Lower Colorado River Multi-Species Conservation Program

Balancing Resource Use and Conservation

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

2014–2015 Annual Report

U.S. Department of the Interior
Bureau of Reclamation

March 2015

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Lower Colorado River Multi-Species Conservation Program

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March 2015

Keggeries, R., Z. Shattuck, B. Albrecht, and R. Rogers. 2015. Sonic Telemetry and Habitat Use of Juvenile Razorback Suckers in Lake Mead, 2014–2015 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
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

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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 tags 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, which also extended into 2014, to better understand juvenile razorback suckers in Lake Mead. This report presents information from the second study year (2014–15) and provides information stemming from both the intensive community sampling (ICS) efforts conducted from September through November (late summer/fall season) and 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 are included for completeness.

During the 2014–15 study year, the habitat use and movements of 18 sonic-tagged, juvenile razorback suckers were monitored through active tracking, which resulted in 120 total contacts that included all individuals. Additionally, nine submersible ultrasonic receivers were deployed throughout the lake to passively detect lake-wide movement of tagged individuals. Five of the receivers detected juvenile razorback suckers and recorded a total of eight contacts. The sonic-tagged, juvenile fish were obtained from the Nevada Department of Wildlife's Lake Mead Fish Hatchery, successfully implanted with appropriately sized sonic tags, 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 was conducted using a wide variety of sampling techniques and gear types, as little is known about this life stage of razorback suckers. During 2014, sampling for this life stage occurred only in locations where sonic-tagged, juvenile razorback suckers were detected.

ICS efforts involved a suite of methods and were composed of 259 total gear sets, 7 seine hauls, and 8,707 seconds of electrofishing, and it resulted in the capture of 2,527 individual fishes from 16 species. Included in the fishes captured were 11 razorback suckers (9 new wild captures, 1 wild recapture, and 1 stocked recapture). All razorback suckers were captured in direct association with sonic-tagged, juvenile razorback suckers in Echo Bay and Las Vegas Bay during

September and November 2014. Fin ray sections were removed from eight individuals for age determination which, when combined with the 493 fish aged during previous studies (Albrecht et al. 2014a, 2014b), brought the total number of fish aged during all Lake Mead razorback sucker studies to date to 501. Of particular interest is the continued documentation of recent (2005–08) recruitment under mostly declining lake elevations. In the past, recruitment pulses in Lake Mead appeared to be associated with relatively high, stable lake levels. However, based on data collected from 2007 to 2013, strong pulses in recruitment that coincide with low, declining lake level trends and high-flow events in the Virgin River have been observed. Age data obtained thus far indicate that Lake Mead razorback sucker recruitment occurs nearly every year, under various lake conditions, and with varying year-class strength. The 2014–15 study increased our understanding of conditions that promote the unique recruitment pattern of razorback suckers in Lake Mead.

For the habitat assessment and physicochemical quantification, over 300 replicates from 110 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 to explain the ecological relationships between habitat and fish species composition and characterize the spatiotemporal habitat association specific to sonic-tagged, juvenile razorback suckers. Generally, sonic-tagged, juvenile razorback suckers were associated with shallow habitat characterized by varying amounts of inundated cover and high turbidities during spring and early summer. Following mid-summer increases in water temperatures, sonic-tagged, juvenile razorback suckers moved offshore into deeper habitat where they remained until fall. During fall, a shift back into shallower habitats with cover was observed. Although much of the sampling in 2013 and 2014 was conducted during the late spring, summer, and early fall seasons, in future study years, we will continue the varied seasonal approach and include focused sampling during the late fall and winter seasons.

Research plans for the 2015–16 study year include implanting additional juvenile razorback suckers to continue the AHS efforts (additional implantations will be necessary in May as current sonic tag batteries near failure) and additional ICS during the late fall and winter seasons (an additional sonic implantation event will occur in December to provide adequate coverage). These two implantation events should provide enough sonic-tagged, juvenile razorback suckers for the 2015–16 study year. These efforts will not only facilitate habitat association data collection during AHS but will also ensure the investigation of juvenile razorback sucker habitat use, foster conspecific capture opportunities, and elucidate seasonal fish community associations. In the end, sonic tagging efforts will inform and enhance our understanding of this early life stage of razorback suckers and specifically allow for identification and a more indepth understanding of recruitment in Lake Mead. While the results contained herein are interesting and informative, additional, more complete information about juvenile razorback suckers and insights into their natural recruitment 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* [Abbott]) 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 with and predation by 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

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 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-millimeter (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 2013b). 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 2007 through 2014 resulted in the capture of 72 wild (unmarked) juvenile razorback suckers (Albrecht et al. 2006a, 2007, 2008a, 2008b, 2010b, 2013a, 2013b, 2014a, 2014b; Kegerries et al. 2009; Shattuck et al. 2011; Kegerries and Albrecht 2013a, 2013b). 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 tags 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 sonic 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 the locations of juvenile razorback suckers. 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 pilot study success, Reclamation (under the LCR MSCP) provided funding for a full-scale juvenile razorback sucker sonic telemetry and habitat use study for multiple locations within Lake Mead during 2013 with optional continuation years (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 2013a, 2013b).

STUDY AREAS

During 2014, all juvenile razorback sucker sonic telemetry and habitat assessment activities in Lake Mead occurred at the locations studied during juvenile sampling and long-term monitoring efforts from 1996 through 2014, 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, 2014a; Kegerries et al. 2009; Shattuck et al. 2011; Shattuck and Albrecht 2014).

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 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 level affects what is called the “wash” or “bay,” the above definitions are used to differentiate the various habitats at the time of sampling.

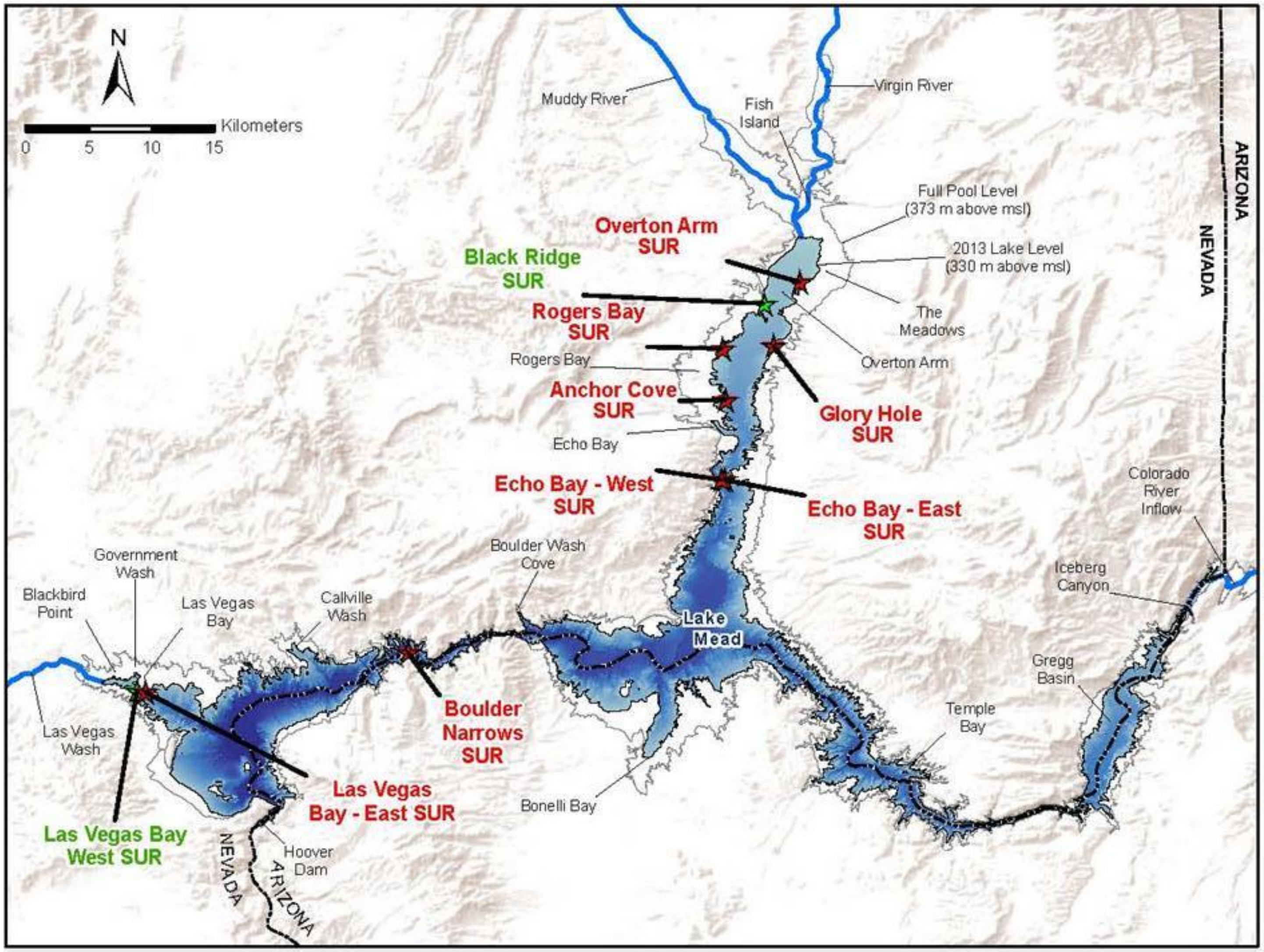

Figure 1.—Juvenile razorback sucker study areas in Lake Mead, Nevada, 2014. Locations of submersible ultrasonic receivers are denoted by red stars (units maintained by BIO-WEST) or green stars (units maintained by the NDOW).

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 of the Overton Arm (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 level, 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 Level and Inflow Discharges

Daily lake levels for the 2014 calendar year are provided for context (note field efforts for this study specifically spanned January 6 – December 11, 2014) and were measured in meters above mean sea level (msl) as obtained from Reclamation's Lower Colorado Regional Office Web site (Reclamation 2014). 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 2014 calendar year (USGS 2014) as available. Gage locations included the 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

Twelve juvenile razorback suckers from NDOW's Lake Mead Fish Hatchery were implanted with sonic tags on March 5, 2014, and subsequently released into Lake Mead on March 6, 2014, with the assistance of the NDOW and Reclamation. Each cohort of four juvenile razorback suckers (i.e., four individuals in Las Vegas Bay, four individuals in Echo Bay, and four individuals in the Virgin River/Muddy River inflow area) were implanted with Sonotronics model IBT-96-6 tags. On September 1, 2014, an additional six juveniles from NDOW's Lake Mead Fish Hatchery were implanted with smaller Sonotronics model PT-4 tags. Two fish with each type of sonic tag were released at each study area the following day.

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 (%) tag-weight-to-fish-weight, ensuring that the sonic tags were not too large for the fish (Bidgood 1980; Winter 1983; Marty and Summerfelt 1990).

For increased battery longevity, all sonic tags were modified by Sonotronics as R-code companion tags (R-cc) to obtain 3- and 12-month battery lives; without the R-cc, these sonic tags had an expected battery life of less than 3 (PT-4) and 8 months (IBT-96-6), respectively. Two tag sizes were implanted in the smallest juvenile individuals possible; this method provides the same result as implanting a larger individual with a larger sonic tag.

The IBT-96-6, 12-month sonic tags had a weight of 3.9 grams (g) and measured 42 mm long by 11 mm in diameter. These tags were implanted into individuals measuring greater than 274 mm TL and weighing more than 195 g (figure 2). Similarly, the PT-4, 3-month sonic tags had a weight of 2.3 g and measured 25 mm long by 9 mm in diameter. These tags were implanted into individuals measuring greater than 226 mm TL and weighing more than 115 g (figure 2). All sonic tags were programmed to use a 75-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. To properly identify tags using the R-cc, the firmware of all submersible ultrasonic receivers (SURs) was updated in the field prior to the release of sonic-tagged individuals, and a Sonotronics USR-08 receiver was used for manual tracking and sonic tag 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,

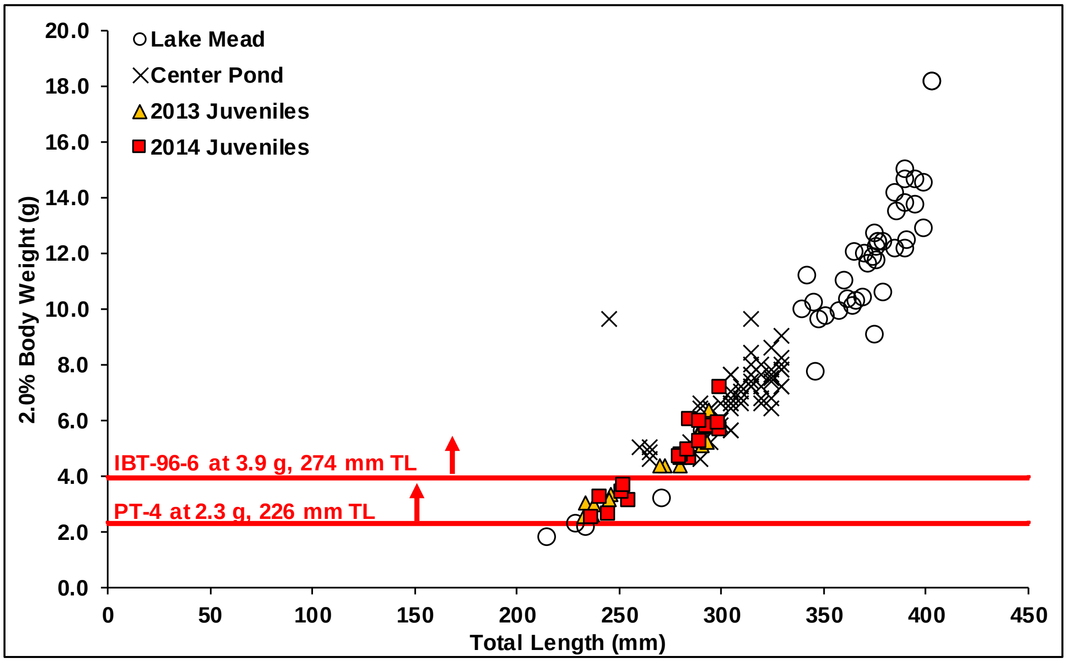

Figure 2.—Sonic tag sizing chart for juvenile razorback suckers surgically implanted in 2014 according to a guideline of tag weight not exceeding 2% of body weight (Bidgood 1980; Winter 1983; Marty and Summerfelt 1990) with a sizing curve based on empirical captures of Lake Mead razorback suckers less 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.

Albrecht et al. 2013a). Surgery was performed at NDOW's Lake Mead Fish 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 sonic tags 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 sonic tag, which was placed between 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 a separate fiberglass tank filled with hatchery water and fitted with air stones attached to a compressed oxygen bottle before being transported to stocking locations via truck and boat. Upon arrival at the 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 sonic tags were rechecked for functionality. All juvenile razorback suckers were either released in locations frequented by other juveniles or in association with dense cover. 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 January 6 to December 11, 2014; 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 (September 1 – November 21, 2014), which was associated with fish community data collection in addition to habitat data collection, tracking was conducted on a weekly basis because of the shorter battery life expectancy of the smaller PT-4 sonic tags. During the AHS period (January 6 – August 31, 2014, and November 22 – December 11, 2014), which was associated solely with habitat data collection and the larger IBT-96-6 sonic tags, tracking was conducted on a monthly basis.

Sonic tracking of 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 tracking of juvenile razorback suckers has shown that individuals often associate with dense IV (known to impact signal reception) (Albrecht et al. 2013a); thus, considerable effort was spent listening in areas with 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; authors' personal experience), listening points were spaced closer together in areas of varying habitat. Additionally, because sonic-tagged razorback suckers were at times located in areas of Lake Mead that were inaccessible by boat (e.g., shallow peripheral habitats and flowing portions of inflow areas), the range of observed fish movements may not fully represent their entire use of a particular area.

Active sonic tracking consisted of listening underwater for coded sonic tags 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 omnidirectional hydrophone was trolled behind the 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 sonic-tracking methods, SURs were deployed in various locations throughout Lake Mead (see figure 1). The advantage of 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 sonic tags, 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 monthly tracking events and can indicate whether or not a juvenile individual has moved into or out of a particular area. Nine SURs were utilized during the 2014–15 study year. These units were situated before the initial stocking of sonic-tagged, juvenile razorback suckers in order to monitor movements of individuals immediately (see figure 1).

Each SUR was programmed to detect the frequencies of adult and juvenile razorback suckers' sonic tags using Sonotronics's SURsoft software with channels that spanned 69–80 kilohertz. In deployment, the semibuoyant SURs were weighted using approximately 57 g of lead and secured to shore using 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 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 (September 1 – November 21, 2014) 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 sampling efforts to specific 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. In cases where razorback suckers were captured, individuals were removed alive from nets and 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, samples were collected from 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, and genetic specimens were 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 25.0 °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 areas by species. Additionally, when species known for razorback sucker predation were captured, TLs of the predatory species and razorback suckers from all lumped study areas were compared to assess potential size differences and potentially determine where and why razorback suckers are captured.

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, 22.9, or 15.2 m long by 1.2 m deep, with an internal panel of 2.5-cm mesh and external panels of 30.5-cm mesh. 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. 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 or 1.8 m in diameter with 10.2-cm throats and 6.4-mm or 12.7-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 areas, seines were used to sample littoral habitats free of obstruction and in areas of flowing water. Seines measured 4.6 m wide by 1.2 m tall with 3.0-mm mesh. Seine haul effort was calculated as area sampled (square meters [m^2]) by multiplying the length of the haul by the width of the net. As with other sampling gears, the effort expended at each sampling 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 2013–14 study year, previously unaged, wild-caught razorback suckers captured via trammel netting were anesthetized, and an 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 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 (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.

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 m^2) or a 36-m radius circle (4,069 m^2) 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, sampling occurred on a weekly basis with habitat described and quantified in conjunction with fish sampling, while during the AHS period, sampling occurred on a monthly basis without additional fish sampling.

For each contacted juvenile, up to five replicate measurements and observations of water quality, substrate, and vegetation were recorded within the predetermined sampling areas described above. The number of replicates was based on the habitat heterogeneity in an effort to capture differences in habitat within each sampling area. Fewer replicates were conducted in sampling areas with more homogenous habitats. 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 outside of the same predetermined sampling site were recorded in a separate site with its own set of replicates. Within each sampling area, 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. 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 [µS/cm]), pH, and turbidity (nephelometric turbidity units [NTUs]). After the water column was assessed for these standard parameters from surface to bottom, a substrate grab sample was collected to visually estimate 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 an 18.9-L bucket for visual percentage composition assessment. Additionally, while assessing the substrate, 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 GPS unit or gridded template was used to create spatial polygons 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 maritime*]); 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 razorback sucker-habitat relationships, associated fish community demographics, and spatial and temporal differences observed throughout the study. Although the data analyzed throughout this annual report pertain to sampling conducted through the 2014–15 study year, data used in multivariate analyses are cumulative and include data collected from the 2013–14 and 2014–15 study years as recommended in Shattuck and Albrecht (2014).

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 area. A one-way analysis of variance (ANOVA) was used to assess the significance of differences in fish catch rates by sampling location, catch rates by sampling gear, mean TLs among razorback suckers and known predatory species, fish TL by season, fish TL by sampling location, and depth of contact for sonic-telemetered fish. 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. 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 sampling 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 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 2012). As information regarding recruitment of razorback suckers and habitat use by young fish is limited, this type of exploratory analysis is useful for identifying and describing overall relationships observed in habitat and fish community data. 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).

In the CCA, 107 total samples and 18 variables were used, with each sample consisting of habitat data tabulated for each sonic-tagged, juvenile razorback sucker encounter. Mean numeric value was used for the habitat variables of depth, temperature, conductivity, DO, pH, turbidity, and substrate-composition percentages, 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”). Data were $\log_{10}$ transformed in CANOCO 5.0, and each variable was tested for normality using a Shapiro-Wilk Test in Statistix 8.1 (Analytical Software 2005; ter Braak and Šmilauer 2012). Subsequently, no variables were significantly different than normal, and the data transformation ensured a standardized dataset. Spatial designation was included to describe differences in juvenile razorback sucker habitat association within Lake Mead by season and by study area. Species data for sampling conducted at each encounter were included as lumped raw abundance for captured species, irrespective of gear type. It was assumed that fishes captured in the sampling area could feasibly associate with any number of habitat or physicochemical variables within that sampling area at a given point in time. Because habitat was recorded and fish sampling was conducted around known juvenile razorback sucker, 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. Although hatchery-reared, sonic-tagged juveniles were not necessarily captured with deployed sampling gears, their presence in the sampling area was known based on sonic telemetry points of contact. 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 5.0 was used to run ordination and variation partitioning (Borcard et al. 1992; ter Braak and Šmilauer 2012). Any encounter events that did not include a complete dataset were assessed for the potential of using recently recorded physicochemical or habitat measurements to supplement missing data. When possible, data collected during 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 2012). As such, two samples were not included in the CCA model due to equipment malfunction, and three samples included an estimated turbidity value. Although sampling data were more limited in multivariate analyses for the 2013–14 study year report, the cumulative dataset that includes data from both the 2013–14 and 2014–15 study years maintains a recommended minimum ratio of observations (n = 107) to variables (n = 18) of 3:1 (McGarigal et al. 2000).

Output plots from CANOCO 5.0 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 99,999 Monte Carlo permutations in a nonparametric randomization test run in CANOCO 5.0 (Borcard et al. 1992; ter Braak and Šmilauer 2012).

Principal Component Analysis

Using a similar data matrix design to 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 a 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 the 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).

Ordinal data for season, sampling site, and the presence or absence of algae and detritus were not included in the data matrix; rather, seasonal samples organized by sampling site were identified post-hoc to monitor differences in physical habitat variation without additional seasonal influence on samples. In total, 196 samples and 15 variables were used in the PCA, data were $\log_{10}$ transformed in CANOCO 5.0, and normality was tested for each variable using a Shapiro-Wilk Test in Statistix 8.1 (Analytical Software 2005; ter Braak and Šmilauer 2012). No variables were significantly different than normal, and the data transformation ensured a standardized dataset (McGarigal et al. 2000). Mean habitat data used in numeric form included depth, temperature, conductivity, DO, pH, turbidity, substrate composition percentages, and cover type percentages. 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 2012). As such, two samples were not included in the PCA model due to equipment malfunction, seven samples included an estimated turbidity value, and three samples included an estimated substrate composition percentage. In determining the significance of the proportion of variance explained by a particular component (i.e., principal component axes), a value was derived from the broken-stick model in post-hoc comparison (Frontier 1976; McGarigal et al. 2000; Peres-Neto et al. 2003; Olden 2011). As in the CCA model, the cumulative dataset that includes data from both the 2013–14 and 2014–15 study years maintains a recommended minimum ratio of observations (n = 196) to variables (n = 15) of 3:1 and meets more conservative recommendations of 10:1 (Hair et al. 1998; McGarigal et al. 2000).

Using the multivariate analysis of a 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 in which physical habitat variables carry the most weight of variation explanation. Output from a PCA can be interpreted; 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 with sonic-tagged, juvenile razorback suckers. Points located at axis extremes are more influenced by the associated variables, while points located near the axes' origins do not show a strong association with or explanation for 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 2014–15 study year, as they essentially describe two different relationships in 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 and provide insight into juvenile razorback sucker locations and why they might recruit in Lake Mead.

RESULTS

Lake Level and Inflow Discharges

In past studies, juvenile razorback suckers appeared to associate with inflow areas and anecdotally depended 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 levels for Lake Mead, mean daily discharges from the Las Vegas Wash, the Virgin River, and the Muddy River were documented to better assess how inflow areas within the lake might affect habitat availability (figure 3).

As lake levels generally declined from January through June, so did mean daily discharges in the Virgin River (see figure 3). The lake level decreased nearly 9.0 m from a high of 338.0 m above msl on February 2, 2014, to a low of 329.2 m above msl on August 12, 2014 (see figure 3). With declines in lake level, expanses of habitat that were inundated during AHS were subsequently dry at the time of ICS. This change in lake level may have influenced the types of habitat available to sonic-tagged, juvenile razorback suckers. Although available data are limited for Virgin River discharge, high flows were not recorded in spring 2014, and discharge continued to decline through March (see figure 3). 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 near 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 into Lake Mead during 2014 was often an order of magnitude more than both the Virgin and Muddy Rivers (see figure 3). In fact, it was not until late summer and fall that the Virgin and Muddy Rivers saw notable increases in the frequency and magnitude of discharge, with high-discharge events stemming from monsoonal rains that occurred from August through September (see figure 3). These seasonal increases in flow appeared to provide 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, which has been noted as an important form of cover for razorback sucker recruitment (Golden and Holden 2003; Albrecht et al. 2010a, 2013a; Shattuck et al. 2011).

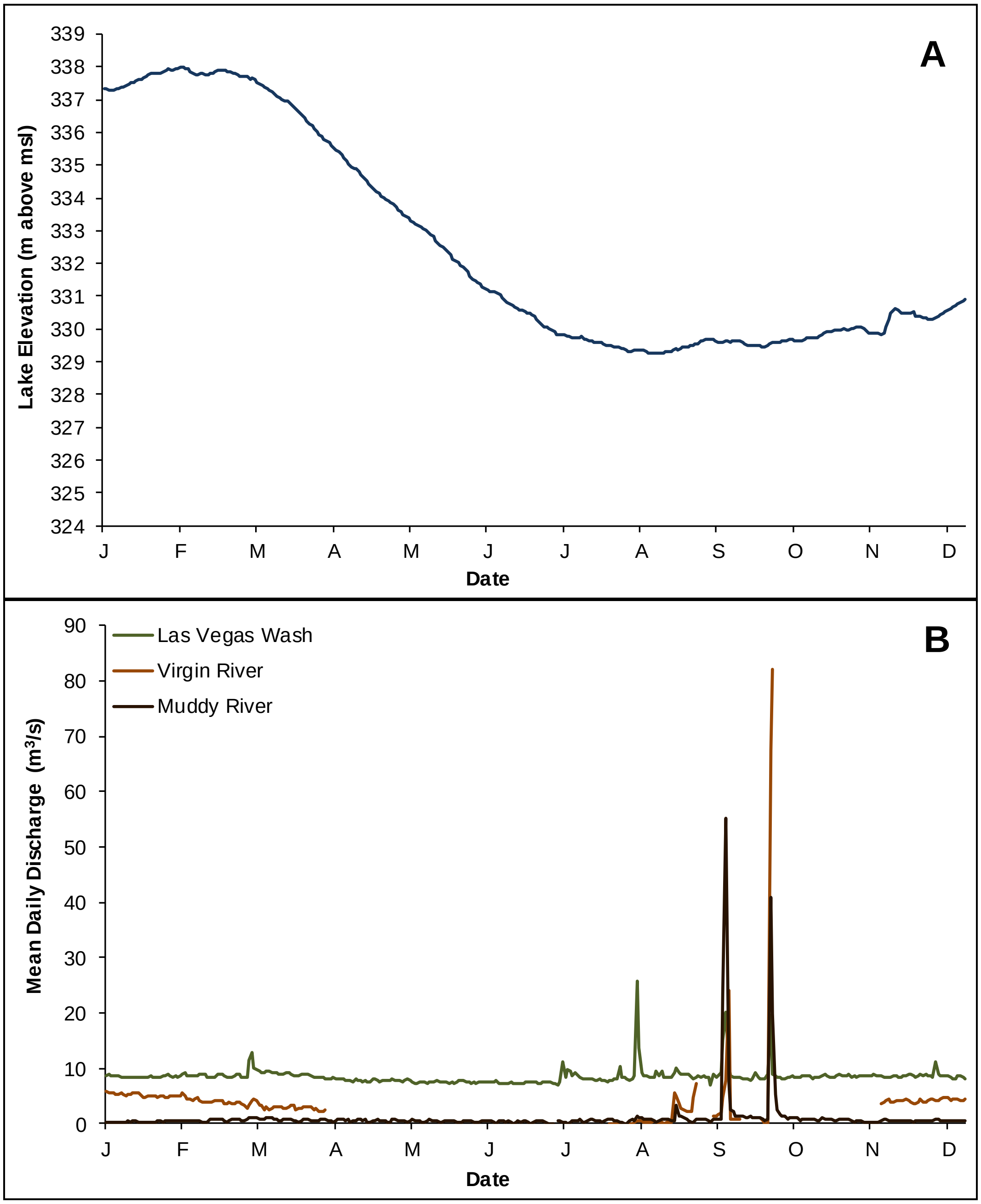

Figure 3.—Daily lake levels (A) for Lake Mead in meters above msl, January 1, 2013 – December 31, 2014 (Reclamation 2014), and mean daily discharges (B) in cubic meters per second for Las Vegas Wash, the Virgin River, and the Muddy River, January 1 – December 31, 2014.
Discharge data are provisional and subject to USGS revision.

Sonic Telemetry

Eighteen juvenile razorback suckers (237–300 mm TL) were successfully implanted with sonic tags 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 twenty active contacts spanning January 7 – December 9, 2014, were made with sonic-tagged, juvenile razorback suckers released in 2014, all of which were contacted at least once (table 1). Only one individual that was tagged and released in 2013 was contacted three times, with the last contact occurring on April 9, 2014. The larger IBT-96-6 sonic tags implanted in 2013 were expected to be active until at least May 2014. Given the life expectancy of the PT-4 sonic tag batteries, it is likely that the PT-4 tags implanted in 2014 are inactive; however, the IBT-96-6 tags should continue to transmit until May or September 2015 depending on the 2014 fish stocking date. Additionally, one fish (code 3003) stocked in May 2013 was recaptured alive in November 2014; however, the sonic tag had expired (table 1).

Generally, sonic-tagged, juvenile razorback suckers remained at their respective release/study areas during 2014, with the exception of three fish (codes 3020, 3027, and 3028) that remained in Echo Bay after stocking and were located within the Virgin River/Muddy River inflow area during summer and fall. A comparison among season and mean depths (in meters) of sonic-tagged fish at contact revealed that they occupy habitats in significantly deeper water during summer and fall compared with spring (ANOVA, $F_{2,224} = 4.98$, $P = 0.0077$; Tukey’s Honestly Significant Difference Test). A significant difference in mean depth at contact among study areas was also documented (ANOVA, $F_{2,226} = 18.2$, $P < 0.0001$). Post-hoc analysis revealed that sonic-tagged fish contacted in or near Echo Bay were occupying the deepest habitats, followed by Las Vegas Bay and the Virgin River/Muddy River inflow area, from deepest to shallowest, respectively.

It appeared that within each study area, local movements transitioned somewhat with season. In Las Vegas Bay, 5 individuals were located for a total of 40 active contacts during 2014 (figure 4). Individuals frequented the western portion of Las Vegas Bay and were regularly contacted from the flowing extent of the Las Vegas Wash eastward and into Government Wash Cove (figure 4). Through spring, relatively few contacts (n = 4) were made with sonic-tagged, juvenile razorback suckers. These contacts were in habitat with an average depth of 4.9 m (SE ± 0.9) near the mouth of Las Vegas Wash and east into the mid-channel (figure 4). As summer progressed, sonic-tagged, juvenile individuals were contacted in somewhat deeper habitat that averaged 6.6 m SE ± 0.9) near Las Vegas Wash. In fall, they were found in habitat with even greater average depths (9.7 m [SE ± 1.0]), mostly within and just outside Government Cove. Most of these individuals were stocked in Government Cove in September (table 1).

Table 1.—Demographic summary with included sonic tag 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, 2014

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	0 (0)	Unknown
LMFH	5/7/2013	3001	273	218	I	LB	LB-W	9/13/2013	0 (0)	Unknown
LMFH	5/7/2013	3002	290	278	I	LB	LB	5/20/2013	0 (0)	Unknown
LMFH	5/7/2013	3003	289	278	I	LB	LB	11/11/2014	0 (0)	Inactive
LMFH	5/7/2013	3012	233	126	I	LB	LB	7/16/2013	0 (0)	Unknown
LMFH	5/7/2013	3013	246	166	I	LB	LB	7/22/2013	0 (0)	Unknown
LMFH	5/7/2013	3004	291	286	I	EB	EB	5/8/2013	0 (0)	Unknown
LMFH	5/7/2013	3005	295	288	I	EB	EB	10/23/2013	0 (0)	Unknown
LMFH	5/7/2013	3006	270	216	I	EB	EB	7/23/2013	0 (0)	Unknown
LMFH	5/7/2013	3007	293	260	I	EB	EB	4/9/2014	3 (0)	Unknown
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	0 (0)	Unknown
LMFH	5/7/2013	3008	293	290	I	OA	OA	7/18/2013	0 (0)	Unknown
LMFH	5/7/2013	3009	294	318	I	OA	OA	7/18/2013	0 (0)	Unknown
LMFH	5/7/2013	3010	280	216	I	OA	OA	5/9/2013	0 (0)	Unknown
LMFH	5/7/2013	3011	294	290	I	OA	OA	7/24/2013	0 (0)	Unknown
LMFH	5/7/2013	3016	237	130	I	OA	OA	7/24/2013	0 (0)	Unknown
LMFH	5/7/2013	3017	238	146	I	OA	OA	5/9/2013	0 (0)	Unknown
2014										
LMFH	5/6/2014	3021	285	298	I	LB	LB	12/8/2014	11 (152)	Active
LMFH	5/6/2014	3022	285	228	I	LB	LB	5/12/2014	0 (351)	Active
LMFH	5/6/2014	3023	281	228	I	LB	LB	9/18/2014	2 (0)	Active
LMFH	5/6/2014	3029	300	282	I	LB	LB	12/8/2014	18 (1632)	Active
LMFH	9/2/2014	3034	245	130	I	LB	LB	10/2/2014	3 (0)	Unknown
LMFH	9/2/2014	3035	253	180	I	LB	LB	9/4/2014	1 (0)	Unknown
LMFH	5/6/2014	3019	281	234	I	EB	EB	5/7/2014	1 (0)	Active
LMFH	5/6/2014	3020	290	260	I	EB	EB	12/9/2014	16 (46)	Active
LMFH	5/6/2014	3027	300	358	I	EB	EB	11/19/2014	14 (203)	Active
LMFH	5/6/2014	3028	293	288	I	EB	OA	12/9/2014	9 (332)	Active
LMFH	9/2/2014	3030	241	160	I	EB	EB	9/3/2014	1 (0)	Unknown
LMFH	9/2/2014	3032	252	170	I	EB	EB	9/8/2014	2 (0)	Unknown
LMFH	5/6/2014	3018	284	244	I	OA	OA	5/13/2014	2 (0)	Active
LMFH	5/6/2014	3024	299	292	I	OA	OA	5/7/2014	1 (0)	Active
LMFH	5/6/2014	3025	280	232	I	OA	OA	12/9/2014	5 (0)	Active
LMFH	5/6/2014	3026	290	296	I	OA	OA	12/9/2014	17 (444)	Active
LMFH	9/2/2014	3031	237	122	I	OA	OA	11/19/2014	9 (0)	Unknown
LMFH	9/2/2014	3033	255	154	I	OA	OA	10/15/2014	5 (852)	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.

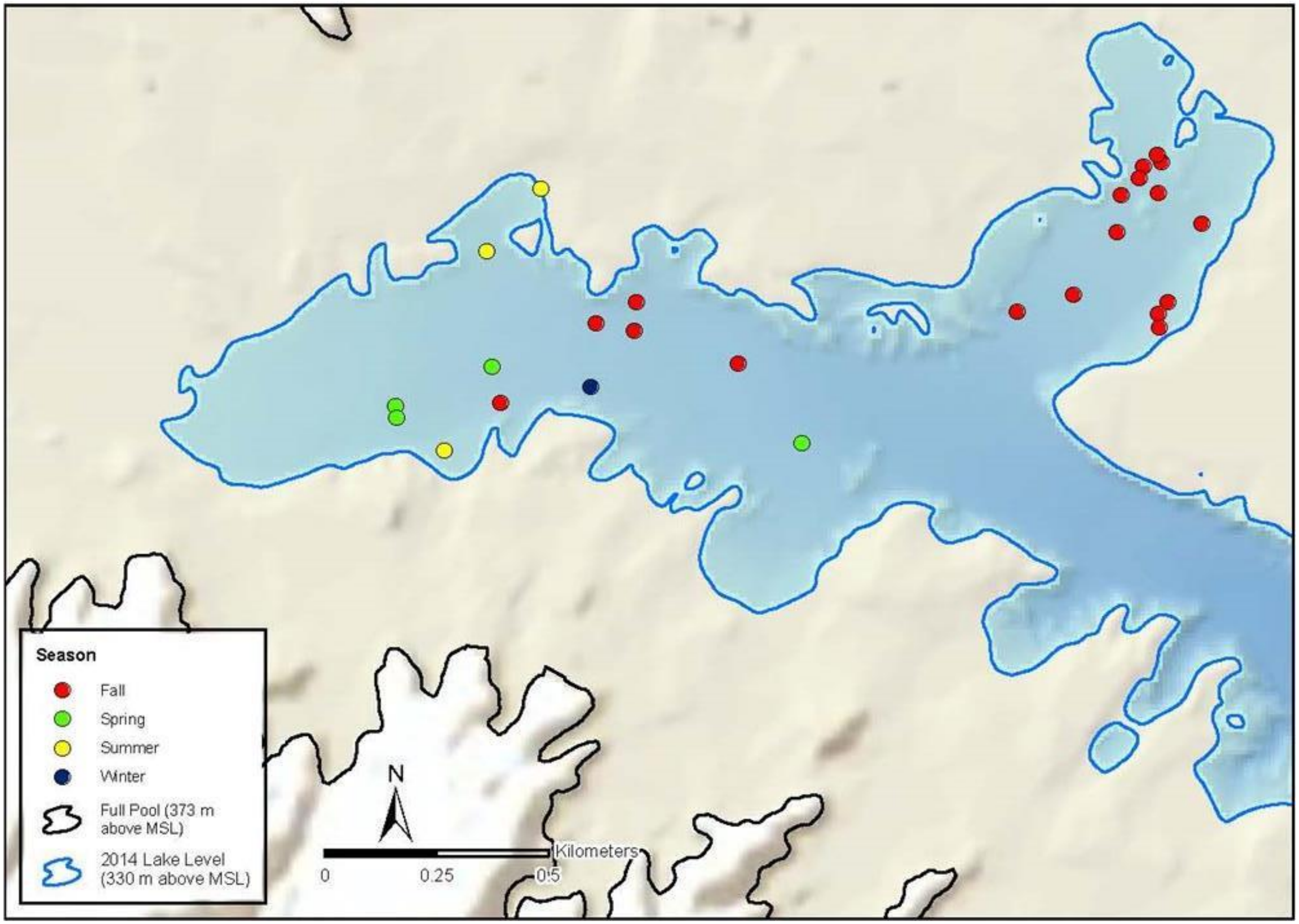

Figure 4.—Distribution of sonic-tagged, juvenile razorback suckers located through active sonic telemetry and designated by season in Las Vegas Bay, 2014.

During 2014 in Echo Bay, 46 total active contacts were made with 7 sonic-tagged, juvenile razorback suckers (figure 5). Contacts made with juveniles in Echo Bay present a relatively clear pattern of seasonal movement. In spring, most fish were located in shallower water, often near the wash inflow of Echo Bay (mean depth 6.8 m [SE ± 1.2]). As summer progressed, these fish moved offshore into deeper habitats (mean depth 11.9 m [SE ± 1.0]). By fall, and after the September stocking (see table 1), most sonic-tagged juveniles were using shallower habitats (mean depth 7.7 m [SE ± 1.0]) and moving toward the shore (figure 5). Sonic-tagged razorback suckers stocked into Echo Bay perhaps displayed some of the largest movements in 2014. Fish stocked in spring moved north near Anchor Cove, while fish stocked in fall moved north, as far as the Overton Arm near the Virgin River/Muddy River inflow area (figure 5). Interestingly, two individuals displaying northern movement out of Echo Bay returned later in fall. Perhaps most interesting was the movement of one fish (code 3027), originally stocked into Echo Bay in spring, which then moved north to near Calico Bay where it resided for several weeks in a small, relatively shallow cove with abundant IV cover (figure 5).

At the Virgin River/Muddy River inflow area, 9 different sonic-tagged juveniles were located for a total of 44 active contacts during 2014 (figure 6). These individuals exhibited a strong association with shallower habitat with dense IV and were often found along the eastern shoreline (figure 6). During spring, individuals were contacted in habitat that had an average depth of 4.0 m (SE ± 0.9). As spring progressed into summer, individuals at the Virgin River/Muddy River inflow area moved farther south into the Overton Arm and appeared to be seeking deeper habitat, which is 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 (3.9 m [SE ± 1.0]). 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). During fall and after the fall stocking, contacts with sonic-tagged juveniles were frequently made along the eastern shorelines and the western shoreline between Stewart's Point and Salt Bay (figure 6). Some of these contacts were with fish originally stocked into Echo Bay. In fall, the mean depth was 4.6 m (SE ± 1.0) at sonic-tagged razorback sucker contact points within the Virgin River/Muddy River inflow area.

From the 9 SURs deployed throughout Lake Mead during 2014, 5 units contacted 8 sonic-tagged, juvenile individuals for a total of 4,012 passive contacts during January 6 – December 11, 2014 (see table 1). In Las Vegas Bay, three individuals (codes 3021, 3022, and 3029) 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). The SURs south of Echo Bay did not contact any sonic-tagged, juvenile razorback suckers during

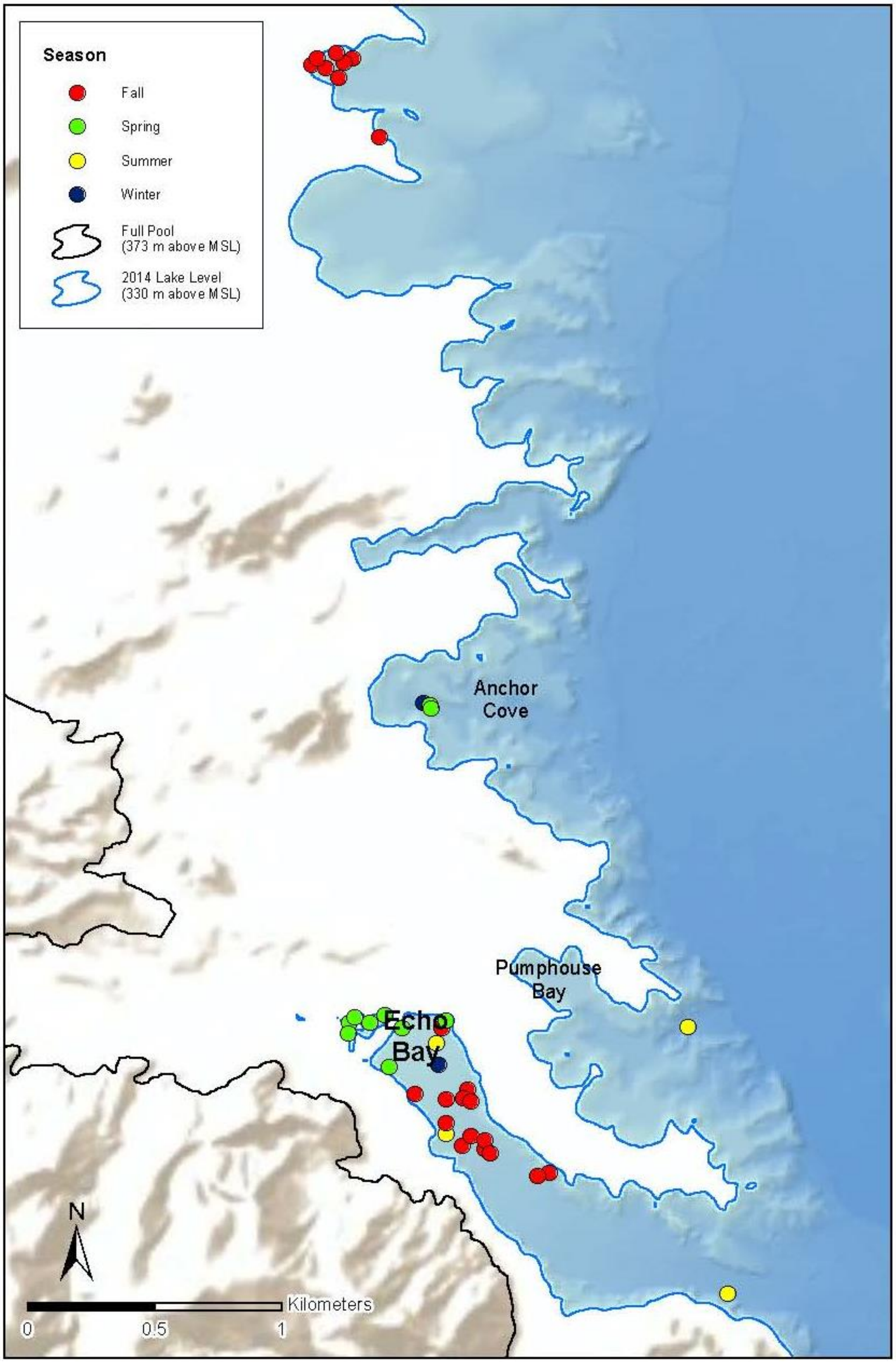

Figure 5.—Distribution of sonic-tagged, juvenile razorback suckers located through active sonic telemetry and designated by season in Echo Bay, 2014.

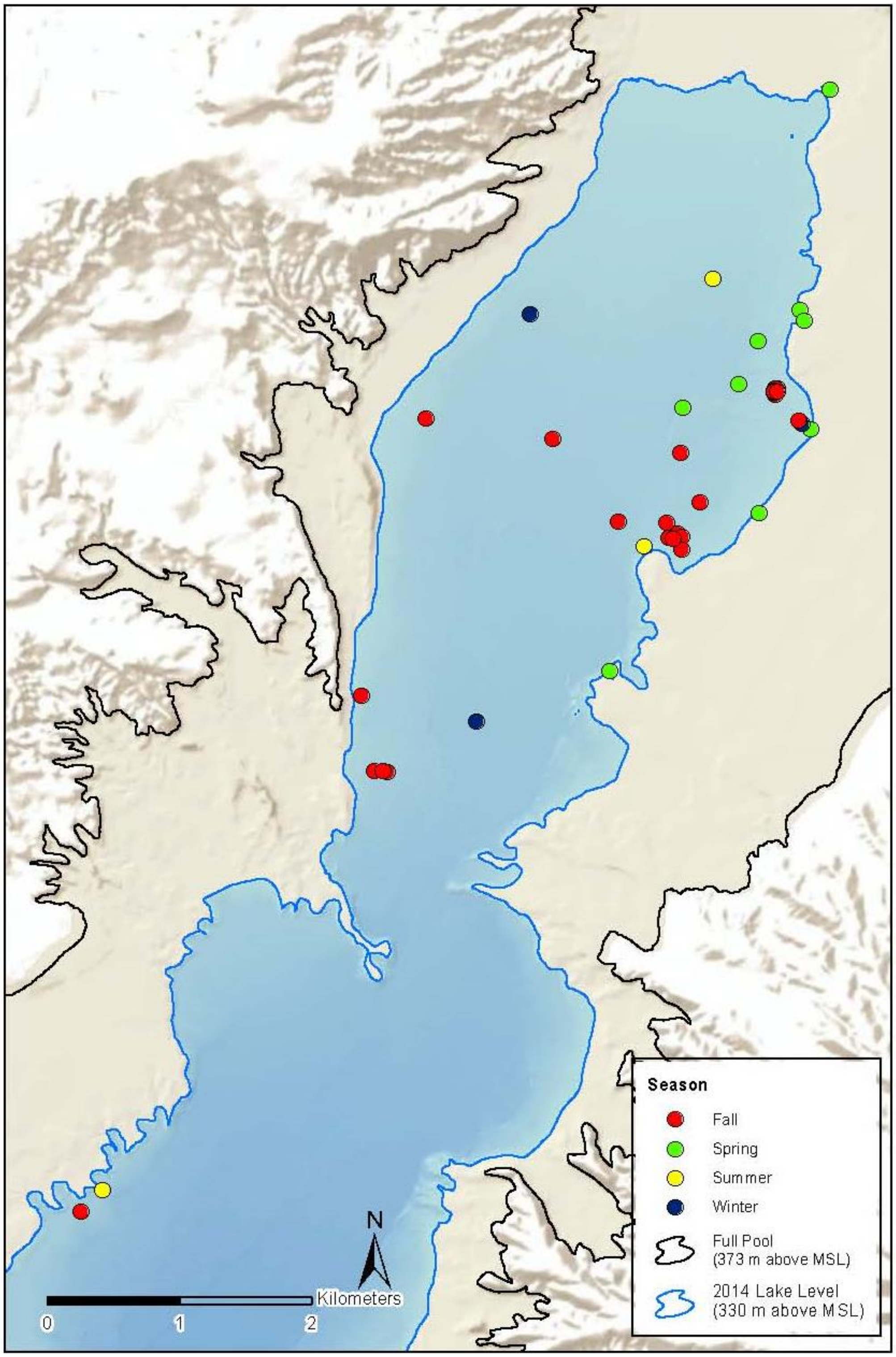

Figure 6.—Distribution of sonic-tagged, juvenile razorback suckers located through active sonic telemetry and designated by season in the Virgin River/ Muddy River inflow area, 2014.

2014; however, the SUR just north of Echo Bay (Anchor Cove) contacted three individuals (codes 3020, 3027, and 3028). These fish were originally released into Echo Bay in May 2014 and displayed northern movement in 2014. Two of those three fish (codes 3020 and 3028) returned to Echo Bay in November and December 2014. Interestingly, sonic-tagged, juvenile fish 3028 had again moved north into the Overton Arm near the Muddy River inflow area by mid-December. One Echo Bay juvenile (code 3027) took up residency near Calico Bay where it was consistently contacted via manual tracking through October and early November 2014 before being contacted via the Blackridge and Glory Hole SURs (see figure 1) in mid-November 2014. Two other sonic-tagged juveniles (codes 3026 and 3033) were located via the Blackridge SUR fairly consistently in June through October. The last contacts with these individuals (December and October 2014 [see table 1]) via manual tracking were within the same general area of the Overton Arm.

Conspecific and Community Sampling

From September 1 through November 21, 2014, 111 hoop nets, 8 minnow traps, 140 trammel nets, 7 seine hauls, and 8,707 seconds of boat electrofishing were used to capture a total of 2,527 fish of 16 species during ICS sampling conducted in direct association with sonic-tagged, juvenile razorback suckers (table 2). Habitat conditions often made the use of seine hauls and minnow traps infeasible, and therefore, those types of gear were not employed as often as trammel nets and hoop nets. Furthermore, as sonic-tagged, juvenile individuals moved from shallower to deeper habitats, gear better suited for lesser depths (i.e., hoop nets and minnow traps) were used less often. Due to the potential for mortalities of razorback suckers from handling stress in adverse environmental conditions, limited fish sampling with short-duration net sets was conducted when water temperatures were higher (> 25 °C) during the early weeks of the ICS period.

Among the fishes captured during the ICS period, 10 wild and 1 stocked razorback sucker were captured in trammel netting efforts (tables 2 and 3). One new, wild razorback sucker was captured via trammel netting in Echo Bay on September 9, 2014, while 10 individuals (9 wild and 1 stocked) were captured in Las Vegas Bay on November 11, 2014, in three 150-foot trammel nets (table 3). The one stocked individual was from the Lake Mead Fish Hatchery and the May 2013 juvenile stocking effort (table 3). Interestingly, growth of that individual was 206 mm in approximately 18 months, which confirms survival, recruitment, and substantial growth of juvenile razorback suckers in Lake Mead. Additionally, one, new juvenile flannelmouth sucker (*Catostomus latipinnis*) (255 mm TL) was captured in the Virgin River/Muddy River inflow area during netting efforts on October 14, 2014 (tables 2 and 3). Numerous nonnative fishes were captured throughout the study areas with a number of different gear types (table 2 and figures 7–9).

Table 2.—Summary of effort expended by study area, gear type, and the subsequent fishes captured during the ICS period at Lake Mead, September 1 – November 21, 2014

Sampling location[a]	Effort by gear[b]					Fish species[c]																
	Hoop nets	Minnow traps	Trammel nets	Seine hauls	Boat electro-fishing (s)	RZ	FM	GZ	TS	RS	CP	BB	CC	SC	SB	BG	GS	SM	LB	BC	BT	Total
LB	33	5	33	0	3,338	10	0	78	2	0	44	0	59	2	52	84	14	4	86	0	39	474
EB	39	3	51	7	3,760	0	0	361	32	5	131	0	31	0	43	35	93	34	51	0	6	822
OA	39	0	56	0	1,609	1	1	744	0	1	168	5	95	0	150	12	2	0	39	9	4	1,231
Total	**111**	**8**	**140**	**7**	**8,707**	**11**	**1**	**1,183**	**34**	**6**	**343**	**5**	**185**	**2**	**245**	**131**	**109**	**38**	**176**	**9**	**49**	**2,527**

[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 (s = seconds sampled]).
[c] Fish species abbreviations: RZ = razorback sucker, FM = flannelmouth 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, GS = green sunfish, SM = smallmouth bass, LB = largemouth bass, BC = black crappie, and BT = blue tilapia.

Table 3.—Summary of study area, 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, September 1 – November 21, 2014

Species	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]
RZ	9/9/2014	EB	3DD.003BC89EAF	–	9/9/2014	NO[e]	625	584	546	2,298	F	-
FM	10/14/2014	OA	3DD.003BC89E71	–	10/14/2014	NO[f]	255	236	207	122	I	–
RZ	11/11/2014	LB	384.1B7969CDBA	–	11/11/2014	NO	501	454	421	1,436	M	7
RZ	11/11/2014	LB	384.1B7969CE35	–	11/11/2014	NO	601	551	485	2,778	F	7
RZ	11/11/2014	LB	384.1B7969DE88	–	11/11/2014	NO	554	503	449	2,040	M	7
RZ	11/11/2014	LB	384.1B7969EF01	–	11/11/2014	NO	632	582	512	3,132	M	8
RZ	11/11/2014	LB	384.1B7969DC06	–	11/11/2014	NO	560	520	452	2,216	M	7
RZ	11/11/2014	LB	384.1B7969DE17	3003	5/8/2013	YES[g]	495	460	402	1,708	M	–
RZ	11/11/2014	LB	3DD.003BA2FAAA	–	3/27/2014	YES[h]	595	557	523	2,482	F	7
RZ	11/11/2014	LB	384.1B7969E6DE	–	11/11/2014	NO	572	531	487	2,192	M	9
RZ	11/11/2014	LB	384.1B7969D7C5	–	11/11/2014	NO	569	527	486	2,278	M	7
RZ	11/11/2014	LB	384.1B7969DF36	–	11/11/2014	NO	552	512	451	2,200	M	6

[a] EB = Echo Bay, OA = Virgin River/Muddy River inflow area of the Overton Arm, and LB = Las Vegas Bay.
[b] Date originally stocked or originally captured.
[c] F = female, I = immature, and M = male.
[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 on the individual during adverse environmental conditions.
[f] Individual was a flannelmouth sucker, and a fin clip was not taken for aging purposes.
[g] A fin clip was not taken for aging purposes, as the individual was stocked as a 2013 sonic-tagged individual from the Lake Mead Fish Hatchery.
[h] A fin clip was previously taken and aged in long-term monitoring efforts earlier in 2014.

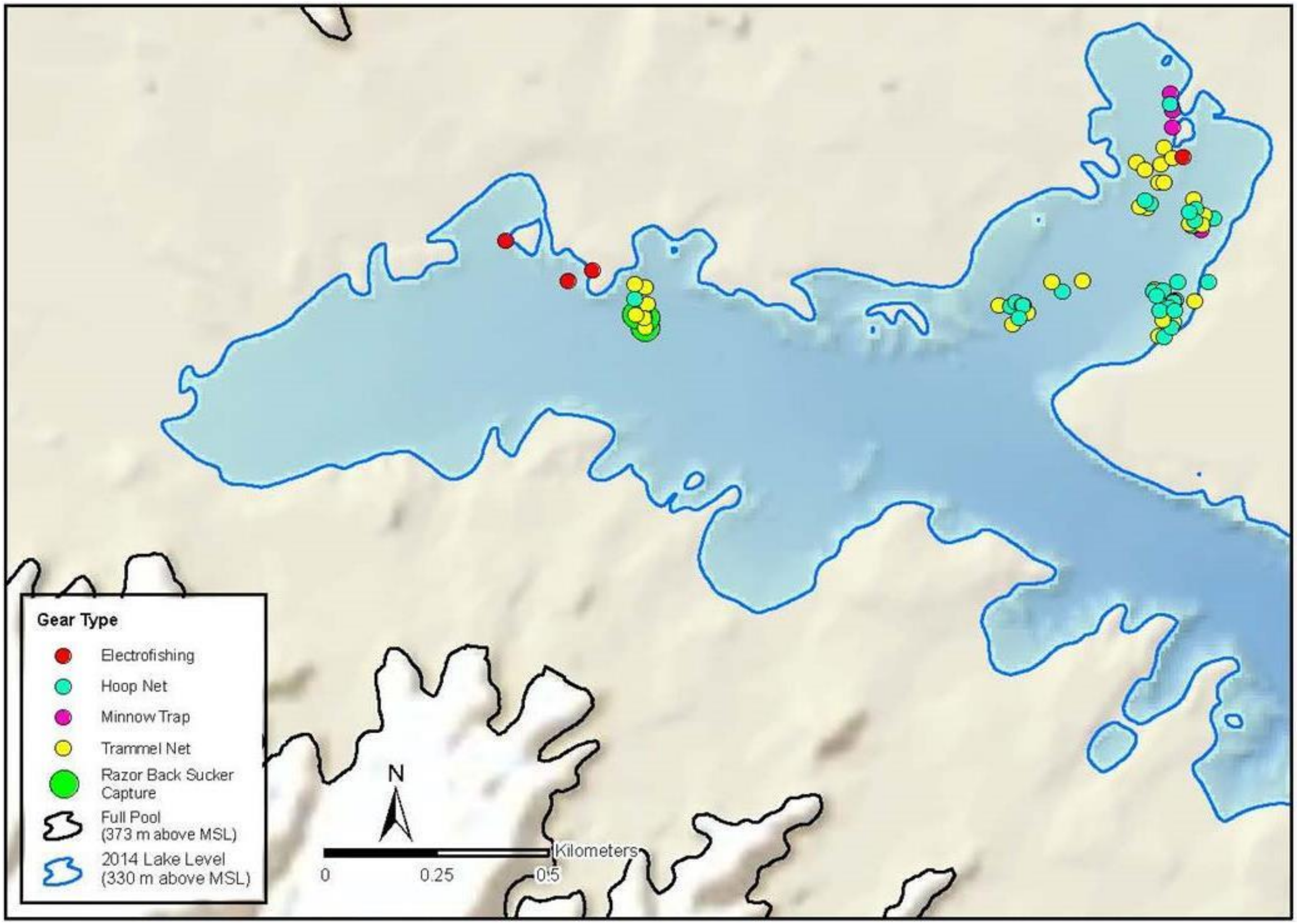

Figure 7.—Locations of fish sampling efforts during the ICS period in direct association with sonic-tagged, juvenile razorback suckers in Las Vegas Bay, 2014.

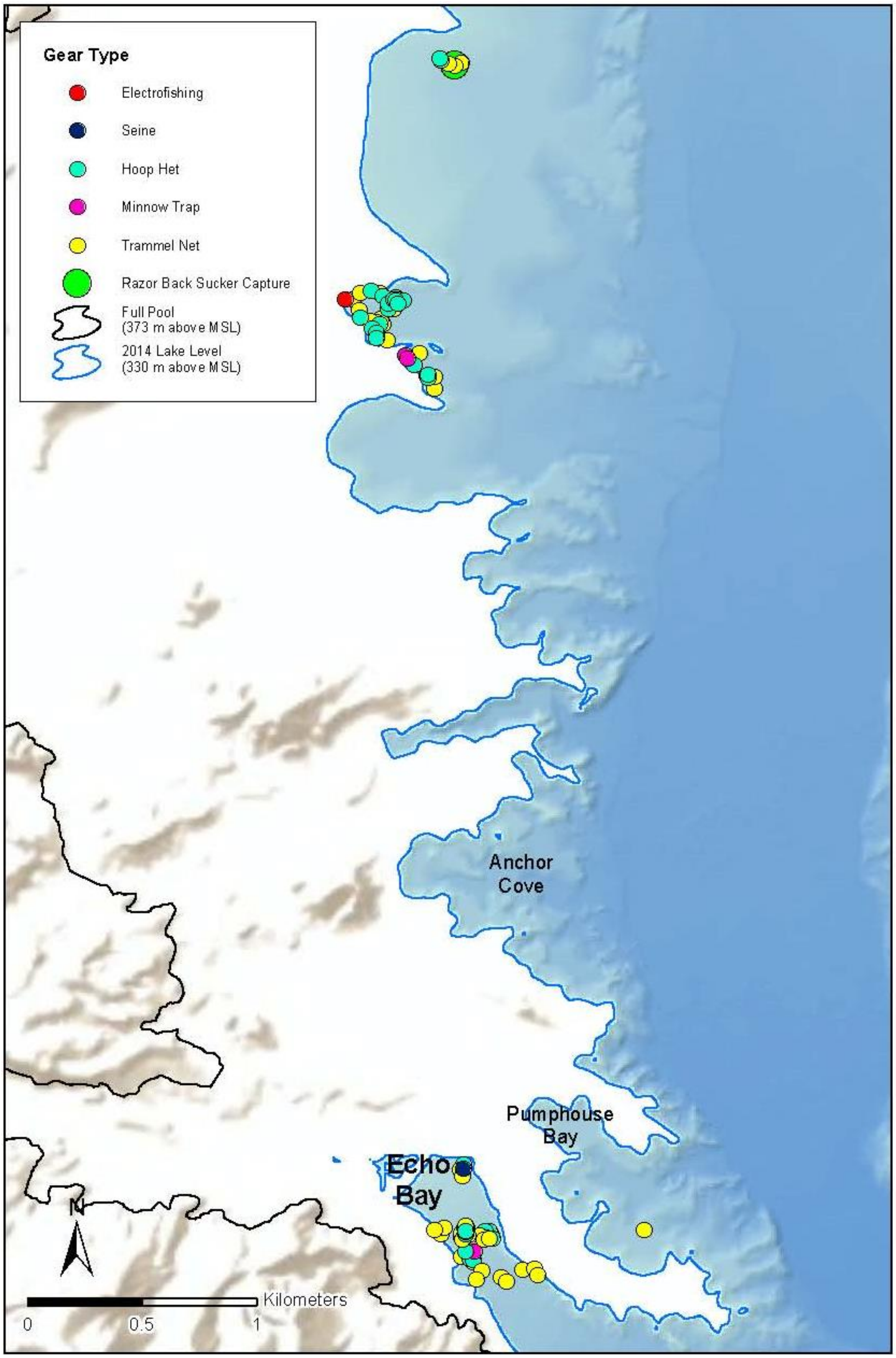

Figure 8.—Locations of fish sampling efforts during the ICS period in direct association with sonic-tagged, juvenile razorback suckers in Echo Bay, 2014.

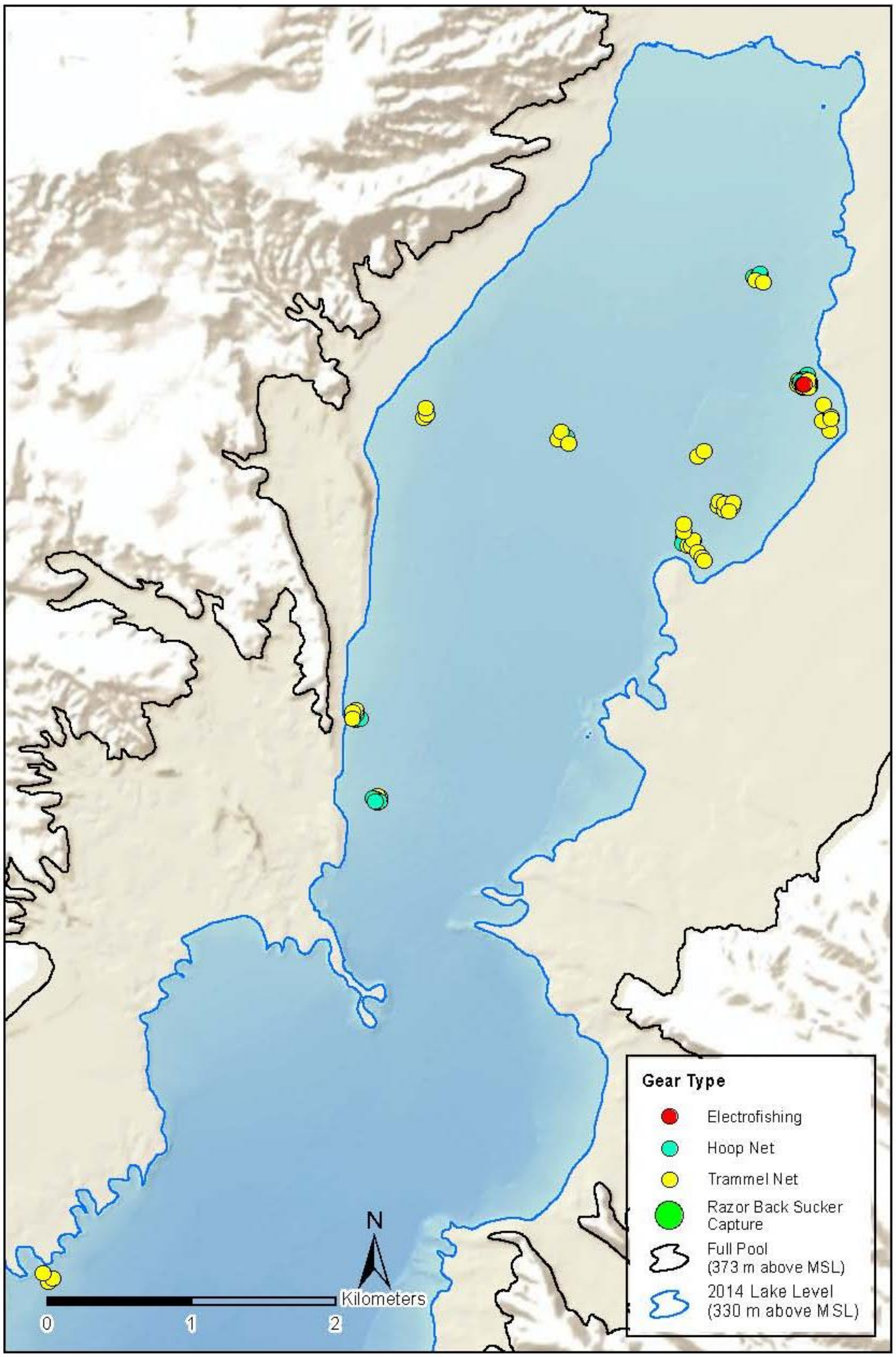

Figure 9.—Locations of fish sampling efforts during the ICS period in direct association with sonic-tagged, juvenile razorback suckers at the Virgin River/Muddy River inflow area, 2014.

For the third consecutive year, wild, adult razorback suckers were captured in direct association with sonic-tagged, juvenile razorback suckers in Las Vegas Bay (Albrecht et al. 2013a; Shattuck and Albrecht 2014). One individual was also captured in Echo Bay. The razorback suckers (three females and eight males) captured in 2014 ranged in size from 495 to 632 mm TL (see table 3). Captures of the razorback suckers occurred just east of the Las Vegas Wash inflow at depths of approximately 11.0 m (see table 3 and figure 7) and north of Echo Bay near Rogers Bay at a depth of approximately 4.6 m (table 3 and figure 8).

Razorback suckers were only captured in trammel nets in Las Vegas Bay and Echo Bay, with the highest catch rate (number of fish per minute) occurring in Las Vegas Bay (figure 10). A comparison among catch rates of all native and nonnative fish revealed no significant difference in the mean number of fish captured per minute at any given sampling site (ANOVA, $F_{2,314} = 313$, $P = 0.4817$). It should be noted that seining data were not used in the catch rate analysis, as the effort is based on area while all other gear types are based on time. When analyzing nonnative fish (the majority of the fish captured), there was a significantly higher catch using electrofishing than with any other gear type (ANOVA, $F_{3,313} = 296$, $P < 0.0001$; Tukey's Honestly Significant Difference Test) (figure 10). This is not surprising considering the amount of area that can be covered while actively seeking habitats containing cover and harboring an abundance of small fish. Post-hoc analysis also revealed that hoop nets , minnow traps, and trammel nets were similar in CPUE.

Of the 16 fish species captured during the ICS period, nearly half of the individuals were gizzard shad (*Dorosoma cepedianum*) (46.8%) (figure 11). Common carp (*Cyprinus carpio*) and striped bass (*Morone saxatilis*) were the second and third most abundant species at 13.6% and 9.7%, respectively (figure 11). The three most dominant species captured totaled approximately 70.0% of the total catch among all study areas with various gear types. Other relatively common species captured were channel catfish (*Ictalurus punctatus*), largemouth bass (*Micropterus salmoides*), bluegill (*Lepomis macrochirus*), and green sunfish (*Lepomis cyanellus*) (figure 11). Razorback and flannelmouth suckers combined only represented approximately 0.44% of the total catch.

Of the 16 species captured and measured during 2014 ICS period, striped bass, common carp, channel catfish, and razorback suckers were among the largest individuals captured (figure 12). Interestingly, those same nonnative fish were some of the most abundant (figure 11). Sonic-tagged, juvenile and wild adult razorback suckers were mostly associated with fish under approximately 400 mm TL. Of the fish captured and measured, relatively few of them exceed the length of the sonic-tagged juveniles present (greater than approximately 300 mm TL) (figure 12).

The seasonal comparison of mean TL (mm) of fish captured revealed that significantly larger fish were captured in summer relative to fall (ANOVA,

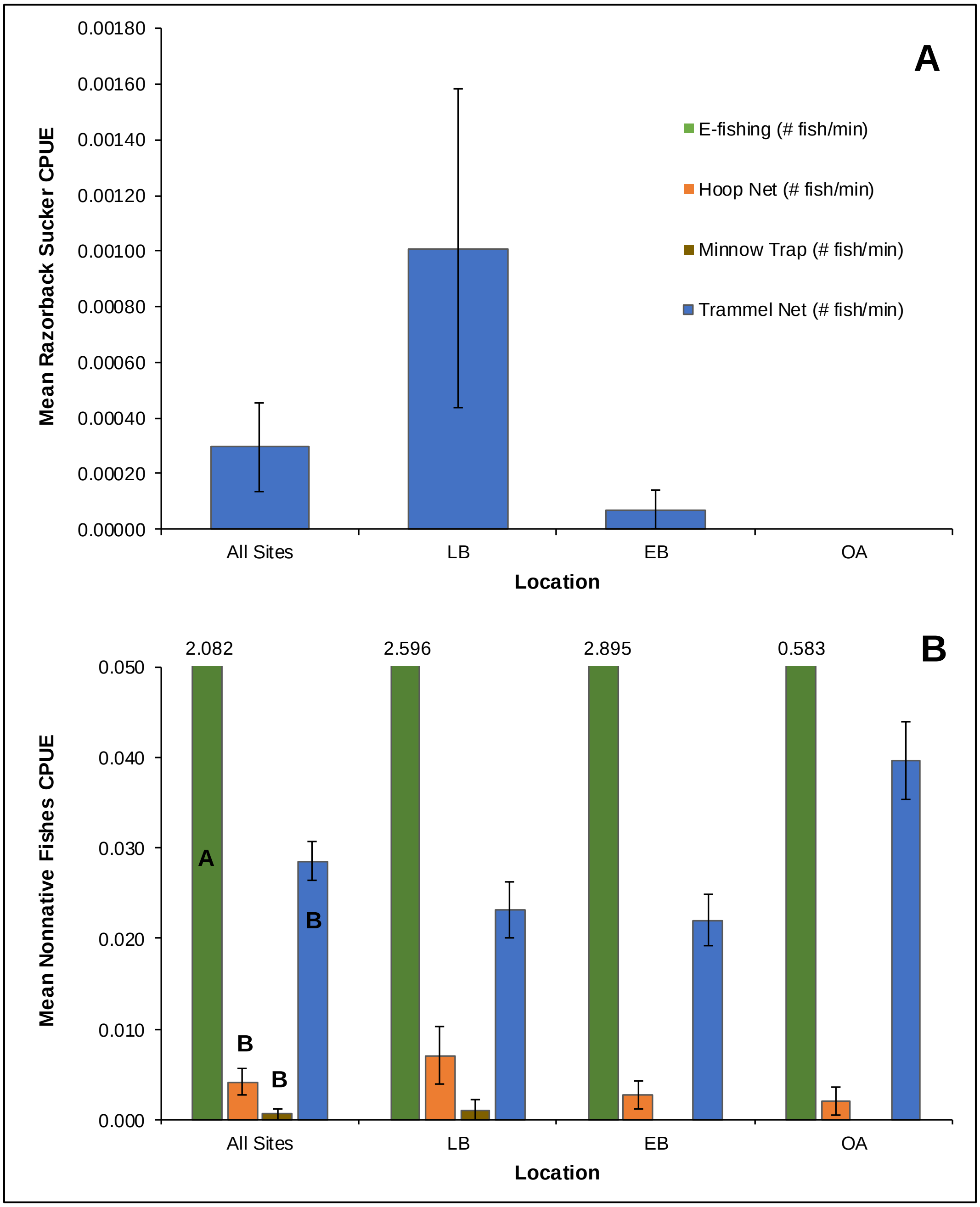

Figure 10.—Mean CPUE values with SE by study area and gear type for razorback suckers (A) and the grouped nonnative fishes (B) captured during the ICS period in direct association with sonic-tagged, juvenile razorback suckers in 2014.
Note: Electrofishing catch rates labeled above the green bars.

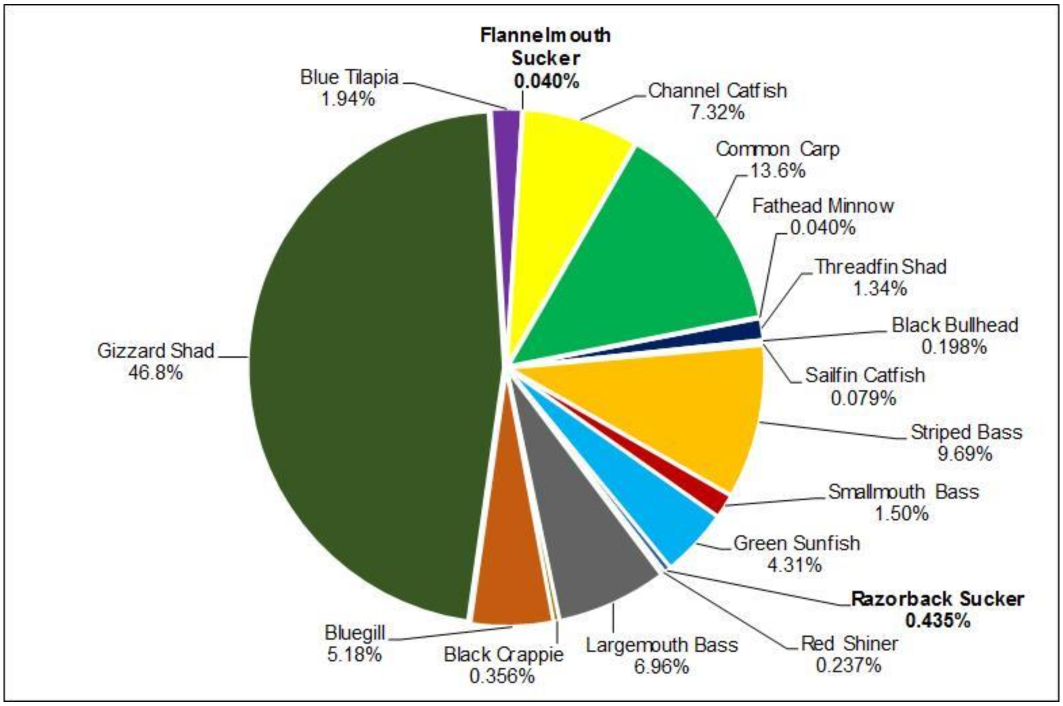

Figure 11.—Fish community composition by species, expressed as percentages of the total number of fishes captured during the ICS period in direct association with sonic-tagged, juvenile razorback suckers in 2014.

$F_{1,1243} = 12.7$, $P = 0.0004$). Based on the telemetry data, there was no difference in depth (m) of contact for sonic-tagged, juvenile razorback suckers in summer and fall (ANOVA, $F_{1,147} = 0.06$, $P = 0.8105$). Additionally, there was no difference in depth of gear set (m) in summer and fall (ANOVA, $F_{1,307} = 0.0$, $P = 0.9980$). The difference in fish length by season could be explained by the proportions of gear types set during each season. In summer, 58 total hoop and trammel nets were set, with trammel nets composing 75% of the net sets. In fall, 266 total hoop, minnow, and trammel nets were set, with trammel nets composing only 58% of the sets. While trammel netting typically results in the capture larger fish, the capture of smaller fish in fall could also be explained by the electrofishing effort, which was only conducted during fall. It is likely that the time spent electrofishing in and around the dense cover of littoral habitats allowed for the capture of smaller individuals that are not susceptible to nets.

In testing for differences in TL by study area, significantly larger fish were captured in the Virgin River/Muddy River inflow compared to Las Vegas Bay or Echo Bay (ANOVA, $F_{2,1243} = 7.13$, $P = 0.0008$; Tukey's Honestly Significant Difference Test). Most fish in the Virgin River/Muddy River inflow were captured with trammel nets, and approximately 74% of the catch consisted of large, adult gizzard shad and common carp. Although sonic-tagged individuals located at the Virgin River/Muddy River inflow were found in significantly

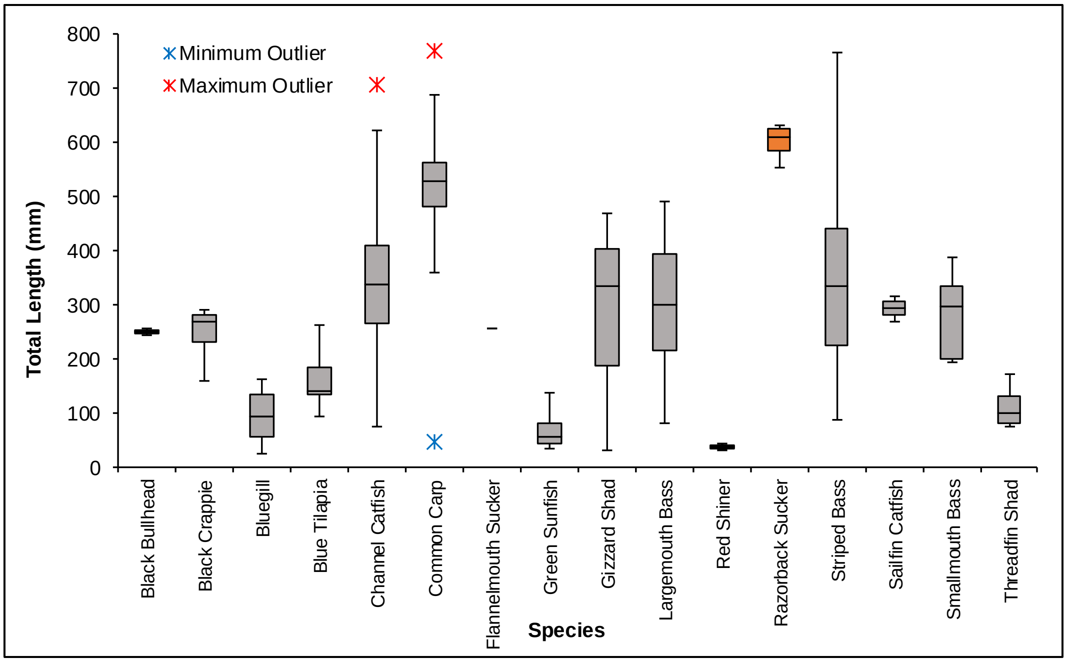

Figure 12.—TL box plots for species captured by the combined gear types with associated medians, upper and lower quartiles, upper and lower whiskers, and denoted outliers for fishes captured during the ICS period in direct association with sonic-tagged, juvenile razorback suckers in 2014.

shallower water than the other study areas (refer to the sonic telemetry results), most of the fish sampling conducted at this location was conducted well offshore in more pelagic habitats.

Among all study areas, 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 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. Although a significant difference was not detected (ANOVA, $F_{4,447} = 0.99$, $P = 0.4116$), razorback suckers had the highest calculated mean total length ($\bar{x}$ = 568.7 [SE ± 148.3]) relative to all other predatory nonnative species (CC [$\bar{x}$ = 296.4 {SE ± 41.4}]; SB [$\bar{x}$ = 356.0 {SE ± 40.0}]; SM [$\bar{x}$ = 291.0 {SE ± 112.8}]; LB [$\bar{x}$ = 310.9 {SE ± 43.8}]) (see figure 12).

Age Determination

During the ICS period of sampling associated with sonic-tagged, juvenile razorback suckers, 11 razorback suckers were captured (10 from Las Vegas Bay and 1 from Echo Bay) (see table 3). Eight of those fish underwent surgical fin ray removal, and definitive ages were calculated for all individuals. These razorback suckers, which ranged in size from 501 to 601 mm TL, were aged from 6 to 9 years old (see table 3) (2005–08 year-classes). All of these year-classes have been noted for their strength in regard to razorback sucker recruitment in Lake Mead in past studies (figure 19 in Albrecht et al. 2014a).

Habitat Observations and Physicochemical Quantification

During May 12 through December 9, 2014, 305 physicochemical replicates within 110 measured habitats were quantified in association with contacted sonic-tagged, juvenile razorback suckers. Among habitats quantified, inshore habitat was most often characterized by shallow depths, a silt substrate, a general presence of algal and detrital material, and usually having the IV cover type. Conversely, offshore habitat was primarily characterized by greater depths, heterogeneous substrate, limited presence of algal and detrital material, and no observable vegetative cover.

As a goal is to determine juvenile razorback sucker requirements for recruitment along a seasonal gradient, physicochemical data were analyzed in the same manner. Additionally, study area-specific data may help in determining differences among available habitat or seasonal changes at a particular location that may be less typical of another (table 4). Although juvenile razorback suckers were located in each study area for each season, differences in physicochemical parameters were documented (table 4). For example, water temperature was lowest in Echo Bay during spring and summer, whereas Echo Bay demonstrated similar water temperatures as the Virgin River/Muddy River inflow in fall (table 4). Las Vegas Bay was the warmest, followed by the Virgin River/ Muddy River inflow and Echo Bay in order of descending water temperature. Spring water temperatures in Echo Bay appear cooler than in the Virgin River/Muddy River inflow or Las Vegas Bay. Summer water temperatures displayed similar results, with Echo Bay being the coolest. Differences among sites are likely not biologically significant because they are similar, and thermal refuge should exist within all areas of Lake Mead.

DO concentrations were relatively stable throughout the year at all study areas; however, they averaged higher in Las Vegas Bay than in the other two study areas for all seasons (table 4). The average turbidity was highest in spring in Las Vegas Bay whereas during summer and fall, the Virgin River/Muddy River inflow displayed the highest turbidity values (table 4). Variations or differences among turbidity are better assessed using CCA and PCA under a multivariate approach. However, differences in turbidity among sites and seasons could play a role in recruitment success as it relates to cover.

Table 4.—Summary of mean seasonal physicochemical and habitat information collected during the ICS and AHS periods in direct association with sonic-tagged, juvenile razorback suckers in 2014

Study area	Physicochemical parameters											
	Temp (°C)[a]	SE (±)	DO (mg/L)	SE (±)	Cond (µS/cm^3)[b]	SE (±)	pH[c]	SE (±)	Turb (NTU)[d]	SE (±)	Depth (m)	SE (±)
	Spring (April 9– June 10, 2014) (n = 203, 170, 125)											
LB[e]	22.48	0.28	9.86	0.16	1.44	0.02	8.61	0.01	41.75	3.60	9.15	0.34
EB[f]	19.40	0.31	8.13	0.07	1.06	0.01	8.39	0.01	23.64	2.05	8.70	0.58
OA[g]	22.78	0.48	9.04	0.12	1.20	0.01	8.54	<0.01	24.65	1.99	4.38	0.12
	Summer (July 5 – September 18, 2014) (n = 367, 355, 206)											
LB	28.55	0.03	9.89	0.12	1.32	0.01	8.88	0.01	20.83	1.06	5.73	0.11
EB	26.66	0.15	9.17	0.07	1.08	<0.01	8.85	0.01	14.85	1.44	13.66	0.44
OA	28.79	0.11	9.04	0.12	1.27	0.01	8.73	0.07	43.63	8.65	5.97	0.22
	Fall (September 29 – December 9, 2014) (n = 305, 378, 306)											
LB	23.89	0.14	9.04	0.06	1.22	0.01	8.69	0.01	14.20	0.97	7.86	0.17
EB	22.63	0.13	8.12	0.03	1.19	<0.01	8.52	<0.01	10.57	0.59	5.78	0.15
OA	22.16	0.17	8.51	0.05	1.29	0.01	8.60	0.01	20.16	2.14	5.00	0.13
	Winter (March 5, 2014) (n = 70)											
EB	13.92	0.11	2.23	0.01	0.95	<0.01	8.62	<0.01	NS[h]	NS	23.30	<0.01

STUDY AREA	SUBSTRATE TYPE %					COVER TYPE %			
	SI[i]	SA[j]	GR[k]	CO[l]	BD[m]	IV	LWD	SAV[n]	NO[o]
Spring (April 9 – June 10, 2014) (n = 24, 30, 20)									
LB	68.8	0.0	0.0	0.0	31.3	0.0	0.0	0.0	100.0
EB	62.0	19.7	10.0	0.0	8.3	2.0	0.0	0.0	98.0
OA	92.5	5.0	2.5	0.0	0.0	0.0	20.0	0.0	80.0
Summer (July 5 – September 18, 2014) (n = 45, 42, 31)									
LB	66.9	4.4	26.7	0.0	2.0	0.7	0.7	0.0	98.6
EB	87.0	1.8	11.2	0.0	0.0	5.0	0.0	0.0	95.0
OA	82.9	4.2	0.0	0.0	12.9	0.0	1.4	0.0	98.6
Fall (September 29 – December 9, 2014) (n = 40, 54, 45)									
LB	67.5	16.8	10.8	0.0	5.0	0.2	0.0	2.4	97.4
EB	86.6	11.5	1.9	0.0	0.0	0.3	0.4	7.7	91.5
OA	84.6	12.0	1.9	0.2	1.3	3.9	1.7	0.0	94.5
Winter (March 5, 2014) (n = 1)									
EB	NS	NS	NS	NS	NS	0.0	0.0	0.0	100.0

[a] Temp = temperature.
[b] Cond = conductivity.
[c] Turb = turbidity.
[d] pH is the mean H+ concentration converted to pH.
[e] LB = Las Vegas Bay.
[f] EB = Echo Bay.
[g] OA = Virgin River/Muddy River inflow area.
[h] NS = Not sampled – equipment failure.
[i] Si = silt.
[j] SA = sand.
[k] GR = gravel.
[l] CO = cobble.
[m] BD = boulder.
[n] SAV = submerged aquatic vegetation.
[o] NO = no cover.

Substrate and cover are likely better assessed using the CCA and PCA under a multivariate approach. However, based on the data collected in association with sonic-tagged, juvenile razorback suckers, silt and sand substrates dominated (see table 4). This is likely a function of availability rather than preference, as silt and sand are common, especially at inflow areas such as Las Vegas Bay and the Virgin River/Muddy River inflow. Interestingly, juvenile razorback suckers did not associate much with vegetative cover in 2014 (see table 4). Again, it is likely that vegetative cover, especially in the form of IV, was not present in high density under the declining water levels. Under these conditions, turbidity is likely the dominant cover type.

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 significantly ($F = 1.8$, $P = 0.01$ in a Monte Carlo permutation test on all axes) explain 27.0% (total inertia = 2.008, sum of all canonical eigenvalues [SAE] = 0.542) of the variability within the fish assemblage associated with sonic-tagged, juvenile razorback suckers through environmental parameters, season, study area, and unexplained variation (figure 13). Of that total of explainable inertia, the first two axes accounted for 43.0% of the variation that could be explained by the included variables. In post-hoc variance partitioning, the pure effect of environmental parameters explained 33.6% ($F_{14} = 1.3$, $P = 0.10$), the pure effect of season explained 15.7% ($F_2 = 2.0$, $P = 0.01$), and the pure effect of study area explained 15.3% ($F_2 = 1.9$, $P = 0.02$). Although the pure effect of environmental parameters was not found to be significant, the pure effects of season and study area were. In total, 107 samples were used in the CCA, which consisted of data taken in association with 24 sonic-tagged, juvenile razorback suckers from Las Vegas Bay, Echo Bay, and the Virgin River/Muddy River inflow area during May 8, 2013 – December 11, 2014.

Factors with the strongest loadings on CCA axis I were the Virgin River/Muddy River inflow study area (biplot score = -0.18), IV cover (-0.18), spring season (-0.17), SAV cover (0.22), fall season (0.24), and the Echo Bay study area (0.24) (figure 13). Factors with the strongest loadings on CCA axis II were no cover (-0.21), fall season (-0.08), average depth (-0.07), SAV cover (0.12), IV cover (0.15), and the presence of algae and detritus (0.21) (figure 13). Green sunfish (*Lepomis cyanellus*) (biplot score = 4.37), smallmouth bass (3.66), blue tilapia (*Oreochromis aureus*) (2.77), and threadfin shad (*Dorosoma petenense*) (2.31) were positively related to CCA axis I and associated with SAV cover, the fall season, the Echo Bay study area, and with larger substrates (figure 13). Black crappie (*Pomoxis nigromaculatus*) (-2.44), red shiner (*Cyprinella lutrensis*) (-1.86), black bullhead (*Ameiurus melas*) (-1.84), and flannelmouth sucker (-0.67) were negatively related to CCA axis I and associated with IV cover, the spring season, the Virgin River/Muddy River inflow study area, and with higher averages of conductivity and turbidity (see figure 13). Red shiner (3.92),

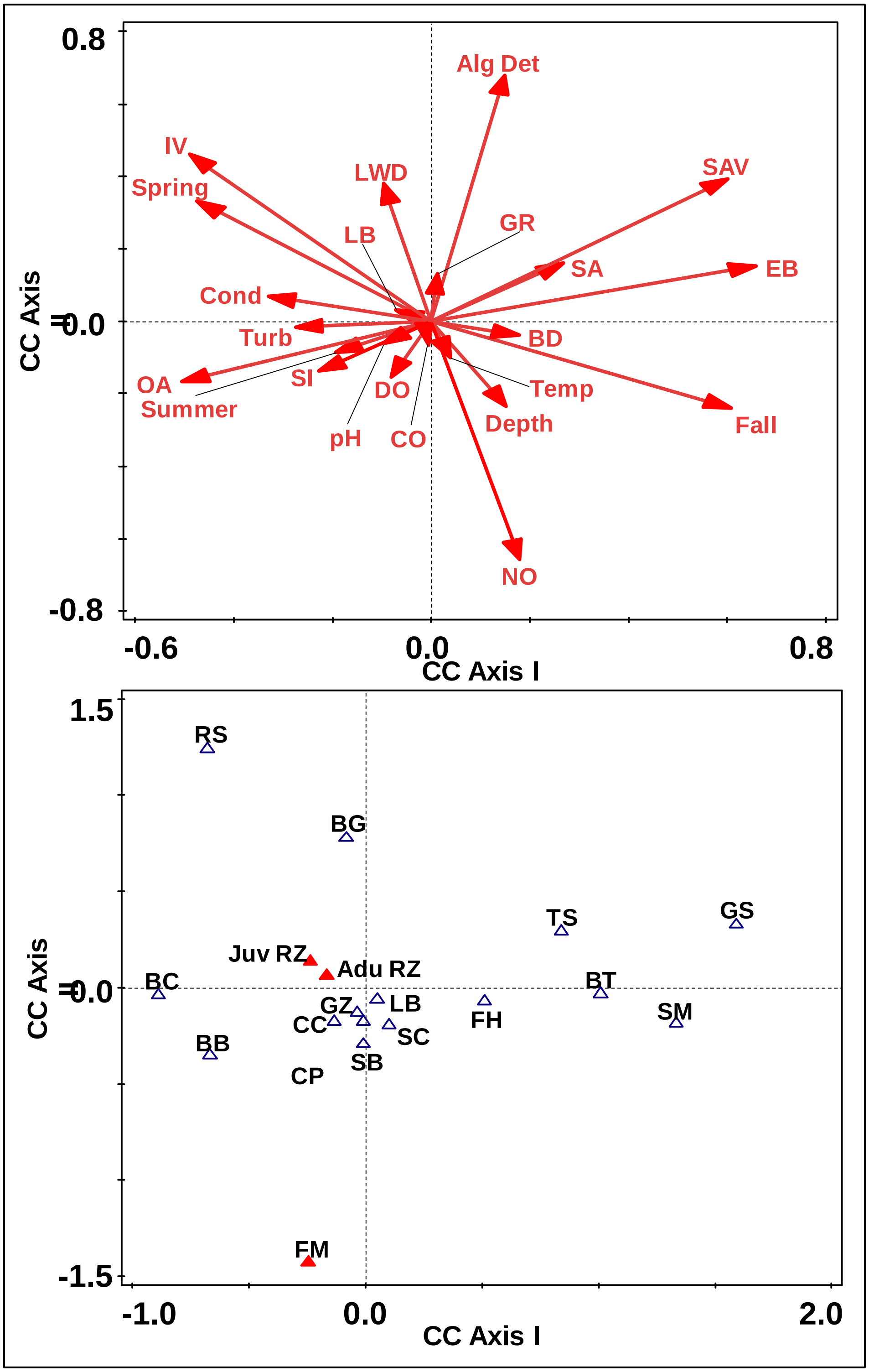

Figure 13.—CCA of the environment, season, study area, and fish community associated with sonic-tagged, juvenile razorback suckers in Lake Mead, May 8, 2013 – December 11, 2014.
Abbreviations are listed in tables 2 and 4.

bluegill (2.46), green sunfish (1.04), and threadfin shad (0.93) were positively related with CCA axis II and associated with the presence of algae and detritus and vegetative cover in the forms of IV, SAV, and LWD (see figure 13). Flannelmouth sucker (-4.52), black bullhead (-1.12), striped bass (-0.93), and vermiculated sailfin catfish (-0.62) were negatively related with CCA axis II and associated with no apparent cover, increased average depth, and higher average temperatures (see figure 13).

Sonic-tagged, juvenile razorback suckers were not strongly related to any particular habitat type, although they appear to have associated with IV, LWD, higher average conductivity, higher average turbidity, and silt substrates during the spring season at the Virgin River/Muddy River inflow area and Las Vegas Bay (see figure 13). Similarly functioning species included gizzard shad and common carp, while green sunfish, red shiner, and smallmouth bass appeared to be least similar. Interestingly, adult razorback suckers partitioned near juvenile razorback suckers in multivariate space; however, the flannelmouth sucker was found to be quite different (see figure 13). Although the capture of only one flannelmouth sucker during sampling may be weighting the apparent difference seen in CCA space, the similar spacing of adult and juvenile razorback suckers is surprising. Although differences in 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), it appears that there may be substantial overlap in Lake Mead.

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 study areas during May 8, 2013 – December 11, 2014. In contrast to the CCA model, 196 samples of habitat data—collected in association with 29 sonic-tagged, juvenile razorback suckers—were used in the PCA. In the PCA model, the first two axes explained 56.5% (PCA axis I = 30.4%, and PCA axis II = 26.1%) of the total variation in environmental parameters among habitats associated with sonic-tagged, juvenile razorback suckers (figure 14). In post-hoc comparison, both principal component axes exceeded the expectations for a model with 15 principal axes in the broken-stick criterion (i.e., PCA axis I total variance > 22.1%, and PCA axis II total variance > 15.5% [Frontier 1976; Olden 2011]) and explained a significant amount of variance. PCA I described a depth, cover, and turbidity gradient with no apparent cover (-1.45), average depth (-1.33), average DO (-0.42), LWD cover (0.68), average turbidity (1.06), and IV cover (1.75) having the strongest loadings on the axis (figure 14). PCA axis II described a substrate, conductivity, and turbidity gradient with silt substrate (-1.35), average conductivity (-0.62), average turbidity (-0.59), cobble substrate (1.06), gravel substrate (1.29), and sand substrate (1.80) having the strongest loadings along the axis (figure 14). Habitats associated with Las Vegas Bay were generally higher in conductivity, higher in

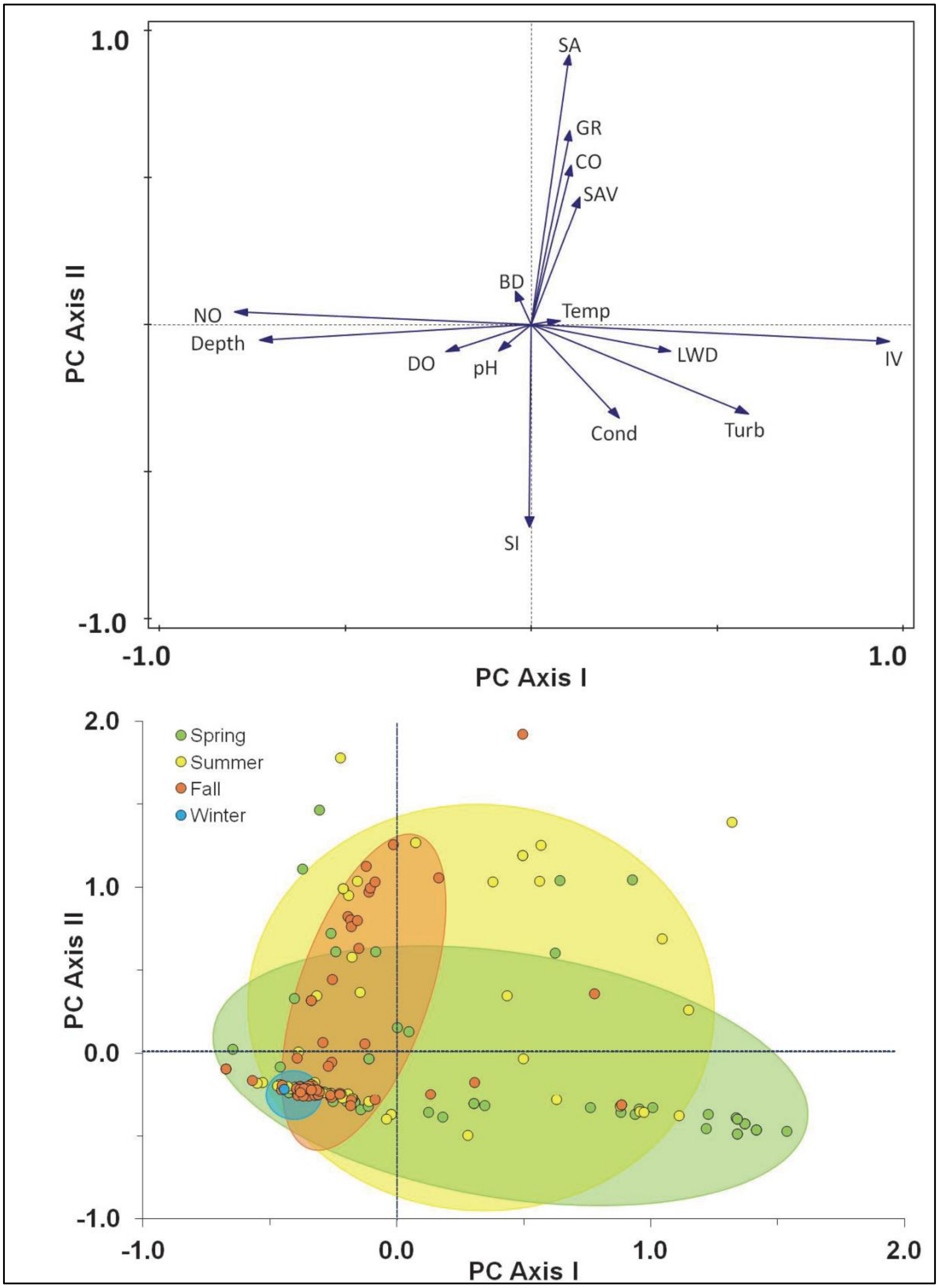

Figure 14.—PCA of the environment parameters associated with sonic-tagged, juvenile razorback suckers in Lake Mead, May 8, 2013 – December 11, 2014, with post-hoc labeling of season (green = spring, yellow = summer, orange = fall, and blue = winter.

Abbreviations are listed in tables 2 and 4.

DO concentrations, silt dominated, and had more LWD (see figure 14). Habitats associated with Echo Bay were characterized as being deeper, with less IV, larger substrates (e.g., gravel, sand, and cobble), and with more SAV (see figure 14). Finally, habitats in the Virgin River/Muddy River inflow area were typically warmer in temperature and higher in turbidity, had a greater presence of algae and detritus, and were dominated by IV (see figure 14).

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 (see figure 14), 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 (see figure 14). Samples exhibiting distances furthest from the origin are considered most different in physicochemical and habitat composition. As such, the summer season occupies the most space in PCA, which is potentially attributable to more variation seen in the habitat with which sonic-tagged, juvenile razorback suckers associated while the seasons transitioned from spring or into fall (see figure 14). Conversely, as fewer samples were analyzed for winter habitat contacts, there appear to be fewer variables that characterize this type of habitat and less variation in its composition (see figure 14). 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, and higher conductivities (see figure 14). Moving into summer, habitat for juvenile individuals is more closely associated with increased depths, a lack of inundated cover, and silt substrate. Fall habitat for juvenile individuals can be described as greater in substrate heterogeneity and with higher amounts of SAV. While winter habitat was characterized similarly to summer habitat, the small sample size ($n = 1$) is not as descriptive as other seasons included in the model at this point in the study (see figure 14).

DISCUSSION AND CONCLUSIONS

Overall, the quantitative, empirical data collected during the 2013–14 and 2014–15 study years have provided a better understanding of razorback sucker recruitment habitat in Lake Mead, particularly during the spring, summer, and fall seasons. Sonic telemetry was reaffirmed as a useful tool for collecting habitat information, and it guided sampling efforts toward the collection of additional razorback suckers. In 2014, an additional 11 razorback suckers were captured in direct association with sonic-tagged, juvenile razorback suckers. One of those fish was a recaptured, stocked juvenile (Shattuck and Albrecht 2014) that essentially recruited within the Lake Mead population during this study. Thus far, information obtained from this study suggests that: (1) recruitment is possible in Lake Mead, (2) recruitment may happen fairly frequently (direct observation of at least 1 of 18 fish stocked in 2013 recruited to adulthood), (3) minimal movement of juvenile razorback suckers is common, and growth is substantial (approximately 200 mm in a single year). Limiting movement and using the energy to grow, utilizing cover, and ultimately reducing their susceptibility to predation may be important survival strategies for Lake Mead's juvenile razorback suckers.

These captures, in conjunction with data collected on habitat associations and seasonal movement, expanded 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 Level 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 2014, typical seasonal variation in Lake Mead levels and discharges of the Las Vegas Wash and Virgin River seemed to complement one another throughout the year by consistently providing different forms of cover at inflow areas (i.e., IV through higher lake levels in spring and summer and turbidity through summer and fall with monsoonal storms creating high-discharge events) (see figure 3).

Lake level 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 vast expanses of otherwise dry 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 area between Three Corner Hole and the Overton Arm boat ramp moving south, there was an approximate increase in depth of 10 m over a distance of 4,000 m (gradient = 0.003) (see figures 1 and 6). In comparison, from the Las Vegas Wash inflow area moving southeast, there was an approximate increase in depth of 10 m over a distance of 650 m (gradient = 0.015), and from the Echo Bay boat ramp moving southeast, there was an approximate increase in depth of 10 m over 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, 2014). 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 area during spring and early summer before moving almost entirely out of the area. This same trend was observed in 2014, with many of the sonic-tagged, juvenile razorback suckers using more offshore habitats near the Meadows and Stewarts Cove areas in late summer into fall. 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 (see figure 1), nearly 15 kilometers away (Shattuck et al. 2011; Albrecht et al. 2013b; Shattuck and Albrecht 2014).

Though sonic-tagged, juvenile razorback suckers were contacted in a number of habitats throughout the Lake Mead study areas, individuals were most frequently contacted in inundated cover during higher lake levels near the Las Vegas Wash inflow area at the western end of Las Vegas Bay and at the northern extent of the Overton Arm near the Virgin River inflow area during the spring season. Juvenile razorback suckers' affinity for shallow water and inundated vegetation was also documented by Mueller and Marsh (1998). In Lake Mead, the fish transitioned to deeper habitats during summer and remained fairly deep but then transitioned to shallower habitats associated with substrate gradients during fall. 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 vegetation and IV and more complex substrate types when the lake declines through summer and into fall, where wave action likely provides scour and sorting of substrates (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 allowed 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 levels and the subsequent loss of this particular habitat (Burdick et al. 2008).

Sonic Telemetry

Sonic telemetry data from juvenile razorback suckers were invaluable in describing specific habitat associations in Las Vegas Bay, Echo Bay, and the Virgin River/Muddy River inflow area during 2014. 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 third 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 inundated cover to deeper habitats farther away from adjacent inflow areas. Generally, sonic-tagged, juvenile razorback suckers remained within the respective study areas in which they were stocked, but as spring transitioned into summer, sonic-tagged, juvenile razorback suckers began to move into significantly deeper habitat lake-wide. By fall, they began transitioning back to shallow habitats. This transition into deeper habitat may have been in response to rising water temperatures in most of the shallow habitat associated with IV and then reversed as summer transitioned into fall (see table 4). This pattern of habitat association was similar to that seen in 2012 and 2013 (Albrecht et al. 2013a; Shattuck and Albrecht 2014). Although not uncommon for adult razorback suckers during the spawning period, sonic-tagged, juvenile razorback suckers were sometimes contacted near other sonic-tagged, juvenile individuals (< 100 m). 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 and, in many cases, suggested shoaling behavior not only within juveniles but with adults. Additionally, it was from sampling in direct association with multiple sonic-tagged, juvenile individuals that 10 razorback suckers were captured in Las Vegas Bay, 1 in the Overton Arm, and a juvenile flannelmouth sucker was also captured in the Overton Arm. With the exception of the juvenile flannelmouth sucker, the razorback suckers were larger than their associated sonic-tagged juveniles. These findings suggest that that juvenile and adult fish share habitats at certain times of the year and apparently shoal together at least during the summer and fall seasons (Shattuck and Albrecht 2014). Similar results were also reported on Lakes Powell and Mohave during a juvenile razorback sucker telemetry study (Muller and Marsh 1998).

Following the initial stocking of sonic-tagged razorback sucker individuals at each of the study areas, most individuals recovered quickly and began exhibiting the pattern of movement and behavior of juvenile razorback suckers noted in past studies (Albrecht et al. 2013a; Shattuck and Albrecht 2014). 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 and 2013 (Albrecht et al. 2013a; Shattuck and Albrecht 2014). However, sonic-tagged, juvenile razorback sucker individuals stocked into Echo Bay appeared to be unable to find suitable habitat following stocking, and these individuals moved outside of Echo Bay proper fairly quickly. Interestingly, by fall, two of the Echo Bay-stocked juvenile razorback suckers had moved back into Echo Bay, and they were found there routinely. Furthermore, Echo Bay is of noted importance for razorback sucker reproduction (Albrecht et al. 2013b), although its importance to juvenile razorback suckers may not be as significant during summer (Shattuck and Albrecht 2014). Conversely, it appears that Echo Bay provides benefits to juvenile razorback suckers at least during fall. This may provide insight into some of the exchange and movement by razorback suckers that has been observed within the greater context of the Overton Arm (Albrecht et al. 2014a). In studies of sonic-tagged 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).

In 2013 and 2014, sonic-tagged, juvenile razorback suckers were often contacted near the Las Vegas Wash and Virgin River inflow areas; however, as lake levels declined and higher-discharge events occurred more frequently during summer and fall, these individuals appeared to move toward deeper habitat. Since all of the sonic-tagged, juvenile fish were contacted at least once, 8 of them were contacted on 5 different SURs, and over 4,000 contacts were made, more data were collected, and greater sampling opportunities existed in 2014 as compared with 2013. Sonic-tagged, juvenile razorback suckers were often contacted in shallow areas, which made tracking difficult; however, great care was taken to target these habitats, and a number of individuals were contacted regularly (see table 1).

Conspecific and Community Sampling

The variety of gears used to target available habitat during characterization of the fish assemblage associated with sonic-tagged, juvenile razorback suckers was successful in capturing additional razorback suckers in 2014. Though sometimes environmental circumstances (e.g., depths > 20 m and dense IV) created challenges for using all gear types at each sampling location, different gear types were used during the ICS period and each targeted a variety of functionally different fish species over a variety of habitats.

The new, wild razorback sucker captures occurred during trammel netting in Las Vegas Bay and Echo Bay, and throughout the year, trammel nets were the most effective at capturing a variety fish lake-wide. Hoop nets and minnow traps were also used, as these types of gear were ideal for setting in association with sonic-tagged, juvenile razorback suckers contacted within dense stands of IV.

Seine hauls were not used as often due to their more specific requirements for effective use, such as shallow, low-gradient shorelines. Although additional razorback suckers were only captured during trammel netting efforts, other gear types should not be precluded or overlooked. The combination of gear types, each with its own gear bias, more completely described the fish assemblage by including a number of species that might not have been caught using a single gear type. For example, electrofishing provided an abundance of smaller-sized fish that we would not have captured via trammel nets and demonstrated the highest catch rates of all gear types. Seining provided similar results in fish size but in lower abundance. Furthermore, the lack of small, juvenile razorback suckers (< 450 mm TL) captures may not be due to gear type; rather, small, juvenile razorback suckers have only been occasionally and sporadically captured during extensive sampling conducted as part of long-term monitoring (Kegerries et al. 2009; Albrecht et al. 2010c, 2013a, 2013b; Shattuck et al. 2011). During 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 4 new, wild, juvenile razorback suckers have been captured at Echo Bay (Holden et al. 1997, 1999). Additionally, two new, wild, juvenile razorback suckers have been captured at the Colorado River inflow area, where the smallest recorded individual on Lake Mead was captured (Kegerries and Albrecht 2013b, 2014). Both of those fish were aged as the 2011 year-class. As gear sets occurred during some of the warmest months of the year, net sets were timed to avoid undue stress to potential razorback sucker captures. Longer net sets and the potential for overnight net sets during winter should improve capture rates of conspecifics and provide insight into the composition of the associated fish assemblage and the interconnectedness of these species with their associated habitats. Additionally, alternative gear types (e.g., miniature fyke nets and varied methods of boat electrofishing) could be explored to more specifically target areas frequented by sonic-tagged, juvenile razorback suckers.

The fish community composition documented during 2014 closely resembled that recorded during the last several years of long-term monitoring (Kegerries et al. 2009; Albrecht et al. 2010b, 2013a, 2013b, 2014a; Shattuck et al. 2011, Shattuck and Albrecht 2014). The fish community of 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, but a variety of species moved through the area (e.g., common carp, gizzard shad, and striped bass). How these nonnative species interact with juvenile razorback suckers is of particular interest.

Certainly there is competition with and predation by most of these species, which makes juvenile razorback sucker mitigation of these trophic obstacles and the fish's ability to recruit in Lake Mead 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 provide 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. 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 2014 ICS sampling period, captured razorback suckers were larger than many nonnative predator counterparts (i.e., channel catfish, striped bass, smallmouth bass, and largemouth bass). In fact, razorback suckers had the highest mean TL of all of those species. Whether it is a function of smaller individuals having already been predated on by nonnative individuals of this size or a behavioral response to associate with smaller fishes, this type of association may help recruitment to occur despite the numerous nonnative, predatory fishes present. 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 chub 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, perhaps lending 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 by the continued captures of new, wild razorback suckers among smaller fishes. Although the new, wild individuals caught during the 2014–15 study year were 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, the capture of a juvenile razorback suckers released as part of the 2013–14 juvenile study provided direct evidence of survival and recruitment of a 250+ mm razorback sucker whose sonic tag had expired. The juvenile fish remained near at least one other juvenile and nine adults. Even more interesting was the 206 mm of growth displayed by this individual in just 18 months. Perhaps the strategy is to find cover, stay put, forage, and convert energy to mass in an effort to avoid predation. More recaptures of these juvenile fish will allow for more analysis regarding growth at age.

Habitat Observations and Physicochemical Quantification

During 2014, 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. They also transitioned back to shallower habitats during fall, apparently driven by substrate differences and depth as temperatures cooled and the season progressed. For the third consecutive year, the Las Vegas Wash and Virgin River inflow areas appeared to be important habitat features during spring and early summer, as the majority of sonic-tagged, juvenile razorback suckers associated with the high turbidity typical of these areas. Notably, during fall, juvenile razorback suckers utilized all study locations, with some of the juvenile fish moving back into Echo Bay from the Overton Arm.

The areas in which sonic-tagged, juvenile razorback suckers were contacted throughout 2012 and 2013 were similar to those quantified in 2014 (Albrecht et al. 2013a; Shattuck and Albrecht 2014); however, a much firmer understanding was obtained lake-wide, with clear trends in habitat associations. Differences were seen in temperature changes, DO concentrations, turbidity, and depths, perhaps signaling an important annual change for juvenile razorback suckers as they generally moved from shallows with vegetative cover into other, more variable cover types (e.g., turbidity and depth). Summer habitat remained quite different from spring habitat; it was generally deeper, with little IV, SAV, algae, and detritus, while fall habitats were generally somewhat intermediary and characterized by fairly apparent substrate-type association gradients. 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) and remains an important influence on seasonal habitat associations. This study quantifies turbidity levels that are associated with juvenile razorback suckers and provides important insight into that important recruitment component (e.g., table 4). 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 habitat that sonic-tagged, juvenile razorback suckers associated with averaged 6.7 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 with 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).

The variability seen among study areas with the lake-wide collection of habitat and physicochemical data 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 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. 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, and it will become more meaningful as the study continues. Interestingly, despite capturing a relatively high number of adult razorback sucker, this “species” was positioned near the juveniles. Both juvenile and adult razorback suckers were partitioned to be more associated with IV cover and increased conductivity and turbidity values, and they were associated with spring. The modeling of this particular life stage is supported, as captures of adult razorback suckers in Las Vegas Bay have occurred in near identical habitats for the third 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; Shattuck and Albrecht 2014). 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 at least during certain periods of a given year. Without that perceived difference, juvenile razorback sucker captures would be higher than observed during the 18-year study. In contrast to both juvenile and adult razorback suckers, the flannelmouth sucker was spatially partitioned distantly, associating with a lack of cover, greater depth, and the summer season in the Virgin River/Muddy River inflow area. This species is taxonomically similar and, although it was partitioned differently in the CCA model, the individual captured was a 255-mm TL juvenile found in direct association with a sonic-tagged, juvenile razorback sucker. Inferences, however, are limited to a single-capture occasion. Overall, cover type and season 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 sucker; and larger substrates and SAV were directly correlated with Echo Bay.

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. It appears that spring habitat is characterized by turbidity, IV cover, and LWD cover. This is rather intuitive, as typically lake levels are at their annual highs, inundating a greater degree of cover while individuals are associating with shallower depths. As these variables are strongly related to seasonally occupied habitat, it is not surprising that heterogeneous substrates and SAV helped define the fall season. While lake levels are not necessarily higher during fall, sonic-tagged, juvenile razorback suckers appear to return to shallower depths as temperatures recede from summer highs; thus, although the lower lake levels do not provide as much IV and LWD cover types, they do allow for wave-induced scouring to provide larger substrates, and they provide lower turbidity conditions to promote SAV abundance. While both winter and summer are associated with greater depths and an apparent lack of cover, the small number of winter samples do not allow for much interpretation (this season will be further investigated during 2015–16). The PCA model suggests that spring habitat associations are partially driven by turbidity and the presence of IV before sonic-tagged, juvenile razorback suckers transition into deeper summer habitat, perhaps seeking thermal refuge. As summer progresses into fall, individuals move back into shallower habitat with greater substrate heterogeneity before moving into winter habitat, potentially similar to that of summer. Increased samples will 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.

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 2014–15 study year mainly encompasses the late summer and fall (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 and 2014, 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 and 2014 confirmed the usefulness of sonic-tagged, juvenile razorback suckers as a means to locate wild razorback suckers. These findings allow for 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 herein will be used to clarify the early life stage requirements of razorback suckers, and that this additional knowledge will contribute not only to promote better understanding of razorback suckers within Lake Mead but also to guide management of the species' recruitment needs in other basin locations.

Efforts to locate smaller (< 350 mm TL) juvenile razorback suckers have clearly demonstrated the elusiveness of this life stage. 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 the first years of growth of juvenile razorback suckers are largely unknown, there remains a need to better understand nearly every aspect of juvenile razorback sucker life history. Although we now have an increased amount of information regarding this life stage during spring, summer, and fall, further efforts focused on winter will likely offer a more complete understanding of why razorback suckers are able to recruit in Lake Mead. Additionally, as sonic tag technology has improved, smaller sonic tags can potentially provide data on movement and habitat use of even smaller razorback suckers (perhaps < 200 mm). Even though capturing razorback suckers of that size has been difficult, technology and sonic telemetry may help fill the void related to habitat association and recruitment habitat data.

2015–16 WORK PLAN

Specific Objectives for the Second Study Year

1. Obtain more data from winter/spring seasons. We believe it is imperative to finish this study by obtaining more seasonal data and anticipate that the efforts for the second option year will be nearly identical to efforts for the 2013–14 and 2014–15 study years. Efforts for the ICS will again be conducted through the duration of the PT-4, 3-month sonic tags; however, the timing of initial sonic tagging of a juvenile razorback suckers (implanting both the PT-4, 3-month tags and the IBT-96-9, 12-month tags) will occur during a different period of the calendar year and at two separate times for the two types of tags. We anticipate implanting IBT-96-9, 12-month tags during May in four fish at each study area to continue AHS efforts. No conspecific or community fish sampling will be conducted during May and December. To capture seasonal variation, the ICS efforts will commence with implanting two fish with PT-4, 3-month sonic tags in December at each study area. Following sonic-tag implantation, tracking, physicochemical data collection, and conspecific and community fish sampling will be conducted weekly for the approximate 12-week period coinciding with the expected battery life of the PT-4, 3-month sonic tags and allowing for more detailed data collection associated with the winter months. No doubt that as adult fish begin to spawn, interesting observations of the juvenile life stage will be made during the study year.

2. 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. Continue to coordinate and work jointly with the ongoing razorback sucker investigations at all of the long-term monitoring study areas and the Colorado River inflow area/lower Grand Canyon, as appropriate. Since 2010, efforts undertaken to document the presence or absence of razorback suckers at the Colorado River inflow area have resulted in

the capture of wild, ripe, adult and larval razorback suckers and the documentation of a spawning aggregate near the Colorado River/ Lake Mead interface. Not only were wild fish documented using this new study area, but sonic telemetry efforts in this portion of Lake Mead helped locate sonic-tagged fish originating from the long-term monitoring study areas and documented sonic-tagged individuals utilizing the Colorado River proper and moving into the lower Grand Canyon (Kegerries and Albrecht 2013a; Albrecht et al. 2014b). In 2014, razorback sucker larvae were captured within the lower Grand Canyon, and spawning above Lava Falls was documented (Albrecht et al. 2014b). Thus, the potential exists for continued, perhaps increased, exchange of sonic-tagged razorback suckers among different areas of Lake Mead though the concurrent studies. With an abundance of small flannelmouth suckers and the confirmed potential for small razorback suckers to be present at the Colorado River inflow, sampling with a variety of gear types may help identify the most efficient and effective method for capturing the juvenile life stage. 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 area or during long-term 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 part of 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 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 suckers has been informative and that it will be important to track these parameters though all seasons as this study progresses. Hence, it is imperative that the final report be somewhat comprehensive so as to capture any important seasonal 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. Furthermore, obtaining the complete dataset will add greater power to statistical analyses and reduce the amount of annual or seasonal bias incorporated within any 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, the 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, and we thank all involved. We also thank Jim Stolberg, Nathan Rudd, Andrea Finnegan, Gregg Garnett, Jeff Lantow, and Sandra Livingston Turner for constructive comments provided during the review process as well as the many others involved with field work, permitting, and other portions of this project.

LITERATURE CITED

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

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

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

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

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

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

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

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

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

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

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

Albrecht, B., Z. Shattuck, and R. Rogers. 2013a. Razorback Sucker Studies on Lake Mead, Nevada and Arizona, 2011–2012 Annual Report. PR-1475-01. Prepared for the Lower Colorado River Multi-Species Conservation Program, Bureau of Reclamation, by BIO-WEST, Inc., Logan, UT.

Albrecht, B., Z. Shattuck, R. Rogers, and R. Kegerries. 2013b. Razorback Sucker Studies on Lake Mead, Nevada and Arizona, 2012–2013 Annual Report. PR-1475-02. Prepared for the Lower Colorado River Multi-Species Conservation Program, Bureau of Reclamation, by BIO-WEST, Inc., Logan, UT.

Albrecht, B., Z. Shattuck, and R. Rogers. 2014a. Razorback sucker *Xyrauchen texanus* Studies on Lake Mead, Nevada and Arizona, 2013–2014 Annual Report. PR-1475-03. Prepared for the Lower Colorado River Multi-Species Conservation Program, Bureau of Reclamation, by BIO-WEST, Inc., Logan, UT.

Albrecht, B., R. Kegerries, J.M. Barkstedt, W.H. Brandenburg, A.L. Barkalow, S.P. Platania, M. McKinstry, B. Healy, J. Stolberg, and Z. Shattuck. 2014b. Razorback Sucker *Xyrauchen texanus* Monitoring in the Colorado River Inflow Area of Lake Mead and the Lower Grand Canyon, Nevada and Arizona, 2014 Annual Report. Prepared for the Bureau of Reclamation, Upper Colorado River Region, by BIO-WEST, Inc., Logan, UT.

Analytical Software. 2005. Statistix 8.1 for Windows. Analytical Software, Tallahassee, FL.

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

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

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

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

Burdick, S.M., H.A. Hendrixson, and S.P. VanderKooi. 2008. Age-0 Lost River sucker and shortnose sucker nearshore habitat use in Upper Klamath Lake, Oregon: a patch occupancy approach. Transactions of the American Fisheries Society 137:417–430.

Bureau of Reclamation (Reclamation). 2014. Historical Lake Mead Reservoir levels.
http://www.usbr.gov/lc/

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

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

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

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

Gregor, M. 2012. Sonotronics, Tucson, AZ, personal communication.

Hair, Jr., J.F., R.E. Anderson, R.L. Tatham, and W.C. Black. 1998. Multivariate Analysis, Fifth Edition. Prentice Hall International: Upper Saddle River, NJ. 768 p.

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

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

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

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

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

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

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

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

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

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

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

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

Karam, A.P. and P.C. Marsh. 2010. Predation of adult razorback suck and bonytail by striped bass in Lake Mohave, Arizona–Nevada. Western North American Naturalist 70(1):117–120.

Karp, C.A. and G. Mueller. 2002. Razorback sucker movements and habitat use in the San Juan River inflow, Lake Powell, Utah, 1995–1997. Western North American Naturalist 62(1):106–111.

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

_____. 2013a. Razorback Sucker Investigations at the Colorado River Inflow Area of Lake Mead, Nevada and Arizona, 2012 Final Annual Report. PR-1310-03. Prepared for the Bureau of Reclamation by BIO-WEST, Inc., Logan, UT.

_____. 2013b. Razorback Sucker Investigations at the Colorado River Inflow Area of Lake Mead, Nevada and Arizona, 2013 Final Annual Report. PR-1310-04. Prepared for the Bureau of Reclamation by BIO-WEST, Inc., Logan, UT.

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

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

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

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

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

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

McCarthy, M.S. and W.L. Minckley. 1987. Age estimation for razorback sucker (Pisces:Catostomidae) from Lake Mohave, Arizona and Nevada. Journal of the Arizona–Nevada Academy of Science 21(2):87–97.

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

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

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

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

Mueller, G.A. 1995. A program for maintaining the razorback sucker in Lake Mohave *in* American Fisheries Society Symposium, American Fisheries Society. pp. 127–135.

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

Mueller, G.A. and P.C. Marsh. 1998. Post-stocking Dispersal, Habitat Use, and Behavioral Acclimation of Juvenile Razorback Suckers (*Xyrauchen texanus*) in two Colorado River Reservoirs. U.S. Geological Survey Open File Report 98-301.

Mueller, G.A. and J.L. Brooks. 2004. Collection of an adult gizzard shad (*Dorosoma cepedianum*) from the San Juan River, Utah. Western North American Naturalist 64(1):135–136.

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

Olden, J.D., editor. 2011. Applied multivariate statistics for ecologists: principal component analysis. Course FSH 560, University of Washington, Seattle.

Palmer, M.W. 1993. Putting things in even better order: the advantages of canonical correspondence analysis. Ecology 74(8):2215–2230.

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

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

Shattuck, Z. and B. Albrecht. 2014. Sonic Telemetry and Habitat Use of Juvenile Razorback Suckers in Lake Mead, 2013–2014 Annual Report. PR-1588-0. Prepared for the Lower Colorado River Multi-Species Conservation Program, Bureau of Reclamation, by BIO-WEST, Inc., Logan, UT.

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

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

ter Braak, C.J.F. and P. Šmilauer. 2012. Canoco reference manual and user's guide: software for ordination (version 5.0). Microcomputer Power, Ithaca NY. 496 p.

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

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

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

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

U.S. Geological Survey (USGS). 2014. Annual water data reports. http://waterwatch.usgs.gov/

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

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

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

Ward, D.L. and R. Morton-Starner. 2013. Effects of water temperature and turbidity on predation vulnerability of juvenile humpback chub to rainbow trout and brown trout. 45th Annual Meeting of the Desert Fishes Council (oral presentation).

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

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

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

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

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