



Lower Colorado River Multi-Species Conservation Program

Balancing Resource Use and Conservation

Sonic Telemetry and Habitat Use of Juvenile Razorback Suckers in Lake Mead

2013–2014 Annual Report



March 2014

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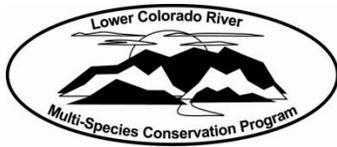
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Lower Colorado River Multi-Species Conservation Program

Sonic Telemetry and Habitat Use of Juvenile Razorback Suckers in Lake Mead

2013–2014 Annual Report

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March 2014

Shattuck, Z. and B. Albrecht. 2014. Sonic Telemetry and Habitat Use of Juvenile Razorback Suckers in Lake Mead, 2013–2014 Annual Report. Submitted to the Bureau of Reclamation, Boulder City, Nevada, by BIO-WEST, Inc., Logan, Utah.

ACRONYMS AND ABBREVIATIONS

AHS	additional habitat sampling
ANOVA	analysis of variance
BIO-WEST	BIO-WEST, Inc.
CCA	canonical correspondence analysis
cm	centimeter(s)
CPUE	catch per unit effort
DO	dissolved oxygen
FL	fork length
g	gram(s)
ICS	intensive community sampling
in	inch(es)
IV	inundated vegetation
km	kilometer(s)
L	liter(s)
LCR MSCP	Lower Colorado River Multi-Species Conservation Program
LWD	large woody debris
m	meter(s)
m ²	square meter(s)
mg/L	milligrams per liter
mL	milliliter(s)
mm	millimeter(s)
MS-222	tricaine methanesulfonate
msl	mean sea level
NDOW	Nevada Department of Wildlife
NTU	nephelometric turbidity unit
PCA	principal component analysis
PIT	passive integrated transponder
R-cc	R-code companion (transmitters)
Reclamation	Bureau of Reclamation
SAV	submerged aquatic vegetation
SE	standard error
SL	standard length
SUR	submersible ultrasonic receiver
TL	total length
USGS	U.S. Geological Survey

Symbols

°C	degrees Celsius
>	greater than
<	less than
≤	less than or equal to
μS/cm	microsiemens per centimeter
%	percent
±	plus or minus

CONTENTS

	Page
Executive Summary	ES-1
Introduction.....	1
Study Areas	3
Methods.....	5
Lake Elevation and Inflow Discharges	5
Sonic Telemetry	6
Sonic Tagging	6
Active Sonic Telemetry	8
Passive Sonic Telemetry	9
Conspecific and Community Sampling	10
Age Determination.....	12
Habitat Observations and Physicochemical Quantification.....	13
Data Analysis	14
Univariate Analyses	15
Canonical Correspondence Analysis	15
Principal Component Analysis	17
Results.....	18
Lake Elevation and Inflow Discharges	18
Sonic Telemetry	20
Conspecific and Community Sampling	27
Age Determination.....	40
Habitat Observations and Physicochemical Quantification.....	40
Discussion and Conclusions	49
Lake Elevation and Inflow Discharges	49
Sonic Telemetry	51
Conspecific and Community Sampling	53
Habitat Observations and Physicochemical Quantification.....	56
Conclusions.....	60
2014–15 Work Plan	61
Specific Objectives for the Second Field Season	61
Acknowledgments.....	63
Literature Cited	65

Tables

Table		Page
1	Demographic summary with included sonic transmitter information, individual sizes, location and date of last contact, and current status of sonic-tagged, juvenile razorback suckers stocked into Las Vegas Bay, Echo Bay, and the Virgin River/Muddy River inflow area, 2013	21
2	Summary of effort expended by study location, gear type, and the subsequent fishes captured during the ICS period at Lake Mead (i.e., Las Vegas Bay, Echo Bay, and the Virgin River/Muddy River inflow area), May 8 – July 26, 2013	28
3	Summary of location, size information, and recapture status for razorback suckers captured during the ICS period in direct association with sonic-tagged, juvenile razorback suckers in Lake Mead (i.e., Las Vegas Bay, Echo Bay, and the Virgin River/Muddy River inflow area), May 8 – July 26, 2013.....	28
4	Summary of mean monthly physicochemical and habitat information collected during the ICS and AHS periods in direct association with sonic-tagged, juvenile razorback suckers for all study sites in Lake Mead (i.e., Las Vegas Bay, Echo Bay, and the Virgin River/Muddy River inflow area), May 8 – December 20, 2013.....	41
5	Summary of mean seasonal physicochemical and habitat information collected during the ICS and AHS periods in direct association with sonic-tagged, juvenile razorback suckers at Las Vegas Bay, Echo Bay, and the Virgin River/Muddy River inflow area, May 8 – December 20, 2013	44

Figures

Figure		Page
1	Juvenile razorback sucker study areas in Lake Mead, Nevada, 2013.....	4
2	Sonic transmitter sizing chart for juvenile razorback suckers surgically implanted in 2013 according to a guideline of tag weight not exceeding 2% of body weight (Bidgood 1980; Winter 1983; Marty and Summerfelt 1990) with a sizing curve based on empirical captures of Lake Mead razorback suckers less than 400 mm TL from 2005 to 2013 (Albrecht et al. 2006a, 2006b, 2007, 2008a, 2008b, 2010a, 2010b, 2013a; Kegerries et al. 2009; Shattuck et al. 2011; Kegerries and Albrecht 2013).....	7

Figures (continued)

Figure	Page
3	Daily lake elevations (A) for Lake Mead in meters above msl, January 1 – December 31, 2013 (Reclamation 2013), and mean daily discharges (B) in cubic meters per second for Las Vegas Wash (USGS gage 09419800), the Virgin River (USGS gage 09415250), and the Muddy River (USGS gage 09419507), January 1 – December 31, 2013.....19
4	Distribution of sonic-tagged, juvenile razorback suckers located through active sonic telemetry and designated by individual code (A) and by season (B) in Las Vegas Bay, May 8 – December 20, 2013.22
5	Distribution of sonic-tagged, juvenile razorback suckers located through active sonic telemetry and designated by individual code (A) and by season (B) in Echo Bay, May 8 – December 20, 2013.23
6	Distribution of sonic-tagged, juvenile razorback suckers located through active sonic telemetry and designated by individual code (A) and by season (B) in the Virgin River/Muddy River inflow area, May 8 – December 20, 2013.....25
7	Depth (m) at point of contact for all sonic-tagged, juvenile razorback suckers in Lake Mead (i.e., Las Vegas Bay, Echo Bay, and the Virgin River/Muddy River inflow area) plotted over time (May 8 – December 20, 2013) and fitted with an unweighted least-squares linear regression ($R^2 = 0.34$, $F_{1,95} = 49.01$, $P < 0.001$).26
8	Mean CPUE values with SE by study site and gear type for razorback suckers (A) and the grouped nonnative fishes (B) captured during ICS in direct association with sonic-tagged, juvenile razorback suckers in Lake Mead (i.e., Las Vegas Bay, Echo Bay, and the Virgin River/Muddy River inflow area), May 8 – July 26, 2013.....29
9	Locations of fish sampling efforts during the ICS period in direct association with sonic-tagged, juvenile razorback suckers in Las Vegas Bay, May 8 – July 26, 2013.31
10	Fish community composition by species (A), expressed as percentages of the mean CPUE values for all gear types combined, and TL box plots for species captured in the combined gear types (B) with associated medians, upper and lower quartiles, upper and lower whiskers, and denoted outliers for fishes captured during the ICS period in direct association with sonic-tagged, juvenile razorback suckers in Las Vegas Bay, May 8 – July 26, 2013.....33

Figures (continued)

Figure		Page
11	Locations of fish sampling efforts during the ICS period in direct association with sonic-tagged, juvenile razorback suckers in Echo Bay, May 8 – July 26, 2013.....	34
12	Fish community composition by species (A), expressed as percentages of the mean CPUE values for all gear types combined, and TL box plots for species captured in the combined gear types (B) with associated medians, upper and lower quartiles, upper and lower whiskers, and denoted outliers for fishes captured during the ICS period in direct association with sonic-tagged, juvenile razorback suckers in Echo Bay, May 8 – July 26, 2013.....	36
13	Locations of fish sampling efforts during the ICS period in direct association with sonic-tagged, juvenile razorback suckers at the Virgin River/ Muddy River inflow area, May 8 – July 26, 2013.....	37
14	Fish community composition by species (A), expressed as percentages of the mean CPUE values for all gear types combined, and TL box plots for species captured in the combined gear types (B) with associated medians, upper and lower quartiles, upper and lower whiskers, and denoted outliers for fishes captured during the ICS period in direct association with sonic-tagged, juvenile razorback suckers at the Virgin River/ Muddy River inflow area, May – July 26, 2013.....	38
15	CCA of the environment, season, site, and fish community associated with sonic-tagged, juvenile razorback suckers in Lake Mead (i.e., Las Vegas Bay, Echo Bay, and the Virgin River/Muddy River inflow area), May 8 – July 26, 2013.....	45
16	PCA of the environment and site parameters associated with sonic-tagged, juvenile razorback suckers in Lake Mead (i.e., Las Vegas Bay, Echo Bay, and the Virgin River/Muddy River inflow area), May 8 – July 26, 2013.	48

EXECUTIVE SUMMARY

In 2012, the Bureau of Reclamation, under the Lower Colorado River Multi-Species Conservation Program (LCR MSCP), provided funding to continue long-term monitoring efforts and initiate a pilot study for juvenile razorback suckers (*Xyrauchen texanus*) in Lake Mead. The pilot study demonstrated that juvenile razorback suckers could be effectively implanted with sonic transmitters and, more importantly, that implanted juvenile fish could lead researchers to other razorback suckers and provide insight into their habitat associations during this life stage. Habitat association information and observations from the 2012 pilot study are provided in Albrecht et al. (2013a). Building on successes and information obtained from the 2012 pilot study, the Bureau of Reclamation (under the LCR MSCP) provided funding for a full sonic telemetry and habitat use study in 2013 to better understand juvenile razorback suckers in Lake Mead. This report presents information from the first study year (2013–14) and provides information stemming from both the intensive community sampling efforts conducted from May through July (spring/summer season) and the additional habitat sampling (AHS) efforts conducted during the remainder of the year. Where applicable, comparisons of data and information between the pilot study and the 2013–14 study will be included for completeness.

During the 2013–14 field season, the habitat use and movements of 18 sonic-tagged, juvenile razorback suckers were monitored through active tracking, which resulted in 100 total contacts with 16 individuals. Additionally, 11 submersible ultrasonic receivers were deployed throughout the lake to passively detect lake-wide movement of tagged individuals. The 18 juvenile fish were obtained from the Nevada Department of Wildlife's Lake Mead Fish Hatchery, successfully implanted with appropriately sized transmitters, and released in groups of six individuals into Las Vegas Bay, Echo Bay, and the Virgin River/Muddy River inflow area. All surgical implantations and stocking efforts were successful, and no known mortality occurred. Upon release of the sonic-tagged, juvenile razorback suckers into each of these locations, intensive sonic telemetry and habitat quantification efforts ensued. In addition, ICS sampling was conducted using a wide variety of sampling techniques and gear types, as little is known about this life stage of razorback suckers. During the 2013 study year, sonic-tagged, juvenile razorback suckers provided the locations for which all sampling occurred for information regarding this life stage.

Sampling efforts involved a suite of methods, which totaled 158 gear sets during the ICS period and resulted in the capture of 687 individual fishes from 13 species. Included in the fishes captured were four new, wild razorback suckers, 521–561 millimeters total length. The new, wild razorback suckers were captured in direct association with sonic-tagged, juvenile razorback suckers in Las Vegas Bay during June and July 2013. Fin ray sections were removed from 3 of the 4 individuals for age determination which, when combined with the 432 fish aged during previous studies (Albrecht et al. 2013b), brings the total

Sonic Telemetry and Habitat Use of Juvenile Razorback Suckers in Lake Mead, 2013–2014 Annual Report

number of fish aged during all Lake Mead razorback sucker studies to date to 436. Of particular interest is the continued documentation of recent (2000–08) recruitment. Age determination techniques continue to show that recruitment pulses in Lake Mead are associated with relatively high, stable lake elevations. However, based on data collected from 2007 to 2013, we have also observed strong pulses in recruitment that coincide with low, declining lake elevation trends and high-flow events in the Virgin River during 2004–05. Aging data obtained thus far indicate that Lake Mead razorback sucker recruitment occurs nearly every year. This report moves us ever closer to understanding conditions that promote the unique recruitment pattern of razorback suckers in Lake Mead.

For the habitat assessment and physicochemical quantification, 435 replicates from 87 habitats were used to characterize the locations directly associated with sonic-tagged, juvenile razorback suckers throughout Lake Mead. Seasonal patterns of habitat association and movement were documented and incorporated into multivariate analyses in order to explain ecological relationships between habitat and fish species composition as well as characterize the spatiotemporal habitat utilization specific to sonic-tagged, juvenile razorback suckers. Generally, sonic-tagged, juvenile razorback suckers associated with shallow habitat characterized by large amounts of inundated cover and high turbidities during spring and early summer. Following an increase in water temperature, sonic-tagged, juvenile razorback suckers began to move offshore into deeper habitats where they remained for much of the year. Although much of the sampling in 2013 was conducted during the spring and summer seasons, in future study years, we will continue the varied seasonal approach and include focused sampling during the fall and winter seasons.

Research plans for the 2014–15 field season include additional juvenile razorback sucker sonic implantations to continue the AHS efforts (additional implantations will be needed during May due to current transmitter battery longevity constraints) and additional ICS during the fall season (an additional sonic implantation event will occur in September to provide transmitter coverage). These two tagging events should provide enough sonic-tagged, juvenile razorback suckers to cover the 2014–15 field season. These efforts will facilitate not only habitat association data to be collected during the AHS but also will ensure that we can investigate juvenile razorback sucker habitat use, foster conspecific capture opportunities, and elucidate fish community associations during fall. In the end, these efforts will inform and enhance our understanding of this early life stage of razorback suckers and specifically allow for identification and understanding of what happens with this rare species during the fall months in particular.

The ultimate goal of this study is to conduct intensive field sampling during each season (summer, fall, and winter/spring; one intensive sampling season per study year) to better understand this relatively understudied yet important life stage. Hence, while the results contained herein are interesting and informative,

**Sonic Telemetry and Habitat Use of Juvenile Razorback Suckers
in Lake Mead, 2013–2014 Annual Report**

additional, more complete information regarding juvenile razorback suckers and insights into the natural razorback sucker recruitment observed in Lake Mead will be obtained as we progress through the entire study design: its true value will be realized in subsequent years.

INTRODUCTION

The razorback sucker (*Xyrauchen texanus*) is one of four endemic, large-river fish species of the Colorado River basin considered endangered by the U.S. Department of the Interior (U.S. Fish and Wildlife Service 1991). Although historically widespread and common throughout the larger rivers of the basin (Minckley et al. 1991), the distribution and abundance of razorback suckers have been greatly reduced. One of the major factors causing the decline of razorback suckers has been the construction of main stem dams and the resultant cool tailwaters and reservoir habitats that replaced warm, riverine environments (Holden and Stalnaker 1975; Joseph et al. 1977; Wick et al. 1982; Minckley et al. 1991). In the years immediately following the closure of Hoover Dam and the subsequent creation of Lake Mead in 1935, razorback suckers were relatively common in the lake (Minckley 1973; McCall 1980; Minckley et al. 1991; Holden 1994; Sjoberg 1995). During the 1970s though, approximately 40 years after closure of the dam, the Lake Mead razorback sucker population followed the trend of razorback sucker populations in other Lower Colorado River Basin reservoirs and noticeably declined (Minckley 1973; McCall 1980; McCarthy and Minckley 1987; Minckley et al. 1991). From 1980 through 1989, neither the Nevada Department of Wildlife (NDOW) nor the Arizona Game and Fish Department collected razorback suckers from Lake Mead (Sjoberg 1995). This may have been partially due to changes in the agencies' lake sampling programs; however, these results fit well within the pattern of other razorback sucker population declines following reservoir development (Minckley 1983; McCarthy and Minckley 1987; Marsh et al. 2005). Competition and predation from nonnative fishes in the Colorado River basin have also contributed to the decline of razorback suckers (Minckley et al. 1991; Mueller 2005); however, this endemic species has persisted in a few locations despite dramatic environmental and biological changes (Albrecht et al. 2010a, 2013a; Dowling et al. 2012). Specifically, the population of razorback suckers in Lake Mead, Nevada and Arizona, continues to exhibit some level of natural recruitment, as new, wild fish are consistently captured, which underscores the relative uniqueness of this population among the Colorado River basin (Albrecht et al. 2010a, 2013a, 2013b; Dowling et al. 2012).

After receiving reports in 1990 from local anglers that razorback suckers were still found in Lake Mead in two areas (Las Vegas Bay and Echo Bay), the NDOW initiated limited sampling. From 1990 through 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). Furthermore, two razorback sucker larvae were collected near Blackbird Point by an NDOW biologist in 1995, confirming suspected spawning in the area (Holden et al. 1997). Following these captures, BIO-WEST, Inc. (BIO-WEST), was contracted to better understand the Lake Mead population of razorback suckers (Holden et al. 1997). Beginning in 1996 and spanning 17 years, BIO-WEST has cooperated with a number of municipal, State, and Federal agencies and groups (i.e., the Southern Nevada

Sonic Telemetry and Habitat Use of Juvenile Razorback Suckers in Lake Mead, 2013–2014 Annual Report

Water Authority, Arizona Game and Fish Department, NDOW, Colorado River Commission of Nevada, Lake Mead Work Group, Bureau of Reclamation's [Reclamation] Lower Colorado River Multi-Species Conservation Program [LCR MSCP], National Park Service, and the U.S. Fish and Wildlife Service and collected a large amount of information regarding razorback suckers in Lake Mead (Albrecht et al. 2008b).

Though much of the research conducted on the Lake Mead population of razorback suckers has focused on adult individuals and aspects of reproductive success, a number of juvenile razorback suckers (i.e., sexually immature individuals less than 450 millimeters (mm) total length [TL], as defined in Shattuck et al. [2011]) have been captured incidentally in recent years (Albrecht et al. 2007, 2008a, 2010b, 2013a; Kegerries et al. 2009; Shattuck et al. 2011; Kegerries and Albrecht 2013). Although sampling specifically targeting juvenile razorback suckers was conducted on a limited basis from 1997 to 2002 with limited success (Holden et al. 1997, 1999, 2001; Welker and Holden 2003), trammel netting targeting spawning, adult razorback suckers during long-term monitoring efforts from 2006 through 2013 resulted in the capture of over 100 wild (unmarked) juvenile razorback suckers (Albrecht et al. 2006a, 2007, 2008a, 2008b, 2010b, 2013a; Kegerries et al. 2009; Shattuck et al. 2011; Kegerries and Albrecht 2013). Despite these captures, only a limited amount of information regarding young, sexually immature razorback suckers in Lake Mead exists. Efforts in 2012 sought to add to the body of information regarding recruitment and the juvenile life stage within Lake Mead (Albrecht et al. 2013a).

In 2012, Reclamation (under the LCR MSCP) provided funding to conduct a pilot study that tiered off long-term monitoring efforts. Four juvenile razorback suckers (one wild caught in Las Vegas Bay and three pond reared at Overton Wildlife Management Area) were implanted with sonic transmitters and released into Las Vegas Bay with the idea that tracking these fish would help us gain a better understanding of why Lake Mead razorback suckers are able to demonstrate consistent, natural recruitment (Albrecht et al. 2013a). Using sonic telemetry and capitalizing on new and smaller tag technology, seasonal movement of individuals was observed, and the habitats these individuals associated with throughout the year were characterized. Furthermore, sampling was conducted in association with sonic-tagged juveniles to describe the overall fish community in relation to where juvenile razorback suckers were located. Although the pilot study was limited in scope (i.e., it only occurred in Las Vegas Bay, included a limited number of tagged individuals, and incorporated a limited number of sampling periods), study findings suggested that juvenile razorback suckers avoid predation by utilizing areas with cover such as turbidity and inundated vegetation (IV), moving from shallow habitat into deeper habitat with the progression of seasons, and associating with other wild razorback suckers. Details of this pilot study, including specific methodological details, findings, and recommendations, are found in Albrecht et al. (2013a).

Following successes in the pilot study, the Bureau of Reclamation (under the LCR MSCP) once again provided funding – this time for a full-scale study of juvenile razorback sucker sonic telemetry and habitat use for multiple study locations within Lake Mead during 2013 with optional years for continuation in 2014 and 2015. The goal of this study is to provide further information regarding how and why razorback suckers continue to recruit in Lake Mead and identify potential areas or types of habitat that may allow for this process to occur. As mentioned in Albrecht et al. (2013a), Lake Mead provides a unique opportunity to study this life stage in a wild form, as it is one of the few remaining locations where wild fish continue to recruit naturally and where wild, juvenile razorback suckers are routinely captured (Albrecht et al. 2010a, 2010b, 2013a; Shattuck et al. 2011; Kegerries and Albrecht 2013).

STUDY AREAS

During 2013, all juvenile razorback sucker sonic telemetry and habitat assessment activities in Lake Mead occurred at the locations studied during long-term monitoring efforts from 1996 through 2013, which included Las Vegas Bay, Echo Bay, and the Virgin River/Muddy River inflow area (figure 1) (Holden et al. 1997, 1999, 2000a, 2000b, 2001; Abate et al. 2002; Welker and Holden 2003, 2004; Albrecht and Holden 2005; Albrecht et al. 2006a, 2006b, 2007, 2008a, 2008b, 2010a, 2010b, 2013a, 2013b; Kegerries et al. 2009; Shattuck et al. 2011).

Specific definitions for the various portions of Las Vegas Bay and Las Vegas Wash in which the study was conducted were given in Holden et al. (2000b). The following definitions are still accurate for various portions of the area:

- Las Vegas Wash is the portion of the channel with stream-like characteristics. In recent years, this section has become a broad, shallow area that is generally inaccessible by boat.
- Las Vegas Bay begins where the flooded portion of the channel widens and the current velocity is reduced. Las Vegas Bay can have a flowing (lotic) and nonflowing (lentic) portion. The flowing portion is typically short (200–400 meters [m]) and transitory between Las Vegas Wash proper and Las Vegas Bay.

Because the 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.

**Sonic Telemetry and Habitat Use of Juvenile Razorback Suckers
in Lake Mead, 2013–2014 Annual Report**

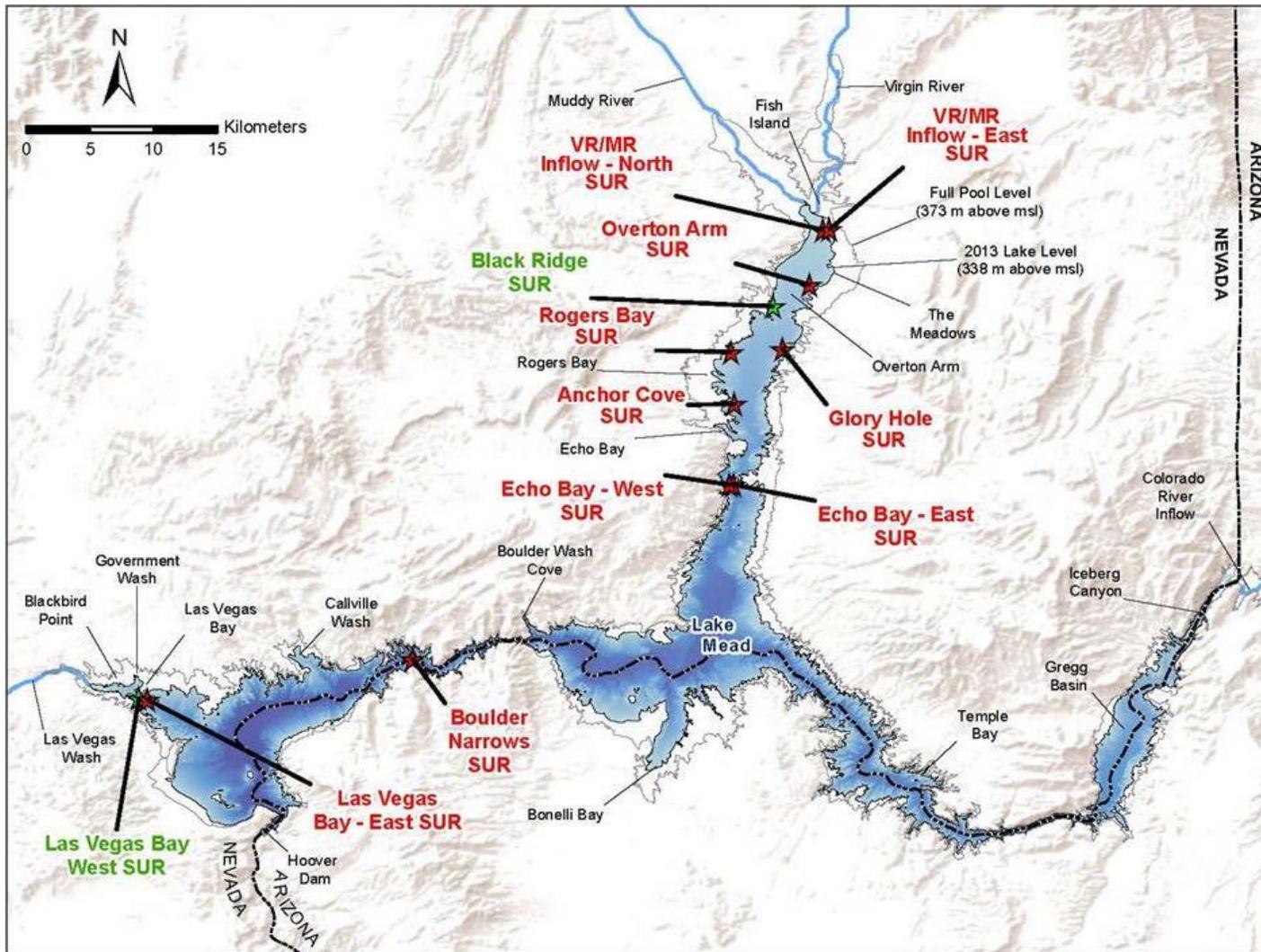


Figure 1.—Juvenile razorback sucker study areas in Lake Mead, Nevada, 2013.
Locations of submersible ultrasonic receivers are denoted by red stars (units maintained by BIO-WEST) or green stars (units maintained by the NDOW).

**Sonic Telemetry and Habitat Use of Juvenile Razorback Suckers
in Lake Mead, 2013–2014 Annual Report**

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)

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

- Virgin River/Muddy River inflow area (the lentic and littoral habitats located around the Muddy River confluence and Virgin River confluence with Lake Mead at the upper end of the Overton Arm)
- Fish Island (located between the Muddy River and Virgin River inflows, bounded on the west by the Muddy River inflow area and on the east by the Virgin River inflow; depending on lake elevation, this area may or may not be an actual island)
- Muddy River and Virgin River proper (the actual flowing, riverine portions that comprise the Muddy and Virgin Rivers, respectively).

METHODS

Lake Elevation and Inflow Discharges

Daily lake elevations for the 2013 calendar year are provided for context (note field efforts for this study specifically spanned May 8 – December 12, 2013) and were measured in meters above mean sea level (msl) as obtained from Reclamation’s Lower Colorado Regional Office Web site (Reclamation 2013). Similarly, mean daily discharges from Las Vegas Wash and the Virgin and Muddy Rivers were measured in cubic meters per second and obtained from the U.S. Geological Survey (USGS) for the 2013 calendar year (USGS 2013). Gage locations included Las Vegas Wash below Lake Las Vegas, near Boulder City, Nevada (USGS gage 09419800); the Virgin River above Lake Mead, near Overton, Nevada (USGS gage 09415250); and the Muddy River at Lewis Avenue, near Overton, Nevada (USGS gage 09419507).

Sonic Telemetry

Sonic Tagging

Eighteen juvenile razorback suckers from NDOW's Lake Mead Fish Hatchery were implanted with sonic transmitters on May 7, 2013, and subsequently released into Lake Mead on May 8, 2013, with the assistance of the NDOW and Reclamation. Each cohort of six juvenile razorback suckers (i.e., six individuals in Las Vegas Bay, six individuals in Echo Bay, and six individuals in the Virgin River/Muddy River inflow area) included two individuals tagged with Sonotronics model PT-4 transmitters and four individuals tagged with Sonotronics model IBT-96-6 transmitters.

A size curve was calculated for juvenile razorback suckers in Lake Mead based on empirical captures from 2005 through 2013 for sexually immature individuals less than 400 mm TL (figure 2). This size curve was then used to calculate minimum length and weight restrictions in order to not exceed a 2-percent (%) transmitter weight to fish weight, ensuring transmitter sizes were not too large for the fish (Bidgood 1980; Winter 1983; Marty and Summerfelt 1990).

In order to meet desired battery longevity, all transmitters were modified by Sonotronics as R-code companion transmitters (R-cc) in order to obtain 3- and 12-month battery lives, whereas without the R-cc these transmitters, they had an expected battery life of less than 3 (PT-4) and 8 months (IVT-96-6), respectively. Two transmitter sizes were used in order to implant the smallest juvenile individuals possible while still allowing for longer battery life of a larger tag when using larger juvenile individuals.

The PT-4, 3-month transmitters had a weight of 2.3 grams (g) and measured 25 mm long by 9 mm in diameter. These transmitters were implanted into individuals measuring greater than 226 mm TL and weighing more than 115 g (figure 2). Similarly, the IBT-96-6, 12-month transmitters had a weight of 3.9 g and measured 42 mm long by 11 mm in diameter. These transmitters were implanted into individuals measuring greater than 274 mm TL and weighing more than 195 g (figure 2). All transmitters were programmed to use a 69-kilohertz frequency and emit a unique code in the form of seven pings in a 3-second period followed by an optimized 4–6 second delay interval between transmissions. In order to properly identify transmitters using the R-cc, the firmware of all submersible ultrasonic receivers (SURs) was updated in the field prior to the release of tagged individuals, and a Sonotronics USR-08 receiver was used for manual tracking and transmitter decoding.

The following surgical protocol was established from procedures developed for use in razorback suckers and other similarly protected species (i.e., humpback chubs [*Gila cypha*] and Colorado pikeminnows [*Ptychocheilus Lucius*] (Tyus 1982; Valdez and Nilson 1982; Valdez and Masslich 1989; Kaeding et al. 1990; Valdez and Trinca 1995; Kegerries and Albrecht 2011; Shattuck et al. 2011; Albrecht et al. 2013a). Surgery was performed at NDOW's Lake Mead Fish

**Sonic Telemetry and Habitat Use of Juvenile Razorback Suckers
in Lake Mead, 2013–2014 Annual Report**

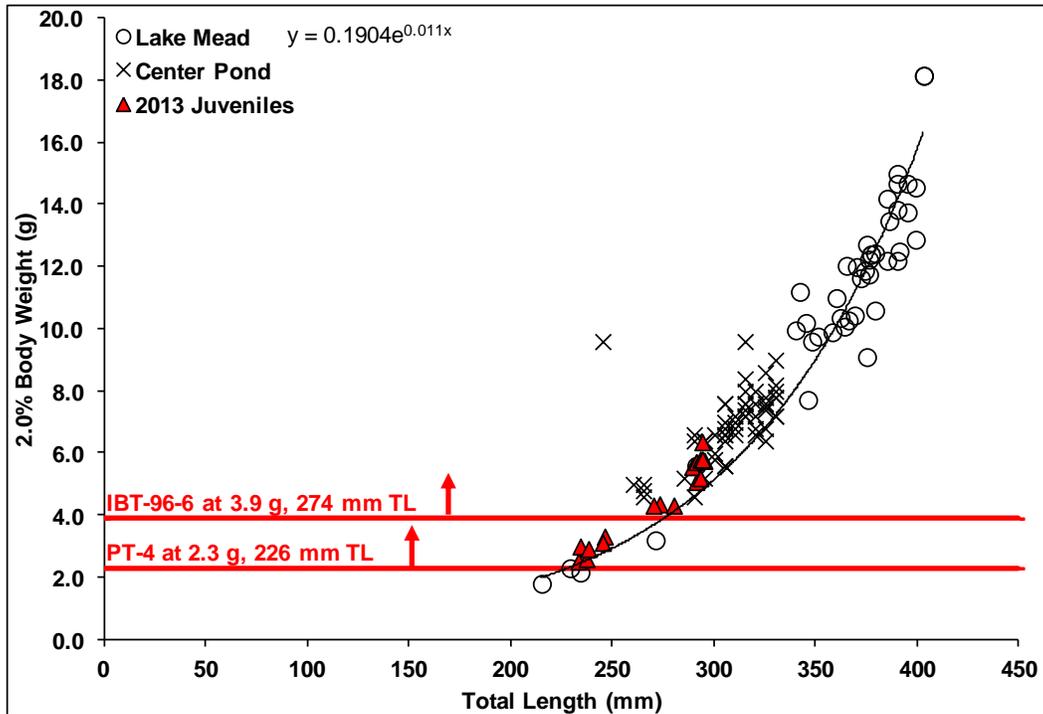


Figure 2.—Sonic transmitter sizing chart for juvenile razorback suckers surgically implanted in 2013 according to a guideline of tag weight not exceeding 2% of body weight (Bidgood 1980; Winter 1983; Marty and Summerfelt 1990) with a sizing curve based on empirical captures of Lake Mead razorback suckers less than 400 mm TL from 2005 to 2013 (Albrecht et al. 2006a, 2006b, 2007, 2008a, 2008b, 2010a, 2010b, 2013a; Kegerries et al. 2009; Shattuck et al. 2011; Kegerries and Albrecht 2013).

Lengths and weights of individuals from Center Pond at the Overton Wildlife Management Area are included for comparison.

Hatchery and involved one surgeon and one assistant. The assistant recorded data, captured pertinent photographs, and monitored fish respiration. Prior to surgery, all fish were placed into a designated tank containing fresh hatchery water, and all transmitters were checked for full function and identification. All surgical instruments were cold sterilized with iodine and 90% isopropyl alcohol and allowed to air dry on a disposable, sterile cloth. Juvenile razorback suckers were initially anaesthetized in 30 liters (L) of hatchery water with a 50-milliliter (mL)/L⁻¹ clove oil/ethanol mixture (0.5 mL clove oil [Anderson et al. 1997] emulsified in 4.5 mL ethanol) (Bunt et al. 1999). After anesthesia was induced, TL, fork length (FL), standard length (SL), and weight (g) were recorded. Juvenile individuals 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 mL/L⁻¹ clove oil/ethanol anesthetic (Bunt et al. 1999). Following introduction to the maintenance anesthetic, the surgeon made a 0.75–1.00 centimeter (cm) incision on the left side, posterior to the left pelvic girdle. A passive integrated transponder (PIT) tag was inserted into the incision followed by the transmitter, which was placed between

Sonic Telemetry and Habitat Use of Juvenile Razorback Suckers in Lake Mead, 2013–2014 Annual Report

the pelvic girdle and urogenital pore. The incision was closed with two to three 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, juvenile individuals were allowed to recover in a tank designated only for tagged individuals at NDOW's Lake Mead Fish Hatchery, partitioned by stocking location cohort (i.e., Las Vegas Bay, Echo Bay, and the Virgin River/Muddy River inflow area). Juvenile individuals were allowed to recover for a period of 24 hours before being assessed for signs of stress and subsequently transported to their appropriate stocking locations. Each cohort of six individuals was placed in separate fiberglass tanks filled with hatchery water and fitted with battery-operated aerators and air pumps before being transported to their stocking locations via truck and boat. Upon arrival at their stocking locations, all tanks were tempered with lake water not to exceed a rate of temperature change of 1 degree Celsius (°C) per 15 minutes. Prior to release, individuals were re-examined for signs of stress, and the transmitters were again checked for full function and identification. Based on associations made during the pilot study, all stocking locations juvenile razorback suckers were released into were less than 2 m deep and adjacent to dense IV (Albrecht et al. 2013a). Tracking ensued immediately after release and continued intensively for 24 hours.

Active Sonic Telemetry

Sonic telemetry data for the juvenile razorback sucker study were collected from May 8 to December 12, 2013; however, effort intensity was dependent on the study objectives for the intensive community sampling (ICS) period, or the additional habitat sampling (AHS) period. During the ICS period (May 8 – July 26, 2013), which was associated with the collection of fish community data in addition to habitat data collection and with the battery life expectancy of the smaller PT-4 transmitters, sonic tracking was conducted on a weekly basis. During the AHS period (July 29 – December 20, 2013), which was associated solely with habitat data collection with the larger IBT-96-6 transmitters, sonic tracking was conducted on a monthly basis for the remainder of the year.

Sonic surveillance for juvenile razorback suckers was largely conducted along shorelines, with listening points spaced approximately 450 m apart, depending on shoreline configuration and other factors that could impact signal reception, as sonic surveillance is line-of-sight, and obstructions can reduce or block a signal. Past experience with juvenile razorback suckers showed that individuals often associated with dense IV (areas known to impact signal reception) (Albrecht et al. 2013a); thus, considerable effort was spent listening in areas with the presence of this cover type. Also, as the effectiveness of a sonic telemetry signal is often reduced in shallow, turbid, and flowing environments (M. Gregor 2012, personal communication; personal experiences of the authors), listening points were spaced closer together with varying habitat. Additionally, because sonic-tagged

Sonic Telemetry and Habitat Use of Juvenile Razorback Suckers in Lake Mead, 2013–2014 Annual Report

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 transmitters using a Sonotronics USR-08 ultrasonic receiver and DH4 hydrophone. The hydrophone was lowered just below the water's surface and rotated 360 degrees to detect sonic-tagged fish presence. Furthermore, in areas less conducive to the use of the DH4 hydrophone (e.g., shallow or flowing water and areas with dense inundated cover), a TH-2 towed omnidirectional hydrophone was trolled behind a boat at a speed not exceeding 5 knots. The use of this towed hydrophone also allowed for broad sonic tracking across large areas in a transect-type manner. Once pinpointed, the juvenile razorback sucker's tag number, Global Positioning System location (decimal degrees), and depth (m) were recorded. Depending on the time of year (ICS), fish sampling then accompanied detailed habitat sampling (e.g., physicochemical characterization, substrate, and cover type composition estimation) to aide in characterizing habitats utilized by this young life stage. In all cases when sonic-tagged juveniles were located within shallow habitats or within inflow riverine portions of Lake Mead, individual fish locations were recorded at the closest point accessible by boat.

Passive Sonic Telemetry

Along with active tracking methods, SURs were deployed in various locations throughout Lake Mead (see figure 1). The advantage to using SURs is their ability to continuously record sonic telemetry data with little associated maintenance. 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, a SUR facilitates an understanding of large-scale juvenile razorback sucker movements during the monthly tracking events and can indicate whether or not a juvenile individual has moved into or out of a particular area. Eleven SURs were utilized during 2013, with the majority of units in place before the initial stocking of sonic-tagged, juvenile razorback suckers, in order to monitor movements of individuals immediately.

The 11 SURs were set at the following locations, where coordinate information was recorded for each unit deployed (see figure 1): across from Sand Island at the southeastern extent of Las Vegas Bay (NDOW, Las Vegas Bay-West), at the northwestern extent of Sand Island (BIO-WEST, Las Vegas Bay-East), on the southern shore across from Rotary Cove in the narrows of Boulder Canyon (BIO-WEST, Boulder Narrows), south of Echo Bay at the constriction point near Ramshead Island on the western and eastern shores (BIO-WEST, Echo Bay-West and BIO-WEST, Echo Bay-East), north of Echo Bay off the northern shore of Anchor Cove (BIO-WEST, Anchor Cove), at the northern extent of Rogers Bay

Sonic Telemetry and Habitat Use of Juvenile Razorback Suckers in Lake Mead, 2013–2014 Annual Report

and south of Bluepoint Cove (BIO-WEST, Rogers Bay), off the southwestern point south of Glory Hole (BIO-WEST, Glory Hole), off Black Ridge on the southeastern edge of Fire Bay (NDOW, Black Ridge), off the southwestern shore of the Meadows across from Salt Bay on the eastern side of the Overton Arm (BIO-WEST, Overton Arm), off the eastern shoreline near Three Corner Hole (BIO-WEST, Virgin River/Muddy River inflow-East), and at the northern extent of the Overton Arm between Three Corner Hole and the Overton boat ramp (BIO-WEST, Virgin River/Muddy River inflow-North) (see figure 1).

Each SUR was programmed to detect implanted, active sonic tag frequencies of both adult and juvenile razorback suckers using Sonotronics's SURsoft software with channels that spanned frequencies 69 through 80 kilohertz. In deployment, the semibuoyant SURs were suspended from an anchor (e.g., rock, anchor, or block) using approximately 0.5 m of rope and secured to shore using a lead of vinyl-coated steel cable. The cable was allowed to sink to the lake bottom, and the remaining visible sections of cable were concealed using surrounding rubble. The SURs were inspected frequently by pulling them up into the boat, and the data were downloaded 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 contact.

Conspecific and Community Sampling

Sampling for conspecific individuals (i.e., other similarly sized razorback suckers) and the general fish community assemblage was conducted during the ICS period (May 8 – July 26, 2013) to target all fishes associated with sonic-tagged, juvenile razorback suckers. Sampling methods consisted of a suite of gear types, including trammel nets, fyke nets, hoop nets, minnow traps, seining, and boat electrofishing (as deemed appropriate based on sonic-tagged fish location and habitat). Though no standardized sampling methods had previously been established for this young life stage (Minckley et al. 1991; Holden et al. 1997, 1999), many of these methods were used during previous studies to catch juvenile razorback suckers (Holden et al. 2000a, 2000b, 2001; Abate et al. 2002; Welker and Holden 2003). However, previous efforts lacked a key component—sonic-tagged, juvenile razorback suckers to help guide efforts to 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, juvenile individuals, and mean catch per unit effort (CPUE) was calculated for each sampling method. For locations with multiple juvenile individuals contacted, the

Sonic Telemetry and Habitat Use of Juvenile Razorback Suckers in Lake Mead, 2013–2014 Annual Report

number of individuals present was recorded, and sampling efforts and collections were duplicated for replicates from the sampling area in multivariate analyses (i.e., rather than conducting two separate sets of sampling efforts and collections in the same area). In cases where razorback suckers were captured, individuals were removed alive from nets and were isolated from other fish species in 94.6-L coolers filled with lake water. Razorback suckers were scanned for PIT tags, PIT tagged if they were not recaptured fish, measured for TL, SL, and FL (mm), weighed (g), and assessed for sexual maturity (e.g., nuptial tubercles, ripeness, or coloration). Additionally, for individuals that were not recaptured fish, a section of a pectoral fin ray was removed for age determination purposes, and a small amount of fin tissue was retained for genetic analyses. Razorback suckers selected for age determination were anesthetized with tricaine methanesulfonate (MS-222) and placed dorsal-side down on a padded surgical cradle for support while a small segment of the second pectoral fin ray was collected. Genetic material (0.5 square centimeter) was removed from the ventral portion of the caudal fin and preserved in 95% nondenatured ethanol, with specimens delivered to Reclamation biologists. After all necessary information had been collected, individuals were released at the point of capture in good health. Native species other than razorback suckers were processed in a similar manner, while all other nonnative fish species were identified, measured for TL and FL, weighed, and enumerated before they were returned to the lake. Finally, as handling stress is increased when surface water temperatures are greater than 25 °C (Hunt et al. 2012), sampling was limited to shorter set times during warmer conditions, and trammel netting was not utilized during times of extreme temperatures. For the most abundant species captured, mean TLs were compared among study sites by species. Additionally, for species known to predate upon razorback suckers, TLs of razorback suckers and known predatory species from all lumped study sites were compared to assess potential size differences in individuals captured, perhaps yielding insight as to where razorback suckers are captured and why.

Trammel nets were used to target deeper habitats both adjacent to shore and offshore. Additionally, trammel nets were often set perpendicular to available shorelines when possible. Trammel nets measured 45.7 m long by 1.2 m deep, with an internal panel of 2.5-cm mesh and external panels of 30.5-cm mesh. In past experience these specific dimensions of trammel netting have been effective in capturing razorback suckers of all sizes while limiting the amount of large suspended debris accumulated in the mesh and allowing for deployment in more diverse habitats with a shorter overall length (Kegerries and Albrecht 2011). Nets were generally set with one end near shore in 1.5–9.1 m of water, with the net extended out into deeper areas. Alternatively, nets were also set to encircle sonic-tagged, juvenile individuals generally when sampling was conducted in pelagic areas. Fyke nets were used in shallower habitats where IV was sparse enough to allow for the placement of a net leader yet with sufficient depth to submerge the trap end. Fyke nets measured 4.6 m long by 1.2 m wide by 0.9 m tall with a 4.9-m-long lead and 3.0-mm mesh. Hoop nets and minnow traps were used in

Sonic Telemetry and Habitat Use of Juvenile Razorback Suckers in Lake Mead, 2013–2014 Annual Report

shallower habitats where trammel nets and fyke nets could not be used due to thick IV. Hoop nets and minnow traps were set near available anchor points among thick IV and often in tandem with each other. Hoop nets measured 2.1 m long by 0.6 m in diameter with 10.2-cm throats and 6.4-mm mesh, while minnow traps measured 44.5 cm long by 22.9 cm in diameter with 2.5-cm throats and 6.4-mm mesh. In wadable habitats, seines were used to sample littoral habitats free of obstruction and in areas with flowing water. Seines measured 9.0 m wide by 2.0 m tall with 6.0-mm mesh. Seine haul effort was calculated as area sampled (square meters [m²]) by multiplying the length of the haul by the width of the net. As with other sampling gears, the effort expended at each site was dependent on the habitat type and amount of accessible area.

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; Albrecht et al. 2013b).

During the 2013 field season, select razorback suckers (i.e., previously unaged, wild caught) captured via trammel netting were anesthetized, and a single (approximately 0.64-cm-long) segment of the second left pectoral fin ray was surgically removed. Fish were anesthetized with a lake-water bath containing MS-222, sodium chloride, and 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. This surgical tool consists of a matched pair of finely sharpened chisels welded to a set of wire-stripping pliers. The connecting membrane between fin rays was cut using a scalpel blade, and the section was placed in a labeled envelope for drying. All surgical equipment was sterilized before use, and subsequent wounds were packed with antibiotic ointment to minimize post-surgical bacterial infections and promote rapid healing. All native suckers undergoing fin ray extraction techniques were immediately placed in a recovery bath of fresh lake water containing a 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 where the assigned age was not agreed upon. If age discrepancies remained after the second reading, all three readers collectively assigned an age. For further information regarding the development of our fin ray aging technique, refer to other annual Lake Mead razorback sucker reports (e.g., Albrecht and Holden 2005; Albrecht et al. 2006b, 2008a, 2013b).

Habitat Observations and Physicochemical Quantification

Multiple methods were used to describe habitat, cover, and substrate in conjunction with the quantification of physicochemical data. In past reports, cover in the forms of turbidity and IV has stood out as an important factor in Lake Mead razorback sucker spawning and recruitment (Golden and Holden 2003), thus warranting efforts to better characterize these components, among others, as they relate to razorback sucker recruitment and habitat use. In total, 435 replicates collected from 87 habitats were used to help characterize sonic-tagged, juvenile razorback sucker habitat associations.

Once the location of a sonic-tagged, juvenile razorback sucker was pinpointed, areas the individual was associating with were quantified and described within one of two sampling designations. As juvenile razorback suckers utilize a variety of habitats from nearshore to offshore, pinpointed locations were defined as either an approximate 200- by 20-m rectangle (4,000 m²) or a 36-m radius circle (4,069 m²) encompassing the location of the sonic-tagged, juvenile individual and the immediately adjacent habitats (Albrecht et al. 2013a). 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 20 m from the shoreline). During the ICS period (May 8 – July 26, 2013), sampling occurred on a weekly basis, with habitat described and quantified in conjunction with fish sampling, while during the AHS period (July 29 – December 20, 2013), sampling occurred on a monthly basis without the addition of fish sampling. During 2013, offshore sampling areas were used more often (n = 68) than nearshore sampling areas (n = 20).

For each contacted juvenile, five replicate measurements and observations of water quality, substrate, and vegetation were recorded within the predetermined sampling areas described above. Multiple juvenile individuals contacted within the same predetermined sampling area were included under one set of replicates (and later duplicated in multivariate analyses); however, individuals contacted

Sonic Telemetry and Habitat Use of Juvenile Razorback Suckers in Lake Mead, 2013–2014 Annual Report

outside of the same predetermined sampling area were recorded as a separate site with their own set of replicates. Within each sampling area, five replicate locations were spaced randomly to collect water quality data. At each randomly spaced replicate, a water column profile was recorded with measurements taken at depth intervals of 0.5–2.0 m and the profile was then averaged for each parameter. In 2013, a total of 2,909 measurements were taken in the collection of 435 replicates from 87 habitats. At each depth interval, a measurement was recorded using a Hydrolab Quanta for the following: temperature (°C), dissolved oxygen (DO) (milligrams per liter [mg/L]), conductivity (microsiemens per centimeter [$\mu\text{S}/\text{cm}$]), pH, and turbidity (nephelometric turbidity units [NTU]). After the water column was assessed for these standard parameters from surface to bottom, a substrate grab sample was collected to visually estimate the substrate type following a modified Wentworth scale (Cummins 1962) (i.e., silt, sand, gravel [< 3 inches {in}], cobble [3–10 in], boulder, and bedrock). Grab samples were collected using a petite PONAR sampler, which removed an approximate 38.7 square centimeters of benthic area, and samples were emptied into a 18.9-L 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 water clarity and accessibility allowed, aquatic cover (primarily dead or live vegetation) was visually estimated, and a handheld Trimble Global Positioning System unit or gridded template was used to create spatial polygons in order to calculate percent of area covered. Cover was categorized as general vegetation types, including IV (e.g., saltcedar [*Tamarix* sp.], tumble pigweed [*Amaranthus albus*], and creosotebush [*Larrea tridentate*]); emergent vegetation (e.g., bulrush [*Typha* sp.], narrowleaf cattail [*Typha angustifolia*], and common reed [*Phragmites* sp.]); submerged aquatic vegetation (SAV), including filamentous algae (e.g., spiny naiad [*Najas marina*], sago pondweed [*Stuckenia pectinate*], and widgeon grass [*Ruppia maritima*]); large woody debris (LWD) (≤ 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 or turbid conditions).

Finally, season was recorded and categorized according to equinoxes and solstices (i.e., vernal equinox [spring: March 20 – June 20], summer solstice [summer: June 21 – September 21], autumnal equinox [fall: September 22 – December 20], and winter solstice [winter: December 21 – March 19]). Categorization of season 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 maintained by BIO-WEST. Data were also incorporated into a variety of univariate and multivariate analyses. 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 study.

Univariate Analyses

CPUE was used as a surrogate for relative abundance, assuming that more abundant species were captured at higher rates than less abundant species. CPUE values were averaged, and the standard error (SE) was calculated by gear type and within sampling location. Additionally, CPUE was used as a complementary metric for fish community composition in which a lumped mean CPUE was calculated for fish captured at a particular study site. A one-way analysis of variance (ANOVA) was used to assess the significance of differences in: mean TLs of species between study sites, mean TLs among razorback suckers and known predatory species, water quality parameters among sites, and water quality parameters among seasons for study sites. Each one-way ANOVA was followed with an examination of all pairwise comparisons using the Tukey's Honestly Significant Difference Test for significant differences of less than or equal to an alpha value of 0.05. For sonic telemetry depths at point of contact, an unweighted least-squares linear regression was used to test the significance of differences in depth through time of year. Finally, for lengths taken from the fish community data, box plots were constructed with medians, upper and lower quartiles, minimum and maximum outliers (points more than one-and-a-half beyond the quartiles), and upper and lower whiskers for the range of lengths measured by species and by study site. All univariate analyses were performed using the program Statistix 8.1 (Analytical Software 2005).

Canonical Correspondence Analysis

Habitat and community assemblage data were analyzed using a constrained ordination technique – specifically, a canonical correspondence analysis (CCA). This multivariate analysis 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 2002). As information regarding recruitment of razorback suckers and habitat use by young fish is limited, this type of exploratory analysis is useful for identifying overall relationships observed in habitat and fish community data in a descriptive manner. Although interpretation of the CCA model should be approached with some caution, the analysis has been shown to perform well despite unideal sampling designs, skewed species distributions, and degrees of multicollinearity (Palmer 1993).

Sonic Telemetry and Habitat Use of Juvenile Razorback Suckers in Lake Mead, 2013–2014 Annual Report

In the CCA, habitat data were tabulated for each sonic-tagged, juvenile razorback sucker encounter, and a mean numeric value was used for the habitat variables of depth, temperature, conductivity, DO, pH, and turbidity. Similarly, substrate composition percentages were included in numeric form, while season, spatial designation (i.e., Las Vegas Bay, Echo Bay, and Virgin River/Muddy River inflow area), 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 Lake Mead by season and by study site. Species data for sampling conducted at each encounter were included as lumped raw abundance for captured species, irrespective of gear type, and abundances were repeated across the five replicate samples. It was assumed that fishes captured in the sampling area were uniformly distributed, and it was thought that juvenile razorback suckers and other fish species could feasibly associate with any number of habitat or physicochemical variables within that sampling area in a given point in time. 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 sonic-tagged juvenile) unless multiple individuals were contacted in the sampling area. Though the hatchery-reared, sonic-tagged juveniles were not captured with deployed sampling gears in 2013, their presence was known based on sonic telemetry. Furthermore, razorback sucker abundances were split into two categories: juveniles (immature individuals less than 450 mm TL [Shattuck et al. 2011]) and adults (either sexually mature or individuals greater than 450 mm TL [Shattuck et al. 2011]). The categorization of razorback suckers by size is based on our hypothesis that 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 2002). Any encounter events that did not include a complete dataset were assessed for the potential of using recent physicochemical or habitat measurements to supplement missing data. When possible, data collected within the last consecutive sampling trip were averaged and used in place of a missing data parameter. If data could not be averaged from the most recent sampling trip, incomplete data were not used in the model iteration to avoid violating model assumptions (ter Braak and Šmilauer 2002). Additionally, although sampling area replicates were fitted with duplicated fish sampling data, the relatively small number of sampling areas ($n = 87$) required a degree of replication to avoid overfitting the data and maintaining a ratio of observations to a variable of 10:1 (Hair et al. 1998).

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 (i.e., 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 (i.e., specialist species or those exhibiting a narrow ecological niche). Axis values do not represent a negative or positive correlation, and a 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 2002).

Principal Component Analysis

Using a similar data matrix as designed in the CCA, 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 sonic-tagged, juvenile razorback suckers throughout Lake Mead and throughout the year (Matthews and Marsh-Matthews 2006). Using the output of eigenvalues in PCA helped define variables for each principal component to reflect the importance of a particular environmental gradient and gave ecological meaning to the physical habitat as it relates to a sonic-tagged, juvenile razorback sucker within the greater context of Lake Mead (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, 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. As in the CCA model, encounter events that did not include a complete dataset were assessed for the potential of using recent physicochemical or habitat measurements to supplement missing data. If data could not be averaged from the most recent sampling trip, incomplete data were not used in the model iteration to avoid violating model assumptions (ter Braak and Šmilauer 2002). 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 2002). 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).

Sonic Telemetry and Habitat Use of Juvenile Razorback Suckers in Lake Mead, 2013–2014 Annual Report

Using the multivariate analysis of PCA allows for a description of habitat changes through season and the spatial confines of Lake Mead for sonic-tagged, juvenile razorback suckers 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 suckers. 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 a numeric scale does not aid in interpretation.

The two multivariate approaches were used in conjunction for the period of study, as they essentially describe two different relationships with regard to sonic-tagged, juvenile razorback suckers: (1) a holistic community interaction snapshot, with habitat and species abundance relationships used to identify and describe associations with sonic-tagged, 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). In conjunction, these two approaches give a theoretical characterization of the habitat and the fish community that juvenile razorback suckers associate with throughout the year, lending insight as to where juvenile razorback suckers go and why they might recruit in Lake Mead.

RESULTS

Lake Elevation and Inflow Discharges

In past studies, juvenile razorback suckers associated strongly with inflow areas and anecdotally appeared to depend on the dynamic nature of these flowing systems to provide a variety of cover (e.g., IV, LWD, and turbidity) throughout the year (Golden and Holden 2003; Welker and Holden 2003; Albrecht et al. 2013a). In addition to evaluating daily lake elevations for Lake Mead, mean daily discharges from the Las Vegas Wash, Virgin River, and Muddy River were documented to better assess how inflow areas within the study sites might affect habitat availability (figure 3).

As lake elevations generally declined from January through June, so did mean daily discharges in the Virgin River (figure 3). Lake Mead decreased in lake elevation nearly 6.0 m from a high of 342.2 m above msl on February 4, 2013, to a low of 336.4 m above msl on November 12, 2013 (figure 3). With declines in lake elevation, expanses of habitat that were initially inundated during the period of sonic-tagged, juvenile razorback sucker stocking were subsequently left dry. This change in lake elevation may have influenced the types of habitat

Sonic Telemetry and Habitat Use of Juvenile Razorback Suckers
in Lake Mead, 2013–2014 Annual Report

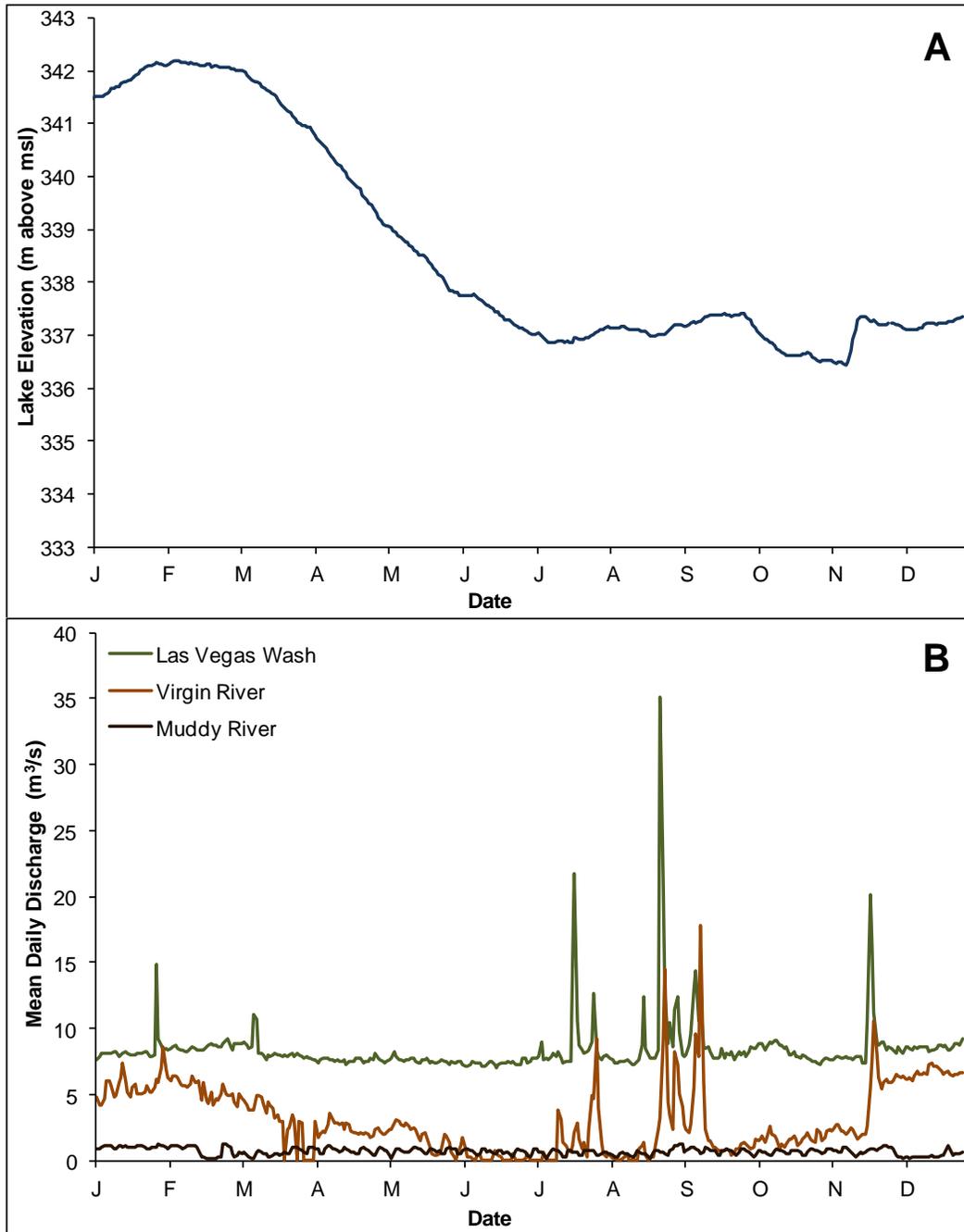


Figure 3.—Daily lake elevations (A) for Lake Mead in meters above msl, January 1 – December 31, 2013 (Reclamation 2013), and mean daily discharges (B) in cubic meters per second for Las Vegas Wash (USGS gage 09419800), the Virgin River (USGS gage 09415250), and the Muddy River (USGS gage 09419507), January 1 – December 31, 2013.

Discharge data are provisional and subject to USGS revision.

Sonic Telemetry and Habitat Use of Juvenile Razorback Suckers in Lake Mead, 2013–2014 Annual Report

available to sonic-tagged, juvenile razorback suckers. Similarly, following higher late winter and spring discharges into the Virgin River, discharges declined into late spring and summer; however, during this time, discharges into Las Vegas Wash and the Muddy River remained relatively consistent likely due to strong anthropogenic influences (e.g., wastewater effluent in Las Vegas Wash and irrigation practices in the Muddy River). Although the Las Vegas Wash does not show the same amount of daily or annual fluctuation as the Virgin River, the amount of discharge brought into Lake Mead during 2013 was often an order of magnitude more than both the Virgin River and Muddy River (figure 3). In fact, it was not until late summer and fall that the Virgin River saw notable increases in the frequency and magnitude of discharge, with high-discharge events stemming from monsoonal rains that occurred from July through October (figure 3). Similar peaks in discharge were seen in Las Vegas Wash, although the same peaks in discharge were likely diverted upstream of the Lewis Avenue gage on the Muddy River; thus, the Muddy River did not appear to contribute substantial inflows during these storms. These seasonal increases in flow appeared to provide inputs of LWD, organic nutrients, and sediment to the inflow areas of Lake Mead. The transport of sediment has been shown to help maintain some of the highest levels of turbidity in Lake Mead, a form of cover of noted importance for razorback sucker recruitment (Golden and Holden 2003; Albrecht et al. 2010a, 2013a; Shattuck et al. 2011).

Sonic Telemetry

Eighteen juvenile razorback suckers (233–295 mm TL) were successfully implanted with sonic transmitters and tracked immediately following their respective post-surgery releases in Las Vegas Bay, Echo Bay, and the Virgin River/Muddy River inflow area. One hundred active contacts were made with sonic-tagged, juvenile razorback suckers spanning May 8 – December 10, 2013, and all but two individuals were contacted at least once (figure 3 and table 1). Although the tag status for the smaller PT-4 transmitters is uncertain due to the expected battery life expiration, the larger IBT-96-6 transmitters are expected to be active until at least May 2014 (table 1).

Generally, sonic-tagged, juvenile razorback suckers remained at each of the respective study sites in which they were released during 2013; however, it appeared that within each study site, local movements transitioned with season. In Las Vegas Bay, five individuals were located for a total of 46 contacts during 2013 (figure 4). Individuals frequented the western portion of Las Vegas Bay, with regular contacts from the flowing extent of the Las Vegas Wash to the mouth of Government Wash Cove (figure 4). From initial stocking through spring (May 8 – June 20, 2013), sonic-tagged, juvenile razorback suckers were contacted in habitat with an average depth of 4.1 m (\pm 0.5 SE) and were often associated with dense IV cover near the mouth of Las Vegas Wash (figure 4). As summer

**Sonic Telemetry and Habitat Use of Juvenile Razorback Suckers
in Lake Mead, 2013–2014 Annual Report**

Table 1.—Demographic summary with included sonic transmitter information, individual sizes, location and date of last contact, and current status of sonic-tagged, juvenile razorback suckers stocked into Las Vegas Bay, Echo Bay, and the Virgin River/Muddy River inflow area, 2013

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
LMFH	5/7/2013	3000	291	254	I	LB	LB	5/13/2013	2 (0)	Active
LMFH	5/7/2013	3001	273	218	I	LB	LB-W	9/13/2013	14 (62)	Active
LMFH	5/7/2013	3002	290	278	I	LB	LB	5/20/2013	2 (0)	Active
LMFH	5/7/2013	3003	289	278	I	LB	LB	11/11/2013	18 (145)	Active
LMFH	5/7/2013	3012	233	126	I	LB	LB	7/16/2013	1 (0)	Unknown
LMFH	5/7/2013	3013	246	166	I	LB	LB	7/22/2013	9 (0)	Unknown
LMFH	5/7/2013	3004	291	286	I	EB	EB	5/8/2013	0 (0)	Active
LMFH	5/7/2013	3005	295	288	I	EB	EB	10/23/2013	8 (0)	Active
LMFH	5/7/2013	3006	270	216	I	EB	EB	7/23/2013	7 (0)	Active
LMFH	5/7/2013	3007	293	260	I	EB	EB	12/10/2013	4 (0)	Active
LMFH	5/7/2013	3014	234	150	I	EB	EB	5/8/2013	0 (0)	Unknown
LMFH	5/7/2013	3015	245	156	I	EB	EB	5/9/2013	1 (0)	Unknown
LMFH	5/7/2013	3008	293	290	I	OA	OA	7/18/2013	4 (0)	Active
LMFH	5/7/2013	3009	294	318	I	OA	OA	7/18/2013	10 (0)	Active
LMFH	5/7/2013	3010	280	216	I	OA	OA	5/9/2013	1 (0)	Active
LMFH	5/7/2013	3011	294	290	I	OA	OA	7/24/2013	10 (46)	Active
LMFH	5/7/2013	3016	237	130	I	OA	OA	7/24/2013	8 (1,735)	Unknown
LMFH	5/7/2013	3017	238	146	I	OA	OA	5/9/2013	1 (0)	Unknown

^a LMFH = Lake Mead Fish Hatchery, LB = Las Vegas Bay, LB-W = Las Vegas Bay-West SUR, EB = Echo Bay, and OA = Virgin River/Muddy River inflow area of the Overton Arm.

^b I = immature.

progressed (June 21 – September 21, 2013), sonic-tagged, juvenile individuals were contacted in deeper habitat that averaged 6.6 m (± 0.8 SE), and they were found in habitat with even greater average depths (18.9 m [± 2.2 SE]) during fall (September – December 20, 2013). During summer and fall, individuals were located further east into Las Vegas Bay and were typically contacted toward the middle portions of the bay and within the historic channel of Las Vegas Wash (figure 4).

In Echo Bay, four sonic-tagged, juvenile razorback suckers were located for a total of 20 contacts during 2013 (figure 5). Unlike juveniles contacted in Las Vegas Bay, these individuals were not as regularly contacted in any particular area of Echo Bay; rather, they appeared to immediately leave Echo Bay proper following initial stocking, with the exception of one individual. This individual (code 3006) behaved similarly to sonic-tagged, juvenile razorback suckers in

**Sonic Telemetry and Habitat Use of Juvenile Razorback Suckers
in Lake Mead, 2013–2014 Annual Report**

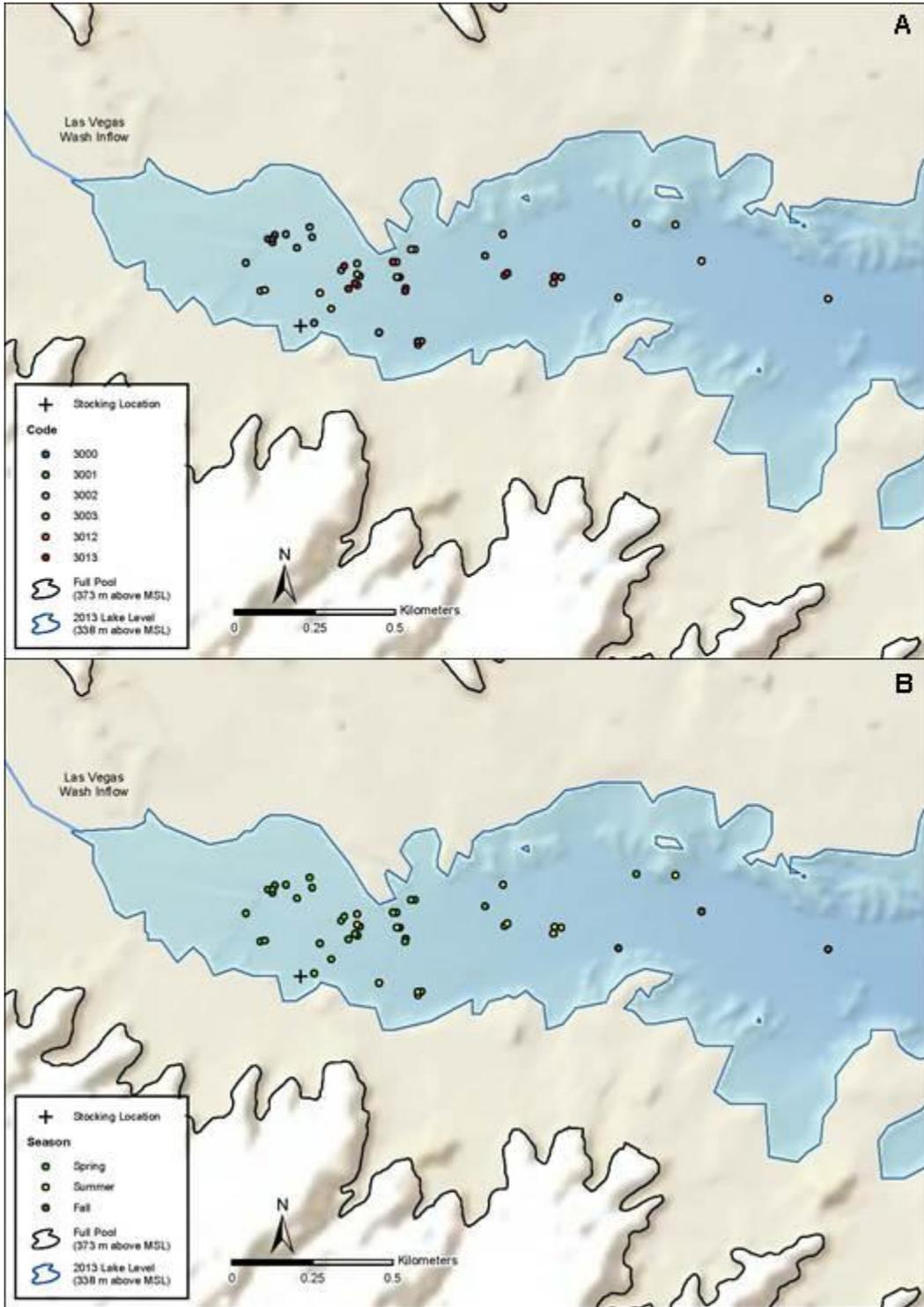


Figure 4.—Distribution of sonic-tagged, juvenile razorback suckers located through active sonic telemetry and designated by individual code (A) and by season (B) in Las Vegas Bay, May 8 – December 20, 2013.

Sonic Telemetry and Habitat Use of Juvenile Razorback Suckers
in Lake Mead, 2013–2014 Annual Report

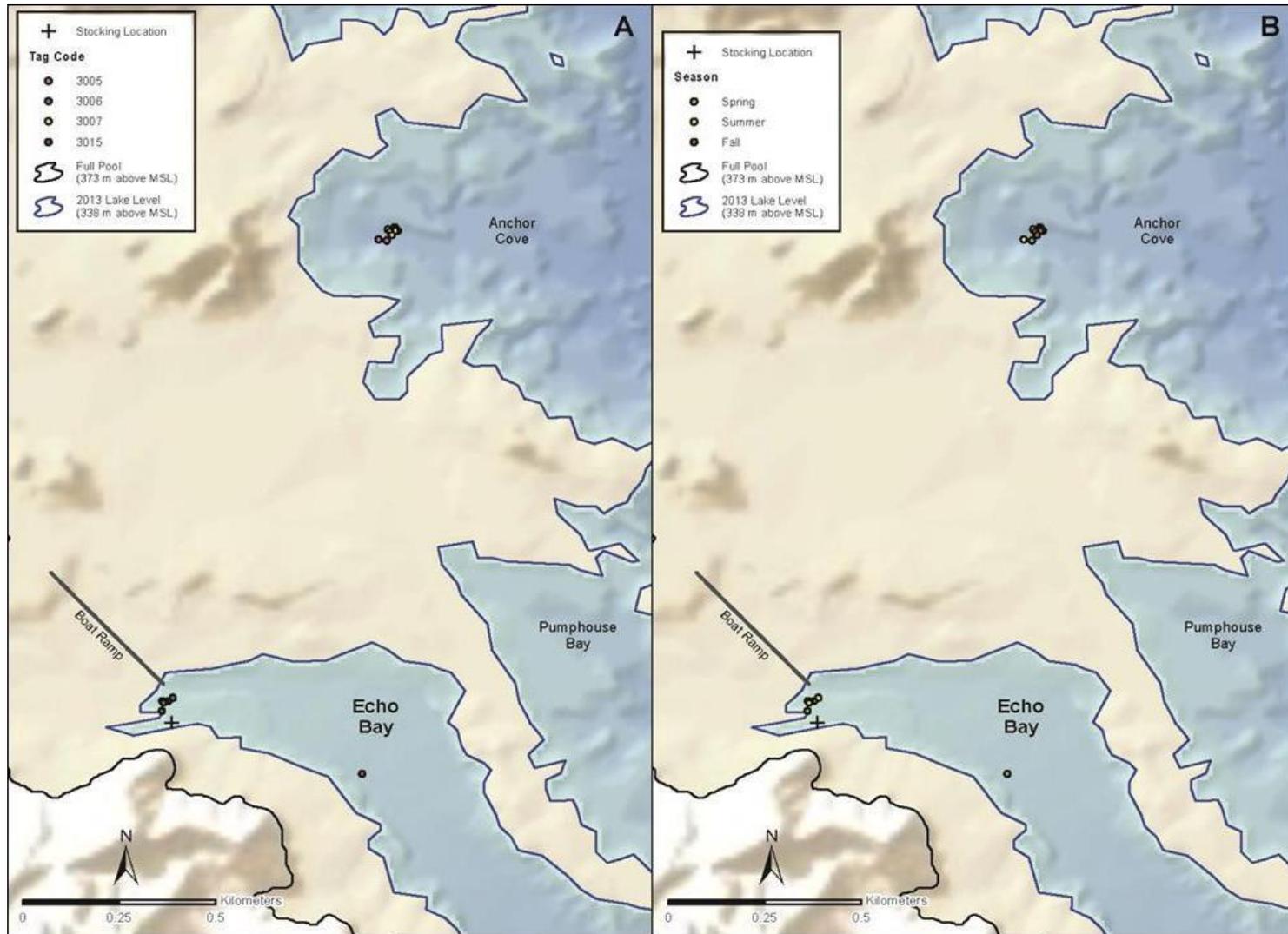


Figure 5.—Distribution of sonic-tagged, juvenile razorback suckers located through active sonic telemetry and designated by individual code (A) and by season (B) in Echo Bay, May 8 – December 20, 2013.

Sonic Telemetry and Habitat Use of Juvenile Razorback Suckers in Lake Mead, 2013–2014 Annual Report

Las Vegas Bay and was contacted in shallow habitat adjacent to dense IV for much of the spring and summer (May 8 – July 23, 2013) (see figure 5). Depth at point of contact for individuals located in spring averaged 10.4 m (± 3.6 SE), and although contact locations during summer did not vary greatly, average depths increased (13.0 m [± 3.4 SE]). However, as summer progressed into fall, sonic-tagged, juvenile razorback suckers stocked into Echo Bay were contacted entirely in Anchor Cove at depths that averaged 22.3 m (± 0.1 SE) (see figure 5).

At the Virgin River/Muddy River inflow area, all 6 individuals initially stocked were located for a total of 34 contacts during 2013 (figure 6). As seen for individuals in Las Vegas Bay and Echo Bay, sonic-tagged, juvenile razorback suckers at the Virgin River/Muddy River inflow area exhibited a strong association with shallow habitat with dense IV and were often found near the Virgin River inflow at the northernmost area of the Overton Arm (figure 6). During spring, individuals were contacted in habitat that had an average depth of 3.2 m (± 1.0 SE), and groups of sonic-tagged juveniles near one another were not uncommon within the vast expanse of inundated saltcedar common to this area. As spring progressed into summer, individuals at the Virgin River/Muddy River inflow area moved further south into the Overton Arm and appeared to be seeking deeper habitat, similar to the pattern of sonic-tagged juveniles in Las Vegas Bay and Echo Bay. However, throughout summer, sonic-tagged juveniles were contacted in areas that had similar average depths to those recorded during spring (3.3 m [± 0.8 SE]). This shift in location without a noticeable shift in average depth could be due in part to the greater scale of the Overton Arm and the relatively flat bathymetry of the area (figure 6). Although exhaustive sonic surveillance was conducted throughout the Overton Arm using both the directional and omnidirectional hydrophones, no additional contacts were made with sonic-tagged, juvenile razorback suckers at the Virgin River/Muddy River inflow area during fall, and no additional individuals from the Echo Bay cohort were located.

Study sites within Lake Mead (i.e., Las Vegas Bay, Echo Bay, and the Virgin River/Muddy River inflow area) have often been similarly characterized with regard to seasonal movement patterns of adult razorback suckers (Shattuck et al. 2011; Albrecht et al. 2013a, 2013b). Comparably, sonic-tagged, juvenile razorback suckers appeared to exhibit a seasonal pattern of movement that was consistent lake-wide. The depth at point of contact for sonic-tagged, juvenile razorback suckers significantly increased with time (least-squares regression, $R^2 = 0.34$, $F_{1,95} = 49.01$, $P < 0.001$) where individuals were contacted in shallower habitat during spring and early summer before moving into deeper habitat through late summer and fall (figure 7). In observing this transition, individuals typically moved 0.2–0.5 kilometer (km) into deeper habitat in Las Vegas Bay, 0.0–0.1 km in Echo Bay, and anywhere from 0.1 km to greater than 3.0 km at the Virgin River/Muddy River inflow area (figures 4–6).

Sonic Telemetry and Habitat Use of Juvenile Razorback Suckers
in Lake Mead, 2013–2014 Annual Report

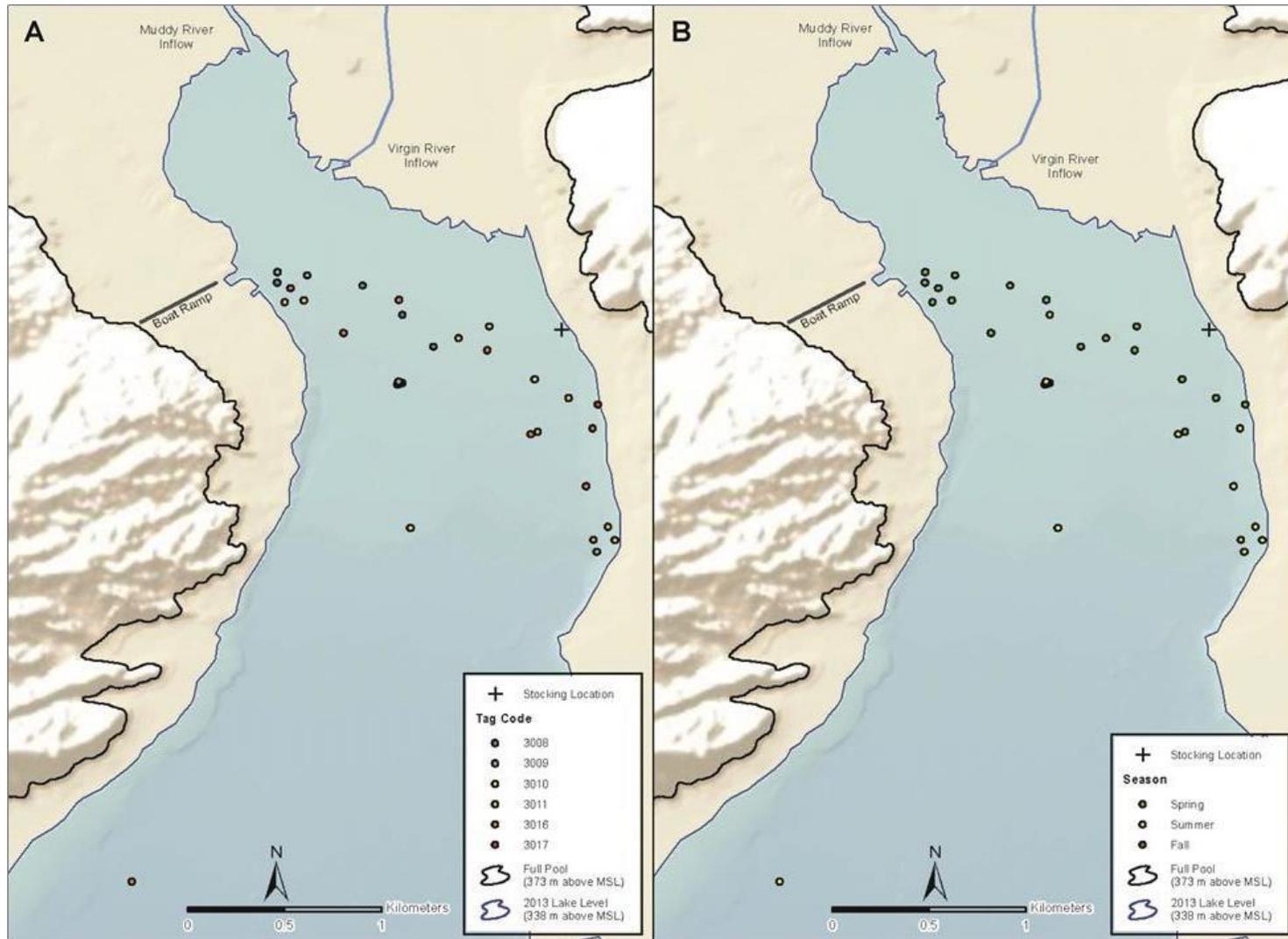


Figure 6.—Distribution of sonic-tagged, juvenile razorback suckers located through active sonic telemetry and designated by individual code (A) and by season (B) in the Virgin River/Muddy River inflow area, May 8 – December 20, 2013.

**Sonic Telemetry and Habitat Use of Juvenile Razorback Suckers
in Lake Mead, 2013–2014 Annual Report**

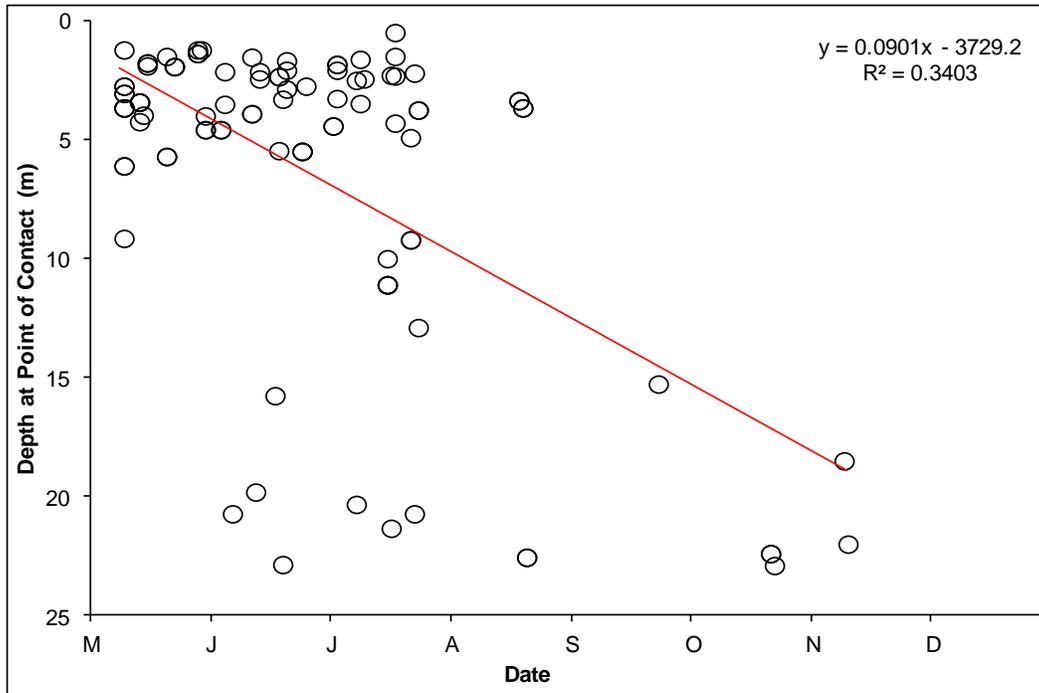


Figure 7.—Depth (m) at point of contact for all sonic-tagged, juvenile razorback suckers in Lake Mead (i.e., Las Vegas Bay, Echo Bay, and the Virgin River/Muddy River inflow area) plotted over time (May 8 – December 20, 2013) and fitted with an unweighted least-squares linear regression ($R^2 = 0.34$, $F_{1,95} = 49.01$, $P < 0.001$).

Though dense IV often made contact with sonic-tagged, juvenile razorback suckers more difficult throughout the study sites, exhaustive efforts were spent targeting this specific cover type; thus, sonic signal oversight during manual sonic tracking was not thought to be likely. However, due to the relatively cryptic nature of the juvenile life stage of razorback suckers—and due to the immensity of Lake Mead—numerous SURs were systematically deployed to aid in sonic telemetry surveillance. As sonic-tagged, juvenile razorback suckers began to exhibit movement from shallower habitat near inflow areas into deeper habitat further out into the bays, it was hoped that any movement beyond the confines of the study sites would be monitored and recorded.

From the 11 SURs deployed throughout Lake Mead, 4 units contacted 4 sonic-tagged, juvenile individuals for a total of 1,988 passive contacts during May 8 – December 20, 2013 (see table 1). In Las Vegas Bay, two individuals (codes 3001 and 3003) were contacted by both of the SURs stationed at the constriction point near Sand Island at the southeastern extent of Las Vegas Bay (Las Vegas Bay-West and Las Vegas Bay-East) (see figure 1). Furthermore, the Las Vegas Bay-West SUR successfully documented the last known location of one individual (code 3001) on September 13, 2013, likely as the individual was moving out of Las Vegas Bay proper, as it was not contacted again in subsequent AHS sampling (see table 1). Though SURs near Echo Bay and throughout the Overton Arm did

not contact any sonic-tagged, juvenile razorback suckers during 2013, two SURs stationed at the northernmost extent of the Overton Arm (Virgin River/Muddy River inflow-North and Virgin River/Muddy River inflow-East) contacted two individuals (see table 1). During July, two individuals (codes 3011 and 3016) were contacted by both SURs that were deployed in an expanse of IV near the Virgin River inflow, and time-stamps produced by the SURs showed that individuals would move further south and contact the Virgin River/Muddy River inflow-East SUR during crepuscular hours (i.e., dawn, dusk). Following contacts through the night, both of these individuals (codes 3011 and 3016) exhibited a pattern of northern movement back into the dense expanse of IV where they were contacted by the Virgin River/Muddy River inflow-North SUR throughout daylight hours. While these diel movements were only observed over a period of 4 days and for only two individuals, they appeared to be relatively consistent, perhaps indicating that sonic-tagged, juvenile razorback suckers exhibit direct movements to avoid or seek out some diel-fluctuating biological or environmental mechanism(s).

Conspecific and Community Sampling

From May 8 through July 26, 2013, 2 fyke nets, 54 hoop nets, 30 minnow traps, 69 trammel nets, and 3 seine hauls were used to capture a total of 687 fish of 13 species during ICS sampling conducted in direct association with sonic-tagged, juvenile razorback suckers (table 2). Additionally, boat electrofishing was conducted in the Virgin River/Muddy River inflow area and Echo Bay for a total of 2,347 seconds (table 2). Habitat conditions often made the use of fyke nets and seine hauls infeasible, and therefore, those gears were not employed as often as trammel nets, hoop nets, and minnow traps. Furthermore, as sonic-tagged, juvenile individuals moved from shallower habitat into deeper habitat, gears better suited for lesser depths (i.e., hoop nets and minnow traps) were used less often. Immediately following the initial stocking of sonic-tagged, juvenile razorback suckers on May 8, 2013, 11 contacts were made; however, no fish sampling or habitat characterization was conducted. It was assumed that these individuals had not yet settled into a more normalized pattern of behavior, and therefore, any sampling associated with these individuals might not be entirely representative of this life stage. Additionally, due to the potential for mortalities of razorback suckers from handling stress in adverse environmental conditions, limited fish sampling was conducted during higher water temperatures ($> 25^{\circ}\text{C}$) associated with sonic-tagged, juvenile razorback suckers contacted in relatively shallow water ($< 3\text{ m}$) during July 9 and July 17–18, 2013.

Among the 687 fishes captured during the ICS period, 4 wild razorback suckers were captured in trammel netting efforts in Las Vegas Bay on June 11 ($n = 1$), June 18, 2013 ($n = 2$), and July 16, 2013 ($n = 1$) (table 3 and figure 8). No additional razorback suckers were captured at any of the other study sites

**Sonic Telemetry and Habitat Use of Juvenile Razorback Suckers
in Lake Mead, 2013–2014 Annual Report**

Table 2.—Summary of effort expended by study location, gear type, and the subsequent fishes captured during the ICS period at Lake Mead (i.e., Las Vegas Bay, Echo Bay, and the Virgin River/Muddy River inflow area), May 8 – July 26, 2013

Sampling location ^a	Effort by gear ^b						Fish species ^c													
	Fyke nets	Hoop nets	Minnow traps	Trammel nets	Seine hauls	Boat electrofishing	RZ	GZ	TS	RS	CP	BB	CC	SC	SB	BG	SM	LB	BC	Total
LB	1	11	5	33	0	0	4	76	2	0	41	0	26	1	9	36	1	36	0	232
EB	1	2	2	14	3	1 (1,241 s)	0	57	0	0	35	1	16	0	8	56	2	22	0	197
OA	0	41	23	22	0	1 (1,106 s)	0	110	6	6	32	4	19	0	9	41	0	27	4	258
Total	2	54	30	69	3	2 (2,347 s)	4	243	8	6	108	5	61	1	26	133	3	85	4	687

^a LB = Las Vegas Bay, EB = Echo Bay, and OA = Virgin River/Muddy River inflow area of the Overton Arm.

^b Gears are listed as the number of nets/traps set or hauled with the exception of boat electrofishing (number of samples [s = seconds sampled]).

^c Fish species abbreviations: RZ = razorback sucker, GZ = gizzard shad, TS = threadfin shad, RS = red shiner, CP = common carp, BB = black bullhead, CC = channel catfish, SC = vermiculated sailfin catfish, SB = striped bass, BG = bluegill, SM = smallmouth bass, LB = largemouth bass, and BC = black crappie.

Table 3.—Summary of location, size information, and recapture status for razorback suckers captured during the ICS period in direct association with sonic-tagged, juvenile razorback suckers in Lake Mead (i.e., Las Vegas Bay, Echo Bay, and the Virgin River/Muddy River inflow area), May 8 – July 26, 2013

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
6/11/2013	LB	384.1B7969E6B3	–	6/11/2013	NO	561	535	491	2,034	U	12
6/18/2013	LB	384.1B7969EE04	–	6/18/2013	NO	532	495	455	1692	U	8
6/18/2013	LB	384.1B7969E345	–	6/18/2013	NO	521	480	453	1786	U	7
7/16/2013	LB	3DD.003BA2FA6E ^e	–	7/16/2013	NO	530	505	490	1710	U	–

^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 A fin clip was not taken for aging purposes to avoid undue stress to the individual during adverse environmental conditions.

during the ICS period (figure 8); however, numerous nonnative fishes were captured throughout the study sites with a number of different gear types (figure 8).

In comparing CPUEs, it appeared that the most effective method of sampling involved using trammel nets and, when possible, seines (figure 8). Trammel nets were effective in capturing larger-bodied fishes, with mean catch rates for nonnative fishes ranging from 0.060 (SE = 0.008) to 0.096 (SE = 0.032) fish per minute, nearly an order of magnitude greater than the mean catch rates for

**Sonic Telemetry and Habitat Use of Juvenile Razorback Suckers
in Lake Mead, 2013–2014 Annual Report**

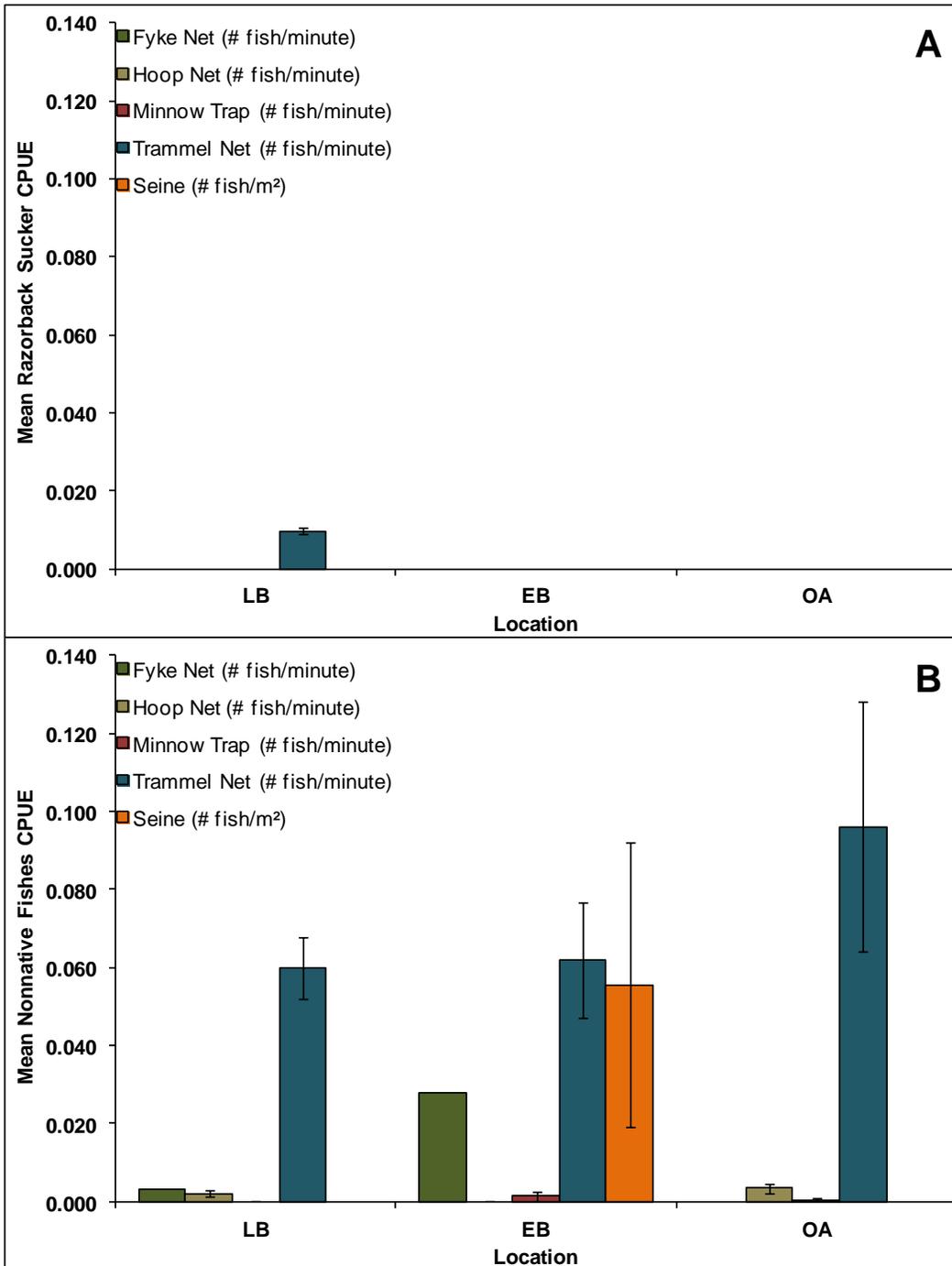


Figure 8.—Mean CPUE values with SE by study site and gear type for razorback suckers (A) and the grouped nonnative fishes (B) captured during ICS in direct association with sonic-tagged, juvenile razorback suckers in Lake Mead (i.e., Las Vegas Bay, Echo Bay, and the Virgin River/Muddy River inflow area), May 8 – July 26, 2013.

Sonic Telemetry and Habitat Use of Juvenile Razorback Suckers in Lake Mead, 2013–2014 Annual Report

razorback suckers (0.010 [SE = 0.001]) (see figure 8). Although seining efforts appeared to be effective in Echo Bay (0.056 [SE = 0.036] fish per m²), their use was limited lake-wide due to the lack of wadable, obstruction-free habitat in areas that sonic-tagged, juvenile individuals were associating with (see figure 8). Furthermore, because trammel nets required a greater degree of open water, smaller gear, such as hoop nets and minnow traps, were relied on more frequently when sonic-tagged, juvenile individuals were contacted in shallower habitat with dense IV. Often, these types of gear captured smaller-bodied fish, but their overall effectiveness appeared to be lower. Mean catch rates for nonnative fishes ranged from 0.002 (SE = 0.001) to 0.003 (SE = 0.001) fish per minute in hoop nets from Las Vegas Bay and the Virgin River/Muddy River inflow area, and mean catch rates for nonnative fishes ranged from 0.0014 (SE = 0.0014) to 0.0004 (SE = 0.0004) fish per minute in minnow traps from Echo Bay and the Virgin River/Muddy River inflow area. No fish were captured in hoop nets at Echo Bay or in minnow traps at Las Vegas Bay (see figure 8). Though boat electrofishing was only used on a somewhat exploratory level due to difficulties in effectively sampling habitat, catch rates were relatively high nonetheless; 1 sample produced 0.524 fish per minute in Echo Bay and another sample produced 1.737 fish per minute at the Virgin River/Muddy River inflow area.

Although catch rates were low in comparison to nonnative fishes, for the second consecutive year, razorback suckers were captured in direct association with sonic-tagged, juvenile razorback suckers in Las Vegas Bay (Albrecht et al. 2013a). The razorback suckers captured in 2013 were new, wild individuals that had not been PIT tagged previously, and they ranged in size from 521 to 561 mm TL (see table 3). All captured individuals were of undetermined sex, and fin clips from three of the four individuals were obtained for aging purposes (see table 3). Although these captured razorback suckers were larger and older than the sonic-tagged juveniles they were associated with, it was interesting to note that 1–2 sonic-tagged juveniles (codes 3001, 3003, and 3013) were nearby each time these larger fish were captured (see table 3). Captures of the new, wild razorback suckers were made near the mouth of Gypsum Wash Cove following the historic Las Vegas Wash channel east through the middle of Las Vegas Bay at depths ranging from 2.3 to 10.0 m (table 3 and figure 9).

Fish sampling efforts in Las Vegas Bay during the ICS period resulted in the capture of a total of 232 fish from 9 species (see table 2). Species that comprised the largest portions of fishes captured were gizzard shad (*Dorosoma cepedianum*) – 33%, common carp (*Cyprinus carpio*) – 18%, bluegill (*Lepomis macrochirus*) – 16%, and largemouth bass (*Micropterus salmoides*) – 16%; with razorback suckers comprising 2% of the total fishes captured (see table 2). Trammel nets were the gear used most often (n = 33); however, as sonic-tagged, juvenile razorback suckers associated with habitat characterized by dense IV, a number of hoop nets (n = 11), minnow traps (n = 5), and 1 fyke net were employed (see table 2).

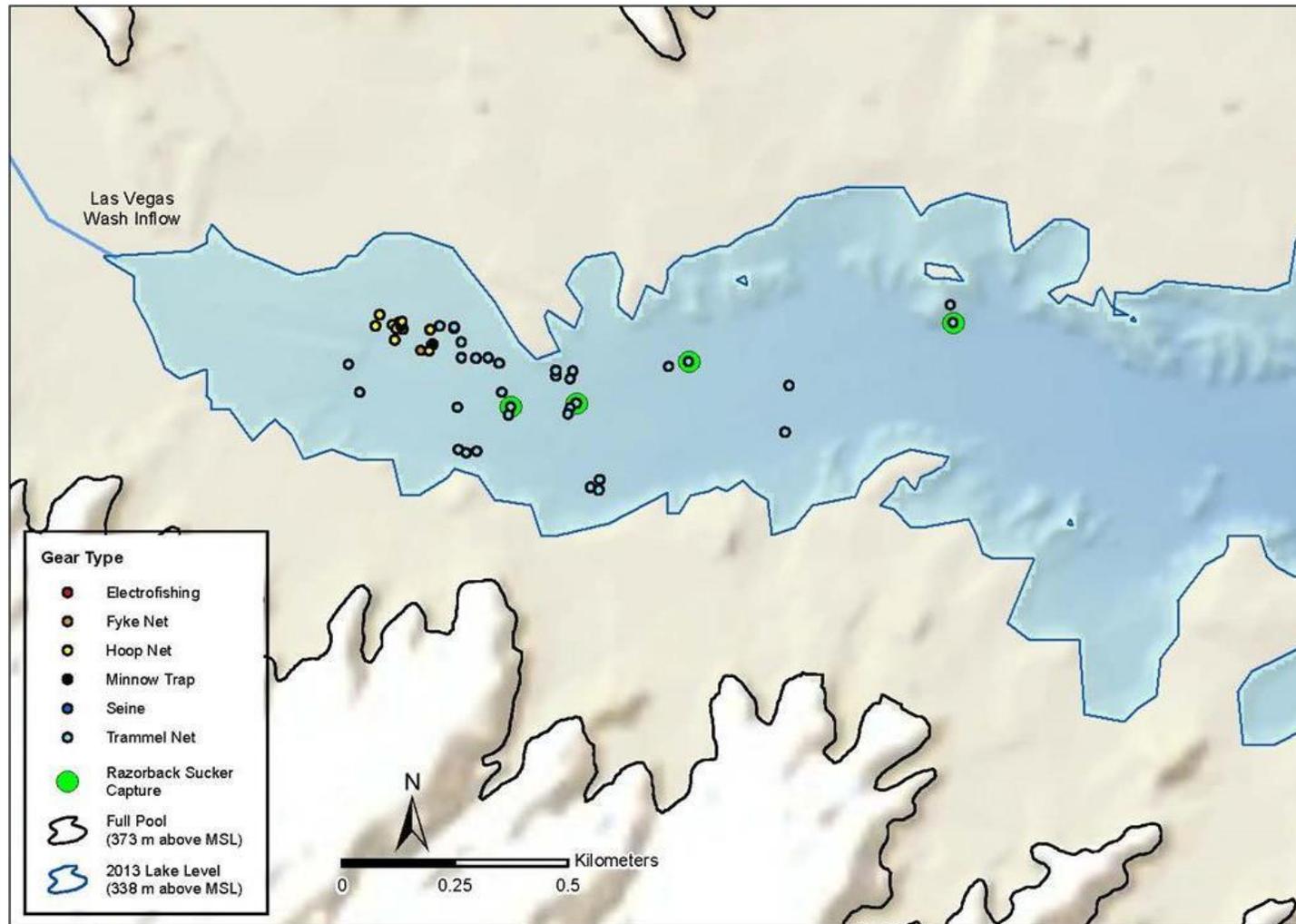


Figure 9.—Locations of fish sampling efforts during the ICS period in direct association with sonic-tagged, juvenile razorback suckers in Las Vegas Bay, May 8 – July 26, 2013.

Sonic Telemetry and Habitat Use of Juvenile Razorback Suckers in Lake Mead, 2013–2014 Annual Report

During spring, sonic-tagged, juvenile razorback suckers were often contacted in shallow littoral habitats with dense IV and LWD near the Las Vegas Wash inflow (see figure 9). Not surprisingly, the fish community in this area, and during this time period, was dominated by the generalist species gizzard shad (with 53 individuals ranging in size from 250 to 541 mm TL) as well as numerous common carp (47–190 mm TL [n = 30]). Furthermore, with ample amounts of inundated cover near the Las Vegas Wash inflow, the lie-and-wait predators bluegill (47–190 mm TL [n = 36]), largemouth bass (205–430 mm TL [n = 35]), and channel catfish (*Ictalurus punctatus*) (230–650 mm TL [n = 23]) were also abundant (see table 2; figures 9 and 10). Though few in overall number, razorback suckers (521–561 mm TL [n = 3]) were most abundantly captured during spring in Las Vegas Bay. At this time, they were some of the largest fish captured, perhaps associating with smaller fishes to avoid predation (figure 10). Additionally, a large (477 mm TL) vermiculated sailfin catfish (*Pterygoplichthys disjunctivus*) was captured, adding to the diverse nonnative fish community (see table 2; figure 10). As spring progressed into summer, sonic-tagged, juvenile razorback suckers moved into deeper habitat in Las Vegas Bay and were often located in open water areas without noticeable complex cover (see figure 9). The fish community associated with the locations of sonic-tagged, juvenile individuals, though similar to that in spring, was characterized by fewer, but typically larger, fish with the addition of more pelagic-type species (e.g., striped bass [*Morone saxatilis*]) and an additional razorback sucker (530 mm TL) (figure 10). The most abundant species was again gizzard shad (225–350 mm TL [n = 23]), followed by common carp (485–655 mm TL [n = 11]); however, no bluegill were captured, and fewer lie-and-wait type predators were collected (one largemouth bass [255 mm TL] and one smallmouth bass [*Micropterus dolomieu*] – 260 mm TL) (figure 10). Additionally, fewer predators such as channel catfish (225–350 mm TL [n = 3]) and striped bass (420–475 mm TL [n = 2]) were captured during summer (figure 10).

Fish sampling efforts in Echo Bay during the ICS period resulted in the capture of a total of 197 fish from 8 species, the least numerous and least speciose of the study sites (see table 2). Species that comprised the largest portions of fishes captured during spring in Echo Bay were similar to those in Las Vegas Bay, where the fish community was dominated by gizzard shad (29%) and bluegill (28%), while common carp (18%) and largemouth bass (11%) remained relatively abundant (see table 2). Trammel nets were used most often (n = 14), although, due to the initial difficulties experienced in locating sonic-tagged juveniles, less fish sampling was conducted (see tables 1 and 2). Furthermore, habitat sonic-tagged, juvenile razorback suckers associated with Echo Bay allowed for most every gear type to be used, including seines (see table 2). Like Las Vegas Bay, sonic-tagged, juvenile razorback suckers associated with habitat characterized by dense IV and shallower depths near littoral habitat during spring; however, due to the smaller scale of Echo Bay, fewer shallow water gears were set (i.e., fyke nets [n = 1], hoop nets [n = 2], and minnow traps [n = 2]) (see table 2; figure 11).

**Sonic Telemetry and Habitat Use of Juvenile Razorback Suckers
in Lake Mead, 2013–2014 Annual Report**

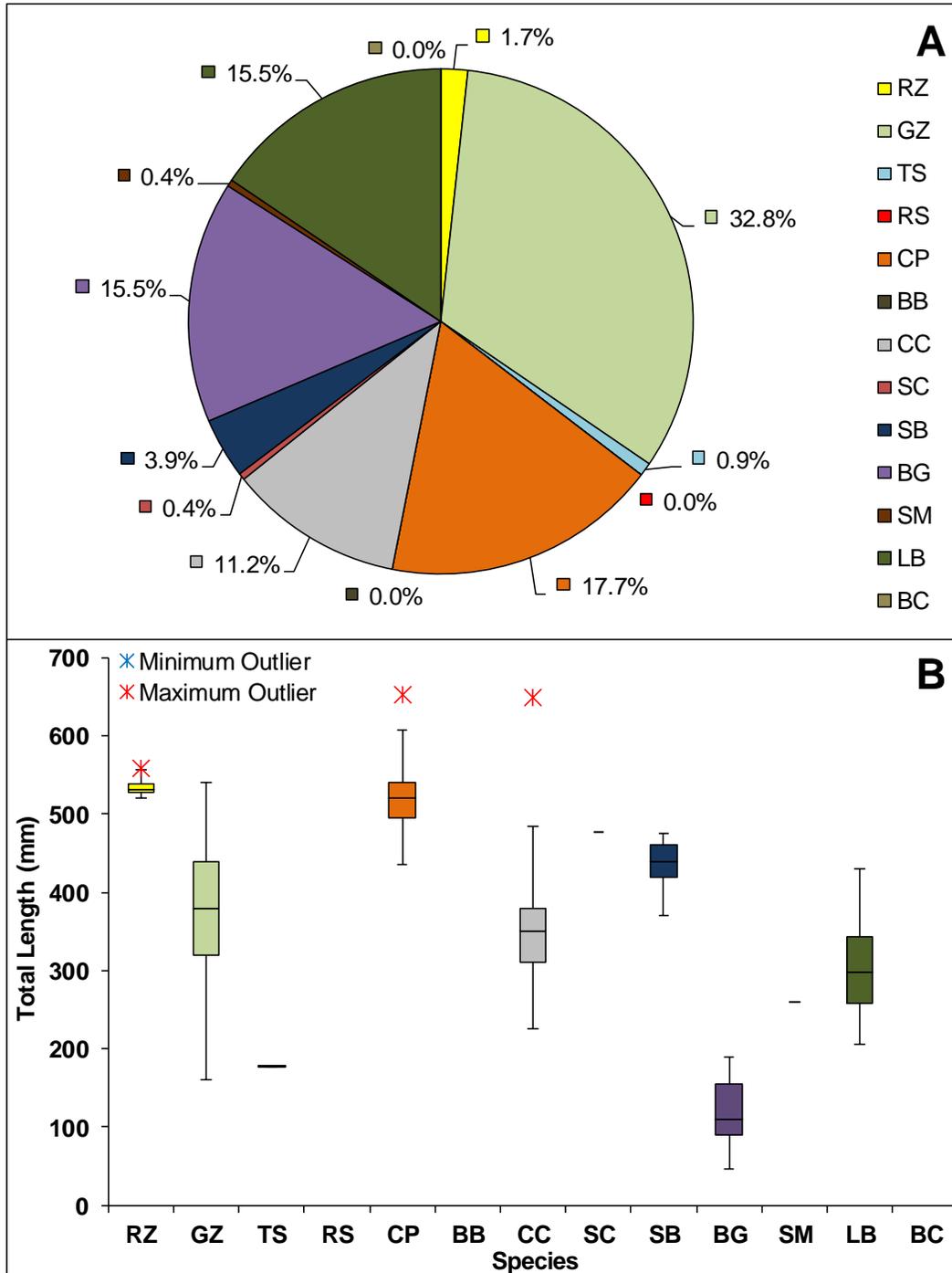


Figure 10.—Fish community composition by species (A), expressed as percentages of the mean CPUE values for all gear types combined, and TL box plots for species captured in the combined gear types (B) with associated medians, upper and lower quartiles, upper and lower whiskers, and denoted outliers for fishes captured during the ICS period in direct association with sonic-tagged, juvenile razorback suckers in Las Vegas Bay, May 8 – July 26, 2013.

**Sonic Telemetry and Habitat Use of Juvenile Razorback Suckers
in Lake Mead, 2013–2014 Annual Report**

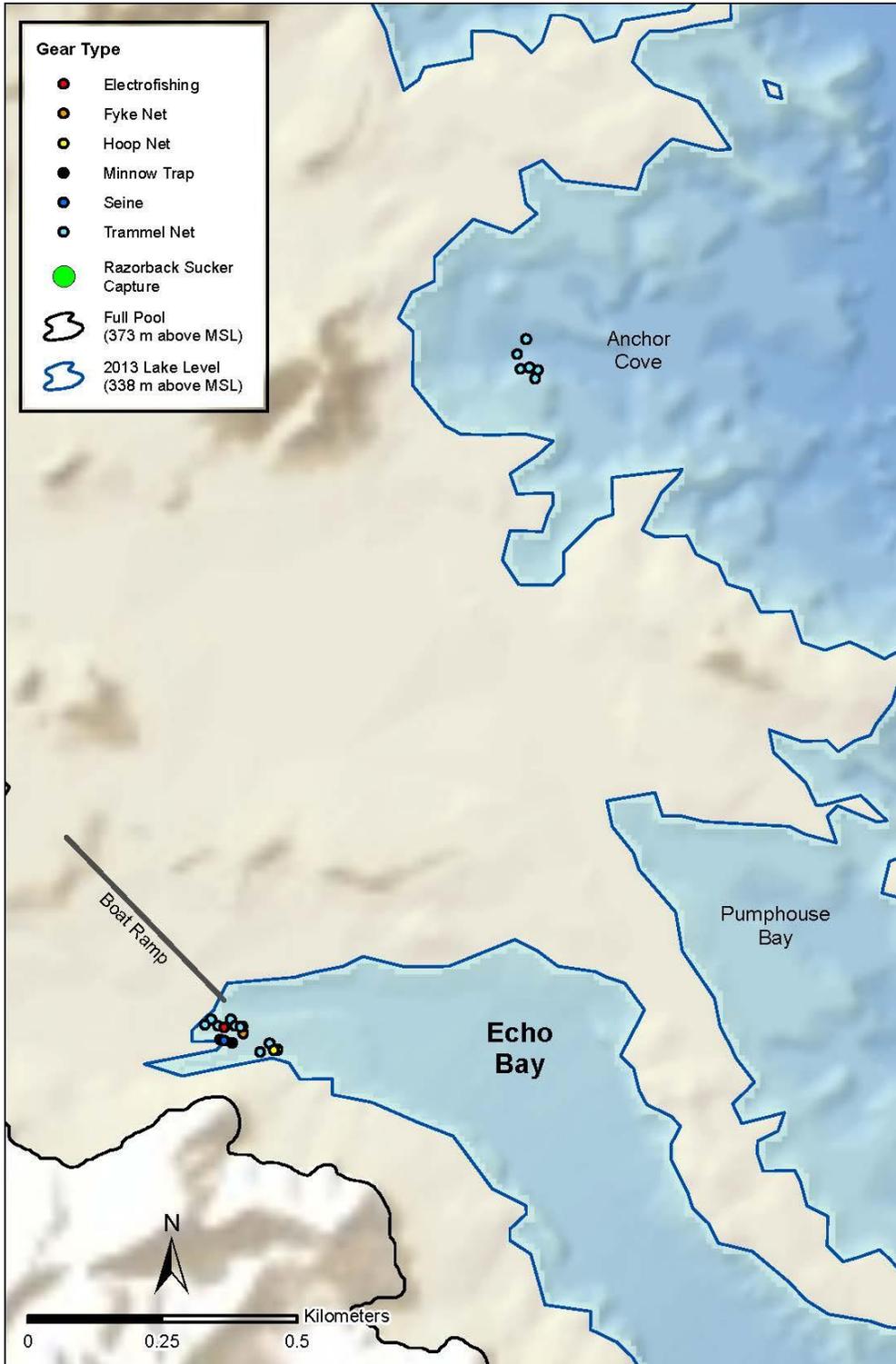


Figure 11.—Locations of fish sampling efforts during the ICS period in direct association with sonic-tagged, juvenile razorback suckers in Echo Bay, May 8 – July 26, 2013.

Sonic Telemetry and Habitat Use of Juvenile Razorback Suckers in Lake Mead, 2013–2014 Annual Report

The fish community in Echo Bay during spring was dominated by gizzard shad (285–488 mm TL [n = 53]) and bluegill (43–250 mm TL [n = 50]), as sonic-tagged, juvenile razorback suckers remained near shallow habitat and stands of IV (figures 11 and 12). Larger-bodied fishes appeared to be more common in Echo Bay, with common carp (434–580 mm TL [n = 23]), largemouth bass (24–444 mm TL [n = 18]), and striped bass (230–482 mm TL [n = 8]) present throughout spring; however, no razorback suckers were captured in Echo Bay (figure 12). Interestingly, regular contacts were made with one sonic-tagged, juvenile razorback sucker in the western extent of Echo Bay throughout spring; during summer, that individual and two others appeared in Anchor Cove (see figure 11). Following a habitat use pattern similar to that seen in Las Vegas Bay, sonic-tagged, juvenile razorback suckers moved into deeper habitat in Anchor Cove during summer and were regularly contacted in open water areas without noticeable cover (see figure 11). The fish community associated with the locations of sonic-tagged, juvenile individuals was characterized by larger fish, of which the most abundant species were common carp (450–565 mm TL [n = 12]) and channel catfish (60–425 mm TL [n = 9]) (figure 12). Although gizzard shad (320–390 mm TL [n = 4]), bluegill (73–205 mm TL [n = 7]), and largemouth bass (60–445 mm TL [n = 4]) were still regularly captured throughout summer, fewer individuals were collected perhaps due in part to a lack of inundated cover (figure 12).

Fish sampling efforts at the Virgin River/Muddy River inflow area during the ICS period resulted in the capture of a total of 258 fish from 10 species, the most numerous and most speciose of the study sites (see table 2). Following a pattern seen in both Las Vegas Bay and Echo Bay, gizzard shad comprised the largest portion (43%) of fishes captured at the Virgin River/Muddy River inflow area (see table 2). Similarly, bluegill (16%), common carp (12%), and largemouth bass (10%) were also abundant. No razorback suckers were captured (see table 2). As much of the northern extent of the Overton Arm included a vast expanse of IV, the most common gears used at the Virgin River/Muddy River inflow area were hoop nets (n = 22) and minnow traps (n = 23) (see table 2; figure 13). Trammel nets were still used frequently (n = 22), although conditions favored smaller gear types, as sonic-tagged, juvenile razorback suckers remained deep within IV for much of spring and early summer (figure 13).

Nowhere else did sonic-tagged, juvenile razorback suckers associate with habitat characterized by dense IV to the extent observed at the Virgin River/Muddy River inflow area (figure 13). During spring, sonic-tagged, juvenile razorback suckers were primarily contacted in shallow littoral habitats with dense IV near the Virgin River inflow (figure 13). As such, the fish community reflected the available habitat that sonic-tagged, juvenile razorback suckers were associating with. Gizzard shad (210–405 mm TL [n = 68]) and common carp (440–690 mm TL [n = 27]) were the most abundant species and some of the larger fish captured during spring (figure 14). Furthermore, with vast stands of IV near the Virgin River inflow, bluegill (35–131 mm TL [n = 14]) and largemouth bass

**Sonic Telemetry and Habitat Use of Juvenile Razorback Suckers
in Lake Mead, 2013–2014 Annual Report**

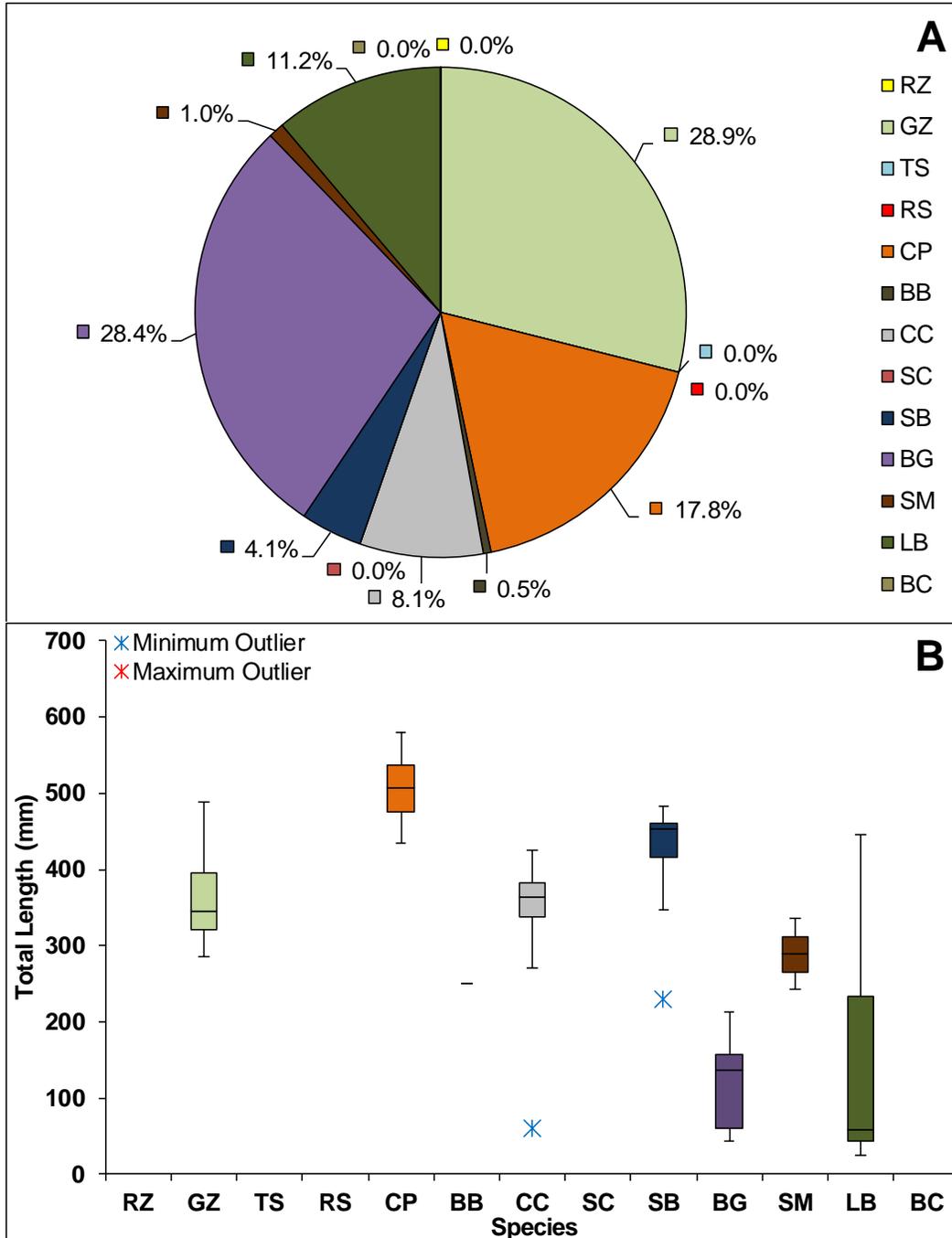


Figure 12.—Fish community composition by species (A), expressed as percentages of the mean CPUE values for all gear types combined, and TL box plots for species captured in the combined gear types (B) with associated medians, upper and lower quartiles, upper and lower whiskers, and denoted outliers for fishes captured during the ICS period in direct association with sonic-tagged, juvenile razorback suckers in Echo Bay, May 8 – July 26, 2013.

Sonic Telemetry and Habitat Use of Juvenile Razorback Suckers
in Lake Mead, 2013–2014 Annual Report

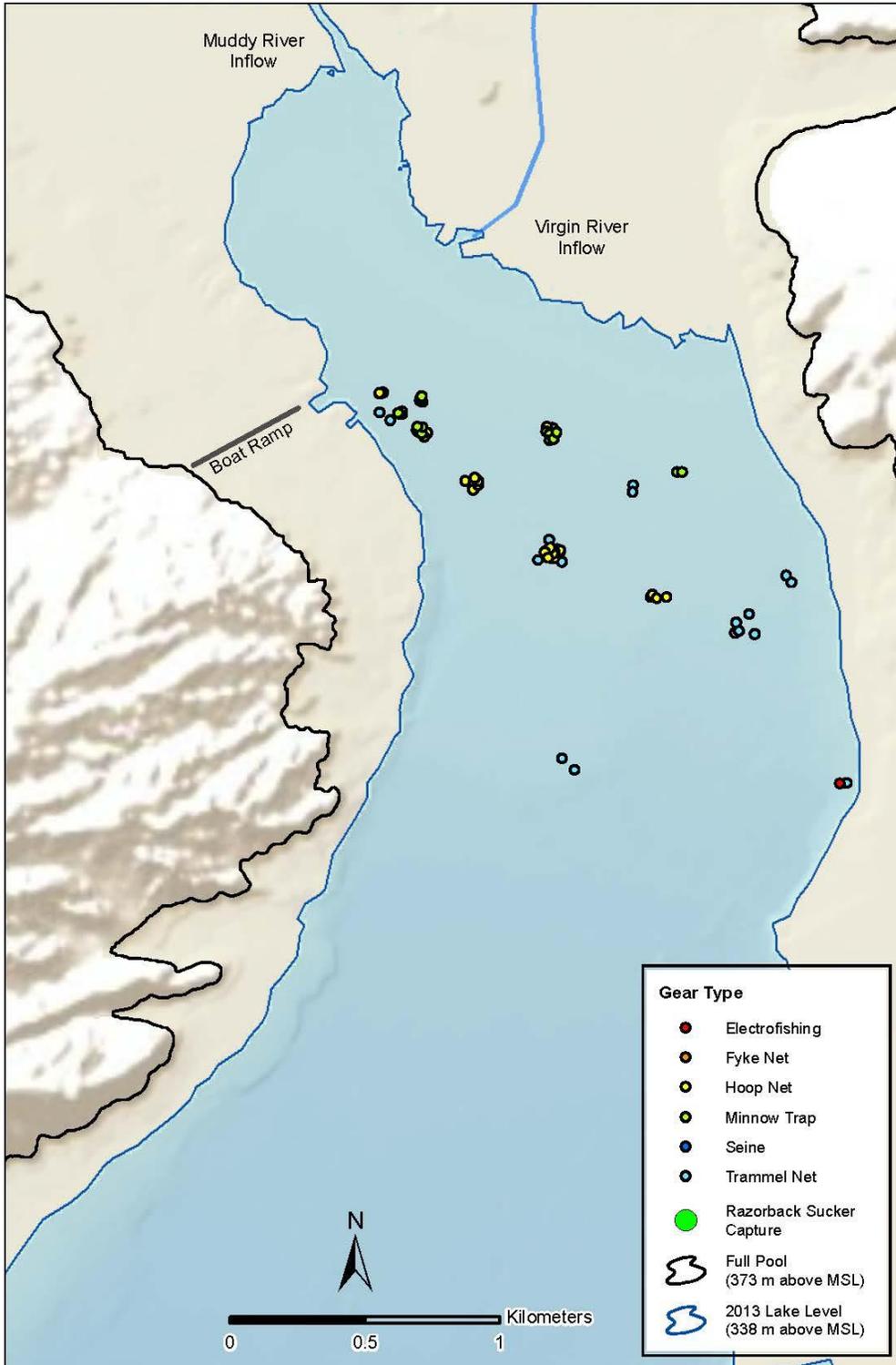


Figure 13.—Locations of fish sampling efforts during the ICS period in direct association with sonic-tagged, juvenile razorback suckers at the Virgin River/ Muddy River inflow area, May 8 – July 26, 2013.

**Sonic Telemetry and Habitat Use of Juvenile Razorback Suckers
in Lake Mead, 2013–2014 Annual Report**

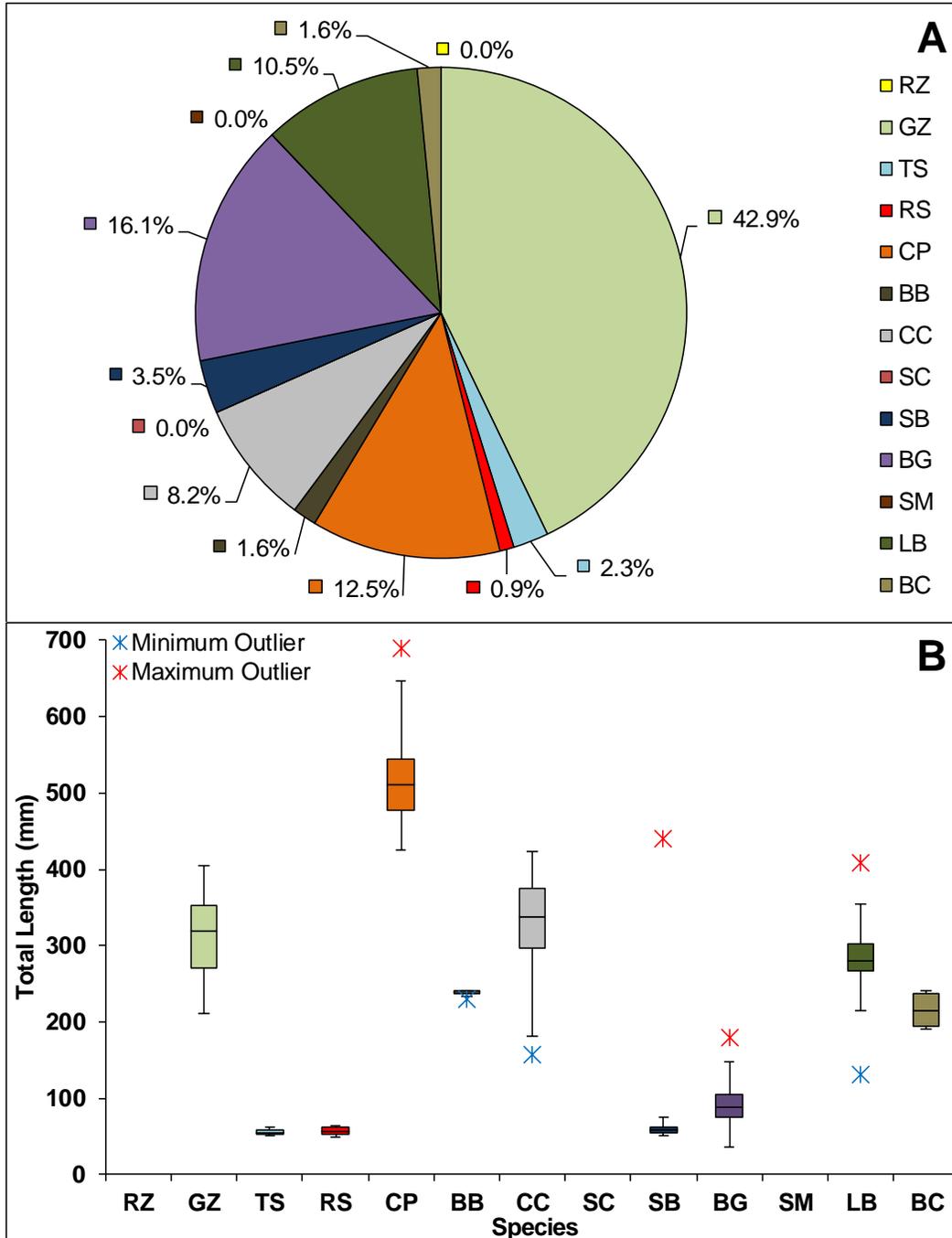


Figure 14.—Fish community composition by species (A), expressed as percentages of the mean CPUE values for all gear types combined, and TL box plots for species captured in the combined gear types (B) with associated medians, upper and lower quartiles, upper and lower whiskers, and denoted outliers for fishes captured during the ICS period in direct association with sonic-tagged, juvenile razorback suckers at the Virgin River/Muddy River inflow area, May – July 26, 2013.

**Sonic Telemetry and Habitat Use of Juvenile Razorback Suckers
in Lake Mead, 2013–2014 Annual Report**

(276–409 mm TL [n = 10]) were relatively abundant. Additionally, likely due to the proximity to the Virgin River, red shiner (*Cyprinella lutrensis*) (48–64 mm TL [n = 6]) were captured.

Although numerous contacts were made with a number of sonic-tagged, juvenile razorback suckers in somewhat confined habitat, no razorback suckers were captured at the Virgin River/Muddy River inflow area (see figures 13 and 14). Sonic-tagged, juvenile razorback suckers remained in the northernmost portion of the Overton Arm through spring and well into summer despite a quickly declining lake elevation and warming summer temperatures. While sonic-tagged, juvenile individuals eventually moved into deeper habitat toward the Meadows area of the Overton Arm, numerous contacts were made among the vast stands of IV near the Virgin River inflow through much of summer (see figure 13). As sonic-tagged juveniles moved further south, the habitat these individuals associated with did not appear to be drastically different from the habitat they associated with in spring, with the exception of greater summer depths. The fish community associated with the locations of sonic-tagged, juvenile individuals during summer at the Virgin River/Muddy River inflow area was similar to the spring community. Gizzard shad (260–400 mm TL [n = 42]) were the most abundant species, and there was an abundance of the lie-and-wait predators – bluegill (35–180 mm TL [n = 27]) and largemouth bass (130–310 mm TL [n = 17]) (see figure 14). Channel catfish (157–400 mm TL [n = 11]) were also abundant, but surprisingly common carp (425–490 mm TL [n = 5]) were not as abundant here as they were at other study sites during summer (see figure 14).

In testing for differences in TLs of the most abundant fish species by study sites (i.e., gizzard shad, bluegill, common carp, largemouth bass, channel catfish, and striped bass), half of these six species were not significantly different among Las Vegas Bay, Echo Bay, and the Virgin River/Muddy River inflow area. Gizzard shad were significantly different in TL between study sites (ANOVA, $F_{2,142} = 7.4$, $P < 0.001$); post-hoc comparison found that the Virgin River/Muddy River inflow area had uniquely smaller individuals ($\bar{x} = 311.0$ [SE = 7.5]) compared to Las Vegas Bay ($\bar{x} = 364.4$ [SE = 11.3]) and Echo Bay ($\bar{x} = 356.5$ [SE = 9.0]). Similarly, striped bass were significantly different in TL (ANOVA, $F_{2,20} = 23.2$, $P < 0.001$), and post-hoc comparison again found that the Virgin River/Muddy River inflow area had uniquely smaller individuals ($\bar{x} = 120.7$ [SE = 38.6]). Finally, a significant difference was detected in TL of largemouth bass by study site (ANOVA, $F_{2,82} = 20.3$, $P < 0.001$), and Echo Bay had significantly smaller individuals ($\bar{x} = 157.4$ [SE = 29.3]) in post-hoc comparison compared with Las Vegas Bay ($\bar{x} = 305.8$ [SE = 10.5]) and the Virgin River/Muddy River inflow area ($\bar{x} = 279.6$ [SE = 10.3]).

Among the lumped study sites (i.e., Las Vegas Bay, Echo Bay, and the Virgin River/Muddy River inflow area), TLs of abundant fish species that have been shown to predate upon razorback suckers (e.g., channel catfish [Marsh and Brooks 1989], striped bass [Karam and Marsh 2010], smallmouth bass [Minckley

Sonic Telemetry and Habitat Use of Juvenile Razorback Suckers in Lake Mead, 2013–2014 Annual Report

1983], and largemouth bass [Mueller 1995]) were compared with the TLs of new, wild razorback suckers captured in direct association with sonic-tagged, juvenile individuals. A significant difference was detected (ANOVA, $F_{4,170} = 11.6$, $P < 0.001$), and razorback suckers were significantly larger than abundant predatory species in post-hoc comparison ($\bar{x} = 536.0$ [SE = 55.0]).

Age Determination

During the ICS period of sampling associated with sonic-tagged, juvenile razorback suckers, four new, wild razorback suckers were captured. Perhaps most striking was that all captured individuals were new, wild, previously unmarked fish. This was the second consecutive year for such a result (Albrecht et al. 2013a). Furthermore, these new individuals were collected entirely from Las Vegas Bay, where the capture of these four razorback suckers equaled the total number of individuals collected from Las Vegas Bay during the 2013 spawning period (Albrecht et al. 2013b). Three of the four new captures underwent surgical fin ray removal, and definitive ages were calculated for all three individuals. These razorback suckers, which ranged in size from 521 to 561 mm TL, were aged from 7 to 12 years old (see table 3). The razorback sucker captured on July 16, 2013, was released prior to anesthesia for the fin clipping process to ensure the health of the individual. The approximate age for that fish was assumed to be near that of similarly sized individuals (approximately 8 years) (see table 3). The largest fish (561 mm) was aged at 12 years old (2001 year-class), while the other two individuals were aged at 7 and 8 years old (2005 and 2006 year-classes, respectively). All of these year-classes have been noted for their strength in regard to razorback sucker recruitment in Lake Mead in past studies (figure 17 *in* Albrecht et al. 2013b).

Habitat Observations and Physicochemical Quantification

During May 8 through December 20, 2013, 435 physicochemical replicates within 87 measured habitats were quantified in association with contacted sonic-tagged, juvenile razorback suckers (table 4). Habitat assessment showed a seasonal shift in the types of habitat that sonic-tagged, juvenile razorback suckers associated with, partially explained by a significant increase in depth throughout the year, as shown in the sonic telemetry data (see figure 7). 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 dominated by the IV cover type. Conversely, offshore habitat was primarily characterized by greater

**Sonic Telemetry and Habitat Use of Juvenile Razorback Suckers
in Lake Mead, 2013–2014 Annual Report**

Table 4.—Summary of mean monthly physicochemical and habitat information collected during the ICS and AHS periods in direct association with sonic-tagged, juvenile razorback suckers for all study sites in Lake Mead (i.e., Las Vegas Bay, Echo Bay, and the Virgin River/Muddy River inflow area), May 8 – December 20, 2013

	Physicochemical						Cover type (%)				Substrate type (%)			
	Temp (°C) ^a	DO (mg/L)	Cond (µS/cm) ^b	pH	Turb (NTU) ^c	Depth (m)	IV	SAV	LWD	NO ^d	SI ^e	SA ^f	GR ^g	CO ^h
May (n = 609, 45)ⁱ														
Mean	24.77	8.20	1.75	8.85	76.97	2.85	51.7	1.7	6.7	39.9	98.6	1.0	0.4	0.0
SE	0.06	0.08	0.04	0.02	4.91	0.07	–	–	–	–	–	–	–	–
Minimum	21.69	1.61	0.10	7.61	5.70	0.50	–	–	–	–	–	–	–	–
Maximum	30.53	15.85	16.30	9.93	1,200.00	6.20	–	–	–	–	–	–	–	–
June (n = 871, 37)														
Mean	26.49	8.67	1.46	8.64	27.92	6.13	11.1	1.7	0.0	87.2	95.2	3.7	0.7	0.4
SE	0.06	0.10	0.03	0.02	1.51	0.23	–	–	–	–	–	–	–	–
Minimum	16.68	2.26	0.94	7.36	2.50	1.00	–	–	–	–	–	–	–	–
Maximum	30.29	17.63	9.76	9.74	241.00	29.75	–	–	–	–	–	–	–	–
July (n = 935, 41)														
Mean	29.64	4.72	1.22	8.07	23.80	6.71	11.6	2.2	0.2	86.0	81.0	11.5	4.4	3.1
SE	0.06	0.06	0.01	0.01	2.34	0.20	–	–	–	–	–	–	–	–
Minimum	18.62	1.09	0.04	7.30	3.00	0.25	–	–	–	–	–	–	–	–
Maximum	33.25	12.78	2.52	8.89	171.00	30.50	–	–	–	–	–	–	–	–
August (n = 159, 6)														
Mean	28.92	8.01	1.22	8.46	29.94	8.77	0.0	0.0	0.0	100.0	100.0	0.0	0.0	0.0
SE	0.23	0.16	0.02	0.02	3.13	0.67	–	–	–	–	–	–	–	–
Minimum	20.07	4.11	0.88	7.66	2.60	1.50	–	–	–	–	–	–	–	–
Maximum	31.45	13.54	2.03	9.02	336.00	24.00	–	–	–	–	–	–	–	–
September (n = 50, 1)														
Mean	26.04	7.89	1.19	8.88	23.87	16.20	0.0	0.0	0.0	100.0	100.0	0.0	0.0	0.0
SE	0.04	0.08	0.01	0.02	10.06	0.03	–	–	–	–	–	–	–	–
Minimum	25.47	5.81	1.10	7.79	2.50	16.00	–	–	–	–	–	–	–	–
Maximum	26.75	8.95	1.41	9.00	480.00	16.50	–	–	–	–	–	–	–	–
October (n = 145, 9)														
Mean	20.10	6.68	1.01	8.71	6.66	22.34	0.0	0.0	0.0	100.0	100.0	0.0	0.0	0.0
SE	0.04	0.03	0.01	0.01	2.34	0.01	–	–	–	–	–	–	–	–
Minimum	19.63	6.09	0.97	8.61	0.00	22.20	–	–	–	–	–	–	–	–
Maximum	20.97	7.77	1.32	8.84	155.00	22.40	–	–	–	–	–	–	–	–
November^j (n = 95, 6)														
Mean	18.14	7.76	1.01	8.88	–	20.16	0.0	0.0	0.0	100.0	100.0	0.0	0.0	0.0
SE	0.06	0.03	0.01	0.00	–	0.18	–	–	–	–	–	–	–	–
Minimum	17.45	7.38	0.96	8.83	–	18.50	–	–	–	–	–	–	–	–
Maximum	18.88	8.41	1.29	8.93	–	22.00	–	–	–	–	–	–	–	–
December (n = 45, 3)														
Mean	13.91	9.05	1.96	8.83	3.00	23.00	0.0	0.0	0.0	100.0	100.0	0.0	0.0	0.0
SE	0.01	0.03	0.42	0.02	0.00	0.00	–	–	–	–	–	–	–	–
Minimum	13.82	8.89	0.98	8.56	3.00	23.00	–	–	–	–	–	–	–	–
Maximum	13.97	9.61	9.82	8.97	3.00	23.00	–	–	–	–	–	–	–	–

^a Temp = temperature.

^b Cond = conductivity.

^c Turb = turbidity.

^d NO = no cover

^e Si = silt.

^f SA = sand.

^g GR = gravel.

^h CO = cobble.

ⁱ The number of physicochemical and cover type and substrate type measurements/observations included for each month.

^j No turbidity measurement was recorded due to equipment malfunction.

Sonic Telemetry and Habitat Use of Juvenile Razorback Suckers in Lake Mead, 2013–2014 Annual Report

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 each study site (see figures 4–6).

As differences were observed in the movement of sonic-tagged, juvenile razorback suckers, physicochemical and habitat data were averaged on a monthly basis to better define conditions during the ICS and AHS sampling periods (see table 4). During this study, monthly means in temperature ranged from 13.91 °C (SE = 0.01) in December to 29.64 °C (SE = 0.06) in July, while DO showed a converse relationship with a range of 9.05 mg/L (SE = 0.03) in December and 4.72 mg/L (SE = 0.06) in July. The seasonal pattern of movement from shallow habitat into deeper habitat may be one of biological necessity, as high temperatures facilitated low DO concentrations, and sonic-tagged, juvenile razorback suckers may have been moving in search of cooler temperatures and higher DO concentrations in deeper habitat (see table 4 and figure 7). Additionally, as sonic-tagged, juvenile razorback suckers moved into deeper habitat, turbidity levels decreased; the lowest mean monthly turbidity levels were recorded in tandem with increases in mean monthly depths (see table 4). Mean monthly turbidity levels ranged from 3.00 NTU in December to 76.97 NTU in May (see table 4). Often, range extremes in physicochemical data were observed in summer (e.g., June – August), while more variation appeared to occur during spring and fall (e.g., May and September), perhaps associated with storm-influenced discharge fluctuations in the Las Vegas Wash and Virgin River (see table 4 and figure 3). Conversely, relatively low amounts of SE associated with monthly parameters were seen for June (0.03–1.51) and October (0.01–2.34), and few discharge disturbances were noted in the hydrographs of the associated inflows (see table 4 and figure 3). Variations in discharge from Las Vegas Wash and the Virgin River may have contributed to the greater amounts of water column variation through the seasons, perhaps further influencing movements, and subsequent habitat associations, of sonic-tagged, juvenile razorback suckers. These storm events can often carry increased loads of sediment, which influence turbidity levels in Lake Mead and, subsequently, the substrate composition (Golden and Holden 2003). Dominant substrate for habitats with which sonic-tagged, juvenile razorback suckers associated was primarily silt (see table 4). Monthly means of substrate showed that silt comprised 81.0–100.0% of the substrate sonic-tagged, juvenile razorback suckers associated with, followed by sand (0.0–11.5%) (see table 4). Similarly, IV was the primary cover type with which sonic-tagged, juvenile razorback suckers were associated, comprising 0.0–51.7% of cover present. However, throughout the year, many of the habitats quantified were seemingly void of cover, and SAV and LWD occurred in low compositions of nearshore habitat with a range of 0.0–6.7% (see table 4). Although turbidity may provide razorback suckers with cover from predators (e.g., Golden and Holden 2003; Knecht and Ward 2012), it hindered assessments of the amounts of vegetative cover (e.g., SAV and LWD) present at sampling sites

due to limited visibility. However, algae and detritus were present in 17.5% of ponar grab samples, potentially indicating some level of cover or productivity in the absence of complex IV cover.

Additionally, as movements of sonic-tagged, juvenile razorback suckers appeared to occur seasonally, physicochemical and habitat variation was summarized by season and by study site in order to characterize environmental conditions observed at a broader context for Las Vegas Bay, Echo Bay, and the Virgin River/Muddy River inflow area throughout the year (table 5). Although the same trends in habitat association can be observed in the seasonal summary of physicochemical and habitat information, differences can be seen in a number of parameters among study sites (table 5). Temperature was significantly different among study sites for each of the spring (ANOVA, $F_{2,198} = 22.8$, $P < 0.001$), summer (ANOVA, $F_{2,179} = 117.0$, $P < 0.001$), and fall (ANOVA, $F_{1,33} = 17.2$, $P < 0.001$) seasons. Throughout the year, Echo Bay had a significantly lower average temperature, ranging in differences of 1–4 °C lower than Las Vegas Bay and the Virgin River/Muddy River inflow area (table 5). Similarly, the DO concentration was significantly different among study sites for spring (ANOVA, $F_{2,198} = 22.8$, $P < 0.001$), summer (ANOVA, $F_{2,198} = 22.8$, $P < 0.001$), and fall (ANOVA, $F_{2,198} = 22.8$, $P < 0.001$) seasons; however, it was Las Vegas Bay that consistently had the highest average DO concentrations for each season (table 5). In comparing turbidity by study site through the seasons, significant differences were only found for the spring (ANOVA, $F_{2,198} = 14.9$, $P < 0.001$) and fall seasons (ANOVA, $F_{1,33} = 69.9$, $P < 0.001$). During spring, average turbidity was highest at the Virgin River/Muddy River inflow area ($\bar{x} = 108.7$ [SE = 9.5]), and during fall, the average turbidity was highest at Las Vegas Bay ($\bar{x} = 22.3$ [SE = 6.3]) (table 5).

Using fish assemblage data from 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 CCA. Using CCA, the model was able to explain 34.47% (total inertia = 1.671, sum of all canonical eigenvalues [SAE] = 0.576) of the variability within the fish assemblage associated with sonic-tagged, juvenile razorback suckers through environmental parameters, season, site, and unexplained variation (figure 15). Of that total of explainable inertia, the first two axes accounted for 53.40% of the variation that could be explained by the included variables. In post-hoc variance partitioning, the pure effect of environmental parameters explained 26.63% ($F = 8.86$, $P = 0.0001$), the pure effect of season explained 3.05% ($F = 13.15$, $P = 0.0001$), and the pure effect of site explained 3.59% ($F = 7.73$, $P = 0.0001$); 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 33.27% of the variation explained, while the total unexplained variation accounted for only 1.2% of the model. Three hundred

**Sonic Telemetry and Habitat Use of Juvenile Razorback Suckers
in Lake Mead, 2013–2014 Annual Report**

Table 5.—Summary of mean seasonal physicochemical and habitat information collected during the ICS and AHS periods in direct association with sonic-tagged, juvenile razorback suckers at Las Vegas Bay, Echo Bay, and the Virgin River/Muddy River inflow area, May 8 – December 20, 2013

Physicochemical																		
	Temp (°C) ^a			DO (mg/L)			Cond (µS/cm) ^b			pH			Turb (NTU) ^c			Depth (m)		
	LB ^d	EB ^e	OA ^f	LB	EB	OA	LB	EB	OA	LB	EB	OA	LB	EB	OA	LB	EB	OA
Spring (May 8, 2013–June 20, 2013) (n = 758, 139, 439)^l																		
Mean	26.13	23.72	25.73	9.64	7.58	6.92	1.87	0.96	1.47	9.16	8.34	8.52	43.62	25.70	108.70	3.68	12.98	3.69
SE	0.07	0.15	0.09	0.10	0.09	0.08	0.03	0.01	0.06	0.02	0.04	0.02	1.61	8.02	9.48	0.07	0.95	0.25
Summer (June 21 – September 21, 2013) (n = 658, 211, 369)																		
Mean	28.82	27.02	30.91	6.07	4.71	4.08	1.39	0.95	1.12	8.22	8.14	8.00	19.06	5.40	39.70	7.31	10.91	2.78
SE	0.08	0.19	0.04	0.08	0.13	0.09	0.01	0.00	0.01	0.01	0.02	0.01	1.67	0.28	4.18	0.20	0.69	0.09
Fall (September 22 – December 20, 2013)^g (n = 145, 190, 0)																		
Mean	21.83	17.89	–	7.60	7.40	–	1.09	1.22	–	8.88	8.74	–	22.32	0.50	–	18.86	22.45	–
SE	0.26	0.18	–	0.04	0.08	–	0.01	0.10	–	0.01	0.01	–	6.26	0.10	–	0.20	0.03	–

Cover type (%)												Substrate type (%)												
	IV			SAV			LWD			NO ^g			Si ^h			SA ⁱ			GR ^j			CO ^k		
	LB	EB	OA	LB	EB	OA	LB	EB	OA	LB	EB	OA	LB	EB	OA	LB	EB	OA	LB	EB	OA	LB	EB	OA
Spring (May 8 – June 20, 2013) (n = 39, 8, 29)^l																								
Mean	20.0	7.3	62.1	0.0	9.4	0.0	6.3	0.0	0.4	73.7	83.3	37.5	99.8	75.4	100.0	0.2	17.9	0.0	0.0	4.6	0.0	0.0	2.1	0.0
SE	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Summer (June 21 – September 21, 2013) (n = 19, 12, 22)																								
Mean	0.1	0.0	23.0	0.0	0.0	0.0	0.0	0.0	0.0	99.9	100.0	77.0	89.8	100.0	75.2	5.9	0.0	19.0	2.6	0.0	3.1	1.8	0.0	2.6
SE	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Fall (September 22 – December 20, 2013)^m (n = 7, 12, 0)																								
Mean	0.0	0.0	–	0.0	0.0	–	0.0	0.0	–	100.0	100.0	–	100.0	100.0	–	0.0	0.0	–	0.0	0.0	–	0.0	0.0	–
SE	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–

^a Temp = temperature.

^b Cond = conductivity.

^c Turb = turbidity.

^d LB = Las Vegas Bay.

^e EB = Echo Bay.

^f OA = Virgin River/Muddy River inflow area.

^g NO = no cover.

^h Si = silt.

ⁱ SA = sand.

^j GR = gravel.

^k CO = cobble.

^l The number of physicochemical and cover type and substrate type measurements/observations included for each season and site.

^m No sonic telemetry contacts were made at the Virgin River/Muddy River inflow area during fall; thus, no habitat data were recorded.

**Sonic Telemetry and Habitat Use of Juvenile Razorback Suckers
in Lake Mead, 2013–2014 Annual Report**

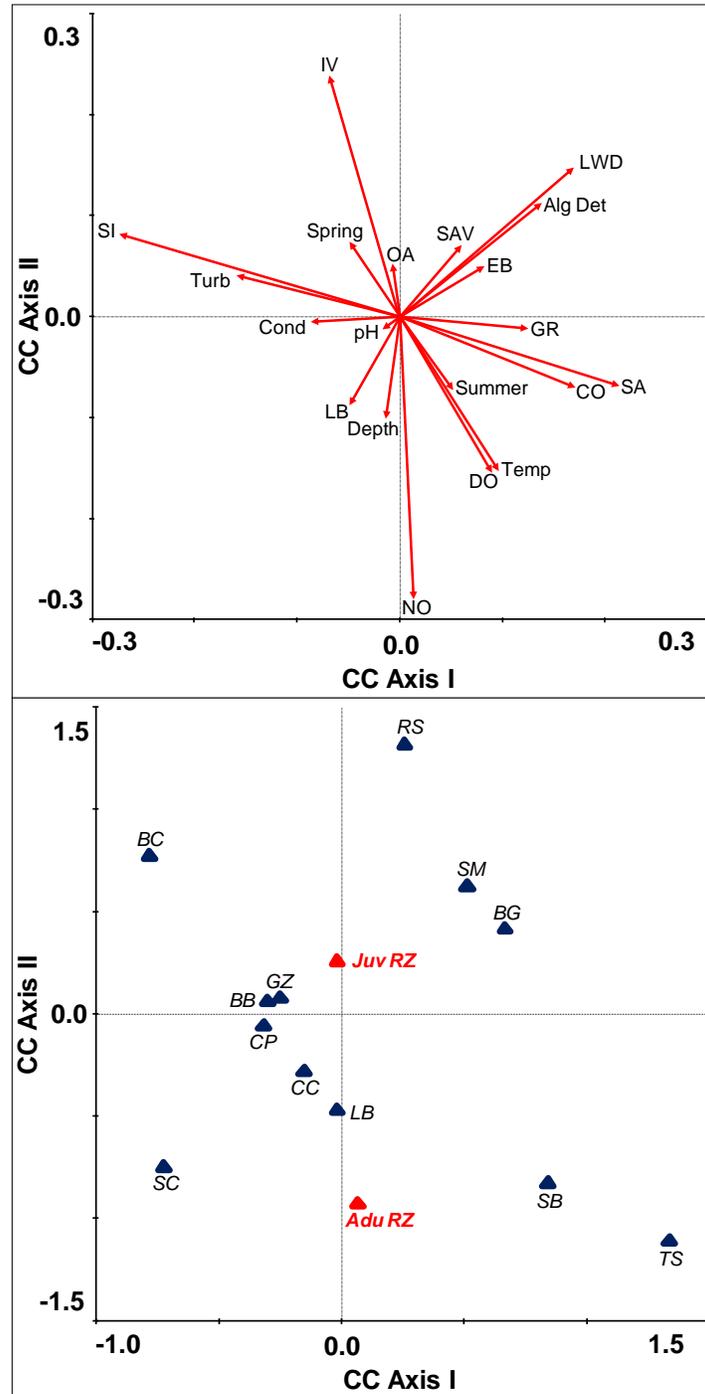


Figure 15.—CCA of the environment, season, site, and fish community associated with sonic-tagged, juvenile razorback suckers in Lake Mead (i.e., Las Vegas Bay, Echo Bay, and the Virgin River/Muddy River inflow area), May 8 – July 26, 2013. The CCA showed that 34.47% (total inertia = 1.671, sum of all canonical eigenvalues [SAE] = 0.576) of the variation seen within the fish community could be explained by environmental parameters, season, and site (abbreviations are listed in tables 2 and 4).

Sonic Telemetry and Habitat Use of Juvenile Razorback Suckers in Lake Mead, 2013–2014 Annual Report

samples were used in the CCA, which consisted of data taken in association with 13 sonic-tagged, juvenile razorback suckers from Las Vegas Bay, Echo Bay, and the Virgin River/Muddy River inflow area during May 8 – July 26, 2013. In preparing data for analysis, habitat data for 15 contacts with sonic-tagged, juvenile razorback suckers were not included, as either fish sampling was not conducted due to inclement weather or physicochemical and habitat data were incomplete due to equipment malfunction. Additionally, turbidity for seven habitats was estimated using a mean turbidity from the most recent consecutive habitat assessment for that study site.

Factors with the strongest loadings on CCA axis I were silt substrate (biplot score = -0.27), average turbidity (-0.16), average conductivity (-0.09), LWD cover (0.17), cobble substrate (0.17), and sand substrate (0.21) (see figure 15). Factors with the strongest loadings on CCA axis II were no cover (-0.28), average DO (-0.15), average temperature (-0.15), the presence of algae and detritus (0.12), LWD cover (0.15), and IV cover (0.24) (see figure 15).

Threadfin shad (*Dorosoma petenense*) biplot score (3.19), striped bass (2.01), bluegill (1.59), and smallmouth bass (1.22) were positively related to CCA axis I and associated with larger substrates (i.e., sand, gravel, and cobble), LWD, and the presence of algae and detritus (see figure 15). Black crappie (*Pomoxis nigromaculatus*) (-1.88), vermiculated sailfin catfish (-1.74), common carp (-0.76), and black bullhead (*Ameiurus melas*) (-0.73) were negatively related to CCA axis I and associated with silt substrate, higher average turbidity, and higher average conductivity (see figure 15). Red shiner (3.61), black crappie (2.11), smallmouth bass (1.71), and bluegill (1.14) were positively related with CCA axis II and associated with vegetative cover in the forms of IV, SAV, and LWD, as well as the Virgin River/Muddy River inflow area, and spring season (see figure 15). Threadfin shad (-3.04), adult razorback sucker (-2.54), striped bass (-2.27), and vermiculated sailfin catfish (-2.05) were negatively related with CCA axis II and associated with no apparent cover, higher average DO, higher average temperatures, and increased average depths (see figure 15).

Sonic-tagged, juvenile razorback suckers were not strongly related to any particular habitat type, although they appear to have associated with IV, higher average turbidity, and silt substrates during the spring season and at the Virgin River/Muddy River inflow area (see figure 15). Similarly functioning species included gizzard shad, black bullhead, and common carp. Interestingly, adult razorback suckers did not partition out in multivariate space near juvenile razorback suckers (see figure 15). 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 2003; Albrecht et al. 2010a; Shattuck et al. 2011).

Sonic Telemetry and Habitat Use of Juvenile Razorback Suckers in Lake Mead, 2013–2014 Annual Report

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 from Las Vegas Bay, Echo Bay, and the Virgin River/Muddy River inflow area during May 8 – December 20, 2013. In contrast to the CCA model, 418 samples of habitat data—collected in association with 13 sonic-tagged, juvenile razorback suckers—were used in the PCA. In preparing data for analysis, habitat data for two contacts with sonic-tagged, juvenile razorback suckers were not included, as physicochemical and habitat data were incomplete due to equipment malfunction. Furthermore, turbidity for seven habitats was estimated using a mean turbidity from the most recent consecutive habitat assessment for that study site.

In the PCA model, the first two axes explained 36.3% (PCA axis I = 18.6% and PCA axis II = 17.7%) of the total variation in environmental parameters and sites among habitats associated with sonic-tagged, juvenile razorback suckers (figure 16). In post-hoc comparison, only the second principal component axis exceeded the expectations for a model with 18 principal axes in the broken-stick criterion (i.e., PCA axis I total variance < 19.42%, and PCA axis II total variance > 13.41% [Frontier 1976; Olden 2011]) and explained a significant amount of variance. Principal component axis I described a depth and cover gradient with no apparent cover (-1.98), average depth (-1.61), Echo Bay (-1.06), average turbidity (1.10), the Virgin River/Muddy River inflow area (1.77), and IV cover (2.04) having the strongest loadings on the axis (figure 16). PCA II described a substrate, depth, conductivity, and cover gradient with silt substrate (-1.71), average conductivity (-1.62), Las Vegas Bay (-1.52), SAV cover (1.11), gravel substrate (1.21), and sand substrate (1.43) having the strongest loadings along the axis (figure 16). Habitats associated with Las Vegas Bay were generally higher in conductivity, higher in DO concentrations, silt dominated, and had more LWD (figure 16). Habitats associated with Echo Bay were characterized as being deeper, with less IV, having larger substrates (e.g., gravel, sand, cobble), and with more SAV (figure 16). Finally, habitats located at the Virgin River/Muddy River inflow area were typically warmer in temperature, higher in turbidity, had a greater presence of algae and detritus, and were dominated by IV (figure 16).

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 16), shows clear shifts in location and habitat composition of areas occupied by sonic-tagged, juvenile razorback suckers throughout the year. Though seasonally delineated samples in PCA space overlap, there appears to be some uniqueness for each of the spring, summer, and fall periods (figure 16). Samples exhibiting distances furthest from the origin are considered most different in physicochemical and habitat composition. As such, the spring season

**Sonic Telemetry and Habitat Use of Juvenile Razorback Suckers
in Lake Mead, 2013–2014 Annual Report**

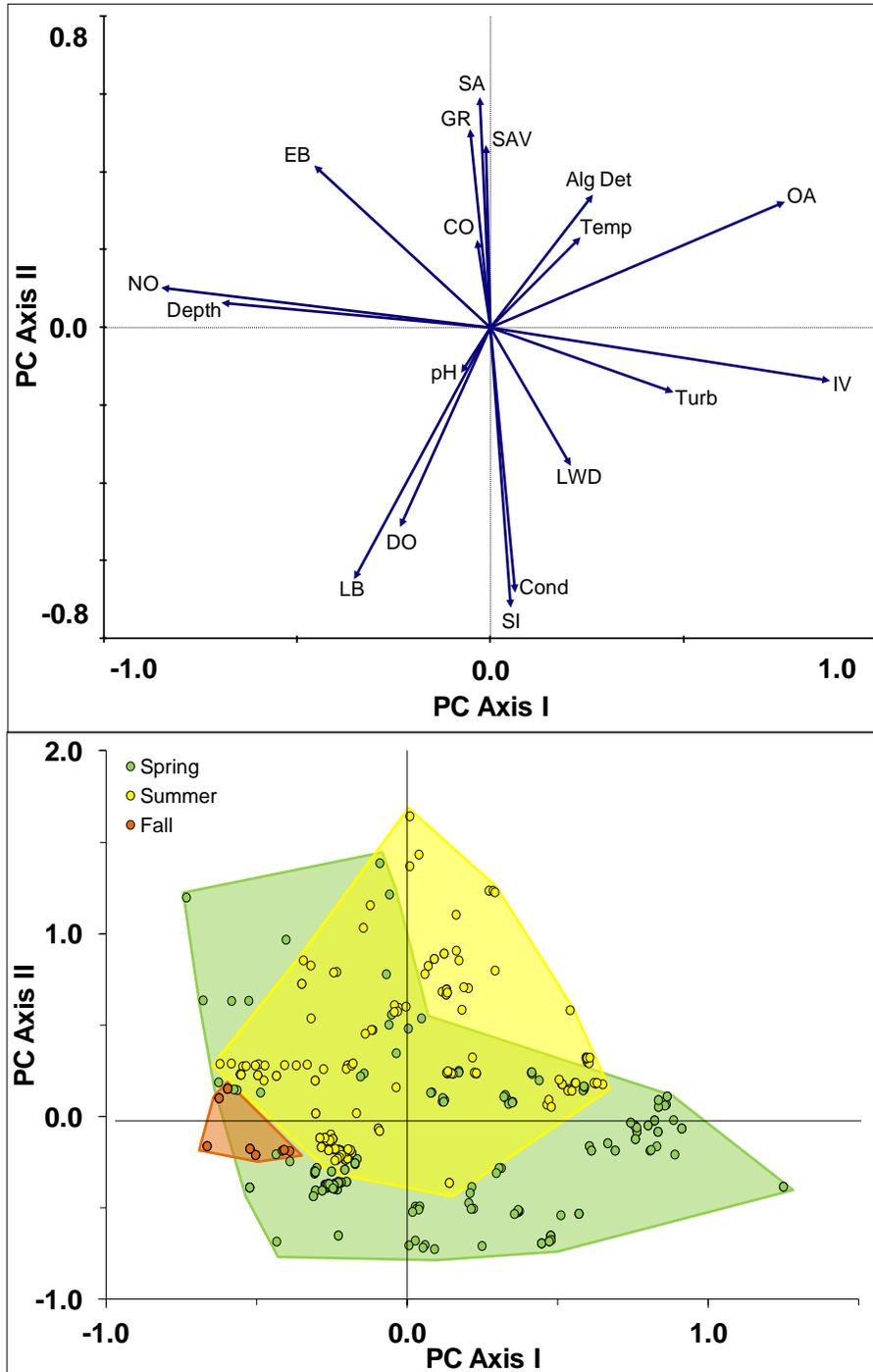


Figure 16.—PCA of the environment and site parameters associated with sonic-tagged, juvenile razorback suckers in Lake Mead (i.e., Las Vegas Bay, Echo Bay, and the Virgin River/Muddy River inflow area), May 8 – July 26, 2013.

The first two principal component axes explained 36.3% of the variation seen within habitats, with post-hoc labeling of season included (green = spring, yellow = summer, and orange = fall; abbreviations are listed in tables 2 and 4).

occupies the most space in PCA, potentially attributable to more variation seen in the habitat with which sonic-tagged, juvenile razorback suckers associated (see figure 16). Conversely, as fewer samples were analyzed for habitat contacts made in fall, there appear to be fewer variables that characterize this type of habitat with less variation seen in its composition (see figure 16). Nonetheless, the observation of seasonal sample partitioning in PCA space offers explanatory power in potentially predicting the annual potadromy of sonic-tagged, juvenile razorback suckers in Lake Mead. During spring, habitat for juvenile individuals appears to be characterized by higher turbidities, an abundance of inundated cover, silt substrate, and higher DO concentrations (see figure 16). Moving into summer, habitat for juvenile individuals is more closely associated with larger substrates, increased depths, and higher temperatures. Finally, fall habitat for juvenile individuals can be described as greater in depth, lower in turbidity, and with no discernable cover; however, due to a smaller sample size, fall habitat may not be as descriptive as other seasons included in the model (see figure 16).

DISCUSSION AND CONCLUSIONS

Overall, the quantitative, empirical data collected during the 2013 study year provided a better understanding of razorback sucker recruitment habitat in Lake Mead, particularly during the spring and summer seasons. Additionally, four new, wild razorback suckers were captured (for the second consecutive year) in direct association with sonic-tagged, juvenile razorback suckers (Albrecht et al. 2013a). Sonic telemetry was reaffirmed as a useful tool for collecting habitat information, and it guided sampling efforts toward the collection of additional razorback suckers.

These captures, in conjunction with data collected on habitat associations and seasonal movement, helped expand our knowledge of the species and its juvenile life stage, which lead to a more precise and informative model with which to characterize recruitment habitat and predict razorback sucker presence. Further descriptions of habitat use, movement patterns, and the fish assemblage associated with juvenile razorback suckers in Lake Mead will help cement important ecological relationships that can be of use not only in other areas of Lake Mead but also in other areas of the Lower Colorado River Basin.

Lake Elevation and Inflow Discharges

The lake and inflow interface has been of noted importance in other razorback sucker studies (e.g., Albrecht et al. 2010b, 2013a; Kegerries and Albrecht 2011; Shattuck et al. 2011) as well as in other systems in North America (Kaemingk et al. 2007). During 2013, typical seasonal variation in Lake Mead elevation and discharges of the Las Vegas Wash and Virgin River seemed to complement one

Sonic Telemetry and Habitat Use of Juvenile Razorback Suckers in Lake Mead, 2013–2014 Annual Report

another by providing different forms of cover consistently throughout the year at inflow areas (i.e., IV through higher lake elevations in spring and summer and turbidity through summer and fall with monsoonal storms creating high-discharge events) (see figure 3).

Lake elevation plays a large role at Lake Mead: annual fluctuations of more than 5 m are not uncommon (Shattuck et al. 2011; Albrecht et al. 2013a, 2013b), and they intermittently inundate or dry vast expanses of habitat. Not surprisingly, the bathymetry of Lake Mead appeared to influence the length of transitional movements sonic-tagged, juvenile razorback suckers made from spring into summer and fall. From the Virgin River inflow between Three Corner Hole and the Overton boat ramp moving south, there is an approximate increase in depth of 10 m for a distance of 4,000 m (gradient = 0.003) (see figures 1 and 6). In comparison, from Las Vegas Wash inflow moving southeasterly, there is an approximate increase in depth of 10 m for a distance of 650 m (gradient = 0.015), and from the Echo Bay boat ramp moving southeasterly, there is an approximate increase in depth of 10 m for a distance of 400 m (gradient = 0.025) (see figures 1, 4, and 5). The dramatic difference in gradient between Las Vegas Bay and the Virgin River/Muddy River inflow area may partially explain why both sonic-tagged, adult and juvenile razorback suckers can often be located in the same general areas of Las Vegas Bay throughout the year (Albrecht et al. 2013b). Conversely, in 2013, it appeared that sonic-tagged, juvenile razorback suckers at the Virgin River/Muddy River inflow area utilized the IV near the Virgin River inflow during spring and early summer before moving almost entirely out of the area (see figure 6). Similar results have been recorded for sonic-tagged adult razorback suckers in Lake Mead, where individuals frequently found near the Virgin River/Muddy River inflow area seasonally moved further south into the areas of Stewarts Cove (south of the Black Ridge SUR) and Rogers Bay, nearly 15 km away (Shattuck et al. 2011; Albrecht et al. 2013b) (see figure 1).

Though sonic-tagged, juvenile razorback suckers were contacted in a number of habitats throughout the study areas in Lake Mead, individuals were most frequently contacted in dense inundated cover during higher lake elevations near the Las Vegas Wash inflow at the western end of Las Vegas Bay and at the northern extent of the Overton Arm near the Virgin River inflow (see figures 4 and 6). Inflows play an important role in the creation and maintenance of habitat in Lake Mead by supplying an influx of nutrients, sediment, and woody debris (Golden and Holden 2003), and it is thought that inflows provide razorback suckers with a potential pathway to move upstream into productive wetland-type habitats during high discharges (Karp and Mueller 2002). As seen in Lake Mead and other systems, both juvenile and adult razorback suckers appear to associate with the flood plain habitat of inundated saltcedar found at inflow areas perhaps for the productive foraging among emergent and IV (Tyus and Karp 1990; Mueller et al. 2000; Karp and Mueller 2002; Albrecht et al. 2013a). In studies focusing on adult razorback suckers in Lake Mead, recruitment peaks appear to coincide anecdotally with recent high-discharge events in the Virgin River

(e.g., 2005), which perhaps allow for conditions conducive to recruitment (Shattuck et al. 2011; Albrecht et al. 2013b). Similarly, juvenile individuals of other sucker species rely on inundated wetland habitat for rearing – so much so that failures in recruitment have been noted to be partially explained by declines in lake elevation and the subsequent loss of this particular habitat (Burdick et al. 2008).

Sonic Telemetry

Sonic telemetry data from juvenile razorback suckers provided invaluable information in determining specific habitat use in Las Vegas Bay, Echo Bay, and the Virgin River/Muddy River inflow area during the spring, summer, and fall of 2013. Furthermore, the use of sonic-tagged, juvenile razorback suckers aided in the placement of sampling gears to capture new, wild razorback sucker cohorts for the second consecutive study year.

Sonic-tagged, juvenile razorback suckers provided information about potential recruitment habitat for the species through their patterned movement from shallow habitats with an abundance of inundated cover to deeper habitats further away from adjacent inflow areas (see figures 4–6). Generally, sonic-tagged, juvenile razorback suckers remained within their respective study sites in which they were stocked (see figures 4–6), and as spring transitioned into summer, sonic-tagged, juvenile razorback suckers began to move into significantly deeper habitat lake-wide (see figure 7). This transition into deeper habitat may have been in response to rising water temperatures in most of the shallow habitat associated with IV (see table 4). As temperatures increased, DO concentrations decreased, making deeper areas with cooler temperatures and higher DO concentrations potentially sought after by sonic-tagged, juvenile razorback suckers. This pattern of habitat association was similar to that seen in 2012 (Albrecht et al. 2013a); however, with the aid of a larger tagging cohort in 2013, a better understanding of these observations was attained. Although not uncommon for adult razorback suckers during the spawning period, sonic-tagged, juvenile razorback suckers were often contacted near other sonic-tagged, juvenile individuals (< 100 m) for much of the spring and summer seasons in Las Vegas Bay and the Virgin River/Muddy River inflow area (see figures 4–6). This relative grouping was interesting, as it indicated that the habitat sonic-tagged, juvenile individuals were associating with was indeed important to the life stage. Additionally, it was from sampling in direct association with multiple sonic-tagged, juvenile individuals that four new, wild razorback suckers were captured in Las Vegas Bay (see table 3 and figure 9). Although the new, wild individuals captured were larger than their associated sonic-tagged juveniles (see table 3), the captures indicated that juvenile and adult fish may share habitats at certain times of the year, perhaps when conditions prohibit much diversity in habitat selection (e.g., high water temperatures and low DO concentrations).

Sonic Telemetry and Habitat Use of Juvenile Razorback Suckers in Lake Mead, 2013–2014 Annual Report

Following the initial stocking of individuals at each of the study sites, most individuals recovered quickly and began exhibiting a pattern of movement and behavior seen for juvenile razorback suckers in the past (Albrecht et al. 2013a). Individuals stocked into Las Vegas Bay and the Virgin River/Muddy River inflow area associated with habitat nearly identical to that of sonic-tagged, juvenile razorback suckers in 2012 (Albrecht et al. 2013a). However, individuals stocked into Echo Bay appeared unable to find suitable habitat following stocking, and individuals moved outside of Echo Bay proper almost immediately, with one exception. One individual remained at the western end of Echo Bay, near the stocking location, for several weeks before moving out of Echo Bay without further contact (see figure 5). Eventually, two individuals were contacted north of Echo Bay in Anchor Cove (see figure 5), but no additional contacts with any individuals were made in Echo Bay for the remainder of 2013. Although Echo Bay is of noted importance for razorback sucker reproduction (Albrecht et al. 2013b), its importance to juvenile razorback suckers may not be as significant, or at least habitat within Echo Bay was associated with on a limited basis by sonic-tagged, juvenile razorback suckers during 2013. In studies of sonic-tagged adult razorback suckers, it was noted that juvenile fish often returned to shallow and turbid habitats with IV sooner than adults (Albrecht et al. 2010b; Shattuck et al. 2011), and data for sonic-tagged juveniles show more frequent movements between these habitats (Albrecht et al. 2013a). While overlap in habitat association may exist, sonic telemetry data suggest slight differences in the timing and areas occupied by juvenile razorback suckers (Albrecht et al. 2013a). Further evidence of this was observed during July 2013 when two individuals exhibited a pattern of movement into and out of the dense expanse of IV near the Virgin River inflow (see figure 6). Though the reason for movement of these two individuals during crepuscular hours was not made clear, it was thought that perhaps anoxic conditions existed within the shallow IV; thus, habitat that was shown to be high in temperature and low in DO with large amounts of decaying organic material among the IV (see table 4) was likely unsuitable at times. Conversely, this same habitat may have offered large amounts of cover from nonnative predators and may have been highly productive for foraging.

In 2013, sonic-tagged, juvenile razorback suckers were often contacted near the Las Vegas Wash and Virgin River inflow areas; however, as lake elevation declined and high-discharge events occurred more frequently during summer and fall, these individuals appeared to move toward deeper habitat (see figures 4 and 6). One hundred contacts were made with sonic-tagged, juvenile razorback suckers, and nearly all individuals were contacted at least once (see table 1). Though passive tracking via SURs contacted four individuals a total of 1,988 times (see table 1), it is surprising that more individuals were not contacted by the 11 SURs deployed at strategic points throughout the lake, particularly as lake elevation declined in late spring and summer and transitions in habitat association were observed in sonic-tagged, juvenile razorback suckers lake-wide (see figures 3 and 7). Sonic-tagged, juvenile razorback suckers were often contacted in shallow areas adjacent to dense IV, making tracking difficult;

however, great care was taken to target these habitats, and a number of individuals were contacted regularly (see table 1). Furthermore, of the 18 individuals implanted with sonic transmitters in 2013, only 2 individuals were not contacted at all; both of these had been stocked into Echo Bay (see table 1).

During surgical implantation and the subsequent stocking of the 18 sonic-tagged, juvenile razorback suckers, great care was taken to ensure that a limited amount of stress was caused. Every effort to acclimate individuals before stocking, and in turn, release individuals into calm, suitable habitat in Lake Mead, was undertaken. Furthermore, great advances have been made in sonic telemetry technology, although tag failure has been noted in past studies on Lake Mead (Albrecht et al. 2006b, 2008a; Kegerries and Albrecht 2011). However, without the explanation of tag failure, many questions arise regarding the location of the unaccounted for sonic-tagged, juvenile razorback suckers in 2013. Inquiries with the manufacturer on limitations of the sonic transmitters found that successful tag transmission is possible despite being covered by approximately 6.1 m of coarse sediment, and sonic tags have been shown to experience a negligible failure rate; thus, other scenarios beyond tag expulsion and subsequent burial might be considered (M. Gregor 2012, personal communication). A more likely reason for lost contact with several individuals in Echo Bay may be due to predation and generally low turbidities (see table 5). Most of the study sites have a substantial piscivorous avian community, and it is not uncommon for numerous American white pelican (*Pelecanus erythrorhynchos*), great blue heron (*Ardea herodias*), and double-crested cormorant (*Phalacrocorax auritus*) to be present at all times of the year. The initial disappearance of sonic-tagged, juvenile individuals following stocking could be explained by bird predation rather than fish predation. Contact could have been made following piscivorous ingestion of a sonic-tagged, juvenile razorback sucker; however, following predation by a bird, the transmitter would likely be out of the water and therefore out of range. Contacts made with two individuals in Anchor Cove, north of Echo Bay, occurred near an area that houses two water pump platforms. Although it is uncertain why these individuals moved into this area and remained there for several months, these sonic locations were pinpointed directly beneath platforms that were coincidentally being heavily utilized by double-crested cormorants and great blue herons for nesting throughout spring and summer (see figure 5). Though attempts to sift through excreted bones left in the avian nests produced no transmitters or distinguishable razorback sucker bones, many bones belonging to other species of fish were found.

Conspecific and Community Sampling

Using a variety of gears to target available habitat in the characterization of the fish assemblage associated with sonic-tagged, juvenile razorback suckers was successful in capturing additional razorback suckers in 2013 (see table 3).

Sonic Telemetry and Habitat Use of Juvenile Razorback Suckers in Lake Mead, 2013–2014 Annual Report

Though numerous environmental circumstances (e.g., depths > 20 m and dense IV) created challenges to using all gear types throughout the year, all gear types were used at some point during the ICS period, and each targeted a variety of functionally different fish species.

The new, wild razorback sucker captures occurred during trammel netting in Las Vegas Bay, and throughout the year, this gear type was found to be the most effective at capturing a variety fish lake-wide (see figure 8). Hoop nets and minnow traps were also often used, as these gears were ideal for setting in association with sonic-tagged, juvenile razorback suckers contacted within dense stands of IV (see figures 4 and 6). Fyke nets and seine hauls were not used as often due to their more specific requirements for effective deployment (e.g., anchor points for fyke nets and areas of open water free of obstructions for fyke nets and seines) (see table 2). Although additional razorback suckers were only captured during trammel netting efforts, the use of other gear types should not be precluded or overlooked. The combination of gear types, each with their own gear bias, helped to more completely describe the fish assemblage by including a number of species that might not be caught using a single gear type (see table 2 and figure 8). Furthermore, the lack of small, juvenile razorback sucker (< 450 mm TL) captures may not be due to gear type; rather, small, juvenile razorback suckers have only been occasionally and sporadically captured in a large amount of sampling conducted during long-term monitoring (Kegerries et al. 2009; Albrecht et al. 2010c, 2013a, 2013b; Shattuck et al. 2011). In past studies at Lake Mead, 58 new, wild, juvenile razorback suckers have been captured at Las Vegas Bay (Holden et al. 2001; Abate et al. 2002; Welker and Holden 2003, 2004; Albrecht et al. 2007, 2008a, 2010b, 2013a; Kegerries et al. 2009; Shattuck et al. 2011); 21 new, wild, juvenile razorback suckers have been captured at the Virgin River/Muddy River inflow area (Albrecht et al. 2008a, 2010b; Kegerries et al. 2009); and only four new, wild, juvenile razorback suckers have been captured at Echo Bay (Holden et al. 1997, 1999). Additionally, one new, wild, juvenile razorback sucker has been captured at the Colorado River inflow area, where the smallest recorded individual was captured in 2013 and aged back to the 2011 year-class (Kegerries and Albrecht 2013). As gear sets occurred during some of the warmest months of the year, net sets were limited in timing to avoid undue stress on potential razorback sucker captures. Longer net sets during the fall and winter seasons should serve to improve 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. Additionally, further exploration of alternative gears could be explored in order to more specifically target areas frequented by sonic-tagged, juvenile razorback suckers (e.g., miniature fyke nets and varied methods of boat electrofishing).

Only one species of native fish (razorback sucker) was captured during the ICS period; 687 individuals from 13 fish species were captured using 158 sets of gear. Throughout the study sites in Lake Mead, the two most dominant fish species

Sonic Telemetry and Habitat Use of Juvenile Razorback Suckers in Lake Mead, 2013–2014 Annual Report

were gizzard chad and bluegill (see table 2). With the exception of common carp, channel catfish, and largemouth bass, most of the other fishes captured were found sporadically and in small abundances (see figures 10, 12, and 14). This finding of fish community makeup is not uncommon, and many of the species' compositions recorded throughout 2013 closely mirrored those recorded in the past several years of long-term monitoring (Kegerries et al. 2009; Albrecht et al. 2010b, 2013a, 2013b.; Shattuck et al. 2011). The fish community in shallower inshore habitats contained numerous species that are often associated with structure (e.g., LWD and IV) as cover. Smaller bluegill, largemouth bass, and other centrarchids were often found in dense IV. Conversely, deeper habitats sampled offshore 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) (see table 2 and figures 10–14). How these nonnative species interact with juvenile razorback suckers is of particular interest.

Certainly there is competition and predation from most of these species, but how juvenile razorback suckers have been able to somewhat mitigate the effects of these trophic obstacles and continue to recruit in Lake Mead is intriguing. Trophic competition with gizzard shad and common carp is of particular interest, as is the efficiency of bluegill and largemouth bass as predators 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 telling as to the long-term success of razorback sucker recruitment at Lake Mead. As inflows bring in nutrients and cover in the forms of turbidity and IV, these areas are often some of the more productive habitats in a lacustrine environment (Karp and Mueller 2002; Golden and Holden 2003; Burdick et al. 2008). Not surprisingly, these areas also have high abundances of zooplanktivores such as gizzard shad (Mueller and Brooks 2004). As a direct competitor with razorback suckers for biological resources (Mueller and Brooks 2004), it is concerning that gizzard shad are so abundant in comparison (see table 2 and figures 10, 12, and 14). Furthermore, though gizzard shad are not often thought of as a predator of razorback suckers, their effective foraging en masse may lead to incidental take of larval razorback suckers (Mueller and Brooks 2004). Alternatively, many centrarchids, including bluegill and largemouth bass, directly predate on larval and juvenile razorback suckers (Mueller 1995), as do common carp, channel catfish, and striped bass (Marsh and Brooks 1989; Karam and Marsh 2010). Interestingly, during the 2013 ICS sampling period, captured razorback suckers were significantly larger than their nonnative predator counterparts (i.e., channel catfish, striped bass, smallmouth bass, and largemouth bass) (see figures 10, 12, and 14). Whether it is a function of smaller individuals having already been predated upon by nonnative individuals of this size or a behavioral response to associate with smaller fishes, this type of association may aid in allowing recruitment to occur despite the numerous nonnative predatory fishes present (see table 2 and figures 10, 12,

Sonic Telemetry and Habitat Use of Juvenile Razorback Suckers in Lake Mead, 2013–2014 Annual Report

and 14). Furthermore, the documented juvenile razorback sucker association with areas that have abundant cover in the forms of IV and turbidity may also be a form of predator avoidance. In recent preliminary findings, Ward and Morton-Starner (2013) found that turbidities of greater than 50 Formazin nephelometric units reduced predation of nonnative brown trout (*Salmo trutta*) and rainbow trout (*Oncorhynchus mykiss*) on humpback chubs by 50% in a laboratory setting. Generally, the turbidities at Las Vegas Bay and the Virgin River/Muddy River inflow area were near or above this threshold (see table 5), perhaps leading to higher rates of survival for juvenile razorback suckers—and thus recruitment—in these areas. The continued observation of this type of association may be illustrated through the continued captures of new, wild razorback suckers among significantly smaller fishes. Although the new, wild individuals caught in 2013 were slightly larger than their sonic-tagged, juvenile counterparts, it is interesting to note their close association with juvenile individuals and vice versa. As seen in past studies, juvenile individuals have been captured somewhat often, albeit sporadically, when sampling and tracking adult individuals during the long-term monitoring study (Holden et al. 2001; Abate et al. 2002; Welker and Holden 2003, 2004; Albrecht et al. 2007, 2008a, 2010b, 2013a; Kegerries et al. 2009; Shattuck et al. 2011).

Finally, as the lake elevation declined during 2013, there appeared to be a decline in the amount of area providing IV cover (see figure 3). As was shown by the close affinity with IV throughout spring and early summer (see tables 4 and 5), sonic-tagged, juvenile razorback suckers associated with areas containing this cover type seasonally and likely relied on areas that remained warmer and more productive for optimal foraging when conditions allowed. Although sonic-tagged, juvenile razorback suckers moved offshore into deeper habitat, it appeared as if these young individuals waited as long as possible, potentially taking advantage of lower DO conditions that may have prohibited nonnative predators from occupying the same habitat or taking advantage of productive feeding opportunities (see figures 4–6).

Habitat Observations and Physicochemical Quantification

During 2013, sonic-tagged, juvenile razorback suckers associated with a number of different habitats in Las Vegas Bay, Echo Bay, and the Virgin River/Muddy River inflow area both daily and seasonally. Generally, sonic-tagged, juvenile razorback suckers showed a seasonal transition, moving from shallow habitat characterized by IV during spring and early summer into deeper habitat with noted turbidity as temperatures increased during summer (see figures 4–6). The Las Vegas Wash and Virgin River inflows appeared to be important habitat

Sonic Telemetry and Habitat Use of Juvenile Razorback Suckers in Lake Mead, 2013–2014 Annual Report

features during spring and early summer (the focus of this study year), as the majority of sonic-tagged, juvenile razorback suckers associated with the dense IV and high turbidity typical of these areas (see table 5 and figures 4 and 6).

The areas in which sonic-tagged, juvenile razorback suckers were contacted throughout 2013 were similar to those quantified in 2012 (Albrecht et al. 2013a); however, a much firmer understanding was obtained lake-wide, with clear trends in habitat associations. Significant differences were seen for changes in temperatures, DO concentrations, and depths, perhaps signaling an important annual change for juvenile razorback suckers as they generally moved from IV into other, more variable cover types (e.g., turbidity and depth) (see tables 4 and 5 and figure 7). Summer habitat was quite different from spring habitat, as it was generally deeper, with larger substrates that held little IV, SAV, algae, and detritus (see tables 4 and 5). Furthermore, the coupling of depth and turbidity may have often limited primary productivity and the establishment of SAV by reducing water clarity and light penetration into the water column (Henley et al. 2000). This stark change in habitat association may have required changes in diet and behavior as well. In this same vein, turbidity in the form of cover has been of noted importance for the recruitment of razorback suckers (Golden and Holden 2003); but like IV, turbidity may only be an important influence on habitat association seasonally (see tables 4 and 5). 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).

Although razorback suckers have been contacted in areas with depths as great as 92.0 m in Boulder Basin (BIO-WEST, unpublished data), the majority of habitat sonic-tagged, juvenile razorback suckers associated with was less than 20 m deep. 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 benthic features at the different study areas could not be well described in these sampling protocols; more simply, benthic structure and variability were quantified by substrate compositions that may have been less descriptive and more a function of substrate availability. Finer substrates like silt and sand were likely more common due to the influence of inflow areas near Las Vegas Wash and the Virgin River, thus making the noted importance of larger substrates such as gravel and cobble to reproductively active razorback sucker adults a potential limiting factor for recruitment success (Shattuck et al. 2011). Additionally, as Echo Bay was not as turbid as Las Vegas Bay or the Virgin River/Muddy River inflow area, and as Echo Bay lacks a perennial inflow, SAV was the most abundant cover type, primarily comprised of spiny naiad (*Najas marina*) in shallow areas (see table 5). Substrate varied more than at the other study sites, with higher compositions of sand, gravel, and cobble in habitats associated with sonic-tagged, juvenile razorback suckers. This difference in

Sonic Telemetry and Habitat Use of Juvenile Razorback Suckers in Lake Mead, 2013–2014 Annual Report

substrate composition may partially explain differences between the amount of association adult and juvenile razorback suckers exhibit with habitat in Echo Bay (see table 5).

The variability seen among sites with the collection of habitat and physicochemical data lake-wide greatly increased our understanding of what characterizes habitat frequently associated with sonic-tagged, juvenile razorback suckers. The potential environmental mechanisms responsible for driving the availability of these types of habitat, coupled with an understating of how the faunal assemblage relationships vary with changing habitats, illustrates a more complete understanding of the razorback sucker recruitment process in Lake Mead. Furthering the collection of habitat data and describing differences observed in sonic-tagged, juvenile razorback sucker seasonal habitat associations helps increase the inference power of multivariate analyses.

Both the CCA and PCA (see figures 15 and 16) 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 fish assemblage structure in Lake Mead through which a number of environmental and habitat variables were highlighted as explaining larger portions of the variation seen in the fish assemblage. However, due to a relatively small sample size that did not exceed a 10:1 ratio of samples to variables (Hair et al. 1998), fish sampling data were duplicated to increase sample size and were lumped for the sampling area and replicated for each habitat replicate. In doing so, a pseudoreplication violation may have been committed in the CCA model. Although fish sampling data were collected in the same time and space manner as the habitat data collection, absolute fish abundances would need to have their own unique habitat replicate in which their collection was associated with, or habitat replicates would need to be averaged by sampling area in order to use one lumped sample of fish collection data. This violation may artificially increase the significance of the CCA model; however, this ordination technique is rather robust and has been shown to perform well despite unideal sampling designs, multicollinearity between environmental variables, and even skewed species distributions and abundances (ter Braak 1987; Palmer 1993; Hair et al. 1998).

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 or contacts with juvenile razorback suckers, the spatial positioning of this life stage continues to become more meaningful. As an example of such meaning, adult razorback suckers were partitioned to be more associated with greater depths, a lack of discernable cover, and increased temperatures and DO concentrations (see figure 15). The modeling of this particular life stage is supported, as captures of adult razorback suckers in

Sonic Telemetry and Habitat Use of Juvenile Razorback Suckers in Lake Mead, 2013–2014 Annual Report

Las Vegas Bay have occurred in near identical habitats for the second consecutive year, and past adult sampling has noted razorback suckers frequenting the area (Albrecht et al. 2008a, 2013a, 2013b; 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 multivariate space. Again, although the model is somewhat theoretical, the output observed makes biological sense: cover-philic taxa were closely associated with IV, SAV, and LWD; functionally similar gizzard shad were plotted near juvenile razorback suckers; and larger substrates and SAV were directly correlated with Echo Bay (see figure 15).

The CCA model captured the variation in samples and attributed relationships based on the whole of the data; however, 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 (see figure 16). It appears that habitat in spring is characterized by turbidity and IV, particularly at the Virgin River/Muddy River inflow area (see figure 16). As these variables are strongly related to seasonally occupied habitat, substrate size and SAV helped define the study site of Echo Bay, while conductivity, DO, and LWD helped define Las Vegas Bay (see figure 16). The PCA model suggests that the spring habitat associations are partially driven by turbidity and the presence of IV before sonic-tagged, juvenile razorback suckers transition into deeper summer habitat with more substrate heterogeneity (see figure 16). Additional fall samples will serve to strengthen observed seasonal variations in habitat and potentially help describe more of the observed variation in the PCA model, yet still there appears to be strong extrapolative power in the model, rooted in observations for Lake Mead in its entirety.

During spring, habitat for juvenile individuals appears to be characterized by higher turbidities, an abundance of inundated cover, silt substrate, and higher DO concentrations (see figure 16). Moving into summer, habitat for juvenile individuals is more closely associated with larger substrates, increased depths, and higher temperatures. Finally, fall habitat for juvenile individuals can be described as greater in depth, lower in turbidity, and with no discernable cover; however, due to a smaller sample size, fall habitat may not be as descriptive as other seasons included in the model (see figure 16).

Conclusions

The collection of multifaceted data in direct association with juvenile razorback suckers makes this study particularly interesting and important for species conservation efforts. The razorback sucker juvenile life stage is one of the most understudied 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 multiyear study seeks to better define juvenile razorback sucker movement and habitat associations. Although the data presented for the 2013 study year mainly encompasses the spring and summer seasons (due to the timing of the ICS period), the real value can be found in the combination of multiple years of data with efforts progressively focused on varying time periods. Throughout 2013, 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 2013 helped match the number of razorback suckers captured during long-term monitoring in Las Vegas Bay and confirmed the usefulness of sonic-tagged, juvenile razorback suckers as a means to locate wild conspecifics. These findings allow for a greater understanding of the species as a whole and help us attain a more accurate 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 manage toward 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 have continued to leave only fundamental recruitment questions about the Lake Mead populations. 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 an understanding of the first years of growth in juvenile razorback suckers is largely unknown, there still remains a need to establish a better understanding of nearly every aspect of juvenile razorback sucker life history. Although we now have an increased amount of information regarding this life stage during the spring and summer seasons, further efforts focused on the fall and winter seasons will likely offer a more complete understanding of why razorback sucker are able to recruit in Lake Mead.

2014–15 WORK PLAN

Specific Objectives for the Second Field Season

1. We anticipate that the efforts for the first option year will be nearly identical to efforts for the 2013–14 study year. Efforts for the ICS will again be conducted through the duration of the PT-4, 3-month sonic transmitters; however, the timing of initial sonic tagging for a juvenile razorback sucker (implanting both the PT-4, 3-month transmitters and the IBT-96-9, 12-month transmitters) will occur during a different period of the calendar year and at two separate times for the two types of transmitters. We anticipate that tagging efforts will occur during the month of May for four fish tagged with IBT-96-9, 12-month transmitters at each site to continue AHS efforts. No conspecific or community fish sampling will be conducted during these monthly efforts. To capture seasonal variation, the ICS efforts will commence with the tagging of two fish with PT-4, 3-month transmitters in September at each site. Following tagging, sonic telemetry, physicochemical data collection, and conspecific and community fish sampling will be conducted on a weekly basis for the 12-week period coinciding with the expected battery life for the PT-4, 3-month transmitters and allowing for more detailed data collection associated with the fall months.
2. We will continue to lend support to the Lake Mead Work Group. In short, this effort will also help us 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 ongoing at all of the long-term monitoring sites and the Colorado River inflow/lower Grand Canyon. Since 2010, efforts undertaken to document the presence or absence of razorback suckers at the Colorado River inflow have resulted in the capture of wild, ripe adult and larval razorback suckers, and 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 have helped locate sonic-tagged fish originating from the long-term monitoring study areas and have documented sonic-tagged individuals utilizing the Colorado River proper and moving into the lower Grand Canyon (Kegerries and Albrecht 2013). Thus, the potential exists for continued, perhaps increased, exchange of sonic-tagged razorback suckers among different areas of Lake Mead though the three ongoing, concurrent studies. Furthermore, it will be important to ascertain whether any of the PIT-tagged fish that may be captured during juvenile fish community sampling are recaptured at the Colorado River inflow or

**Sonic Telemetry and Habitat Use of Juvenile Razorback Suckers
in Lake Mead, 2013–2014 Annual Report**

during long-time monitoring efforts (or vice versa). Coordination and collaboration between all field crews and studies will continue, as necessary, to achieve the best possible research system for more holistically understanding Lake Mead razorback suckers.

4. Continue to document and 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 the overall goal of the juvenile study, as contained in this report, 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. Findings to date suggest that additional effort pertaining to the early life stages of Lake Mead razorback sucker has been informative and that it will be important to track these parameters through all seasons as this study progresses. Hence, it is imperative to conduct this study for multiple years so as to capture any important seasonality components. Information gained in capturing seasonal variation with regard to recruitment will likely allow for a more complete understanding of the complex processes that have created the unique wild recruiting population of razorback suckers in Lake Mead, which is potentially the last population of its kind. Furthermore, 3 years of data will add greater power to statistical analyses and reduce the amount of annual or seasonal bias incorporated with a single year of study.
5. Sonic tag wild-caught juvenile razorback suckers from Lake Mead if/when they are captured so as to increase inferences regarding this relatively understudied life stage and to promote effective, efficient study efforts in the future.

ACKNOWLEDGMENTS

This project was funded by Reclamation (under the LCR MSCP) and was a cooperative effort among BIO-WEST, Reclamation, Southern Nevada Water Authority, NDOW, Arizona Game and Fish Department, National Park Service, and the U.S. Fish and Wildlife Service. Sampling, logistics, and planning strategies were conducted jointly among these groups in various capacities. We thank Ron Kegerries, Jim Stolberg, Nathan Rudd, and Sandra Livingston Turner for constructive comments provided during the review process as well as the many others involved.

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