Lower Colorado River Multi-Species Conservation Program

Balancing Resource Use and Conservation

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

2015–2016 Annual Report

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

July 2017

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Lower Colorado River Multi-Species Conservation Program

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ACRONYMS AND ABBREVIATIONS

AHS	additional habitat sampling
BIO-WEST	BIO-WEST, Inc.
CCA	canonical correspondence analysis
cm	centimeter(s)
FL	fork length
g	gram(s)
ICS	intensive community sampling
IV	inundated vegetation
L	liter(s)
LCR MSCP	Lower Colorado River Multi-Species Conservation Program
LWD	large woody debris
m	meter(s)
mg/L	milligrams per liter
mm	millimeter(s)
MS-222	tricaine methanesulfonate
msl	mean sea level
n =	sample size
NaCl	sodium chloride
NDOW	Nevada Department of Wildlife
NTU	nephelometric turbidity units
PCA	principal component analysis
pH	the mean H+ concentration converted to pH
PIT	passive integrated transponder
R-cc	R-code companion tag
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

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

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EXECUTIVE SUMMARY

In 2012, the Bureau of Reclamation's Lower Colorado River Multi-Species Conservation Program (LCR MSCP) provided funding to continue long-term monitoring efforts and initiate a pilot study of juvenile razorback suckers (*Xyrauchen texanus* [Abbott]) in Lake Mead. The pilot study demonstrated that juvenile razorback suckers can be effectively implanted with sonic tags and provide insight into their habitat associations during this life stage, and that those implanted juvenile fish could lead researchers to other razorback suckers. Habitat association data from the 2012 pilot study are provided in Albrecht et al. (2013a). Building on the successes of, and information obtained from, the 2012 pilot study, the LCR MSCP provided funding for a full sonic telemetry and habitat use study in 2013, which also extended through 2016, to better understand juvenile razorback suckers in Lake Mead. This report presents information from the third study year (2015–16) and provides information stemming from both the intensive community sampling (ICS) efforts conducted from December through March (late fall/winter season) and additional habitat sampling efforts conducted during the remainder of the year. The report also includes holistic seasonal analyses of habitat and fish community sampling conducted since 2013.

During the 2015–16 study year, the habitat use and movements of sonic-tagged, juvenile razorback suckers were monitored through active tracking, resulting in 83 contacts with 17 individuals released in 2014 and 2015. Additionally, six submersible ultrasonic receivers were deployed throughout the lake to passively detect lake-wide movement of tagged individuals. Five of the receivers detected 16 unique juvenile razorback suckers. 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 Overton Arm near the Virgin River/Muddy River inflow area. 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. During the study period, sampling for this life stage occurred only in locations where sonic-tagged juvenile razorback suckers were detected.

ICS efforts involved a suite of methods, were composed of 197 total gear sets, and resulted in the capture of 1,038 individual fishes from 16 species. Included in the fishes captured were 10 adult razorback suckers. All razorback suckers were captured in direct association with sonic-tagged juvenile razorback suckers in all sampling locations. Fin ray sections were removed from captured individuals for age determination. The razorback suckers captured ranged in age from 5 to 14 years. 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, data collected from 2007 to 2013 show that strong

pulses in recruitment coincided with low, declining lake level trends and high-flow events in the Virgin River. Aging 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.

For the habitat assessment and physicochemical quantification presented here, we characterized 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 and winter, a shift back into shallower habitats with cover was observed. Although some seasonal and site variation did occur throughout the study, the holistic analysis revealed much overlap in habitat use of juvenile razorback suckers for all seasons at all sites.

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). Historically widespread and common throughout the larger rivers of the basin, the distribution and abundance of long-lived razorback suckers are now greatly reduced (Minckley et al. 1991) principally due to anthropogenic causes. 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 construction 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, 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 the pattern of other razorback sucker population declines following reservoir development (Minckley 1983; McCarthy and Minckley 1987; Marsh et al. 2005). Competition and predation from non-native fishes in the Colorado River and its reservoirs have also contributed to the decline of this endemic species (Minckley et al. 1991; Mueller 2005); however, razorback suckers have persisted in a few locations despite dramatic environmental and biological changes (Albrecht et al. 2010a, 2013a, 2014b; Dowling et al. 2012). Within Lake Mead, wild fishes are regularly captured, thereby emphasizing the uniqueness and natural complexity of this reservoir's razorback sucker population.

In 1990, after receiving reports 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 investigate the Lake Mead population of razorback suckers (Holden et al. 1997). Since 1996, 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, the Bureau of Reclamation's [Reclamation] Lower

Colorado River Multi-Species Program [LCR MSCP], National Park Service, and the U.S. Fish and Wildlife Service) to study various questions regarding the razorback suckers' persistence in Lake Mead (Albrecht et al. 2008b).

Though much of the research conducted thus far has focused on adult individual razorback suckers and aspects of reproductive success, a number of juveniles (i.e., sexually immature individuals less than 450 millimeters (mm) total length (TL) (Shattuck et al. 2011) have been captured incidentally in recent years (Albrecht et al. 2007, 2008a, 2010b, 2013a, 2014b; Kegerries et al. 2009; Shattuck et al. 2011; Kegerries and Albrecht 2013b). Targeted sampling for 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), but trammel netting targeting spawning adult razorback suckers during long-term monitoring efforts from 2007 through 2015 has resulted in the capture of 73 wild (unmarked) juvenile razorback suckers (Albrecht et al. 2006, 2007, 2008a, 2008b, 2010b, 2013a, 2013b, 2014a, 2014b; Kegerries et al. 2009; Shattuck et al. 2011; Kegerries and Albrecht 2013a, 2013b; Mohn et al. 2015). Despite what appears to be plentiful captures, only limited information about young, sexually immature razorback suckers in Lake Mead exists. Pilot efforts in 2012 sought to add to the body of information regarding recruitment of the juvenile life stage within Lake Mead (Albrecht et al. 2013a).

In 2012, the LCR MSCP provided funding for a razorback sucker recruitment pilot study that would also complement long-term monitoring efforts in Lake Mead (Albrecht et al. 2013a). Using newly available, smaller sonic tag technology, four juvenile razorback suckers (one wild caught in Las Vegas Bay and three pond reared at the Overton Wildlife Management Area) were implanted with sonic tags and released into Las Vegas Bay. The seasonal movement of individuals and their associated habitats were characterized throughout the year. Sampling was also conducted in association with sonic-tagged juvenile razorback suckers to capture wild juveniles and describe the overall fish community in relation to their location. Although the pilot study was limited in scope (i.e., it only occurred in Las Vegas Bay), study findings suggested that juvenile razorback suckers avoid predation by utilizing areas with heavy cover (which include turbidity and inundated vegetation [IV]), moving from shallow habitat into deeper habitat with the progression of seasons, and closely associating with other wild razorback suckers (Albrecht et al. 2013a).

Following the successes of the pilot study, the LCR MSCP provided funding in 2013 for a full-scale, juvenile razorback sucker sonic telemetry and habitat use study that was conducted in multiple locations within Lake Mead and included optional continuation years (2014 and 2015). Similar to the pilot study, the goal of this study is to provide a better understanding of how and why razorback suckers are uniquely able to recruit in Lake Mead and identify potential areas or types of habitat that allow for successful recruitment.

STUDY AREAS

During 2015–16, all juvenile razorback sucker sonic telemetry and habitat assessment activities in Lake Mead occurred at the locations studied during long-term monitoring efforts from 1996 through 2016, which included Las Vegas Bay, Echo Bay, and the Overton Arm (figure 1) (Holden et al. 1997; Mohn et al. 2015).

Because the lake level affects what is called the "wash" or "bay," the following definitions are used to differentiate the various habitats at the time of sampling:

- 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. It is sometimes referred to as the flowing portion (the area closest to, or within, Las Vegas Wash).

- 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 non-flowing (lentic) portion. The flowing portion is typically short (200–400 meters [m]) and transitory between Las Vegas Wash proper and Las Vegas Bay. This is sometimes referred to as the non-flowing portion (usually has turbid water but very little, if any, current).

Additionally, the location of juvenile razorback suckers in the northern portion of the Overton Arm necessitates a description of these areas.

- 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).

- The 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 2015–16 study year are provided for context (note field efforts for this study specifically spanned January 5, 2015 – March 4, 2016) and were measured in meters above mean sea level (msl) as obtained from Reclamation's Lower Colorado Regional Office Web site (Reclamation 2016). Similarly, mean daily discharges for Las Vegas Wash and the Virgin and Muddy Rivers were measured in cubic meters per second and obtained

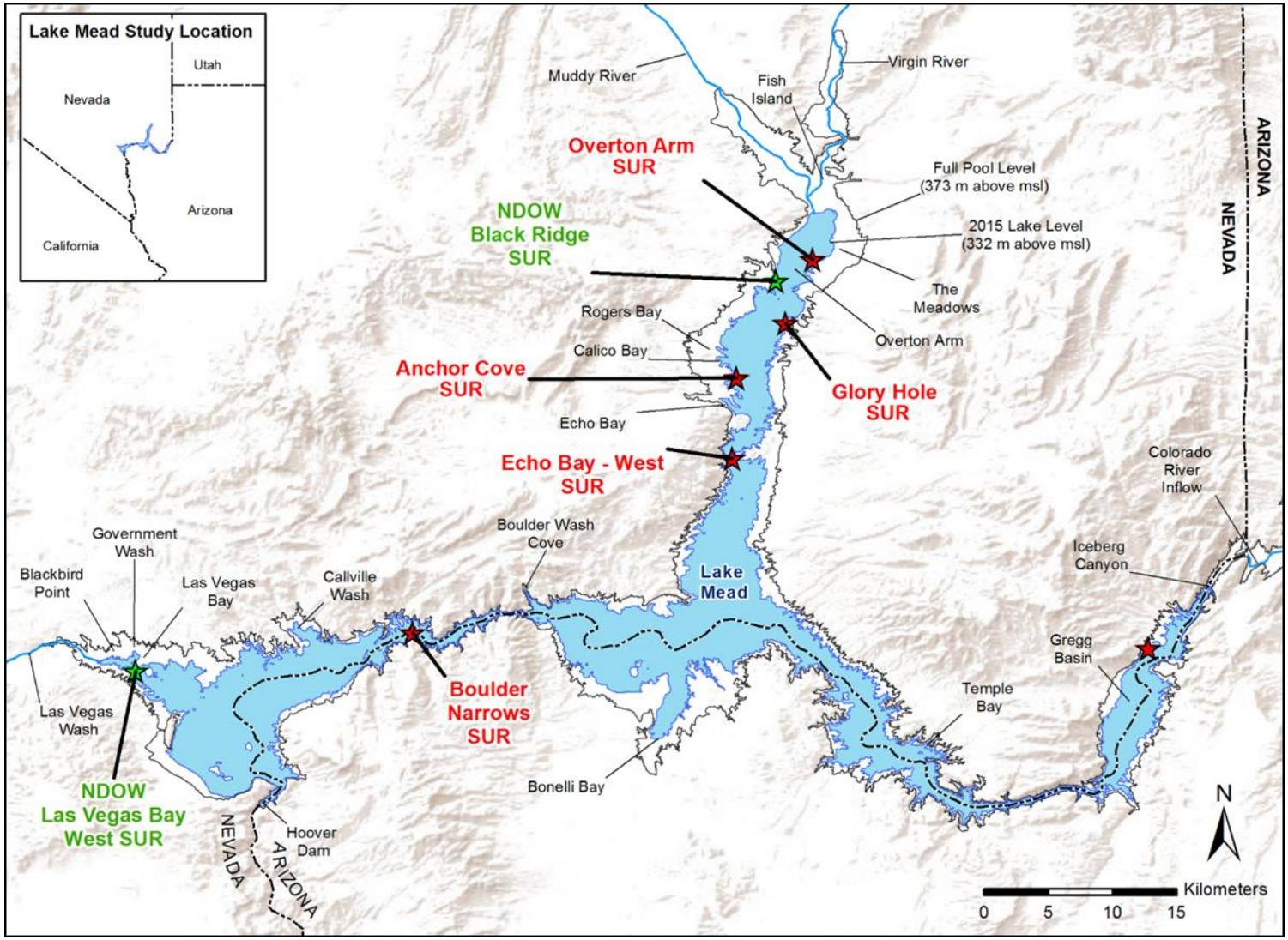

Figure 1.—Juvenile razorback sucker study areas in Lake Mead, Nevada, 2015 and 2016.
Locations of submersible ultrasonic receivers are denoted by red stars (units maintained by BIO-WEST) or green stars (units maintained by the NDOW).

from the U.S. Geological Survey (USGS) for the 2015–16 study year (USGS 2016) 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

Eleven juvenile razorback suckers from the NDOW Lake Mead Fish Hatchery were implanted with sonic tags on May 4, 2015, and subsequently released into Lake Mead on May 4–5, 2015, with the assistance of NDOW and Reclamation. Four individuals were released into Las Vegas Bay, three individuals into Echo Bay (one less due to tag malfunction at time of implantation), and four individuals into the Virgin River/Muddy River inflow area. All were implanted with Sonotronics model IBT-96-6 tags during the May event. On December 1, 2015, seven additional juveniles from the NDOW Lake Mead Fish Hatchery were implanted with smaller Sonotronics model PT-4 tags. Two fish implanted with each type of sonic tag were released at each study area the following day, with the exception of Echo Bay where three tagged fish were released in an effort to replace a single tag malfunction that occurred during the May implantation event.

A size curve was calculated for juvenile razorback suckers in Lake Mead based on empirical capture data 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% 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-month and 12-month battery lives; without the R-cc, these sonic tags had an expected battery life of less than 90 days and 8 months, respectively. Two tag sizes were implanted in the smallest juvenile individuals as possible; this method provided 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 between transmissions. To properly identify tags using the R-cc, the firmware of all submersible ultrasonic receivers (SURs) was

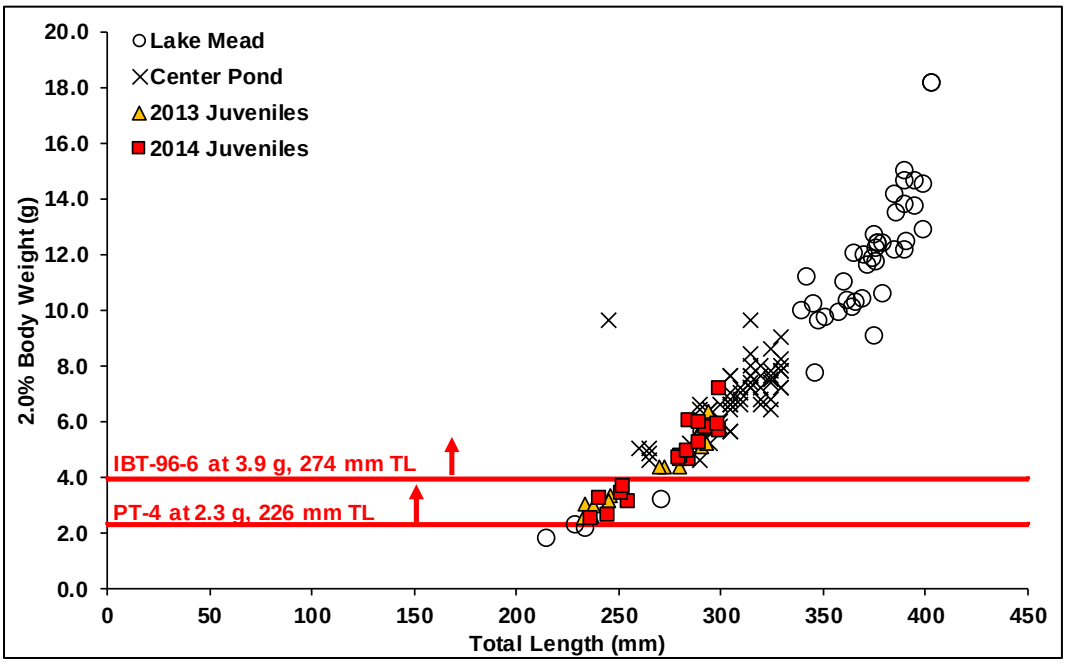

Figure 2.—Sonic tag sizing chart for juvenile razorback suckers surgically implanted in 2014 according to a guideline of tag weight not exceeding 2% of body weight (Bidgood 1980; Winter 1983; Marty and Summerfelt 1990) with a sizing curve based on empirical captures of Lake Mead razorback suckers < 400 mm TL from 2005 to 2013 (Kegerries and Albrecht 2013b).
Lengths and weights of individuals from Center Pond at the Overton Wildlife Management Area are included for comparison.

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 chub [*Gila cypha*] and Colorado pikeminnow [*Ptychocheilus Lucius*]) (Tyus 1982; Valdez and Nilson 1982; Valdez and Masslich 1989; Kaeding et al. 1990; Valdez and Trinca 1995; Kegerries and Albrecht 2011; Shattuck et al. 2011; Albrecht et al. 2013a). Surgery was performed at the NDOW 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, the TL, fork length (FL), standard length (SL) (mm), 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 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 the NDOW Lake Mead Hatchery, partitioned by stocking location cohort (i.e., Las Vegas Bay, Echo Bay, the Virgin River/Muddy River inflow area). 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 5, 2015, to March 4, 2016; however, effort intensity was dependent on study objectives for the intensive community sampling (ICS) or additional habitat sampling (AHS) period. During ICS (December 7, 2015 – March 4, 2016), 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 AHS (January 5 – December 6, 2015), which was associated solely with habitat data collection and the larger IBT-96-6 sonic tags, tracking was conducted on a monthly basis. The season was recorded for all sonic-tagged fish encounters 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).

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 or 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 triangulated to the highest accuracy possible, 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 with 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, the SUR facilitates an understanding of large-scale juvenile razorback sucker movements during monthly tracking events and can indicate whether a juvenile individual has moved into or out of a particular area. Seven SURs were utilized during the 2015–16 study year. These units were situated before the initial stocking of sonic-tagged juvenile razorback suckers to immediately monitor individuals' movements (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 with 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 data were frequently 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 analyses, 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 ICS (December 7, 2015 – March 4, 2016) 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 attempt capture of 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 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, and coloration). Additionally, samples were collected from individuals that were not recaptured fish: A section of pectoral fin ray was removed for aging 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% non-denatured 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 non-native 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 size differences and potential razorback sucker predation.

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. The 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 juvenile sonic-tagged 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.

Age Determination

The 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 non-lethal technique of fin ray section extraction developed in 1999 and refined during ongoing, long-term monitoring (Holden et al. 2000a; Mohn et al. 2015).

During the 2015–16 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 (NaCl), and slime-coat protectant to reduce surgery-related stresses, speed recovery, and avoid accidental injury to fish during surgical procedures. During the surgery, standard

processing was simultaneously conducted (i.e., weighing, measuring, PIT tagging, and photographing), and a sample was surgically collected using custom-made bone snips originally developed by BIO-WEST. This surgical tool consists of a matched pair of finely sharpened chisels welded to a set of wire-stripping pliers. The connecting membrane between fin rays was cut using a scalpel blade, and the section was placed in a labeled envelope for drying. All surgical equipment was sterilized before use, and subsequent wounds were packed with antibiotic ointment to minimize post-surgical bacterial infections and promote rapid healing. All native suckers undergoing fin ray extraction techniques were immediately placed in a recovery bath of fresh lake water containing slime-coat protectant and NaCl, allowed to recover, and released as soon as they regained equilibrium and appeared recovered from the anesthesia. Vigilant monitoring was conducted during all phases of the procedure.

In the laboratory, fin ray segments were embedded in thermoplastic epoxy resin and heat cured. This technique allowed the fin rays to be perpendicularly sectioned using a Buhler isomet low-speed saw. Resultant sections were then mounted on microscope slides, sanded, polished, and examined under a stereo-zoom microscope. Each sectioned fin ray was aged independently by at least three readers. Sections were 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.

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-m by 20-m rectangle (4,000 square meters) or a 36-m radius circle (4,069 square meters) 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 ICS, 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. For example, fewer replicates were conducted in deep, offshore habitats where replicates have been deemed similar from past studies (Shattuck and Albrecht 2014; Kegerries et al. 2015b). 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 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 temperature (˚C), dissolved oxygen (milligrams per liter), conductivity (microsiemens per centimeter [µS/cm]), pH, and turbidity (nephelometric turbidity units). After the water column was assessed for these standard parameters from surface to bottom, a substrate grab sample was collected to visually estimate the substrate type following a modified Wentworth scale (Cummins 1962) (i.e., silt, sand, gravel [< 3 inches], cobble [3–10 inches], 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 types were 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 hand-held Trimble Global Positioning System unit or gridded template was used to create spatial polygons to calculate the percent of area covered. Cover was categorized as general vegetation types, including IV (e.g., saltcedar [*Tamarix* sp.], tumble pigweed [*Amaranthus albus*], and creosotebush [*Larrea tridentate*]), emergent vegetation (e.g., bulrush [*Typha* sp.], narrowleaf cattail [*Typha angustifolia*], and common reed [*Phragmites* sp.]), submerged aquatic vegetation (SAV), including filamentous algae (e.g., spiny naiad [*Najas marina*], sago pondweed [*Stuckenia pectinate*], and widgeon grass [*Ruppia maritima*]), large woody debris (LWD) (≤ 4 inch diameter [Webb and Erskine 2003]), or none (i.e., no observable cover types, typically in deeper areas of open water or turbid conditions).

Finally, the 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 Microsoft Access® database maintained by BIO-WEST. Field data were checked post-entry for quality assurance and quality control. A variety of univariate and multivariate analyses were used to describe 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 2015–16 study year, data used in multivariate analyses are cumulative and include data collected from the 2013–14, 2014–15, and 2015–16 study years as recommended in Shattuck and Albrecht (2014).

Univariate Analyses

The program Statistix 8.1® was used for all statistical analyses. For nearly all data analyzed in this report, the distribution was positively skewed (right skew). A Shapiro-Wilk test was used to confirm non-normal data distribution, while an assessment of residual plots indicated non-normal residual distribution for the majority of the data. A Kruskal-Wallis test was used for all data comparisons to maintain continuity in results. Mean and/or median values for appropriate data are reported. When significant differences were found, a post-hoc analysis was performed using the Kruskal-Wallis all-pairwise comparisons in Statistix® to differentiate homogeneous groups. For all tests, α was set at 0.05.

For lengths taken from the fish community data, length frequency distributions for both razorback sucker and non-native fish species were constructed. Additionally, a kernel density plot was used to estimate the probable density of fish by length for each season (Sanvicente-Añorve et al. 2003). In Microsoft Excel®, with the NumXL add-on tool, the data were selected using the kernel density estimation function with a Gaussian Kernel and selecting for the optimal bandwidth. The output values were then plotted on a graph to compare length distribution densities by season.

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 allocates the observed variation in a CCA model among explanatory variables (i.e., environment and season) and the unexplained variation (Borcard et al. 1992; ter Braak and Šmilauer 2012). As information regarding recruitment of razorback suckers and habitat use by young fishes 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 multi-collinearity (Palmer 1993).

In the CCA, 142 total samples with 18 response variables (species) and 23 explanatory variables (environmental) were used in the analysis, with each sample consisting of data tabulated for each sonic-tagged juvenile razorback sucker encounter. The 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, or the Overton Arm), 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”). The data were $\log_{10}$ transformed and centered in the program CANOCO 5.0 (ter Braak and Šmilauer 2012) to ensure a standardized dataset. Spatial designation was included to describe differences in juvenile razorback sucker habitat association within Lake Mead by season and study area. Species data from 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 suckers, the abundance of juvenile razorback suckers was included as at least one individual (i.e., the sonic-tagged juvenile), unless multiple individuals were contacted in the sampling area, in which all were included. Although hatchery-reared, sonic-tagged juveniles were not necessarily captured with deployed sampling gears, their presence in the sampling area was known from 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 the 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 the ordination and variation partitioning (Borcard et al. 1992; ter Braak and Šmilauer 2012). The cumulative dataset that includes data from 2013–16 maintains a recommended minimum ratio of observations (n = 142) to variables (n = 41) of 3:1 (McGarigal et al. 2000).

Output plots from program CANOCO 5.0 using species scaling can be interpreted as the length of the arrows (explanatory variables or environmental gradients) indicating 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 vary 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 the numeric scale does not aid in interpretation; rather, the values corresponding to a particular species or eigenvector simply help in the distancing of samples. The significance of variation attributed to a particular category (i.e., environment, species, season, and the unexplained) through post-hoc variance partitioning was tested using 99,999 Monte Carlo permutations in a non-parametric randomization test run in program 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, 270 samples and 15 response variables were used in the PCA analysis. The data were $\log_{10}$ transformed and environmental variables centered in program CANOCO 5.0 (ter Braak and Šmilauer 2012) to ensure a standardized dataset. Mean habitat data used in numeric form included depth, temperature, conductivity, DO, pH, and 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. 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 = 0) to variables (n = 15) of 3:1 (McGarigal et al. 2000) and exceeds a more conservative recommendation of 10:1 (Hair et al. 1998).

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 as follows: 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 the habitat associated with encounters with sonic-tagged juvenile razorback suckers, and 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 the numeric scale does not aid in interpretation.

The two multivariate approaches were used in conjunction for the 2013–16 study years, 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 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 for 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 and connectivity (figure 3).

Lake levels decreased nearly 5.0 m from a high of 332.0 m above msl on January 21, 2015, to a low of 327.5 m above msl on June 26, 2015 (figure 3). Lake elevations increased continuously during the winter ICS, which potentially

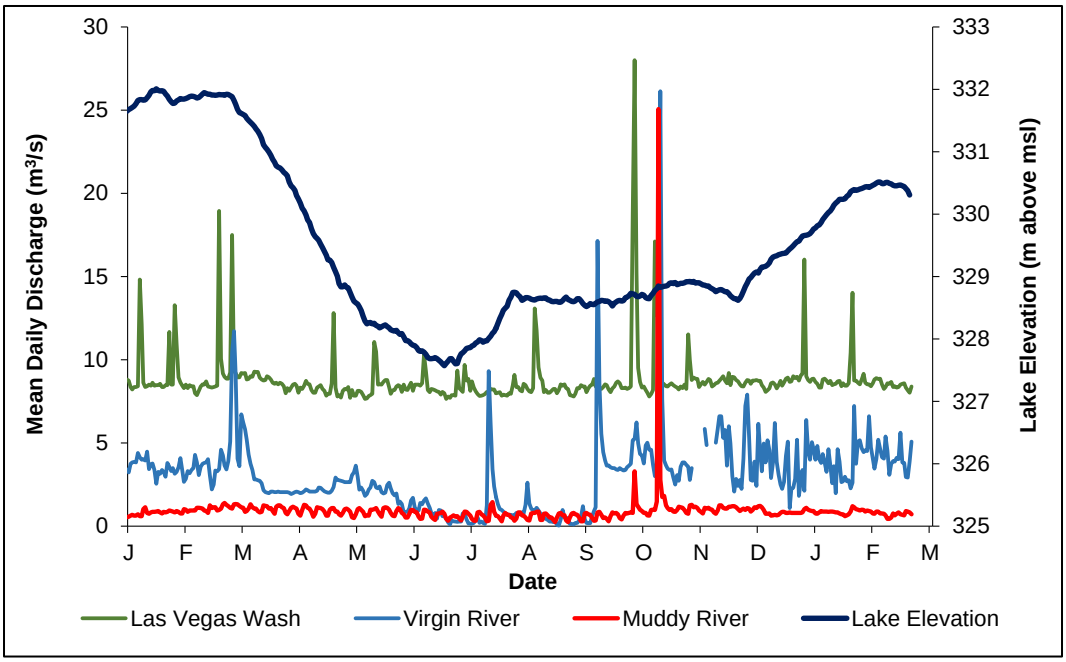

Figure 3.—Daily lake levels for Lake Mead in meters above msl, January 5, 2015 – March 4, 2016 (Reclamation 2016) and mean daily discharges in cubic meters per second for Las Vegas Wash, the Virgin River, and the Muddy River, January 5, 2015 – March 4, 2016.
Some discharge data are provisional and subject to USGS revision.

allowed juvenile fish to access new, formerly vegetated areas that may provide additional cover. The Virgin River experienced four high-discharge events exceeding 10 cubic meters per second during the study period. Discharges from Las Vegas Wash were consistently higher than Muddy River or Virgin River discharges, with peaks in January and February 2015 and 2016 and an additional high-discharge event in October 2015. Muddy River flows remained relatively consistent except for two discharge spikes in October, which corresponded with similar increases in discharge from the Virgin River and Las Vegas Wash (see figure 3). These discharge events 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, an important form of cover for razorback sucker recruitment (Golden and Holden 2003; Albrecht et al. 2010a; Mohn et al. 2015).

Sonic Telemetry

Eighteen juvenile razorback suckers (210–299 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. Eighty-three manual contacts spanning January 6,

2015 – March 2, 2016, were made, with 11 sonic-tagged juvenile razorback suckers released in 2015 (table 1). Six sonic-tagged juvenile razorback suckers released in 2014 were also contacted a total of 16 times during the study, with the last manual contact occurring on October 16, 2015 (table 1).

Generally, sonic-tagged juvenile razorback suckers remained at their respective release/study areas during 2015–16, with the exception of one fish (code 3043), which was stocked in Echo Bay in May 2015 and later located on the west shore of the Overton Arm near Fire Cove. Other fish movement was documented from two fish (codes 3028 and 3042). Sonic-tagged fish 3028 was released in Echo Bay in 2014, after which it traveled to the Overton Arm and then to the Colorado River inflow area where it was last contacted in April 2015. Sonic-tagged fish 3042 was released in Echo Bay in May 2015, where it remained until traveling south out of Echo Bay, north to the Overton Arm, and back to Echo Bay in January 2016. A comparison of depth (meters) at contact of sonic-tagged fish among seasons over all sites revealed no significant variation throughout the study period (Kruskal-Wallis test, $X^2 = 2.113$, df = 3, P = 0.5558). However, depth varied significantly among study areas ($X^2 = 16.225$, df = 2, P = 0.0002). Post-hoc comparisons revealed that sonic-tagged fish contacted in or near Echo Bay were in deeper water than fish contacted in the Overton Arm. Depth at contact in Las Vegas Bay was midway between (not statistically different from) Echo Bay and the Overton Arm. Depths compared individually by site and season indicated that fish occupied significantly deeper water in the Overton Arm during the summer season ($X^2 = 6.17$, df = 2, P = 0.046). Fish in Echo Bay occupied areas 2 m deeper on average during the summer and fall season, but these differences were not significant ($X^2 = 3.191$, df = 3, P = 0.363). No seasonal difference in depth was detected within Las Vegas Bay ($X^2 = 3.553$, df = 3, P = 0.314).

It appeared that within each study area, local movements somewhat transitioned with season. In Las Vegas Bay, 5 individuals were located for a total of 16 active contacts during 2015 (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 ($n = 6$) were made with sonic-tagged juvenile razorback suckers. These contacts were in habitat with an average depth of 7.2 m (standard error [SE] ± 1.4) near the mouth of Las Vegas Wash and east into the mid-channel (figure 4). As summer progressed, sonic-tagged juvenile individuals were only contacted once in shallow water near Las Vegas Wash. In fall, one of the newly released juveniles was found in habitat with even greater average depths (9.75 m [SE ± 0.3]), in a cove on the north side of Las Vegas Bay near the wash. Following that initial sighting, neither of the juveniles released in December 2015 have been located. During winter, these fish remained in similar depths (8.7 m [SE ± 0.52]) near the wash.

Table 1.—Demographic summary with included sonic tag information, individual sizes, location, date of last contact, and number of contacts during the current study for sonic-tagged juvenile razorback suckers stocked into Las Vegas Bay, Echo Bay, and the Virgin River/Muddy River inflow area, 2015

Date tagged	Tag code	TL (mm) at tagging	Weight (g) at tagging	Stocking location[a]	Last location[a]	Date of last location	Contacts made: active (passive)
2013							
5/7/2013	3000	291	254	LB	LB	5/13/2013	0 (0)
5/7/2013	3001	273	218	LB	LB-W	9/13/2013	0 (0)
5/7/2013	3002	290	278	LB	LB	5/20/2013	0 (0)
5/7/2013	3003	289	278	LB	LB	11/11/2014	0 (0)
5/7/2013	3012	233	126	LB	LB	7/16/2013	0 (0)
5/7/2013	3013	246	166	LB	LB	7/22/2013	0 (0)
5/7/2013	3004	291	286	EB	EB	5/8/2013	0 (0)
5/7/2013	3005	295	288	EB	EB	10/23/2013	0 (0)
5/7/2013	3006	270	216	EB	EB	7/23/2013	0 (0)
5/7/2013	3007	293	260	EB	EB	4/9/2014	0 (0)
5/7/2013	3014	234	150	EB	EB	5/8/2013	0 (0)
5/7/2013	3015	245	156	EB	EB	5/9/2013	0 (0)
5/7/2013	3008	293	290	OA	OA	7/18/2013	0 (0)
5/7/2013	3009	294	318	OA	OA	7/18/2013	0 (0)
5/7/2013	3010	280	216	OA	OA	5/9/2013	0 (0)
5/7/2013	3011	294	290	OA	OA	7/24/2013	0 (0)
5/7/2013	3016	237	130	OA	OA	7/24/2013	0 (0)
5/7/2013	3017	238	146	OA	OA	5/9/2013	0 (0)
2014							
5/6/2014	3021	285	298	LB	LB	4/10/2015	4 (196)
5/6/2014	3022	285	228	LB	LB	5/12/2014	0 (0)
5/6/2014	3023	281	228	LB	LB	9/18/2014	0 (0)
5/6/2014	3029	300	282	LB	LB	7/14/2015	4 (15)
9/2/2014	3034	245	130	LB	LB	10/2/2014	0 (0)
9/2/2014	3035	253	180	LB	LB	9/4/2014	0 (0)
5/6/2014	3019	281	234	EB	EB	5/7/2014	0 (0)
5/6/2014	3020	290	260	EB	EB	1/6/2015	1 (0)
5/6/2014	3027	300	358	EB	EB	10/16/2015	1 (109)
5/6/2014	3028	293	288	EB	CI	4/23/2015	5 (3,075)
9/2/2014	3030	241	160	EB	EB	9/3/2014	0 (0)
9/2/2014	3032	252	170	EB	EB	9/8/2014	0 (0)
5/6/2014	3018	284	244	OA	OA	5/13/2014	0 (0)
5/6/2014	3024	299	292	OA	OA	5/7/2014	0 (0)
5/6/2014	3025	280	232	OA	OA	12/9/2014	0 (0)
5/6/2014	3026	290	296	OA	OA	2/4/2015	1 (0)
9/2/2014	3031	237	122	OA	OA	11/19/2014	0 (0)
9/2/2014	3033	255	154	OA	OA	10/15/2014	0 (0)

Table 1.—Demographic summary with included sonic tag information, individual sizes, location, date of last contact, and number of contacts during the current study for sonic-tagged juvenile razorback suckers stocked into Las Vegas Bay, Echo Bay, and the Virgin River/Muddy River inflow area, 2015

Date tagged	Tag code	TL (mm) at tagging	Weight (g) at tagging	Stocking location[a]	Last location[a]	Date of last location	Contacts made: active (passive)
2015							
5/4/2015	3043	289	288	EB	OA	6/16/2015	3 (9)
5/4/2015	3042	289	298	EB	EB	3/2/2016	30 (100)
5/4/2015	3048	281	206	EB	EB	2/8/2016	13 (6)
5/4/2015	3066	237	150	EB	EB	5/4/2015	0 (0)
12/2/2015	3069	245	166	EB	EB	12/3/2016	0 (33)
12/2/2015	3063	210	118	EB	EB	12/2/2015	0 (0)
5/5/2015	3051	299	268	LB	LB	8/2/2015	3 (629)
5/5/2015	3049	281	224	LB	LB	5/5/2015	0 (0)
5/5/2015	3052	284	222	LB	LB	5/5/2015	0 (79)
12/2/2015	3044	296	296	LB	LB	6/15/2015	3 (0)
12/2/2015	3064	235	128	LB	LB	12/2/2015	0 (0)
12/2/2015	3067	214	108	LB	LB	12/15/2015	2 (42)
5/5/2015	3041	298	268	OA	OA	9/23/2015	3 (144)
5/5/2015	3045	293	290	OA	OA	1/28/2016	14 (197)
5/5/2015	3046	298	264	OA	OA	2/3/2016	6 (0)
5/5/2015	3050	292	248	OA	OA	9/30/2015	4 (2,125)
12/2/2015	3065[b]	210	106	OA	OA	12/16/2015	2 (61)
12/2/2015	3068	233	106	OA	OA	12/3/2015	0 (139)

[a] LB = Las Vegas Bay, LB-W = Las Vegas Bay-West SUR, EB = Echo Bay, OA = Virgin River/Muddy River inflow area of the Overton Arm, and CI = Colorado River inflow.
[b] Confirmed predation and mortality by smallmouth bass (*Micropterus dolomieu*) on 12/16/2015.

In Echo Bay, 45 total active contacts were made with four sonic-tagged juvenile razorback suckers (figure 5). Contacts made with juveniles in Echo Bay showed a less-clear pattern of seasonal movement than during past years. In spring, fish were located in medium to very deep water in all areas of the basin (6.5 –30 m). As summer progressed, these fish stayed offshore in deeper habitats near the Cliffs at the southwest end of Echo Bay (mean depth 11.6 m [SE ± 2.7]). By fall, most sonic-tagged juveniles were more active, using all areas of the bay and slightly shallower habitats (mean depth 9.9 m [SE ± 1.1]) (figure 5). Additional sonic-tagged razorback suckers were stocked into Echo Bay in December 2015. All of these fish immediately left Echo Bay and have not been contacted since.

In the Overton Arm, 9 different sonic-tagged juveniles were located for a total of 34 active contacts during 2015 (figure 6). These individuals exhibited a strong association with shallower habitat with dense IV (figure 6). During spring, individuals were contacted in habitat that had an average depth of 6.6 m (SE ± 0.8). Individuals at the Virgin River/Muddy River inflow area likely

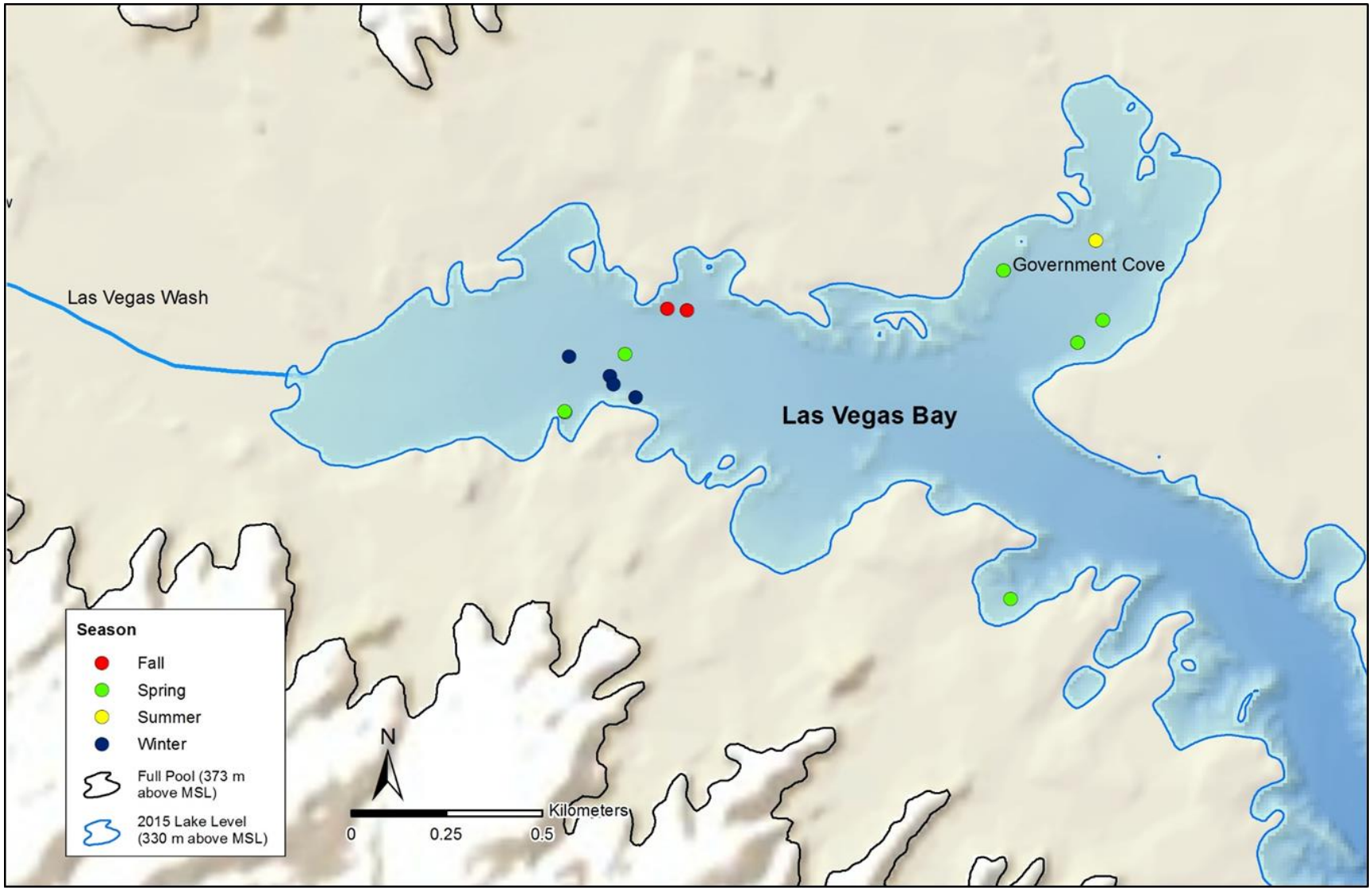

Figure 4.—Distribution of sonic-tagged juvenile razorback suckers located through active sonic telemetry and designated by season in Las Vegas Bay, 2015–16.

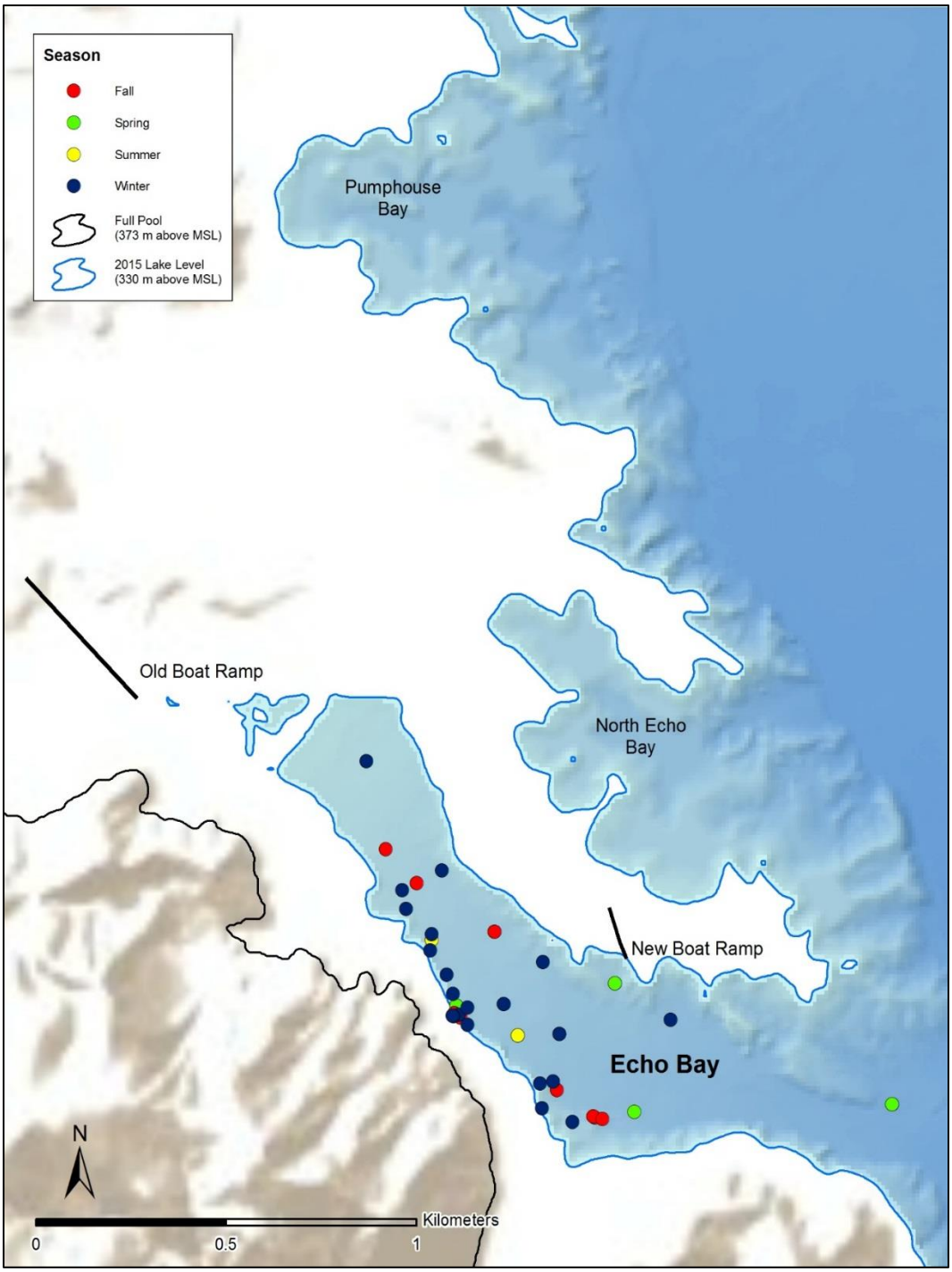

Figure 5.—Distribution of sonic-tagged juvenile razorback suckers located through active sonic telemetry and designated by season in Echo Bay, 2015–16.

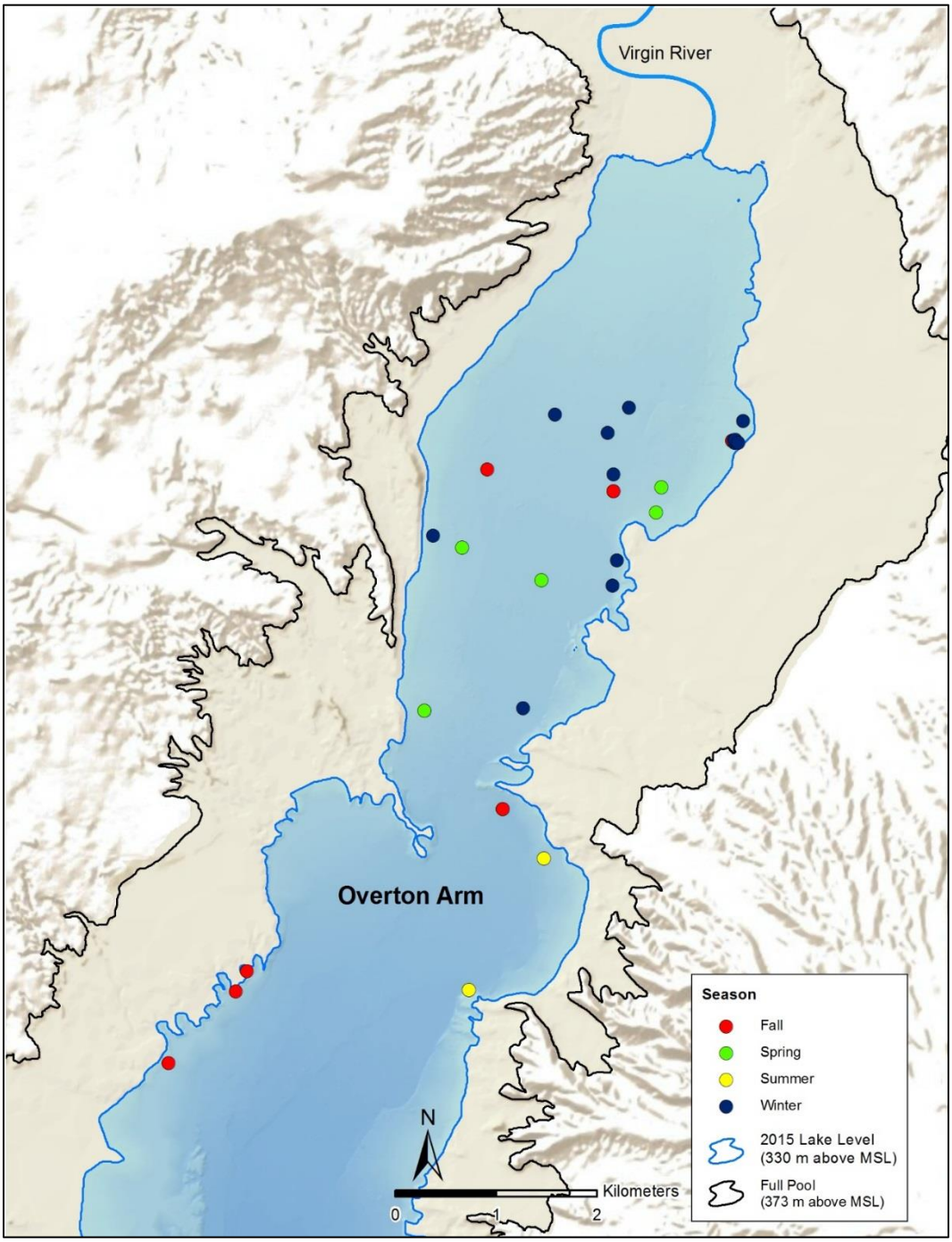

Figure 6.—Distribution of sonic-tagged juvenile razorback suckers located through active sonic telemetry and designated by season in the Overton Arm, 2015–16.

moved farther south into the Overton Arm and appeared to be seeking deeper habitat, which is somewhat similar to the pattern of sonic-tagged juveniles in Las Vegas Bay and Echo Bay. The two sonic-tagged juveniles contacted were in significantly deeper areas than contacts made during the other three seasons (13.5 m [SE ± 3.6]). During fall, contacts with sonic-tagged juveniles were frequently made along both shorelines, often in less than 3 m of water (see figure 6). On average, juveniles contacted during fall were found in depths similar to the spring and summer locations (6.6 m [SE ± 1.4]). Following stocking in December, only one of those two fish was subsequently contacted near Calico Bay. One of these tags was recovered from an 18-inch smallmouth bass (*Micropterus dolomieu*) capture, which was nearest to the most recent razorback sucker contact location. Juveniles originally stocked in May 2015 were contacted throughout the northern portion of the Overton Arm in depths ranging from 0.6 to 13.9 m.

From the 6 SURs deployed throughout Lake Mead during the study, 5 units contacted 16 sonic-tagged juvenile razorback suckers 6,959 times from January 2, 2015 to January 26, 2016 (see table 1). Of the fish originally released in 2014, four were contacted by SURs (tags 3021 and 3029 in Las Vegas Bay and tags 3027 and 3028 in Echo Bay). Sonic-tagged fish 3028, while originally released into Echo Bay, was contacted throughout the Overton Arm. Of fish released in 2015, 12 were contacted by SURs. In Las Vegas Bay, three individuals (codes 3051, 3052, and 3067) were contacted. The SUR south of Echo Bay contacted one individual (code 3042), while the Anchor Cove SUR detected five unique individuals (codes 3042, 3043, 3048, 3068, and 3069). The Glory Hole SUR in the Overton Arm recorded five juvenile sonic-tagged fish (codes 3041, 3045, 3050, and 3065), while the Blackridge SUR contacted none.

Conspecific and Community Sampling

From December 7, 2015, to March 4, 2016, 56 hoop nets, 9 minnow traps, 20 fyke nets, and 112 trammel nets were used to capture a total of 1,038 fish of 16 species during ICS conducted in direct association with sonic-tagged juvenile razorback suckers (table 2). When sonic-tagged juvenile individuals moved from shallower to deeper habitats, gears better suited for lesser depths (i.e., hoop nets and minnow traps) were used less often. Because water temperatures never exceeded 25 °C during this winter sampling period, mortalities and stress associated with netting in warmer temperatures were not an issue.

Ten wild, razorback suckers were captured in trammel nets in direct association with sonic-tagged juvenile razorback suckers in 2015 and 2016 (tables 2 and 3). For the fourth consecutive year, a wild, adult razorback sucker was captured in Las Vegas Bay (Albrecht et al. 2013a; Shattuck and Albrecht 2014). Three new,

Table 2.—Summary of effort expended by study area, gear type, and the subsequent fishes captured during ICS at Lake Mead, December 7, 2015, to March 4, 2016

Sampling location[a]	Effort by gear[b]				Fish species[c]																
	Hoop nets	Minnow traps	Fyke nets	Trammel nets	RZ	FM	GZ	TS	RS	CP	BB	CC	SC	SB	BG	GS	SM	LB	BC	BT	Total
LB	1	0	0	5	1	0	67	0	0	6	0	8	1	18	12	0	0	47	0	2	162
EB	37	1	13	73	7	4	150	0	0	43	0	29	0	10	16	18	13	25	1	0	316
OA	18	8	7	34	2	0	314	1	1	99	2	39	0	19	20	1	2	43	15	2	560
Total	**56**	**9**	**20**	**112**	**10**	**4**	**531**	**1**	**1**	**148**	**2**	**76**	**1**	**47**	**48**	**19**	**15**	**115**	**16**	**4**	**1,038**

[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 number of nets/traps set.
[c] Fish species abbreviations: RZ = razorback sucker, FM = flannelmouth sucker (*Catostomus latipinnis*), GZ = gizzard shad (*Dorosoma cepedianum*), TS = threadfin shad (*Dorosoma petenense*), RS = red shiner (*Cyprinella lutrensis*), CP = common carp (*Cyprinus carpio*), BB = black bullhead (*Ameiurus melas*), CC = channel catfish (*Ictalurus punctatus*), SC = vermiculated sailfin catfish (*Pterygoplichthys disjunctivus*), SB = striped bass (*Morone saxatilis*), BG = bluegill (*Lepomis macrochirus*) GS = green sunfish (*Lepomis cyanellus*), SM =smallmouth bass (*Micropterus dolomieu*), LB = largemouth bass (*Micropterus salmoides*), BC = black crappie (*Pomoxis nigromaculatus*), and BT = blue tilapia (*Oreochromis aureus*).

Table 3.—Summary of study area, size information, and recapture status of razorback suckers and flannelmouth suckers (*Catostomus latipinnis*) captured during ICS in direct association with sonic-tagged juvenile razorback suckers in Lake Mead, December 7, 2015, to March 4, 2016

Species	Date	Capture location[a]	PIT tag number	Original capture	Recapture?	TL (mm)	FL (mm)	SL (mm)	Weight (g)	Sex[b]	Age[c]
RZ	12/8/2015	OA	3DD.003BA2088C		No	433	404	371	768	U	5
RZ	12/14/2015	LB	3DD.003BC89EED		No	550	471	408	2,086	M	9
RZ	2/8/2016	EB	3D9.257C60BE38	2/22/2011	Yes	531	496	454	1,784	M	13
RZ	2/9/2016	OA	3DD.003BCBA318		No	503	460	428	1,557	F	6
RZ	2/16/2016	EB	3D9.257C629ACA	2/3/2010	Yes	563	516	481	2,098	M	9
RZ	2/16/2016	EB	3DD.003BCB93CA		No	540	496	461	1,668	M	7
RZ	2/18/2016	EB	3DD.003BCB93D7		No	634	592	551	3,428	F	9
RZ	2/29/2016	EB	384.1B7969ED6E	3/20/2014	Yes	578	545	508	2,240	M	11
RZ	2/29/2016	EB	3DD.003BA2FA86	3/19/2008	Yes	582	537	506	2,326	M	14
RZ	2/29/2016	EB	3DD.003BCB93C1		No	631	585	542	2,828	F	9
FM	2/16/2016	EB	3DD.003BCB93DB		No	381	356	330	436	M	–[d]
FM	3/2/2016	EB	3DD.003BA2F9A6	3/26/2013	Yes	450	418	394	786	M	–[d]
FM	3/2/2016	EB	3DD.003BCB93CD		No	473	444	409	808	U	–[d]
FM	3/2/2016	EB	3DD.003BCB93DB	2/16/2016	Yes	–	–	–	–	M	–[d]

[a] OA = Virgin River/Muddy River inflow area of the Overton Arm, LB = Las Vegas Bay, and EB = Echo Bay.
[b] U = unidentified, M = male, and F = female,.
[c] Age (years) as determined through fin clip and post-hoc aging analyses.
[d] Ages were not determined for captured flannelmouth suckers.

wild razorback suckers were captured via trammel netting in Echo Bay in addition to four recaptured individuals. Two new razorback suckers were also captured in the Overton Arm.

The razorback suckers (three females, six males, one undetermined) captured in 2015 and 2016 ranged in size from 433 to 634 mm TL (see table 3). Additionally, two new flannelmouth suckers (*Catostomus latipinnis*) were captured in Echo Bay during netting efforts, while two recaptures were also netted. Numerous non-native fishes were captured throughout the study areas with a number of different gear types (see table 2).

Razorback suckers were only captured in trammel nets, and they were captured at all sites. The highest catch rate (number of fish/minute) occurred in Las Vegas Bay, followed by Echo Bay and the Overton Arm (figure 7). Only one razorback sucker was captured in Las Vegas Bay with a limited number of net-sets; therefore, catch rates were high because sonic-tagged juveniles were only present during one sampling trip. A comparison among catch rates of razorback suckers by location revealed no significant difference in the mean number of fish captured per minute between any of the sites ($X^2 = 2.235$, df = 2, P = 0.3287). Catch rates of non-native fishes were significantly different for each location ($X^2 = 18.33$, df = 2, P = 0.0001), with Las Vegas Bay having significantly higher catch rates of non-native fishes followed by the Overton Arm and Echo Bay.

Of the 16 fish species captured during the 2015–16 ICS period, over one-half of the individuals were gizzard shad (*Dorosoma cepedianum*) (51.2%) (figure 8). Common carp (*Cyprinus carpio*) and largemouth bass (*Micropterus salmoides*) were the second and third most abundant species at 13.9% and 10.9%, respectively (figure 8). The three most dominant species captured composed over 75% of the total catch among all study areas with various gear types. Other relatively common species captured were channel catfish (*Ictalurus punctatus*), striped bass (*Morone saxatilis*), bluegill (*Lepomis macrochirus*), and green sunfish (*Lepomis cyanellus* (figure 8). Razorback and flannelmouth suckers combined only represented approximately 0.44% of the total catch. Species composition by season for the holistic study was similar to ICS composition in 2015 and 2016 (figure 9). Gizzard shad dominated catch in all seasons, followed by common carp. Bluegill, channel catfish, and largemouth and smallmouth bass were also more common. Notable differences in species composition were more bluegill captures in spring, more striped bass captures in fall, and more gizzard shad captures in winter (figure 9).

Of the 16 species captured and measured during ICS, striped bass, common carp, largemouth bass, channel catfish, and razorback suckers were among the largest individuals captured. Among all study areas, TLs of abundant fish species that have been shown to predate on razorback suckers (e.g., channel catfish [Marsh and Brooks 1989], striped bass [Karam and Marsh 2010],

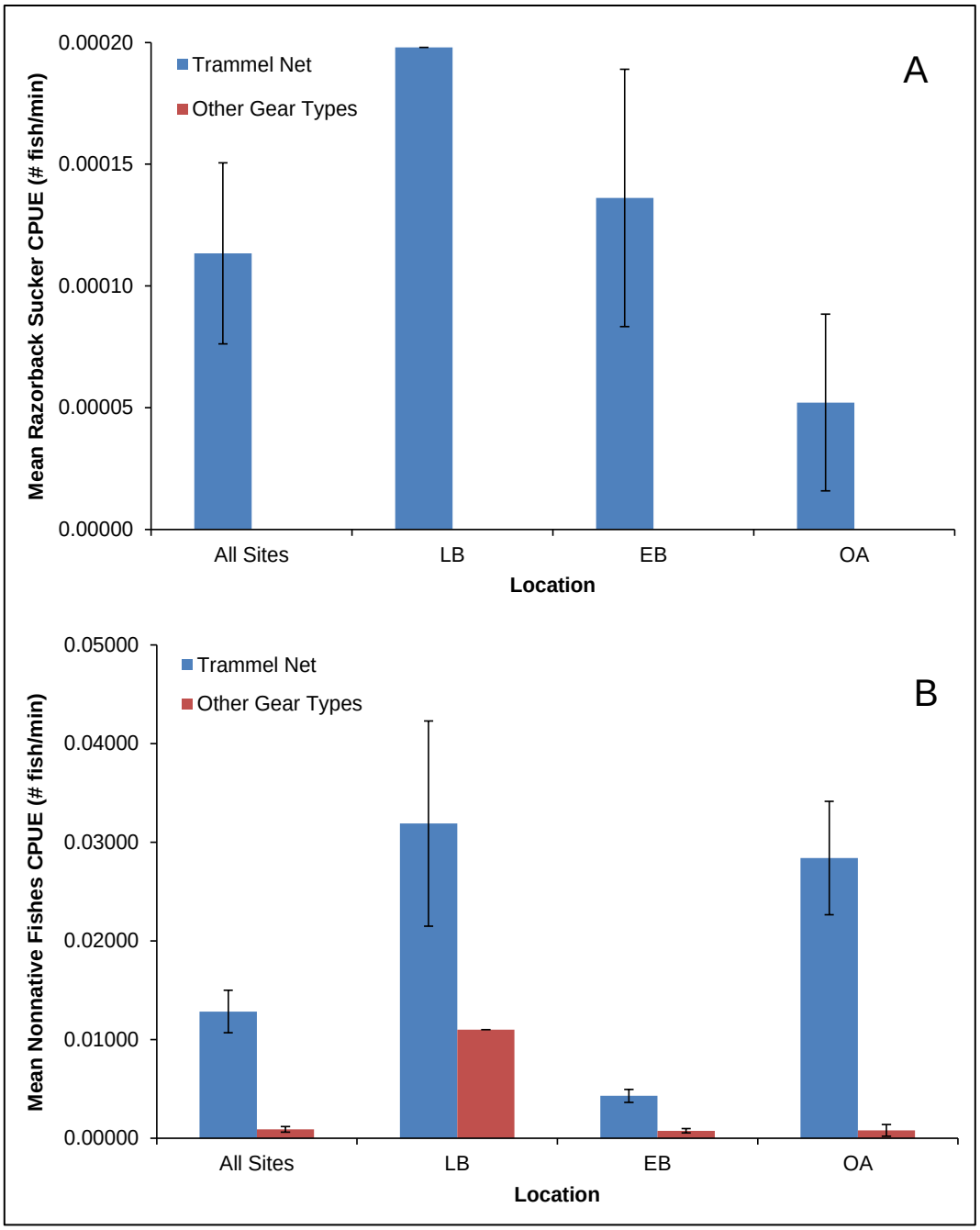

Figure 7.—Mean catch per unit effort values (± SE) by study area and gear type for razorback suckers (A) and the grouped non-native fishes (B) captured during ICS in direct association with sonic-tagged juvenile razorback suckers in 2015 and 2016.

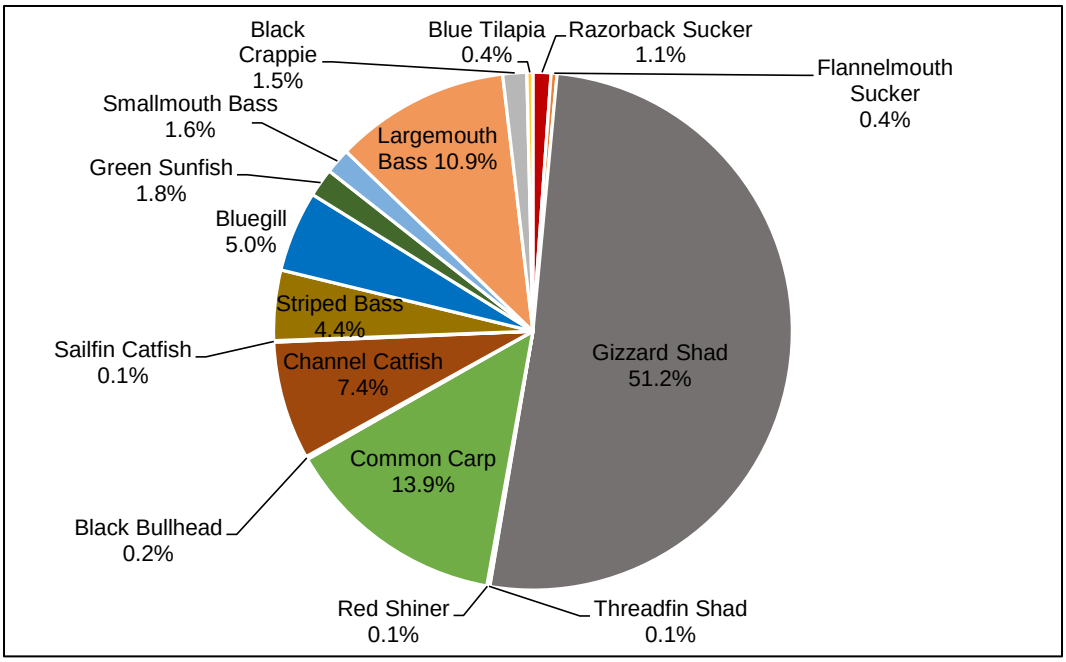

Figure 8.—Fish community composition by species expressed as percentages of the total number of fishes captured during ICS in direct association with sonic-tagged juvenile razorback suckers in 2015 and 2016.

smallmouth bass [Minckley 1983], and largemouth bass [Mueller 1995]) were compared with the TLs of captured razorback suckers. Juvenile sonic-tagged and wild, adult razorback suckers were mostly associated with predators under approximately 400 mm TL (figure 10). Approximately 75% of predators were 400 mm TL or less. Predators similar in length to large razorback suckers were large striped bass and channel catfish. TLs of potential razorback sucker competitors showed a higher degree of overlap (55.6 %; figure 9). A holistic seasonal comparison of all fishes captured throughout the juvenile razorback sucker study showed a significant difference in TL (Kruskal-Wallis test, $X^2 = 64.41$, df = 3, $P < 0.0001$). The post-hoc analysis indicates that the largest fish were captured in winter and the smallest fish in fall. TLs of fish captured in summer and spring were similar (figure 11).

Age Determination

During the ICS period (December through March [late fall/winter season]) associated with sonic-tagged juvenile razorback suckers, 10 razorback suckers were captured (7 from Echo Bay, 2 from the Overton Arm, and 1 from Las Vegas Bay; see table 3). Six of those fish had not been previously captured and underwent surgical fin ray removal to calculate definitive ages. These razorback suckers, which ranged in size from 433 to 634 mm TL, were aged from 5 to 9 years old (2006–10 year classes; see table 3).

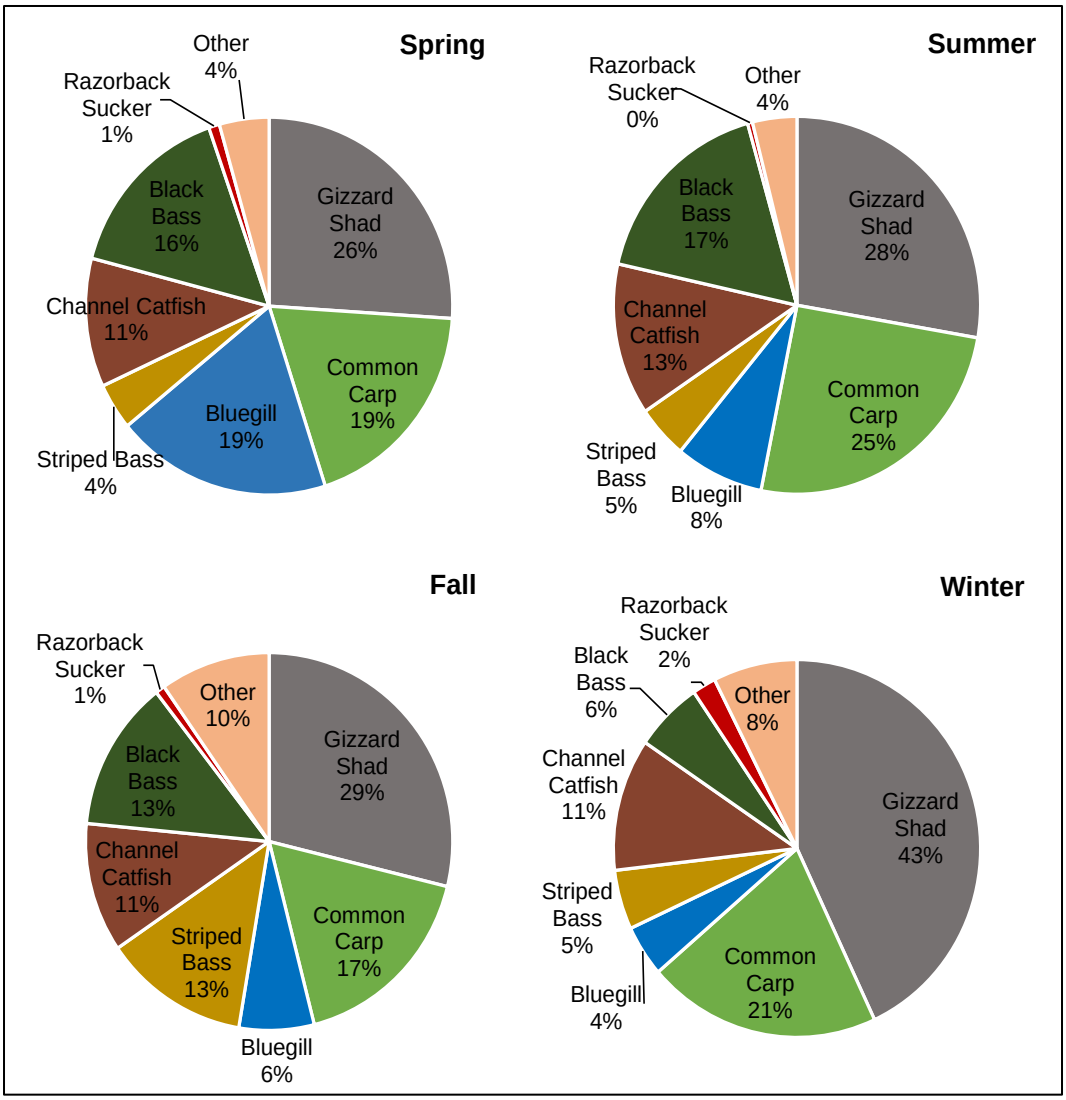

Figure 9.—Fish community composition by species expressed as percentages of the total number of fishes captured during ICS for each season of the study in direct association with sonic-tagged juvenile razorback suckers in 2013–16.

Habitat Observations and Physicochemical Quantification

From May 13, 2013, to March 2, 2016, 938 physicochemical replicates within 270 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 materials, and usually having the IV cover type. Conversely, offshore habitat was primarily characterized by greater depths, heterogeneous substrate, limited presence of algal and detrital materials, and no observable vegetative cover.

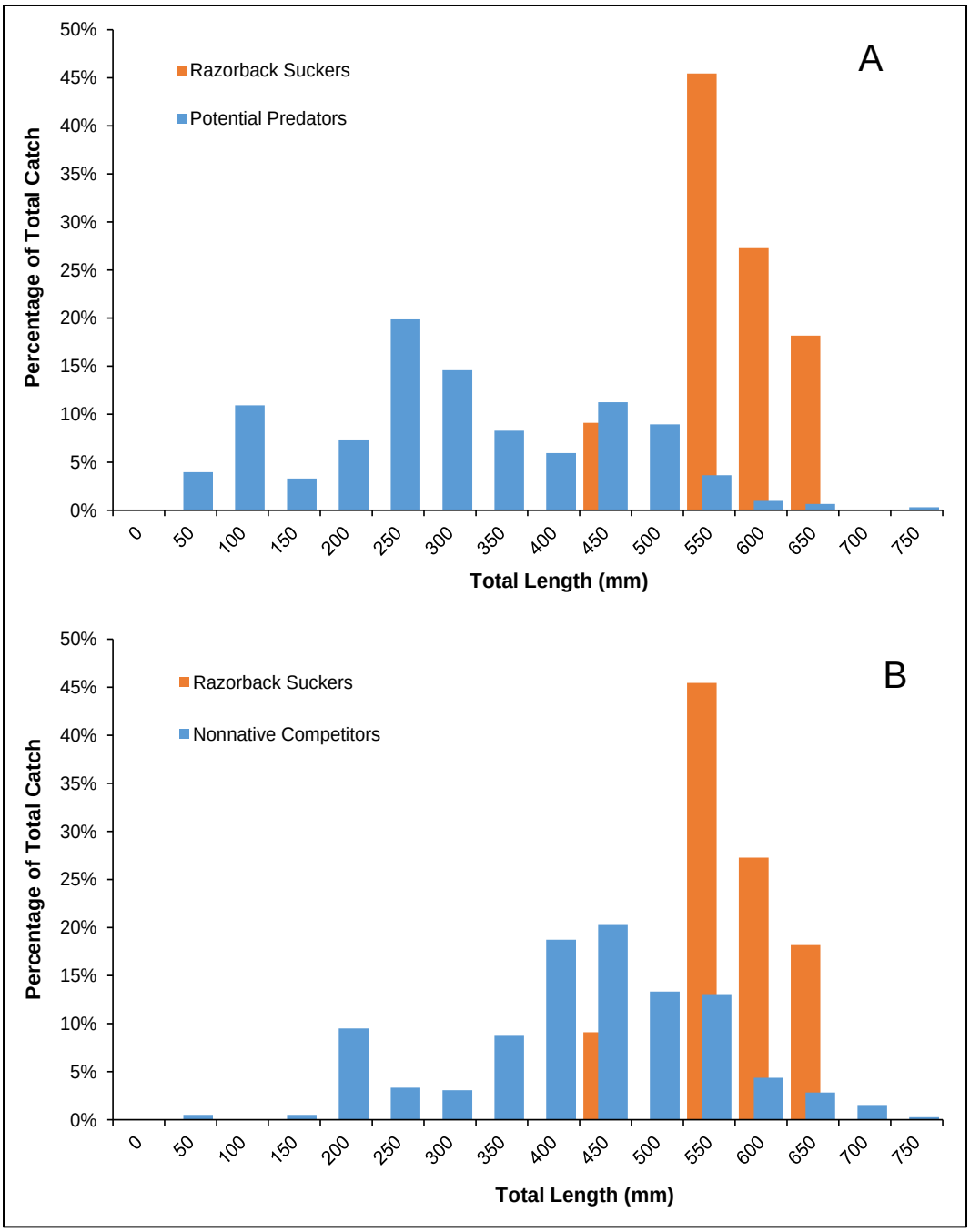

Figure 10.—A comparison of TL of razorback suckers and potential predators (A) and non-native competitors (B) captured during ICS in 2015 and 2016.

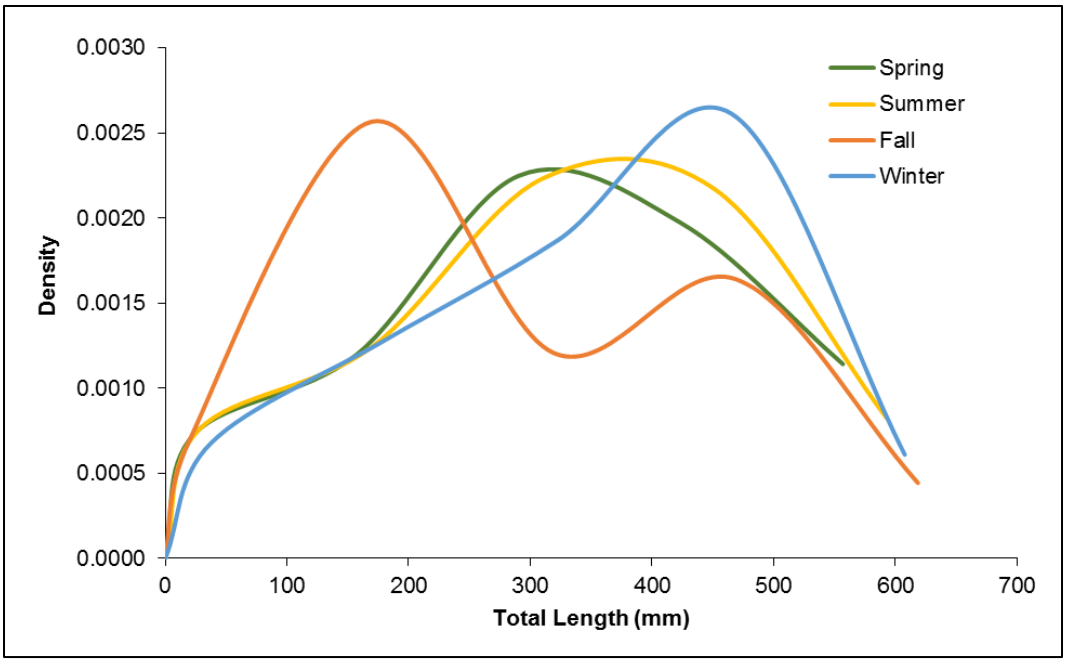

Figure 11.—The density of all fish captured by TL grouped by season using a kernel density function for all seasons (2013–16).
The shape of the curve depends on the number (density) of localized data points in a given area. The area under each curve is standardized to equal a value of 1.0.

One study goal was to characterize juvenile razorback sucker habitat along a seasonal gradient; thus, physicochemical data were analyzed in that manner. Additionally, study area-specific data may help determine differences among available habitat or seasonal changes at a particular location that may be less typical than others (table 4). Although juvenile razorback suckers were located in each study area during each season, differences in physicochemical parameters were documented (table 4). For example, water temperature was lowest in Echo Bay during spring, summer, and fall, whereas Echo Bay temperatures were similar to winter water temperatures in the Overton Arm (table 4). Las Vegas Bay was the warmest in spring, fall, and winter, but the Overton Arm was warmer in summer. As they are similar, differences among sites are likely not biologically significant, and thermal refuge should exist within all areas of Lake Mead.

Dissolved oxygen concentrations were relatively stable throughout all seasons at all study areas; however, they averaged higher in Las Vegas Bay than in the other two study areas for all seasons except winter (table 4). As expected, the lowest DO concentrations were found during the summer, with the Overton Arm having the lowest overall concentrations (table 4).

Average turbidity was highest in the Overton Arm for all seasons except winter, when Las Vegas Bay was more turbid. Echo Bay consistently had the lowest

Table 4.—Summary of mean seasonal physicochemical and habitat information collected during ICS and AHS in direct association with sonic-tagged juvenile razorback suckers from 2013–16

Site	*n*	Physicochemical parameters											
		Temp. (°C)[a]	SE (±)	DO (mg/L)[b]	SE (±)	Cond. (µS/cm³)	SE (±)	pH[c]	SE (±)	Turb. (NTU)[d]	SE (±)	Depth (m)	SE (±)
Spring													
LB[e]	1,051	25.61	0.89	9.94	0.08	1.72	0.02	8.74	< 0.01	40.31	1.37	5.51	0.12
EB[f]	350	21.80	0.20	8.88	0.10	1.03	< 0.01	8.33	< 0.01	23.43	2.05	10.60	0.49
OA[g]	489	24.71	0.15	7.74	0.08	1.46	0.06	8.65	< 0.01	72.43	7.10	4.26	0.23
Summer													
LB	1,050	28.90	1.10	7.59	0.08	1.38	< 0.01	8.34	< 0.01	22.58	1.10	5.97	0.08
EB	800	26.82	0.10	7.31	0.08	1.03	< 0.01	3.44	< 0.01	15.40	0.89	13.49	0.30
OA	843	29.40	0.06	6.03	0.09	1.17	< 0.01	8.16	< 0.01	34.31	4.50	5.15	0.14
Fall													
LB	498	22.51	0.16	8.52	0.05	1.17	< 0.01	8.76	< 0.01	15.16	1.50	11.22	0.25
EB	789	19.96	0.14	7.99	0.03	1.22	0.04	8.71	< 0.01	9.33	0.45	11.16	0.27
OA	533	21.50	0.17	8.07	0.05	1.22	< 0.01	8.82	< 0.01	17.97	1.57	5.38	0.11
Winter													
LB	37	14.80	0.22	8.17	0.04	1.33	0.05	8.65	< 0.01	16.81	2.20	8.03	0.10
EB	462	12.41	0.05	9.00	0.15	0.98	< 0.01	8.65	< 0.01	5.82	0.34	12.29	0.30
OA	183	11.91	0.12	9.99	0.11	1.06	< 0.01	8.89	< 0.01	8.64	1.60	6.76	0.32

Site	*n*	Substrate type (%)					Cover type (%)			
		Silt	Sand	Gravel	Cobble	Boulder	IV[h]	LWD[i]	SAV[j]	NO[k]
Spring										
LB	1,051	98.8	0.3	0.0	0.0	1.0	10.4	3.3	0.0	86.3
EB	350	62.7	26.6	6.7	2.3	1.7	1.9	0.0	1.9	96.3
OA	489	99.6	0.3	0.1	0.0	0.0	23.9	1.3	0.0	74.9
Summer										
LB	1,050	89.3	5.0	4.1	1.5	0.1	0.4	0.3	0.0	99.3
EB	800	92.2	2.2	5.1	0.5	0.0	4.5	0.2	5.9	89.4
OA	843	79.2	13.3	2.0	3.6	1.9	11.6	0.4	0.0	88.0
Fall										
LB	498	91.5	4.6	2.6	0.0	1.2	0.2	0.0	1.9	98.0
EB	789	86.8	1.9	4.4	0.0	7.0	0.2	0.6	4.9	94.3
OA	533	72.1	11.9	3.4	0.1	12.5	2.7	1.1	0.0	96.2
Winter										
LB	37	61.5	38.5	0.0	0.0	0.0	0.0	0.0	0.0	100.0
EB	462	72.4	8.1	4.1	7.4	8.0	1.8	0.4	1.6	96.3
OA	183	91.2	1.8	7.0	0.0	0.0	1.8	0.8	0.0	97.4

[a] Temp. = temperature.
[b] DO = dissolved oxygen in milligrams per liter.
[c] pH = the mean H+ concentration converted to pH.
[d] Turb. = turbidity in nephelometric turbidity units.
[e] LB = Las Vegas Bay.
[f] EB = Echo Bay.
[g] OA = Virgin River/Muddy River inflow area.
[h] IV= inundated vegetation.
[i] LWD = large woody debris.
[j] SAV = submerged aquatic vegetation.
[k] NO = no cover.

turbidity of the three sampling sites for all seasons (see table 4). Differences in turbidity among sites and seasons could play a role in recruitment success as it relates to 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 juvenile sonic-tagged 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 (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_{21} = 2.0, P < 0.01 in a Monte Carlo permutation test on all axes) explain 25.7% (total inertia = 1.921, sum of all canonical eigenvalues = 0.494) of the variability within the fish assemblage associated with sonic-tagged juvenile razorback suckers through environmental parameters, season, study area, and unexplained variation (figure 12). Of that total of explainable inertia, the first two axes accounted for 40.0% of the variation that could be explained by the included variables. In post-hoc variance partitioning, the pure effect of environmental parameters explained 40.4% (F_{16} = 1.5, P < 0.01), the pure effect of season explained 13.6% (F_3 = 1.8, P < 0.01), and the pure effect of study area explained 14.5% (F_2 = 2.3, P < 0.01), all of which were significant. In total, 142 samples were used in the CCA analysis, which consisted of data taken in association with sonic-tagged juvenile razorback suckers from Las Vegas Bay, Echo Bay, and the Overton Arm during May 8, 2013 – March 3, 2016.

Factors with the strongest loadings on CCA axis I were the Echo Bay study area (biplot score = 0.37), the fall season (0.33), SAV cover (0.31), silt substrate (-0.30), the Overton Arm (-0.28), turbidity (-0.28), and the spring season (-0.27) (figure 12). Factors with the strongest loadings on CCA axis II were the presence of algae or detritus (-0.36), no cover (-0.35), IV cover (0.29), SAV cover (0.26), LWD cover (0.23), and depth (-0.21) (figure 12). Green sunfish (2.51), smallmouth bass (2.09), blue tilapia (*Oreochromis aureus*) (1.25), and threadfin shad (*Dorosoma petenense*) (0.80) were positively related to CCA axis I and associated with SAV cover, the fall season, the Echo Bay study area, and larger substrates (figure 12). Red shiner (*Cyprinella lutrensis*) (-1.41), black bullhead *Ameiurus melas* (-1.31), black crappie (*Pomoxis nigromaculatus*) (-1.29), and adult razorback suckers (-0.52) were negatively related to CCA axis I (figure 12).

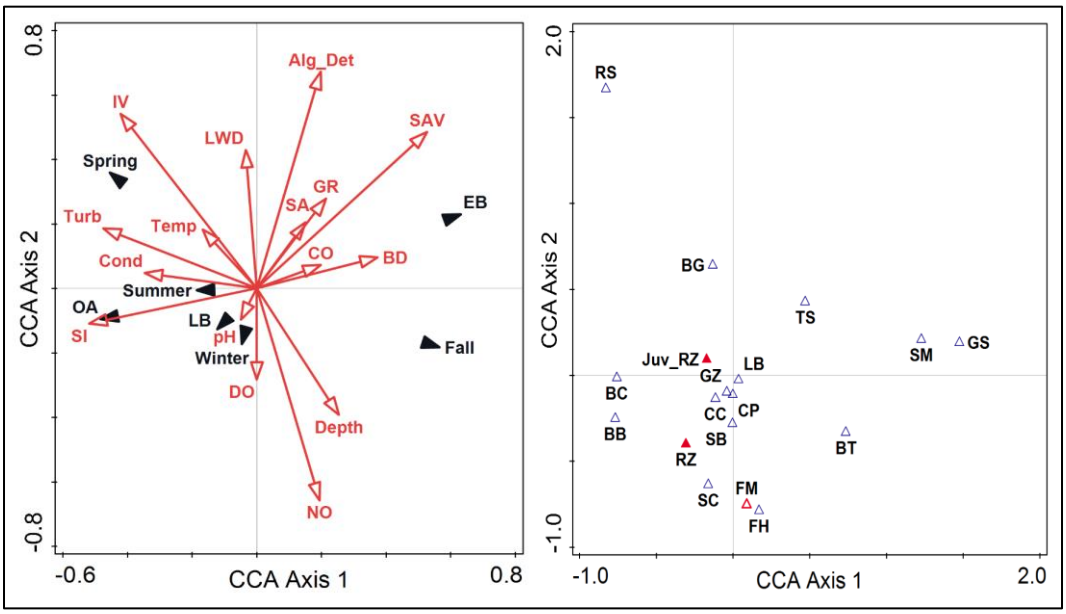

Figure 12.—Biplots for CCA of the environment, season, study area, and fish community associated with sonic-tagged juvenile razorback suckers in Lake Mead, May 8, 2013 – March 3, 2016.
Abbreviations are listed in table 2; substrates are SI = silt, SA = sand, GR = gravel, CO = cobble, and BD = boulder.

Red shiner (3.14), bluegill (1.21), threadfin shad (0.80), and smallmouth bass (0.39) were positively related with CCA axis II (figure 12). Fathead minnows (*Pimephales promelas*) (-1.49), flannelmouth suckers (-1.42), vermiculated sailfin catfish (*Pterygoplichthys disjunctivus*) (-1.20), and adult razorback suckers (-0.76) were negatively related with CCA axis II (see figure 12). When comparing site, season, substrate, and cover, adult razorback suckers were more associated with Las Vegas Bay, the fall season, sand and gravel substrates, and no cover.

Sonic-tagged juvenile razorback suckers were not strongly related to any particular habitat type, location, or season (see figure 12). This was expected since, by design, they were present at all sampling locations, in all seasons, at all locations targeted for sampling. Similarly functioning species included gizzard shad, common carp, channel catfish, and largemouth bass. Green sunfish, red shiner, and smallmouth bass appeared to be least similar. Adult razorback suckers partitioned closer than flannelmouth suckers to juvenile razorback suckers in multivariate space (see figure 12).

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 the Las Vegas Bay, Echo Bay, and the Overton Arm study areas during May 8, 2013–March 3, 2016. In contrast to the CCA model, 270 samples of habitat data—collected in

association with sonic-tagged juvenile razorback suckers—were used in the PCA analysis. In the PCA model, the first two axes explained 52.72% (PC axis I = 28.44%, PC axis II = 24.28%) of the total variation in environmental parameters among habitats associated with sonic-tagged juvenile razorback suckers (figure 13). 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., PC axis I total variance > 22.1%, PC axis II total variance > 15.5% [Frontier 1976; Olden 2011]) and explained a significant amount of variance. Principal component axis I described a substrate gradient with silt (-1.56), sand (1.46), gravel (1.23), cobble (0.99), and boulder (0.88) having the strongest loadings on the axis (figure 13). Principal component axis II described a depth and cover gradient with IV (1.90), no cover (-1.58), depth (-1.49), and turbidity (1.21) having the strongest loadings along the axis (figure 13). Habitats associated with all sampling locations were generally deeper with silt substrates; however, Echo Bay and the Overton Arm contained more diverse substrates and cover (figure 13).

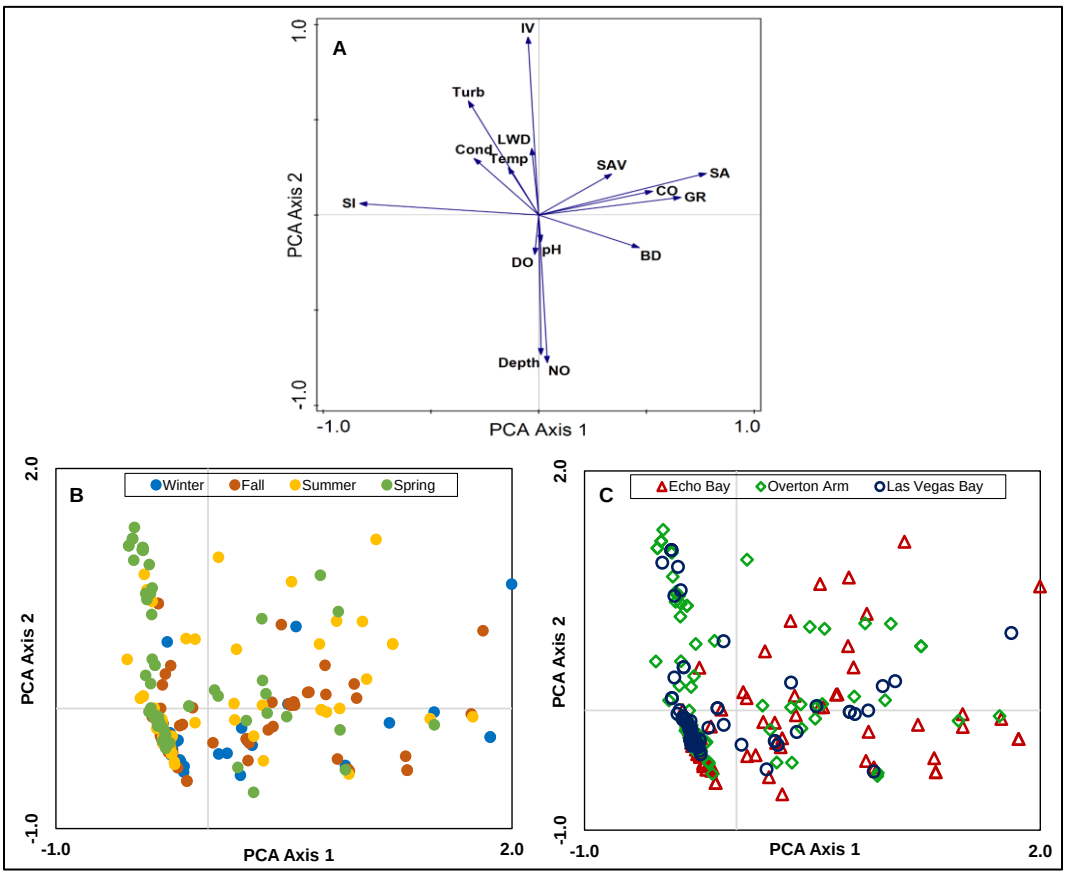

Figure 13.—PCA of the environment parameters (A) associated with sonic-tagged juvenile razorback suckers in Lake Mead May 8, 2013 – March 3, 2016, with post-hoc labeling of season (B) and location (C).
Abbreviations are listed in tables 2 and 4.

The general pattern of season, highlighted for samples post-hoc (see figure 13), shows fairly consistent habitat use by juvenile razorback suckers. Though seasonally delineated samples in PCA space overlap, there appears to be some uniqueness (see figure 13). Samples exhibiting distances furthest from the origin are considered most different in physicochemical and habitat composition. As such, the spring and summer seasons occupy 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 winter or into fall (see figure 13). The use of cover and shallower habitats is also demonstrated for spring. 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.

Discussion and Conclusions

The quantitative, empirical data collected during the study (2013–16) have provided a better understanding of razorback sucker recruitment habitat in Lake Mead. Sonic telemetry continues to be a useful tool for collecting habitat information and guiding sampling efforts toward the collection of additional razorback suckers. Throughout the study, 25 razorback suckers were captured in direct association with sonic-tagged juvenile razorback suckers. Thus far, information obtained from this study suggests that (1) recruitment is possible in Lake Mead; (2) recruitment may happen fairly frequently (direct observation that at least 1 of 18 juvenile fish stocked in 2013 was recruited to adulthood during this study and that 2 of 18 juvenile fish stocked in 2014 were captured during subsequent 2016 sampling efforts on Lake Mead [BIO-WEST, unpublished data]); (3) minimal movement of juvenile razorback suckers is common, this life stage is highly cryptic, and growth is substantial (approximately 200 mm in a single year); and (4) cover (vegetation and turbidity) is an important habitat component for juvenile-sized razorback suckers in Lake Mead. Limiting movement and using the energy to grow, utilizing cover, and ultimately reducing their susceptibility to predation are likely survival and recruitment strategies for Lake Mead's juvenile razorback suckers. Predation of juvenile razorback sucker (< 50 mm TL) by smallmouth bass was also confirmed in 2015, highlighting the persistent threat to recruitment in Lake Mead and the species' ability to recruit despite non-native predators.

These captures, in conjunction with data collected on habitat associations and seasonal movement, expanded the knowledge of the species' juvenile life stage. Further descriptions of habitat use, movement patterns, and the fish assemblage associated with juvenile razorback suckers in Lake Mead will help determine important ecological relationships critical in Lake Mead and perhaps also in other areas of the 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. 2014b; Mohn et al. 2015; Kegerries et al. 2015a) as well as in other systems in North America (Kaemingk et al. 2007). During 2015 and early 2016, typical seasonal variation in Lake Mead levels and discharges of the Las Vegas Wash and Virgin River appeared 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).

The lake level plays a large role at Lake Mead: annual fluctuations of more than 5 m are not uncommon (Mohn et al. 2015), which intermittently inundates vast expanses of otherwise dry, often vegetated habitat (Shattuck et al. 2011). 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. The dramatic difference in gradient between Las Vegas Bay and the Overton Arm (Kegerries et al. 2015b) area may partially explain why both adult and juvenile sonic-tagged razorback suckers can often be located in the same general areas of Las Vegas Bay throughout the year (Shattuck and Albrecht 2014; Kegerries et al. 2015b; Mohn et al. 2015). 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 winter and spring. Juvenile razorback suckers' affinity for shallow water and IV was also documented by Mueller and Marsh (1998). In Lake Mead, the fish generally transitioned to deeper habitats during summer and remained fairly deep but then transitioned to shallower habitats associated with substrate gradients during the late 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; Mohn et al. 2015). 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; Mohn et al 2015). 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 telemetered juvenile razorback suckers were invaluable for collecting habitat association data in Las Vegas Bay, Echo Bay, and the Overton Arm during this study. Furthermore, the use of sonic-tagged juvenile razorback suckers aided in the placement of sampling gear to capture new, wild razorback suckers.

Juvenile sonic-tagged razorback suckers provided information about potential recruitment habitat for the species. Generally, sonic-tagged juvenile razorback suckers remained within the respective study areas in which they were released, but as spring transitioned into summer, sonic-tagged juvenile razorback suckers began to move into deeper habitats at some sites. By late 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). 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 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 by juveniles but by adults as well.

Additionally, it was from sampling in direct association with sonic-tagged juveniles that other, larger razorback suckers were captured. These findings

suggest that that juvenile and adult fish share habitats at certain times of the year. Similar results were also reported on Lakes Powell and Mohave during similar juvenile razorback sucker telemetry studies (Mueller and Marsh 1998).

Following the initial release of sonic-tagged razorback sucker individuals at each of the study areas over the course of the study, most individuals recovered quickly and remained near the release location, exhibiting daily and seasonal movement patterns described herein and in past reports (Shattuck and Albrecht 2014; Kegerries et al. 2015b). The exceptions were individuals released into Echo Bay in 2013, 2014, and 2015 that traveled north into the Overton Arm and fish released into Las Vegas Bay that were never relocated after their winter 2015 release. The use of Echo Bay and the Overton Arm by individual razorback suckers has been documented throughout razorback sucker monitoring on Lake Mead (e.g., Albrecht et al. 2013b and 2014a).

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. Though sometimes environmental circumstances (e.g., depths > 20 m, dense IV) created challenges for using all gear types at each sampling location, different gear types were used during ICS and each targeted a variety of functionally different fish species over a variety of habitats.

Wild razorback sucker captures occurred at all sampling locations through the duration of the study, and trammel nets were the most effective throughout at capturing a variety fish lake-wide. Hoop nets, fyke nets, and minnow traps were also used, as these gear types were ideal for setting in association with sonic-tagged juvenile razorback suckers contacted in shallow water and 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 in 2014 provided an abundance of smaller-sized fish that would not have been captured via trammel nets and demonstrated the highest catch rates of all gear types (Kegerries et al. 2015b). Seining provided similar results in fish size but in lower abundance (Shattuck and Albrecht 2014; Kegerries et al. 2015b). Furthermore, the lack of small juvenile razorback sucker (< 450 mm TL) captures may not be due to gear type; rather, small juvenile razorback suckers have only been occasionally and sporadically captured 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, less than 100 wild juvenile razorback suckers have been captured (Mohn et al. 2015). 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 overnight net-sets during the winter likely improved the capture rates of conspecifics and provided insight into the composition of the associated fish assemblage and the interconnectedness of these species with their associated habitats.

The fish community composition documented throughout this study 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; Mohn et al. 2015). The fish community of shallower, inshore habitats contained numerous species that often associate 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 non-native 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 common carp, and more recently gizzard shad, is of particular interest, as is the efficiency of bluegill and largemouth bass as predators on young razorback suckers. Though the impact of other non-native species on razorback suckers has often been studied (e.g., Marsh and Brooks 1989; Rupert et al. 1993; Tyus and Saunders, III 2000), attention specific to Lake Mead and the dominant non-native 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 all of the ICS periods, captured razorback suckers were larger than many non-native 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 non-native 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 non-native, 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 nephelometric turbidity units reduced predation of non-native 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 capture of new, wild razorback suckers among smaller fishes.

Finally, the direct capture of juvenile razorback suckers released as part of the 2013–14 and 2014–15 juvenile studies provided evidence of survival and recruitment of several 250+ mm TL razorback suckers whose sonic tags had expired (Shattuck and Albrecht 2014; BIO-WEST, unpublished data 2016). These juvenile fish remained in direct association with other juveniles and adults. Even more interesting was the high level of growth (in some cases nearly 200 mm per year) displayed by these young individuals. Perhaps the recruitment strategy in Lake Mead is quite simply to find cover, stay put, forage, and convert energy to mass in an adapted effort to avoid predation.

Habitat Observations and Physicochemical Quantification

Sonic-tagged juvenile razorback suckers associated with a number of different habitats in all sampling locations 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 and winter, as temperatures cooled and the season progressed. Although razorback suckers have been contacted in areas with depths as great as 92 m in Boulder Basin (BIO-WEST, unpublished data), the habitat that sonic-tagged juvenile razorback suckers associated with averaged 8.1 m deep. 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).

Seasonal and site differences were documented in temperature, 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). Habitat used in spring was generally shallower, more turbid, and had more vegetative cover compared to other seasonal habitats, which were deeper and had little cover. With datasets from all four seasons now available, the partitioning of utilized habitat types by season is not as pronounced. 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, illustrate 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 analyses explained significant amounts of variation in the assessment of relationships among 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 by design, this was 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. Adult razorback suckers were partitioned from juveniles likely as adult captures were more associated with deeper water lacking cover. The partitioning of adult and juvenile razorback suckers somewhat differently from one another, along with 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 should be higher than observed during the 19-year study. In contrast to both juvenile and adult razorback suckers, flannelmouth suckers were spatially partitioned distantly, more strongly associating with a lack of cover and greater depth. This species is taxonomically similar to and, although it was partitioned differently in the CCA model, the individuals captured were found in direct association with a sonic-tagged juvenile razorback sucker. Overall, cover type and season appeared to explain much of the observed partitioning in multivariate space.

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. Spring appeared to partition more heavily to cover and turbidity, while most other seasonal samples were less partitioned. Much of the sampling, regardless of season, occurred in deeper water with silt present. Thus, much of the PCA scoring was clustered together. Similar partitioning was also shown by location with much overlap regardless of sampling location. This indicates that juvenile razorback suckers are able to find conducive habitats regardless of location, and perhaps each location is similar in habitat characteristics.

Conclusions

The collection of multifaceted data in direct association with juvenile razorback suckers makes this study particularly important for species conservation efforts. The razorback sucker juvenile life stage is one of the most understudied of the species, and information regarding spatiotemporal patterns of habitat use for a naturally recruiting population will hopefully aid in the species' overall recovery. This multi-year study sought to better define juvenile razorback sucker movement and habitat associations. Although the data presented for the 2015–16 study year mainly encompass winter (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. These findings allow for a greater understanding of the species and help attain a more accurate understanding of where, how, and why razorback suckers demonstrate continued, natural recruitment in Lake Mead. It is hoped that the framework defined herein will be used to better describe the early life stage requirements of Lake Mead razorback suckers and that this additional knowledge will also help inform 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.

As this multi-year study concludes, thought must be given to the continuation or expansion of juvenile-targeted research while natural recruitment still persists within Lake Mead. Ideas such as the use of PIT tag scanners or smaller acoustic tags (or a combination thereof) could be employed to gather additional movement and habitat-related data for larger groups of even smaller razorback suckers. As turbidity and cover have been documented as important for all razorback suckers, focused efforts within Las Vegas Wash or the Virgin River inflow could be valuable. Additional sampling methods, such as electrofishing, might allow for a greater area to be covered, especially when cover is inundated in winter and spring, to target the juvenile life stage. Using microchemistry to determine natal origin and areas that razorback suckers occupied while recruiting to adults could be explored, especially given the amount of fin ray material collected over the course of Lake Mead long-term monitoring. To date, a large amount of sampling effort has occurred near known spawning locations in Lake Mead; perhaps it is time to look beyond the known locations in search of not only adults but also early life stages, as much could be learned from a broader sampling regime. Finally, it may be valuable to use existing long-term data to better understand the non-native fish community and how that community may differentially impart predation and competition effects on juvenile razorback suckers in Lake Mead (and perhaps in comparison with other similar Colorado River Basin locations) during various recruitment years. We recommend that the Lake Mead Work Group make a determination for the direction of future juvenile razorback sucker research, as appropriate.

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