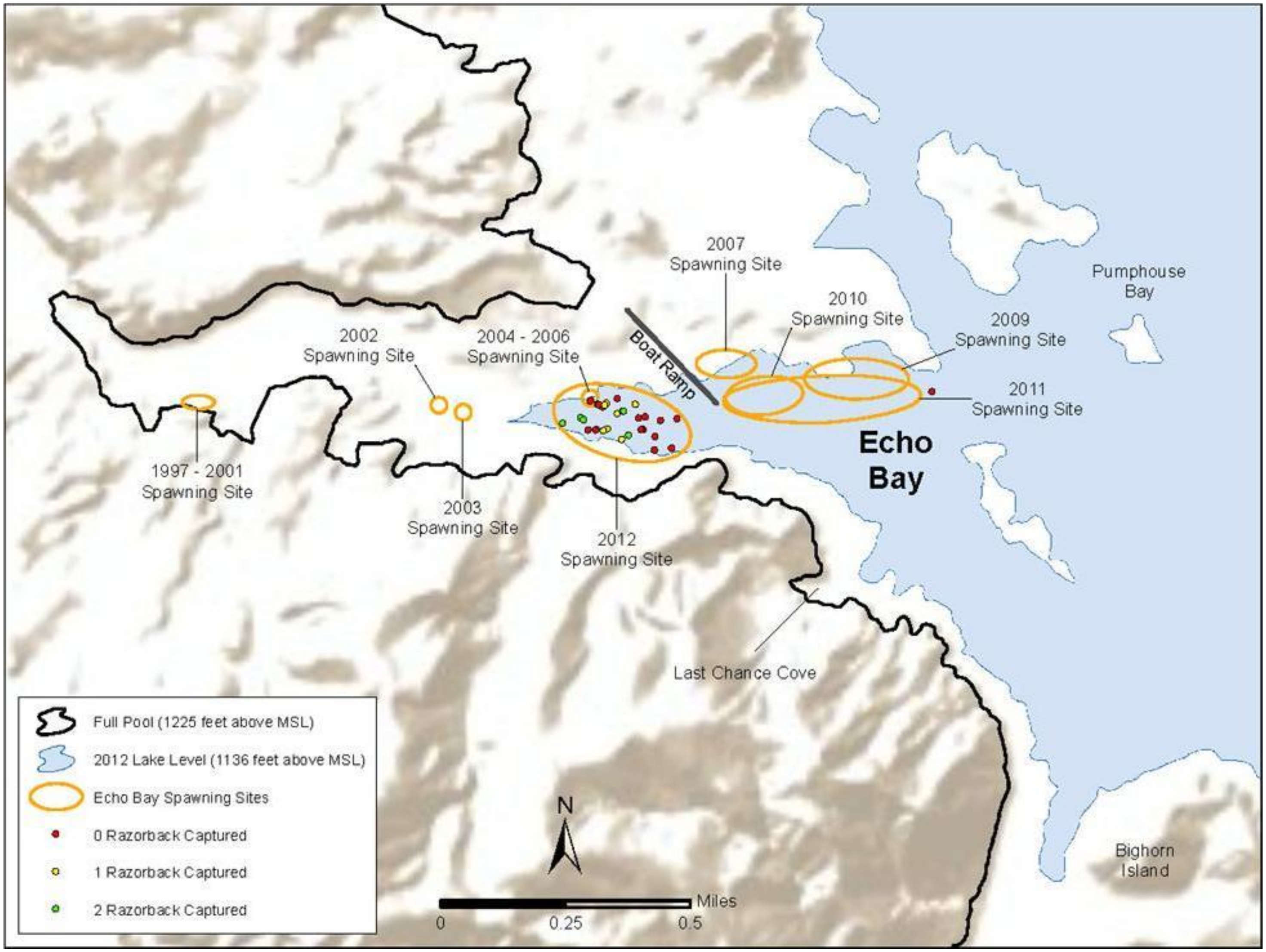


Figure 1-10.—Echo Bay study area showing locations of trammel netting and numbers of fish captured, February 2012 – April 2012.

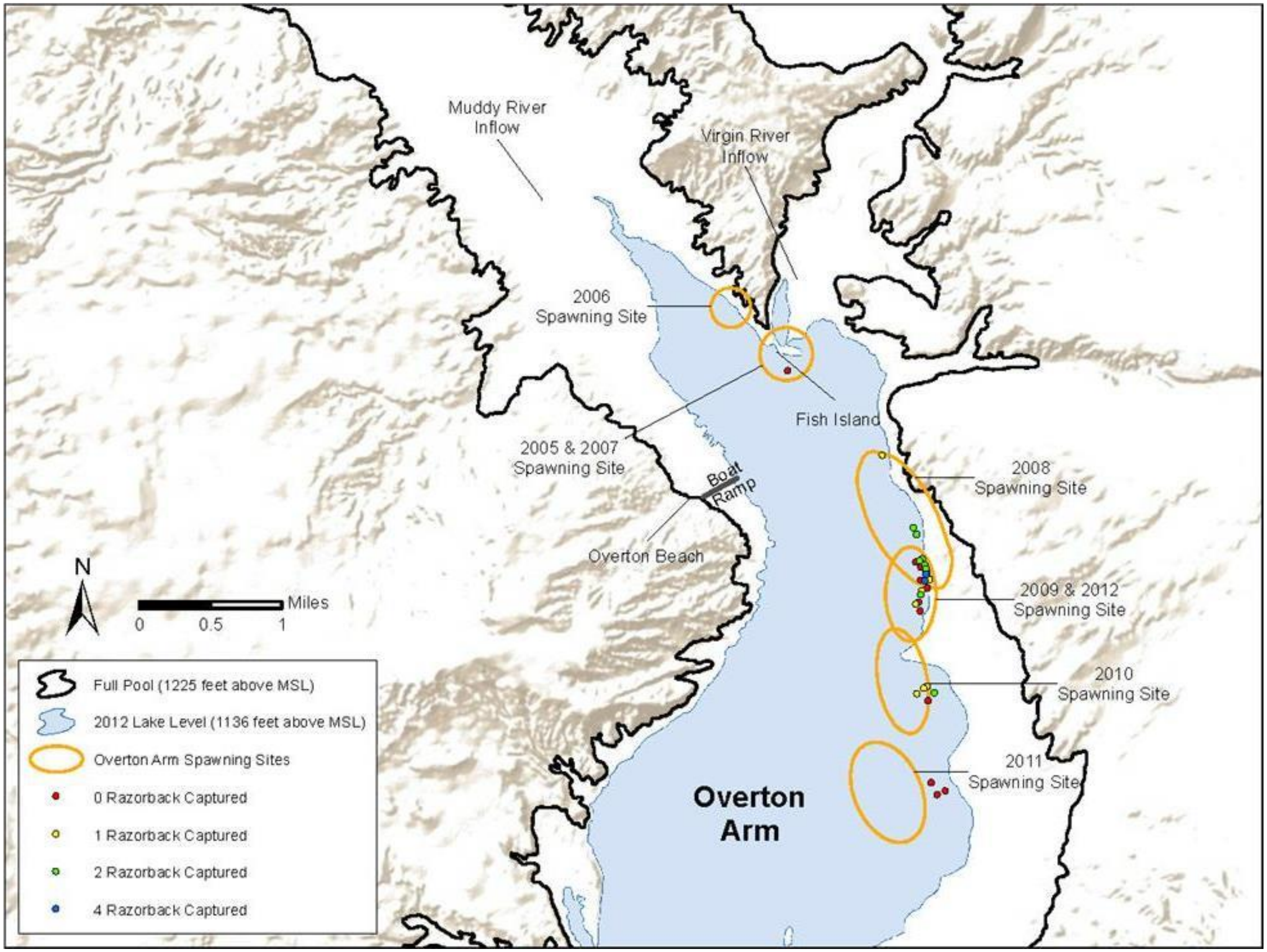


Figure 1-11.—Muddy River/Virgin River inflow study area showing locations of trammel netting and numbers of fish captured, February 2012 – April 2012.

Table 1-3.—Location, tagging, and size information for razorback suckers captured in Lake Mead from February 2012 to April 2012

Date	Capture location[a]	PIT tag number	Sonic tag	Date stocked[b]	Recapture?	TL[c]	FL[d]	SL[e]	Wt[f]	Sex[g]
1/31/2012	OA	3D9.1C2D26878D		4/19/2011	YES	529	489	448	1,780	M
1/31/2012	OA	3D9.1C2D260644		1/31/2012	NO	604	564	529	2,728	F
1/31/2012	OA	3D9.1C2C8572D2		1/31/2012	NO	570	525	484	1,960	M
2/1/2012	OA	384.1B796EE0D6	448	1/4/2011	YES	525	480	446	1,788	M
2/7/2012	OA	3D9.1C2D26990C		2/22/2011	YES	544	505	470	1,780	M
2/7/2012	OA	3D9.1C2C83C396		2/7/2012	NO	525	486	445	1,708	M
2/8/2012	OA	3D9.1C2D262764		2/8/2012	NO	623	581	523	2,796	F
2/8/2012	OA	3D9.1C2C841587		2/8/2012	NO	536	477	442	1,638	M
2/8/2012	OA	3D9.1C2C843FA8		2/8/2012	NO	501	459	408	1,404	M
2/9/2012	EB	3D9.1C2D2690E3		2/9/2012	NO	619	575	531	2,704	F
2/9/2012	EB	1F4A16047D/ 3D9.1C2C840F6D[h]		1/22/2002	YES	644	605	551	4,020	F
2/16/2012	EB	4515412C47/ 3D9.1C2D268EAF	365	12/2/2008	YES	565	515	486	2,098	M
2/16/2012	EB	3D9.1C2C84147F		2/16/2012	NO	559	518	485	1,934	M
2/16/2012	EB	5325515754/ 3D9.1C2C7F4DA8		2/1/2006	YES	706	648	599	4,000	F
2/21/2012	OA	384.1B7969CC00		2/21/2012	NO	566	522	480	2,006	F
2/21/2012	OA	384.1B7969E573		2/21/2012	NO	590	550	512	2,727	F
2/22/2012	EB	384.1B7969D60C		2/22/2012	NO	589	540	500	2,028	M
2/22/2012	EB	384.1B7969E02A		2/22/2012	NO	548	504	471	1,978	M
2/28/2012	LB	3D9.1C2C7EF161	222	2/28/2012	NO	425	395	360	808	I
2/29/2012	LB	532574067F/ 3D9.1C2C844C24		2/27/2007	YES	648	604	553	3,688	M
3/1/2012	EB	3D9.1C2C840ECD		3/1/2012	NO	585	539	496	2,872	F
3/7/2012	EB	3D9.1C2C841C6D		2/23/2011	Yes	572	533	508	2,056	M
3/7/2012	EB	384.1B7969D618		3/7/2012	NO	663	614	576	3,629	F
3/13/2012	OA	384.1B7969D59B		3/13/2012	NO	555	509	451	2,020	F
3/13/2012	OA	384.1B7969D3E6		3/13/2012	NO	521	480	425	1,588	M
3/13/2012	OA	384.1B7969DB4E		3/13/2012	NO	618	575	533	2,098	F
3/13/2012	OA	384.1B7969D41E		3/13/2012	NO	610	565	529	2,598	F
3/14/2012	OA	3D9.257C6096E1	3578	1/4/2011	YES	561	524	500	1,898	F
3/14/2012	OA	384.1B7969D59B		3/13/2012	YES	Quick release[i]				F
3/14/2012	OA	3D9.257C619794		2/22/2011	YES	610	551	526	2,310	F
3/14/2012	OA	3D9.257C5F52BD		3/17/2010	YES	615	578	545	2,748	F
3/14/2012	OA	384.1B7969D9F8		3/14/2012	NO	530	486	455	1,568	M
3/14/2012	OA	384.1B7969E350		3/14/2012	NO	539	440	400	1,886	M
3/15/2012	OA	384.1B7969E16B		3/15/2012	NO	576	530	498	1,894	F

Table 1-3.—Location, tagging, and size information for razorback suckers captured in Lake Mead from February 2012 to April 2012

Date	Capture location[a]	PIT tag number	Sonic tag	Date stocked[b]	Recapture?	TL[c]	FL[d]	SL[e]	Wt[f]	Sex[g]
3/15/2012	OA	3D9.1C2D268EC1		2/22/2011	YES	540	496	461	1,728	M
3/15/2012	OA	384.1B7969D849		3/15/2012	NO	574	530	496	2,206	F
3/15/2012	OA	384.1B7969D27B		3/15/2012	NO	546	505	475	1,760	M
3/15/2012	OA	3D9.257C6096E1	3578	1/4/2011	YES	561	524	500	1,898	F
3/21/2012	OA	384.1B7969DCC6		3/21/2012	NO	559	513	469	2,008	F
3/22/2012	EB	3D9.1C2C83E120		2/1/2011	YES	603	561	521	2,568	F
3/22/2012	EB	384.1B7969D204		3/22/2012	NO	620	569	529	2,388	F
3/26/2012	EB	3D9.1C2C840759		3/15/2011	YES	607	565	529	2,518	F
3/28/2012	OA	384.1B7969EBE1		3/28/2012	NO	573	526	498	2,248	F
3/29/2012	EB	384.1B7969DD97		3/29/2012	NO	571	528	489	1,652	M
3/29/2012	EB	384.1B7969DE3C		3/29/2012	NO	595	549	518	2,288	F
3/29/2012	EB	3D9.1C2D268469		2/23/2011	YES	586	539	507	2,188	F
3/29/2012	EB	7F7D2B2D5F/ 384.1B7969EE45		4/2/1993	YES	610	561	532	2,694	M
4/4/2012	OA	384.1B7969D573		4/4/2012	NO	575	531	494	2,238	F
4/4/2012	OA	384.1B7969E475		4/4/2012	NO	551	510	471	1,826	M
4/11/2012	OA	3D9.1C2C83E2AA		2/22/2011	YES	504	468	431	1,578	M
4/11/2012	OA	3D9.1C2D269C8A		4/11/2012	NO	535	491	458	1,514	M
4/12/2012	EB	3D9.1C2D2636A6		4/12/2012	NO	571	527	492	2,266	F
4/19/2012	OA	384.1B7969DCC6		3/21/2012	YES	Quick release	F			
4/23/2012	LB	3D9.1C2D6C7451	368	4/23/2012	NO[j]	345	318	290	484	I
4/23/2012	LB	3D9.1C2D6CD635	337	4/23/2012	NO[j]	390	357	320	714	I
4/24/2012	LB	3D9.1C2D6D0B6C	452	4/24/2012	NO[j]	340	319	294	468	I

[a] OA = Overton Arm (Muddy River/Virgin River inflow area), EB = Echo Bay, and LB = Las Vegas Bay.
[b] Date originally stocked or originally captured.
[c] TL = Total length in millimeters.
[d] FL = Fork length in millimeters.
[e] SL = Standard length in millimeters.
[f] Weight (grams).
[g] F = female, M = male, U = unidentified, and I = immature (sex not determined).
[h] Two PIT tag numbers may be present in older, recaptured individuals that were marked originally with an older style PIT tag (e.g., 400 kilohertz) and recently tagged again with a new, 12.5-millimeter, 134.2-kilohertz style PIT tag.
[i] No measurements were taken due to the proximity of the date of capture to date of recapture; individual was released immediately to avoid unnecessary stress.
[j] These three fish were stocked by the NDOW/BIO-WEST into Las Vegas Bay. They are pond-reared fish from the Overton Wildlife Management Area Ponds (Center Pond) and were introduced for purposes of the juvenile pilot study, which is to be described in chapter 2 of this report.

tagged in the Muddy River/Virgin River inflow area, and one of the recaptured fish was sonic-tagged fish 365, which was stocked into Echo Bay during the 2008 tagging events (Kegerries et al. 2009). At the Muddy River/Virgin River inflow area, 11 of 33 (33.3%) razorback suckers caught in 2012 were recaptures. Of the 11 recaptures from the Muddy River/Virgin River inflow area, one was a fish originally tagged in Echo Bay, and two of the recaptures were a single sonic-tagged fish (code 3578) that was captured on two distinct occasions. For netting efforts during the 2012 field season, captures from all of the Lake Mead long-term monitoring sites combined were approximated to be comprised of 55% females, 43% males, and 2% immature fish. We note that overall captures were low in Las Vegas Bay (only one adult male and one juvenile were captured in 2012). We also highlight that the only juvenile razorback sucker captured in 2012 came from Las Vegas Bay. At Echo Bay, the ratio of females to males was 11:7, and in the Muddy River/Virgin River inflow area, this same ratio was 18:15 during 2012.

One adult and one juvenile razorback sucker were captured at Las Vegas Bay during the 2012 spawning period (see table 1-3). Both the adult and juvenile fish were captured from the back of Las Vegas Bay, near the Las Vegas Wash inflow. In comparison, nine razorback suckers (four adult and five juvenile fish) were captured in the bay in 2011, and 20 were captured in 2010 (Albrecht et al. 2010b; Shattuck et al. 2011). The razorback sucker catch per unit effort (CPUE) from trammel netting at the Las Vegas Bay area was 0.07 fish/net-night for the 2012 field season. This rate is lower than the past 3 years' rates (2009 = 1.96 fish/net-night, 2010 = 1.00 fish/net-night, 2011 = 0.43 fish/net-night); however, it falls within the CPUE values observed throughout the course of this study (Shattuck et al. 2011) (figure 1-12). It should be noted that the lowest CPUE values observed in Las Vegas Bay were 0.04 fish/net-night during the 2003–04 field season, followed by the CPUE value of 0.07, which was observed during the 2004–05 and current (2011–12) field seasons.

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 (see figure 1-10). 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 comprising larger substrates (e.g., cobble and boulders) and along the southern shore in an area of recently inundated vegetation and appropriate cobble/gravel substrates. We were fortunate in 2012 to be able to sample much of the western end (back portions) of Echo Bay, while avoiding boat ramp and public access conflicts. With the conditions described above, 18 adult razorback suckers were captured in 31 net-nights (see tables 1-2, 1-3, and figure 1-12). In comparison, 15 razorback suckers were captured during the 2011 spawning season, 13 razorback suckers were captured during the 2010 spawning season, and only 4 adult razorback suckers were collected from Echo Bay in 2009. No juvenile fish were captured from Echo Bay during the 2012

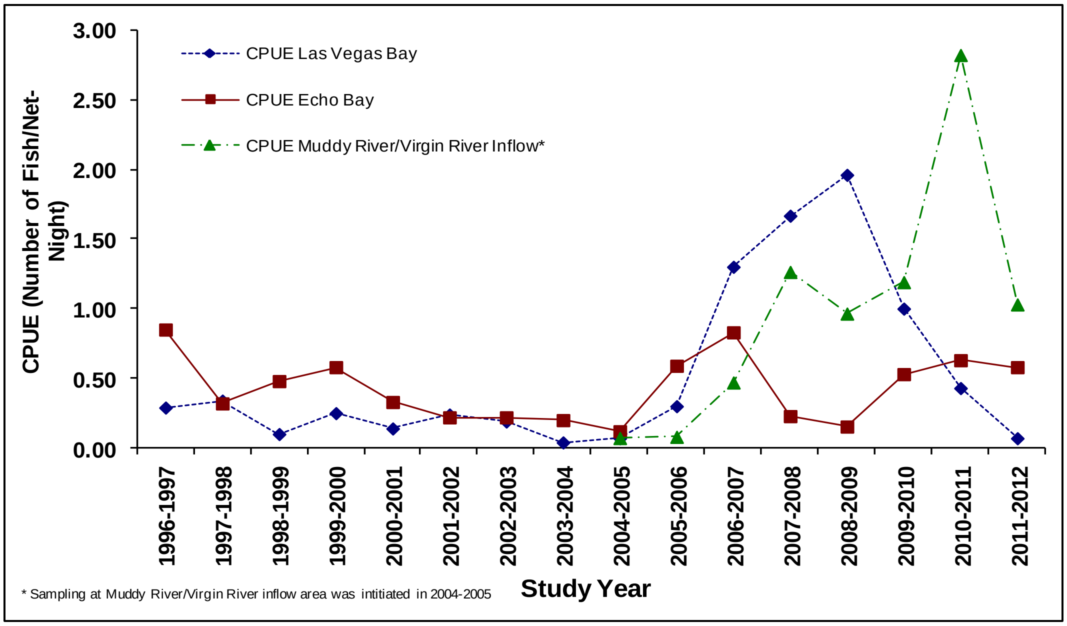


Figure 1-12.—Trammel netting CPUE in number of fish per net-night during studies on Lake Mead razorback sucker, 1996–2012.

spawning period, marking the fifth year without juvenile captures in this area. The 2012razorback sucker CPUE for trammel netting at Echo Bay was 0.58 fish/net-night, which falls between the catch rates observed during the previous two field seasons (0.63 fish/net-night in 2011 and 0.53 fish/net-night in 2010) (see figure 1-12).

We were again successful at capturing razorback suckers at the Muddy River/ Virgin River inflow area during the 2012 field season (see figure 1-11). In fact, the highest CPUE rates and total numbers of razorback suckers captured at any location during the 2012 long-term monitoring occurred there. Trammel netting in 2012 resulted in the capture of 33 adult razorback suckers at the Muddy River/Virgin River inflow area. Most of these fish were captured over gravel and small-cobble substrates along the eastern shoreline south of the Virgin River inflow and near the 2009 spawning area (see figure 1-11). The razorback sucker CPUE for trammel netting at the Muddy River/Virgin River inflow area was 1.03 fish/net-night, the highest rate for all three long-term monitoring sites on Lake Mead in 2012 (see figure 1-12). For the third consecutive year since sampling began at the Muddy River/Virgin River inflow area, CPUE rates exceeded those from both the Las Vegas Bay and Echo Bay study areas (Muddy River/Virgin River inflow area CPUE 2010 = 1.19 fish/net-night, and 2011 = 2.82 fish/net-night) (see figure 1-12). Despite a lower CPUE in Las Vegas Bay this year compared to the recent past several seasons (figure 1-12), the overall Lake Mead CPUE for 2012 (0.57 fish/net-night) is the same as the average, combined (all long-term monitoring sites), historical CPUE (0.57 fish/net-night).

It should be noted that during the 2012 spawning period, two flannelmouth suckers were captured, both from the Muddy River/Virgin River inflow area. One flannelmouth sucker was a new, wild, unmarked individual, and we obtained a fin ray section for aging purposes. The other fish was a recaptured individual that was originally captured in 2011 in the Muddy River/Virgin River inflow area and also was subjected to fin ray aging procedures during 2012. The 2012 CPUE for flannelmouth suckers in the Muddy River/Virgin River inflow area was 0.06 fish/net-night (in 2011, it was 0.05 fish/net-night). Flannelmouth suckers have been captured at the Muddy River/Virgin River inflow area in low numbers since 2010, with 2012 marking the third consecutive year that flannelmouth suckers have been documented during long-term monitoring efforts.

Another observation from 2012 is the continued and elevated CPUE of razorback suckers in the Muddy River/Virgin River inflow area, marking the third consecutive year the CPUE in this study area exceeded the CPUE in Las Vegas and Echo Bays (see figure 1-12). Sixty-two percent of the razorback suckers captured in 2012 came from the Muddy River/Virgin River inflow area, while 4% of the total annual razorback sucker catch came from Las Vegas Bay and a notable 34% came from Echo Bay. Perhaps most interesting is that the majority of the fish captured at the Muddy River/Virgin River inflow area continue to be wild, unmarked individuals. In all, the 2012 spawning period was fairly average for razorback sucker captures as evidenced by CPUE values (see figure 1-12). In 2012, Echo Bay again contributed a substantial percentage (34%) of razorback suckers to the overall catch, many of which were fairly large and fairly old, recaptured individuals. This indicates that Lake Mead razorback suckers can and do survive for substantial periods of time despite many potential stressors and causes of mortality (see table 1-3 and attachment 1).

In summary, 661 unique individual razorback suckers have been identified at long-term monitoring sites during this 16-year study by multiple agencies (BIO-WEST, NDOW, and the USFWS). In Las Vegas Bay, 312 unique individuals have been PIT tagged. One hundred seventy-six unique individuals have been captured and PIT tagged in Echo Bay, and 173 unique individuals have been captured in the Muddy River/Virgin River inflow area. Note that the 661 fish total does not include razorback suckers found at the CRI area. Those results are found in the 2012 CRI area companion report (Kegerries and Albrecht 2013).

Growth

Although 20 razorback suckers were recaptured during the 2012 field season (1 from Las Vegas Bay, 8 from Echo Bay, and 11 from the Muddy River/Virgin river inflow area), annual growth analyses were only performed using data from 17 of these individuals. All recaptures were not included in the analyses because some individuals were captured more than once during the 2012 field season (e.g., more than once between February 2012 and April 2012). The difference in TL between capture periods was used to determine mean annual growth (table 1-4). Four stocked fish and 13 wild fish were used to calculate growth data

Table 1-4.—Lake Mead razorback sucker growth histories for fish recaptured during the February 2012 – April 2012 field season

Pit tag Number	Date stocked[a]	TL (mm)[b]	Last date recaptured	TL (mm)	Total growth (mm)[c]	Days between measurements	Growth/year (mm/365 days)[c]
Las Vegas Bay							
Wild fish							
532574067F	2/27/2007	650	2/29/2012	648	-2	1,828	-0.4
						Mean annual growth	**N/A[d]**
Echo Bay							
Stocked fish							
1F4A16047D	4/17/2002	583	2/9/2012	644	61	3,585	6.2
4515412C47	12/2/2008	496	2/16/2012	565	69	1,171	21.5
						Mean annual growth	**13.9**
Wild fish							
5325515754	2/1/2006	705	2/16/2012	706	1	2,206	0.2
3D9.1C2C841C6D	2/23/2011	545	3/7/2012	572	27	378	26.1
3D9.1C2C83E120	2/1/2011	571	3/22/2012	603	32	415	28.1
3D9.1C2C840759	3/15/2011	575	3/26/2012	607	32	377	31.0
3D9.1C2D268469	2/23/2011	552	3/29/2012	586	34	400	31.0
7F7D2B2D5F	1/27/1997	590	3/29/2012	610	20	5,540	1.3
						Mean annual growth	**19.6 ±2.3**
Muddy River/Virgin River inflow area							
Stocked fish							
384.1B796EE0D6	1/4/2011	502	2/1/2012	525	23	393	21.4
3D9.257C6096E1	1/4/2011	541	3/14/2012	561	20	435	16.8
						Mean annual growth	**19.1**
Wild fish							
3D9.1C2D26878D	4/19/2011	515	1/31/2012	529	14	287	17.8
3D9.1C2D26990C	2/22/2011	524	2/7/2012	544	20	350	20.9
3D9.257C619794	2/22/2011	585	3/14/2012	610	25	386	23.6
3D9.257C5F52BD	3/17/2010	600	3/14/2012	615	15	728	7.5
3D9.1C2D268EC1	2/22/2011	508	3/15/2012	540	32	387	30.2
3D9.1C2C83E2AA	2/22/2011	501	4/11/2012	504	3	414	2.6
Mean annual growth							**17.1 ±4.2**
Mean annual growth of all wild Las Vegas Bay, Echo Bay, and Overton Arm fish							**16.9 ±3.5**
Mean annual growth of all stocked Echo Bay and Overton Arm fish							**16.5 ±3.6**
Mean annual growth of all Las Vegas Bay, Echo Bay, and Overton Arm fish							**16.8 ±2.8**

[a] The date a fish was stocked into Lake Mead or the date a wild fish was originally captured.
[b] Total length in millimeters.
[c] Negative values attributable to measurement error.
[d] Mean could not be calculated from growth of one individual.

for 2012. The combined (all long-term monitoring sites) mean annual growth of all razorback suckers recaptured from Lake Mead during 2012 was 16.8 millimeters [mm]/year (see table 1-4), compared to 24.7 mm/year in 2011 (Shattuck et al. 2011). The mean annual growth of wild fish captured in Lake Mead in 2012 was 16.9 mm/year (see table 1-4), compared to 19.3 mm/year in 2011 (Shattuck et al. 2011). The mean annual growth of stocked fish was 16.5 mm/year for 2012 (see table 1-4), compared to 35.5 mm/year in 2011 (Shattuck et al. 2011).

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 January 30, 2012. With few exceptions, four to eight monitoring sites were sampled weekly in February, March, and April 2012 for each of the three primary spawning sites. Larvae were first collected on February 1, 2012, at Las Vegas Bay over a variety of substrates and at temperatures near 13 °C (55 °F). The initial captures at Las Vegas Bay were from a small cove on the southwestern shoreline just outside of Las Vegas Wash (figure 1-13). However, larvae were collected throughout the back portions of Las Vegas Bay in 2012, primarily at temperatures between 15–21 °C (59–70 °F). The back of Las Vegas Bay, as a spawning area, corresponds with primary spawning sites identified in the past by Albrecht et al. (2008a), Kegerries et al. (2009), Albrecht et al. (2010b), and Shattuck et al. (2011). The capture of larval fish from both the northern to southern shores, in conjunction with sonic-tagged fish locations and limited trammel netting data, helped define the location of the 2012 spawning site (figures 1-4 and 1-13). In all, Las Vegas Bay yielded a total of 274 larval fish captured within 1,530 minutes of sampling, providing a catch per minute (CPM) value of 0.179 (table 1-5). Razorback sucker larvae CPM at Las Vegas Bay in 2012 was higher than that observed in 2010, but it represents one of the lower overall CPM values observed since 2007 (table 1-6).

At Echo Bay, the first razorback sucker larvae were captured on February 29, 2012, over gravel/cobble substrates at temperatures of 12–14 °C (54–57 °F) toward the northwestern portion of the bay. Collection efforts in Echo Bay returned the highest total number of captures and CPM values for larval razorback sucker in any study area during 2012. The collection of 439 larval razorback suckers resulted in a CPM value of 0.220 (table 1-5). Larval fish were found on both the northern and southern shorelines, with nearly all collections from the back (behind the boat ramp) portions of the bay (figure 1-14). The 2012 Echo Bay larval razorback sucker captures confirmed spawning success in Echo Bay during 2012; hence, Echo Bay continues to be an important spawning area for Lake Mead razorback suckers (table 1-6).

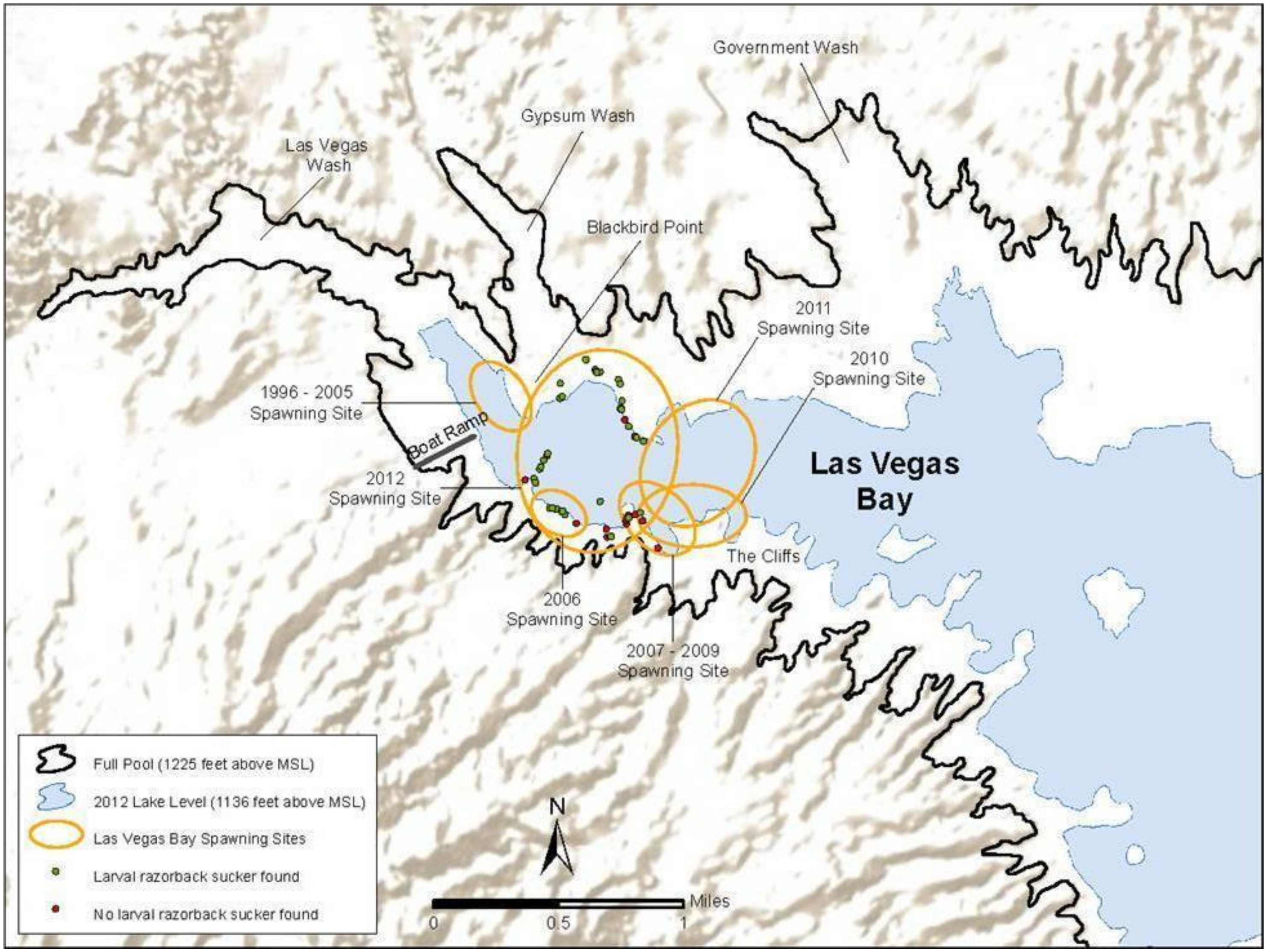


Figure 1-13.—Las Vegas Bay study area showing larval razorback sucker sampling and capture locations, February 2012 – April 2012.

Table 1-5.—Number of razorback sucker larvae collected at Las Vegas Bay, Echo Bay, and the Muddy River/Virgin River inflow area of Lake Mead during February 2012 – April 2012

Date	Las Vegas Bay sampling sites			Echo Bay sampling sites			Muddy River/Virgin River inflow sampling sites		
	Minutes sampled	Larvae captured	CPM	Minutes sampled	Larvae captured	CPM	Minutes sampled	Larvae captured	CPM
01/30/12							150	0	0.000
01/31/12				120	0	0.000			
02/01/12	180	18	0.100						
02/06/12							90	0	0.000
02/07/12				90	0	0.000			
02/09/12	120	21	0.175						
02/14/12	210	1	0.005						
02/15/12				120	0	0.000			
02/20/12							150	0	0.000
02/21/12				150	0	0.000			
02/22/12	210	45	0.214						
02/29/12				120	1	0.008			
03/01/12	120	25	0.208						
03/05/12	150	90	0.600						
03/07/12				180	116	0.644			
03/09/12	90	21	0.233						
03/12/12				150	253	1.687			
03/14/12							180	1	0.006
03/20/12							120	1	0.008
03/21/12				120	18	0.150			
03/26/12	180	49	0.272						
03/27/12							180	0	0.000
03/28/12				168	39	0.232			
04/02/12				150	2	0.013			
04/03/12							120	0	0.000
04/09/12	150	0	0.000						
04/10/12				150	0	0.000			
04/11/12				150	0	0.000			
04/16/12	120	4	0.033						
04/18/12							120	2	0.017
04/24/12				210	7	0.033			
04/25/12				120	3	0.025			
Totals	**1,998**	**439**	**0.220**	**1,530**	**274**	**0.179**	**1,110**	**4**	**0.004**

Table 1-6.—Larval razorback sucker CPM comparisons by primary study area for 2007–12

Primary study area	2007	2008	2009	2010	2011	2012
Las Vegas Bay	0.390	0.430	0.342	0.093	0.282	0.179
Echo Bay	0.430	0.024	0.021	0.269	1.482	0.220
Muddy River/Virgin River inflow	0.001	0.116	0.107	0.011	0.013	0.004

At the Muddy River/Virgin River inflow study area, the first razorback sucker larvae of the season were captured on March 14, 2012, over sand and cobble substrates at temperatures of 13–14 °C (55–57 °F), approximately 2 mi (3.2 km) south of the Muddy River/Virgin River inflow area along the eastern shoreline of the Overton Arm, near the 2009 spawning area (figures 1-1 and 1-15). Larval captures occurred in the same vicinity as multiple adult razorback sucker captures from trammel netting collections and near areas routinely frequented by sonic-tagged individuals (table 1-5 and figure 1-15), although in numbers disproportionate to the abundance of adult captures (as has been typical and relative to values observed at this location to date). Although numerous adult razorback suckers were captured and documented as being reproductively ready near sites where larvae were collected, other environmental variables (e.g., high winds in the Overton Arm) may have played a part in the low observed larval abundance in the Muddy River/Virgin River inflow area relative to other Lake Mead study areas. In 2012, larval captures in the Muddy River/Virgin River inflow area were comparable with the majority of previous years' captures and occurred at temperature ranges of 14–22 °C (57–72 °F). Four larval razorback suckers were captured, resulting in a CPM of 0.004 (tables 1-5 and 1-6).

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 during this 16-year study. However, favorable runoff conditions in 2011 served to temporarily increase lake elevations, and at the beginning of 2012, the lake elevation was at a 5-year high of approximately 1,134 ft (345.6 m) AMSL (figure 1-16). As a result of variable lake elevations throughout the last decade, Lake Mead razorback suckers have continually shifted spawning sites to accommodate varying conditions.

Though it was difficult to assign a primary spawning site for Las Vegas Bay during the 2011–12 field season, the primary area for reproductive activity (i.e., capture of reproductively ready individuals, collection of larval individuals, and the presence of sonic-tagged individuals) for this year overlapped with the designated spawning site from the 2005–06 field season. The 2011–12 field

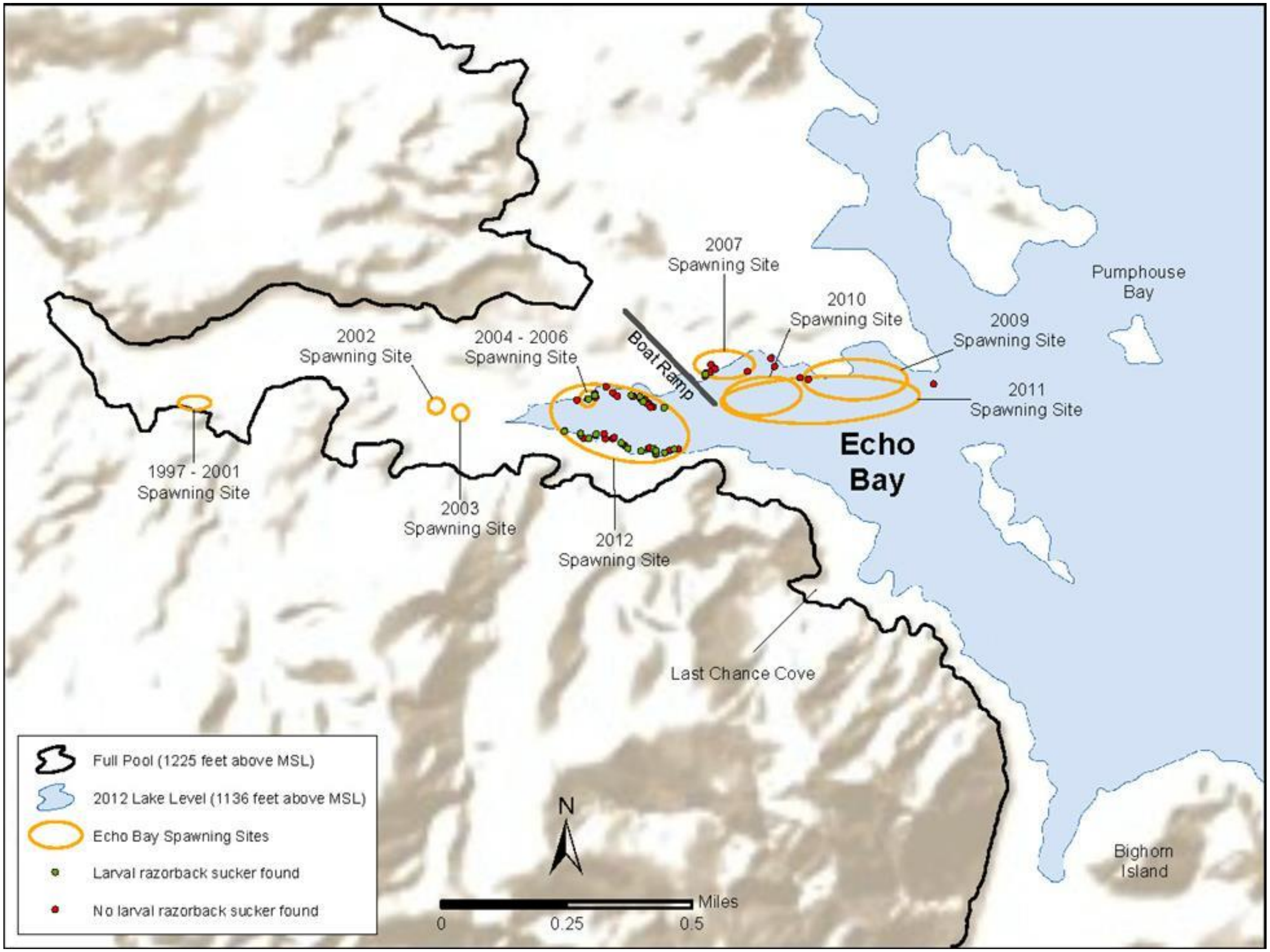


Figure 1-14.—Echo Bay study area showing larval razorback sucker sampling and capture locations, February 2012 – April 2012.

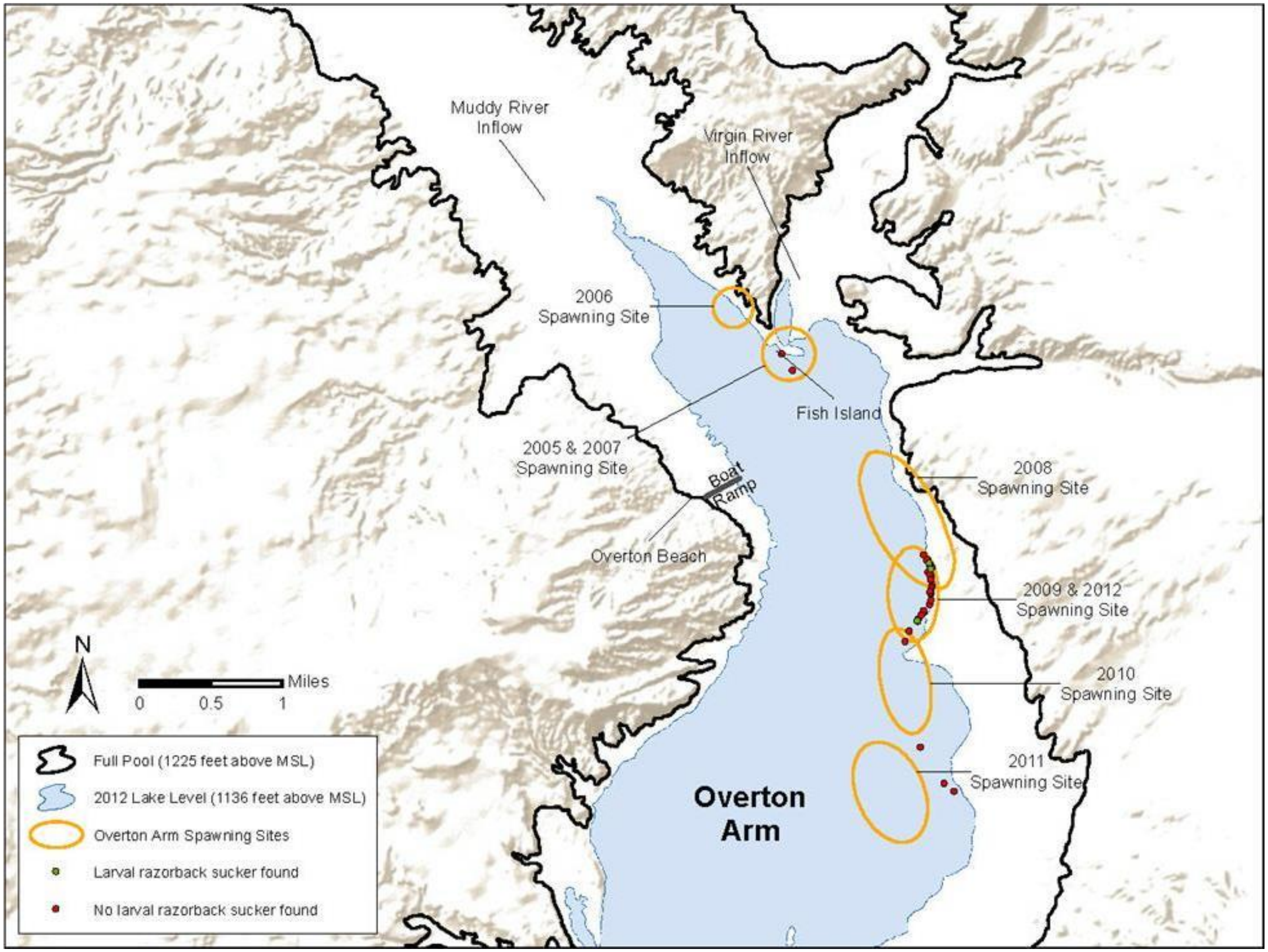


Figure 1-15.—Muddy River/Virgin River inflow study area showing larval razorback sucker sampling and capture locations, February 2012 – April 2012.

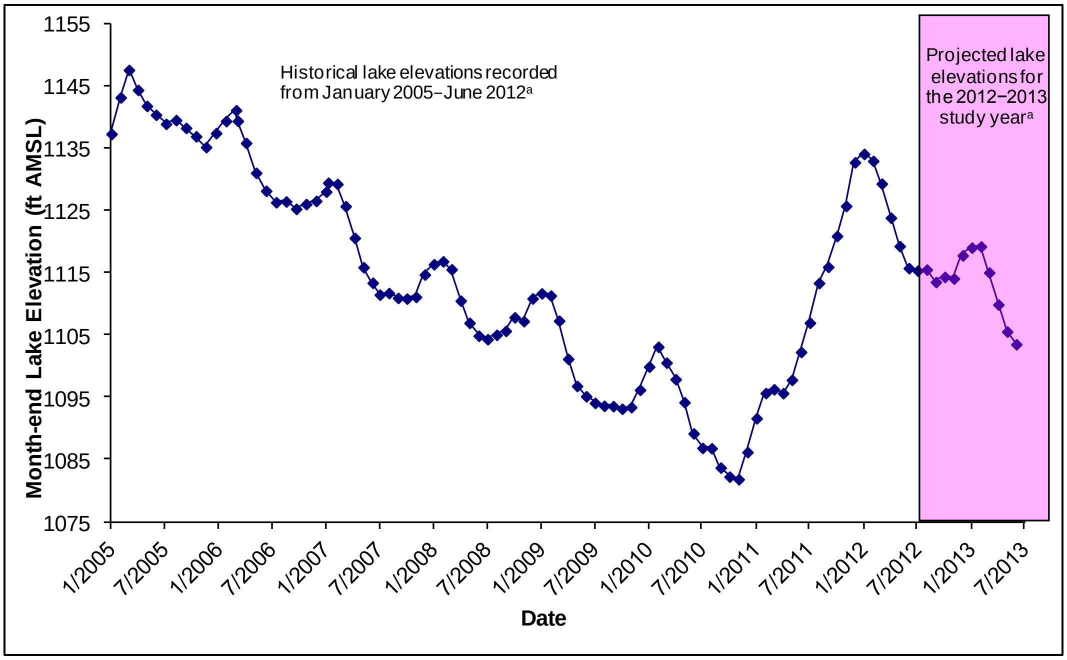


Figure 1-16.—Historical Lake Mead month-end lake elevations in ft AMSL from January 2005 to June 2012 and projected lake elevations for the 2012–13 study year.
Data from Reclamation (2012).

season spawning area was located 0.3 mi (0.5 km) south of the Las Vegas Wash inflow area, along the southwestern shoreline of the bay (Albrecht et al. 2006b). For the past 4 years, the razorback suckers' primary spawning site was in the same general vicinity, although it shifted with receding lake elevations further southeast of the 2006 spawning site (see figure 1-13). Similar to the 2010–11 field season, during the 2011–12 field season, sonic-tagged razorback suckers 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 were collected (see figure 1-13). Despite a low trammel netting CPUE, successful spawning of razorback suckers 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 et al. 2003, 2004; Albrecht et al. 2005, 2006b), receding lake elevations resulted in eastward shifts of the primary Echo Bay spawning site. As was observed in Las Vegas Bay, the Echo Bay spawning site for the 2011–12 field season overlapped the spawning area for the 2005–06 field season (see figure 1-14). This overlap was not surprising, as 2011–12 lake elevations closely matched those seen in 2005–06 and possibly influenced the return of numerous older, recaptured individuals to Echo Bay.

Trammel netting collections, sonic-tagged individual presence, and larval fish collections occurred most abundantly in the far western and northern shorelines of Echo Bay, approximately 0.1 mi (0.2 km) southwest of the boat ramp (see figure 1-14). Rising lake elevations in 2012 temporarily increased the size of Echo Bay, and spawning individuals were able to return to shallowly inundated vegetation southwest of the boat ramp.

Of the three long-term monitoring study areas on Lake Mead, the least understood with regard to habitat and reproductive activity is the Muddy River/Virgin River inflow area. While areas of Las Vegas Bay and Echo Bay mirrored spawning sites used during the 2005–06 field season, the Muddy River/Virgin River inflow area did not follow that general trend. Here, the spawning site for the 2011–12 field season was identified further south of the 2005–06 area, with a location across from Overton Beach, which was nearly identical to the 2008–09 field season spawning site (see figure 1-15). Similar to the 2007–11 field seasons, the collection of numerous ripe, adult razorback suckers in 2012 (and relative to other sites in Lake Mead) signified that spawning was likely occurring there. Furthermore, the capture of larval fish confirmed successful spawning in the northeastern part of the lake. The spawning site in the Muddy River/Virgin River inflow area was approximately 2 mi (3.2 km) south of the Virgin River inflow along the eastern shoreline of the Overton Arm (see figure 1-15). Future efforts in the Muddy River/Virgin River inflow area will be important in determining changes in the size of the spawning aggregate, changes in spawning sites, and the degree to which successful spawning and recruitment are occurring.

Age Determination

To date, a definitive age has been determined for 395 Lake Mead razorback suckers captured during long-term monitoring efforts. In 2012, ages were obtained from 35 razorback suckers captured in trammel nets on Lake Mead (attachment 1; figure 1-17). The youngest fish was 6 years old (2006 year-class), measured 551 mm (TL), and was sexually mature, while the oldest fish was a 29-year-old female (1983 year-class) with a TL of 644 mm. The majority of fish aged (60.0%, n = 21) ranged from 9 to 12 years old (2000–2003 year-classes), while nine of the fish (25.7%) were 7–8 years old (2005–06 year-classes). Finally, three fish (8.5%) were 13–14 years old (1998–99 year-classes). Additionally, a wild juvenile (425 mm TL) was captured and surgically implanted with a sonic tag (code 222) for use in the juvenile razorback sucker pilot study (see chapter 2). A fin clip to determine age was not collected from this individual to avoid overstressing the fish.

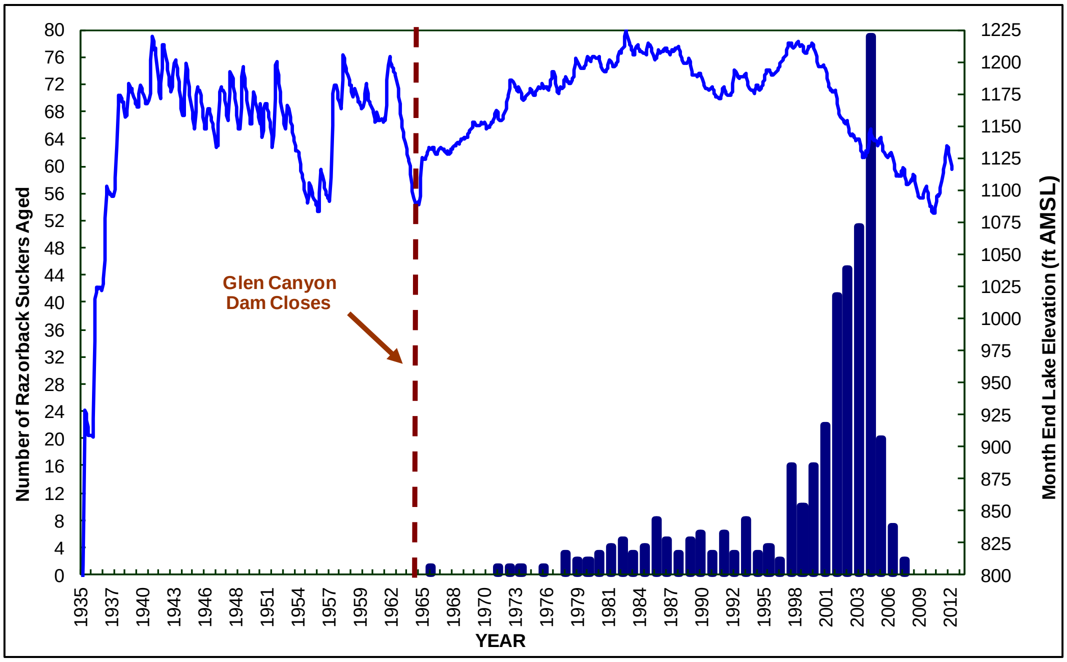


Figure 1-17.—Lake Mead month-end lake elevations in ft AMSL from January 1935 to June 2012, with the number of aged razorback suckers spawned each year.

To date, all fish aged have undergone back-calculation techniques and have been assigned to a specific year-class (spanning 1972–2008), with the exception of one individual from the 1966 age-class (attachment 1). Until the last six field seasons, the majority of aged fish were spawned during high lake elevations between 1978–89 and 1997–99 (see figure 1-17). However, data to date clearly show Lake Mead razorback sucker recruitment occurring beyond 1999, which coincides with the steady decline of lake elevations during more recent study years. Based on the cumulative dataset, the largest number of individuals (258) was spawned from 2001 to 2006. Within that period, 79 individuals were aged from 2005 year-class alone, which exemplifies a pulse of natural recruitment for razorback suckers in Lake Mead. It also appears that some level of recruitment is possible in Lake Mead regardless of lake elevation, as natural recruitment occurred nearly every year through 2008 (see figure 1-17). Furthermore, it is anticipated that fish spawned and recruited from 2009 to 2012 will become susceptible to sampling gear in the near future (perhaps as early as the 2012–13 field season).

In addition to razorback suckers, ages were determined for two flannelmouth suckers captured at the Virgin River/Muddy River inflow area in 2012. One fish was a new, wild fish, and one fish was a recaptured fish from 2011. The new fish was 7 years old (year-class 2005) with a TL of 504 mm, and the recaptured fish was a 465-mm, 6-year-old individual (year-class 2006).

Population and Survival Rate Estimation

Population Estimation

Using data from 2010 to 2012, the Las Vegas Bay estimate resulted in 96 individuals bounded, with a 95% confidence interval (CI) of 49 and 238 individuals (table 1-7). The combined Echo Bay and Muddy River/Virgin River inflow area population was estimated at 589 individuals (CI = 409–891), while the combined estimate (all long-term monitoring sites), using data from all long-term monitoring sites, was estimated at 695 individuals (CI = 497–1,014). The combined long-term monitoring and CRI area estimates were calculated at 596 individuals (CI = 468–786) (table 1-7). Model ranking according to AICc weights and model likelihoods for estimates produced in MARK can be found in attachment 3. These results were similar to those generated by CAPTURE (attachment 2).

Table 1-7.—Population estimates for razorback suckers in Lake Mead using mark-recapture data from 2010 to 2012 from MARK

Site	Population estimate	95% CI (lower)	95% CI (upper)	Capture histories	Capture probability
Las Vegas Bay	96	49	238	32	0.0098
Echo Bay and Muddy River/Virgin River inflow	589	409	891	35	0.0079
Combined (all long-term monitoring sites)	695	497	1,014	35	0.0080
Combined (long-term monitoring and CRI areas)	596	468	786	41	0.0116

Survival Rate Estimation

The model ranking in MARK found the best fit CJS model carried 100.0% of the AICc weight, and the best-fit Pradel model carried 99.9% of the AICc weight (attachment 4). The CJS survival model calculated an estimated apparent survival rate of 0.92 (CI = 0.87–0.95), and the Pradel model calculated an estimated apparent survival rate of 0.87 (CI = 0.83–0.91) (table 1-8).

Table 1-8.—Combined apparent survival rate estimates for razorback sucker in Lake Mead using mark-recapture data from 2010 to 2012

Model	Apparent survival rate estimate	95% CI (lower)	95% CI (upper)	Capture histories	Capture probability
CJS	0.92	0.87	0.95	41	0.0249
Pradel	0.87	0.83	0.91	41	0.0368

DISCUSSION AND CONCLUSIONS

Long-term monitoring information collected during the 2011–12 field season (16th field season) has expanded our knowledge of spawning behavior, habitat use, recruitment patterns, growth, and age 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 responses 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 suckers and juvenile fish in Lake Mead. Additional data on annual razorback sucker growth have confirmed rates documented during previous years. Also, aging data from 35 razorback suckers collected in 2012 were added to the 360 fish aged from 1998 to 2011, bringing the total number of fish aged during the course of our studies to 395. These data (to date) demonstrate nearly annual recruitment and continued production of new, wild razorback suckers in Lake Mead. To our knowledge, these processes have not been documented to this degree, for this species, anywhere else in the Colorado River Basin within the recent past.

Lake Elevation

Lake elevations at Lake Mead steadily declined through the 2011–12 field season (see figures 1-2 and 1-16) and provided opposite conditions compared to increasing lake elevations observed and reported during the 2011 razorback sucker spawning season (Shattuck et al. 2011). Instead of habitat being reinundated and lake levels increasing, the 2011–12 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 2012 spawning season, razorback suckers reused some of their historical spawning locations (e.g., figures 1-13–1-15). 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 individuals tagged during previous field seasons and evident at Echo Bay during the 2012 spawning period. More on this subject is included in the “Adult Sampling” and “Spawning Site Identification and Observations” sections below.

We remain hopeful that the lake elevation increases observed in 2011 helped to provide conditions sufficient to allow for another strong year for razorback sucker recruitment (similar to observations of a recruitment pulse seen in 2004–05). 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 refuge for adults, juveniles, and larvae. Turbidity can also increase spatially in the Muddy River/Virgin River inflow area during these high flows, providing 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 suckers in Lake Mead have been observed to require this amount of time (at minimum) to grow and become susceptible to our gear (Albrecht et al. 2008b; Shattuck et al. 2011).

Sonic Telemetry

Sonic telemetry was a vital tool during the 2011–12 field season, helping to define spawning sites, place trammel nets, and document lake-wide movement. Contact was maintained with all eight fish from the 2011 long-term monitoring tagging event, one fish from the 2010 CRI area tagging event, and four fish from the 2008 long-term monitoring tagging event (not including one individual contacted at the CRI area [Kegerries and Albrecht 2013]). Along with general habitat characterization at point of contact and movement data, sonic-tagged fish provided information regarding specific locations of the razorback sucker population, greatly enhancing our ability to catch adults, juveniles, and larvae during the 2012 field season.

Sonic-tagged fish played an essential role in determining trammel net placement for the capture of razorback suckers in Lake Mead, especially at Echo Bay and the Muddy River/Virgin River inflow area. Sonic-tagged razorback suckers in these areas helped demonstrate the connectivity between spawning sites throughout the Overton Arm by using both Echo Bay and the Muddy River/Virgin River inflow area (see figures 1-5 and 1-6). As in previous years, in 2012, sonic-tagged fish helped narrow potential netting locations in the spacious Overton Arm and Muddy River/Virgin River inflow areas and ultimately helped in the collection of new, wild individuals. Though the Muddy River/Virgin River inflow area has been somewhat limited with regard to the presence of sonic-tagged fish in the past (Albrecht et al. 2010b), the few individuals that have remained in the area since 2011 have added a large amount of data that have aided in the understanding of seasonal movement of individual razorback suckers. Furthermore, one individual sonic tagged in 2011 and stocked into the Muddy River/Virgin River inflow area was the sole sonic-tagged fish used to help define the spawning site location for the Echo Bay area in 2012, which aided in the capture of additional razorback suckers. Conversely, a number of adult sonic-tagged individuals were contacted in Las Vegas Bay during the 2011–12 field season. However, finer-scale definition of a spawning area was difficult, and relatively few additional razorback suckers were captured in nearby trammel net sets (see figure 1-4), which is a testament to implementing a multi-method approach that utilizes several aspects of razorback sucker reproduction to designate spawning sites. Sonic-tagged individuals in Las Vegas Bay helped characterize habitat use, specifically use of inundated vegetation and Las Vegas Wash. Additionally, sonic-tagged individuals helped influence netting efforts that resulted in the capture of the only juvenile individual during long-term monitoring in 2012 as well as numerous successful larval collections in Las Vegas Bay (see table 1-5 and figure 1-9).

The continuation of a sonic-based study at Lake Mead has given insight into the seasonal movement and behavior of razorback suckers. Increasing lake levels at the beginning of the 2011–12 field season seemed to aid in moving sonic-tagged individuals into shallow, inundated, vegetated habitat adjacent to major inflows at Lake Mead (e.g., Las Vegas Wash and the Muddy River/Virgin River inflow), underlining the potential importance of cover for these fish. Though it is often difficult to track sonic-tagged fish in inflow and shallow areas, numerous individuals were contacted in this type of habitat (see figure 1-2), which aided exploration of the Las Vegas Wash and the Virgin River inflow. However, it is plausible that some of the "unknown" sonic-tagged fish (see table 1-1) may have avoided detection in these shallow areas of the lake, which remained partially inaccessible by boat. No fish were found occupying the Virgin River proper, though a number of adults were contacted in the Las Vegas Wash proper (codes 357, 678, and 3775). Additionally, a large number of contacts were made with sonic-tagged individuals using habitat approximately 0.5 mi (0.8 km) outside of the aforementioned inflow areas. As such, the use of these areas may provide support for previously suggested hypotheses (Albrecht et al. 2010b; Shattuck et al. 2011) that inflow areas are important to Lake Mead razorback suckers. It may also support the idea that increased turbidity and inundated vegetation provide cover for razorback suckers in Lake Mead (Golden and Holden 2003; Knecht and Ward 2012). As noted by researchers working in other large river basins, inflow habitats provide unique conditions that can support large numbers of species and life stages through habitat diversity and associated increases in niche availability (Kaemingk et al. 2007).

Sonic-tagged fish will continue to provide invaluable data on changes in razorback sucker movement patterns, habitat use, and selected spawning sites. For instance, spawning sites in the Muddy River/Virgin River inflow have moved further in location interannually than any other long-term monitoring site (see figure 1-6). However, sonic-tagged fish have closely followed those fluctuations, and their movements pose interesting questions regarding the similarity of behavior between wild fish and hatchery-reared fish. Though we acknowledge that particular differences may exist, it is interesting to note that the sonic-tagged individuals (hatchery reared or pond reared) in Lake Mead consistently congregate with wild, sexually active razorback suckers from year to year. This is especially interesting, given the possibility that some catostomid fishes may not spawn every year (Geen et al. 1966; Perkins and Scoppettone 2000). As in previous field seasons, sonic-tagged fish were rarely captured despite being targeted during net sets. Only two active sonic-tagged individuals were captured in 2012 despite consistently setting nets near most of the sonic-tagged individuals during trammel netting efforts. This underscores the elusiveness of razorback suckers. Unmarked fish were captured quite consistently, possibly indicating there may be more razorback suckers in Lake Mead than capture rates and population estimates suggest.

Further adding complexity to the possibility of increased numbers of razorback suckers is the ability of stocked, sonic-tagged individuals to move great distances (i.e., between the CRI area, Las Vegas Bay, and the Overton Arm) across Lake Mead. Past reports have discussed long-distance movements (Albrecht et al. 2010c; Shattuck et al. 2011) of particular sonic-tagged individuals, a similar pattern of behavior observed for three fish (codes 357, 678, 3355) during the 2001–12 field season. In 2010, two sonic-tagged fish originally from the Muddy River/Virgin River inflow area and Las Vegas Bay were found in the CRI area, which suggests that stocked razorback suckers can move throughout Lake Mead and leave their original stocking location to join other spawning aggregates (Albrecht et al. 2010c). In 2011, one sonic-tagged individual moved from the CRI area to the Muddy River/Virgin River inflow area, and another sonic-tagged individual moved from Echo Bay to Las Vegas Bay, utilizing Bonelli Bay along the way (Shattuck et al. 2011). Similar behavior was observed in 2011–12 during increased monitoring efforts in areas of Lake Mead not normally sampled except by SURs (e.g., Virgin Basin). One fish (code 678) that made long-distance movements in 2010–11 made a strikingly similar movement in 2011–12, using Bonelli Bay in the summer months, returning to Las Vegas Bay in fall through spring, and again returning to Bonelli Bay in May 2012 (see figures 1-4 and 1-7). This individual helped us gather habitat information for Las Vegas Bay and reaffirmed the potential importance of Bonelli Bay as a productive post-spawn foraging area. Finally, the collection of long-term movement data is important in assessing temporal changes in Lake Mead razorback sucker habitat use, and these individuals may also help inform us about razorback sucker endurance and spawning and recruitment success in spite of Lake Mead's regularly increasing/decreasing lake levels. Replication of these efforts using wild, sonic-tagged fish would help clarify these observations.

During the 2011–12 field season, SURs were increasingly helpful tools for assessing the timing of returning individuals to spawning sites as well as the post-reproductive quiescence and movement into summer foraging areas. Additionally, the ability to monitor areas unfrequented by regular sonic surveillance aided in documenting razorback sucker movements between long-term monitoring sites and helped account for individuals that have gone undetected for expanses of time. Additionally, SUR data, in conjunction with active sonic telemetry efforts, have led to a more complete timeline of visual representation of movement patterns throughout Lake Mead (see figures 1-7 and 1-8). The use of SURs in long-term monitoring may continue to help inform us regarding razorback sucker whereabouts outside of the spawning period, as stated in past reports (Shattuck et al. 2011). The use of SURs could increase the efficiency of monitoring locations outside of the established sampling areas (e.g., Bonelli Bay). Finally, though not directly related to sonic telemetry, a substantial step was taken during the 2011–12 field season to update older PIT tags to newer, more powerful 134-kilohertz PIT tags for passive monitoring. This measure was undertaken to assure positive identification of recaptured fish in the future with advancing technology; however, the stronger tags also lend to the possibility of using a remote PIT-tag reader in the future, if determined to be useful for this mostly wild population, as discussed in Shattuck et al. (2011).

Adult Sampling and Spawning Site Observations

Trammel netting results in 2012 documented the continued presence of wild, adult and juvenile razorback suckers, many of which were captured in the Muddy River/Virgin River inflow area (42%, n = 22). The presence of numerous new, wild fish in the Muddy River/Virgin River inflow area follows the trend noted in Albrecht et al. (2008a), Kegerries et al. (2009), and Shattuck et al. (2011), who reported high numbers of younger fish (< 7 years of age) present in Lake Mead. The Lake Mead population still appears to be relatively young, though fewer individuals 7 years old or younger were captured in 2012 compared with 2011 (attachment 1). Additionally, eight razorback sucker year-classes were identified in 2012 (attachment 1 and figure 1-17), and one additional year-class would likely be included with the juvenile individual captured in Las Vegas Bay that was not aged to avoid additional stress (chapter 2). It also appears that the strong year-class from the 2004 to 2005 field season had recruited to the adult population, a finding made in past reports (Kegerries et al. 2009; Albrecht et al. 2010a, 2010b, 2010c; Shattuck et al. 2011). The capture of these younger fish demonstrates that natural recruitment of razorback suckers continues at Lake Mead despite changing lake elevations.

Juvenile fish were found at or near spawning habitat during the spawning period and, as monitoring results from 2008 to 2012 demonstrate, a relatively high abundance of young razorback suckers have been captured in Lake Mead, specifically Las Vegas Bay. However, it is not fully understood why catching juveniles has proven difficult and rather stochastic. The difficulties of sampling this younger life stage have been discussed in Albrecht et al. (2006a, 2008b), and further efforts directed specifically at this life stage are detailed in chapter 2. Continued monitoring of razorback suckers in all three long-term study areas of Lake Mead through sonic telemetry, trammel netting, and larval sampling will be invaluable in describing habitat use, determining spawning sites, and understanding recruitment patterns.

Though the numbers of captures in 2012 can be considered a success, the lower catch rates at many of the long-term monitoring sites are cause for more discussion (see figure 1-12). As lake levels were at a 5-year high at the beginning of 2012 (see figure 1-16), 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, and the habitat was used frequently by sonic-tagged individuals. However, the heavy cover these fish were associating with made net placement difficult. Not only was the heavy inundated cover likely providing protection for razorback suckers using this habitat, it often prevented consistent net placement and made it nearly impossible for the trammel net to rest on the bottom. 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 2012 was the overwhelming abundance of nonnative fish in our gear, specifically gizzard shad. Though nets may not have been effective for bottom fishing, mid-water captures contained enough gizzard shad to hypothetically load the nets and render them unavailable to other fishes.

Despite continued changes in lake elevations (see figure 1-2) and subsequent changes in associated habitat, successful razorback sucker spawning is still occurring in Lake Mead; it was documented at all of the long-term monitoring study sites in 2012. The 2012 primary spawning sites shifted from the previous year's spawning sites, yet they were often closely aligned with sites designated under similar lake level conditions (i.e., 2006) (Albrecht et al. 2006b, 2007, 2008a, 2010b; Kegerries et al. 2009; Shattuck et al. 2011). In Las Vegas Bay and Echo Bay, spawning sites overlapped those designated in 2006 (see figures 1-13 and 1-14). However, the designated spawning site at the Muddy River/Virgin River inflow directly overlapped the 2009 spawning site (see figure 1-15) (Kegerries et al. 2009). The difference in spawning site overlap at the Muddy River/Virgin River inflow area may be due to the nature of that particular site because 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 site (see figure 1-6), 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 suckers return to the same spawning sites year after year (Tyus and Karp 1990).

The 2012 spawning site in Las Vegas Bay was more difficult to define than in previous years. Although a number of sonic-tagged individuals frequented the suspected spawning site briefly, few sexually mature adults were collected. In past field seasons, we have seen a less definitive spawning site location in Las Vegas Bay and have questioned what may drive a potential shift in the 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 and numerous larvae. 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 2012 spawning occurred earlier than expected in Las Vegas Bay. The first larval razorback sucker was collected on February 1, 2012, 2 weeks earlier than in 2011 (Shattuck et al. 2011) and nearly a month earlier than in the Overton Arm (see table 1-5). It should be noted that we did not initiate larval sampling until February 1, 2012, and larval fish were already present, which also suggests that successful spawning had already occurred. Because many larval collections were made on the southern shore and sonic-tagged razorback suckers were using areas on the northern shore, it was more accurate to include the entire western end of Las Vegas Bay in the 2012 suspected spawning site designation. Anecdotally, the warmer water from Las Vegas Wash may play a significant role in cueing sexually ready razorback suckers to spawn earlier than at other 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).

During the 2012 field season, the continued presence of young fish in Las Vegas Bay was documented despite lower total captures here than in previous years. The presence of young razorback suckers may be due to the area's highly productive environment, coupled with the increase in available habitat seen with rising lake elevations in 2012. In general, juvenile razorback suckers have been somewhat scant in our netting collections, which have focused on areas where adult fish are congregating to spawn. This may lead to the poor understanding of juvenile habitat use in Lake Mead, which is a topic for future investigations and discussed in chapter 2 (Albrecht 2008a, 2010b).

The 2012 spawning site in Echo Bay was identified based on larval fish collection data (see figure 1-14), adult fish collections (see figure 1-10), and sonic-tagged fish locations (see figure 1-5). In recent years, Echo Bay spawning sites have been on the northern side of the bay and appeared to follow receding lake elevations. However, lake levels in 2012 closely resembled those in 2006. As such, razorback suckers in Echo Bay appeared not only to follow historic trends and return to the same spawning site of years past but also expanded their activity to include most all of the western end of the bay. Similar to Echo Bay, a clearly defined spawning site at the Muddy River/Virgin River inflow area in 2012 was based on a combination of larval collection data (see figure 1-15), adult collections (see figure 1-11), and sonic-tagged fish locations (see figure 1-6). Sonic-tagged fish were contacted frequently in the 2009 designated spawning area at the Muddy River/Virgin River inflow (see figure 1-6), and the placement of trammel nets near these sonic-tagged fish yielded high densities of adult razorback suckers exhibiting reproductive readiness (e.g., colored and tuberculated individuals freely giving milt or eggs). Although larval collection data were included in the determination of the 2012 spawning site, the

Muddy River/Virgin River inflow area had relatively low larval catch rates. The low larval catch rates in this area have persisted since the Muddy River/Virgin River inflow area was included in long-term monitoring (Albrecht et al. 2006b, 2007, 2008a, 2010b; Kegerries et al. 2009; Shattuck et al. 2011).

Interestingly, a number of adults contacted through sonic surveillance and trammel netting used both the Muddy River/Virgin River inflow and Echo Bay during the spawning period. According to recapture data, five wild razorback suckers moved between Echo Bay and the Muddy River/Virgin River inflow area. Furthermore, one wild individual that was tagged at the Muddy River/Virgin River inflow area was recaptured this year at the CRI area. 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 2012 suggest that the Muddy River/Virgin River inflow area spawning aggregate is one of the largest in Lake Mead, as evidenced by the relative numbers and catch rates of adult fish there (see table 1-7 and figure 1-12). Furthermore, elevated trammel netting capture rates occurred in this area, aided in part by sonic-tagged fish. The broad use of spawning habitats throughout the northern portion of Lake Mead is extremely important in terms of the overall status of Lake Mead razorback suckers, suggesting that the total numbers of fish inhabiting the lake may be higher than previously thought. However, the three primary long-term monitoring study areas at Lake Mead have changed dramatically over the last 16 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 suckers 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 2012 spawning period. Overall, results from the 2012 field season fell within the range of larval fish CPM values from past study years (Albrecht et al. 2008a, 2010b; Kegerries et al. 2009; Shattuck et al. 2011). Given that some level of natural razorback sucker recruitment has occurred nearly every year in Lake Mead, we remain optimistic about the future of the larval fish produced by this interesting population of razorback suckers in 2012.

In 2012, Las Vegas Bay experienced the second lowest larval catch rate observed since 2006 (see table 1-6). Reasons for the relatively low CPM values are likely related to the overall decline in lake elevation and the rather rapid desiccation of littoral shoreline habitats observed near the Las Vegas Wash inflow/delta area (similar observations apply to the other long-term study areas during the 2012 spawning season). The relative absence of reproductively ready adult razorback sucker in trammel netting also suggests that, although successful spawning occurred, larval captures could have been even higher with a more specific spawning site on which to key. As in 2010 and 2011, larval captures in 2012 suggest that some of the Las Vegas Bay spawning aggregate may have successfully reproduced along both the northern and southern shorelines during the 16th study year.

Larval sampling in Echo Bay resulted in the highest CPM value from among the long-term monitoring sites in 2012 (see table 1-6). Continued larval razorback sucker yields at Echo Bay also helped demonstrate the long-term resiliency of razorback suckers as a species. For example, during the 2006–07 and 2007–08 field seasons, larval captures appeared to suffer greatly from a number of hypothesized environmental and anthropogenic disturbances such as declining lake elevations, reduction of spawning habitat, and anthropogenic influences in Echo Bay (Albrecht et al. 2008a, 2010b). Despite similar disturbances and a notable decline in lake levels in 2012, the Echo Bay razorback sucker aggregate once again spawned successfully.

Overall, the 2012 larval catch rates in the Muddy River/Virgin River inflow area remained relatively low. Typical of past years, larval razorback sucker catch rates at this location were the lowest of the long-term monitoring sites in 2012 (see table 1-6) (Albrecht et al. 2010b; Shattuck et al. 2011). Low capture rates of larval razorback sucker at the Muddy River/Virgin River inflow area appears to be "normal" for this spawning area (based on sampling to date), but this remains somewhat perplexing particularly given the rather high number of adult and juvenile razorback sucker captures at the Muddy River/Virgin River inflow area over the past several seasons. One potential explanation for low larval CPM values from the Muddy River/Virgin River inflow area may be high winds and a spawning site that is located at the far end of an extreme fetch. Wind movement of larvae (common on Lake Mead during spring months) has been suggested as a potential complicating issue for larval sampling in Lake Mead in previous reports (Albrecht et al. 2010b; Shattuck et al. 2011). Additionally, it has been postulated that high winds and associated wave action could be a cause of mortality in larval razorback suckers in nearby Lake Mohave (Bozek et al. 1990) and a source of movement for larvae (M. Urban 2011, personal communication). Similarly, in Oregon's Upper Klamath Lake, high winds are likely the cause of mortality and dispersal from rearing grounds in larval catostomids (Cooperman et al. 2010). Movement of larval fish due to wind currents is likely, although larval sampling north and south of the suspected spawning site still produced very few individuals. Further research within the Muddy River/Virgin River inflow area is warranted to help determine the factors that may be limiting sampling efforts and/or observed larval production. Use of larval light traps, as discussed in Kegerries and Albrecht (2013), and/or increased levels of sampling/effort would likely provide further insight into larval razorback suckers at the Muddy River/Virgin River inflow.

As in past field seasons, BIO-WEST teamed with biologists from the NDOW and Reclamation to collect additional larval razorback suckers for future repatriation efforts. These fish are being held and reared by the NDOW, and BIO-WEST continues to work with the 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 suckers remains at Lake Mead (Albrecht et al. 2006b). We have attributed the initiation of recruitment of Lake Mead razorback suckers to a change in the management of the lake. From the 1930s to 1963, Lake Mead was either filling (a time when initial recruitment likely occurred and created the original lake population of razorback sucker), or it was operated with a sizable annual fluctuation. The lake was drawn down approximately 100 ft (30.5 m) in the mid-1960s as Lake Powell filled, and since that time, it has been operated with relatively small annual fluctuations but relatively large multi-year fluctuations. It has been suspected that the drawdown of Lake Mead (for filling of Lake Powell and a subsequent drawdown in the 1990s) allowed terrestrial vegetation to become well established around the shoreline. This vegetation was then inundated as lake levels rose, but (with small annual fluctuations) the vegetation remained intact for many years and provided cover in coves and other habitat that young razorback suckers may inhabit. Furthermore, vegetation and turbidity (an additional form of cover) near the inflow areas apparently resulted in continued recruitment. Before 1970, vegetation was unlikely to establish because of relatively large, annual reservoir fluctuations. The presence of individual razorback suckers older than 30 years indicates that limited recruitment may have occurred from 1966 to 1978, a period of slowly rising lake levels. Lake elevations reached their highest levels from 1978 to 1987 when the maximum amount of intact inundated vegetation probably existed in the lake.

Golden and Holden (2003) showed that cover, in terms of turbidity and vegetation, is more abundant in Echo Bay and Las Vegas Bay than in other Lake Mead or Lake Mohave coves. Furthermore, it has been accepted for years that turbidity plays a role in the susceptibility of young razorback suckers to predation (Johnson and Hines 1999). This information led to the hypothesis that low, annual fluctuations and large, multi-year lake elevation changes that promote the growth of vegetation around the lake, the inundation of that vegetation, and turbid conditions (compared with other locations within the Lower Colorado River Basin) are likely major reasons for continued razorback sucker recruitment in Lake Mead. 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). During the last four field seasons, a pulse of recruitment that coincides with lake condition and water year has been observed (Shattuck et al. 2011). Figure 1-17 best exemplifies the pulses in razorback sucker recruitment in relation to lake elevation and lake input, and Shattuck et al. (2011) illustrated the similarity between 2005 and 2011 with regard to flood-related cover influxes via the Virgin River. 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, turbidity may be much more important for razorback sucker recruitment than once thought, an environmental variable that has proven to significantly reduce nonnative predation of similar Colorado River fishes (D. Ward 2012, personal communication; Knecht and Ward 2012). Additionally, large 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 suckers. 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) identified items to evaluate in terms of turbidity and its effects on razorback sucker recruitment. For example, have turbidity levels increased in recent years (e.g., since 1999 when the lake was at/near full pool)? Has there been a recent increase in the productivity of Lake Mead, especially near known spawning sites? What impacts have low lake elevations had on the recruitment and status of littoral predatory fishes, and with rising lake elevations, will these relationships change? Is it possible that fluctuating lake elevations have also impacted nonnative fish populations (such as green sunfish [*Lepomis cyanellus*], bluegill [*Lepomis macrochirus*], and other littoral fishes), and are these data even available for evaluation? Is it possible that larger deltas near the inflows, with their increased sediment loads and turbidity levels, could in fact provide habitat essential for recruitment of razorback suckers? Are there other water quality parameters that may have recently changed in Lake Mead, parameters that might impact early life stage fishes and particularly affect young razorback sucker survival?

It is 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 suckers. Hence, cover in the form of turbidity increases, ultimately leading to increased recruitment. Because data obtained from 2007 to 2012 show that pulses in razorback sucker recruitment are possible at both low (e.g., 2002–06) and high (e.g., 1978–85 and 1998–99) lake elevations, habitat characteristics—such as cover in the form of turbidity and/or vegetation, similar to that found in Lake Mead—are potential keys to understanding (and perhaps enhancing) the sustainability of the species throughout the Colorado River Basin.

Growth and Aging

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-class has been documented by Kegerries et al. (2009) and Albrecht et al. (2010b) (see figure 1-17) and is further evident, as 26% of the fish aged in 2012 were less than 7 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 1970s.

Further evidence of a younger, quick-growing population is the relatively high growth rate (16.8 mm/year in 2012) in Lake Mead. In contrast, other populations of razorback suckers throughout the Colorado River Basin (e.g., Lake Mohave [Minckley 1983] and the Green River [Tyus 1987]) have lower annual growth rates (2–5 mm/year). Additional information about Lake Mead CRI area razorback sucker and flannelmouth sucker age determination results are found in Kegerries and Albrecht (2013).

Population and Survival Rate Estimation

Population Estimation

Although the population estimates for the period of 2010–12 yielded lower abundance rates than given in the previous year's annual report (Shattuck et al. 2011), lower overall, combined catch numbers in 2012 may have driven lower abundance estimates. 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 suckers 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 model, immigration and emigration are accounted for, and those assumptions are somewhat mitigated. For example, Echo Bay and the Muddy River/Virgin River inflow were combined due to movement of individuals between those two sites. Furthermore, the combined (long-term monitoring and CRI areas) population estimates include efforts from the CRI area because of confirmed fish movement between that area and long-term monitoring sites.

Interestingly, based on empirical field data (attachment 2), the population estimates produced in CAPTURE from 2008 to 2012 seem to suggest the population abundance of razorback suckers is increasing (Albrecht et al. 2008a, 2008b, 2010b; Kegerries et al. 2009; Shattuck et al. 2011). This trend appears to be consistent with or without the inclusion of CRI area data in regression analyses. Least-squares linear regression indicated a statistical significance with a relatively high level of goodness of fit for the combined (all long-term monitoring sites) estimate ($r^2 = 0.89$, $F[1,3] = 24.35$, $P = 0.01$) (figure 1-18). When the CRI area is included with long-term monitoring sites, the trend remains significant, with a high level of goodness of fit ($r^2 = 0.75$, $F[1,3] = 9.20$, $P = 0.05$) (figure 1-18). Furthermore, this increasing population estimate trend is supported through relatively strong CPUE values observed since 2005 (see figure 1-12). Given this is an annual report, data selection was limited to these five estimates, and combined (long-term monitoring and CRI area) estimates were only generated to illustrate the generally increasing population of wild razorback suckers observed in Lake Mead. Continued monitoring may provide a greater understanding of population dynamics, and additional data will improve our ability to detect significant correlations among population estimates through time.

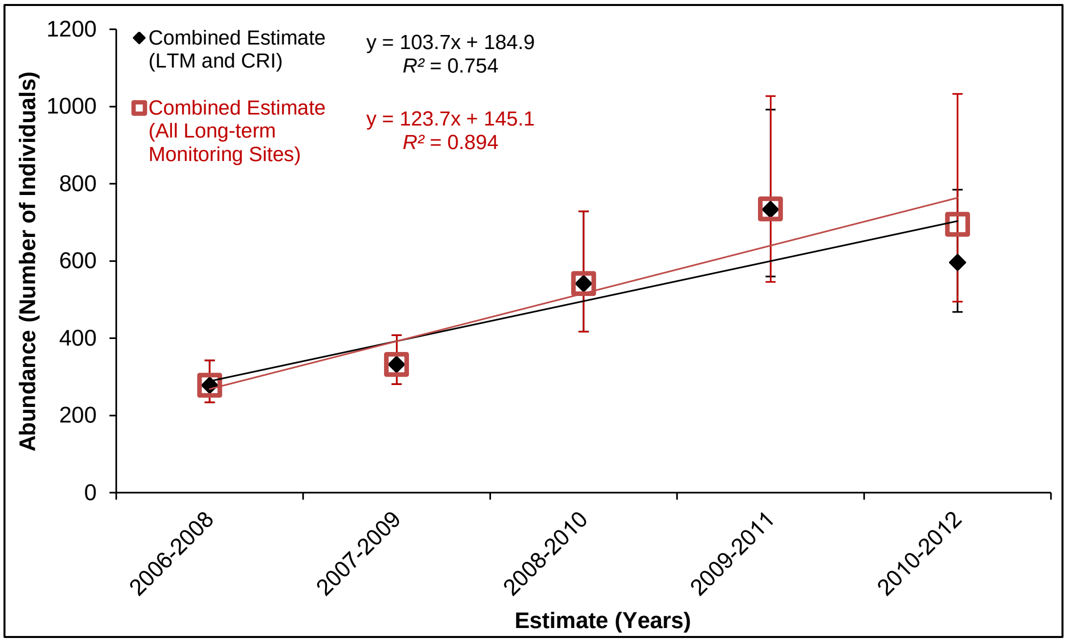


Figure 1-18.—Population estimates of both of the combined estimates (i.e., long-term monitoring and CRI areas, and all long-term monitoring sites) for Lake Mead razorback sucker mark-recapture data spanning from 2006 to 2012.
Error bars include 95% CI boundaries. Data are fitted with least-squares linear regression (long-term monitoring and CRI areas [r^2 = 0.75, F[1,3] = 9.20, P = 0.05] and all long-term monitoring sites [r^2 = 0.89, F[1,3] = 24.35, P = 0.01]).

Survival Rate Estimation

Apparent survival rate estimates for razorback suckers in Lake Mead were included in this report to provide an additional understanding of this relatively young population. Apparent survival estimates have been reported for prominent razorback sucker populations in other Colorado River Basin locations (e.g., Zelasko et al. 2011; Kesner et al. 2012). However, this aspect of the Lake Mead razorback sucker population had not been previously explored, and these new estimates further the ability to make relative comparisons within the Colorado River Basin. The Lake Mead Pradel and CJS estimates demonstrate high apparent survival with relatively narrow CI bounds (i.e., Pradel = 0.83–0.91 CI and CJS = 0.87–0.95 CI) (see table 1-8).

Sampling on Lake Mead focuses on the spawning adult population, although juvenile fish are captured periodically during trammel netting efforts. In comparison, according to data from 1992 to 2010 (Kesner et al. 2012), the post-stocking apparent survival for Lake Mohave razorback suckers ranged from 0.70 to 0.80 for large (> 500 mm TL), adult repatriated fish. Furthermore, results from the Green River and upper Colorado River subbasins show that apparent survival ranged from 0.67 to 0.97 for stocked adult razorback suckers over 500 mm TL (Zelasko et al. 2011). Although survival appears to be similar among Lake Mead, the Green River, and the upper Colorado River subbasins, apparent survival at Lake Mead includes razorback suckers less than 500 mm TL, with survival generally increasing with fish length (Miller et al. 1988). The 2010–12 dataset (including CRI area data) used for this analysis includes Lake Mead razorback suckers ranging from 234 to 706 mm TL, with 59 individuals being less than 500 mm TL. The disparity in size between Lake Mead razorback suckers and razorback suckers in other areas of the Colorado River Basin may suggest that a factor other than TL drives the higher apparent survival rate estimate and subsequent recruitment.

It is hypothesized that general survival in Lake Mead may be a function of habitat or ecological conditions in terms of cover as discussed by Golden and Holden Golden (2003). Future efforts in monitoring the apparent survival rate for Lake Mead razorback suckers could provide further insights pertaining to higher apparent survival under given lake conditions. Until recently, adult sampling has been the primary focus of efforts on Lake Mead; apparent survival rates of juveniles remain unknown. Future studies focusing on smaller cohorts may provide more information about the survival and recruitment of younger, wild razorback suckers.

Conclusions

The 2011–12 field season was exceptional in that we met all long-term monitoring objectives. Multiple life stages of razorback suckers were captured, sampled, and surveyed using a wide variety of methodologies in a dynamic environment. Although it is unclear how changing lake elevations 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 2012. As reported by Shattuck et al. (2011), we remain particularly positive regarding the 2011 year-class of razorback suckers, which appears to have been subjected to conditions similar to those experienced by the relatively strong, 2005 year-class (see figure 1-17). With the capture of larval fish at all known spawning sites in 2012, the status of Lake Mead razorback suckers remains optimistic. While there is concern for the Las Vegas Bay spawning aggregate 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 this location. This underscores the importance of long-term monitoring and long-term datasets. Furthermore, the capture of another juvenile razorback sucker in Las Vegas Bay provides continued, direct evidence of wild and natural razorback sucker recruitment in Lake Mead. 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 suckers are able to naturally maintain a population despite fluctuating habitat conditions.

2012–13 WORK PLAN (LONG-TERM MONITORING)

Specific Objectives for the 17th Field Season

1. Continue data collection, including tracking the remaining active, sonic-tagged Floyd Lamb Park razorback suckers in hopes of (1) continuing to document natural, wild razorback sucker recruitment in Lake Mead; (2) following spawning populations to evaluate whether any further shifts in spawning site selection occur; (3) continuing 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.

   Continued long-term monitoring efforts should include larval sampling, trammel netting, and fin ray collection and aging techniques, with particular emphasis on PIT tagging and aging juvenile and adult razorback suckers. Data stemming from continued monitoring will further assist with understanding the size and habitat use of the populations of razorback suckers in Lake Mead, help document the exchange of fish between sites, identify problems or habitat shifts associated with the known spawning aggregates (e.g., Echo Bay), and elucidate 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.

   Considering that it has been 5 years since the last comprehensive report (Albrecht 2008b), it is suggested that a similar effort be conducted to encompass and summarize data developed over this time period. A comprehensive effort will help provide insight to the overall data analysis and development of contemporary, long-term trends regarding razorback suckers in Lake Mead.

2. Continue to lend support to the LMWG. In short, this effort will also help to more easily achieve the overall goals and objectives under the LCR MSCP that are related to razorback suckers.

3. When/as applicable, we will continue to coordinate and work jointly with the razorback sucker investigations occurring in the CRI area. In 2010, efforts were undertaken to document the presence or absence of razorback suckers at this area. Through the capture of wild, ripe adult and larval razorback suckers, these efforts have resulted in the documentation of a spawning aggregate near the Colorado River/Lake Mead interface. Not only were wild fish documented using this new study area, but sonic telemetry efforts in this portion of Lake Mead helped to locate sonic-tagged fish originating from the long-term monitoring study areas and helped document sonic-tagged individuals utilizing the Colorado River proper and moving into the lower Grand Canyon (Kegerries and Albrecht 2013). Thus, the potential exists for the continued, perhaps increased, exchange of sonic-tagged razorback suckers among 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 area (or vice versa). Coordination and collaboration among field crews will continue, as necessary, to achieve the best possible research system for more holistically understanding Lake Mead razorback suckers.

4. Continue to search for avenues to investigate the physicochemical and biological factors that allow continued Lake Mead razorback sucker recruitment. This research item was originally posed by Albrecht et al. (2008b) and is now contained within the current Lake Mead Razorback Sucker Management Plan (Albrecht et al. 2009). Ultimately, it is important to investigate and try to understand why Lake Mead razorback suckers are recruiting despite the nonnative fish pressures and habitat modifications that are common throughout the historical range of this species. Chapter 2 presents the latest developments in trying to achieve this goal and presents the results of a pilot study conducted in 2012. Findings suggest that additional effort pertaining to the early life stages of Lake Mead razorback suckers may be warranted.

5. Sonic tag wild-caught razorback suckers from Lake Mead if/as needed to maintain effective, efficient, long-term monitoring efforts and gain additional information pertaining to this unique, wild population. Use of wild fish will undoubtedly allow for comparisons between data collected from stocked, Floyd Lamb State Park razorback suckers. Floyd Lamb 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 the habitat use and spawning preferences as well as other components important to the wild razorback sucker population within Lake Mead.

Chapter 2: Wild, Juvenile Razorback Sucker Pilot Study

INTRODUCTION AND BACKGROUND

In 1996, the SNWA and the Colorado River Commission of Nevada, in cooperation with the NDOW, initiated a study to develop information about the federally endangered razorback sucker populations at Lake Mead, Nevada. More recently, funding has been provided under the LCR MSCP for research on and monitoring of this unique population, which appeared to increase in size in recent years (Shattuck et al. 2011). Implanting adult razorback suckers with sonic telemetry tags was a key method implemented in Lake Mead razorback studies during 1996–97 (Holden et al. 1997), and these efforts continue to date. It was thought, and later confirmed, that sonic telemetry would provide valuable biological data regarding razorback sucker movement, habitat use, and spawning locations throughout the lake. Tagging events occurred periodically, usually when the majority of previously tagged individuals were no longer locatable or tags reached the end of their battery life. Razorback sucker conservation has benefited from this research, which has ascertained that native fish can coexist with nonnative predators in Lake Mead. Perhaps most importantly, research and monitoring conducted to date have allowed for documentation of natural, wild recruitment of razorback suckers within a highly modified system.

In recent years, a comprehensive review of the entire Lake Mead razorback sucker dataset (obtained from 1996 to 2007) was finalized (Albrecht et al. 2008a). This report summarized the lessons learned, methods used, and findings accumulated regarding Lake Mead razorback suckers to date. The comprehensive review also provided data-driven recommendations for future monitoring and research on Lake Mead. Of the various management actions/needs presented in that report, several were highlighted by the LMWG for long-term attention. Chapter 1 of this document presents information pertaining to the LMWG's desire and need to continue long-term monitoring of razorback suckers in Lake Mead. This chapter presents information pertaining to the development of further understanding of where, why, and how young razorback suckers are able to demonstrate recruitment in Lake Mead. This research need was also identified by Albrecht et al. (2008a) during their comprehensive review of Lake Mead data, was incorporated into the LMWG's management plan (Albrecht et al. 2009), and was conducted as a pilot study during 2012 in response to the 2012 contract objectives/goals (see the "Introduction" section of chapter 1).

From 2006 to 2011, trammel netting targeting spawning adults resulted in the fortuitous, yet inadvertent capture of over 100 wild (unmarked) juvenile (sexually immature, as defined in the "Methods" section of chapter 1) razorback suckers during long-term monitoring and research efforts (Albrecht et al. 2006a, 2007, 2008a, 2008b, 2010a; Kegerries et al. 2009; Shattuck et al. 2011). To date, only limited efforts have been directed specifically at capturing this young and rare razorback sucker life stage. This specific life stage is imperative to understanding where, how, and why razorback sucker recruitment continues to occur in Lake Mead. The results presented herein are a positive first step toward understanding this rare life stage and providing a framework for future and additional efforts to address questions pertaining to recruitment of razorback suckers in Lake Mead.

Given that the Lake Mead razorback sucker population is the only one currently known to demonstrate continued, wild recruitment and self-sustainability in the Colorado River Basin (Albrecht et al. 2010b), there is a unique opportunity to investigate the habitat use of immature razorback suckers and use sonic-tagged individuals to help locate and sample habitats utilized by these small, wild fish (similar to the approach used for adult studies currently conducted within Lake Mead). Our goal for the pilot study was to implant new, wild, juvenile razorback suckers captured during the 2012 long-term monitoring season (chapter 1) with sonic tags to obtain insight into the habitat use of young, nonspawning fish while simultaneously developing further understanding of wild, adult razorback sucker habitat use in Lake Mead. Given the nature of a pilot study, we limited the scope of our activities to wherever the first wild, juvenile fish was captured. Las Vegas Bay was the only location where a juvenile razorback sucker was captured during the 2011–12 field season. Subsequently, since no additional wild, juvenile razorback suckers were captured during the remainder of the 2011–12 field season, three Overton Wildlife Management Area juveniles were tagged for use in the pilot study. The NDOW collaborated and aided in obtaining and releasing these individuals.

Based on observations from the long-term monitoring of razorback suckers in Lake Mead, we hypothesized that the generally known, historical spawning areas would be the most likely places where juvenile razorback suckers might survive predation (i.e., areas with cover such as turbidity and vegetation). Furthermore, and perhaps more specifically, during long-term monitoring efforts, we have documented adult Lake Mead razorback sucker's tendency to use a variety of habitats during nonspawning months when they move away from the spawning locations and occupy more pelagic areas of the lake (see chapter 1). Hence, the second hypothesis tested in the pilot study was that juvenile fish do not display the same seasonal movement patterns as adults and likely use littoral zone areas more routinely (perhaps even year round) to avoid predation. Use of sonic-tagged, wild, juvenile razorback suckers (capitalizing on new and smaller tag technology) was the core technique implemented to address these hypotheses. The details of this pilot study, including specific methodological details, findings, and recommendations, are presented below.

STUDY AREAS

Most pilot study activities occurred at the Las Vegas Bay long-term monitoring site, a site that has a lengthy (1996–2012) history of razorback sucker use and recruitment (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; Kegerries et al. 2009; Shattuck et al. 2011) (figure 2-1).

Areas of the lake, including the Muddy River/Virgin River inflow area and Echo Bay, were monitored monthly using both active and passive methods of sonic telemetry. Sampling for juvenile razorback suckers, however, was only performed in Las Vegas Bay, as all tagged juvenile fish remained (to the best of our knowledge) at this location throughout the duration of the pilot study.

Specific definitions for the various portions of the Las Vegas Bay and Las Vegas Wash in which the study was conducted were first presented in Holden et al. (2000b) and are included in the "Study Areas" section of chapter 1.

METHODS

The methods used in the juvenile pilot study mirrored much of those used in the long-term monitoring study as included in chapter 1. Any discrepancies between the two studies are included herein (under the appropriate heading), with additional information detailing those methods used solely for the juvenile pilot study.

Lake Elevation

Daily lake elevations for 2012, including the juvenile pilot study field season (April 1, 2011 – December 4, 2012), were measured in ft AMSL and obtained from Reclamation's Lower Colorado Regional Office Web site (Reclamation 2012). Similarly, mean daily discharge for Las Vegas Wash was measured in cubic feet per second (ft^3/s) and obtained from the U.S. Geological Survey (USGS) (USGS 2012) below Lake Las Vegas, Nevada (USGS gauge 09419800). The effect of fluctuating lake levels and inflow discharges on razorback sucker habitat was also documented by written observations and photographs during sampling trips to the study sites.

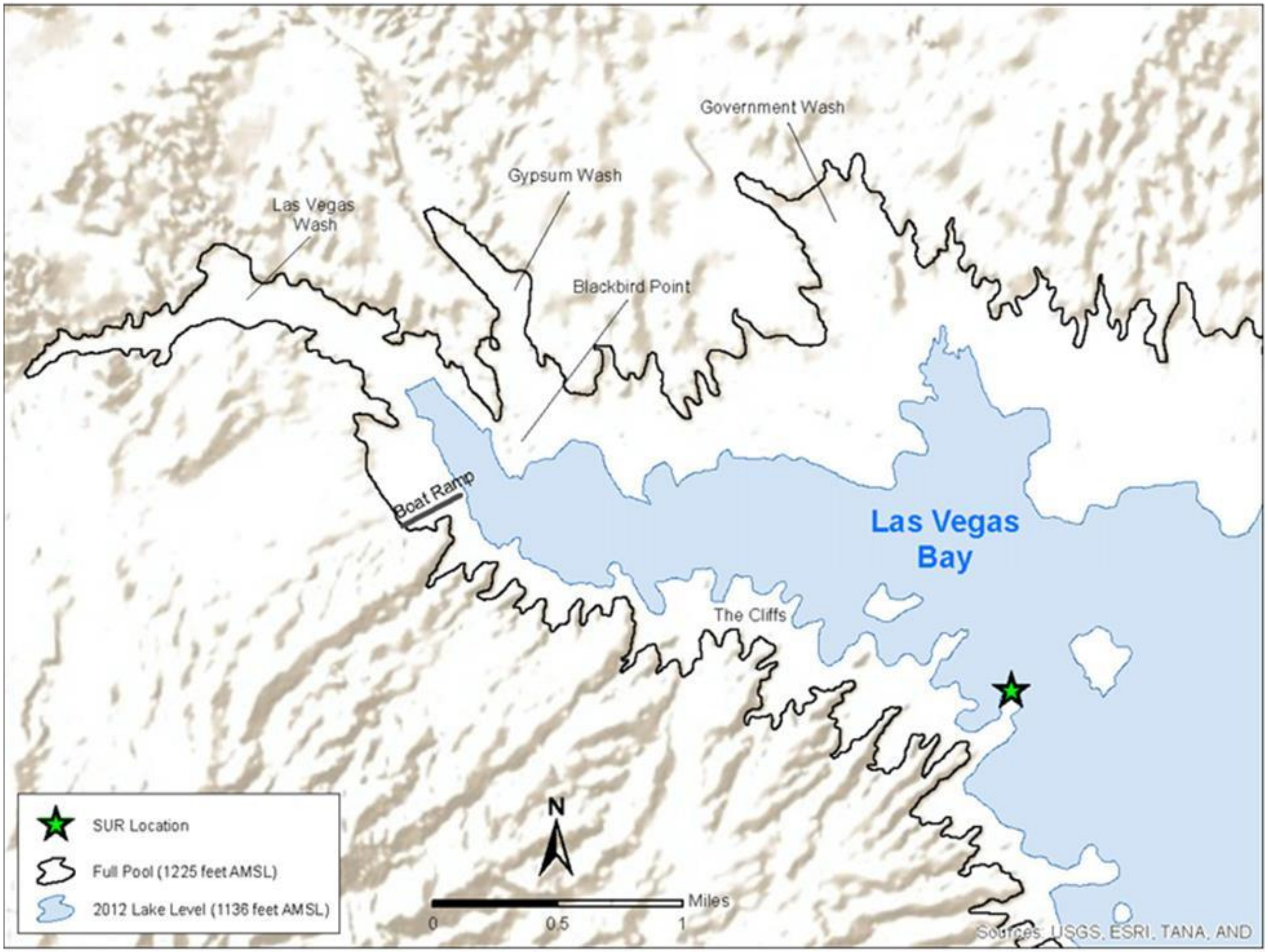


Figure 2-1.—Las Vegas Bay, Lake Mead, general study area.
The location of the SUR is denoted by a green star (unit maintained by the NDOW).

Sonic Telemetry

Sonic Tagging

Four juvenile razorback suckers were sonic tagged for the pilot study in spring 2012. One juvenile was a wild individual captured during 2012 long-term monitoring (chapter 1), while the other three individuals were collected from Center Pond at the Overton Wildlife Management Area with assistance from the NDOW. Juveniles 250–350 mm TL and at least 190 grams (g) were implanted with a Sonotronics Model IBT-96-9-I (9-month) tag; individuals 350–450 mm TL and at least 480 g were implanted with a Sonotronics Model CT-82-2-I (14-month) tag (figure 2-2). The 9-month tags weighed 3.8 g and measured 47.0 mm long by 10.5 mm in diameter, while the 14-month tags weighed 9.5 g and measured 53.0 mm long by 15.6 mm in diameter. Each tag had a unique code, and tags used frequencies of 72, 73, 74, and 76 kilohertz.

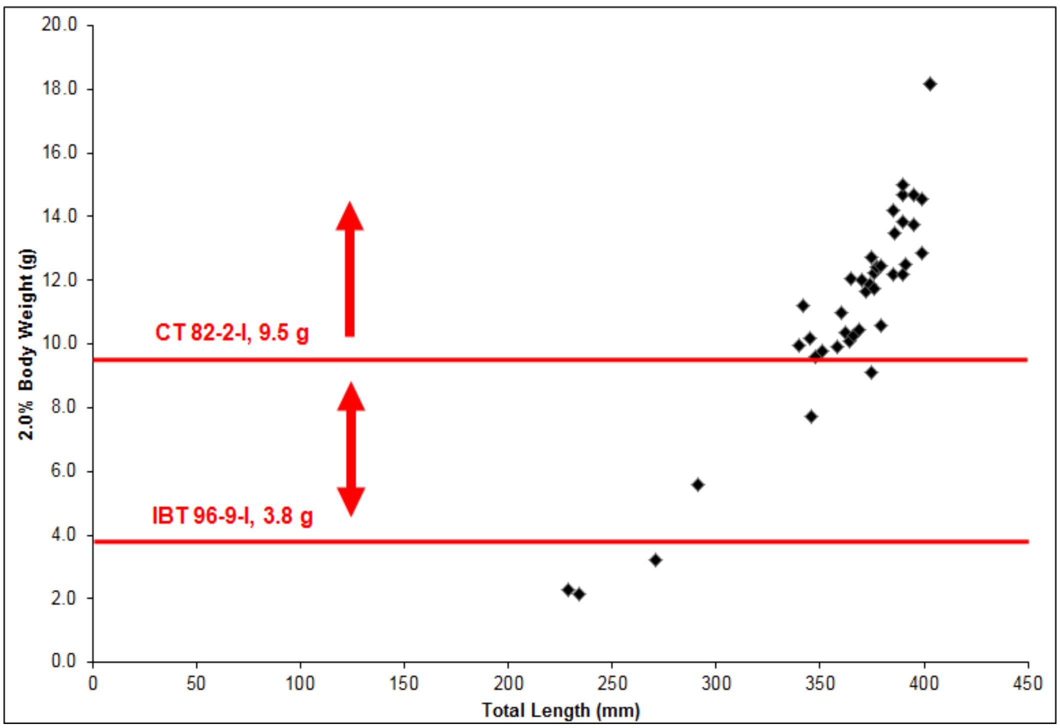


Figure 2-2.—Sonic transmitter sizing chart for juvenile Lake Mead razorback suckers according to the 2% of body weight guideline (Bidgood 1980; Winter 1983; Marty and Summerfelt 1990) and based on captures of Lake Mead razorback suckers less than 400 mm TL from 2005 to 2011 during long-term monitoring efforts on Lake Mead.

The following surgical protocol was established from procedures developed by Valdez and Nilson (1982), Kaeding et al. (1990), and Valdez and Trinca (1995) for humpback chubs; Tyus (1982) for Colorado pikeminnows (squawfish); and Valdez and Masslich (1989) for Colorado pikeminnows (squawfish) and razorback suckers (Kegerries and Albrecht 2011; Shattuck et al. 2011). A transmitter weight to fish weight of 2% (Bidgood 1980; Winter 1983; Marty and Summerfelt 1990) was used as a guideline to ensure that tags were not too large for the fish (see figure 2-2). Surgery was performed on shore and involved one surgeon and two assistants. The assistants recorded data, captured pertinent photographs, and monitored fish respiration. Prior to surgery, each fish was placed in a live well containing fresh lake water. All surgical instruments were cold sterilized with iodine and 90% isopropyl alcohol and allowed to air dry on a disposable, sterile cloth. Razorback suckers were initially anaesthetized in 30 liters of lake water with a 50-milliliter/L-1 clove oil/ethanol mixture (0.5 milliliter of clove oil [Anderson et al. 1997] emulsified in 4.5 milliliters of ethanol) (Bunt et al. 1999). After anesthesia was induced, TL, FL, SL, and weight ([g]) were recorded. Fish were then placed dorsal-side down on a padded surgical cradle for support during surgery. The head and gills were submerged in 20 L of fresh pond water with a maintenance concentration of 25 milliliters/L-1 clove oil/ethanol anesthetic (Bunt et al. 1999). Following fish introduction to the maintenance anesthetic, the surgeon made a 2–3 cm incision on the left side, posterior to the left pelvic girdle. A PIT tag was inserted into the incision followed by the transmitter, which was placed between the pelvic girdle and urogenital pore. The incision was closed with two to four 3-0 Maxon absorbable poliglecaprone 25 monofilament sutures using an attached PS-1 reverse-cutting, curved needle. Surgery times typically ranged from 2 to 5 minutes per fish.

Once surgical implantation was complete, fish were allowed to recover in a floating net pen (in Lake Mead for the wild-caught individual and in Center Pond for the pond-reared individuals) prior to transport to Lake Mead. Upon arrival at Las Vegas Bay, the wild-caught individual was released near its point of capture in the northwest portion of Gypsum Wash Cove, while the other three hatchery-reared individuals were hauled to the Las Vegas Wash inflow area and the northwest portion of Gypsum Wash Cove. Prior to release of the wild-caught individual on February 28, 2012, the fish was re-examined for signs of stress. Similarly, prior to release of the hatchery-reared individuals on April 23–24, 2012, the fish were re-examined for signs of stress. Tracking ensued immediately after release and continued intensively for 48 hours, while detailed tracking continued for several weeks following surgery.

Active Sonic Telemetry

During the sonic telemetry monitoring season (June – January) of the long-term monitoring study, juvenile and adult sonic-tagged fish were located monthly, tiering juvenile efforts off of the existing monitoring efforts to accomplish this task (chapter 1). However, during the portion of the long-term monitoring field season that coincided with the razorback sucker spawning period (February – May), sonic-tagged fish were typically located weekly or as the more intense long-term monitoring sampling allowed. Juvenile fish searches were conducted similarly to those for adults (chapter 1), although more detailed searches were conducted along shorelines and more effort was spent listening in areas of heavy inundated vegetation (areas known to impact signal reception). These listening locations were stationed approximately 450 m (depending on conditions and field crew expertise) from the previous listening location and were repeated throughout Las Vegas Bay and surrounding areas. Additionally, efforts were spent on tracking individuals in portions of Las Vegas Wash where the effectiveness of a sonic telemetry signal can be reduced (e.g., shallow, turbid, and/or flowing environments). Methods similar to those employed in the long-term monitoring study were used to track portions of Las Vegas Wash in appropriate areas. However, in portions of the wash too shallow for navigation from the lake, a kayak was used to float from the Northshore Road Bridge downstream to the lake interface. Listening was conducted continuously using a towable hydrophone, with the exception of areas that were portaged around (e.g., shallow riffle sections and sections with exceptional rapids). Occasional foot tracking was conducted in Las Vegas Wash as conditions allowed. As in the long-term monitoring study (chapter 1), juvenile sonic-tagged razorback suckers were at times located in areas of Lake Mead inaccessible by boat (e.g., shallow peripheral habitats and flowing portions of inflow areas); thus, the range of observed movements may not fully represent the use of a particular area in its entirety. Active tracking equipment was identical to that used in long-term monitoring (chapter 1), with the additional use of a trailing, omnidirectional towable hydrophone for more efficient listening in flowing conditions. During the spawning period (February – May), and once the position of the juvenile sonic-tagged fish was pinpointed, the fish's tag number, GPS location, and depth were recorded. However, during the sonic telemetry monitoring season (June – January), more detailed habitat information was recorded with additional fish (conspecific and community) sampling (detailed below) to aide in understanding recruitment habitats utilized by this young life stage.

Passive Sonic Telemetry

As in the long-term monitoring study, SURs were deployed in various locations throughout Lake Mead. The use of passive SURs aided in tracking juvenile sonic-tagged individuals during the weeks between sampling and tracking trips. Although multiple SURs were deployed for the purposes of long-term monitoring, the one set by the NDOW at Sand Island at the southeastern extent of Las Vegas Bay for a concurrent Lake Mead striped bass (*Morone saxatilis*) telemetry study was relied on to help confirm that sonic-tagged juveniles did not leave the bay during the 2012 juvenile pilot study (see chapter 1, figure 1-1). As in chapter 1, the data were processed through Sonotronics's SURsoftDPC software to ascertain the time, date, and frequency of positive sonic-tagged fish detections within 2 millisecond-interval units (e.g., a range of 898–902 for a 900-interval tag). To avoid any false-positive contacts due to environmental "noise" in data analysis, a minimum of two records were required within a 5-minute period for a record to be considered a positive contact.

Conspecific and Community Sampling

Sampling for conspecific (i.e., other similarly sized razorback suckers) and the fish community assemblage was conducted May – December to target nonspawning razorback suckers (particularly juveniles) and any other potentially associated species. Summer sampling methods consisted of a suite of methodologies, including trammel nets, minnow traps, hoop nets, fyke nets, and seining (as deemed appropriate based on sonic-tagged fish location and habitat). Many of these methods were used during previous studies to catch juvenile fish (Holden et al. 2000a, 2000b, 2001; Abate et al. 2002; Welker and Holden 2003), although efforts in 2012 utilized a key component that previous studies lacked—sonic-tagged juvenile razorback suckers to inform specific sampling locations.

All sampling gear was set and timed to allow for calculations of effort, with netting locations selected based on the locations of sonic-tagged juveniles. The mean CPUE was calculated for each sampling method (trammel nets, fyke nets, hoop nets, seines, and minnow traps). In cases in which razorback suckers were captured, fish were removed alive from nets and held in 100-quart (94.6-liter) coolers filled with lake water. Razorback suckers were isolated from other fish species and held in aerated live wells. Other fish species were measured for TL (mm), weighed (g), and enumerated before they were returned to the lake. As in the long-term monitoring adult sampling (see chapter 1), razorback suckers were scanned for PIT tags, PIT tagged if they were not recaptured fish, measured (TL, SL, and FL), weighed (g) and, if possible, individuals were assessed for sexual maturity. Methods for age determination were as described in chapter 1 of this document, and after all necessary information was collected, fish were released at the point of capture unharmed.

Trammel nets were used to target deeper habitats adjacent to shore and habitats offshore. Additionally, trammel nets were often set perpendicular to available shorelines when possible. Trammel nets measured 150 ft (45.7 m) long by 4 ft (1.2 m) deep with an internal panel of 1-in (2.54-cm) mesh and external panels of 12 in (30.48 cm) mesh. These specific dimensions of trammel netting have been the most effective in capturing razorback suckers of all sizes, while limiting the amount of large, suspended debris accumulated in the mesh (e.g., sticks and submerged aquatic vegetation) and allowing for more versatility in targeting a specific sonic-tagged individual or particular habitat in net settings with a shorter length (Kegerries and Albrecht 2011). Nets were generally set with one end near shore in 5–30 ft (1.5–9.1 m) of water, with the net stretched out into deeper areas. Alternatively, nets were set to encircle juvenile sonic-tagged fish, generally when sampling in characteristically pelagic areas.

Hoop nets were used in habitats too shallow or too crowded with inundated vegetation for trammel netting; they were the primary gear used in sampling Las Vegas Wash. Hoop net dimensions had 2.0-ft (0.61-m)-diameter mouths and were 6.0 ft (2.1 m) long with 0.25-in (6.4-mm) mesh. Effort expended at each site depended on the habitat type and amount of accessible area, again with sampling time recorded to calculate effort.

In wadable habitats, seines were used to sample for littoral and smaller-bodied species in areas with flowing water or limited inundated cover. Two sizes of seines were used depending on the size of habitat available. Nets measured 3.9 ft (1.2 m) by 14.8 ft (4.5 m) with a 0.1-in (3.0-mm) mesh and 6.6 ft (2.0 m) by 29.5 ft (9.0 m) with a 0.2-in (6.0-mm) mesh. Seine haul efforts were calculated as area sampled by multiplying the length of haul (ft) by the width of the net used (i.e., 14.8 or 29.5 ft). As with other sampling gears, the effort expended at each site depended on the habitat type and amount of accessible area.

Finally, in available habitats, standard Gee minnow traps were used to sample smaller-bodied fishes in areas inaccessible to larger gear (e.g., in heavy inundated cover and shallow habitats). Minnow traps measured 9.0 in (22.9 cm) in diameter by 17.5 in (44.5 cm) long with a 1.0-in (2.5-mm) opening and 0.25-in (0.6-mm) mesh. Minnow traps were often set in conjunction with hoop nets or trammel nets and hoop nets to spread effort across species and individuals of smaller sizes. As with other gears, time sampled was recorded for calculating effort.

Age Determination

Methods for determining the age of razorback suckers captured during the juvenile sampling efforts were identical to those used for adult long-term monitoring studies, which employed a nonlethal technique of fin ray section extraction developed in 1999 and refined during ongoing, long-term monitoring (Holden et al. 2000a) (see the "Methods" section in chapter 1).

Habitat Observations and Physicochemical Quantification

Multiple methods were used to describe vegetative cover and to collect water quality data, specifically methods modified from Golden and Holden (2003). In past reports, cover in the forms of turbidity and inundated vegetation has stood out as an important factor in Lake Mead razorback sucker spawning and recruitment (Golden and Holden 2001, 2002, 2003), warranting efforts to better characterize these and other physicochemical components as they relate to razorback sucker recruitment.

When a sonic-tagged individual was contacted, its location was pinpointed via sonic telemetry methods to accurately describe habitat(s) the individual was associating with. The sampling sites varied by sampling trip, as sonic-tagged fish moved between locations within Las Vegas Bay and Las Vegas Wash (see figure 2-1). As juvenile razorback suckers utilized a variety of habitats from nearshore to offshore, each site was defined as either an approximate 656-ft (200-m) by 66-ft (20-m) rectangle (43,056 square feet [4,000 square meters]) or a 118-ft (36-m) radius circle (43,798 square feet [4,069 square meters]) encompassing the location of the fish and immediately adjacent habitats (figure 2-3). The sampling area was dependent on situational locations of sonic-tagged juvenile razorback suckers, with a rectangle approach often more appropriate for shallower locations nearshore and a circular approach often more appropriate for deeper, offshore locations (generally greater than 66 ft [20 m] from the shoreline) (figure 2-3). As with other portions of this pilot study, sampling occurred monthly throughout the year.

At each site, replicate measurements/observations of water quality, substrate, and vegetation were recorded within the predetermined areas described above. Within each site or area, five locations were spaced randomly to collect water quality data. At each randomly spaced replicate, a water column profile was recorded, with a measurement taken at intervals of 1.6–3.3 ft (0.5–1.0 m) in depth. At each interval, a measurement was recorded using a Hydrolab Quanta for temperature (˚C), dissolved oxygen (DO) (milligrams per liter), saturation of DO (%), conductivity (microsiemens/cm), pH, turbidity (nephelometric turbidity units [NTU]), and total dissolved solids (TDS) (grams/liter). After the water column was assessed for these standard parameters from surface to bottom, a substrate grab sample was collected to visually estimate substrate following a modified Wentworth scale (Cummins 1962) (i.e., silt, sand, gravel [< 3 in], cobble [3–10 in], boulder, and bedrock). Grab samples were collected using a petite PONAR sampler, which removed an approximate 38.7-square centimeter (6.0-square inch) area, and samples were emptied into a 5-gallon (18.9-liter) bucket for visual percentage composition assessment. Additionally, while assessing the substrate, the presence of algal and detrital vegetation was noted (present or absent) as an additional indicator of cover or productivity.

In areas where aquatic cover (primarily dead or live vegetation) could be determined, each site was mapped using a hand-held Trimble GPS unit, creating spatial polygons to calculate the area covered. Cover was categorized as general vegetation types, including inundated vegetation (e.g., saltcedar [*Tamarix* sp.], tumble pigweed [*Amaranthus albus*], creosotebush [*Larrea tridentata*]), emergent vegetation (e.g., bulrush [*Typha* sp.], narrowleaf cattail [*Typha angustifolia*], common reed [*Phragmites* sp.]), submerged aquatic vegetation, including filamentous algae (e.g., spiny naiad [*Najas marina*], sago pondweed [*Stuckenia pectinata*], widgeon grass [*Ruppia maritima*]), large woody debris (≤ 4-in diameter [10.1 cm] [Webb and Erskine 2003]), or none (i.e., no observable cover types, typically in deeper areas of open water). Cover composition was visually estimated as water clarity and accessibility allowed. In instances where conditions were not suitable to quantify area of cover using a Trimble GPS unit, a general estimate of percent vegetative cover (i.e., lumped category of inundated vegetation, submerged aquatic vegetation, and large woody debris) was recorded at each sampling location.

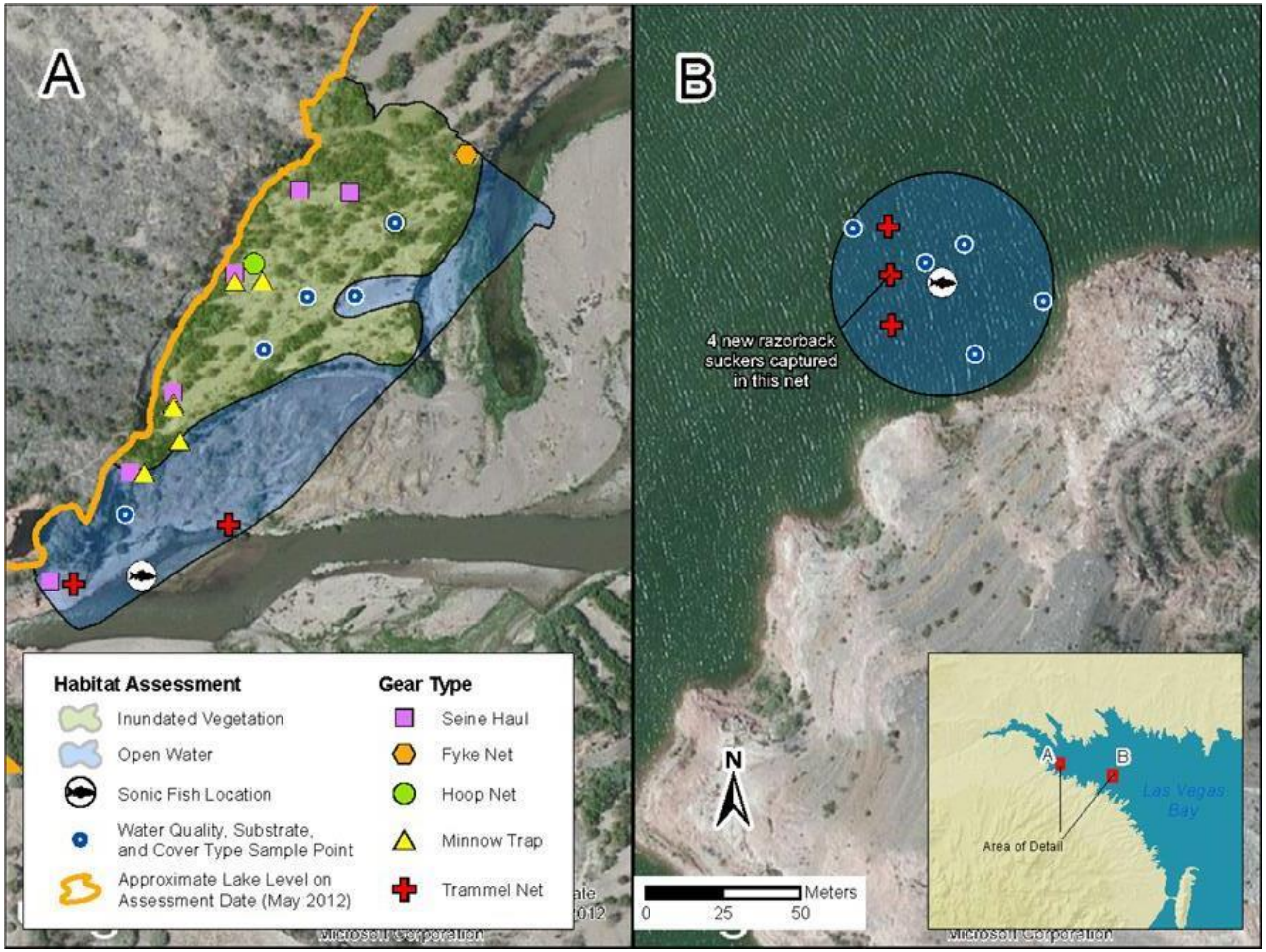


Figure 2-3.—Examples of the two approaches used in habitat assessment and fish sampling for associated sonic-tagged juvenile razorback suckers: (A) the 200- by 20-m nearshore approach, and (B) the 36-m radius offshore approach.
Detailed aerial imagery is overlaid with sonic-tagged juvenile razorback sucker locations, physicochemical sampling locations, approximate lake elevation at time of assessment, fish sampling locations and gear types, and mapped areas of observed habitat types.

Finally, seasons in this chapter were recorded and categorized according to equinoxes and solstices (i.e., vernal equinox [spring: March 20 – June 19], summer solstice [summer: June 20 – September 21], autumnal equinox [fall: September 21 – December 20], and winter solstice [winter: December 21 – March 19). Categorization of seasons helped group patterns of razorback sucker movement and habitat use with respect to annual fluctuations in the environment, thus helping to more narrowly define variations seen within the fish community and timing of available habitats.

Data Analysis

All data collected were entered into a database managed by BIO-WEST and incorporated into a variety of univariate and multi-variate analyses (described below). Field data were checked post-entry for quality assurance and quality control. Analytical attention was focused on the description of juvenile fish habitat relationships, associated fish community demographics, and spatial and temporal differences observed throughout the pilot study.

CPUE rates were used as a surrogate for relative abundance, assuming that more abundant species were captured at higher rates than less abundant species. Additionally, CPUE was used as a complementary metric for fish community composition, where CPUE was calculated for fish captured per minute, and data associated with a particular sonic-tagged juvenile razorback suckers were analyzed separately.

Canonical Correspondence Analysis

Habitat and community assemblage data were analyzed using a constrained ordination technique, specifically canonical correspondence analysis (CCA). The multi-variate analysis, CCA, describes dominant ecological relationships as explained by environmental and species variation (McGarigal et al. 2000). Furthermore, post-hoc variance partitioning separates the observed variation seen in a CCA model and groups the attributed variation to a particular category (i.e., environment, species, season, and the unexplained) (Borcard et al. 1992; ter Braak and Šmilauer 1997). As information regarding recruitment of razorback suckers and habitat use by young fish is limited, this type of analysis is useful for describing major patterns observed in habitat and fish community data.

In the CCA, habitat data were tabulated for each encounter (sonic-tagged juvenile razorback sucker contact with associated habitat data), and a mean numeric value was used for the habitat variables of depth, temperature, conductivity, DO, pH, TDS, and turbidity. Similarly, substrate composition percentages were included in numeric form, while season, spatial designation, and the presence or absence of algal or detrital vegetation were included as ordinal data (i.e., in the form of dummy variables "0" or "1"). Spatial designation was included to describe differences in juvenile razorback sucker habitat association within Las Vegas Bay by season (i.e., seasonal utilization of habitat near the Las Vegas Wash inflow). Spatial designations in Las Vegas Bay were sectioned according to topographic and hydrological features (i.e., Las Vegas Wash, Gypsum Wash, the Cliffs, and Government Wash). Species data for sampling conducted at each encounter was included as raw abundance for captured species, irrespective of gear type, and abundances were repeated across the five replicate samples. Because habitat was recorded and fish sampling was conducted around known juvenile razorback suckers, abundance for a juvenile razorback sucker was included as at least one individual (i.e., the wild sonic-tagged juvenile). Though the pond-reared sonic-tagged juveniles were not captured with deployed sampling gears, their presence was known based on sonic telemetry. Furthermore, razorback sucker abundances were split into two categories – those of juveniles (immature individual < 450 mm TL) and those of adults (either sexually mature or an individual > 450 mm TL). The categorization of razorback suckers by size is based on our hypothesis that these two different life stages (i.e., juveniles and adults) may utilize different habitats and are therefore warranted as separate "species" in the CCA model. Once the data were tabulated into a matrix, the program CANOCO 4.5 was used to run the ordination and variation partitioning (Borcard et al. 1992; ter Braak and Šmilauer 1997). Any encounter events that did not include a complete dataset were not used in the model iteration to avoid violating model assumptions.

Output plots from CANOCO 4.5 can be interpreted, as the length of the arrows (explanatory variables or environmental gradients) indicate the amount of variation explained via that eigenvector, with the longer arrows holding more importance than shorter arrows. Species are plotted relative to the environmental gradients that explain the variations in that particular species' abundance. Species plotted close to the origin of axes tend to exhibit less of an association with a particular environmental gradient (generalist species or those with a broad ecological niche), while those plotted at axis extremes are varied based on the occurrence of a particular environmental gradient (specialist species or those exhibiting a narrow ecological niche). Axis values do not represent a negative or positive correlation, and the numeric scale does not aid in interpretation; rather, the values corresponding to a particular species or eigenvector simply help in the distancing of samples. The significance of variation attributed to a particular category (i.e., environment, species, season, and the unexplained) through post-hoc variance partitioning was tested using 9,999 Monte Carlo permutations in a nonparametric randomization test run in CANOCO 4.5 (Borcard et al. 1992; ter Braak and Šmilauer 1997).

Principal Component Analysis

Using a data matrix similar to the CCA design, environmental and habitat data were analyzed using the unconstrained ordination technique of principal component analysis (PCA). Spatial and temporal variations in physical habitat were analyzed using PCA for each sonic-tagged juvenile razorback sucker throughout Las Vegas Bay and throughout the year (Matthews and Marsh-Matthews 2006). Using the output of eigenvalues in PCA help define variables for each principal component to reflect the importance of a particular environmental gradient and give ecological meaning to the physical habitat as it relates to a sonic-tagged juvenile razorback sucker (McGarigal et al. 2000).

Seasonal ordinal data were not included in the data matrix; rather, seasonal samples were identified post-hoc to monitor differences in physical habitat variation without additional seasonal influence on the samples. Mean physical habitat data used included depth, temperature, conductivity, DO, pH, TDS, and turbidity. Additionally, substrate-composition percentages and cover type percentages were included in numeric form, while spatial designation and the presence or absence of algal or detrital vegetation was included as ordinal data. All data were entered into the matrix, z-score transformed ($Z_i = [x_i - \bar{x}]/s$), and tested for normality in CANOCO 4.5 to meet model assumptions in PCA (ter Braak and Šmilauer 1997). The significance of the proportion of variance explained by a particular component (i.e., principal component axes) was derived from the broken-stick model in post-hoc comparison (Frontier 1976; McGarigal et al. 2000; Peres-Neto et al. 2003; Olden 2011).

Using the multi-variate analysis of PCA allows for a description of habitat changes through seasons and the spatial confines of Las Vegas Bay for a particular sonic-tagged juvenile razorback sucker and provides a metric for which physical habitat variables carry the most weight of variation explanation. Output from PCA can be interpreted, as the physical habitat variables (eigenvalues) carrying the most weight create a gradient along the first two principal component axes that explain seasonal and spatial variation in encounters of sonic-tagged juvenile razorback sucker. Points located at axis extremes are more influenced by the associated variables, while points located near the origin of axes do not show a strong association or explanation with any particular variable. Again, axis values do not represent a negative or positive correlation, and the numeric scale does not aid in interpretation.

The two multi-variate approaches were used in conjunction for the period of study, as they essentially describe two different relationships with regard to juvenile razorback suckers: (1) a holistic community interaction snapshot, with habitat and species abundance relationships used to explain causal mechanisms in juvenile razorback sucker presence (CCA); and (2) an observed trajectory of habitat utilization specific to sonic-tagged juvenile razorback suckers through time and space irrespective of other fish species or razorback sucker individuals (PCA).

RESULTS

Lake Elevation

Lake elevations in 2012 began at nearly 1133 ft (345.3 m) AMSL on January 1, 2012, wetting habitat not inundated since 2006 (see figure 1-16). As the year progressed however, lake elevations steadily declined to nearly 1,115 ft (339.9 m) AMSL on July 1, 2012. From July through November, lake elevations seemed to plateau and reflect conditions similar to those seen in 2008–09 (see figures 1-16 and 2-4). This marked shift in lake elevation had a noticeable impact on habitat availability at inflow areas such as Las Vegas Bay. Terrestrial vegetation inundated in early 2012 continued to be desiccated throughout much of the year, leaving less cover in this form of habitat available for juvenile razorback sucker utilization. However, as the year progressed into late November and December, lake elevations began to rise and reached 1,117 ft (340.6 m) AMSL on December 4, 2012 (figure 2-4).

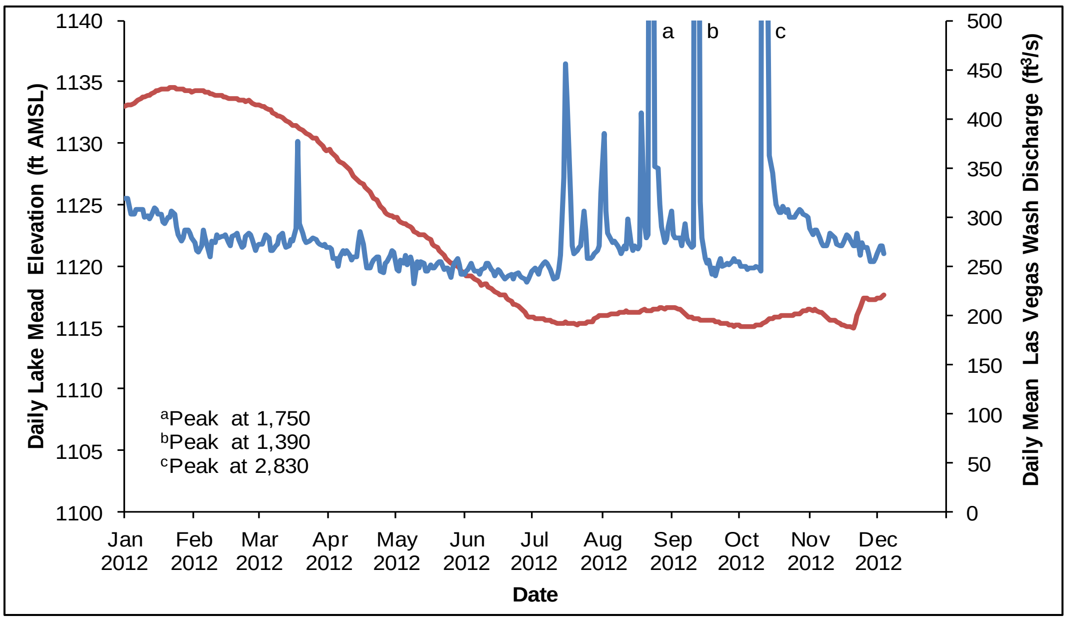


Figure 2-4.—Lake Mead daily lake elevations (red line) in ft AMSL, January 1 – December 4, 2012 (Reclamation 2012), and Las Vegas Wash mean daily discharge (blue line) in ft^3/s below Lake Las Vegas, Nevada (USGS gauge 09419800 [USGS 2012]), January 1 – December 4, 2012.
Discharge data are provisional and subject to USGS revision.
[a,b,c] Peak discharges outside displayed range.

As lake elevations declined through spring, summer, and into fall, the mean daily discharge from Las Vegas Wash decreased from an average of 285.8 ft^3/s in late winter to an average of 255.0 ft^3/s in spring. However, throughout summer and early fall, there was an increase in the frequency and magnitude of high-discharge events (see figure 2-4). Mean daily discharge increased in summer, with an average of 313.2 ft^3/s, and continued to climb through fall, with an average of 328.6 ft^3/s. High-discharge events, stemming from summer monsoonal rains, occurred on a near-monthly basis from July through October (see figure 2-4), with a maximum discharge of 2,830 ft^3/s recorded on October 12, 2012 (see figure 2-4). This seasonal increase in flow appeared to provide inputs of large woody debris, organic nutrients, and sediment to the Las Vegas Wash/Lake Mead interface (Golden and Holden 2002). The transport of sediment then, in turn, helps maintain some of the highest levels of turbidity in Lake Mead (Golden and Holden 2002), a form of cover of noted importance for razorback sucker recruitment (Golden and Holden 2002; Albrecht et al. 2010a; Shattuck et al. 2011).

Sonic Telemetry

Four juvenile razorback suckers were successfully implanted with sonic tags and tracked immediately following their respective post-surgery releases in Las Vegas Bay and Las Vegas Wash. Forty-seven active contacts were made with sonic-tagged juvenile razorback suckers spanning February 28 – December 4, 2012, entirely within the Las Vegas Bay and Las Vegas Wash areas (table 2-1). The juvenile razorback suckers implanted with sonic tags varied in size, although an equal number of each of the two sizes of sonic tags were used in this study. The largest two immature razorback suckers were the wild-caught individual (code 222) that measured 425 mm TL and one of the pond-reared individuals (code 337) that measured 390 mm TL. Both of the larger juveniles were implanted with the larger sonic tags (CT-82-2-I), while the smaller sonic tags (IBT-96-9-I) were implanted into the other pond-reared individuals that measured 345 mm TL (code 368) and 340 mm TL (code 452) (see figure 2-2 and table 2-1).

Table 2-1.—Demographic summary, with included sonic tag information, location and date of last contact, and current tag status for sonic-tagged juvenile razorback suckers stocked into Las Vegas Bay and Las Vegas Wash, Lake Mead; February 28 – December 4, 2012

Capture location[a]	Date tagged	Tag code	TL (mm) at tagging	Weight (g) at tagging	Sex[b]	Stocking location[a]	Last location[a]	Date of last location	Contacts made: active (passive)	Current tag status
2012										
LB	2/28/2012	222	425	808	I	LB	LB	12/4/2012	38 (615)	Active
CPD	4/23/2012	337	390	714	I	LW	LB	5/16/2012	7 (0)	Unknown
CPD	4/23/2012	368	345	484	I	LW	LW	4/24/2012	1 (0)	Unknown
CPD	4/24/2012	452	340	468	I	LB	LB	4/24/2012	1 (0)	Unknown

[a] LB = Las Vegas Bay, CPD = Center Pond, and LW = Las Vegas Wash.
[b] I = immature.

Contact was made with each juvenile at least once following sonic tag implantation, although the majority of contacts made in 2012 were with the wild, juvenile individual (code 222). Fish 222 was contacted a total of 38 times from February 28 to December 4, 2012, and frequented Government Wash and the western portion of Las Vegas Bay, including the areas of Gypsum Wash and Las Vegas Wash (figure 2-5). Fish 222 was contacted while occupying a variety of habitats that seasonally ranged in depth from 5 to 124 ft (1.5 to 37.8 m). From the end of February through the middle of April, fish 222 occupied habitats in and adjacent to Las Vegas Wash and Gypsum Wash Cove that were typically characterized by dense inundated vegetation and in nearshore littoral areas that had an average depth of 12 ft (3.7 m) and ranged from 6 to 29 ft (1.8 to 8.8 m) (figure 2-5). The furthest upstream contact made in Las Vegas Wash with fish 222 occurred in March at a point directly across from the Las Vegas Bay boat ramp in 7 ft (2.1 m) of water and dense inundated vegetation. In contrast, from May through September and in November, fish 222 appeared to move offshore to deeper, open water areas of Las Vegas Bay near the mouth of Government Wash (figure 2-5). Depths utilized during these months averaged 56 ft (17.1 m) and ranged from 7 to 124 ft (2.1 to 37.8 m). Habitat was seemingly characterized only by the changes in bathymetry. In October, fish 222 returned to habitats similar to those occupied during winter and spring; however, these types of habitats had spatially shifted southeast with the corresponding decreases in lake elevation (figure 2-5). Again, habitat occupied was characterized by inundated vegetation, and the average and range of depth occupied was 7 ft (2.1 m). Finally, in December, fish 222 was found occupying both nearshore habitats off the northern shore of the Cliffs area as well as offshore habitat near the mouth of Government Wash. The habitat fish 222 associated with amongst the complex coves of the Cliffs area was characterized by inundated vegetation and ranged in depth from 21 to 36 ft (6.4 to 11.0 m), with an average depth of 28 ft (8.5 m). Conversely, the associated habitat near the mouth of Government Wash was similar to that of previous months (i.e., May – September and November) and consisted of open water with bathymetric features and an average and range of depth equal to 68 ft (20.7 m).

Fish 337 was the second most frequently contacted juvenile razorback sucker; seven contacts were made from April 24 to May 16, 2012. This pond-reared individual was primarily contacted at the Las Vegas Wash/Lake Mead interface, below the Las Vegas Bay boat ramp (figure 2-5). Fish 337 was contacted in habitats ranging in depths of 4–14 ft (1.2–4.2 m), with an average depth of 9 ft (2.7 m) and associated with an area of the Las Vegas Wash inflow noted for its high turbidity levels and dense inundated vegetation. Though this individual was contacted frequently at the Las Vegas Wash/Lake Mead interface, periodically fish 337 moved upstream into the Las Vegas Wash proper and occupied deeper (approximately 10 ft [3.0 m]) eddies where the wash was undercutting banks of inundated vegetation. This individual was last contacted at the Las Vegas Wash/Lake Mead interface on May 16, 2012.

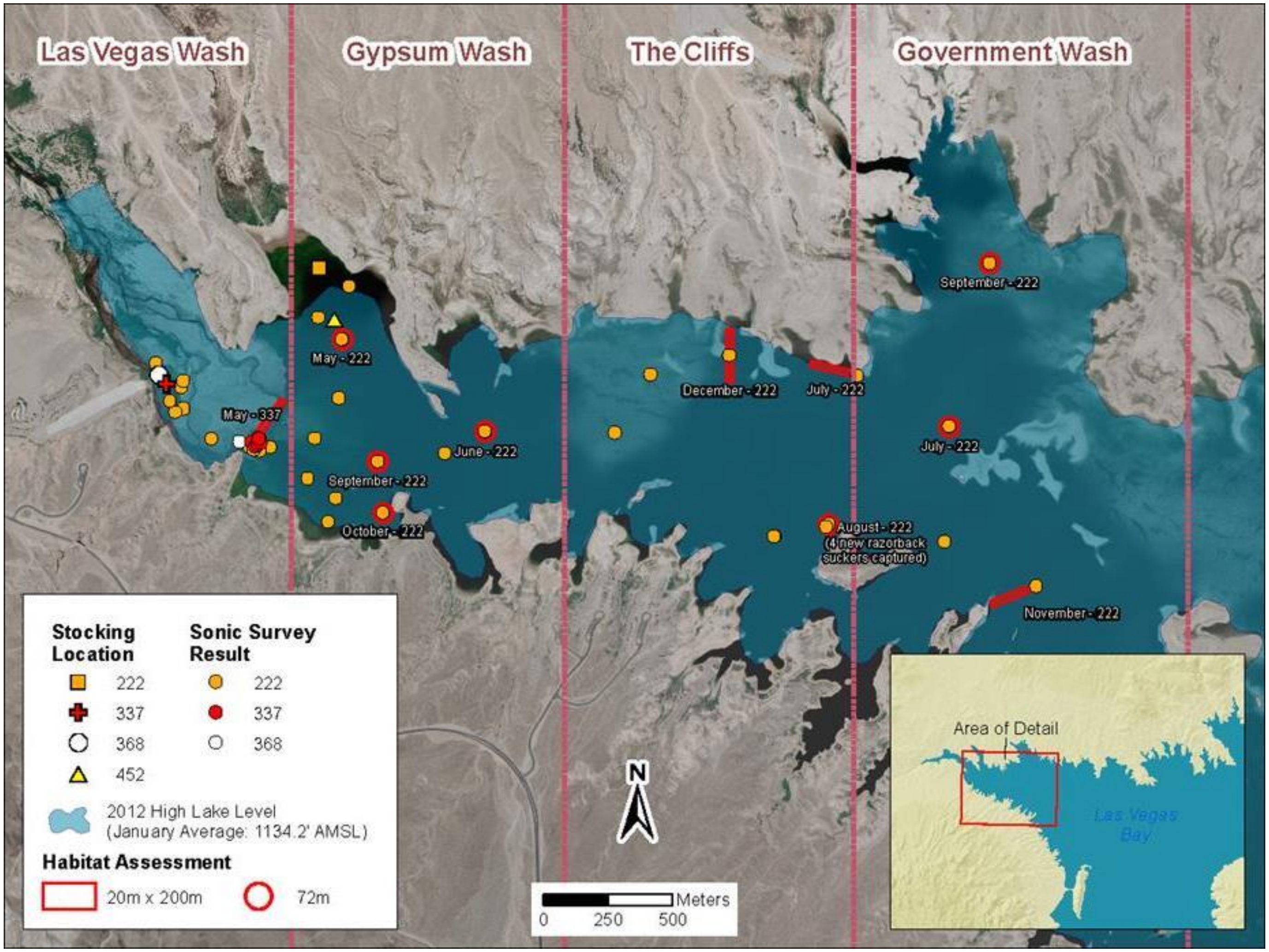


Figure 2-5.—Overview of stocking locations and sonic tag contacts made in Las Vegas Bay and Las Vegas Wash for the four sonic-tagged, juvenile razorback suckers, February 28 – December 4, 2012. Red boundary lines divide Las Vegas Bay into major bathymetric designated units: Las Vegas Wash, Gypsum Wash, the Cliffs, and Government Wash.

The other pond-reared individuals (codes 368 and 452) were contacted once each during the juvenile pilot study. They were both last contacted on April 24, 2012. Fish 368 was last contacted at the Las Vegas Wash/Lake Mead interface in 6 ft of water associated with inundated vegetation and high levels of turbidity. Fish 452 was last contacted after its release in the back of Gypsum Wash Cove in 7 ft (2.1 m) of water and among large expanses of inundated vegetation (see figure 2-5).

Though dense inundated vegetation hindered clear contact with sonic-tagged juvenile razorback suckers, exhaustive efforts were spent targeting this specific cover type; sonic signal oversight is unlikely. Additionally, extensive efforts to actively track the relatively unmonitored Las Vegas Wash were undertaken numerous times during the pilot study. Foot tracking on a bimonthly basis was unsuccessful in locating unaccounted for sonic-tagged juvenile individuals. Listening was conducted at suitable points in the Las Vegas Wash (i.e., less turbulent habitats such as eddies or pools) for approximately 1.2 mi (1.9 km) upstream of the Las Vegas Wash/Lake Mead interface. Furthermore, the Las Vegas Wash was tracked in its entirety by kayak from the Northshore Road Bridge downstream to the Lake Mead inflow during August. During these efforts, the omnidirectional towable hydrophone was used to track areas of flowing, turbulent habitat, as well as less turbulent habitat, although no contacts were made with sonic-tagged juvenile individuals.

Upstream movement of sonic-tagged juvenile razorback suckers into the Las Vegas Wash was monitored through active tracking; passive monitoring of the upper bounds of the Las Vegas Wash was also conducted using a SUR deployed in April 2012. The SUR was initially deployed approximately 0.5 mi (0.8 km) downstream from the Northshore Road Bridge; however, after 3 months without contact, the SUR was moved further downstream to an eddy approximately 0.5 mi (0.8 km) upstream of the Las Vegas Wash/Lake Mead interface in July 2012. No contacts were recorded on the Las Vegas Wash SUR at the downstream point from July to September, and further passive monitoring of the Las Vegas Wash was forgone after the SUR was lost. A high-discharge event at the end of September 2012 (see figure 2-4) likely dislodged the SUR from its anchor point and washed the unit downstream to be buried in sediment. Efforts to locate the SUR proved unsuccessful, and it was decided that the SUR in the Las Vegas Wash would not be replaced since no contacts had been made and continued summer and fall storms were likely.

In an effort to account for sonic-tagged juvenile razorback sucker movement out of the Las Vegas Bay area, an SUR placed by the NDOW at a constriction point near Sand Island for an unrelated study was utilized. This particular SUR contacted one sonic-tagged juvenile razorback sucker (code 222) a total of 615 times from June 9 to December 4, 2012. The absence of passive contacts from late February through mid-June 2012 concurs with the active contacts with sonic-tagged juvenile individuals primarily utilizing habitat on the western end of

Las Vegas Bay into Las Vegas Wash during this timeframe. It was not until late spring and summer that sonic-tagged juveniles began to stray from the Las Vegas Wash inflow area and move into deeper waters near Government Wash and Sand Island (i.e., near listening proximity of the NDOW SUR at Sand Island). Additionally, effort was spent tracking areas adjacent to Las Vegas Bay (e.g., portions of Callville Bay and the Boulder Basin), though no contacts were made.

As the lake elevation declined in late spring and summer (see figure 2-4), a transition in habitat association was observed in sonic-tagged juvenile razorback suckers. An association with nearshore habitats containing large amounts of inundated vegetation shifted to an association with deeper habitats further offshore. Similarly, as the lake elevation decreased, so did the available areas in which a sonic-tagged juvenile razorback sucker could move out of the Las Vegas Bay area undetected. This factor, in conjunction with vast sonic telemetry efforts, lends support to the idea that sonic tag detections were not simply overlooked.

Conspecific and Community Sampling

From May 7 through December 4, 2012, 25 trammel nets, 5 hoop nets, 16 minnow traps, 1 fyke net, and 6 seine hauls were used to capture a total of 204 individuals from 10 fish species during sampling conducted around sonic-tagged juvenile razorback suckers. In this time, a number of exploratory seine hauls in the area of Las Vegas Wash were conducted; however, these efforts were excluded from quantified analyses, as they were not associated with any particular sonic-tagged juvenile individual. Hoop nets were used during May and December sampling, and fyke nets were used in May sampling, as sonic-tagged juvenile individuals were not often contacted in sufficiently shallow habitats for these gear types. Similarly, seine hauls were pulled near shoreline habitat near the Las Vegas Wash only during May sampling, as shallow habitat with little obstruction for this gear type was present only during this month. Minnow traps were used in May and October – December where habitat allowed, and trammel nets were used throughout the year with the exception of June. No fish sampling was conducted during June, as fish 222 moved from habitat near Gypsum Wash (28 ft [8.5 m]) into deeper (75 ft [22.9 m]) habitat near Government Wash, and no discrete location could be determined for sampling. An additional contact location was recorded near Government Wash, and it appeared the individual was passing through this location. Furthermore, only the habitat assessment sampling portions of our methodology were conducted near Gypsum Wash, as this was likely an area previously occupied by the sonic-tagged juvenile, although the individual was no longer present. Similarly, an additional habitat assessment location was sampled in July without associated fish sampling because no sonic-tagged juveniles were present at the time of sampling. Finally, another habitat assessment location was sampled in September, and additional sampling was conducted for associated fishes.

Four wild razorback suckers were captured in Las Vegas Bay during August sampling efforts (table 2-2); they were found in association with the wild sonic-tagged juvenile (code 222) (see figure 2-5). All four razorback suckers were captured south of the Government Wash area in depths ranging from 34 to 70 ft (10.4 to 21.3 m) along an underwater rock ledge. TLs of the individuals ranged from 480 to 540 mm, and all individuals were PIT tagged and fin clipped for aging purposes (table 2-2). No additional razorback suckers were captured during sampling for the remainder of the year. In terms of community composition, species collected varied by location within Las Vegas Bay and by the particular sonic-tagged juvenile individual they were associated with. During May, the CPUE associated with fish 337 showed that gizzard shad comprised the largest portion of captured individuals (68%), while bluegill comprised the smallest portion (3%) of the total catch (figure 2-6). For fish 222, CPUE effort for May through December showed that gizzard shad also comprised the largest portion of the catch (53%), with green sunfish comprising the smallest portion (2%). Razorback sucker comprised 2.9% of the total catch associated with fish 222, which had a CPUE of 0.0006 fish per minute (figure 2-6).

Table 2-2.—Location, tag, and size information for razorback suckers captured in Las Vegas Bay during conspecific and community sampling for the juvenile pilot study May 7 – December 4, 2012

Date	Capture location[a]	Pit tag number	Sonic tag	Date stocked[b]	Recapture	TL (mm)	FL (mm)	SL (mm)	Weight (g)	Sex[c]	Age[d]
8/8/2012	LB	3D9.1C2D26076E	–	4/19/2011	NO	495	454	423	1,508	U	6
8/8/2012	LB	3D9.1C2C857730 [e]	–	4/19/2011	NO	480	446	418	–	U	6
8/8/2012	LB	3D9.1C2D262C68 [e]	–	4/19/2011	NO	521	484	455	–	U	6
8/8/2012	LB	3D9.1C2D263586 [e]	–	4/19/2011	NO	540	505	466	–	U	7

[a] LB = Las Vegas Bay.
[b] Date originally stocked or originally captured.
[c] U = unidentified.
[d] Age (years), as determined through fin clip and post-hoc aging analyses.
[e] No weight measurement was taken due to scale malfunction and to avoid unnecessary stress on the individual.

During spring sampling efforts, several gear types were used to characterize the fish community associated with sonic-tagged juvenile razorback suckers, and sampling was conducted in shallow littoral areas. Striped bass, though typically more pelagic in nature, were captured in seine hauls near the mouth of Las Vegas Wash in May; however, the striped bass ranged in size from 17 to 25 mm (figure 2-6). Red shiner (*Lepomis cyanellus*), small gizzard shad (20–25 mm), and bluegill (22–88 mm) were also common near Las Vegas Wash and were collected primarily in spring and fall. Summer sampling consisted mainly of gizzard shad, largemouth bass (*Micropterus salmoides*), bluegill, and smallmouth

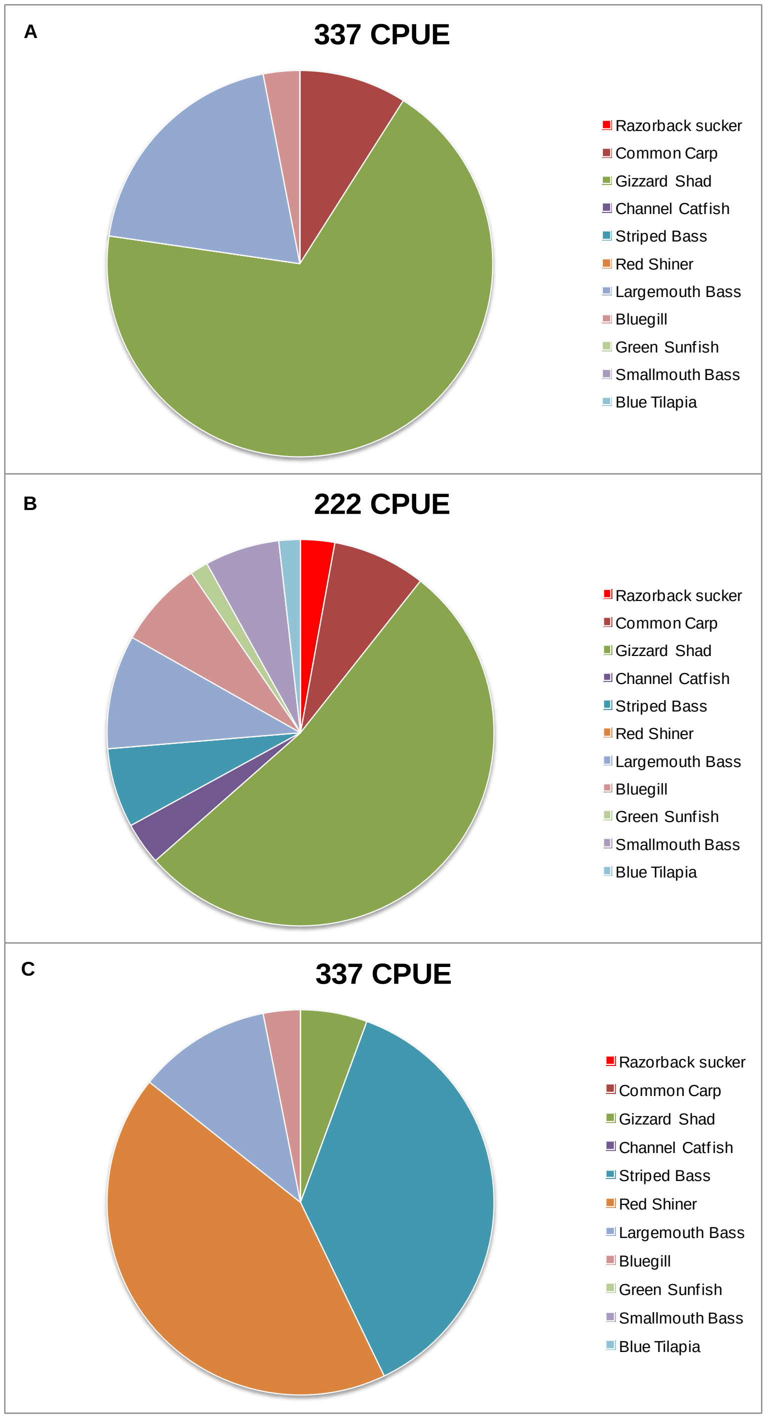


Figure 2-6.—CPUE as a percentage of composition by species associated with sonic-tagged juvenile razorbacks sucker in Las Vegas Bay during May 7 – December 4, 2012, for the number of individuals captured per minute for all gear types combined (except seines) near (A) fish 337 and (B) fish 222 and the number of individuals captured per square foot during seining (4 x 15 ft) near (C) fish 337.

bass (*Micropterus dolomieu*), whereas a number of common carp were captured during fall sampling, in addition to numerous gizzard shad and various centrarchids.

During summer, sonic-tagged juvenile razorback suckers were located offshore in deeper habitats, and only trammel nets and minnow traps were used to characterize the fish community in these areas (although no fish were captured in minnow traps). Additionally, due to the inherent selectivity of trammel nets, the majority of fish captured were larger-bodied species, including gizzard shad, common carp, and smallmouth bass.

Efforts to locate additional juvenile razorback suckers outside of locations associated with a particular sonic-tagged juvenile individual were conducted in Las Vegas Wash. During June, eight seine hauls were conducted using a 6.6 x 29.5 ft (2.0 x 9.0 m) seine. No native fish were captured during these efforts, although 67 red shiners and 2 largemouth bass (150 mm and 85 mm TL) were captured in run- and eddy-type habitats. Further efforts conducted in Las Vegas Wash with a smaller (3.9 x 14.8 ft [1.2 x 4.5 m]) seine during July produced 758 red shiners, 2 largemouth bass (81 mm and 143 mm TL), and 2 blue tilapia (*Oreochromis aureus*) (68 and 71 mm in TL) but no native fish in 21 seine hauls. Habitat sampled in Las Vegas Wash generally consisted of larger substrate types (i.e., cobble and gravel) in slow-moving eddy and pool habitats dominated by silt. Furthermore, woody debris and overhanging vegetation were the most common forms of cover in Las Vegas Wash, which had depths ranging from < 1 ft (0.3 m) to approximately 6 ft (1.8 m). No additional seining efforts were conducted in Las Vegas Wash during the remainder of the year, as sonic-tagged razorback suckers were not utilizing the wash/lake interface.

Age Determination

The wild, juvenile razorback sucker (code 222) used in this study was a new individual captured during long-term monitoring studies. However, we did not collect a fin clip to determine age to avoid additional stress during and after the implant surgery. Similarly sized (350–450 mm) razorback suckers captured during the 2008–10 spawning period on Lake Mead were aged at 3–5 years old (Albrecht et al. 2008a, 2009, 2010b). Should this individual (code 222) be captured in the future, a fin clip will be taken to verify age.

The four new, wild razorback suckers that were captured during August sampling efforts were fin clipped, and definitive ages were calculated for all four individuals. These individuals, which ranged in size from 480 to 540 mm TL, were aged from 6 to 7 years old (see table 2-2). The largest fish (540 mm) was aged at 7 years old (2005 year-class), while the other three individuals were aged at 6 years old (2006 year-class). Both of these year-classes have been noted for their strength in regard to razorback sucker recruitment in Lake Mead (see chapter 1, figure 1-17).

Habitat Observations and Physicochemical Quantification

Fifty-five habitat replicates were measured, according to the presence of sonic-tagged juvenile razorback suckers, from May 7, 2012, through December 4, 2012. Twenty inshore habitat replicates and 35 offshore habitat replicates were quantified as sonic-tagged juvenile razorback suckers associated with a variety of areas throughout the study. A habitat assessment showed a seasonal shift in the types of habitat that sonic-tagged juvenile razorback suckers associated with, similar to that shown in the sonic telemetry data (see figure 2-5). Among habitats quantified, inshore habitat was most often characterized by shallow depths, a silt substrate, a general presence of algal and detrital material, and as being dominantly composed of inundated vegetation. Conversely, offshore habitat was primarily characterized by greater depths, heterogeneous substrate, limited presence of algal and detrital material, and no observable vegetative cover. As variation in habitat was recorded, so were changes in the use of particular locations within Las Vegas Bay. Throughout the pilot study, the habitats sampled, and thus the areas associated with sonic-tagged juvenile razorback suckers, were primarily located in the area of Government Wash (36.3%), followed in frequency by Gypsum Wash (27.3%), the Cliffs (27.3%), and Las Vegas Wash (9.1%) (see figure 2-5).

As differences were observed in the movement of sonic-tagged juvenile razorback suckers, physicochemical information was averaged on a monthly basis to better define conditions during sampling events and highlight any seasonal variation observed. During the May 7 – December 4, 2012, study period, monthly means in temperature ranged from 63.79 to 84.8 °F (17.66 to 29.35 °C), monthly means of DO ranged from 7.99 to 17.16 milligrams per liter, and monthly means in turbidity ranged from 0.95 to 35.83 NTUs (table 2-3). Mean depths of habitats sonic-tagged juvenile razorback suckers associated with ranged from 3.7 to 52.1 ft (1.13 to 15.89 m), with the greatest depths associated with occurring in December and the shallowest depths occurring in October (table 2-3). Often, range extremes in physicochemical data were observed in summer (e.g., July and August) and fall (e.g., November and December), which may describe a seasonal gradient of conditions found in Las Vegas Bay or simply differences among areas sampled (e.g., differences in depths between the Las Vegas Wash inflow area and Government Wash Cove) (table 2-3).

With the exception of turbidity, August had the greatest variation of physicochemical data for sonic-tagged juvenile razorback sucker habitat, with

Table 2–3.—Mean monthly physicochemical and habitat summary for locations of sonic–tagged juvenile razorback suckers within Las Vegas Bay, May 7 – December 4, 2012

	Physicochemical								Cover type					Substrate type			
	Temp. (°C)[a]	Cond. (µS/cm)[b]	DO (mg/L)[c]	pH	TDS (g/L)[d]	DO (% sat)	Turb. (NTU)[e]	Depth (m)	IV[f]	SAV[g]	LWD[h]	NO[i]	SI[j]	SA[k]	GR[l]	CO[m]	BD[n]
May																	
Mean (SE)[o]	21.74 (0.04)	2.03 (0.01)	10.09 (0.10)	9.37 (0.02)	1.29 (0.01)	114.39 (0.94)	23.39 (7.95)	1.25	50.0	0.5	0.0	49.5	65.0	18.0	17.0	0.0	0.0
Min.	20.94	1.87	8.75	9.11	1.20	101.50	3.30	–	–	–	–	–	–	–	–	–	–
Max.	22.35	2.24	13.81	9.59	1.40	125.30	451.00	3.50	–	–	–	–	–	–	–	–	–
June																	
Mean (SE)	25.45 (0.09)	1.47 (0.02)	8.55 (0.09)	10.51 (0.02)	0.93 (0.02)	104.31 (1.11)	12.72 (1.68)	4.12	0.0	0.0	0.0	100.0	77.0	0.0	3.0	0.0	20.0
Min.	24.19	1.27	7.07	10.29	0.80	84.70	3.20	–	–	–	–	–	–	–	–	–	–
Max.	26.65	1.80	9.75	10.70	1.10	119.80	59.70	9.00	–	–	–	–	–	–	–	–	–
July																	
Mean (SE)	28.60 (0.03)	1.23 (0.001)	8.61 (0.06)	10.86 (0.01)	0.80 (0.00)	111.38 (0.78)	19.38 (6.08)	3.89	0.0	0.0	0.0	100.0	40.0	26.3	33.8	0.0	0.0
Min.	27.71	1.22	7.39	10.65	0.80	94.30	1.60	–	–	–	–	–	–	–	–	–	–
Max.	28.71	1.25	9.01	10.91	0.80	116.80	208.00	10.00	–	–	–	–	–	–	–	–	–
August																	
Mean (SE)	29.35 (0.31)	1.35 (0.03)	8.81 (0.50)	10.77 (0.04)	0.86 (0.02)	115.76 (7.32)	35.78 (2.39)	6.40	0.0	0.0	0.0	100.0	75.0	12.5	12.5	0.0	0.0
Min.	24.35	1.05	4.58	10.48	0.70	54.30	13.30	–	–	–	–	–	–	–	–	–	–
Max.	31.74	1.91	13.37	11.29	1.00	183.30	66.10	13.50	–	–	–	–	–	–	–	–	–
September																	
Mean (SE)	27.07 (0.03)	1.27 (0.02)	9.91 (0.12)	8.64 (0.01)	0.82 (0.01)	124.02 (1.61)	15.14 (4.10)	4.65	0.0	0.0	0.0	100.0	66.3	20.2	13.5	0.0	0.0
Min.	26.21	1.10	3.14	8.15	0.70	27.70	4.40	–	–	–	–	–	–	–	–	–	–
Max.	27.55	1.93	10.96	8.75	1.20	138.30	413.00	15.00	–	–	–	–	–	–	–	–	–
October																	
Mean (SE)	24.71 (0.04)	1.16 (0.00)	17.16 (0.11)	9.16 (0.01)	0.72 (0.00)	203.53 (1.62)	35.83 (0.59)	1.13	23.0	4.0	0.0	73.0	84.0	0.0	0.0	16.0	0.0
Min.	22.55	1.10	9.03	8.57	0.70	79.30	16.80	–	–	–	–	–	–	–	–	–	–
Max.	26.34	1.60	21.24	9.43	1.00	259.90	81.20	3.00	–	–	–	–	–	–	–	–	–
November																	
Mean (SE)	19.19 (> 0.01)	1.01 (> 0.01)	7.99 (> 0.01)	8.74 (> 0.01)	0.63 (> 0.01)	85.466 (0.05)	2.69 (0.12)	15.26	0.0	0.0	0.0	100.0	100.0	–	–	–	–
Min.	19.01	0.99	7.40	8.62	0.60	78.80	0.00	–	–	–	–	–	–	–	–	–	–
Max.	19.54	1.03	8.57	8.77	0.70	89.10	42.50	81.70	–	–	–	–	–	–	–	–	–
December																	
Mean (SE)	17.66 (> 0.01)	0.98 (> 0.01)	8.58 (0.01)	8.87 (> 0.01)	0.60 (> 0.01)	88.94 (0.05)	0.95 (0.07)	15.89	0.0	0.0	0.0	100.0	51.7	56.7	31.7	80.0	0.0
Min.	17.17	0.98	8.13	8.76	0.60	84.50	0.00	–	–	–	–	–	–	–	–	–	–
Max.	18.00	0.99	9.03	8.91	0.60	94.10	19.80	88.90	–	–	–	–	–	–	–	–	–

[a] Temperature.
[b] Conductivity.
[c] Dissolved oxygen in milligrams per liter.
[d] Total dissolved solids in gallons per liter.
[e] Turbidity.
[f] Inundated vegetation.
[g] Submerged aquatic vegetation.
[h] Large woody debris.
[i] No cover.
[j] Silt.
[k] Sand.
[l] Gravel.
[m] Cobble.
[n] Boulder.
[o] Standard error.

higher amounts of standard error seen for most parameters among monthly means (0.02 – 0.50) (table 2-3). Conversely, July and December had the least amount of variation, with lower amounts of standard error for most parameters among monthly means (<0.01 – 0.07) (see table 2-3). Variations in discharge from Las Vegas Wash may have contributed to the greater amounts of water column variation through the seasons, thus influencing movements of sonic-tagged juvenile razorback suckers through observed physicochemical conditions.

Though more predictable seasonal shifts appeared in much of the physicochemical data, large amounts of variation in turbidity were seen throughout the pilot study (see table 2-3). Turbidity measurements among all months ranged from 0.00 to 451.00 NTUs, with a range in standard error of 0.07–7.95 (see table 2-3). Mean turbidity was highest in October, followed by August, with seasonal storms influencing increased discharges in Las Vegas Wash (see figure 2-2), which further influenced fluctuations in NTU levels (see table 2-3). These storm events often carried increased loads of sediment, which influenced turbidity levels in Lake Mead and, subsequently, the substrate composition of Las Vegas Bay (Golden and Holden 2003).

Las Vegas Wash directly contributes to the substrate composition of Las Vegas Bay and influences turbidity throughout the remainder of Lake Mead (Golden and Holden 2002). Dominant substrate for habitats that sonic-tagged juvenile razorback suckers were associated with was primarily silt (see table 2-3). Silt comprised 40.0–100.0% of the substrate sonic-tagged juvenile razorback sucker associated with on a monthly average (see table 2-3). The next most dominant substrates sampled were sand (0.0–56.7%) and gravel (0.0–33.8%), while larger substrates of cobble, boulder, or bedrock were less often associated with sonic-tagged juvenile razorback suckers.

Similar to silt substrate, inundated vegetation was the primary cover type with which sonic-tagged juvenile razorback suckers were associated. It comprised 0.0–50.0% of cover present, with nearshore habitats characterized primarily by this cover type. However, throughout the pilot study, many of the habitats quantified were seemingly void of cover (see table 2-3). Submerged aquatic vegetation occurred in low compositions in nearshore habitat with a range of 0.0–4.0% (see table 2-3). As turbidity may provide razorback suckers with cover from predators (e.g., Golden and Holden 2002; Knecht and Ward 2012), turbidity also hindered assessments of the amounts of cover present at sampling sites due to limited visibility. However, algae and detritus were present in 44.4% of ponar grab samples and may indicate some level of cover or productivity.

Using fish assemblage data from the community and conspecific sampling, in conjunction with physicochemical and habitat information collected from locations of sonic-tagged juvenile razorback suckers, more specific ecological relationships were explained through the CCA. Canonical correspondence analysis explained 99.1% (total inertia = 1.625, sum of all eigenvalues = 1.610) of the variability within the fish assemblage associated with sonic-tagged juvenile razorback suckers through environmental parameters, season, site, and unexplained variation (figure 2-7). In post-hoc variance partitioning, the pure effect of environmental parameters explained 22.28% ($F = 41.7$, $P = 0.0001$), the pure effect of season explained 0.49% ($F = 6.4$, $P = 0.0087$), and the pure effect of site explained 5.17% ($F = 47.2$, $P = 0.0001$); all of which were significant. A large amount of variation was explained by two- and three-way interactions (e.g., environmental parameters and season combined, season and site combined), totaling 71.16% of the variation explained, while the total unexplained variation accounted for only 0.9% of the model. Forty-four samples were used in the CCA analysis, which mainly consisted of data taken in association with the wild, juvenile individual (n = 39, code 222). However, 11 samples were not included in the analysis, as fish sampling was not conducted in association with a sonic-tagged juvenile razorback sucker during June or July (10 replicates), and equipment malfunction prevented physicochemical data from being collected for one replicate in August.

Factors with the strongest loadings on CCA axis I were average DO (biplot score = -0.47), average TDS (-0.44), average conductivity (-0.44), average depth (0.45), summer season (0.47), and the Cliffs (0.79) (figure 2-7). Factors with the strongest loadings on CCA axis II were Las Vegas Wash (-0.89), spring season (-0.79), average conductivity (-0.78), average DO (0.72), fall season (0.73), and Gypsum Wash (0.81) (figure 2-7). Green sunfish (biplot score = 2.65), smallmouth bass (2.06), common carp (1.76), and adult razorback sucker (0.94) were positively related to CCA axis I and associated with the Cliffs and Government Wash, summer season, greater depths, and higher pH values. Red shiner (-0.57), gizzard shad (-0.36), bluegill (-0.36), and largemouth bass (-0.35) were negatively related to CCA axis I and associated with increased amounts of vegetative cover in the forms of inundated vegetation and submerged aquatic vegetation, higher presence of algae and detritus, higher turbidity, and higher temperature. Gizzard shad (0.64), blue tilapia (0.38), channel catfish (0.32), and adult razorback sucker (0.27) were positively related with CCA axis II and associated with Gypsum Wash, fall season, higher DO, higher temperature, increased amounts of vegetative cover in the forms of inundated vegetation and submerged aquatic vegetation, and silt substrate. Red shiner (-1.28), striped bass (-0.87), common carp (-0.20), and largemouth bass (-0.20) were negatively related with CCA axis II and associated with Las Vegas Wash, spring season, higher turbidity, higher TDS and conductivity, larger substrates (sand and gravel), and a lack of inundated cover.

In general, sonic-tagged juvenile razorback suckers were not strongly associated with any particular habitat type, as they were sampled somewhat ubiquitously; however, they were plotted in multi-variate space in relation to areas of Government Wash and the Cliffs, with higher pH values, greater depths, and during the summer season. Similarly functioning species included adult

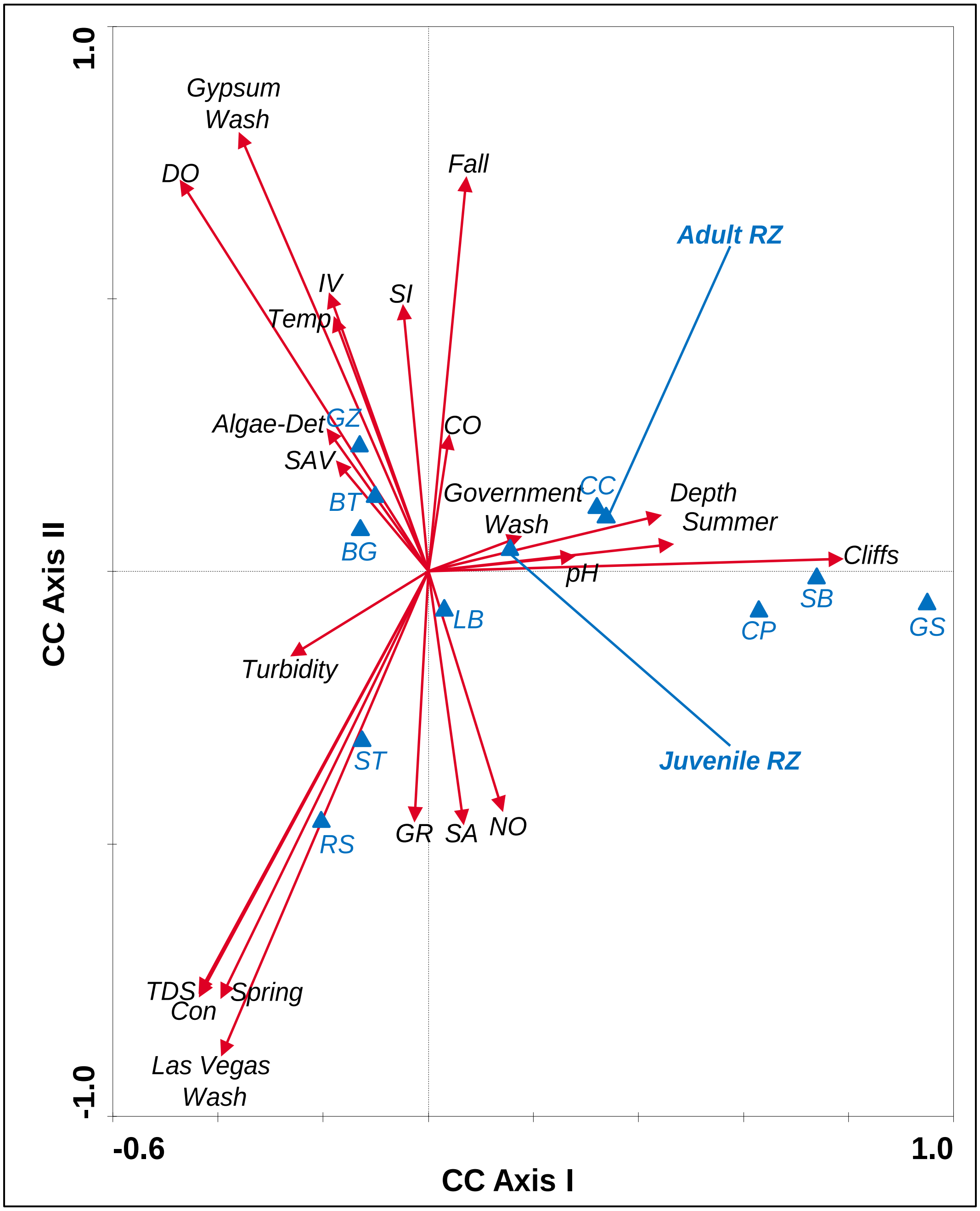


Figure 2-7.—CCA of the environment, season, site, and fish community associated with sonic-tagged juvenile razorback suckers in Las Vegas Bay from May 7 to December 4, 2012.
The CCA showed that 99.1% (total inertia = 1.625, sum of all eigenvalues = 1.610) of the variation seen within the fish community could be explained by environmental parameters, season, and site.

razorback suckers, channel catfish, and common carp. Interestingly, adult razorback suckers did not partition out too differently than sonic-tagged juvenile razorback suckers in CCA space, though much of the data included for juvenile razorback suckers were derived from one sonic-tagged individual. Although the capture of few adult razorback suckers during sampling may be weighting the apparent difference seen in CCA space, the subtle differences in habitat and fish community may have meaning, as predation and habitat needs differ for differing sizes and life stages of razorback suckers (Golden and Holden 2002; Albrecht et al. 2010a; Shattuck et al. 2011).

Seasonal variation in habitat associations were explained through PCA by using the physicochemical and habitat information collected from locations of and specific to sonic-tagged juvenile razorback suckers. In contrast to the CCA model, 54 samples of habitat data were used in the PCA analysis, including June and July habitat information specific to a juvenile razorback sucker, despite the lack of associated fish sampling. Additionally, and similar to the CCA model, one replicate sample was not included in the analysis due to equipment malfunction in collection of physicochemical data during August. In the PCA model, the first two axes explained 38.0% (PC axis I = 22.8%, PC axis II = 15.2%) of the total variation in environmental parameters and sites among habitats associated with sonic-tagged juvenile razorback suckers (figure 2-8). In post-hoc comparison, both principal component axes exceeded the expectations of the broken-stick criterion (i.e., PC axis I total variance > 17.99%, PC axis II total variance > 12.99% [Frontier 1976; Olden 2011]) and explained a significant amount of variance. Principal component axis I described a depth and cover gradient with average depth (-1.47), Government Wash (-1.39), no cover (-0.94), presence of algae and detritus (1.45), inundated vegetation (1.55), and Gypsum Wash (1.66) having the strongest loadings on the axis (figure 2-8). Principal component axis II described a substrate, depth, conductivity, and TDS gradient, with silt (-1.61), Gypsum Wash (-0.92), average depth (-0.83), average TDS (1.47), average conductivity (1.50), and Las Vegas Wash (1.94) having the strongest loadings along the axis (figure 2-8). Habitats associated with Las Vegas Wash were generally more turbid and had higher conductivity values, higher TDS values, and larger substrates. Habitats associated with Gypsum Wash were characterized with more vegetative cover (i.e., inundated vegetation and submerged aquatic vegetation), higher presence of algae and detritus, silt substrates, and higher DO. Conversely, habitats located in Government Wash and the Cliffs were typically deeper, with higher temperatures, higher pH values, and larger substrates (i.e., gravel, sand, and boulders).

Seasonal shifts in movement and habitat use shown in sonic telemetry data and the seasonal changes in physicochemical and habitat data were supported in theory by the PCA model. The general pattern of season, highlighted for samples post-hoc (figure 2-8), shows clear shifts in location and habitat composition of areas occupied by sonic-tagged juvenile razorback sucker throughout the year. Samples in PCA space show a stronger uniqueness for the spring and fall seasons, with samples exhibiting distances further from the origin, while the summer season has more overlap with spring and fall, and samples are plotted closer to the origin (figure 2-8). The observation of seasonal sample partitioning in PCA space offers explanatory power in potentially predicting the annual potadromy of juvenile razorback suckers in Las Vegas Bay (figure 2-8). Typically, sonic-tagged juvenile razorback sucker habitat sampled in spring was characterized by higher turbidities, larger substrates, and higher abundances of vegetative cover in the Las Vegas Wash area. Summer habitat for sonic-tagged juvenile razorback suckers was characterized by greater depths, higher temperatures, and larger substrates in the Cliffs and Government Wash areas. Finally, fall habitat for sonic-tagged juvenile razorback suckers seemed to be transitional and was characterized by inundated vegetation and submerged aquatic vegetation cover, with higher DO, and silt substrate in the Gypsum Wash and Government Wash areas.

DISCUSSION AND CONCLUSIONS

Overall, the baseline data collected during the 2012 juvenile pilot study provided a better understanding of razorback sucker recruitment habitat in Lake Mead as well as quantitative, empirical information on juvenile razorback suckers. Important habitat and seasonal movement information was collected, and four new, wild razorback sucker conspecifics were captured, which doubled the capture of razorback suckers in Las Vegas Bay during long-term monitoring in the 2011–12 study year (chapter 1). Data collected during the 2012 juvenile pilot study helped expand our knowledge of habitat use, movement patterns, and the associated fish assemblage of juvenile razorback suckers in Lake Mead and provided a quantitative characterization of habitat use throughout the year. Sonic telemetry was reaffirmed as a useful tool for collecting habitat information and guided sampling efforts toward the collection of additional razorback suckers.

Lake Elevation

Typical seasonal variation in Lake Mead elevation and discharge of Las Vegas Wash seemed to complement one another by providing different forms of cover consistently throughout the year (i.e., inundated vegetation through higher lake elevations in spring and summer and turbidity through summer and fall storms and high-discharge events). Sonic-tagged juvenile razorback suckers were frequently contacted near the Las Vegas Bay boat ramp in Las Vegas Wash in heavy inundated cover and during higher lake elevations. Conversely, as lake levels declined and high-discharge events occurred more frequently during summer and fall, sonic-tagged juveniles appeared to use the immediate Las Vegas Wash inflow area less frequently. During this time, they used deeper habitat

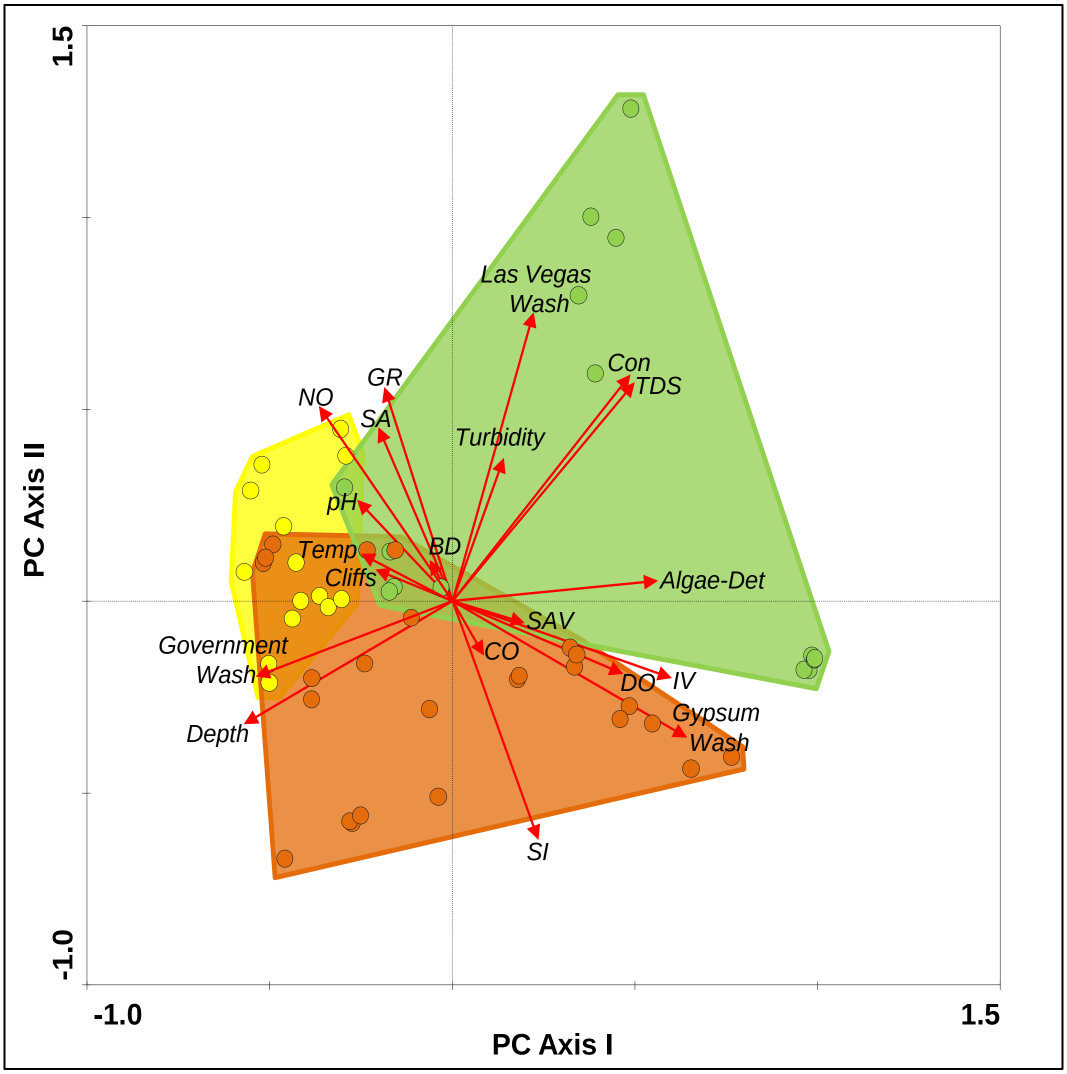


Figure 2-8.—PCA of the environment and site parameters associated with sonic-tagged juvenile razorback suckers in Las Vegas Bay from May 7 to December 4, 2012.
The first two principal component axes explained 38.0% of the variation seen within habitats, with post-hoc labeling of season included (green = spring, yellow = summer, and orange = fall).

further into the main portions of Las Vegas Bay where cover occurred in the form of turbidity. The lake and inflow interface relationship has been of noted importance in other razorback sucker studies (Albrecht et al. 2010b; Kegerries and Albrecht 2011; Shattuck et al. 2011) as well as in other systems in North America (Kaemingk et al. 2007).

Sonic Telemetry

Sonic telemetry data from tagged juvenile razorback suckers proved invaluable in determining habitat use in Las Vegas Bay during the spring, summer, and fall seasons of 2012. Furthermore, the sonic-tagged individuals provided information about potential recruitment habitat for razorback suckers through their patterned movement from shallow habitats, with an abundance of inundated cover to deeper habitat further away from adjacent inflow areas. As spring transitioned into summer, juvenile razorback suckers began to move further away from the Las Vegas Wash inflow and seemed proximal to other adult sonic-tagged razorback suckers. Although many of the sonic telemetry data were collected from one juvenile individual, the capture of four new, wild razorback suckers in direct association with a juvenile individual indicates that juvenile and adults fish may share habitats at certain times of the year. However, based on long-term monitoring of sonic-tagged adults, it appears that juvenile fish often return to shallow and turbid habitats with inundated vegetation sooner than adults (Albrecht et al. 2010b; Shattuck et al. 2011), and data from the pilot study show more frequent movements between these habitats. While overlap in habitat use may exist, sonic telemetry data suggest slight differences in the timing and areas occupied by juvenile razorback suckers. Further study and additional data will provide greater insight into seasonal movements of juvenile fish.

Juvenile razorback suckers were often contacted in shallow areas adjacent to Las Vegas Wash, but sampling and tracking in the Las Vegas Wash/Lake Mead interface area was often difficult. Dense inundated vegetation and shallow depths made boat tracking and fish sampling infeasible during particular times of the year. Though tracking and sampling were conducted on foot and by kayak to assess habitat availability and potential utilization by sonic-tagged juvenile razorback suckers, three sonic-tagged individuals were not contacted shortly after stocking. These individuals may have moved out of Las Vegas Bay immediately after being released. There are a number of often secluded areas in Las Vegas Bay that are inaccessible by boat. At the time of release, lake elevations still allowed for movement through a shallow passage from Government Wash Cove southeast into Boulder Basin; however, the proximity of the mouth of Government Wash Cove allows for the majority of movement to be recorded by the NDOW SUR at Sand Island. Additionally, the effect inundated vegetation has on sonic signal strength and clarity can often be cumbersome. During spring and early summer, sonic-tagged juvenile razorback suckers appeared to associate frequently with dense inundated vegetation. As lake elevations decreased, much of this habitat was inaccessible by boat, and variations in lake bathymetry may have prevented an already hindered signal from being heard. Despite efforts to monitor potential movement in and out of Las Vegas Wash, it is possible that an individual was able to move upstream without being detected during a period when the deployed SUR was located further upstream. Once the SUR was moved closer to the Lake Mead interface, an individual could have remained in an area of

Las Vegas Wash between the two SUR deployments and may have avoided active tracking by using turbulent habitat that makes contact more difficult. Though great advances have been made in sonic telemetry technology, tag failure has been noted in past studies on Lake Mead (Albrecht et al. 2006b, 2008a; Kegerries and Albrecht 2011). Without the explanation of tag failure, many questions arise regarding the location of the unaccounted for sonic-tagged juvenile razorback suckers. Inquiries with the manufacturer of the sonic transmitters document successful transmission of tag signals despite being covered by approximately 20 ft (6.1 m) of coarse sediment, and sonic tags have been shown to experience a negligible failure rate. Thus, other scenarios might be considered (M. Gregor 2010, personal communication). Both of the smaller sonic tags (IBT-96-9-I) were only contacted for approximately 48 hours, and one of the larger sonic tags (CT-82-2-I) was only contacted for approximately 1 month. Las Vegas Wash has a large angler presence as well as a substantial piscivorous avian community due to the productivity of the area. It is not uncommon for numerous white pelican (*Pelecanus erythrorhynchos*), great blue heron (*Ardea herodias*), and double-crested cormorant (*Phalacrocorax auritus*) to occur at all times of the year. These species could prey on a razorback suckers less than 450 mm TL.

Although this study was preliminary, a number of lessons were learned regarding using sonic telemetry as a method of tracking young razorback suckers. Every attempt was made to minimize potential issues; however, in-the-field experience proved which efforts worked. The most important factor for staying in contact with sonic-tagged juvenile individuals was probably the ability to regularly contact and monitor these fish (i.e., weekly and even daily tracking may be required after initial release). When the wild, juvenile sonic-tagged individual was captured in February 2012, weekly tracking was conducted concurrently with long-term monitoring efforts. Conversely, the three additional juveniles tagged at the end of April were only regularly tracked for a short period before efforts were shifted to a monthly tracking regime as required by the condensed scope of the pilot study. The lapse in time between tracking trips allowed for a greater probability of losing contact with an individual even with strategic placement of SURs.

Conspecific and Community Sampling

Using a variety of gears to target available habitat in the characterization of the fish assemblage associated with juvenile razorback suckers was successful in capturing additional razorback suckers in 2012. Though numerous environmental circumstances (e.g., depths > 100 ft, thick inundated vegetation) created challenges in using all gear types throughout the year, all gear types were used at some point during the pilot study and each targeted a variety of functionally different fish species. The additional razorback sucker captures occurred during trammel netting, and throughout the year, this gear type, as well as minnow traps, seemed to be the most applicable and easiest to set. Fyke nets and hoop nets were not set as often, as many of the contacts with sonic-tagged juvenile razorback suckers occurred offshore where there was nothing to anchor a net to. These types of gear, however, were more efficient in areas of dense, inundated cover and in flowing water (i.e., Las Vegas Wash). In further studies that may target inflow areas more often, hoop nets and fyke nets would certainly be of use and may be more applicable than trammel nets. Although additional razorback suckers were only captured during trammel netting efforts, the use of other gear types in the future should not be precluded or overlooked. Similarly, the fact that only larger (> 450 mm TL) razorback suckers were captured by trammel netting does not suggest that this gear is inefficient at catching smaller-sized native fishes. Though small juvenile razorback suckers have only been occasionally and sporadically captured during long-term monitoring (Kegerries et al. 2009; Albrecht et al. 2010c; Shattuck et al. 2011), small individuals are certainly susceptible to this gear type: 10 small razorback suckers (229–350 mm; 2–3 years of age) have been captured in the past. Additionally, during 3 years of research at the CRI area, 104 small flannelmouth suckers (204–350 mm) have been captured (Albrecht et al. 2010c; Kegerries and Albrecht 2011, 2013), which suggests the general rarity of smaller razorback suckers (< 350 mm TL) and prompts further questions as to where individuals of this life stage might reside. Along these lines, seining was a promising methodology for capturing a variety of species. This may show that we could capture small, early life stage razorback suckers in shallow water during portions of their first year.

In general, the nonnative fish community at inshore sampling sites contained numerous species that are often associated with structure (e.g., large woody debris and inundated vegetation) as cover. Bluegill, largemouth bass, and other centrarchids were often found in thick inundated vegetation. Conversely, offshore habitats sampled seemingly lacked inundated cover, with the exception of bathymetric variations, and contained a variety of species moving through the area (e.g., common carp, gizzard shad, and striped bass). Overall, the fish assemblage throughout the year was dominated by the nonnative species gizzard shad, largemouth bass, and common carp. This unfortunately is not uncommon, and much of the species compositions recorded throughout the pilot study closely mirrored those recorded in the past several years of long-term monitoring (Kegerries et al. 2009; Albrecht et al. 2010b; Shattuck et al. 2011). As more data are collected, the relationships these species have with juvenile razorback suckers may be of increasing interest in terms of understanding the nuances of wild razorback sucker recruitment in Lake Mead. Trophic competition with gizzard shad and common carp is of particular interest as is the efficiency of largemouth bass as a predator on young razorback suckers. Though the impact of other nonnative species on razorback suckers has often been studied (e.g., Marsh and Brooks 1989; Rupert et al. 1993; Tyus and Saunders 2000), attention specific to Lake Mead and the dominant nonnative biota found therein may be of more interest with regard to the long-term success of razorback sucker recruitment at Lake Mead.

Conducting further sampling efforts on a more regular basis (i.e., weekly rather than monthly) will give us more inference from the associated fish assemblage and additional captures of associated razorback sucker, which will help to critically assess habitats used during the juvenile life stage and what potentially poses the greatest threats to these areas. Additionally, the use of all gear types should be continued to "hedge bets" until a reliable and consistent gear for capturing juvenile razorback suckers is identified. Furthermore, while our efforts were successful, the amount of time spent sampling near sonic-tagged juvenile razorback suckers was limited. Longer net sets may improve the capture rates for conspecifics and give more insight into the composition of the associated fish assemblage and the interconnectedness of these species with their associated habitats.

Habitat Observations and Physicochemical Quantification

During the 2012 pilot study, sonic-tagged juvenile razorback suckers used a number of different habitats in Las Vegas Bay, both daily and seasonally. Generally, sonic-tagged juvenile razorback suckers showed a seasonal transition, moving from shallow habitat characterized by inundated vegetation during the early spring and late fall into deeper habitat with noted turbidity as temperatures increased during summer. Las Vegas Wash first appeared to be an important habitat feature during spring and early summer, as the majority of sonic-tagged juvenile razorback suckers used this area. Two sonic-tagged juvenile razorback suckers were released into Las Vegas Wash proper and contacted there several times, and then they were no longer heard from. Thick inundated vegetation and high turbidity seemed to play an important role for these individuals during the beginning of this pilot study. Las Vegas Wash and the area immediately adjacent to the inflow (i.e., Gypsum Wash Cove) were quantified as having the highest abundance of submerged aquatic vegetation and inundated vegetation and had a high presence of algae and detritus. The most frequently observed inundated vegetation primarily consisted of shoreline terrestrial plants that were established during lower lake elevations. During higher lake elevations, these areas became available for use through inundation and provided potential cover for early life stages of razorback suckers and other fish species (Golden and Holden 2002). The most frequently encountered submerged aquatic vegetation was spiny naiad, and its presence was notable in shallow areas in the western end of Las Vegas Bay. As the seasons changed, the movement and habitat associations of one individual in particular (fish 222) also changed. Although initially captured and released in Gypsum Wash Cove, fish 222 briefly shared similar summertime habitat preferences with another sonic-tagged juvenile razorback sucker (fish 337) before it was found frequently in proximity to adult sonic-tagged fish.

The areas in which fish 222 was found during summer were quantified as being different than habitats occupied in spring due to their higher temperatures and pH values. Summer habitat was generally deeper, and offshore, and substrates held little submerged aquatic vegetation or algae and detritus. The depths at which sonic-tagged juvenile razorback suckers used habitat in summer were unexpected, and these conditions were a challenge to sampling efforts. Depths may have made the observation and subsequent quantification of inundated vegetation and submerged aquatic vegetation difficult. However, the coupling of depth and turbidity often limit primary productivity and the establishment of submerged aquatic vegetation by reducing water clarity and light penetration into the water column (Henley et al. 2000). In this same vein, turbidity in the form of cover has been of noted importance for the recruitment of razorback suckers (Golden and Holden 2002); however, turbidity is also an important influence of other water quality parameters. The amount of particulate material stratified in the water column influences other water quality parameters by increasing water temperatures and decreasing DO concentrations with suspended material (Henley et al. 2000). Razorback suckers have been observed in depths as great as 302 ft (92.0 m) in Boulder Basin (BIO-WEST, unpublished data); however, more research would help define the role of depth as another important form of cover in relation to razorback sucker recruitment. Furthermore, the association with particular areas of Las Vegas Bay and particular types of habitat may be a function of observed preference, although the associated substrate compositions quantified for sonic-tagged juvenile razorback suckers may have been less descriptive and more a function of substrate availability. Smaller substrates (e.g., silt and sand) are likely more common due to the influence of nearby Las Vegas Wash, thus making the noted importance of larger substrates (e.g., gravel and cobble) to reproductively active razorback sucker adults a potentially limiting factor for recruitment success (Shattuck et al. 2011). The abundance of recorded cover compositions and substrates in Las Vegas Bay are likely underestimated. Similarly, decreases in lake elevation may have diluted the importance of inundated vegetation as a cover type, as shallow habitat and the littoral portions of Lake Mead were reduced by declining lake elevations during the pilot study. As environmental conditions were often challenging, the rigid methodology of habitat assessment type (i.e., nearshore 66 x 656 ft [20 x 200 m] rectangle approach versus offshore 236-ft [72-m]-diameter circle approach) was not as applicable as initially thought. During October and November, modifications were made to the type of assessment. In October, the 236-ft (72-m)-diameter circle was better suited to characterize nearshore habitat, while the 66 x 656 ft (20 x 200 m) rectangle was better suited to give a profile to the habitat occupied by a sonic-tagged individual in November. Nonetheless, both approaches sampled a similarly sized area, and the combination of both approaches throughout the year helped cement important habitat, environmental, and faunal assemblage relationships, all of which are potentially important components of the overall recruitment picture. Further collection of habitat data will help specify inferences about differences in sonic-tagged juvenile razorback sucker seasonal habitat use and increase the inference power of multi-variate analyses.

Both the CCA and PCA analyses (figures 2-7 and 2-8) explained significant amounts of variation in the assessment of relationships between sonic-tagged juvenile razorback suckers and their associated habitats and fish species. The CCA model provided a common sense understanding of the Las Vegas Bay fish assemblage structure, through which a number of environmental and habitat variables were highlighted as explaining larger portions of the variation seen in the fish assemblage. Sonic-tagged juvenile razorback suckers did not partition far from the origin of the model (i.e., the intersection of CCA axes I and II), although this is somewhat expected, as juvenile razorback sucker captures ubiquitously included at least one individual (i.e., the sonic-tagged individual around which sampling was conducted). With additional captures of juvenile razorback suckers, the spatial positioning of this life stage could become more meaningful. As an example of such meaning, adult razorback suckers were partitioned to be more associated with greater depths and the areas of Government Wash and the Cliffs during summer. The modeling of this particular life stage is supported, as both Government Wash and the Cliffs were frequented by adult razorback suckers during past summers (Albrecht et al. 2008a; Kegerries et al. 2009; Shattuck et al. 2011). Though adult and juvenile razorback suckers were not partitioned drastically differently from one another, the paucity of juvenile captures during long-term monitoring suggests that these life stages may occupy different areas. Without that perceived difference, juvenile razorback sucker captures would be higher than observed during the 17-year study. Overall, water quality and cover type appeared to explain much of the observed partitioning in multi-variate space. Again, although the model is somewhat theoretical, the output observed makes biological sense; cover-philic taxa were closely associated with inundated vegetation and submerged aquatic vegetation, functionally similar channel catfish and common carp were plotted near adult razorback suckers, and larger substrates and higher conductivity were directly correlated with Las Vegas Wash.

One unexpected finding was the relationship between both life stages of razorback suckers and turbidity and inundated vegetation. Based on previous studies, these environmental variables have been of noted importance to razorback sucker recruitment for their use as cover (Golden and Holden 2003; Kegerries et al. 2009; Albrecht et al. 2010b; Shattuck et al. 2011). However, in the CCA model, both razorback sucker life stages appeared to not associate strongly with these variables. This may be due in part to the limited amount of data collected during the 2012 pilot study as well as a factor of the analysis itself. The CCA model captured the variation in samples and attributed relationships based on the whole of the data. By utilizing PCA in conjunction with CCA, a more complete understanding was attained. In the PCA model, seasonal variation was observed in the collected samples of habitat and environment for sonic-tagged juvenile razorback suckers. It appears that, although the CCA model did not show a strong association of sonic-tagged juvenile razorback suckers with turbidity and inundated vegetation, on the whole (see figure 2-7), these variables are strongly related to seasonally occupied habitat (see figure 2-8). The PCA model suggests that spring habitat associations are partially driven by turbidity before sonic-tagged juvenile razorback suckers transition into deeper summer habitat and then into fall habitat, which has a strong inundated vegetation contribution. Additional samples would strengthen observed seasonal variations in habitat and potentially help describe more of the observed variation in the PCA model, thus improving the extrapolative power of the model beyond Lake Mead's Las Vegas Bay.

Conclusions

The collection of multi-faceted data in direct association with juvenile razorback suckers makes this study particularly interesting and important. The razorback sucker juvenile life stage is one the least understood aspects of the species, and information regarding spatiotemporal patterns of habitat use for a naturally recruiting population could aid in the species' overall recovery. This pilot study sought to better define juvenile razorback sucker movement and quantify occupied habitats. Although the study occurred over a short time period, much progress was made in describing critical components that help define and determine wild razorback sucker recruitment in Lake Mead, and a foundation for future study was laid with a sound and repeatable quantitative approach. Methods employed during the 2012 pilot study helped double the number of razorback suckers captured during long-term monitoring in Las Vegas Bay and confirmed the usefulness of sonic-tagged juvenile razorback suckers. Although aspects of the pilot study are limited in their inferences, scaling up efforts and continuing to build on these findings will allow for a greater understanding of the species as a whole and help us attain a more realistic understanding of where, how, and why razorback suckers demonstrate continued, natural recruitment in Lake Mead. It is our hope that the framework defined here will be used to clarify the early life stage requirements of razorback suckers and that this additional knowledge will contribute not only to promote a better understanding of razorback suckers within Lake Mead but also to the species' recruitment needs in other basin locations.

Efforts to locate smaller (< 350 mm TL) juvenile razorback suckers have demonstrated the allusiveness of this life stage. Increased efforts to track and characterize the habitat use and movement patterns of these smaller fish will be vital to answering fundamental recruitment questions about Lake Mead. Furthermore, with improvements in sonic tag technology and battery life, smaller and lighter tags may be employed to increase descriptions of smaller razorback sucker cohorts and narrow the information gap between larval and adult life stages. Currently, only a handful of individuals captured during the long-term monitoring study have been aged at 2 years, yet back-calculation of captured individuals' ages shows that recruitment occurs on a near annual basis. As understanding of the first years of growth in juvenile razorback suckers are largely unknown, there is a need to establish a better understanding of nearly every aspect of juvenile razorback sucker life history.

CONSIDERATIONS FOR FUTURE STUDY

1. Overall, there is a general lack of information on the juvenile razorback sucker life stage, and all information is valuable at face. The need for additional data is of utmost importance, as increased data is essential for strengthening multi-variate modeling relationships. We propose collecting more habitat information in addition to increasing the amounts of fish sampling over a more intensive sampling regime (i.e., weekly rather than monthly), with attention to characterizing all seasons.

2. With the need for additional information, there is a need to surgically implant additional juvenile razorback sucker individuals with sonic tags and monitor and track them with greater intensity and regularity. This will provide movement and habitat use data from more than a few individuals. By increasing the number of sonic-tagged individuals, annual bias in collected data will be reduced. We submit that there may be a reason and need to tag smaller juvenile razorback suckers (<350 mm TL) to increase the likelihood of capturing similarly sized cohorts. Furthermore, we suggest increasing the number of sonic-tagged juvenile individuals both within Las Vegas Bay and throughout the long-term monitoring sites of Lake Mead (i.e., Echo Bay and the Muddy River/Virgin River inflow area).

3. The ability to make multi-year comparisons of data will increase the applicability of inference (more sites evaluated within Lake Mead) and lead to a greater understanding of recruitment habitat in Las Vegas Bay and throughout Lake Mead, with gaining an understanding of recruitment as the ultimate goal. Developing our knowledge of juvenile razorback sucker habitat associations throughout the seasons and years ultimately increases the understanding of factors that may drive recruitment.

ACKNOWLEDGMENTS

This project was funded under the LCR MSCP and was a cooperative effort between BIO-WEST, Reclamation, the SNWA, the NDOW, the AGFD, the National Parks Service, and the USFWS. Sampling, logistics, and planning strategies were conducted jointly among these groups in various capacities. We thank Ron Kegerries, Jim Stolberg, Nathan Rudd, Sandra Livingston Turner, Chadd VanZanten, and Paul Holden, who provided constructive comments during the review process, as well as the many others involved.

LITERATURE CITED

Abate, P.D., T.L. Welker, and P.B. Holden. 2002. Razorback Sucker Studies on Lake Mead, Nevada, 2001–2002 Annual Report. Prepared for the Department of Resources, Southern Nevada Water Authority, by BIO-WEST, Inc., Logan, Utah. PR-578-6.

Albrecht, B. and P.B. Holden. 2005. Razorback Sucker Studies on Lake Mead, Nevada, 2004–2005 Annual Report. Prepared for the Department of Resources, Southern Nevada Water Authority, by BIO-WEST, Inc., Logan, Utah. PR-960-1.

Albrecht, B., P.B. Holden, and M. Golden. 2006a. Lake Mead Razorback Sucker Monitoring Recommendations, 2005–2006 Report. Prepared for the Department of Resources, Southern Nevada Water Authority, by BIO-WEST, Inc., Logan, Utah. PR-977-1.

_____. 2006b. Razorback Sucker Studies on Lake Mead, Nevada, 2005–2006 Annual Report. Prepared for the Department of Resources, Southern Nevada Water Authority, by BIO-WEST, Inc., Logan, Utah. PR-977-1.

Albrecht, B., T. Sanderson, and P.B. Holden. 2007. Razorback Sucker Studies on Lake Mead, Nevada, 2006–2007 Annual Report. Prepared for the Bureau of Reclamation and the Department of Resources, Southern Nevada Water Authority, by BIO-WEST, Inc., Logan, Utah. PR-1093-1.

Albrecht, B., R.B. Kegerries, and P.B. Holden. 2008a. Razorback Sucker Studies on Lake Mead, Nevada and Arizona, 2007–2008 Annual Report. Prepared for the Bureau of Reclamation and the Department of Resources, Southern Nevada Water Authority, by BIO-WEST, Inc., Logan, Utah. PR-1161-1.

Albrecht, B., T. Sanderson, and P.B. Holden. 2008b. Razorback Sucker Studies on Lake Mead, Nevada and Arizona, 1996–2007 Comprehensive Report. Prepared for the Bureau of Reclamation and the Department of Resources, Southern Nevada Water Authority, by BIO-WEST, Inc., Logan, Utah. PR-1093-2.

Albrecht, B., P.B. Holden, and R. Kegerries. 2009. Long-Term Management Plan for the Conservation of Razorback Sucker in Lake Mead, Nevada and Arizona. Prepared for the Bureau of Reclamation, by BIO-WEST, Inc., Logan, Utah. PR-1161-03.

Albrecht, B., P.B. Holden, R. Kegerries, and M.E. Golden. 2010a. Razorback sucker recruitment in Lake Mead, Nevada–Arizona, why here? Lake and Reservoir Management 26(4):336–344.

Albrecht, B., R. Rogers, R. Kegerries, and P.B. Holden. 2010b. Razorback Sucker Studies on Lake Mead, Nevada and Arizona, 2009–2010 Annual Report. Prepared for the Bureau of Reclamation, Southern Nevada Water Authority, by BIO-WEST, Inc., Logan, Utah. PR-1303-01.

Albrecht, B., R. Kegerries, R. Rogers, and P.B. Holden. 2010c. Razorback Sucker Investigations at the Colorado River Inflow Area of Lake Mead, Nevada and Arizona. Prepared for the Bureau of Reclamation, by BIO-WEST, Inc., Logan, Utah. PR-1310-01.

Anderson, W.G., R.S. McKinley, and M. Colavecchia. 1997. The use of clove oil as an anesthetic for rainbow trout and its effects on swimming performance. North American Journal of Fisheries Management 17:301–307.

Bidgood, B.F. 1980. Field Surgical Procedure for Implantation of Radio Tags in Fish. Fisheries Research Report No. 20. Alberta Fish and Wildlife Division, Department of Energy and Natural Resources. 10 p.

Borcard, D., P. Legendre, and P. Drapeau. 1992. Partialling out the spatial component of ecological variation. Ecology 73:1045–1055.

Bozek, M.A., L.J. Paulson, and G.R. Wilde. 1990. Effect of ambient Lake Mohave temperatures on development, oxygen consumption, and hatching success of the razorback sucker. Environmental Biology of Fishes 27:255–263.

Bunt, C.M., S.J. Cooke, C. Katopodis, and R.S. McKinley. 1999. Movement and summer habitat of brown trout (*Salmo trutta*) below a pulsed discharge hydroelectric generating station. Regulated Rivers: Research and Management 15:395–403.

Bureau of Reclamation (Reclamation). 2012. Historical Lake Mead Reservoir Levels.
http://www.usbr.gov/lc/

Burke, T. 1995. Rearing wild razorback sucker larvae in lake-side backwaters, Lake Mohave, Arizona/Nevada. Proceeding of the Desert Fishes Council 26:35 (abstract only).

Carpenter, J. and G.A. Mueller. 2008. Small nonnative fishes as predators of larval razorback suckers. Southwestern Naturalist 53(2):236–242.

Cooch, E. and G. White, editors. 2011. Program MARK: A Gentle Introduction, 9th edition. Cornell University, Ithaca, New York.
http://www.phidot.org/software/mark/docs/book/

Cooperman, M.S., D.F. Markle, M. Terwilliger, and D.C. Simon. 2010. A production estimate approach to analyze habitat and weather effects on recruitment of two endangered freshwater fish. Canadian Journal of Fisheries and Aquatic Sciences 67(1):28–41.

Cormack, R.M. 1964. Estimates of survival from the sighting of marked animals. Biometrika 51:429–438.

Cummins, K.W. 1962. An evaluation of some techniques for the collection and analysis of benthic samples with special emphasis on lotic waters. American Midland Naturalist 67(2):477–504.

Dowling, T.E., M.J. Saltzgiver, D. Adams. and P.C. Marsh. 2012a. Genetic variability in a recruiting population of endangered razorback suckers from Lake Mead, Arizona–Nevada. Transactions of the American Fisheries Society 141(4):990–999.

Dowling, T.E., M.J. Saltzgiver, and P.C. Marsh. 2012b. Genetic structure within and among populations of the endangered razorback sucker (*Xyrauchen texanus*) as determined by analysis of microsatellites. Conservation Genetics 13:1073–1083.

Frontier, S. 1976. Étude de la décroissance des valeurs propres dans une analyse en composantes principals: comparaison avec le modèle du bâton brisé. Journal of Experimental Marine Biology and Ecology 25:67–75.

Geen, G.H., T.G. Northcote, G.F. Hartman, and C.C. Lindsey. 1966. Life histories of two species of catostomid fishes in Sixteenmile Lake, British Columbia, with particular reference to inlet stream spawning. Journal of the Fisheries Research Board of Canada 23:1761–1788.

Golden, M.E. and P.B. Holden. 2003. Determining Conditions that Promote Razorback Sucker Recruitment in Lake Mead: A Summary of the 2000–2002 Pilot Study. Prepared for the Department of Resources, Southern Nevada Water Authority, by BIO-WEST, Inc., Logan, Utah. PR-784-2.

Gregor, M. 2010. Sonotronics, Tucson, Arizona, personal communication.

Henley, W.F., M.A. Patterson, R.J. Neves, and A.D. Lemly. 2000. Effects of sedimentation and turbidity on lotic food webs: a concise review for natural resource managers. Reviews in Fisheries Science 8(2):125–139.

Herndon, D. 2011. Nevada Department of Wildlife, Boulder City, Nevada, personal communication.

Holden, P.B. 1994. Razorback Sucker Investigations in Lake Mead, 1994, Final Report. Prepared for the Department of Resources, Southern Nevada Water Authority, by BIO-WEST, Inc., Logan, Utah. PR-470-1.

Holden, P.B. and C.B. Stalnaker. 1975. Distribution of fishes in the Dolores and Yampa River systems of the upper Colorado Basin. Southwestern Naturalist 19:403–412.

Holden, P.B., P.D. Abate, and J.B. Ruppert. 1997. Razorback Sucker Studies on Lake Mead, Nevada, 1996–1997 Annual Report. Prepared for the Department of Resources, Southern Nevada Water Authority, by BIO-WEST, Inc., Logan, Utah. PR-578-1.

Holden, P.B., P.D. Abate, and J.B. Ruppert. 1999. Razorback Sucker Studies on Lake Mead, Nevada, 1997–1998 Annual Report. Prepared for the Department of Resources, Southern Nevada Water Authority, by BIO-WEST, Inc., Logan, Utah. PR-578-2.

_____. 2000a. Razorback Sucker Studies on Lake Mead, Nevada, 1998–1999 Annual Report. Prepared for the Department of Resources, Southern Nevada Water Authority, by BIO-WEST, Inc., Logan, Utah. PR-578-3.

_____. 2000b. Razorback Sucker Studies on Lake Mead, Nevada, 1999–2000 Annual Report. Prepared for the Department of Resources, Southern Nevada Water Authority, by BIO-WEST, Inc., Logan, Utah. PR-578-4.

Holden, P.B., P.D. Abate, and T.L. Welker. 2001. Razorback Sucker Studies on Lake Mead, Nevada, 2000–2001 Annual Report. Prepared for the Department of Resources, Southern Nevada Water Authority, by BIO-WEST, Inc., Logan, Utah. PR-578-5.

Hunt, T.A., D.L. Ward, C.R. Propper, and A.C. Gibb. 2012. Effects of capture by trammel net on Colorado River fishes. Journal of Wildlife Management 3:133–141.

Johnson, J.E. and R.T. Hines. 1999. Effect of suspended sediment on vulnerability of young razorback suckers to predation. Transactions of the American Fisheries Society 128:648–655.

Jolly, G.M. 1965. Explicit estimates from capture–recapture data with both death and immigration-stochastic model. Biometrika 52:225–247.

Joseph, T.W., J.A. Sinning, R.J. Behnke, and P.B. Holden. 1977. An Evaluation of the Status, Life History, and Habitat Requirements of Endangered and Threatened Fishes of the Upper Colorado River System. U.S. Fish and Wildlife Service, Office of Biological Services, Fort Collins, Colorado. FWS/OBS Report 24, part 2. 183 p.

Kaeding, L.R., B.D. Burdick, P.A. Schrader, and C.W. McAda. 1990. Temporal and spatial relations between the spawning of humpback chub and roundtail chub in the Upper Colorado River. Transactions of the American Fisheries Society 119:135–144.

Kaemingk, M.A., B.D.S. Graeb, C.W. Hoagstrom, and D.W. Willis. 2007. Patterns of fish diversity in a mainstem Missouri River and Reservoir and associated delta in South Dakota and Nebraska, USA. River Research and Applications 23:786–791.

Kegerries, R. and B. Albrecht. 2011. Razorback Sucker Investigations at the Colorado River Inflow Area of Lake Mead, Nevada and Arizona. Prepared for the Bureau of Reclamation, by BIO-WEST, Inc., Logan, Utah. PR-1310-02.

_____. 2013. Razorback Sucker Investigations at the Colorado River Inflow Area of Lake Mead, Nevada and Arizona. Prepared for the Bureau of Reclamation, by BIO-WEST, Inc., Logan, Utah. PR-1310-03.

Kegerries, R., B. Albrecht, and P.B. Holden. 2009. Razorback Sucker Studies on Lake Mead, Nevada and Arizona, 2008–2009 Annual Report. Prepared for the Bureau of Reclamation and the Department of Resources, Southern Nevada Water Authority, by BIO-WEST, Inc., Logan, Utah. PR-1161-02.

Kesner, B.R., A.P. Karam, C.A. Pacey, K.A. Patterson, and P.C. Marsh. 2012. Demographics and Post-stocking Survival of Repatriated Razorback Sucker in Lake Mohave. Prepared for the Lower Colorado River Multi-Species Conservation Program, Bureau of Reclamation, Boulder City, Nevada, by Marsh and Associates LLC, Tempe, Arizona.

Knecht, T. and D. Ward. 2012. What environmental factors reduce predation vulnerability for native fish? Poster presented at the 44th Annual Meeting of the Desert Fishes Council, Death Valley, California.

Marsh and Associates. 2012. March 2012 Razorback Sucker Summary, Lake Mohave, AZ-NV. Marsh and Associates LLC, Tempe, Arizona.

Marsh, P.C. and J.E. Brooks. 1989. Predation by ictalurid catfishes as a deterrent to re-establishment of hatchery-reared razorback suckers. The Southwestern Naturalist 34(2):199–195.

Marsh, P.C., C.A. Pacey, and B.R. Kesner. 2003. Decline of razorback sucker in Lake Mohave, Colorado River, Arizona and Nevada. Transactions of the American Fisheries Society 132:1251–1256.

Marsh, P.C., B.R. Kesner, and C.A. Pacey. 2005. Repatriation as a management strategy to conserve a critically imperiled fish species. North American Journal of Fisheries Management 25:547–556.

Marty, G.D. and R.C. Summerfelt. 1990. Wound healing in channel catfish by epithelialization and contraction of granulation tissue. Transactions of the American Fisheries Society 115:577–589.

Matthews, W.J. and E. Marsh-Matthews. 2006. Temporal changes in replicated experimental stream fish assemblages: predictable or not? Freshwater Biology 51:1605–1622.

McCall, T. 1980. Fishery Investigation of Lake Mead, Arizona-Nevada, from Separation Rapids to Boulder Canyon, 1978–79, Final Report. Arizona Game and Fish Department, Water and Power Resources Service, Boulder City, Nevada. Contract Number 8-07-30-X0025. 197 p.

McGarigal, K., S. Cushman, and S. Stafford. 2000. Multivariate Statistics for Wildlife and Ecology Research. Springer Science+Business Media, Inc., New York. 283 p.

Miller, T.J., L.B. Crowder, J.A. Rice, and E.A. Marschall. 1988. Larval size and recruitment mechanisms in fishes: toward a conceptual framework. Canadian Journal of Fisheries and Aquatic Sciences 45:1657−1670.

Minckley, W.L. 1973. Fishes of Arizona. Arizona Game and Fish Department, Phoenix, AZ.

_____. 1983. Status of the razorback sucker, *Xyrauchen texanus* (Abbott), in the Lower Colorado River Basin. Southwestern Naturalist 28:165–187.

Minckley, W.L., P.C. Marsh, J.E. Brooks, J.E. Johnson, and B.L. Jensen. 1991. Management toward recovery of razorback sucker *in* W.L. Minckley and J.E. Deacon, editors. Battle Against Extinction: Native Fish Management in the American West. Tucson: University of Arizona Press. pp. 303–357.

Modde, T., Z.H. Bowen, and D.C. Kitcheyan. 2005. Spatial and temporal use of a spawning site in the middle Green River by wild and hatchery-reared razorback suckers. Transactions of the American Fisheries Society 134:937–944.

Mueller, G.A. 2005. Predatory fish removal and native fish recovery in the Colorado River mainstem: what have we learned? Fisheries 30(9):10–19.

_____. 2006. Ecology of Bonytail and Razorback Sucker and the Role of Off-Channel Habitats to Their Recovery. Scientific Investigations Report 2006–5065. U.S. Department of the Interior, U.S. Geological Survey. 64 p.

Mueller, G.A., P.C. Marsh, G. Knowles, and T. Wolters. 2000. Distribution, movements, and habitat use of razorback sucker (*Xyrauchen texanus*) in a lower Colorado River reservoir, Arizona-Nevada. Western North American Naturalist 60(2):180–187.

Olden, J.D., editor. 2011. Applied Multivariate Statistics for Ecologists: Principal Component Analysis. Course FSH 560, University of Washington, Seattle.

Peres-Neto, P.R., D.A. Jackson, and K.M. Somers. 2003. Giving meaningful interpretation to ordination axes: assessing loading significance in principal component analysis. Ecology 84(9):2347–2363.

Perkins, D.L. and G.G. Scoppettone. 2000. Reproductive Biology and Demographics of Endangered Lost River and Shortnose Suckers in Upper Klamath Lake, Oregon. U.S. Geological Survey report to the Bureau of Reclamation.

Pradel, R. 1996. Utilization of capture-mark-recapture for the study of recruitment and population growth rate. Biometrics 52:703–709.

Rexstad, E. and K. Burnham. 1992. User's Guide for Interactive Program CAPTURE. Colorado Cooperative Fish and Wildlife Research Unit, Colorado State University, Fort Collins, Colorado.

Rupert, J.B., R.T. Muth, and T.P. Nesler. 1993. Predation on fish larvae by adult red shiner, Yampa and Green rivers, Colorado. The Southwestern Naturalist 38(4):397–399.

Ryel, R. 2001. Utah State University, Logan, Utah, personal communication.

Schooley, J.D., A.P. Karam, B.R. Kesner, P.C. Marsh, C.A. Pacey, and D.J. Thornbrugh. 2008. Detection of larval remains after consumption by fishes. Transactions of the American Fisheries Society 137:1044–1049.

Seber, G.A.F. 1965. A note on the multiple-recapture census. Biometrika 52:249–259.

Shattuck, Z., B. Albrecht and R. Rogers. 2011. Razorback Sucker Studies on Lake Mead, Nevada and Arizona, 2010–2011 Annual Report. Prepared for the Lower Colorado River Multi-Species Conservation Program, Bureau of Reclamation, Boulder City, Nevada, by BIO-WEST, Inc., Logan, Utah.

Sjoberg, J.C. 1995. Historic distribution and current status of the razorback sucker in Lake Mead, Nevada-Arizona. Proceedings of the Desert Fishes Council 26:24–27.

ter Braak, C.J.F. and P. Šmilauer. 1997. CANOCO for Windows Version 4.5. Biometris-Plant Research International, Wageningen, Netherlands.

Tyus, H.M. 1982. Fish Radiotelemetry: Theory and Application for High Conductivity Rivers. FWS/OBS-82/38. U.S. Department of the Interior, U.S. Fish and Wildlife Service, Washington, D.C.

_____. 1987. Distribution, reproduction, and habitat use of the razorback sucker in the Green River, Utah, 1979–1986. Transactions of the American Fisheries Society 116:111–116.

Tyus, H.M. and C.A. Karp. 1990. Spawning and movements of razorback sucker, *Xyrauchen texanus*, in the Green River Basin of Colorado and Utah. Southwestern Naturalist 35(4):427–433.

Tyus, H.M. and J.F. Saunders III. 2000. Nonnative fish control and endangered fish recovery: lessons from the Colorado River. Fisheries 25(9):17–24.

Urban, M. 2011. National Park Service, Boulder City, Nevada, personal communication.

U.S. Fish and Wildlife Service (USFWS). 1991. Endangered and threatened wildlife and plants; the razorback sucker (*Xyrauchen texanus*) determined to be an endangered species; Final rule. Federal Register 56 (23 October 1991):54957–54967.

_____. 1997. Final Biological and Conference Opinion on Lower Colorado River Operations and Maintenance-Lake Mead to Southerly International Boundary. U.S. Fish and Wildlife Service, Phoenix, Arizona.

U.S. Geological Survey (USGS). 2012. Annual Water Data Reports. http://waterdata.usgs.gov/nv/nwis/nwisman/?site_no=09419800

Valdez, R.A. and B.C. Nilson. 1982. Radiotelemetry as a means of assessing movement and habitat selection of humpback chub. Transactions of the Bonneville Chapter of the American Fisheries Society 182:29–39.

Valdez, R.A. and W.J. Masslich (BIO-WEST, Inc.). 1989. Winter Habitat Study of Endangered Fish – Green River: Wintertime Movement and Habitat of Adult Colorado Squawfish and Razorback Suckers. BIO-WEST Report No. 136-2. Contract No. 6-CS-40-04490. U.S. Department of the Interior, Bureau of Reclamation, Salt Lake City, Utah. 184 p.

Valdez, R.A. and L. Trinca. 1995. Data Collection Plan, Supplement No. I., Life History and Ecology of the Humpback Chub (*Gila cypha*) in the Colorado River, Grand Canyon, Arizona. Bureau of Reclamation, Upper Colorado River Region, Salt Lake City, Utah.

Ward, D. 2012. U.S. Geological Survey, Flagstaff, Arizona, personal communication.

Webb, A.A. and W.D. Erskine. 2003. Distribution, recruitment, and geomorphic significance of large woody debris in an alluvial forest stream: Tonghi Creek, southeastern Australia. Geomorphology 51:109–126.

Welker, T.L. and P.B. Holden. 2003. Razorback Sucker Studies on Lake Mead, Nevada, 2002–2003 Annual Report. Prepared for the Department of Resources, Southern Nevada Water Authority, by BIO-WEST, Inc., Logan, Utah. PR-578-7.

_____. 2004. Razorback Sucker Studies on Lake Mead, Nevada, 2002–2003 Annual Report. Prepared for the Department of Resources, Southern Nevada Water Authority, by BIO-WEST, Inc., Logan, Utah. PR-578-8.

Wick, E.J., C.W. McAda, and R.V. Bulkley. 1982. Life history and prospects for recovery of the razorback sucker. Pages 120–126 *in* W.H. Miller, H.M. Tyus, and C.A. Carlson, editors. Fishes of the Upper Colorado River System: Present and Future. American Fisheries Society, Western Division, Bethesda, Maryland.

Winter, J.D. 1983. Underwater biotelemetry. Pages 371–395 *in* L.A. Nielsen and D.L. Johnson, editors. Fisheries Techniques. American Fisheries Society, Bethesda, Maryland.

Zelasko, K.A., K.R. Bestgen, and G.C. White. 2011. Survival Rate Estimation of Hatchery-reared Razorback Suckers *Xyrauchen texanus* Stocked in the Upper Colorado River Basin, Utah and Colorado 2004–2007. Final report for the Recovery Implementation Program for Endangered Fishes in the Upper Colorado River Basin. U.S. Fish and Wildlife Service, Denver, Colorado. Larval Fish Laboratory Contribution 162.

ATTACHMENT 1

Razorback Sucker Aging Data

Table A1-1.—Ages determined from razorback sucker pectoral fin ray sections collected from Lake Mead

Date collected	Total length (millimeters)	Age	Presumptive year spawned
Las Vegas Bay			
5/10/1998	588	10[a]	1987
12/14/1999	539	13	1986
12/14/1999	606	17+	1979 – 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	494	4	1998
2/5/2003	385	4	1998
2/18/2003	443	5	1997
3/4/2003	635	19	1983

Table A1-1.—Ages determined from razorback sucker pectoral fin ray sections collected from Lake Mead

Date collected	Total length (millimeters)	Age	Presumptive year spawned
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
3/3/2004	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

Table A1-1.—Ages determined from razorback sucker pectoral fin ray sections collected from Lake Mead

Date collected	Total length (millimeters)	Age	Presumptive year spawned
3/6/2007	565	6	2001
3/13/2007	586	7	2000
3/13/2007	636	25	1982
3/13/2007	524	5	2002
4/2/2007	704	9	1998
4/9/2007	644	11	1996
2/12/2008	425	5	2003
2/12/2008	390	3	2005
2/12/2008	490	3	2005
2/12/2008	430	4	2004
2/12/2008	379	4	2004
2/12/2008	399	4	2004
2/12/2008	430	4	2004
2/12/2008	413	4	2004
2/12/2008	554	9	1999
2/12/2008	426	9	1999
2/18/2008	385	3	2005
2/25/2008	605	6	2002
2/25/2008	655	36	1972
4/3/2008	468	4	2004
4/3/2008	619	7	2001
4/3/2008	640	10	1998
4/3/2008	560	11	1997
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

Table A1-1.—Ages determined from razorback sucker pectoral fin ray sections collected from Lake Mead

Date collected	Total length (millimeters)	Age	Presumptive year spawned
2/13/2009	395	5	2004
2/13/2009	528	11	1998
2/13/2009	630	15	1994
2/17/2009	510	8	2001
2/17/2009	440	5	2004
2/17/2009	420	5	2004
2/18/2009	376	4	2005
2/18/2009	411	4	2005
2/18/2009	427	4	2005
2/24/2009	438	5	2004
2/24/2009	403	6	2003
2/24/2009	446	6	2003
3/3/2009	416	4	2005
3/3/2009	565	8	2001
3/3/2009	431	5	2004
3/3/2009	340	5	2004
3/3/2009	539	8	2001
3/3/2009	521	8	2001
3/3/2009	419	6	2003
3/3/2009	535	6	2003
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

Table A1-1.—Ages determined from razorback sucker pectoral fin ray sections collected from Lake Mead

Date collected	Total length (millimeters)	Age	Presumptive year spawned
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[c]	1999
3/3/2011	364	7	2004
3/3/2011	434	4	2007
3/24/2011	411	4	2007
3/24/2011	390	3	2008
3/29/2011	379	6	2005
3/29/2011	346	4	2007
3/29/2011	376	3	2008
Echo Bay			
1/22/1998	381	5	1993
1/9/2000	527	13	1987
1/9/2000	550	13	1987
1/9/2000	553	13	1987
1/9/2000	599	12 – 14	1986 – 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

Table A1-1.—Ages determined from razorback sucker pectoral fin ray sections collected from Lake Mead

Date collected	Total length (millimeters)	Age	Presumptive year spawned
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[d]	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
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

Table A1-1.—Ages determined from razorback sucker pectoral fin ray sections collected from Lake Mead

Date collected	Total length (millimeters)	Age	Presumptive year spawned
2/14/2007	501	4	2003
3/2/2007	590	11	1996
3/9/2007	660	12	1995
3/16/2007	691	21	1986
3/28/2007	564	13	1994
2/28/2008	640	25	1983
2/29/2008	635	8	2000
3/5/2008	653	24	1984
3/19/2008	532	6	2002
3/19/2008	510	7	2001
2/20/2009	602	7	2002
2/26/2009	662	16	1993
2/18/2010	520	7	2003
2/25/2010	465	5	2005
3/10/2010	535	7	2003
3/10/2010	530	9[e]	2001
3/24/2010	451	4	2006
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

Table A1-1.—Ages determined from razorback sucker pectoral fin ray sections collected from Lake Mead

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

Table A1-1.—Ages determined from razorback sucker pectoral fin ray sections collected from Lake Mead

Date collected	Total length (millimeters)	Age	Presumptive year spawned
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
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

Table A1-1.—Ages determined from razorback sucker pectoral fin ray sections collected from Lake Mead

Date collected	Total length (millimeters)	Age	Presumptive year spawned
4/15/2009	390	3	2006
4/15/2009	365	3	2006
4/15/2009	375	3	2006
4/15/2009	399	3	2006
4/15/2009	362	3	2006
4/15/2009	386	4	2005
4/15/2009	390	4	2005
2/3/2010	455	3	2007
2/3/2010	475	5	2005
2/3/2010	441	5	2005
2/3/2010	495	7	2003
2/3/2010	532	8	2002
2/9/2010	491	5	2005
2/9/2010	444	5	2005
2/9/2010	500	5	2005
2/9/2010	464	6	2004
2/9/2010	471	6	2004
2/17/2010	494	6	2004
2/17/2010	470	7	2003
2/17/2010	479	7	2003
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

Table A1-1.—Ages determined from razorback sucker pectoral fin ray sections collected from Lake Mead

Date collected	Total length (millimeters)	Age	Presumptive year spawned
2/1/2011	601	7	2004
2/1/2011	571	6	2005
2/1/2011	556	7	2004
2/1/2011	586	6	2005
2/1/2011	506	8	2003
2/1/2011	572	8	2003
2/1/2011	500	6	2005
2/22/2011	501	7	2004
2/22/2011	534	6	2005
2/22/2011	506	6	2005
2/22/2011	508	6	2005
2/22/2011	524	7	2004
2/22/2011	517	8	2003
2/22/2011	580	5	2006
2/22/2011	509	8	2003
2/22/2011	586	6	2005
2/22/2011	512	7	2004
2/22/2011	585	6	2005
2/23/2011	545	6	2005
2/23/2011	500	6	2005
2/23/2011	527	7	2004
2/23/2011	552	5	2006
3/1/2011	510	10	2001
3/1/2011	573	9	2002
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

Table A1-1.—Ages determined from razorback sucker pectoral fin ray sections collected from Lake Mead

Date collected	Total length (millimeters)	Age	Presumptive year spawned
3/1/2011	599	9	2002
3/1/2011	560	5	2006
3/9/2011	556	7	2004
3/9/2011	534	6	2005
3/9/2011	549	7	2004
3/9/2011	494	4	2007
3/9/2011	505	6	2005
3/15/2011	575	8	2003
3/15/2011	551	8	2003
3/15/2011	515	7	2004
3/15/2011	558	8	2003
3/15/2011	576	8	2003
3/15/2011	587	8	2003
3/15/2011	572	7	2004
3/15/2011	575	10	2001
3/15/2011	551	7	2004
3/15/2011	561	7	2004
3/15/2011	566	9	2002
3/15/2011	542	6	2005
3/15/2011	577	8	2003
4/5/2011	521	7	2004
4/5/2011	495	6	2005
4/12/2011	572	8	2003
1/31/2012	604	7	2005
1/31/2012	570	7	2005
2/1/2012	525	12	2000
2/7/2012	525	9	2003
2/8/2012	536	7	2005
2/8/2012	501	9	2003
2/8/2012	623	12	2000
2/21/2012	566	10	2002
2/21/2012	590	10	2002

Table A1-1.—Ages determined from razorback sucker pectoral fin ray sections collected from Lake Mead

Date collected	Total length (millimeters)	Age	Presumptive year spawned
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

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

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

[c] Fish stocked from Floyd Lamb Park ponds, sonic tagged in 2008 (code 3355).

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

[e] Fish was a mortality; found dead in net with obvious net predation/wounds. Fin ray aging results validated using otoliths.

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

ATTACHMENT 2

Razorback Sucker Population Estimate – Program CAPTURE

Table A2-1.—Population estimates for razorback suckers in Lake Mead using mark-recapture data from 2010–2012 in the program CAPTURE

Estimator	Capture histories	2010–12 estimate	95-percent confidence interval	Capture probability
Echo Bay and Muddy River/Virgin River inflow areas				
Model M_o	35	589	410 – 889	0.0079
Chao M_h		631	413 – 1,028	0.0074
Model selection procedure				
Jackknife		606	481 – 777	0.0077
Las Vegas Bay				
Model M_o	32	96	50 – 234	0.0098
Chao M_h		87	45 – 225	0.0108
Model selection procedure				
Jackknife		73	50 – 123	0.0128
Lake-wide (including the Colorado River inflow area)				
Model M_o	41	596	468 – 785	0.0116
Chao M_h		686	501 – 986	0.0101
Model selection procedure				
Jackknife		782	626 – 995	0.0088

ATTACHMENT 3

Razorback Sucker Population Estimate – Model Selection Summary

Table A3-1.—Model selection summary information for closed-capture population estimates for razorback suckers in Lake Mead using mark-recapture data from 2010–12 and generated in the program MARK

Model[a]	AICc[b]	Delta AICc[c]	AICc weight[d]	Model likelihood[e]	Number of parameters[f]	Deviance[g]
Las Vegas Bay						
π(.)ρ(.)N(.)	111.5730	0.0000	0.1831	1.0000	2	106.4357
π(.)ρ(.)N(t)	111.5730	0.0000	0.1831	1.0000	2	106.4357
π(t)ρ(.)N(.)	111.5730	0.0000	0.1831	1.0000	2	106.4357
π(t)ρ(.)N(t)	111.5730	0.0000	0.1831	1.0000	2	106.4357
π(.)ρ(t)N(.)	113.5875	2.0145	0.0669	0.3652	3	106.4357
π(.)ρ(t)N(t)	113.5875	2.0145	0.0669	0.3652	3	106.4357
π(t)ρ(t)N(.)	113.5875	2.0145	0.0669	0.3652	3	106.4357
π(t)ρ(t)N(t)	113.5875	2.0145	0.0669	0.3652	3	106.4357
Echo Bay and Muddy River/Virgin River inflow						
π(.)ρ(.)N(.)	119.9784	0.0000	0.1828	1.0000	2	273.5229
π(.)ρ(.)N(t)	119.9784	0.0000	0.1828	1.0000	2	273.5229
π(t)ρ(.)N(.)	119.9784	0.0000	0.1828	1.0000	2	273.5229
π(t)ρ(.)N(t)	119.9784	0.0000	0.1828	1.0000	2	273.5229
π(.)ρ(t)N(.)	121.9808	2.0024	0.0672	0.3675	3	273.5229
π(.)ρ(t)N(t)	121.9808	2.0024	0.0672	0.3675	3	273.5229
π(t)ρ(t)N(.)	121.9808	2.0024	0.0672	0.3675	3	273.5229
π(t)ρ(t)N(t)	121.9808	2.0024	0.0672	0.3675	3	273.5229
Combined estimate (long-term monitoring sites)						
π(.)ρ(.)N(.)	85.2848	0.0000	0.1828	1.0000	2	278.0595
π(.)ρ(.)N(t)	85.2848	0.0000	0.1828	1.0000	2	278.0595
π(t)ρ(.)N(.)	85.2848	0.0000	0.1828	1.0000	2	278.0595
π(t)ρ(.)N(t)	85.2848	0.0000	0.1828	1.0000	2	278.0595
π(.)ρ(t)N(.)	87.2868	2.0020	0.0672	0.3675	3	278.0595
π(.)ρ(t)N(t)	87.2868	2.0020	0.0672	0.3675	3	278.0595
π(t)ρ(t)N(.)	87.2868	2.0020	0.0672	0.3675	3	278.0595
π(t)ρ(t)N(t)	87.2868	2.0020	0.0672	0.3675	3	278.0595
Combined estimate (lake-wide all sites)						
π(.)ρ(.)N(.)	161.9069	0.0000	0.1828	1.0000	2	367.4369
π(.)ρ(.)N(t)	161.9069	0.0000	0.1828	1.0000	2	367.4369
π(t)ρ(.)N(.)	161.9069	0.0000	0.1828	1.0000	2	367.4369
π(t)ρ(.)N(t)	161.9069	0.0000	0.1828	1.0000	2	367.4369
π(.)ρ(t)N(.)	163.9086	2.0017	0.0672	0.3675	3	367.4369
π(.)ρ(t)N(t)	163.9086	2.0017	0.0672	0.3675	3	367.4369
π(t)ρ(t)N(.)	163.9086	2.0017	0.0672	0.3675	3	367.4369
π(t)ρ(t)N(t)	163.9086	2.0017	0.0672	0.3675	3	367.4369

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

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

[c] AICc minus the minimum AICc.

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

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

[f] Number of parameters.

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

ATTACHMENT 4

Razorback Sucker Apparent Survival Rate Estimate –
Model Selection Summary

Table A4-1.—Model selection summary information for closed-capture apparent survival rate estimates for razorback suckers in Lake Mead using mark-recapture data from 2010–12 and generated in the program MARK

Model[a]	**AICc**[b]	**Delta AICc**[c]	**AICc weight**[d]	**Model likelihood**[e]	**Number of parameters**[f]	**Deviance**[g]
Cormack-Jolly-Seber						
ϕ(.) p(.)	449.4744	0.0000	1.0000	1.0000	2	259.5116
ϕ(.) p(t)	486.8902	37.4158	0.0000	0.0000	35	218.5033
ϕ(t) p(.)	511.3466	61.8722	0.0000	0.0000	35	242.9596
ϕ(t) p(t)	579.2661	129.7917	0.0000	0.0000	67	205.7544
Pradel						
ϕ(.) p(.) f(t)	1838.0300	0.0000	0.9999	1.0000	11	297.9495
ϕ(.) p(t) f(t)	1856.9200	18.8905	0.0001	0.0001	40	243.6694
ϕ(.) p(t) f(.)	1857.1020	19.0723	0.0001	0.0001	37	252.3853
ϕ(.) p(.) f(.)	1868.5850	30.5555	0.0000	0.0000	3	345.5520
ϕ(t) p(.) f(t)	1900.6880	62.6583	0.0000	0.0000	45	272.6332
ϕ(t) p(.) f(.)	1911.6320	73.6019	0.0000	0.0000	36	309.7041
ϕ(t) p(t) f(t)	1947.4970	109.4671	0.0000	0.0000	71	228.4232
ϕ(t) p(t) f(.)	1952.9400	114.9102	0.0000	0.0000	70	237.8788

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

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

[c] AICc minus the minimum AICc.

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

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

[f] Number of parameters.

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