Lower Colorado River Multi-Species Conservation Program

Balancing Resource Use and Conservation

Demographics and Monitoring of Repatriated Razorback Suckers in Lake Mohave

2016 Annual Report

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National Park Service
Bureau of Land Management
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Lower Colorado River
Multi-Species Conservation Program

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ACRONYMS AND ABBREVIATIONS

AIC_c	Akaike's information criterion adjusted for small sample size
CI	confidence interval
cm	centimeter(s)
GOF	goodness-of-fit
kHz	kilohertz
LCR MSCP	Lower Colorado River Multi-Species Conservation Program
m	meter(s)
M&A	Marsh & Associates, LLC
MARK	computer program MARK
M, C, R	mark, capture, recapture
mm	millimeter(s)
n	sample size
PIT	passive integrated transponder
PVC	polyvinylchloride
$QAIC_c$	Akaike's information criterion adjusted for overdispersion
Reclamation	Bureau of Reclamation
RKM	river kilometer(s)
TL	total length
U-CARE	computer program Utilities- CApture-REcapture
USFWS	U.S. Fish and Wildlife Service
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
%	percent
±	plus or minus
P	recapture
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 estimate the abundance of all repatriated and wild razorback suckers marked with either 400- or 134.2-kHz PIT tags.

Ten razorback suckers were handled at the Marsh & Associates, LLC, camp during the March roundup from March 14 through March 18, 2016; no razorback suckers were captured at any other times of the reporting year. There were no original capture or stocking data in the Lower Colorado River Native Fish Database for 1 of the 10 captures. Of the nine remaining individuals, all were PIT-tagged repatriates with paired stocking and capture data in the database. Based on 2015 and 2016 monitoring data, it was determined that no effective wild razorback sucker population remains in Lake Mohave. The repatriated razorback sucker population for 2015 based on 2015 and 2016 March roundup data is estimated to number 1,707 (95% confidence interval [CI] from 603 to 3,897).

The total deployment time for remote PIT scanners from October 1, 2015, through September 30, 2016, was 37,859 scan-hours, resulting in 230,666 PIT tag contacts representing 3,244 unique PIT tags for which 3,128 had a razorback sucker marking record in the database (as of September 30, 2016). Among fish with a marking record, 3,110 were repatriates, 10 were wild, and 8 were of unknown origin.

Lake Mohave was subdivided for analytical purposes into four stocking zones, and 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 (> 85%) of fish released in River and Basin were contacted in their zone of release regardless of release year. Razorback suckers released in Liberty were generally contacted elsewhere (River and Basin). Among the three zones scanned in 2015 and 2016 (River, Liberty, and Basin), remote PIT scanning detected little movement of razorback suckers between years, with 96% of individuals (1,597 out of 1,668) contacted in the same zone in both years. Dispersal in Katherine was not evaluated because there were limited stockings and captures and no scanning in that zone.

Based on 2015 and 2016 remote PIT scanning, the 134.2-kHz PIT-tagged Lake Mohave repatriate population was estimated at 3,656 (95% CI from 3,418 to 3,912). The Basin and River subpopulation estimates based on zone-specific scanning in 2015 and 2016 also were calculated. The Basin

subpopulation was estimated at 1,947 (95% CI from 1,761 to 2,151) and the River subpopulation at 2,158 (95% CI from 1,960 to 2,377). The subpopulation in Liberty was not estimated due to a lack of scanning effort there during the sampling season. All 10 wild razorback suckers contacted in 2016 were also contacted in 2015. Too few wild fish were contacted to estimate the Basin and River subpopulations separately (three and seven contacts, respectively). The lake-wide estimate of the wild population based on PIT scanning in 2015 and 2016 was 12 fish (95% CI from 7 to 23).

A multi-state mark-recapture model assessment in the computer program MARK estimated 5.1% (95% CI from 3.5 to 7.3%) of razorback suckers transitioned from Basin to River from 2014 to 2015 and 4.2% (95% CI from 3 to 5.8%) from River to Basin. From 2013 to 2014, apparent annual survival in Basin was estimated at 94.3% (95% CI from 91.6 to 96.1%), and in River it was estimated at 89% (95% CI from 85.3 to 91.8%). Apparent survival was estimated at 93.8% (95% CI from 91.2 to 95.7%) in Basin from 2014 to 2015 and 88.3% (95% CI from 84.7 to 91.2%) in River during the same time period. Survival and transition were confounded with recapture rates and could not be accurately estimated for 2015 to 2016.

Biannual netting efforts continue to collect essential growth, health, census, and genetic data for razorback suckers. Combined collection efforts upstream of Willow Beach captured more than 1,500 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) should continue with a nominal effort like that applied during the past year. Additional scanning efforts have extended to Liberty to determine if other aggregations of razorback suckers exist and to further evaluate their dynamics of dispersal and distribution.

INTRODUCTION

Lake Mohave once was home to the largest known population of wild razorback suckers (*Xyrauchen texanus*), 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 < 100 individuals by 2010 (Dowling et al. 2014). Since 2010, the wild population has been too rare to estimate abundance and can be considered functionally extirpated. The last calculated wild estimate, based on 2010 and 2011 March roundup data, was 13 fish (95% confidence interval [CI] from 4 to 250). In the early 1990s, a repatriation program to restore razorback suckers in Lake Mohave was established (Mueller 1995). Wild larvae produced naturally in the lake were harvested, reared in protective captivity, and repatriated to the reservoir after growing to a nominal size of 300 millimeters (mm) total length (TL) or more.

There have been several adjustments to the program that incorporate new information 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). A recommended minimum stocking TL of 500 mm to increase post-stocking survival and population size has proven difficult to produce in sufficient numbers (M. Olson 2009, personal communication), and even fish of this size are subject to predation (Karam and Marsh 2010). In February 2015, a change in rearing strategy at the Willow Beach National Fish Hatchery (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 > 400 mm TL. The decrease in the number of fish stocked per year also reduces the larval collection goal, which is now 18,000 per year.

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 NFH (Bureau of Reclamation [Reclamation] 2015, Work Task B2) and from lakeside ponds (Reclamation 2015, Work Task B7) is conducted under the Fish Augmentation component of the program (Reclamation 2006). The Lake Mohave repatriation program is one element of an overall conservation plan for razorback suckers within the LCR MSCP. This program, and other conservation plans upon which it was based (Minckley et al. 2003; U.S. Fish and Wildlife Service [USFWS] 2005), incorporate a population component that will occupy the lower Colorado River main stem, but it may be impractical or impossible to accommodate that component. 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 such a strategy should contribute to maintenance of this endangered species both in Lake Mohave and throughout the lower Colorado River. Moreover, the results of this research

provide critical demographic information and management recommendations to help ensure long-term persistence of a genetically viable stock of adult razorback suckers in Lake Mohave.

Historically, estimates of post-stocking survival based on multiple years of telemetry were used to evaluate predictions of mark-recapture models that relied extensively on data generated from routine monitoring (Kesner et al. 2012). While telemetry results have generally been consistent with the mark-recapture model, fish released at smaller sizes (mean TL 380 mm) have significantly lower post-stocking survival than those released at larger sizes (> 450 mm mean TL). However, subadult (mean TL 380 mm) razorback sucker post-stocking survival varied from 7% (1 of 15 fish) (Kesner et al. 2008a) to 67% (6 of 9 fish; Kesner et al. 2012) for fish released just 1 year apart. Mark-recapture models that included annual variations in survival failed to provide accurate estimates due to the low recapture rate in annual March data (Marsh et al. 2005). Traditional sampling approaches, such as an increase in intensive trammel netting, are less than ideal strategies due to budget and personnel limitations, habitat constraints, the potential to repeatedly capture the same individuals, and the availability of a viable alternative. The repatriate population now is comprised primarily of individuals containing 134.2-kilohertz (kHz) passive integrated transponder (PIT) tags, so remote PIT scanning can be used to accurately estimate the population size and answer fundamental demographics questions that will improve ongoing conservation strategies (Kesner et al. 2008b).

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 adult razorback suckers.

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

4. Marking of 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 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 River Miles 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 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 second 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

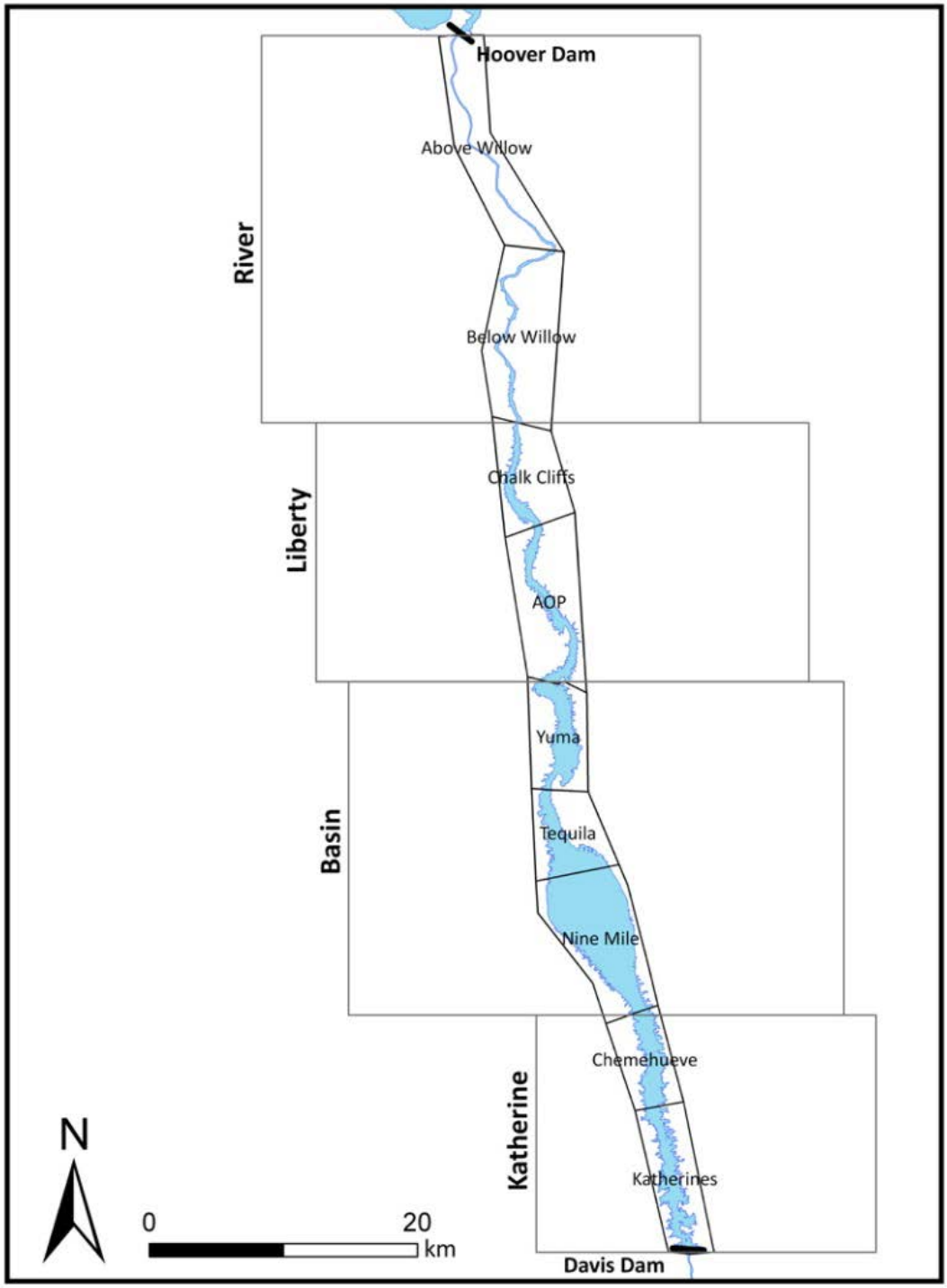

Figure 1.—Map of Lake Mohave, Arizona and Nevada, depicting two zoning schemes, general (large boxes) and specific (smaller boxes); only the former are used in this report.

specific location of focus within that zone (i.e., Liberty and Katherine) or describes the general characteristic of that zone (i.e., Basin and River). Remote PIT scanning was conducted in River, Liberty, and Basin. Katherine was excluded due to a lack of known razorback sucker aggregation sites in that zone.

Annual sampling periods 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 November or December and March multi-agency survey events. During both events, December 2015 and March 2016, Marsh & Associates, LLC (M&A) occupied a field camp on Lake Mohave at Carp Cove, Arizona (the Basin zone), near River Mile 298 (miles upstream of the Southerly International Boundary with Mexico) for 4 to 5 days at a time. At each sampling event, as many as six trammel nets (four to six 91.4 meters [m] long x 1.8 m wide with 3.8-centimeter [cm] stretch mesh, and up to two 45.7 m x 1.8 m with 3.8-cm stretch mesh) were fished continuously along the Arizona shoreline from Pot Cove upstream to Carp Cove.

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 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 analyses (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.

Remote Monitoring

Remote PIT scanning systems were deployed 1 week of every month during the 2016 sampling season on shallow gravel bars that extend into the Colorado River upstream of Willow Beach (the River zone; objective 5). Three models of PIT scanners were utilized. One type of unit (shore based) is comprised of an antenna and scanner housed in a 2.3 x 0.7 m polyvinylchloride (PVC) frame connected by 45.7 m of cable to a waterproof box that protected the logger and battery and was secured to shore. A 6-volt, 12 ampere-hour sealed lead acid battery and a solar

panel provided power to the scanner, eliminating the need for manually removing and charging the battery more than once per month. The unit started scanning at 18:00 hours, ran for 24 hours, and stopped scanning for 24 hours. This cycle was repeated 3 weeks per month. During the week of active PIT scanning in River, this unit was allowed to scan continuously (24 hours per day). Two models of sinking submersible units were employed (0.8 x 0.8 m and 1.2 x 0.8 m) and were comprised of a PVC frame antenna attached to a scanner and logger contained in watertight PVC piping. Power to submersible units was provided by a 20.8 ampere-hour lithium-ion battery pack contained in a watertight, 2-inch (5.08-cm) PVC pipe. Submersible units scanned continuously for up to 96 hours, but the batteries were generally changed every 24 hours. Five to eight submersible units were employed throughout the monitoring season.

Five locations established in 2013 as fixed sites were Gio's Point, Black Bar, Sauna Cave, Ringbolt Rapids, and Boy Scout Canyon (figure 2), and each received at least one submersible deployment per day each sampling trip. These fixed deployments were created 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. The sites were all 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 the year. One shore-based device was deployed throughout the 2016 sample season at Boy Scout Canyon. The deployment locations of additional scanners not set at fixed sites varied between trips depending on observed or reported fish concentrations. Scanner units monitored fish presence monthly from January through September for 4 nights and 3 days (approximately 90 continuous hours) each trip.

Information downloaded from the 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 Basin and Liberty (see figure 1) was conducted by Reclamation with support from M&A (objective 5). Semipermanent shore-based devices were deployed in Basin for continuous scanning from 2015 to 2016. One shore-based PIT scanner was deployed at Tequila Cove. The unit operated continuously from November 2015 to May 2016 and was powered by a deep-cycle marine battery and a 60-watt solar panel. Two shore-based devices were also deployed in Basin at both Half Way Wash and Yuma Cove and attached to a solar aeration system for power.

All sites with semipermanent shore-based devices represent known spawning aggregation sites and have been collection sites for March monitoring since

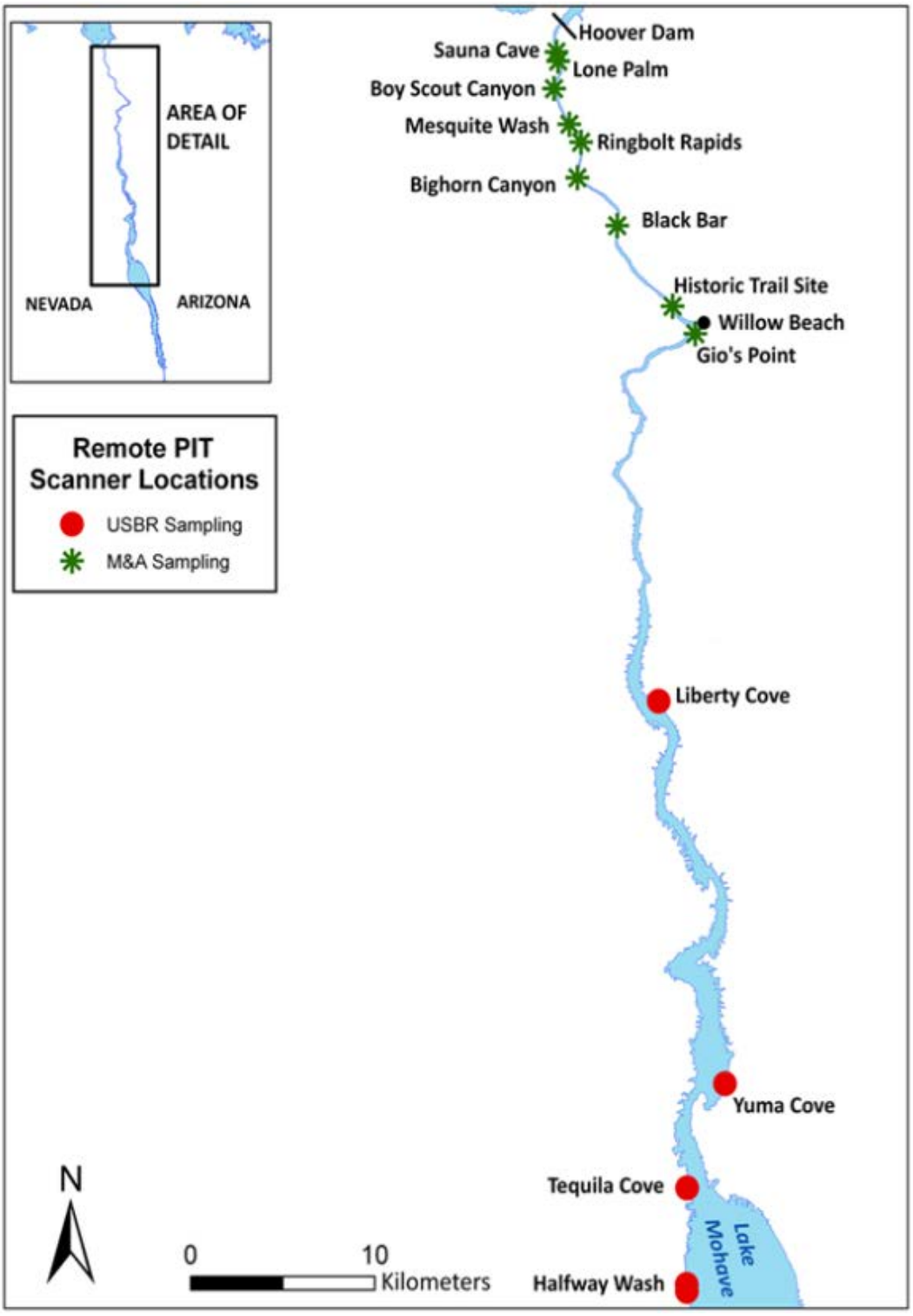

Figure 2.—Location of M&A and Reclamation remote PIT scanners in the River, Liberty, and Basin zones, Lake Mohave, Arizona and Nevada.

collections began. 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 is 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 repatriated razorback suckers that were released from October 1, 2008, through September 30, 2014, were summarized. The beginning of this interval marks the consistent use of 134.2-kHz PIT tags in Lake Mohave, and in order to ensure that an individual is a fully recruited member of the Lake Mohave population, only those fish that have been at large for 1 year prior to the beginning of the scanning year are included in the analysis. Release records were grouped into "cohorts" based on the location and date of release. Contact data within each cohort were tabulated for all fish contacted by remote PIT scanning for the 2016 sample year. The sample year followed the same fiscal calendar as routine monitoring (October 1, 2015, through September 30, 2016) since scanning in Basin started as early as November. The proportion of each cohort that was contacted in 2016 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 < 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[1] from all agencies participating in the roundup 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 population size for 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 2015. 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

[1] March data include the entire month of March although the March roundup occurs during a single week.

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:

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

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 recaptures (*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 the population estimates. Razorback suckers released on or after March 1 of the previous population year were removed from the population estimates based on March roundup captures. Repatriated fish lacking information on the date and location of release into Lake Mohave were also excluded from the population estimates. Actual values for *M, C, R,* and the population estimates calculated for this report may differ slightly from previous reported values due to updates, additions, and corrections to the database. CIs were derived using Poisson approximation tables and *R* as the entering variable (Seber 1973).

Movement and Survival

The multi-state mark-recapture model developed in Wisenall et al. (2016) was updated to include 2016 PIT scanning data to improve estimates of transition (movement) and survival of adult razorback suckers between the River and Basin zones of Lake Mohave. 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 2016. Individuals that were scanned in 2016 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 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 the computer program MARK (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 0s, 1s, and 2s: 0 – not observed, 1 – observed in River, and 2 – observed in Basin. There were five encounter occasions, one per year from 2012 to 2016; 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). Four time periods (2012 to 2013, 2013 to 2014, 2014 to 2015, and 2015 to 2016) resulted in the maximum number of parameters in the most general model at 20 (4 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 with time and state because PIT scanning efforts 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 MARK based on an Akaike's information criterion score (Akaike 1974). This value reported in 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 the variance inflation factor (ĉ; 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 > 0.9 (Johnson and Omland 2004); otherwise, estimates were based on model averaging.

In 2016, an analysis of goodness-of-fit (GOF) was completed for the most general model with computer program U-CARE (Utilities- CApture-REcapture). For multi-state data, a time- and state-dependent JollyMoVe model was used (Choquet et al. 2005). Primary assumptions of the JollyMoVe model are that past encounter history has no effect on future encounters, and there is no difference between an animal that has been captured and one that has not (Pradel et al. 2005). There are two main components of the JollyMoVe GOF tests that test for these assumptions (Pradel et al. 2005). The first component, TEST 3G, tests the effect of history on future encounters. Three subcomponents of this test are: TEST 3G.SR to test for transience, TEST WBWA ("Where Before Where After") to test for memory, and TEST 3G.Sm, a complementary composite of memory and transience (Pradel et al. 2005). The second component of the JollyMoVe GOF tests is TEST M, which compares animals that are encountered on an occasion with those that are not (Pradel et al. 2005). A subcomponent, TEST M.ITEC, tests for short-term trap dependence, and TEST M.LTEC is a complementary test. These GOF tests were run on the data as well as a final

overall GOF, which combined all the subcomponent tests. Overdispersion (ĉ) was calculated as the ratio of the Pearson statistic χ^2 by the number of degrees of freedom, which can be done for each component or calculated for the overall model. Generally, lack of fit is solely from overdispersion when the ĉ ratio is > 1 for all components and no ĉ ratio exceeds the others for any one component (Choquet et al. 2009). This is generally accepted if the overall ratio is < 3, sometimes 5 (Burnham and Anderson 2002).

RESULTS

Routine Monitoring

Ten razorback suckers were handled during 2015 and 2016 monitoring events, with March 2016 monitoring activities accounting for 100% of the captures (table 1). The sex was determined for fish at capture, and the majority captured were female (n = 7). All 10 fish captured were PIT tagged, and 9 were repatriates; 1 fish was captured with no original stocking or capture data in the database and was omitted from further analyses.

Table 1.—Adult razorback sucker monitoring summary by capture month, PIT tag, history, and sex during the March 2016 monitoring event, Lake Mohave, Arizona and Nevada

		PIT tag?		History		Sex		
Capture month (year)	Total	Yes	No	Repatriate	Wild	Female	Male	Juvenile
March (2016)	10	10	0	10[a]	0	7	3	0

[a] One fish with no original stocking or capture data in the database, marked as a "repatriate" in the database, is included in this table but not in the remaining tables.

Of the nine PIT-tagged repatriates with paired data (i.e., fish with both stocking and capture data), one fish was < 350 mm TL at stocking, four fish were 350 to 450 mm TL at stocking, and four fish were > 450 mm TL at stocking (table 2). Mean TL at stocking was 428 mm, and mean TL at capture was 611 mm, with all nine fish > 500 mm TL at capture. Both sexes appeared to exhibit similar growth over their time at large, ranging from 2 to 4 mm/month, except for one male that grew 13 mm/month. The mean growth rate was approximately 4 mm/month. Years at large for all fish ranged from 1 to 13 years, with a mean time of 6 years. Six fish were captured during 2015/2016 monitoring for the first time since their stocking into Lake Mohave, with one fish at large for 9 years prior to its first capture. Four fish with year-class information were approximately 1 to 4 years old at stocking, with an approximate mean of 3 years old at stocking.

Lakeside backwaters and offsite facilities contributed seven and two fish to the PIT-tagged repatriates with paired data, respectively (table 3). Fish were reared at two different backwaters, Arizona Juvenile and Yuma, and all were stocked into

Table 2.—Adult razorback sucker monitoring summary for nine paired stocking-capture data per fish PIT tag number with calculated growth rate (capture TL in mm minus stocking TL in mm then divided by months at large) and 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.)

	Date		TL (mm)			Capture history					
PIT tag	Release	Capture	Release	Capture	Growth rate/month	Sex	Days at large	Months at large	Years at large	Number of captures	Comments
1C2D8C1D62[a]	5/16/12	3/14/16	489	619	3	F	1,398	47	4	2	First capture in 2016
003BCC66EA[b]	1/21/15	3/15/16	355	530	13	M	419	14	1	2	First capture in 2016
36F2B263D6[c]	10/22/12	3/15/16	520	635	3	F	1,240	41	3	2	First capture in 2016
257C60B28B[d]	6/13/07	3/16/16	460	665	2	F	3,199	107	9	2	First capture in 2016
1C2C856E15[c]	5/19/10	3/16/16	470	610	2	M	2,128	71	6	2	First capture in 2016
1B796B5742[e]	12/8/11	3/18/16	410	617	4	F	1,562	52	4	2	First capture in 2016
257C60EEF3[d]	10/2/02	3/14/16	265	554	2	M	4,912	164	13	3	First capture in 2007, second in 2016
1B7969D55B[c]	10/13/11	3/17/16	450	660	4	F	1,617	54	4	3	First capture in 2015, second in 2016
1C2D6D1839[a]	5/16/12	3/16/16	429	606	4	F	1,400	47	4	3	First capture in 2012, second in 2013, third in 2016
Average			428	611	4	–	1,986	66	5	2	–

[a] 2008 year-class; reared at Arizona Juvenile.
[b] 2013 year-class; reared at the Willow Beach NFH.
[c] No year-class; reared at Yuma Cove.
[d] No year-class; reared at Arizona Juvenile.
[e] 2010 year-class; reared at the Achii Hanyo Fish Hatchery.

Table 3.—Adult razorback sucker monitoring summary, March 2016

(Data are for nine fish with paired release-capture data by rearing type and location and release and capture locations. The release 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 RKM)	Fish (n)
Type	**Location**	**Location**	**State[1]**	**RKM**	**Zone**	**Location**	**State[1]**	**RKM**	**Zone**		
Lakeside backwaters	Arizona Juvenile	Lakeside at Arizona Juvenile	AZ	25	Basin	Carp Cove (inside)	AZ	33	Basin	8	1
						Carp Cove (north point)		34		9	1
						Cottonwood Cove East (100 m inside, north shore)		32		7	1
						Cottonwood Cove East (1st point south of north point)					1
	Yuma	Lake Mohave at Yuma Cove		39		Cottonwood Cove East (100 m inside, north shore)					2
						Cottonwood Cove East (2nd point south of north point)					1
Average distance traveled										**7**	**7**
Offsite facilities	Achii Hanyo Fish Hatchery	Willow Beach boat ramp	AZ	85	River	Cottonwood Cove East (north point)	AZ	32	Basin	53	1
	Willow Beach NFH	Liberty Cove		62	Liberty	Cottonwood Cove East (100 m inside, north shore)				30	1
Average distance traveled										**41**	**2**

[1] AZ = Arizona.

the main channel adjacent to these locations. Offsite rearing facilities included the Achii Hanyo Fish Hatchery and Willow Beach NFH. Fish reared in lakeside backwaters traveled an average of 7 river kilometers (RKM) from stocking to the capture site, while fish reared in offsite facilities traveled an average of 41 RKM.

Based on monitoring data from March roundup sampling in 2015 and 2016, it is estimated that there is effectively no wild razorback sucker population remaining in Lake Mohave. The estimated repatriate razorback sucker population is 1,707 (95% CI from 603 to 3,897).

Remote Monitoring

PIT scanners were deployed in Lake Mohave for 37,859 hours of scanning time: 10,363 hours using shore-based devices and 27,496 hours with submersible units. The 2016 scanning year resulted in 230,666 total contacts, 3,244 of which were unique PIT tags, with 3,128 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, 3,110 were repatriates, 10 were wild, and 8 were of unknown origin.

Remote PIT scanning in River resulted in 7,370 hours of scanning; 946 hours with shore-based devices and 6,424 hours with submersible units. Mean deployment times were 86 hours and 22 hours for shore-based devices and submersible scanners, respectively. Among 10,862 total contacts, 1,544 were unique PIT tags, and 1,524 of those were in the Lower Colorado River Native Fish Database. Repatriated razorback suckers accounted for 1,515 tags with a marking record, 7 were noted as wild individuals, and 2 had unknown histories.

Contacts at fixed station sites in River were compared during the sampling season. Of a possible 240 fixed site replicates (12 trips x 5 sites x 4 replicates[2]), 211 replicates were available for analyses. The January trip had only 3 nights of scanning, which accounts for five missing from the total number of replicates available. In October, November, and December 2015, low water levels resulted in fewer overnight scanning deployments at Boy Scout Canyon and Sauna Cave, accounting for 24 replicates missing from the total. All other trip and location combinations had four replicates. The most contacts were recorded at Black Bar from December through March, becoming fewer in subsequent months (figure 3). Boy Scout Canyon had the most contacts in three of the remaining six sample periods.

Remote submersible PIT scanners in Liberty were deployed for 915 hours of scanning. The mean deployment time for submersible scanners was 76.2 hours. Eight PIT tag contacts were recorded, representing seven unique razorback suckers. Six of these individuals were repatriates, and one was of unknown origin.

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

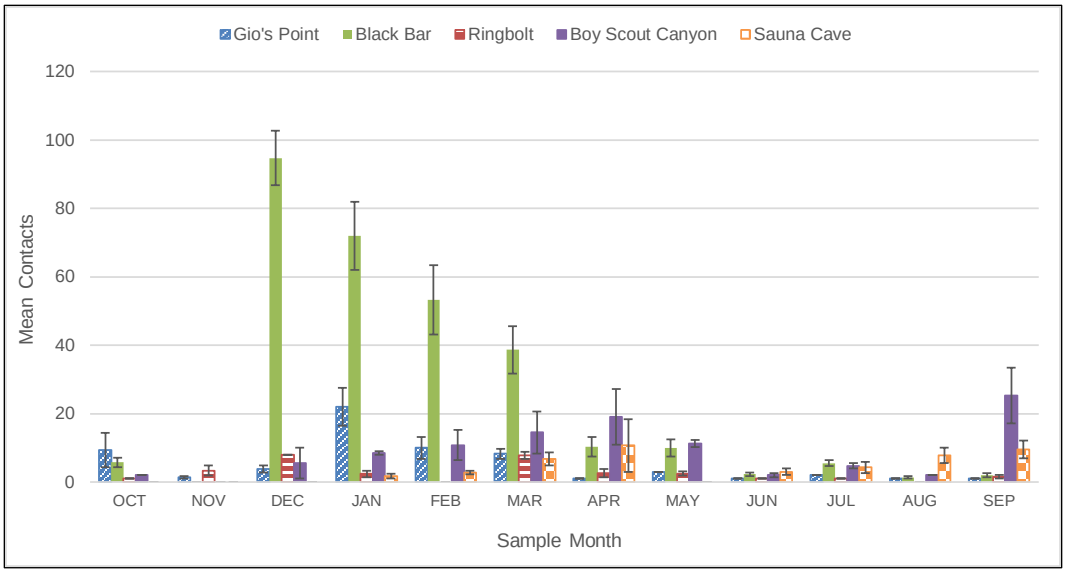

Figure 3.—Unique razorback sucker PIT tag contacts recorded from October 1, 2015, to September 30, 2016, at five fixed stations in the River zone, Lake Mohave, Arizona and Nevada.
Error bars represent ±1 standard error; n = 4 except for all sites in January and Boy Scout Canyon and Sauna Cave October through December.

Both shore-based devices and submersible units were deployed in Basin and accumulated 29,574 total hours of scanning: 9,417 hours with shore-based devices and 20,157 hours with submersible units. Mean deployment times for shore-based devices and submersible units were 214 hours and 106.7 hours, respectively. A total of 219,796 contacts was recorded, representing 1,859 unique PIT tags for which 1,781 had a marking record in the Lower Colorado River Native Fish Database, and 1,760 of which were razorback suckers (21 bonytail [*Gila elegans*]). 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 1,750 of the unique encounters, 3 were wild, and 7 were of unknown origin.

Post-stocking dispersal out of the zone of release was minimal for two of the three main stocking zones, excluding individuals that were stocked into Liberty (figure 4). Of the 3,128 razorback suckers contacted in 2016 with a marking record, only 2,533 razorback suckers met the criteria for further analyses (repatriate released between October 1, 2008, and September 30, 2014, with a 134.2-kHz tag). An additional 142 fish (5.6%) were contacted in multiple zones and removed from further comparisons. Of the remaining fish, 1,158 (45.7%) were released into River. The majority (> 80%) of these fish were contacted in River for all release years except 2013 (figure 5). There were no fish contacted in 2016 from the 2014 release year and only 10 contacted that were released in 2013. The same trend was also noted in Basin, where more than 80% of individuals were contacted in their

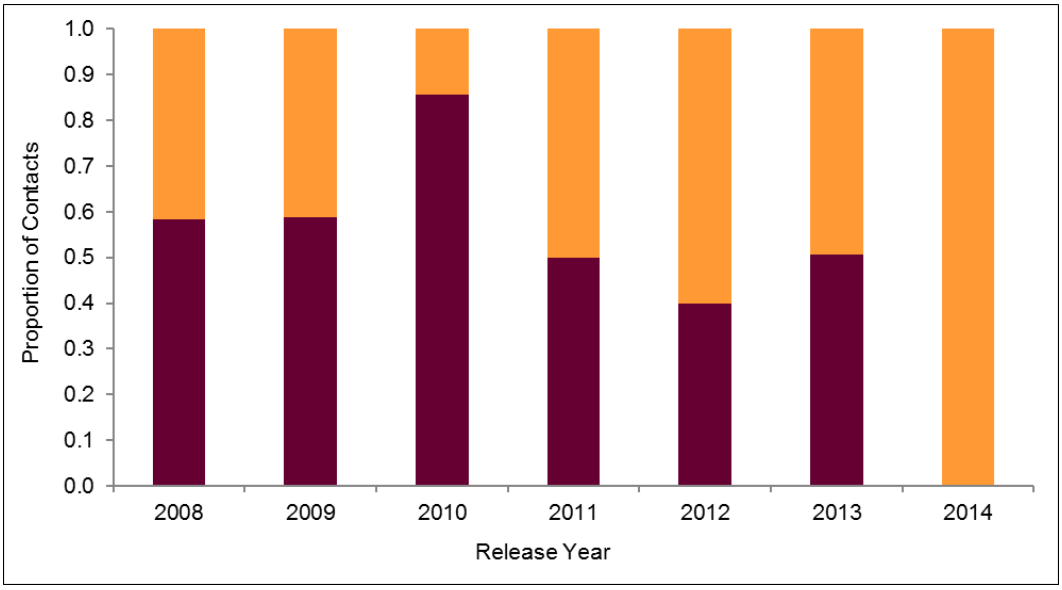

Figure 4.—Proportion of razorback sucker PIT tag contacts in 2016 among scanning zones in Lake Mohave – River (orange) and Basin (maroon) for fish released in Liberty; there were no contacts in Liberty.
Fish were released between October 1, 2008, and October 1, 2014, and contacted during PIT scanning activities from October 1, 2015, to September 30, 2016.

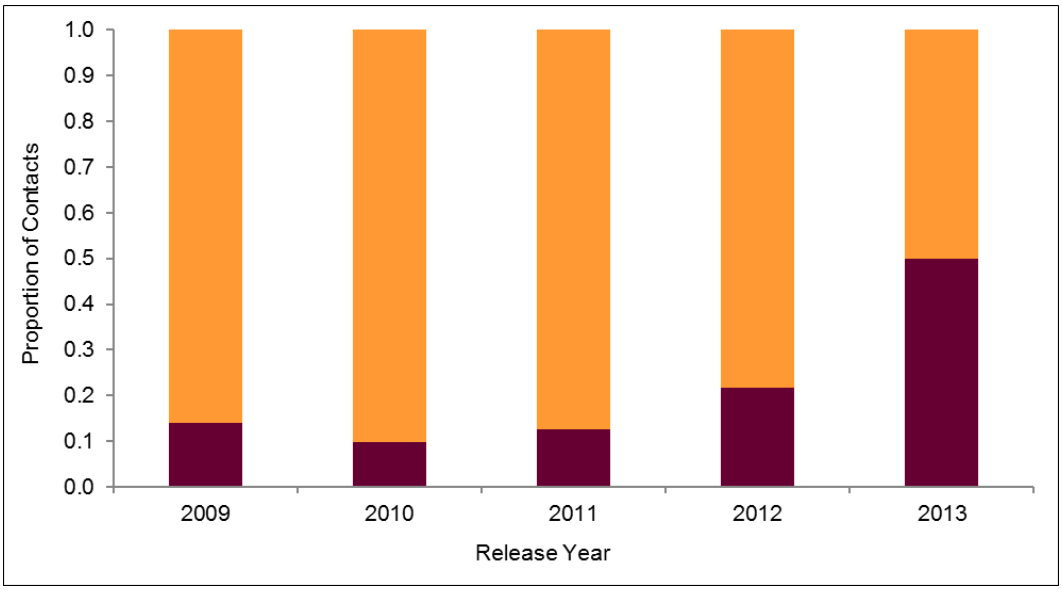

Figure 5.—Proportion of razorback sucker PIT tag contacts in 2016 among scanning zones in Lake Mohave – River (orange) and Basin (maroon) for fish released in River; there were no contacts in Liberty.
Fish were released between October 1, 2008, and October 1, 2014, and contacted during PIT scanning activities from October 1, 2015, to September 30, 2016.

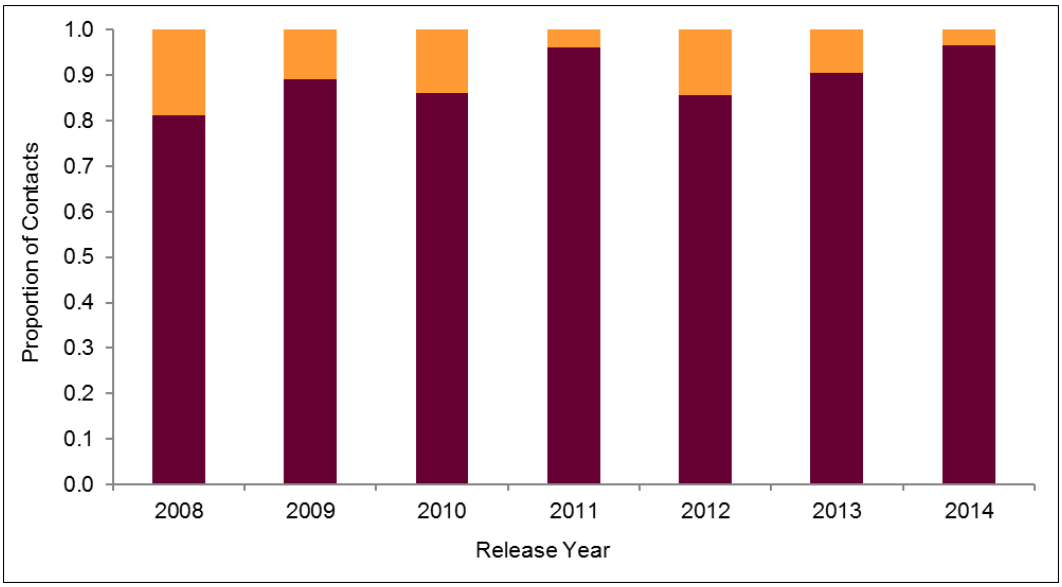

Figure 6.—Proportion of razorback sucker PIT tag contacts in 2016 among scanning zones in Lake Mohave – River (orange) and Basin (maroon) for fish released in Basin; there were no contacts in Liberty.
Fish were released between October 1, 2008, and October 1, 2014, and contacted during PIT scanning activities from October 1, 2015, to September 30, 2016.

zone of release regardless of release year (figure 6). Basin-released fish accounted for 41.2% (984) of the razorback suckers contacted. PIT scanning was not conducted in Katherine in 2016; however, 44 fish released there were contacted in Basin, and 6 were contacted in River.

Adult subpopulations in River, Liberty, and Basin exchanged few individuals from 2015 to 2016 (table 4). Among 1,835 razorback suckers contacted in both years, 1,668 (90.9%) were contacted in only one zone. Individuals contacted in a different zone each year, but only one zone per year, exhibited almost the same amount of movement from River to Basin (38 fish; 2.3%) as from Basin to River (33 fish; 2%). Remaining fish were contacted in multiple zones in a year; 63 fish were contacted in multiple zones in 2015, 88 in multiple zones in 2016, and 16 fish were contacted in multiple zones both years.

In River, five cohorts released at the Willow Beach boat ramp (October 13 and 23, 2009; January 7, 2010; October 4, 2011; and December 8, 2011) made up 93% of the fish contacted in 2016 (table 5). These five cohorts made up the majority of fish contacted but only account for 35% of fish released in River. Of 11,537 River-released fish in 2012, 2013, and 2014 (mean TL 342 mm), only 35 were contacted in 2016 (< 1%).

Although little PIT scanning was conducted in Liberty, cohorts released there 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

Table 4.—Razorback suckers contacted by remote PIT scanning in 2016 that were also contacted in 2015 broken down by zone of contact in Lake Mohave, Arizona and Nevada
(Fish contacted in more than one zone in the same year were excluded from analysis.)

2015	2016		
	River	Liberty	Basin
River	851	0	38
Liberty	0	0	0
Basin	33	0	746

from 374 to 382 mm), were contacted in 2016 (1.6–3.4%), a proportion similar to that of Willow Beach released cohorts in March and April 2012 (mean TL of 375 and 373 mm). The cohort with the highest contact rate was 444 razorback suckers released in March 2011, with a mean TL of 414 mm at release.

For fish released in Basin, there were four cohorts that made up most of the fish scanned in 2016 (59%) but less than one-half of those released (31%) (table 5). The mean sizes of fish in these four cohorts were > 450 mm TL at release, and three of these were released at Cottonwood Cove in 2009 (two were reared at the Bubbling Ponds Fish Hatchery and the other at the Achii Hanyo Fish Hatchery) and contained 125, 209, and 413 individuals, respectively. The cohort with the highest contact rate in all three sample years was a group of 101 individuals reared at the Yuma Cove backwater and released at Yuma Cove with a mean TL at release of 478 mm (table 5). Five other cohorts with the largest number of fish released (71%) were contacted the least (table 5), and all five of these had a mean TL at release < 350 mm. Excluded from the cohort analysis were 143 release cohorts that were released with < 100 fish per cohort, 129 of which were released into Basin from lakeside backwaters. Over 17% (585 of 3,357 releases) of individuals released in these cohorts were contacted by scanning in 2016. The mean TL for these smaller cohorts (in number of released fish) was 445 mm. For comparison, 455 razorback suckers were contacted in 2016 from cohorts that met the criteria for table 5 (100 or more fish released) out of 16,204 releases (2.8%).

Population Estimates

Based on monitoring data from 2015 and 2016, there was no effective wild razorback sucker population remaining in Lake Mohave. The repatriated razorback sucker population was estimated at 1,707 (95% CI from 603 to 3,897), representing < 1% of the total number of repatriates released in Reach 2 as of March 1, 2015.

Table 5.—Razorback sucker repatriation cohorts (fish released at a given location on the same date) from October 1, 2008, to September 30, 2014, and their remote PIT scanning contact rates in 2016, Lake Mohave, Arizona and Nevada

Release zone	Release location	Release date	Releases	mean TL (mm)	2016	
					Contacted	Percent contacted
River	Willow Beach boat ramp	10/4/2011	500	441	106	21.2
	Willow Beach boat ramp	10/23/2009	2,234	421	391	17.5
	Willow Beach boat ramp	1/7/2010	2,077	423	275	13.2
	Willow Beach boat ramp	12/8/2011	1594	394	207	13.0
	Willow Beach boat ramp	10/13/2009	2,588	416	155	6.0
	Willow Beach boat ramp	12/7/2010	504	398	28	5.6
	Willow Beach boat ramp	4/4/2012	118	373	3	2.5
	Willow Beach boat ramp	3/8/2012	549	375	12	2.2
	Willow Beach boat ramp	12/12/2011	408	351	7	1.7
	North Hatchery Cove	4/19/2013	217	336	3	1.4
	Painted 8 Cove	12/18/2009	1,436	347	12	0.8
	Willow Beach boat ramp	12/7/2012	1,510	368	9	0.6
	Ringbolt Rapids	2/13/2013	1,725	330	5	0.3
	Ringbolt Cove	1/6/2010	1,493	334	4	0.3
	Ringbolt Rapids	12/16/2010	1,509	324	4	0.3
	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
	Willow Beach boat ramp	1/29/2014	1,441	333	0	0.0
	Ringbolt Rapids	1/30/2013	597	327	0	0.0
	Ringbolt Rapids	1/30/2014	1,541	331	0	0.0
Liberty	Liberty Cove	3/16/2011	444	414	25	5.6
	Liberty Cove	2/28/2013	1,271	356	48	3.8
	Wrong Cove	12/17/2009	917	374	31	3.4
	Liberty Cove	1/29/2013	1,186	326	29	2.4
	Red Tail Cove	12/17/2009	897	382	19	2.1
	Liberty Cove	12/17/2009	1,521	379	24	1.6
	Six Mile Coves	1/5/2010	1,584	329	8	0.5
	Liberty Cove	1/5/2011	1,896	339	8	0.4
	Liberty Cove	1/5/2012	1,920	330	5	0.3
	Liberty Cove	1/14/2014	1,825	326	2	0.1
Basin	Yuma Cove	5/19/2010	101	478	41	40.6
	Cottonwood Cove	3/26/2009	125	463	39	31.2
	Cottonwood Cove	3/20/2009	209	508	64	30.6
	Cottonwood Cove	12/3/2009	413	448	125	30.3
	Cottonwood Cove	12/6/2012	1,019	389	54	5.3
	Lake Mohave at North Chemehuevi Cove backwater	10/14/2008	176	451	7	4.0
	Lake Mohave at North Nine Mile Coves backwater	1/6/2010	980	374	34	3.5
	Carp Cove	12/5/2012	400	391	13	3.3
	Lake Mohave at Dandy Cove backwater	10/8/2008	158	438	5	3.2
	Cottonwood Cove	12/12/2013	415	402	7	1.7
	Cottonwood Cove East	1/28/2014	1,412	338	13	0.9
	Cottonwood Cove East	1/24/2013	3,206	336	27	0.8
	Yuma Cove	12/18/2009	1,611	329	7	0.4
	Owl Point Cove	1/26/2012	1,022	324	4	0.4
	Lake Mohave at North Nine Mile Coves backwater	1/27/2014	2,372	331	9	0.4
	Nine Mile Coves (north of)	1/6/2011	1,892	341	5	0.3
	Yuma Cove	1/18/2012	693	328	1	0.1
Katherine	Princess Cove ramp	12/5/2012	1,073	380	11	1.0
	Princess Cove ramp	1/14/2014	2,725	335	9	0.3
	Princess Cove ramp	1/23/2013	4,330	336	11	0.3
	Princess Cove ramp	1/18/2012	1,689	335	4	0.2

Based on 2015 and 2016 remote PIT scanning, the 134.2-kHz PIT tagged Lake Mohave repatriate population for 2015 was estimated at 3,656 individuals (95% CI from 3,418 to 3,912). Population estimates using zone-specific scanning for 2015 estimated the Basin zone population at 1,947 (95% CI from 1,761 to 2,151) and the River zone population at 2,158 (95% CI from 1,960 to 2,377); no estimate was calculated for the Liberty zone. All 10 wild razorback suckers contacted in 2016 were also contacted in 2015. Too few wild razorback suckers were contacted to estimate the Basin and River subpopulations separately (three and seven contacts, respectively). The lake-wide estimate of the wild population based on PIT scanning in 2015 and 2016 was 12 fish (M = 11, C = 10, R = 10; 95% CI from 7 to 23).

Movement and Survival

The results from the multi-site model within MARK were similar to the previous year. For the "movement" and survival model, ĉ was significantly different than 1, estimated at 2.473 (95% CI from 1.946 to 2.982) based on median ĉ estimation within MARK. This value was used to adjust AIC_c values ($QAIC_c$). Parameter estimates were based on model averaging since no model had more than a 0.9 model weight (table 6). The top six models all had $QAIC_c$ weights > 0.05. Based on the structure of these five models, there was little support for survival and transition to vary with time. Estimates of yearly transition were slightly different among zones but similar across years (2012–15); 5.1 to 5.4% (95% CI from 3.5 to 8.2%, 3.6 to 7.4%, and 3.5 to 7.3% in each year, respectively) of fish transitioned from Basin to River. An estimated 4.1 to 4.2% (95% CI from 2.7 to 6.2%, 2.9 to 5.9%, and 3.0 to 5.8%) of fish transitioned from River to Basin each year (table 7). The most recent transition parameter for both zones, the 2015 to 2016 sample period, was confounded and removed from the table.

Estimates of survival were lower in River than in Basin for any given year (table 8). Survival for all sample periods was 88 to 89% in River compared to 93 to 94% for those same periods in Basin. The most recent survival parameter for both zones, the 2015 to 2016 sample period, was confounded with the recapture rate and removed from the table. Recapture estimates in River varied between 63 and 74% of the marked population in a given year (table 9). Estimates were higher but just as varied for recapture in Basin (78–93%). The last parameter in the recapture estimates was confounded with survival and was unreliable (removed from table).

Estimated ĉ for the same general multi-state model in 2015 was significantly > 1, 2.869 (95% CI from 1.905 to 3.832), indicating a lack of fit for the general multi-state model (Wisenall et al. 2016). In 2016, program U-CARE was used to assess GOF of the most general model. The first test, TEST 3G.SR, a test for transience,

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

(φ = apparent survival, P = recapture, and Ψ = transition. P [recapture] parameters were time varying and different among 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)	4922.3	0.0	0.497	1.000	12
φ(state) P(state*t) Ψ(.)	4923.6	1.3	0.255	0.513	11
φ(state) P(state*t) Ψ(state+t)	4926.4	4.1	0.064	0.130	15
φ(state+t) P(state*t) Ψ(state)	4927.3	5.0	0.041	0.083	15
φ(state+t) P(state*t) Ψ(.)	4928.0	5.7	0.029	0.058	14
φ(state) P(state*t) Ψ(t)	4928.1	5.8	0.027	0.055	14
φ(state*t) P(state*t) Ψ(state)	4929.0	6.7	0.018	0.035	16
φ(state+t) P(state*t) Ψ(state*t)	4929.0	6.7	0.017	0.035	18
φ(state*t) P(state*t) Ψ(.)	4929.4	7.1	0.014	0.028	15
φ(state) P(state*t) Ψ(state*t)	4930.1	7.8	0.010	0.020	18
φ(state*t) P(state*t) Ψ(state+t)	4931.1	8.8	0.006	0.013	18
φ(state+t) P(state*t) Ψ(state+t)	4931.4	9.1	0.005	0.011	18
φ(state*t) P(state*t) Ψ(t)	4931.4	9.1	0.005	0.011	17
φ(state+t) P(state*t) Ψ(t)	4932.2	9.9	0.003	0.007	17
φ(state*t) P(state*t) Ψ(state*t)	4932.8	10.5	0.003	0.005	20
φ(.) P(state*t) Ψ(state)	4932.8	10.5	0.003	0.005	11
φ(.) P(state*t) Ψ(.)	4935.3	13.0	0.001	0.002	10
φ(t) P(state*t) Ψ(state)	4935.3	13.0	0.001	0.002	13
φ(.) P(state*t) Ψ(state+t)	4936.8	14.5	0.000	0.001	14
φ(t) P(state*t) Ψ(state+t)	4937.3	15.0	0.000	0.001	15
φ(t) P(state*t) Ψ(.)	4937.9	15.6	0.000	0.000	12
φ(t) P(state*t) Ψ(state*t)	4939.0	16.7	0.000	0.000	17
φ(.) P(state*t) Ψ(t)	4940.0	17.7	0.000	0.000	13
φ(.) P(state*t) Ψ(state*t)	4940.4	18.1	0.000	0.000	17
φ(t) P(state*t) Ψ(t)	4940.5	18.2	0.000	0.000	14

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

(Models exclude fish scanned only in 2016 and individuals released in Liberty due to limited scanning there.)

Zone	Period	Estimate	Lower CI	Upper CI
River	2012–13	0.041	0.027	0.062
	2013–14	0.041	0.029	0.059
	2014–15	0.042	0.030	0.058
Basin	2012–13	0.054	0.035	0.082
	2013–14	0.052	0.036	0.074
	2014–15	0.051	0.035	0.073

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

(Models exclude fish scanned only in 2016 and individuals released in Liberty due to limited scanning there.)

Zone	Period	Estimate	Lower CI	Upper CI
River	2012–13	0.883	0.847	0.911
	2013–14	0.890	0.853	0.918
	2014–15	0.883	0.847	0.912
Basin	2012–13	0.939	0.911	0.958
	2013–14	0.943	0.916	0.961
	2014–15	0.938	0.912	0.957

Table 9.—MARK model recapture estimates (model averaged) for razorback suckers released in River or Basin, at large > 730 days, and scanned in River or Basin after 2011

(Models exclude fish scanned only in 2016 and individuals released in Liberty due to limited scanning there.)

Zone	Period	Estimate	Lower CI	Upper CI
River	2012–13	0.733	0.664	0.792
	2013–14	0.630	0.574	0.683
	2014–15	0.742	0.689	0.789
Basin	2012–13	0.933	0.873	0.966
	2013–14	0.783	0.730	0.828
	2014–15	0.822	0.775	0.860

yielded significant results (table 10) and led to the rejection of the null hypothesis, "there is no difference in the probability of being later re-encountered between "new" and "old" individuals encountered simultaneously" (Choquet et al. 2009). Except for Basin in 2013, p values were significant for all occasions and states (zones). TEST WBWA, which tests for memory, also yielded significant results (table 11), causing for rejection of the null hypothesis, "there is no difference in the expected state of next re-encounter among individuals previously encountered in the different states," except for River in 2013 (Choquet et al. 2009). The ĉ ratios calculated to determine overdispersion for the transience model were all > 1, and overall ĉ was > 5 for both tests (7.522 and 17 for 3G.SR and WBWA, respectively), indicating that an important component has likely been left out of the model (Choquet et al. 2009).

Table 10.—U-CARE GOF TEST 3G.SR (test of transience) of a generalized JollyMoVe model for River and Basin
(Index of test is χ2(1) distribution.)

Zone	Occasion	χ^2 statistic	p value	GOF
River	2013	5.051	0.025	1
	2014	6.02	0.014	1
	2015	9.771	0.002	1
Basin	2013	1.611	0.204	1
	2014	11.606	0.001	1
	2015	11.072	0.001	1

Table 11.—U-CARE GOF TEST WBWA (test of memory) of a generalized JollyMoVe model for River and Basin
(Index of test is Fisher exact test.)

Zone	Occasion	χ^2 statistic	p value	GOF
River	2013	3.231	0.072	1
	2014	21.223	0.000	1
	2015	13.018	0.000	1
Basin	2013	14.411	0.000	1
	2014	21.402	0.000	1
	2015	28.73	0.000	1

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. Most of the known population of 134.2-kHz tagged fish is being contacted over each sample year. Mark-recapture estimates of survival and transition based on these data are improving our understanding of the population dynamics within Lake Mohave. Annual adult apparent survival is 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 between the two subpopulations (Basin and River). Although estimates of monthly transition rates indicated a net migration upstream from the Basin to River subpopulations (Wisenall et al. 2015), the difference in the rate of exchange on an annual basis was very small and not statistically significant, as indicated by overlapping CIs. The estimate of the variance inflation factor ($\hat{c}$) was significantly > 1, indicating overdispersion in comparison to the multi-nomial expectation (Lebreton et al. 1992). Although it is generally accepted that values of $\hat{c} < 3$ are acceptable (Lebreton et al. 1992; Cooch & White 2016), the source of the deviance from expected is of critical importance. Values of $\hat{c} > 1$ can indicate a structural problem with the model or additional residual variation that is unaccounted for in the multi-nomial model.

Additional GOF diagnostics were performed to determine fit of the model and the source of overdispersion. There was significant lack of fit to the general JollyMoVe model for both the memory and transience GOF tests. Based on these tests, it appears that, from year to year, the same fish are more likely to be contacted, something akin to trap dependence (Lebreton et al. 1992; Cormack 1989). PIT scanning does not involve capturing or luring of fish, and therefore, it is unlikely that the cause of this overdispersion is due to "trap-happy" or "trap-shy" behavior. One potential source for the lack of fit is that razorback suckers exhibit site fidelity to spawning sites. Although some fish are detected at multiple sites, they are often contacted at the same site year to year. If there are primary spawning sites for razorback suckers that are not part of routine PIT scanning, then only the rare odd contact would be made with these fish. Extensive deployments beyond the typical "hotspots" within Basin and River may reduce the lack of fit due to incomplete geographic coverage. Survival would be underestimated if a major transient effect was occurring but not properly modeled (Choquet et al. 2005). It is unlikely that the high estimate of adult survival from PIT scanning (about 90% annually) compared to the previous capture-based estimate (about 75%) is higher due to the lack of fit. In fact, adult survival in Lake Mohave may be higher still.

Population estimates for each subpopulation based on mark-recapture data derived from remote PIT scanning and March monitoring data were relatively stable during the study year. The lake-wide 2015 population estimate based on

remote PIT scanning data was the highest since scanning was initiated, which is a trend that has been observed over the past several years. The estimate for Basin based on PIT scanning, 1,947 (95% CI from 1,761 to 2,151) is higher but similar to the lake-wide estimate based on March monitoring data 1,707 (95% CI from 603 to 3,897). As was the case for adult survival, this is consistent with the limited geographic scope of March netting activities, which are generally restricted to Basin. Given the lack of netting activities upstream of Willow Beach during the March roundup and the lack of exchange indicated by PIT scanning, the March roundup estimate should be considered an estimate of the subpopulation in Basin and not a lake-wide estimate (Wisenall et al. 2016). March monitoring estimates include fish with 400-kHz PIT tags,[3] or no tags at all prior to first capture, and are therefore expected to trend higher than PIT scanning estimates in the same subpopulation.

In 2015, Reclamation and the Willow Beach NFH initiated a plan to rear larger razorback suckers while minimizing the potential for loss in genetic integrity, which also meant lower stocking numbers and a reduction in the production of other species. In the plan, approximately 9,000 razorback suckers, most with a TL > 400 mm, will be stocked per year after being held on station for 5 years. The first cohort of this new size class of razorback suckers will be released in 2018, and fish are expected to have a mean TL of 450 mm. The new yearly larval harvest goal based on the stocking plan is 18,000. To accurately represent the razorback sucker subpopulation residing upstream of Willow Beach, one-half of the larvae collected (9,000 individuals) should come from this zone. In 2016, the USFWS, Reclamation, and M&A collected 1,633 larvae above Willow Beach. The goal to collect an equal share of larvae from River and Basin remains unmet but is potentially possible with increased effort.

After a 3-year absence from the Willow Beach NFH, rainbow trout (*Oncorhynchus mykiss*) are now being reared for stocking in both Lake Mohave and below Davis Dam. While there may be no direct impact on razorback suckers on station at Willow Beach NFH from overcrowding, 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.

Although razorback sucker abundance has been relatively stable, a release cohort analysis based on PIT scanning in River continues to present compelling data that new cohorts are not replacing declining older ones (Wisenall et al. 2016). In River, individual release cohorts from 2009 to 2011 continue to dominate PIT scanning data in 2016. More recent releases from 2012 to 2014 were not scanned

[3] In March collections over the last 3years, 9.5% (99 out of 1,046) were fish with a 400-kHz PIT tag (unpublished data).

in similar numbers, indicating that these cohorts experienced lower survival. Only 35 of more than 11,500 individuals released in River from 2012 to 2014 were scanned in 2016 (see table 5). The size at release of these fish (mean TL of 342 mm) was well below the Lake Mohave Native Fish Work Group target size of 500 mm, and post-stocking survival was likely very low. 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). Additional years of poor post-release survival could put this subpopulation at greater risk. The current strategy to release fewer but larger razorback suckers from the Willow Beach NFH should result in additional recruitment to the subpopulation in River within a few years.

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 > 400 mm TL at release. This alone may account for their relatively high contribution to capture in M&A roundup data (seven of nine fish captured with release data) as well as PIT scanning contacts. The cohort analysis has relied on cohorts with > 100 fish stocked to increase the probability that differences in contact rates are reflective of survival discrepancies rather than chance. However, this excludes nearly all lakeside backwater releases because most backwaters are stocked with 100 or fewer fish. 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.

As of this writing, 236,200 razorback suckers have been repatriated to Lake Mohave (Lower Colorado River Native Fish Database), and that effort has maintained a population of a few thousand fish. This repatriation program is a primary facet of a broader conservation strategy, and it plays a critical role in maintaining Lake Mohave as the only genetic reservoir for the species throughout its range (Dowling et al. 1996a, 1996b, 2005) and, thus, requires continuation. While the stocking program has changed little over the past decade, additional data-based adjustments are being implemented to increase stocking size and maintain genetic diversity. 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, it must be maintained until a successful backwater conservation strategy (Minckley et al. 2003; USFWS 2005) or an alternative can be realized, and long thereafter.

CONCLUSIONS

Biannual netting operations during autumn and spring monitoring have proven effective in collecting growth, health, census, and genetic data from wild and repatriate razorback suckers in Lake Mohave. There currently is no other mechanism to acquire these critical data, and it is suggested that these activities continue.

Post-stocking survival of razorback suckers in Lake Mohave has been largely correlated to size at release. It is therefore suggested that razorback suckers stocked into Lake Mohave be at the largest individual size possible 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 program. Directing stockings both spatially and temporally will also provide opportunities to assess razorback sucker metapopulation dynamics and the effect of stocking location on these dynamics. In recent years, it was recommended to distribute fish equally among the three monitoring zones (River, Liberty, and Basin). Currently, there appears to be little utility in stocking fish at Liberty since fish do not seem to remain there long term. Razorback sucker apparent survival estimates based on multi-state mark-recapture models continue to be higher in Basin than in River, making stocking in Basin appear a better option. However, the difference is small enough to continue favoring stocking both sites and thereby providing redundancy as a bulwark against catastrophic loss for either subpopulation. In order to adequately compare individual stocking cohorts repatriated to each zone (Basin and River), it is suggested that cohorts be as close as possible to the same mean size and total number, and releases should be within a few days to at most a few weeks of each other. 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 analyses.

Remote PIT scanning continues to be the most effective means of monitoring razorback sucker subpopulations in Lake Mohave. It is suggested that remote PIT scanning deployments in River be conducted at least monthly to continue monitoring this subpoluation. M&A will continue to work with Reclamation biologists to ensure a similar scanning effort in Basin as well as Liberty. The location of deployments would be based on past results and continued input from visual surveys. Regardless of positive results from visual surveys, PIT scanners should be deployed on a routine basis in new locations within River (e.g., downstream from Willow Beach) and zones (i.e., Katherine) as time, equipment, and weather permit.

Finally, it is suggested that Reclamation and its LCR MSCP partners move aggressively forward with the backwater program. Even before full implementation of the backwater conservation strategy is achieved, these sites can be utilized for grow-out in addition to hatchery space to get fish in future cohorts as large as possible before they are released into the lake.

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