Lower Colorado River Multi-Species Conservation Program

Balancing Resource Use and Conservation

Demographics and Monitoring of Repatriated Razorback Suckers in Lake Mohave

2017 Annual Report

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Lower Colorado River Multi-Species Conservation Program

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2017 Annual Report

Prepared by:

Jamie B. Leavitt, Brian R. Kesner, Carol A. Pacey, and Paul C. Marsh

Marsh & Associates, LLC
5016 South Ash Avenue, Suite 108
Tempe, Arizona 85282

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

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ACRONYMS AND ABBREVIATIONS

AIC	Akaike's information criterion
AIC_c	Akaike's information criterion adjusted for small sample size
Center	Southwestern Native Aquatic Resources and Recovery Center in Dexter, New Mexico (formerly the Dexter National Fish Hatchery & Technology Center)
CI	confidence interval
kHz	kilohertz
km	kilometer(s)
LCR MSCP	Lower Colorado River Multi-Species Conservation Program
m	meter(s)
M&A	Marsh & Associates, LLC
M, C, R	mark, capture, recapture
mm	millimeter(s)
mm/mo	millimeters per month
P	recapture
PIT	passive integrated transponder
PVC	polyvinyl chloride
$QAIC_c$	Akaike's information criterion adjusted for overdispersion
Reclamation	Bureau of Reclamation
RM	river mile
TL	total length
USFWS	U.S. Fish and Wildlife Service
Willow Beach	Willow Beach Marina
Willow Beach NFH	Willow Beach National Fish Hatchery

Symbols

φ	apparent survival
$\hat{c}$	c-hat, variance inflation factor
Δ	difference or change in quantity
$>$	greater than
$<$	less than
$\leq$	less than or equal to
%	percent
$\pm$	plus or minus
Ψ	transition

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EXECUTIVE SUMMARY

Repatriated razorback suckers (*Xyrauchen texanus*) in Lake Mohave have been monitored for more than 20 years, but low recapture rates have inhibited the evaluation of factors contributing to highly variable post-stocking survival. In 2011, deployment of remote passive integrated transponder (PIT) scanners able to detect 134.2-kilohertz (kHz) PIT tags was initiated to increase the number of encounters with marked fish. The program was expanded in 2012 and 2013, while traditional capture methods continued to be employed to collect comparable long-term monitoring data and to estimate abundance of all repatriated and wild razorback suckers marked with either 400- or 134.2-kHz PIT tags.

Eleven razorback suckers were handled by Marsh & Associates, LLC, during fiscal year 2017: seven fish on December 5, 2016, with assistance from the Arizona Game and Fish Department and Arizona Department of Environmental Quality, and four fish during spring monitoring from March 14 through March 16, 2017. One fish was a first-time capture, not previously PIT tagged, and 10 fish were previously PIT-tagged repatriates of which 9 had paired stocking and capture data in the Lower Colorado River Native Fish Database; 1 fish with unknown stocking or capture data was omitted from further analysis. Based on the 2016 and 2017 monitoring data, it was determined that there is no effective wild razorback sucker population remaining in Lake Mohave. The repatriated razorback sucker population for 2016, based on March 2016 and 2017 monitoring data, was estimated to be 1,291 (95% confidence interval [CI] from 531 to 3,436).

The total deployment time for remote PIT scanners from October 1, 2016, through September 30, 2017, was 54,850 scan-hours, resulting in 71,434 PIT tag contacts representing 3,707 unique PIT tags for which 3,490 had a razorback sucker marking record in the database (as of September 30, 2017). Among fish with a marking record, 3,462 were repatriates, 9 were wild, and 19 were of unknown origin.

Lake Mohave was subdivided for analytical purposes into four stocking zones; up- to downstream these were River, Liberty, Basin, and Katherine. Post-stocking dispersal from zone to zone over the course of the study period was limited. The majority of fish released in River and Basin were contacted in their zone of release regardless of release year. Razorback suckers released in Liberty and Katherine were generally contacted elsewhere (River and Basin). Among the four zones scanned in 2016 and 2017, remote PIT scanning detected little movement of razorback suckers between years, with 83% of individuals (1,762 out of 2,125) contacted in one zone for 2 years.

Based on 2016 and 2017 remote PIT scanning, the 134.2-kHz tagged repatriate population in 2016 was 3,815 (95% CI from 3,573 to 4,073). The Basin and River subpopulation estimates based on zone-specific scanning in 2016 and 2017 also were calculated. The Basin subpopulation was estimated at 2,008 (95% CI

from 1,848 to 2,181) and River at 2,213 (95% CI from 1,976 to 2,479). The subpopulation in Liberty was not estimated because there were no recaptures there. Too few wild fish were contacted to estimate the Basin and River subpopulations separately (two and seven contacts, respectively). The lake-wide estimate of the wild population based on PIT scanning in 2016 and 2017 was 10 fish (95% CI from 5 to 23).

A multi-state mark-recapture model assessment in the computer program MARK estimated 6.1% (95% CI from 4.7 to 7.9%) of razorback suckers transitioned from Basin to River from 2015 to 2016 and 4.3% (95% CI from 3.3 to 5.5%) from River to Basin. From 2014 to 2015, apparent annual survival in Basin was estimated at 93.7% (95% CI from 91.5 to 95.4%), and in River it was estimated at 91.7% (95% CI from 89.2 to 93.8%). Apparent survival was estimated at 93.3% (95% CI from 90.8 to 95.1%) in Basin from 2015 to 2016 and 91.2% (95% CI from 87.5 to 93.9%) in River during the same time period. Survival and transition could not be accurately estimated for 2016 to 2017 due to confounding with recapture rates.

Biannual netting efforts continue in order to collect essential growth, health, census, and genetic data for razorback suckers. Combined collection efforts upstream of Willow Beach Marina (Willow Beach) resulted in the capture of more than 5,700 larvae, indicating that an equal share of larvae from River and Basin could be collected if effort is increased and distributed throughout the upper reach. Deployment of remote PIT scanners to monitor the two known subpopulation centers (River and Basin) will continue to be an effective means of contacting razorback sucker aggregates. Additional scanning efforts have extended to Liberty and Katherine to determine if other aggregations exist and to further evaluate the dynamics of razorback sucker dispersal and distribution.

INTRODUCTION

Lake Mohave once was home to the largest known population of wild razorback suckers (*Xyrauchen texanus*), an endangered "big river" fish endemic to the Colorado River Basin. This population contained more than 73,000 fish from 1980 to 1993 (Marsh 1994), but numbers declined to fewer than 100 individuals by 2010 (Dowling et al. 2014). Since 2010, the wild population has generally been too rare to estimate abundance and is functionally extirpated.

The continued existence of a genetically diverse adult razorback sucker population in Lake Mohave is entirely due to the timely efforts of the Native Fishes Work Group in establishing a repatriation program (Dowling et al. 2005; Marsh et al. 2015). The program began in the early 1990s, and within a few years it had developed into a system of wild larvae collection, protective rearing, and repatriation into the reservoir after the fish grew to a nominal size of 300 millimeters (mm) total length (TL) or more (Mueller 1995). There have been several adjustments to the repatriation program that incorporate new information that may help to increase the survival of stocked fish, primarily an increased size of stocked fish to reduce predation mortality, but results thus far have not met expectations (Marsh et al. 2005, 2015).

The Lower Colorado River Multi-Species Conservation Program (LCR MSCP) currently oversees and funds stocking and monitoring of razorback suckers in Lake Mohave. Stocking razorback suckers into Lake Mohave from the Willow Beach National Fish Hatchery (Willow Beach NFH) (LCR MSCP 2015, Work Task B2), Lake Mead Hatchery, and from lakeside ponds (LCR MSCP 2015, Work Task B7) is conducted under the Fish Augmentation component of this program (LCR MSCP 2006). The Lake Mohave repatriation program is one element of an overall conservation plan for razorback suckers within the LCR MSCP. The LCR MSCP, and other conservation plans upon which it was based (Minckley et al. 2003; U.S. Fish and Wildlife Service [USFWS] 2005), incorporates a population component that will occupy the lower Colorado River main stem, but absent changes in the fish community, it may be impractical or impossible to accommodate that component.

A recommended minimum stocking TL of 500 mm, based on previous assessments of the relationship between size and survival (Marsh et al. 2005; Kesner et al. 2008a, 2012), has proven difficult to produce in sufficient numbers (M. Olson 2009, personal communication). In February 2015, a change in the rearing strategy at Willow Beach NFH was implemented. About 8,000 to 10,000 fish will be held on station for 5 years and then released as 1 cohort regardless of size (smaller fish will not be culled out). The goal is to increase mean fish size, likely greater than 400 mm TL. The decrease in the number of fish stocked per year reduced the larval collection goal, which was updated to 18,000 per year, but will be subject to change dependent on augmentation needs. Unfortunately, in November 2016, approximately

30,000 razorback suckers at the Willow Beach NFH were lost due to a catastrophic outbreak of the parasitic protozoan *Ichthyophthirius multifiliis* ("ich"). Due to this tremendous loss, the number of fish available to be stocked into Lake Mohave over the next several years, especially those of a larger size, has dramatically decreased, and the larval goal for 2017 was 33,000 individuals.

The relationship between size at release and survival was clearly defined in mark-recapture models based on captures of razorback suckers during annual surveys (Marsh et al. 2005), but precision was low due to low recapture rates. Increasing the recapture rate through an increase in netting effort was considered less than ideal due to budget and personnel limitations, habitat constraints, potential to repeatedly capture the same individuals, and the availability of a viable alternative. The alternative, remote passive integrated transponder (PIT) scanning, became viable when the repatriate population became comprised primarily of the individuals containing 134.2-kilohertz (kHz) PIT tags. Use of 134.2-kHz PIT tags in Lake Mohave began in 2006; 400-kHz PIT tags were implanted into Lake Mohave razorback suckers prior to that year. Remote PIT scanning has been used since 2010 to increase contact rates with repatriate razorback suckers and to improve precision in mark-recapture models. These models have been used to estimate post-release and adult survival, population size, and to answer fundamental demographic questions, which will improve ongoing conservation strategies (Kesner et al. 2008b). Long-term monitoring using traditional capture methods continues to provide important comparative health and dispersal information as well as contact data on untagged or older 400-kHz tagged individuals. These are the only methods that remain for acquiring necessary genetic data from wild and repatriate razorback suckers in Lake Mohave.

It is an objective of the research and monitoring portion of the Lake Mohave razorback sucker program, the subject of this report, to provide information needed to determine how the Lake Mohave repatriation program should contribute to maintenance of this endangered species both in Lake Mohave and throughout the lower Colorado River. Moreover, results of this research provide critical demographic information and inform management to help ensure long-term persistence of a genetically viable stock of adult razorback suckers in Lake Mohave.

Thirteen specific objectives were outlined to achieve the goals of this research:

1. Locating and capturing adult razorback suckers.

2. Recording biological data (e.g., sex, TL, and weight), documenting the PIT tag number, and examining the general health and condition of captured razorback suckers.

3. Collecting tissue samples from adult razorback suckers for genetic analysis.

4. Marking captured adult razorback suckers with 134.2-kHz PIT tags for individual identification (only if fish have not been previously tagged).

5. Using mobile remote PIT tag sensing units capable of deployment in both slack water and riverine sections of Lake Mohave (it is anticipated that most remote sensing will occur in River Miles (RM) 330–342 for 1 week of every month during the contract year. An alternate monitoring schedule of equivalent time and effort may be proposed based on contractor expertise).

6. Participating in a maximum of two annual, weeklong, multi-agency survey events to take place in autumn (November or December) and spring (March) of each contract year (most of the effort related to these events will be restricted to RM 290–305). In the event these surveys do not take place, the contractor may conduct additional remote scanning during these periods.

7. Estimating current repatriate, and if possible, wild razorback sucker populations.

8. Assimilating Lake Mohave razorback sucker capture/contact data collected by other Federal and non-Federal entities into population estimates.

9. Providing monthly progress reports summarizing all field, laboratory, or office work completed during this effort.

10. Providing copies of all datasets generated during this work to the designated Bureau of Reclamation (Reclamation) Contracting Officer's Technical Representative.

11. Providing a draft annual report during each contract year for review by the LCR MSCP.

12. Providing a final annual report for each completed contract year.

13. Attending the annual Colorado River Aquatic Biologist meeting and presenting monitoring results.

This report summarizes the third year of data as part of ongoing demographic and post-stocking survival studies of repatriated razorback suckers in Lake Mohave. Population estimates for wild and repatriate populations were updated based on results from standard monitoring; repatriate population estimates include remote

PIT scanning data collected in the basin and riverine portions of the lake, and survival and transition were estimated for the Basin and River subpopulations based on multi-state mark-recapture models.

METHODS

For the purposes of this study, Lake Mohave (LCR MSCP Reach 2) has been divided into four distinct zones based on geographic features of the lake and razorback sucker demographics as determined from previous studies (figure 1) (Kesner et al. 2012). Each zone has a descriptive name that represents either a specific location of focus within that zone (i.e., Liberty and Katherine), or it describes the general characteristic of that zone (i.e., Basin and River). Remote PIT scanning was conducted in the River, Liberty, Basin, and Katherine zones.

Annual sampling followed the federal fiscal calendar, October 1 through September 30, which coincides with annual spawning behavior (i.e., the annual sampling event in autumn is reported together with the following March monitoring data each year, representing a single spawning season).

Routine Monitoring

Objectives 1, 2, 3, 4, and 6 were accomplished through participation in the December and March multi-agency survey events. During both events, December 2016 and March 2017, Marsh & Associates, LLC (M&A) personnel occupied a field camp on Lake Mohave at Carp Cove, Arizona (the Basin zone), near RM 298 (miles upstream of the Southerly International Boundary with Mexico) for 5 days at a time. At each sampling event, as many as six trammel nets (four to six 91.4 x 1.8 meters [m], 3.8-centimeter stretch mesh) were fished continuously along the Arizona shoreline from Pot Cove upstream to Carp Cove. One net was placed inside Carp Cove, one at the point of the Carp Cove entrance and four along the Arizona shoreline in Cottonwood Cove East and Water Wheel Coves.

Native fish encountered were processed and released (objective 1). Nets were run and cleared, and the fish processed twice daily, once each in the morning and evening. Processing included measuring TL, assessing sex and spawning condition (expression of gametes), scanning for a PIT tag and tagging if none was present (objective 4), and examining the fish for general health and condition (objective 2). A fin clip was taken from each razorback sucker, placed in 1 milliliter of 95% ethanol in a labeled snap-cap tube, and returned to the laboratory for genetic analysis (objective 3; results reported elsewhere by others). All relevant data were entered into the comprehensive Lower Colorado River Native Fish Database maintained by M&A.

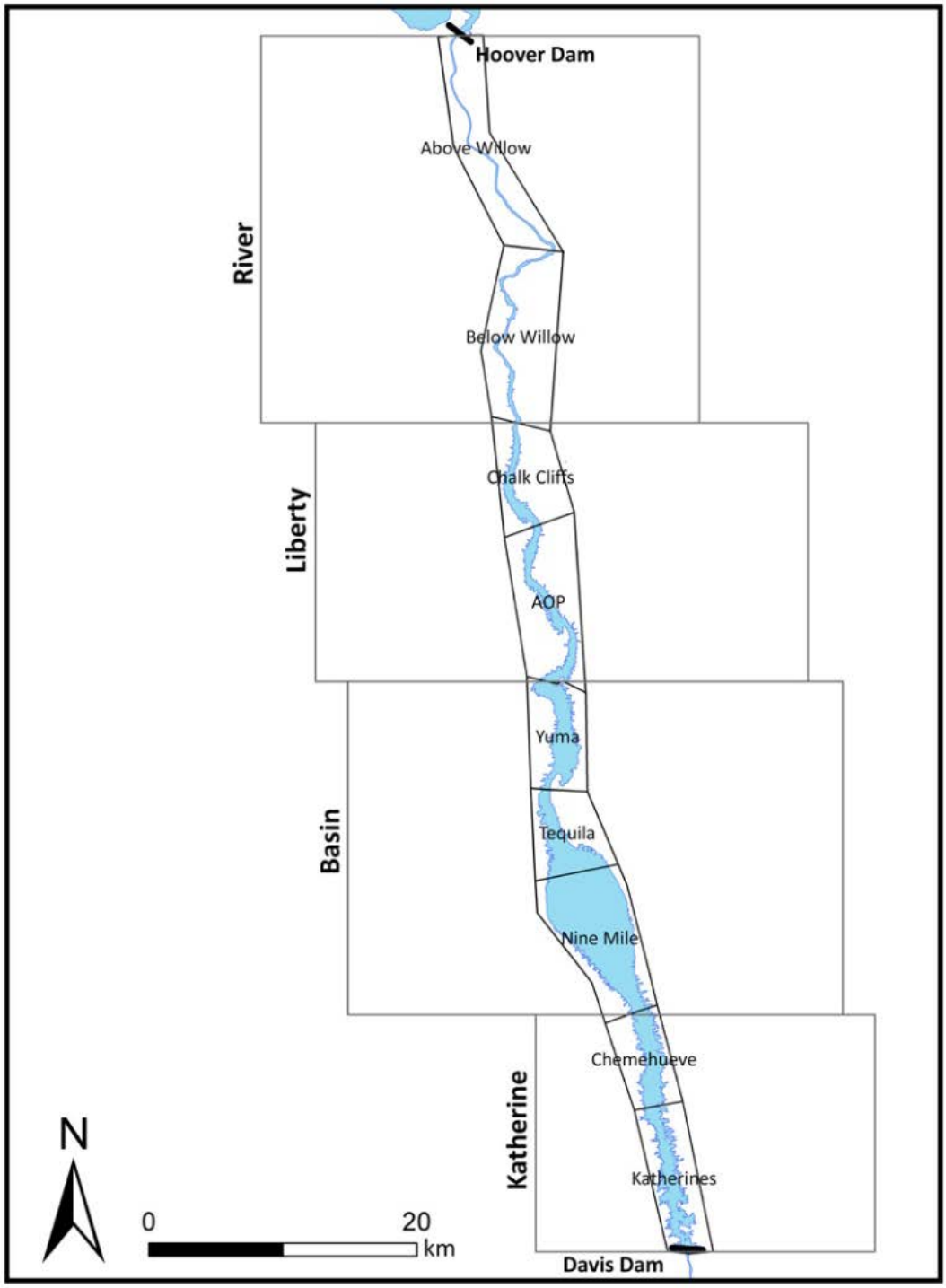

Figure 1.—Map of Lake Mohave, Arizona and Nevada, depicting two zoning schemes, general (large boxes) and specific (smaller boxes); only the former are used in this report.

Remote Monitoring

Remote PIT scanning systems were deployed 1 week of every month during the 2017 sampling season on shallow gravel bars that extend into the Colorado River upstream of Willow Beach Marina (Willow Beach) (the River zone; objective 5) and throughout Liberty. Three models of sinking submersible PIT scanning units were employed (0.8 x 0.8 m and 1.2 x 0.8 m [standard power] and 1.2 x 0.8 m [decreased power consumption]) and were comprised of a polyvinyl chloride (PVC) frame antenna attached to a scanner and logger contained in watertight PVC piping. Power to submersible units was provided by a 20.8 or 28 ampere-hour lithium-ion battery pack contained in a watertight, 2-inch (5.08-centimeter) PVC pipe. Submersible units scanned continuously for up to 441 hours, but batteries were generally changed every 24 hours. Fourteen to 18 submersible units were employed throughout the monitoring season.

Five locations established in 2013 as fixed sites were Gio's Point, Black Bar, Ringbolt Rapids, Boy Scout Canyon, and Sauna Cave (figure 2), and each received at least one submersible deployment per day each sampling trip (Kesner et al. 2014). These locations were initially examined and evaluated in 2011, PIT scanned periodically in 2011 and 2012, and determined to be utilized by razorback suckers at different times of year. Fixed sites at these five locations were established to test the hypothesis that razorback sucker aggregation sites change over the course of the year, centering on Black Bar during spawning, but shifting upstream toward Hoover Dam as the spawning season ends. Thus far, the results have not supported any directed movement of razorback sucker aggregations (Wisenall et al. 2015), but year-round data collected since 2015 continue to show seasonal variation in site contact rates (Wisenall et al. 2016).

Additional PIT scanning was conducted this year downstream from known spawning aggregates in the River zone to determine if any additional aggregates exist downstream from Willow Beach. M&A set 10 submersible PIT scanners per trip within a preselected 1- to 2-mile section of the reservoir between Willow Beach and Liberty Cove. Each month, a different reservoir section was targeted. Reclamation deployed 10 submersible units per trip working in 1- to 2-mile increments moving upstream each sample trip from Basin to Liberty Cove. The general locations of deployments for each trip were determined by subjectively targeting suspected razorback sucker habitat while attempting to maintain uniform coverage across the entire 1- to 2-mile reach. These areas included shallow gravel bars and cobble substrates as well as cattail stands where razorback suckers have been observed in the past (J. Stolberg, 2016, personal communication). Reclamation also expanded their scanning effort to Katherine during the 2017 sample season and conducted seven sampling trips in this zone from December 2016 to June 2017. Reclamation crews worked downstream in four sections, scanning both sides of the river, and deployed units in almost every cove in Katherine, subjectively targeting cattails (*Typha* spp.) and bulrush (*Scirpus* spp.).

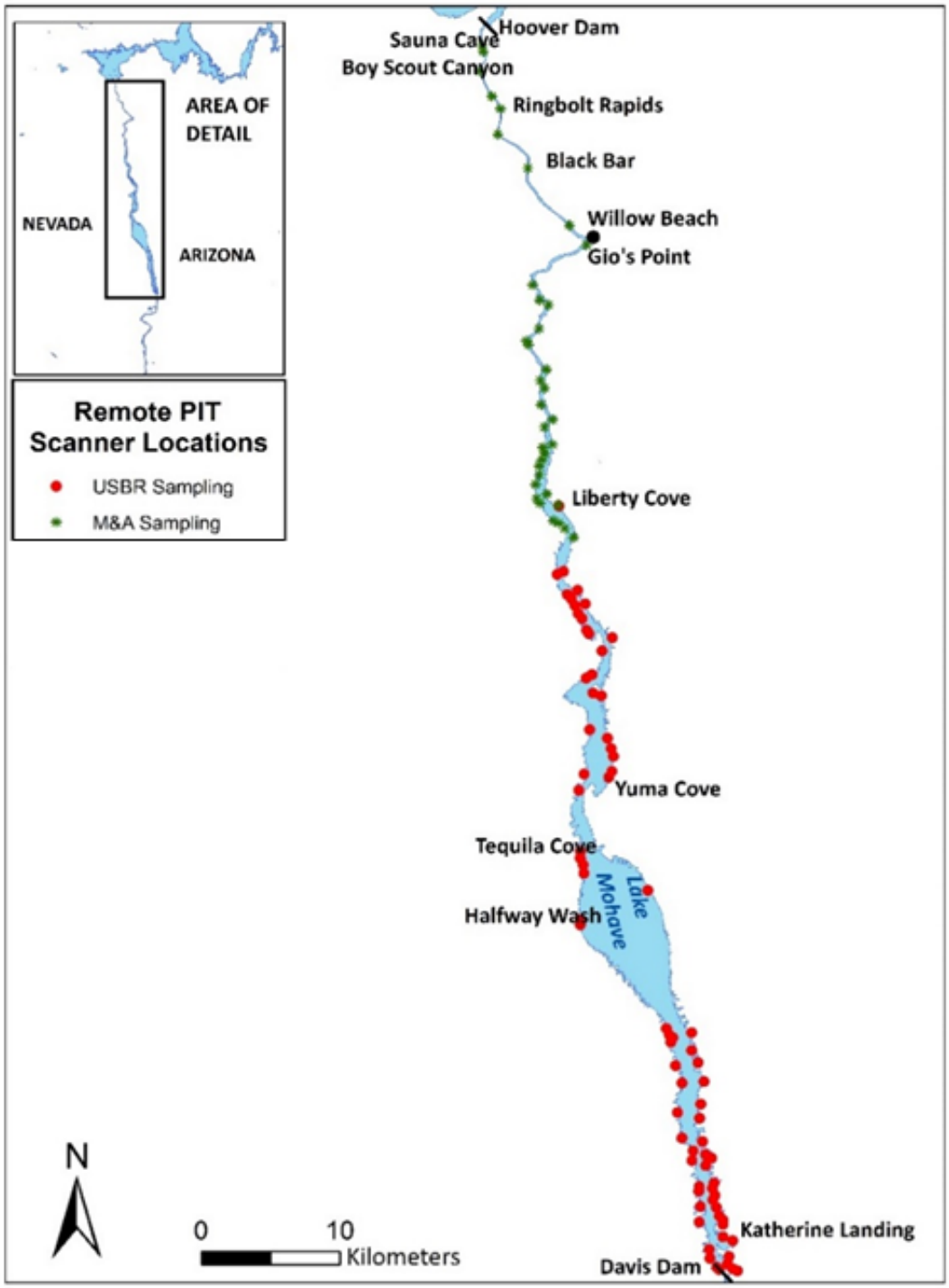

Figure 2.—Location of M&A and Reclamation remote PIT scanners in the River, Liberty, Basin, and Katherine zones of Lake Mohave, Arizona and Nevada, 2017.

One submersible unit with decreased power consumption was deployed throughout the 2017 sample season at Lone Palm Hot Spring and Black Bar. This unit's antenna had twice the wire turns as standard antennas, which resulted in lower power consumption. The unit was deployed during scanning trips and left to scan between trips as a replacement of the shore-based continuous scanner deployed at Boy Scout Canyon in previous years. Deployment locations of additional scanners not set at fixed sites or downstream from Willow Beach varied between trips depending on observed or reported fish concentrations. Scanner units monitored fish presence monthly from October through September for 4 nights and 3 days (approximately 90 continuous hours) each trip.

Information downloaded from scanning units was recorded as follows: general location or site name, Universal Transverse Mercator coordinates, water depth in meters, time and date of deployment and retrieval, logger and battery numbers, logger start and stop times, and the scanning interval. Narrative descriptions of weather, riverflows, etc., were recorded on field sheets or in data books.

Remote PIT scanning in the Basin zone (figures 1 and 2) was conducted by Reclamation with support from M&A (objective 5). Semipermanent shore-based units were deployed in Basin for continuous scanning from 2016 to 2017. One shore-based PIT scanner was deployed at Tequila Cove and two at Half Way Wash. The units operated continuously from December 2016 to May 2017 and were powered by a deep-cycle marine battery and a 60-watt solar panel. A shore-based unit deployed at Yuma Cove was attached to a solar aeration system for power.

All sites with semipermanent shore-based units represent known spawning aggregation sites and have been collection sites for March monitoring since collections began. Remote PIT scanning data, along with location and effort, were provided by Reclamation, and all data acquired from PIT scanning on Lake Mohave were incorporated into a MySQL database, maintained by M&A and hosted by Hostmonster.com (http://www.hostmonster.com/). Access to summary reports of scanning data as well as all raw data files are available through a password-protected section of the M&A Web site (http://www.nativefishlab.net) (objective 10).

Post-stocking contact rates for PIT-tagged repatriate razorback suckers that were released from October 1, 2008, through September 30, 2015, were summarized. The beginning of this interval marks the year when all razorback suckers being repatriated into Lake Mohave contained a 134.2-kHz PIT tag.[1] Contacts with

[1] After the initial switch from 400- to 134.2-kHz PIT tags in 2006, a portion of razorback suckers in hatcheries and backwaters still contained the older 400-kHz tag.

razorback suckers at large for less than 1 year prior to the beginning of the scanning year were excluded from the analysis to ensure individuals contacted were fully recruited into the Lake Mohave adult population. Release records were grouped into "cohorts" based on location and date of release. Contact data within each cohort were tabulated for all fish contacted by remote PIT scanning for the 2017 sample year. The sample year followed the same fiscal calendar as routine monitoring (October 1, 2016, through September 30, 2017). The proportion of each cohort that was contacted in 2017 was calculated as a relative index of long-term survival of each cohort. This comparison assumes that all razorback suckers alive in Lake Mohave with a 134.2-kHz PIT tag have an equal probability of encountering a PIT scanner over the course of the scanning year. These fish are considered "available" to PIT scanning equipment. Cohorts with fewer than 100 fish released were excluded from tabulation to reduce the probability that differences in contact proportion were due to chance alone.

Population Estimates

The razorback sucker population in Lake Mohave was estimated from two data sources (objective 7). First, March monitoring data[2] from all agencies participating in the spring survey were used to estimate overall populations of wild and repatriated fish in Lake Mohave using mark-recapture (objective 8). Data for population estimates from capture data were restricted to encounters in March because the highest number of encounters with razorback suckers occurs then and the marking event must be short relative to the interval between marking and capturing events to meet assumptions of the estimate (Ricker 1975). Second, remote PIT scanning data were used to estimate the lake-wide population as well as the River and Basin subpopulations of repatriated and wild razorback suckers with 134.2-kHz PIT tags in 2016. PIT scanning data for the marking period were restricted to March, but the capture period was extended to include the entire scan-year, with the assumption that only deletions (mortality and emigration) occur. Remote PIT scanning and routine monitoring data were treated separately for repatriate estimates because some repatriate razorback suckers contain only a 400-kHz tag, which is rarely detected by remote PIT scanners. Combining the two sources would not accurately estimate the repatriate population.

Regardless of the data source, mark-recapture estimates were based on the modified Peterson formula:

$$N^* = \frac{(M+1)(C+1)}{R+1} \qquad \text{(Ricker 1975)}$$

[2] March data includes the entire month of March although March monitoring occurs during a single week.

For each mark-recapture estimate, the number of individual PIT tags contacted in March of the previous population year was the mark (*M*), the number contacted in the current population year the capture (*C*), and the number in common between both years the recapture (*R*). For remote PIT scanning estimates, any contacts with razorback suckers released after the initiation of the marking year (January 1 of the previous population year) were removed from population estimates. Razorback suckers released on or after March 1 of the previous population year were removed from population estimates based on March monitoring captures. Repatriated fish lacking information on the date and location of release into Lake Mohave were also excluded from population estimates. The actual values for *M*, *C*, *R*, and population estimates calculated for this report may differ slightly from previous reported values due to updates, additions, and corrections to the Lower Colorado River Native Fish Database. Confidence intervals (CIs) were derived using Poisson approximation tables, using *R* as the entering variable, or with normal distribution when recaptures were greater than 30 (Seber 1973).

Movement and Survival

The multi-state mark-recapture model developed in Wisenall et al. (2016) was updated to include 2017 PIT scanning data to improve estimates of transition (movement) and survival of adult razorback suckers between the River and Basin zones. As in the previous year, the model included individuals at large for at least 730 days (2 years) and scanned in River or Basin from January through March from 2012 to 2017. Individuals that were scanned in 2017 only were removed from the model because, for this analysis, the first time an individual is scanned is considered the mark, and marks in the final sampling period do not inform model parameter estimates. This scanning period was selected because during this period there was consistent remote PIT scanning in both River and Basin. By excluding fish that were released but not scanned, no estimate of post-stocking survival (up to 2 years from release) was estimated. If included, post-release survival would add complexity to the model since it is known to be size dependent (Marsh et al. 2005).

The multi-state live recaptures only model within program MARK contains three parameter groups: apparent survival (φ), recapture (P), and transition (Ψ). These parameters can vary with time, age, and state (zone). For this model, age was not considered a factor. Razorback suckers included in the model were at large for more than 2 years prior to being observed (PIT scanned), and all were assumed to be members of an adult age class.

The multi-state model included two states (zones) coded numerically depending on where fish were scanned: 1 – River and 2 – Basin. Capture histories were derived for fish scanned as a series of 0's, 1's, and 2's; 0 – not observed,

1 – observed in River, and 2 – observed in Basin. There were six encounter occasions, one per year from 2012 to 2017; therefore, parameter estimates of apparent survival and transition were annual values.

The most general model contained different parameterizations across states (zones) and time for all three parameters (e.g., φ state*time). A total of five time periods (2012 to 2013, 2013 to 2014, 2014 to 2015, 2015 to 2016, and 2016 to 2017) resulted in the maximum number of parameters in the most general model at 26 (5 time periods x 2 locations x 3 parameter groups minus 4 confounded parameters). Comparison models included additive and interactive effects of time and state as well as models that constrain time and state to be constant. The recapture rate was consistently modeled to vary interactively with time and state because PIT scanning effort varied between both, and "catchability" (probability that a razorback sucker encounters a PIT scanner when one is deployed) is at least seasonally variable.

Models were ranked within program MARK based on an Akaike's information criterion (AIC) score (Akaike 1974). This value reported in program MARK is a modified value (AIC_c) that adjusts for small sample sizes (Burnham and Anderson 2002). AIC_c was adjusted for overdispersion with the median estimate of $\hat{c}$ (c-hat) when appropriate ($QAIC_c$) (Cooch and White 2016). Reported parameter values were based on the highest ranked model (lowest AIC_c or $QAIC_c$) when the $QAIC_c$ weight for the top model was greater than 0.9 (Johnson and Omland 2004); otherwise, estimates were based on model averaging. No additional analysis on goodness of fit for the movement and survival mark-recapture model was performed in 2017.

RESULTS

Routine Monitoring

Eleven razorback suckers were handled at two different M&A monitoring events during fiscal year 2017: seven on December 5, 2016, with assistance from the Arizona Game and Fish Department and Arizona Department of Environmental Quality, and four during March 2017 monitoring activities (table 1). Sex was determined at both events, and all were female. One of the 11 was a first-time capture, not previously PIT tagged, and 9 fish were PIT-tagged repatriates with original stocking data in the Lower Colorado River Native Fish Database; 1 fish with unknown stocking or capture data was omitted from further analysis (table 2). Of the nine PIT-tagged fish, two were 350 mm TL or shorter at stocking, with one at 285 mm and the other at 350 mm, and the rest were longer or equal to 410 mm TL. The mean TL at stocking was 428 mm, and the mean TL at capture was 632 mm, with seven fish greater than 620 mm TL at capture. Fish at large for more than 1 year exhibited similar growth rates ranging from 1 to 3 millimeters

Table 1.—Adult razorback sucker monitoring summary by capture month, PIT tag, history, and sex during the fiscal year 2017 monitoring events, Lake Mohave, Arizona and Nevada

		PIT tag?		History			Sex		
Capture date	**Total n**	**Yes**	**No**	**Repatriate**	**Wild**	**Unknown**	**Female**	**Male**	**Unknown**
December 5	7	6	1	6	0	1	7	0	0
March 14–16	4	4	0	4	0	0	4	0	0
Total	**11**	**10**	**1**	**10**	**0**	**1**	**11**	**0**	**0**

per month (mm/mo). One fish, at large for 11 months, grew at a rate of 12 mm/mo. The mean growth rate was approximately 3 mm/mo at large. Years at large for all fish ranged from less than 1 to 14 years, with a mean of 8 years. Seven fish were captured during fiscal year 2017 monitoring for the first time since their stocking into Lake Mohave, with one fish at large for 14 years prior to its first capture. Six fish had year-class information, with five fish approximately 1 to 8 years old at stocking and the other from 5 to 7 years old at stocking, as its stocking was a mixed batch of 2002, 2003, and 2004 year-classes.

Lakeside backwaters and offsite facilities contributed two and seven fish to the PIT-tagged repatriates with paired data, respectively (table 3). Of the lakeside backwaters, one fish was reared at Arizona Juvenile, one fish was reared at North Chemehuevi, and both were stocked into the main channel adjacent to their rearing locations. Offsite rearing facilities included the Achii Hanyo Native Fish Rearing Facility, the Bubbling Ponds Fish Hatchery, the Southwestern Native Aquatic Resources and Recovery Center in Dexter, New Mexico (formerly the Dexter National Fish Hatchery & Technology Center) (Center), the Overton Wildlife Management Area, Center Pond, and the Willow Beach NFH. Two fish reared in lakeside backwaters traveled an average of 20 river kilometers from stocking to the capture site, while the seven fish reared in offsite facilities traveled an average of 17 river kilometers.

Based on monitoring data from March 2016 and 2017, it is estimated that there is no effective wild razorback sucker population remaining in Lake Mohave. The repatriated razorback sucker population in 2016 was estimated at 1,291 (95% CI from 531 to 3,436).

Remote Monitoring

PIT scanners were deployed in Lake Mohave for 54,850 hours of total scanning time: 10,257 hours using shore-based devices and 44,593 hours with submersible units. The 2017 scanning year resulted in 71,434 total contacts, 3,707 of which were unique PIT tags, with 3,490 of those having a marking history in the Lower Colorado River Native Fish Database (i.e., have a marking record). Among fish with a marking record, 3,462 were repatriates, 9 were wild, and 19 were of unknown origin.

Table 2.—Adult razorback sucker monitoring summary for nine fish with paired stocking-capture data with calculated growth rate (capture TL in mm minus stocking TL in mm then divided by months at large), time at large (capture date minus stocking date then divided by 30 days for months at large or 365 days for years at large), and capture history

(Data are in order by number of captures, then capture date, and include year-class information where available. The release date is when fish were stocked into Lake Mohave.)

PIT tag	Date		Capture history						TL (mm)		Growth rate (mm/mo at large)
	Release	Capture	Sex	Days at large	Months at large	Years at large	Number of captures	Comments	Release	Capture	
1C2D60F707[a]	12/3/2009	12/5/2016	F	2,559	85	7	1	First capture in 2017	445	671	3
003BE5B93B[b]	1/13/2016	12/5/2016	F	327	11	< 1	1	First capture in 2017	410	543	12
1C2D697D4D[c]	2/19/2014	12/5/2016	F	1,020	34	3	1	First capture in 2017	510	572	2
5324140160[d]	7/25/2002	12/5/2016	F	5,247	175	14	1	First capture in 2017	285	646	2
257C60995F[e]	6/13/2007	3/14/2017	F	3,562	119	10	1	First capture in 2017	480	665	2
4648701437[f]	1/25/2006	3/15/2017	F	4,067	136	11	1	First capture in 2017	410	685	2
1C2C3435B7[g]	3/20/2009	3/16/2017	F	2,918	97	8	1	First capture in 2017	490	626	1
53453C2E26[h]	6/18/2004	3/16/2017	F	4,654	155	13	2	First capture in 2013, second in 2017	350	645	2
1C2D267788[i]	10/5/2011	12/5/2016	F	1,888	63	5	3	First capture in March 2011, second in October 2011, third in 2016	475	634	3
			Average	**2,916**	**97**	**8**	–		428	632	3

[a] 2008 year-class; reared at the Achii Hanyo Native Fish Rearing Facility.
[b] 2014 year-class; reared at the Willow Beach NFH.
[c] 2008 year-class; reared at the Overton Wildlife Management Area, Center Pond.
[d] No year-class; reared at the Center.
[e] No year-class; reared at the Arizona Juvenile lakeside backwater.
[f] 2003 year-class; reared at the Willow Beach NFH.
[g] 2002, 2003, or 2004 year-class; reared at the Bubbling Ponds Fish Hatchery.
[h] No year-class; reared at the Willow Beach NFH.
[i] 2008 year-class; reared at the North Chemehuevi lakeside backwater.

Table 3.—Adult razorback sucker monitoring summary, March 2017

(Data are for nine fish with paired release-capture data by rearing type and location and release and capture locations. Stocking location is where fish were stocked into Lake Mohave. Data are in alphabetical order of rearing type and location.)

Rearing		Release				Capture				Distance traveled (change in km)	n fish
Type	Location	Location	State[1]	River km[2]	Zone	Location	State	River km	Zone		
Lakeside backwaters	Arizona Juvenile	Lake Mohave at Arizona Juvenile backwater	AZ	24	Basin	Cottonwood Cove East (100 meters inside, north shore)	AZ	34	Basin	19	1
	North Chemehuevi	Lake Mohave at North Chemehuevi Cove backwater	NV	21	Basin	Carp Cove	AZ	34	Basin	21	1
									Average distance traveled	**20**	**2**
Offsite facilities	Achii Hanyo Native Fish Rearing Facility	Cottonwood Cove	NV	36	Basin	Carp Cove	AZ	34	Basin	12	1
	Bubbling Ponds Fish Hatchery	Cottonwood Cove	NV	36	Basin	Cottonwood Cove East (100 meters inside, north shore)	AZ	34	Basin	12	1
	Center	Princess Cove ramp	AZ	8	Katherine	Carp Cove	AZ	34	Basin	29	1
	Overton Wildlife Management Area, Center Pond	Half-Way Wash	NV	30	Basin	Carp Cove	AZ	34	Basin	15	1
	Willow Beach NFH	Catclaw to Great West Cove	AZ	52	Above Owl Point	Cottonwood Cove East (between north point and 1st point south)	AZ	32	Basin	20	1
		Half-Way Wash	NV	30	Basin	Carp Cove	AZ	32	Basin	15	1
		Wrong Cove	AZ	52	Above Owl Point	Carp Cove	AZ	34	Basin	18	1
									Average distance traveled	**17**	**7**

[1] AZ = Arizona, and NV = Nevada.
[2] km = kilometer(s).

Remote PIT scanning in the River zone resulted in 10,393 hours of scanning, all with submersible units. The mean deployment time for submersible units was 30 hours. Among 29,939 contacts, 2,182 were unique PIT tags, and 2,060 of those were in the Lower Colorado River Native Fish Database. Repatriated razorback suckers accounted for 2,048 tags with a marking record, 7 were noted as wild individuals, and 5 had unknown histories.

Contacts at fixed sites in River were compared during the sampling season. Of a possible 240 fixed site replicates (12 trips x 5 sites x 4 replicates[3]), 230 replicates were available for analysis. In October and November 2016, low water levels resulted in fewer overnight scanning deployments at Boy Scout Canyon and Sauna Cave, accounting for three replicates missing from the total. A scanner malfunction in December 2016 at Black Bar resulted in four replicates missing from the total number available. One replicate is missing from each of the February, April, and August monitoring trips, resulting in three replicates being removed from the total available. All other trip and location combinations had four replicates. The most contacts were recorded at Black Bar from November through May (except December, which is attributed to scanner failure), becoming fewer in subsequent months (figure 3). Sauna Cave and Boy Scout Canyon had the most contacts in three of the remaining six sample periods.

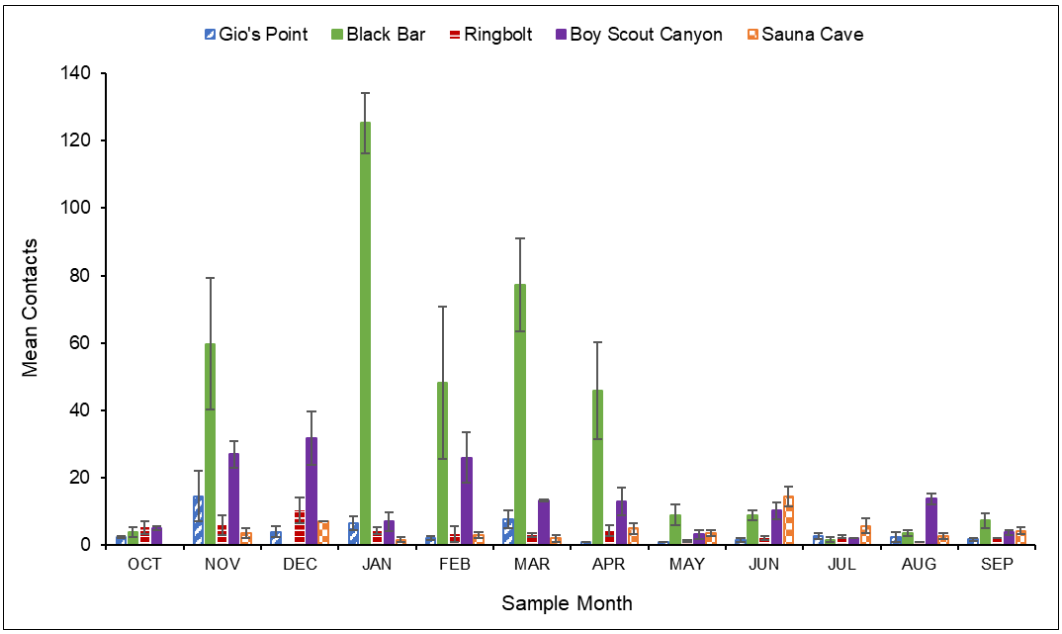

Figure 3.—Unique razorback sucker PIT tag contacts recorded from October 1, 2016, to September 30, 2017, at five fixed stations in the River zone, Lake Mohave, Arizona and Nevada.
Error bars represent ±1 standard error. n = 4 except for Boy Scout Canyon and Sauna Cave in October (n = 3 and n = 0, respectively), Boy Scout Canyon and Sauna Cave in November (n = 3), and Gio's Point in December (n = 0).

[3] A replicate is defined as one overnight scanning period.

Remote submersible scanners in Liberty were deployed for 7,906 hours of scanning. The mean deployment time for submersible scanners was 50 hours. A total of 68 PIT tag contacts were recorded, representing 52 unique razorback suckers; 49 of these individuals were repatriates and 1 was of unknown origin. Of the 49 repatriates contacted in Liberty in 2017, 48 were contacted prior to 2017 by remote PIT scanning in Basin or River.

Both shore-based and submersible units were deployed in Basin and accumulated 30,958 total hours of scanning: 10,257 hours with shore-based units and 20,701 hours with submersible units. The mean deployment times for shore-based and submersible units were 180 and 141 hours, respectively. A total of 41,056 contacts were recorded, representing 1,770 unique PIT tags for which 1,665 had a marking record in the Lower Colorado River Native Fish Database. This excludes fish that are in the database but do not have a proper marking record, and fish that were marked and released in a backwater but do not have a record of release into the reservoir. Repatriated razorback suckers accounted for 1,647 of the unique encounters: 2 were wild and 16 were of unknown origin.

Remote submersible PIT scanners were deployed in Katherine for 5,593 hours of scanning. The mean deployment time for submersible scanners was 82 hours. A total of 371 PIT tag contacts were recorded, representing 59 unique PIT tags, 54 of which had a marking history in the Lower Colorado River Native Fish Database. All were razorback sucker repatriates. Of the 54 repatriates contacted in Katherine in 2017, 39 were contacted on remote PIT scanners in River or Basin. Thirteen of the 15 razorback suckers contacted in Katherine during the 2017 scan-year (October 1, 2016, through September 30, 2017), but not contacted previously in River or Basin, were at large for less than 2 years prior to the beginning of the 2017 scan-year (i.e. were released after January 1, 2015).

Post-stocking dispersal out of the release zone was minimal for two of the four main stocking zones, excluding individuals that were stocked into Liberty and Katherine (figures 4 and 5).

In Liberty, 231 fish were released, and only 1 fish each was scanned in Liberty and Katherine; the remainder were scanned in River (136) and Basin (93) (figure 4). Two of 45 fish released in Katherine were scanned there, 11 were scanned in River, and 32 in Basin (figure 5). Of the 3,490 razorback suckers contacted in 2017 with a marking record, 2,801 razorback suckers met the criteria for further analysis (repatriate released between October 1, 2008, and September 30, 2015, with a 134.2-kHz tag). An additional 292 fish (10.4%) were contacted in multiple zones and removed from further comparisons. Of the remaining fish, 1,281 (51.1%) were released into River. The majority (> 80%) of these fish were contacted in River for all release years except 2013 (figure 6).

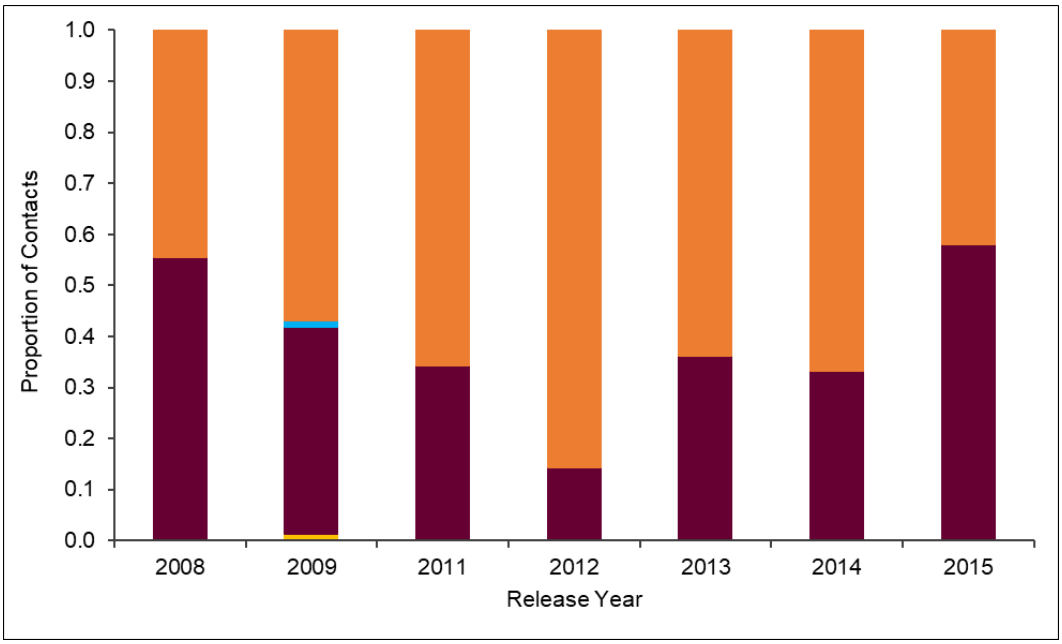

Figure 4.—Proportion of razorback sucker PIT tag contacts in 2017 among scanning zones in Lake Mohave; Katherine (yellow), Basin (maroon), Liberty (blue), and River (orange), for fish released in Liberty.
Fish were released between October 1, 2008, and October 1, 2015, and contacted during PIT scanning activities from October 1, 2016, and September 30, 2017.

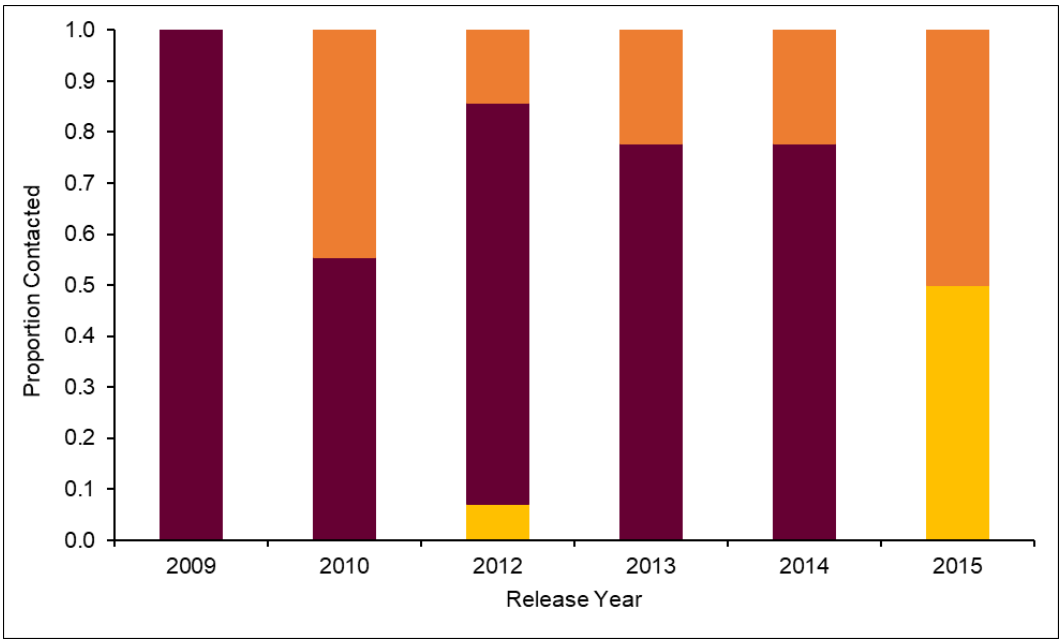

Figure 5.—Proportion of razorback sucker PIT tag contacts in 2017 among scanning zones in Lake Mohave; Katherine (yellow), Basin (maroon), Liberty (blue), and River (orange), for fish released in Katherine.
Fish were released between October 1, 2008, and October 1, 2015, and contacted during PIT scanning activities from October 1, 2016, to September 30, 2017.

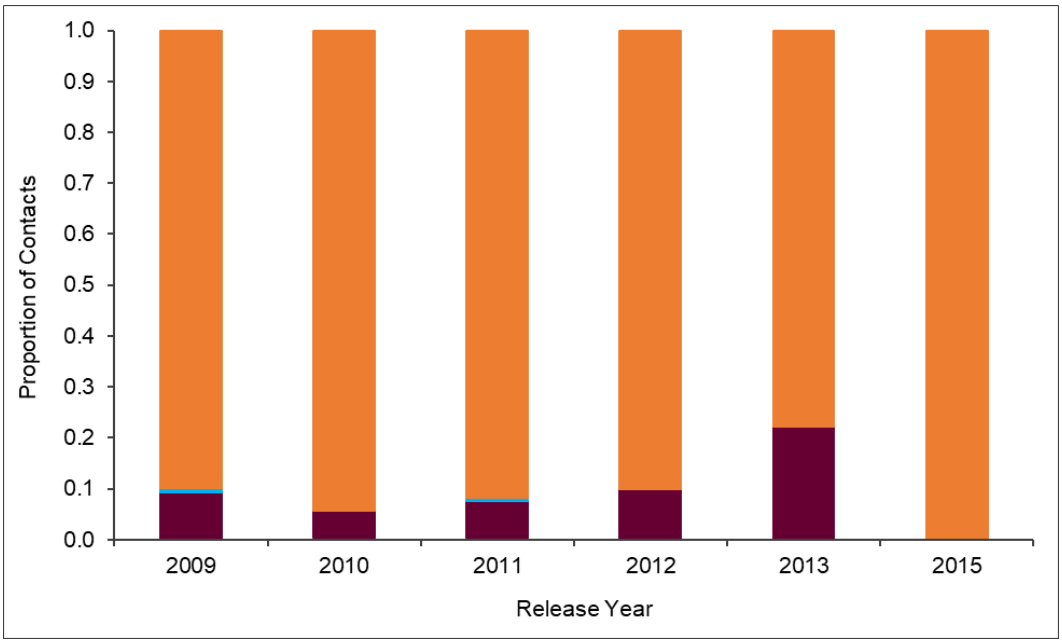

Figure 6.—Proportion of razorback sucker PIT tag contacts in 2017 among scanning zones in Lake Mohave; Katherine (yellow), Basin (maroon), Liberty (blue), and River (orange), for fish released in River.
Fish were released between October 1, 2008, and October 1, 2015, and contacted during PIT scanning activities from October 1, 2016, to September 30, 2017.

There were no fish contacted in 2017 from the 2014 release year, nine contacted that were released in 2013, and only four contacted from the 2015 release year.

The same trend was also noted in Basin, where most individuals were contacted in their zone of release regardless of release year (figure 7). Basin-released fish accounted for 38% (952) of the razorback suckers contacted.

Adult subpopulations in River, Liberty, Basin, and Katherine exchanged few individuals from 2016 to 2017 (table 4). Among 2,125 razorback suckers contacted in both years, 1,834 (86.3%) were contacted in one zone each year, and 83% of individuals (1,762 out of 2,125) were scanned in the same zone through the 2 years of scanning (October 1, 2015 through September 30, 2016). Individuals contacted in a different zone each year, but only one zone per year, exhibited similar amounts of movement from Basin to River (42 fish; 2.3%) as from River to Basin (24 fish; 1.3%). There was limited scanning in Katherine and Liberty in 2016, and the number of individuals exchanged between zones is very small. Remaining fish were contacted in multiple zones in a year; 70 fish were contacted in multiple zones in 2016, 174 in multiple zones in 2017, and 47 fish were contacted in multiple zones both years.

Contact rates for 2017 continued to be highest for release cohorts with fewer and larger fish. In River, five cohorts released at the Willow Beach boat ramp

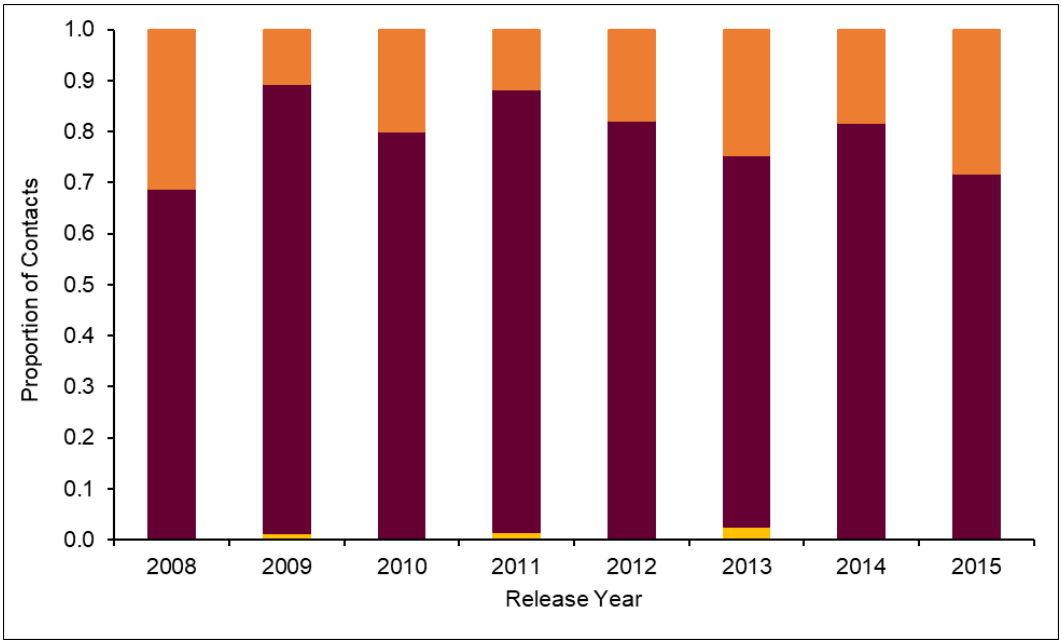

Figure 7.—Proportion of razorback sucker PIT tag contacts in 2017 among scanning zones in Lake Mohave; Katherine (yellow), Basin (maroon), Liberty (blue), and River (orange), for fish released in Basin.
Fish were released between October 1, 2008, and October 1, 2015, and contacted during PIT scanning activities from October 1, 2016, to September 30, 2017.

Table 4.—Razorback suckers contacted by remote PIT scanning in 2017 that were also contacted in 2016, broken down by zone of contact in Lake Mohave, Arizona and Nevada
(Fish contacted in more than one zone were excluded from analysis.)

2016	2017			
	River	Liberty	Basin	Katherine
River	951	3	24	0
Liberty	0	0	0	0
Basin	42	1	811	2
Katherine	0	0	0	0

(October 13 and 23, 2009; January 7, 2010; October 4, 2011; and December 8, 2011) made up 93% of fish contacted in 2017 (table 5). These five cohorts made up most fish contacted but only account for 30% of fish released in River. Of 15,561 River-released fish in 2012, 2013, 2014, and 2015 (mean TL 342 mm), only 40 were contacted in 2017 (< 1%).

Table 5.—Razorback sucker repatriation cohorts (fish released at a given location on the same date) from October 1, 2008, to September 30, 2015, and their remote PIT scanning contact rates in 2017, Lake Mohave, Arizona and Nevada

Release zone	Release location	Release date	Releases	Mean TL (mm)	2017	
					Contacted	Percent contacted
River	Willow Beach boat ramp	10/4/2011	500	441	132	26.4
	Willow Beach boat ramp	10/23/2009	2,234	421	422	18.9
	Willow Beach boat ramp	1/7/2010	2,077	423	339	16.3
	Willow Beach boat ramp	12/8/2011	1,594	394	224	14.1
	Willow Beach boat ramp	10/13/2009	2,588	416	194	7.5
	Willow Beach boat ramp	12/7/2010	504	398	34	6.7
	Willow Beach boat ramp	4/4/2012	118	373	4	3.4
	North Hatchery Cove	4/19/2013	217	336	4	1.8
	Willow Beach boat ramp	3/8/2012	549	375	10	1.8
	Willow Beach boat ramp	12/12/2011	408	351	5	1.2
	Painted 8 Cove	12/18/2009	1,436	347	13	0.9
	Ringbolt Rapids	12/16/2010	1,509	324	8	0.5
	Willow Beach boat ramp	12/7/2012	1,510	368	8	0.5
	Black Bar	1/12/2015	1,036	347	4	0.4
	Ringbolt Rapids	2/13/2013	1,725	330	5	0.3
	Ringbolt Cove	1/6/2010	1,493	334	4	0.3
	Black Bar	1/5/2015	999	347	2	0.2
	Ringbolt Rapids	1/29/2013	575	326	1	0.2
	Ringbolt Rapids	1/22/2013	1,486	331	1	0.1
	Ringbolt Rapids	1/5/2012	1,778	332	1	0.1
	Ringbolt Rapids	1/30/2013	597	327	0	0.0
	Willow Beach boat ramp	1/29/2014	1,441	333	0	0.0
	Ringbolt Rapids	1/30/2014	1,541	331	0	0.0
	Ringbolt Rapids	1/5/2015	989	339	0	0.0
	Ringbolt Rapids	1/12/2015	1,000	339	0	0.0

Table 5.—Razorback sucker repatriation cohorts (fish released at a given location on the same date) from October 1, 2008, to September 30, 2015, and their remote PIT scanning contact rates in 2017, Lake Mohave, Arizona and Nevada

Release zone	Release location	Release date	Releases	Mean TL (mm)	2017	
					Contacted	Percent contacted
Liberty	Liberty Cove	3/16/2011	444	414	27	6.1
	Liberty Cove	2/28/2013	1,271	356	52	4.1
	Wrong Cove	12/17/2009	917	374	34	3.7
	Liberty Cove	1/29/2013	1,186	326	31	2.6
	Red Tail Cove	12/17/2009	897	382	20	2.2
	Liberty Cove	12/17/2009	1,521	379	33	2.2
	Liberty Cove	1/14/2015	1,000	346	16	1.6
	Liberty Cove	1/21/2015	1,070	341	13	1.2
	Owl Point Cove	1/26/2012	1,022	324	5	0.5
	Owl Point Cove	1/6/2015	987	361	4	0.4
	Liberty Cove	1/5/2011	1,896	339	7	0.4
	Liberty Cove	1/14/2014	1,825	326	6	0.3
	Owl Point Cove	1/13/2015	986	350	3	0.3
	Liberty Cove	1/5/2012	1,920	330	4	0.2

Table 5.—Razorback sucker repatriation cohorts (fish released at a given location on the same date) from October 1, 2008, to September 30, 2015, and their remote PIT scanning contact rates in 2017, Lake Mohave, Arizona and Nevada

Release zone	Release location	Release date	Releases	Mean TL (mm)	2017	
					Contacted	Percent contacted
Basin	Lake Mohave at Yuma Cove backwater	5/19/2010	101	478	36	35.6
	Cottonwood Cove	3/26/2009	125	463	39	31.2
	Cottonwood Cove	3/20/2009	209	508	62	29.7
	Cottonwood Cove	12/3/2009	413	448	113	27.4
	Lake Mohave at North Chemehuevi Cove backwater	10/14/2008	176	451	8	4.5
	Cottonwood Cove	12/6/2012	1,019	389	42	4.1
	Lake Mohave at North Nine Mile Coves backwater	1/6/2010	980	374	33	3.4
	Lake Mohave at Dandy Cove backwater	10/8/2008	158	438	5	3.2
	Carp Cove	12/5/2012	400	391	12	3.0
	Cottonwood Cove Landing, Resort and Marina	12/12/2014	484	390	13	2.7
	Cottonwood Cove Landing, Resort and Marina	1/12/2015	999	371	17	1.7
	Cottonwood Cove Landing, Resort and Marina	1/5/2015	1,004	372	15	1.5
	Cottonwood Cove	12/12/2013	415	402	5	1.2
	Nellis Cove	1/13/2015	1,038	340	9	0.9
	Cottonwood Cove East	1/24/2013	3,206	336	25	0.8
	Cottonwood Cove East	1/28/2014	1,412	338	11	0.8
	Lake Mohave at North Nine Mile Coves backwater	1/27/2014	2,372	331	11	0.5
	Lake Mohave at Yuma Cove backwater	12/18/2009	1611	329	7	0.4
	Nellis Cove	1/20/2015	1,015	337	4	0.4
	Six Mile Coves	1/5/2010	1,584	329	6	0.4
	Nine Mile Coves (north of)	1/6/2011	1,892	341	7	0.4
	Lake Mohave at Yuma Cove backwater	1/18/2012	693	328	1	0.1

Table 5.—Razorback sucker repatriation cohorts (fish released at a given location on the same date) from October 1, 2008, to September 30, 2015, and their remote PIT scanning contact rates in 2017, Lake Mohave, Arizona and Nevada

Release zone	Release location	Release date	Releases	Mean TL (mm)	2017	
					Contacted	Percent contacted
Katherine	Princess Cove ramp	12/5/2012	1,073	380	10	0.9
	Princess Cove ramp	1/14/2014	2,725	335	12	0.4
	Princess Cove ramp	1/18/2012	1,689	335	5	0.3
	Princess Cove ramp	1/23/2013	4,330	336	10	0.2
	Princess Cove ramp	1/12/2015	1,160	344	1	0.1
	Princess Cove ramp	1/5/2015	1,183	322	1	0.1

Cohorts released in Liberty were scanned in similar proportions to releases elsewhere for fish of comparable size. Fish released into three coves in Liberty on December 17, 2009 (mean TL from 374 to 382 mm) were contacted in 2017 (2.2–3.7%), a proportion similar to that of cohorts released at the Willow Beach boat ramp in March and April 2012 (mean TL of 375 and 373 mm). The cohort with the highest contact rate (6.1%) was 444 razorback suckers released in March 2011 with a mean TL of 414 mm at release.

For razorback suckers released in Basin, there were four cohorts that made up the majority of fish scanned in 2017 (51%) but less than one-half of those released (29%) (see table 5). The mean TL of fish in these four cohorts was longer than 440 mm TL at release, and three of these cohorts were released at Cottonwood Cove in 2009 (two were reared at Bubbling Ponds Fish Hatchery and the other at the Achii Hanyo Native Fish Rearing Facility) and contained 125, 209, and 413 individuals, respectively. The cohort with the highest contact rate in all 3 sample years was a group of 101 individuals reared at the Yuma Cove backwater and released into Yuma Cove with a mean TL at release of 478 mm (see table 5). Five other cohorts with the largest number of fish released (71%) (see table 5) were contacted the least, and all five of these had a mean TL at release shorter than 350 mm. Excluded from the cohort analysis were 161 release cohorts that were released with fewer than 100 fish per cohort, 142 of which were released into Basin from lakeside backwaters. More than 15% (611 of 4,001 releases) of individuals released in these cohorts were contacted by scanning in 2017. The mean TL for these smaller cohorts (in number of released fish) was 443 mm. For comparison, 481 razorback suckers were contacted in 2017 from cohorts that met the criteria for table 5 (100 or more fish released) out of 21,306 releases (2.2%).

Population Estimates

Based on monitoring data from 2016 and 2017, there was no effective wild razorback sucker population remaining in Lake Mohave. It was estimated that the repatriated razorback sucker population as of March 1, 2016, was 1,291 (95% CI from 531 to 3,436), representing a fraction of a percent of the total number of repatriates released into the reach since stocking began.

Based on 2016 and 2017 remote PIT scanning, the 134.2-kHz PIT tagged Lake Mohave repatriate population for 2016 was estimated at 3,815 individuals (95% CI from 3,573 to 4,073). Population estimates using zone-specific scanning for 2016 estimated the Basin population at 2,008 (95% CI from 1,848 to 2,181) and the River population at 2,213 (95% CI from 1,976 to 2,479); no estimate was calculated for Liberty because no effort was applied in that zone during the marking period (March 2016). Too few wild fish were contacted to estimate

Basin and River subpopulations separately (two and seven contacts, respectively). The lake-wide estimate of the wild population based on PIT scanning in 2016 and 2017 was 10 fish (M = 5, C = 9, R = 5; 95% CI from 5 to 23).

Movement and Survival

The results from the multi-site model within program MARK were similar to the previous year. For the "movement and survival" model, ĉ was significantly different than 1, estimated at 2.147 (95% CI from 1.873 to 2.422) based on median ĉ estimation within program MARK. This value was used to adjust AIC_c values ($QAIC_c$). Parameter estimates were based on model averaging because no model had more than 0.9 model weight (table 6). There is some support for time varying survival and transition since these occur in several models with $\Delta QAIC_c \leq 7$ (at least some support). There is more support for location effects on these parameters, as survival or transition vary by location for all models with $\Delta QAIC_c$ in this range. Estimates of yearly transition were slightly different between zones, but similar across years (2012–16); 5.7% to 6.1% (95% CI from 4.2 to 8.1%, 4.2 to 7.7%, 4.2 to 7.7%, and 4.7 to 7.9% in each year, respectively) of fish transitioned from Basin to River. An estimated 4.0 to 4.3% (95% CI from 2.8 to 5.7%, 2.9 to 5.5%, 3.0 to 5.4%, and 3.3 to 5.5%) of fish transitioned from River to Basin each year (table 7). The most recent transition parameter for both zones, the 2016 to 2017 sample period, was confounded and removed from the table.

Estimates of survival were somewhat lower in River than in Basin for any given year (table 8). Survival for all sample periods was 91 to 92% in River compared to 93 to 94% for those same periods in Basin. The most recent survival parameter for both zones, the 2016 to 2017 sample period, was confounded with the recapture rate and removed from the table. Recapture estimates in River varied between 56 and 71% of the marked population each year (table 9). Estimates were higher but just as varied in Basin (77–93%). The last parameter in the recapture estimates was confounded with survival and was unreliable (removed from table).

DISCUSSION

Remote sensing through deployment of PIT scanners in the Basin and River zones of the reservoir continues to be effective in contacting razorback sucker aggregates. Expanded remote PIT scanning in Katherine and Liberty has produced additional contacts, but there is no evidence of any fidelity to these areas. Based on population estimates and year-to-year PIT contact comparisons, a majority of the known razorback sucker population of 134.2-kHz tagged fish in Lake Mohave is contacted each sample year. Mark-recapture estimates of annual

Table 6.—Program MARK movement and survival models for adult razorback suckers, Lake Mohave, Arizona and Nevada

(φ is apparent survival, P is recapture, and Ψ is transition. P[recapture] parameters were time varying and different between zones in all models.)

Model	$QAIC_c$	$\Delta QAIC_c$	$QAIC_c$ weights	Model likelihood	Number of parameters
φ(state) P(state*t) Ψ(state)	8048.2	0.0	0.467	1.000	14
φ(state+t) P(state*t) Ψ(state)	8049.7	1.5	0.222	0.476	17
φ(.) P(state*t) Ψ(state)	8051.5	3.3	0.089	0.191	13
φ(state) P(state*t) Ψ(state+t)	8052.2	4.0	0.062	0.132	18
φ(state) P(state*t) Ψ(.)	8053.6	5.4	0.031	0.066	13
φ(t) P(state*t) Ψ(state)	8053.7	5.5	0.030	0.064	16
φ(state+t) P(state*t) Ψ(state+t)	8053.8	5.6	0.029	0.061	21
φ(state+t) P(state*t) Ψ(.)	8054.0	5.8	0.025	0.054	16
φ(.) P(state*t) Ψ(state+t)	8055.4	7.2	0.013	0.027	17
φ(state+t) P(state*t) Ψ(state*t)	8057.5	9.3	0.004	0.010	24
φ(t) P(state*t) Ψ(state+t)	8057.6	9.5	0.004	0.009	20
φ(.) P(state*t) Ψ(.)	8057.6	9.5	0.004	0.009	12
φ(state) P(state*t) Ψ(t)	8057.7	9.5	0.004	0.009	17
φ(state) P(state*t) Ψ(state*t)	8057.8	9.6	0.004	0.008	22
φ(state*t) P(state*t) Ψ(state)	8058.8	10.6	0.002	0.005	22
φ(state*t) P(state*t) Ψ(state+t)	8058.9	10.7	0.002	0.005	24
φ(state*t) P(state*t) Ψ(.)	8059.0	10.8	0.002	0.005	19
φ(t) P(state*t) Ψ(.)	8059.5	11.4	0.002	0.003	15
φ(state*t) P(state*t) Ψ(state*t)	8060.7	12.5	0.001	0.002	26
φ(.) P(state*t) Ψ(state*t)	8061.1	13.0	0.001	0.002	21
φ(t) P(state*t) Ψ(state*t)	8061.4	13.3	0.001	0.001	23
φ(.) P(state*t) Ψ(t)	8061.8	13.6	0.001	0.001	16
φ(state+t) P(state*t) Ψ(t)	8062.1	13.9	0.000	0.001	22
φ(state*t) P(state*t) Ψ(t)	8063.1	15.0	0.000	0.001	23
φ(t) P(state*t) Ψ(t)	8063.6	15.5	0.000	0.000	19

Table 7.—Program MARK model transition estimates (model averaged) for razorback suckers released into River or Basin, at large for >730 days, and scanned in River or Basin after 2011

(Models exclude fish scanned only in 2017 and individuals released into Liberty due to limited scanning there.)

Zone	Period	Estimate	Lower CI	Upper CI
River	2012–13	0.040	0.028	0.057
	2013–14	0.040	0.029	0.055
	2014–15	0.040	0.030	0.054
	2015–16	0.043	0.033	0.055
Basin	2012–13	0.059	0.042	0.081
	2013–14	0.057	0.042	0.077
	2014–15	0.057	0.042	0.077
	2015–16	0.061	0.047	0.079

Table 8.—Program MARK model survival estimates (model averaged) for razorback suckers released into River or Basin, at large for >730 days, and scanned in River or Basin after 2011

(Models exclude fish scanned only in 2017 and individuals released into Liberty due to limited scanning there.)

Zone	Period	Estimate	Lower CI	Upper CI
River	2012–13	0.911	0.874	0.938
	2013–14	0.925	0.891	0.949
	2014–15	0.917	0.892	0.938
	2015–16	0.912	0.875	0.939
Basin	2012–13	0.933	0.904	0.953
	2013–14	0.943	0.912	0.964
	2014–15	0.937	0.915	0.954
	2015–16	0.933	0.908	0.951

Table 9.—Program MARK model recapture estimates (model averaged) for razorback suckers released into River or Basin, at large for >730 days, and scanned in River or Basin after 2011
(Models exclude fish scanned only in 2017 and individuals released into Liberty due to limited scanning there.)

Zone	Period	Estimate	Lower CI	Upper CI
River	2013	0.717	0.654	0.773
	2014	0.599	0.549	0.647
	2015	0.689	0.646	0.729
	2016	0.561	0.517	0.605
Basin	2013	0.930	0.875	0.962
	2014	0.779	0.730	0.821
	2015	0.817	0.775	0.853
	2016	0.939	0.907	0.961

adult apparent survival continue to be about 90%, significantly higher than previously estimated (75%, Marsh et al. 2005). This discrepancy was likely due to the limited geographic scope of previous sampling activities and the limited exchange of individuals among the two subpopulations (Basin and River). Estimates of monthly transition rates indicated a net migration upstream from Basin to River subpopulations (Wisenall et al. 2015), but the difference in rate of exchange on an annual basis was small and not statistically significant, as indicated by overlapping CIs.

Population estimates for each subpopulation based on mark-recapture data derived from remote PIT scanning and March monitoring data are beginning to diverge. The lake-wide 2016 population estimate based on remote PIT scanning data (3,815 [95% CI from 3,573 to 4,073]) was the highest since scanning was initiated, which is a trend that has been observed over the past several years, and is outside the range of the CI for the population estimate based on March monitoring data 1,291 (95% CI from 531 to 3,436). This is consistent with the limited geographic scope of March netting activities, which are generally restricted to Basin. The estimate for Basin based on PIT scanning, 2,008 (95% CI from 1,848 to 2,181) is closer to the March monitoring estimate. Given the lack of netting activities upstream of Willow Beach during March monitoring and the lack of exchange indicated by PIT scanning, the March survey estimate should be considered an estimate of the subpopulation in Basin and not a lake-wide estimate (Wisenall et al. 2016).

PIT scanning-based population estimates are restricted to 134.2-kHz tagged razorback suckers, but March monitoring estimates include fish with 400-kHz PIT

tags[4] or no tags at all prior to first capture. Therefore, the March monitoring estimate would be expected to trend higher. Contrary to expectation, the PIT scanning Basin subpopulation estimate is higher than the March survey estimate, which may be due to differences in temporal coverage between the two estimates. The marking and capture periods for the March survey estimate are restricted to data from the month of March. The marking period for the PIT scanning estimate is also restricted to March, but the capture period encompasses the full year and thus includes the entirety of the spawning season. A temporal analysis of the PIT scanning data will be pursued to determine if a portion of the adult razorback sucker population is not available for capture in March.

No additional analysis on goodness of fit for the movement and survival mark-recapture model was performed in 2017. The median estimate of $\hat{c}$ declined from 2.473 (95% CI from 1.946 to 2.982) in 2016 to 2.147 (95% CI from 1.873 to 2.422) in 2017. One potential source considered in 2016 for the lack of fit was razorback sucker site fidelity to spawning locations. Although some fish are detected at multiple sites, they are often contacted at the same site year to year. In 2017, M&A and Reclamation deployed PIT scanners beyond the typical "hotspots" within Basin and River. Although this did not result in a large number of contacts, or a large proportion of fish that had not been contacted elsewhere, the additional geographic coverage likely reduced the probability that any razorback suckers in Lake Mohave were unavailable to sampling gear for the sample year. Data to support this hypothesis will require continuing the expanded distribution of PIT scanner deployments.

Although razorback sucker abundance has been relatively stable, release cohort analysis based on PIT scanning in River continues to present compelling data that recent numerically large release cohorts are not replacing declining older ones (Wisenall et al. 2016). In the River zone, individual release cohorts from 2009 to 2011 continue to dominate PIT scanning data in 2017. More recent releases from 2012 to 2015 were not scanned in similar numbers. Only 378 of more than 53,000 individuals (< 1%) released there from 2012 to 2015 were scanned in 2017 (see table 5). The size at release of these fish (mean TL of 347 mm) was well below the Lake Mohave Native Fish Work Group target size of 500 mm, and post-stocking survival was likely very low.

In Basin, backwater-released fish are contributing disproportionately to the subpopulation compared to hatchery-released fish based on their stocking numbers. This is at least due in part to individual size at release. Razorback suckers stocked into lakeside backwaters prior to release into Lake Mohave are given an extra growing season and are on average longer than 400 mm TL at release. This alone may account for their relatively high contribution to capture monitoring data as well as PIT scanning contacts, and the stability of the Basin

[4] In March collections over recent years, a 400-kHz tag was detected in 9.5% (99 out of 1,046) of fish captured (unpublished data).

subpopulation is likely due to these releases. TL at release may not be the only reason backwater released fish are overrepresented in recapture and PIT scanner contact data (i.e., increased post-stocking survival due to backwater grow-out cannot be discounted completely). However, any analysis of backwater grow-out benefits must account for the additional losses experienced in backwaters prior to release compared to hatchery losses.

The relationship between size at release and survival for razorback suckers has been supported by numerous lines of evidence (e.g., Minckley et al. 2003; Marsh et al. 2005; Zelasko et al. 2010). The current program at the Willow Beach NFH to release fewer, but larger razorback suckers, should result in additional recruitment within a few years after releases begin. However, the fishkill at the hatchery in autumn 2016 has delayed this program, and harvest from lakeside backwaters and releases from the Lake Mead Fish Hatchery will be the only sources of large razorback suckers for Lake Mohave in the short term. The current stability of population estimates and high relative contribution of the backwater and Lake Mead hatchery releases are evidence that the delay will not cause a significant reduction in population size.

The new yearly larval harvest goal based on the stocking plan is 18,000, but it was increased in 2017 to 33,000 to account for the loss of razorback suckers at the Willow Beach NFH. To accurately represent the razorback sucker subpopulation residing upstream of Willow Beach, it is suggested that one-half of the larvae collected (9,000 individuals based on original harvest goal) come from this zone. In 2017, the USFWS, Reclamation, and M&A collected 5,760 larvae above Willow Beach, many more than in previous years when collections here have been fewer than 2,000. The goal to collect an equal share of larvae from River and Basin remains unmet but potentially possible with increased effort.

After a 3-year absence from the Willow Beach NFH, rainbow trout (*Oncorhynchus mykiss*) again are being reared for stocking in both Lake Mohave and below Davis Dam. While there may be no direct impact on razorback suckers at the Willow Beach NFH from overcrowding, etc., there is potential for an increase in predation in the reservoir. Rainbow trout provide a food source for striped bass (*Morone saxatilis*), which are one of the main predators of razorback suckers in the system. An increased abundance of larger striped bass, even with the advent of stocking larger razorback suckers, may become an important factor to consider when managing this native species in the future. Furthermore, striped bass are known to aggregate in areas where fish are routinely released, so stocking events for rainbow trout and razorback suckers should be spatially and temporally separated to mitigate potential exacerbation of predation issues.

A substantial number of razorback suckers have been repatriated into Lake Mohave – 221,195 fish as of this writing (Lower Colorado River Native Fish Database) – and that effort has been the sole source of the current population of a few thousand individuals. This repatriation program is a primary component of the species'

conservation strategy in the Lower Colorado River Basin, and it plays a critical role in maintaining Lake Mohave as the only genetic reservoir for the razorback sucker throughout its range (Dowling et al. 1996 a, 1996b, 2005). Adjustments to the repatriation program have been made over the years, and data-based recommendations now are being implemented to increase post-stocking survival and population size. The genetic legacy of razorback suckers embodied in the Lake Mohave population represents the "cornerstone for razorback sucker conservation" (Marsh et al. 2015) and, as such, is important to maintain until a successful backwater conservation strategy (Minckley et al. 2003; USFWS 2005) or an alternative can be realized, and long thereafter.

LESSONS LEARNED

Autumn and spring monitoring provide information on growth, health, fish without 134.2-kHz PIT tags, and genetics for wild and repatriate razorback suckers in Lake Mohave. There currently is no other mechanism to acquire these critical data.

Efforts are ongoing to stock razorback suckers into Lake Mohave at the largest individual size and in the greatest number possible. If there is a choice between a smaller number of larger fish and a larger number of smaller fish, all available data indicate the former strategy will best further the goals of the repatriation program. Stocking cohorts in each zone (Basin and River) at approximately the same time (within days to a few weeks at most) and near the same mean TL will support the goal of assessing razorback sucker metapopulation dynamics and the effect of stocking location on these dynamics. The difference in survival estimates between Basin (93–94%) and River (91–92%) from multi-state mark-recapture models is small enough to continue stocking both sites, thereby providing redundancy as a bulwark against catastrophic loss for either subpopulation. Based upon the results of this study, releases of at least 500 fish per location and stocking event should result in adequate future PIT scanning contacts to support sound analysis.

Monthly remote PIT scanning deployments in River have proven effective for monitoring this subpopulation of razorback suckers, and it is suggested that these efforts are maintained. M&A will continue to work with Reclamation biologists to ensure a similar scanning effort in Basin as well as Liberty. The locations of deployments will be based on past results and continued input from visual surveys. Regardless of positive results from visual surveys, PIT scanners will continue to be deployed on a routine basis in new locations within River (e.g., downstream from Willow Beach) and in zones where past monitoring effort was minimal (i.e., Katherine) as time, equipment, and weather permit.

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