Lower Colorado River Multi-Species Conservation Program

Balancing Resource Use and Conservation

2017 ANNUAL REPORT
Demographics and Monitoring of Repatriated Razorback Sucker in Lake Mohave

Work conducted under LCR MSCP Work Task D8

December 2017

Lower Colorado River Multi-Species Conservation Program Steering Committee Members

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U.S. Fish and Wildlife Service
National Park Service
Bureau of Land Management
Bureau of Indian Affairs
Western Area Power Administration

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Lower Colorado River
Multi-Species Conservation Program

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December 2017

Leavitt, J.B., B.R. Kesner, C.A. Pacey, and P.C. Marsh. 2017. Demographics and monitoring of repatriated razorback sucker in Lake Mohave, 2017. Draft annual report submitted to Lower Colorado River Multi-Species Conservation Program, Bureau of Reclamation, Boulder City, Nevada, by Marsh & Associates, LLC, Tempe, Arizona, under contract No. R15PD00130. 39 p.

ACRONYMS AND ABBREVIATIONS

AIC – Akaike's Information Criterion
amp-h – ampere hour
AZDEQ – Arizona Department of Environmental Quality
AZGFD – Arizona Game and Fish Department
CI – confidence interval
cm – centimeter(s)
FWS – Fish and Wildlife Service
kHz – kilohertz
km – kilometer(s)
LCR – Lower Colorado River
LCR MSCP – Lower Colorado River Multi-Species Conservation Program
M&A – Marsh & Associates, LLC
m – meter(s)
M, *C*, *R* – mark, capture, recapture
mL – milliliter(s)
mm – millimeter(s)
NDOW – Nevada Department of Wildlife
NFH – National Fish Hatchery
NFWG – Native Fish Work Group
NPS – National Park Service
PIT – passive integrated transponder
PVC – polyvinylchloride
Reclamation – Bureau of Reclamation
RM – river mile
SFH – State Fish Hatchery
SNARRC – FWS Southwestern Native Aquatic Resources and Recovery Center
TL – total length
UTM – Universal Transverse Mercator

Symbols

% – percent
® – Registered
™ – Trademark

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SUMMARY

Repatriated razorback sucker (*Xyrauchen texanus*) in Lake Mohave have been monitored for more than 20 years, but low recapture rates have inhibited 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 abundance of all repatriated and wild razorback sucker marked with either 400 or 134.2 kHz PIT tags.

Eleven razorback sucker were handled by Marsh & Associates during FY2017; seven fish on December 5, 2016 with assistance from Arizona Game and Fish Department (AZGFD) and Arizona Department of Environmental Quality (AZDEQ), 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 nine had paired stocking and capture data in the database; one fish with unknown stocking or capture data was omitted from further analysis. Based on 2016 and 2017 monitoring data, we determined there is no effective wild razorback sucker population remaining in Lake Mohave. The repatriated razorback sucker population for 2016 based on 2016 and 2017 March monitoring data was estimated to number 1,291 (95% confidence interval [CI] from 531 to 3,436).

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, nine 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 sucker 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 sucker between years with 83% of individuals (1,762 out of 2,125) contacted in one zone for two 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). 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 zone was not estimated because there were no recaptures there. 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 (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 sucker 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 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.

Bi-annual netting efforts continue to collect essential growth, health, census, and genetic data for razorback sucker. Combined collection efforts upstream of Willow Beach captured 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 the Liberty and Katherine zones 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 sucker (*Xyrauchen texanus*), an endangered "big river" fish endemic to the Colorado River basin. This population contained more than 73,000 fish from 1980 – 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 Workgroup in establishing a repatriation program (Dowling et al. 2005, Marsh et al. 2015). The program began in the early 1990's, and within a few years it had developed into a system of wild larvae collection, protective rearing, and repatriation to the reservoir after growing to a nominal size of 300 mm in total length (TL) or more (Mueller 1995). There have been several adjustments to the program that incorporate new information to increase 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 sucker in Lake Mohave. Stocking razorback sucker into Lake Mohave from Willow Beach National Fish Hatchery (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 the program (LCR MSCP 2006). The Lake Mohave repatriation program is one element of an overall conservation plan for razorback sucker 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 [FWS] 2005), incorporate a population component that will occupy the lower Colorado River mainstem, 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, Kesner et al. 2012), has proven difficult to produce in sufficient numbers (M. Olson, Willow Beach NFH, January 2009, personal communication). In February of 2015, a change in rearing strategy at Willow Beach was implemented. About 8,000 to 10,000 fish will be held on station for five years and then released as one 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 number of fish stocked per year also reduced the larval collection goal, which was updated to 18,000 per year, but will be subject to change dependent on program needs. Unfortunately, in November 2016, approximately 30,000 razorback sucker at 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 sucker during annual surveys

(Marsh et al. 2005), but precision was low due to low recapture rate. Increasing 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 availability of a viable alternative. The alternative, remote passive integrated transponder (PIT) scanning, became viable when the repatriate population became comprised primarily of 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 sucker prior to that year. Remote PIT scanning has been used since 2010 to increase contact rates with repatriate razorback sucker and improve precision in mark-recapture models. These models have been used to estimate post-release and adult survival, population size, and to answer fundamental demographics questions that will improve ongoing conservation strategies (e.g., Kesner et al. 2008b). Long-term monitoring using traditional capture methods continues to provide important comparative health and dispersal information, as well as collecting contact data on untagged or older 400 kHz tagged individuals, and remain the only methods for acquiring necessary genetic data from wild and repatriate razorback sucker 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 sucker in Lake Mohave.

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

1 Locating and capturing adult razorback sucker

2 Recording biological data (e.g., sex, TL, weight), documenting the

PIT tag number, and examining the general health and condition of captured razorback sucker

3 Collecting tissue samples from adult razorback sucker for genetic analysis

4 Marking of captured adult razorback sucker 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 one 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 the 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 nonfederal 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 data sets 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 LCR MSCP staff

12 Providing a final annual report for each completed contract year
13 Attending the annual Colorado River Aquatic Biologist (CRAB) 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 sucker 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 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 describes the general characteristic of that zone (i.e., Basin and River). Remote PIT scanning was conducted in 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 (Basin zone), near River Mile

(RM) 298 (miles upstream of the Southern International Boundary) for five 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 [cm] 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.

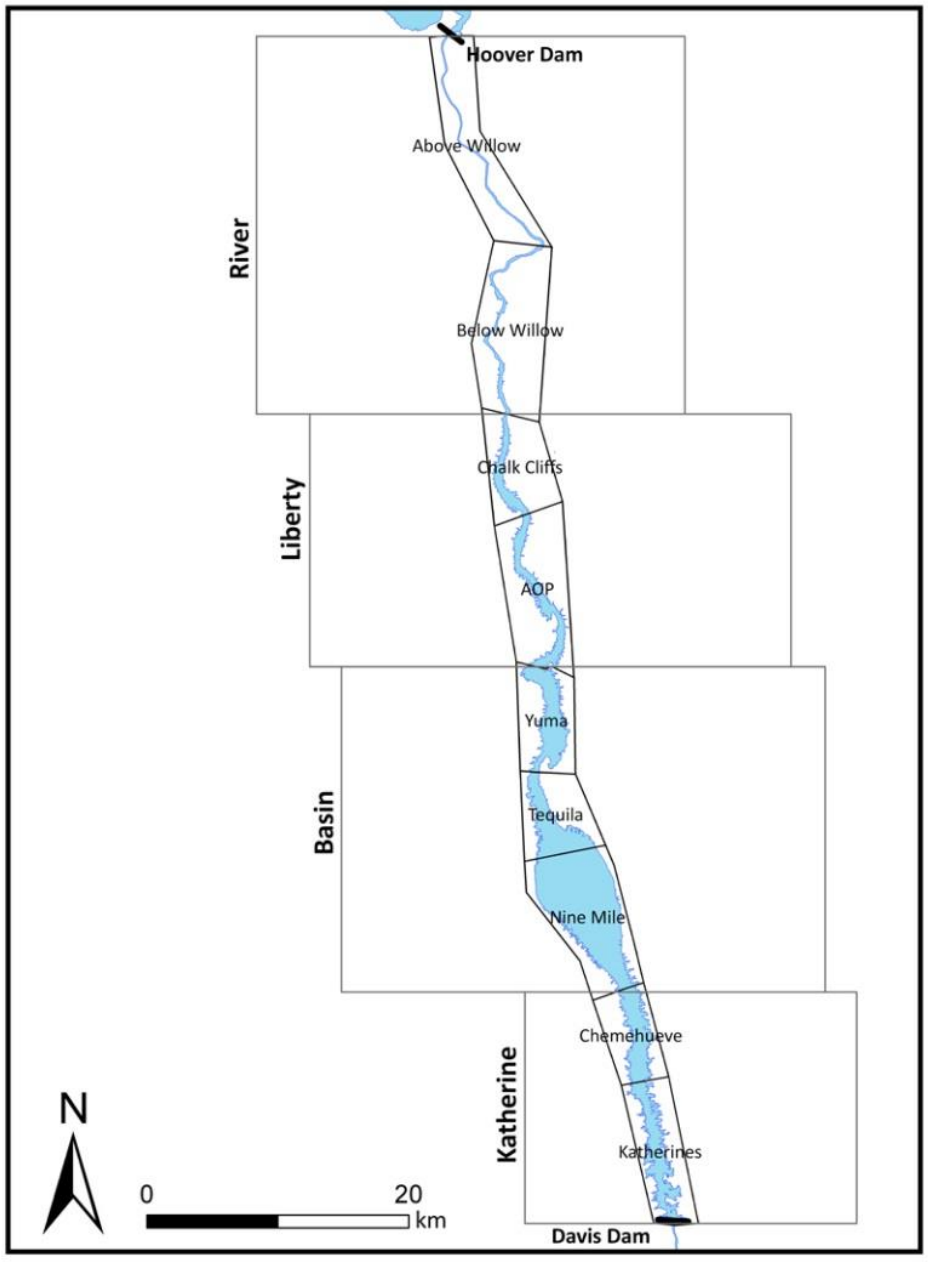

Figure 1. – Map of Lake Mohave, Arizona and Nevada, depicting two zoning schemes, general (large boxes) and specific (smaller boxes); only the former are used in this report.

Native fishes encountered were processed and released (Objective 1). Nets were run and cleared, and 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 (mL) 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 (LCR) Native Fishes Database maintained by M&A.

Remote Monitoring

Remote PIT scanning systems were deployed one week of every month during the 2017 sampling season on shallow gravel bars that extend into the Colorado River upstream of Willow Beach (River zone, Objective 5) and throughout the Liberty zone. 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 PVC frame antenna attached to a scanner and logger contained in watertight polyvinylchloride (PVC) piping. Power to submersible units was provided by a 20.8 or 28 ampere (amp)-hour (h) lithium-ion battery pack contained in a watertight, 2-inch (5.08 cm) 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 sucker 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 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 of known spawning aggregates in the River zone to determine if any additional aggregates exist downstream of Willow Beach. M&A set 10 submersible PIT scanners per trip within a preselected one to two 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 one to two mile increments moving upstream each sample trip from Basin to Liberty Cove. General location of deployments for each trip were determined by subjectively targeting suspected razorback sucker habitat while attempting to maintain uniform coverage across the entire one to two mile reach. These areas included shallow gravel bars and cobble substrates, as well as cattail stands where razorback sucker have been observed in the past (J. Stolberg, Bureau of Reclamation, July 2016, personal communication). Reclamation also expanded their scanning effort to the Katherine zone during the 2017 sample season and conducted seven sampling trips in this zone in 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 zone, subjectively targeting cattail/bulrush.

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 of Willow Beach varied between trips depending on observed or reported fish concentrations. Scanner units monitored fish presence monthly from October through September for four nights and three days (approximately 90 continuous h) each trip.

Information downloaded from scanning units was recorded as follows: general location or site name, Universal Transverse Mercator (UTM) 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, river flows, etc. were recorded on field sheets or data books.

Remote PIT scanning in Basin (Figure 1 and Figure 2) was conducted by Reclamation with support from M&A personnel (Objective 5). Semi-permanent shore based units were deployed in Basin for continuous scanning from 2016 – 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 semi-permanent 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 and 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 website (http://www.nativefishlab.net, Objective 10).

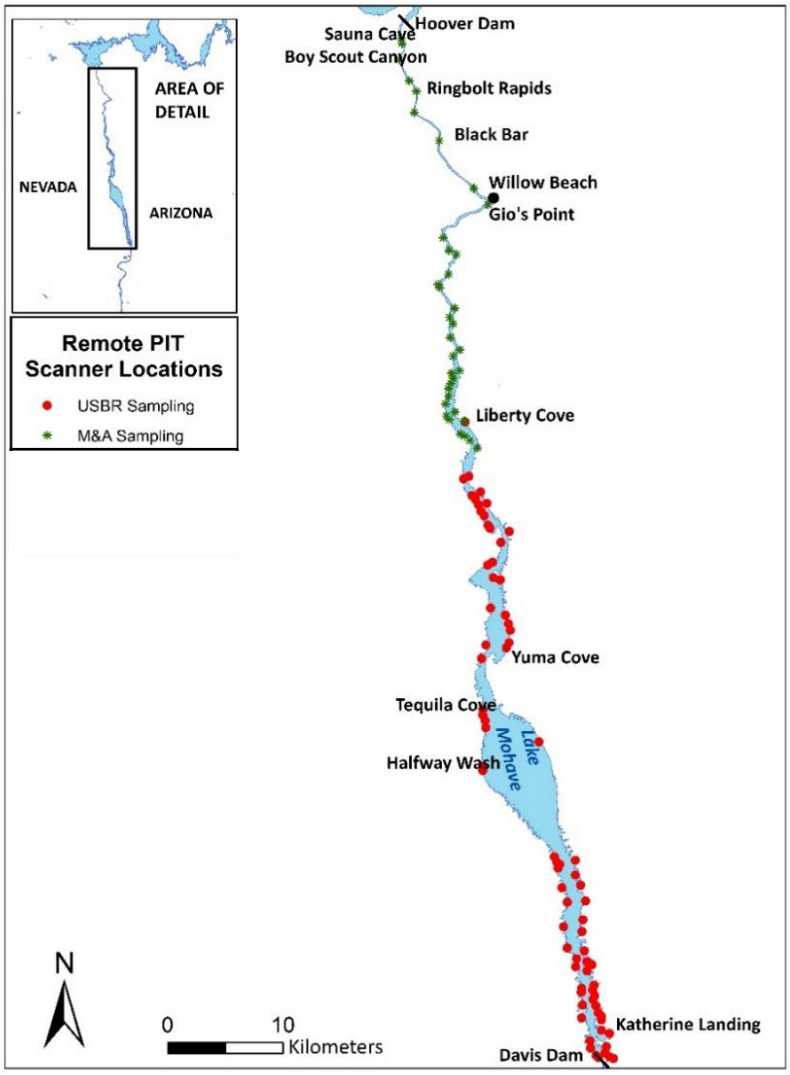

Figure 2. – Location of M&A and Reclamation remote PIT scanners in River, Liberty, Basin, and Katherine zones of Lake Mohave, Arizona and Nevada, 2017.

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

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

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 sucker 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 sucker 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 population size for the lake-wide population as well as River and Basin subpopulations of repatriated and wild razorback sucker 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 sucker contain only a 400 kHz tag, which is rarely detected by remote PIT

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

scanners. Combining the two sources would not accurately estimate the repatriate population.

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

$$N^* = \frac{(M+1)(C+1)}{R+1}$$ (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 sucker released after the initiation of the marking year (January 1 of the previous population year) were removed from population estimates. Razorback sucker 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. 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 database. Confidence intervals 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 sucker between River and Basin zones of Lake Mohave. As in the previous year, the model included individuals at large for at least 730 days (two years) and scanned in River or Basin from January through March from 2012 – 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 two 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 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 sucker included in the model were at large for more than two 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, 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 (five time periods x two locations x three parameter groups minus four 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. Recapture rate was consistently modeled to vary interactively with time

and state because PIT scanning effort varied among 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 Akaike's Information Criterion (AIC) score (Akaike 1974). This value reported in MARK is a modified value (AICc) that adjusts for small sample sizes (Burnham and Anderson 2002). AICc was adjusted for over-dispersion with the median estimate of ĉ (c-hat) when appropriate (QAICc) (Cooch and White 2016). Reported parameter values were based on the highest ranked model (lowest AICc or QAICc) when QAICc 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 sucker were handled at two different M&A monitoring events during FY2017; seven on December 5, 2016 with assistance from AZGFD and AZDEQ 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 nine fish were PIT tagged repatriates with original stocking data in the database; one 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 and the other at 350 mm, and the rest were longer or equal to 410 mm TL. Mean TL at stocking was 428 mm and mean TL at capture was 632 mm with seven fish greater than 620 TL at capture. Fish at large for more than one year exhibited similar growth rates ranging from 1 to 3 mm/month. One fish, at large for 11 months, grew at a rate of 12 mm/month. Mean growth rate was approximately 3 mm/month at large. Years at large for all fish ranged from less than one to 14 years with mean at eight

years. Seven fish were captured during FY2017 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 one to eight years old at stocking and the other from five to seven years old at stocking as its stocking was a mixed batch of 2002, 2003, and 2004 year classes.

Table 1. – Adult razorback sucker monitoring summary by capture month, PIT tag, history, and sex during the FY2017 monitoring events, Lake Mohave, Arizona and Nevada

Capture date	Total n	PIT tag?		History			Sex		
		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

Lakeside backwaters and off-site 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. Off-site rearing facilities included Achii Hanyo, Bubbling Ponds Fish Hatchery, Dexter NFH (SNARRC), Overton Wildlife Management Area, Center Pond, and Willow Beach NFH. Two fish reared in lakeside backwaters traveled an average 20 river km from stocking to capture site, while the seven fish reared in off-site facilities traveled an average 17 river km.

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

Table 2. – Adult razorback sucker monitoring summary for nine paired stocking-capture data per fish PIT tag number with calculated growth rate (capture total length [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. Release date is when fish were stocked into Lake Mohave

	Date		Capture History						TL (mm)		Growth rate
PIT Tag	Release	Capture	Sex	Days at large	Months at large	Years at large	Number of captures	Comments	Release	Capture	(mm/months at large)
1C2D60F707[a]	03-Dec-09	05-Dec-16	F	2,559	85	7	1	First capture in 2017	445	671	3
003BE5B93B[b]	13-Jan-16	05-Dec-16	F	327	11	< 1	1	First capture in 2017	410	543	12
1C2D697D4D[c]	19-Feb-14	05-Dec-16	F	1,020	34	3	1	First capture in 2017	510	572	2
5324140160[d]	25-Jul-02	05-Dec-16	F	5,247	175	14	1	First capture in 2017	285	646	2
257C60995F[e]	13-Jun-07	14-Mar-17	F	3,562	119	10	1	First capture in 2017	480	665	2
4648701437[f]	25-Jan-06	15-Mar-17	F	4,067	136	11	1	First capture in 2017	410	685	2
1C2C3435B7[g]	20-Mar-09	16-Mar-17	F	2,918	97	8	1	First capture in 2017	490	626	1
53453C2E26[h]	18-Jun-04	16-Mar-17	F	4,654	155	13	2	First capture in 2013, second in 2017	350	645	2
1C2D267788[i]	05-Oct-11	05-Dec-16	F	1,888	63	5	3	First capture in March 2011, second in October 2011, third in 2016	475	634	3
			Avg	2,916	97	8	-		428	632	3

[a] 2008 year class, reared at Achii Hanyo FH

[b] 2014 year class, reared at Willow Beach NFH

[c] 2008 year class, reared at Overton Wildlife Management Area, Center Pond

[d] No year class, reared at Dexter NFH (SNARRC)

[e] No year class, reared at Arizona Juvenile lakeside backwater

[f] 2003 year class, reared at Willow Beach NFH

[g] 2002, 2003 or 2004 year class, reared at Bubbling Ponds Fish Hatchery

[h] No year class, reared at Willow Beach NFH

[i] 2008 year class, reared at North Chemehuevi lakeside backwater

Table 3. – Adult razorback sucker monitoring summary, March 2017. Data are for four 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					
Type	Location	Location	State	River km	Zone	Location	State	River km	Zone	Distance traveled (change in km)	n fish
	Arizona Juvenile	Lake Mohave at Arizona Juvenile backwater	AZ	24	Basin	Cottonwood Cove East (100 m inside, north shore)	AZ	34	Basin	19	1
Lakeside backwaters	North Chemehuevi	Lake Mohave at North Chemehuevi Cove backwater	NV	21	Basin	Carp Cove	AZ	34	Basin	21	1
									Avg distance traveled	20	2
	Achii Hanyo FH	Cottonwood Cove	NV	36	Basin	Carp Cove	AZ	34	Basin	12	1
	Bubbling Ponds	Cottonwood Cove	NV	36	Basin	Cottonwood Cove East (100 m inside, north shore)	AZ	34	Basin	12	1
	Dexter NFH (SNARCC)	Princess Cove ramp	AZ	8	Lower Lake	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
		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
Off-site facilities	Willow Beach NFH	Wrong Cove	AZ	52	Above Owl Point	Carp Cove	AZ	34	Basin	18	1
									Avg distance traveled	17	7

Remote Monitoring

PIT scanners were deployed in Lake Mohave for a total of 54,850 h of total scanning time; 10,257 h using shore based devices and 44,593 h 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 Native Fish Database (i.e. have a marking record). Among fish with a marking record, 3,462 were repatriates, nine were wild, and 19 were of unknown origin.

Remote PIT scanning in River zone resulted in a total of 10,393 h of scanning, all with submersible units. Mean deployment time for submersible units was 30 h. Among 29,939 contacts, 2,182 were unique PIT tags and 2,060 of those were in the Native Fish Database. Repatriated razorback sucker accounted for 2,048 tags with a marking record, seven were noted as wild individuals, and five had unknown histories.

Contacts at fixed sites in River were compared during the sampling season. Of a possible 240 fixed site replicates (twelve trips x five sites x four replicates[3]), 230 replicates were available for analysis. In October and November of 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 of 2016 at Black Bar resulted in four replicates missing from the total number available. One replicate is missing from each 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 we attribute 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.

Remote submersible scanners in Liberty were deployed for a total of 7,906 h of

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

scanning. The mean deployment time for submersible scanners was 50 h. A total of 68 PIT tag contacts was recorded representing 52 unique razorback sucker. Forty-nine of these individuals were repatriates and one 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 zones.

Both shore based and submersible units were deployed in Basin and accumulated 30,958 total h of scanning; 10,257 h with shore based and 20,701 h with submersible units. Mean deployment times for shore based and submersibles were 180 h and 141 h respectively. A total of 41,056 contacts was recorded representing 1,770 unique PIT tags for which 1,665 had a marking record in the 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 sucker accounted for 1,647 of the unique encounters, two were wild, and 16 were of unknown origin.

Remote submersible PIT scanners were deployed in Katherine for a total of 5,593 h of scanning. Mean deployment time for submersible scanners was 82 h. A total of 371 PIT tag contacts was recorded representing 59 unique PIT tags, 54 of which had a marking history in the 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 sucker 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 two years prior to the beginning of the 2017 scan year (i.e. were released after January 1, 2015).

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

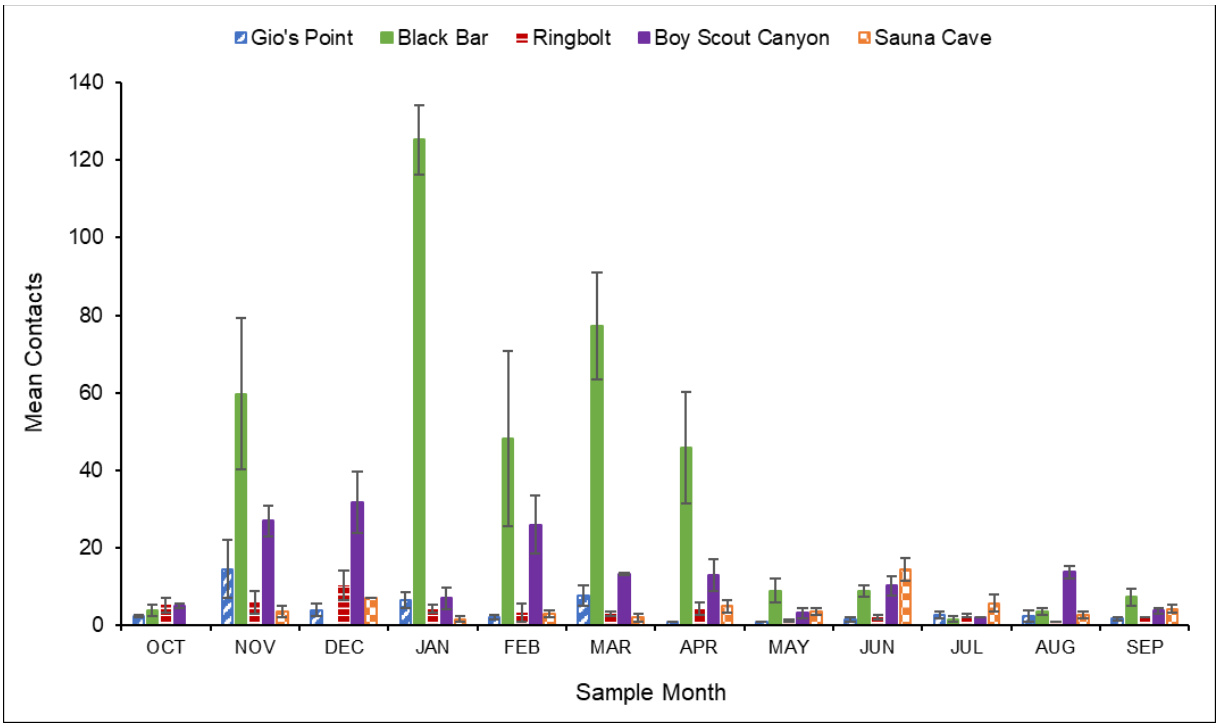

Figure 3. – Unique razorback sucker PIT tag contacts recorded October 1, 2016 to September 30, 2017 at five fixed stations in River zone, Lake Mohave, Arizona and Nevada. Error bars represent ±1 SE. n=4 except for Boy Scout Canyon and Sauna Cave in October (n=3 and n=0, respectively), Boy Scout Canyon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

In Liberty, 231 fish were released and only one fish each was scanned in Liberty and Katherine, the remainder of which 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 sucker contacted in 2017 with a marking record, 2,801 razorback sucker 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). 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 razorback sucker contacted.

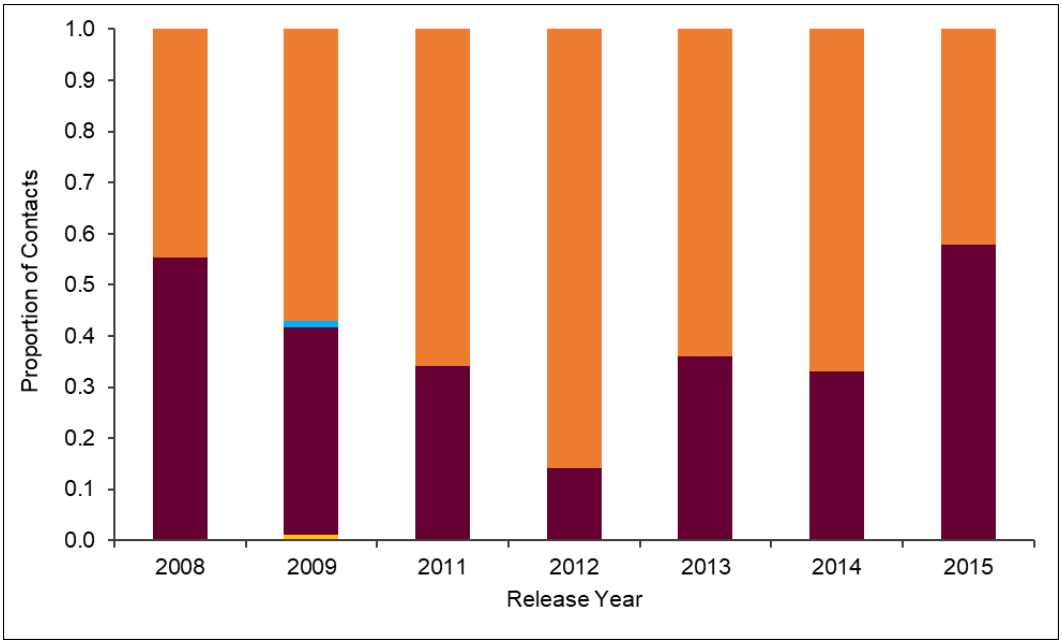

Figure 4. – Proportion of razorback sucker PIT tag contacts in 2017 among scanning zones in Lake Mohave; Katherine (yellow), Basin (maroon), Liberty (blue), and River (orange), for fish released in Liberty. Fish were released between October 1, 2008 and October 1, 2015 and contacted during PIT scanning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

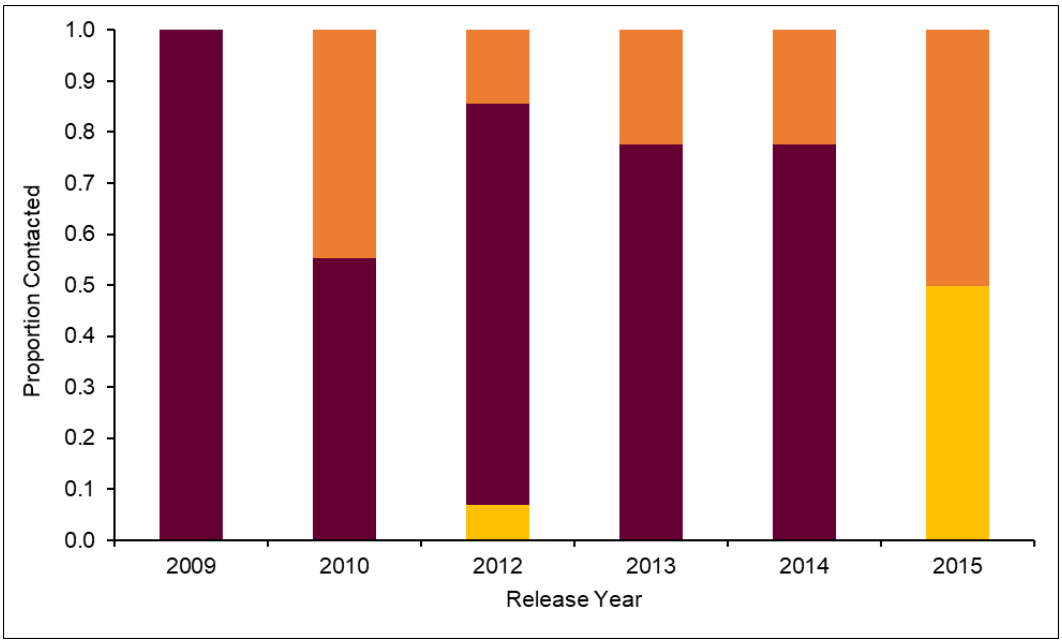

Figure 5. – Proportion of razorback sucker PIT tag contacts in 2017 among scanning zones in Lake Mohave; Katherine (yellow), Basin (maroon), Liberty (blue), and River (orange), for fish released in Katherine. Fish were released between October 1, 2008 and October 1, 2015 and contacted during PIT scanning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

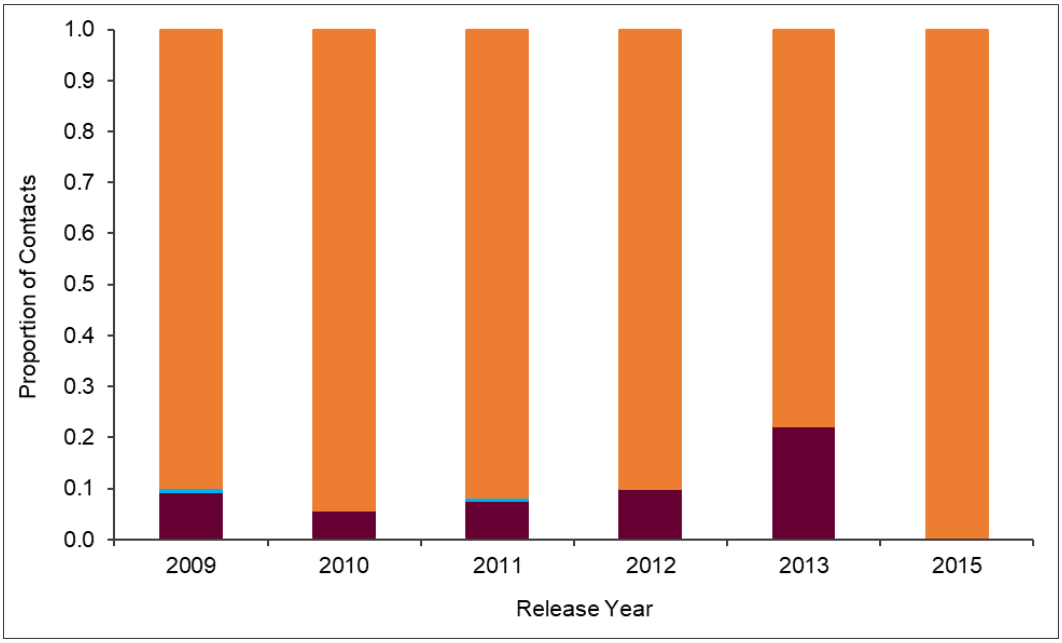

Figure 6. – Proportion of razorback sucker PIT tag contacts in 2017 among scanning zones in Lake Mohave; Katherine (yellow), Basin (maroon), Liberty (blue), and River (orange), for fish released in River. Fish were released between October 1, 2008 and October 1, 2015 and contacted during PIT scanning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

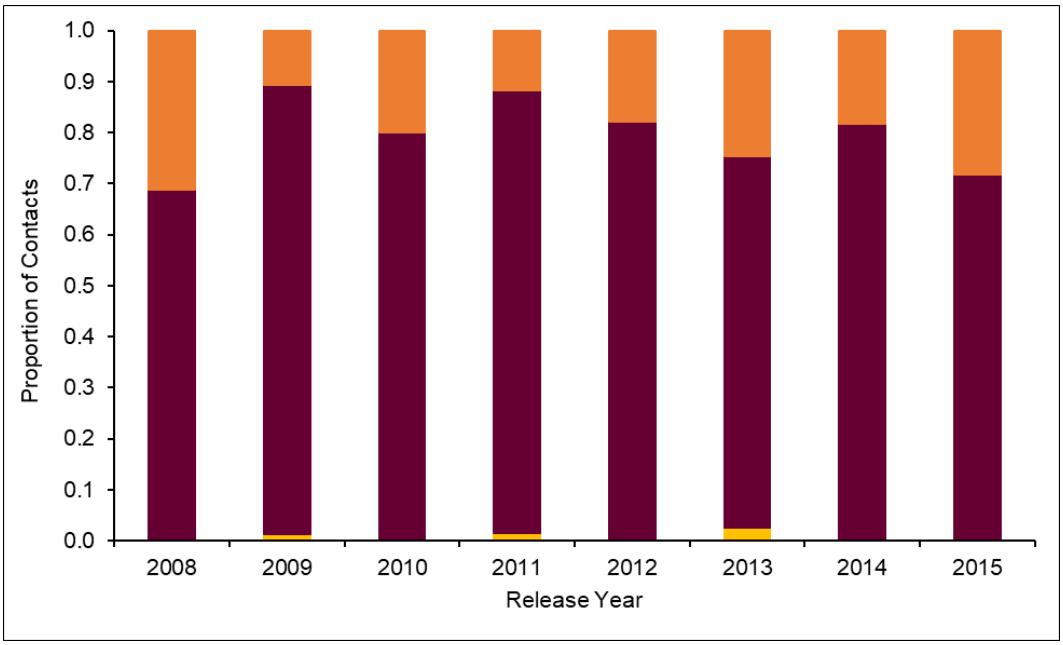

Figure 7. – Proportion of razorback sucker PIT tag contacts in 2017 among scanning zones in Lake Mohave; Katherine (yellow), Basin (maroon), Liberty (blue), and River (orange), for fish released in Basin. Fish were released between October 1, 2008 and October 1, 2015 and contacted during PIT scanning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

Adult subpopulations in River, Liberty, Basin, and Katherine zones exchanged few individuals from 2016 to 2017 (Table 4). Among 2,125 razorback sucker 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 two 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 Willow Beach boat ramp (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%).

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 Willow Beach released cohorts in March and April 2012 (mean TL of 375 and 373 mm). The cohort with the highest contact rate (6.1%) was 444 razorback sucker released in March of 2011 with a mean TL of 414 mm at release.

For razorback sucker released in Basin, there were four cohorts that made up the majority of fish scanned in 2017 (51%), but less than half of those released (29%)

(Table 5). 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 and the other at Achii Hanyo) 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 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 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. Mean TL for these smaller cohorts (in number of released fish) was 443 mm. For comparison, 481 razorback sucker 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%).

Table 4. – Razorback sucker 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

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

Population Estimates

Based on monitoring data from 2016 and 2017, there was no effective wild razorback sucker population remaining in Lake Mohave. We 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

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

					2017	
Release Zone	**Release Location**	**Release Date**	**Releases**	**Mean TL (mm)**	**Contacted**	**% Contacted**
River	Willow Beach boat ramp	10/4/2011	500	441	132	26.4%
	Willow Beach boat ramp	10/23/2009	2234	421	422	18.9%
	Willow Beach boat ramp	1/7/2010	2077	423	339	16.3%
	Willow Beach boat ramp	12/8/2011	1594	394	224	14.1%
	Willow Beach boat ramp	10/13/2009	2588	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	1436	347	13	0.9%
	Ringbolt Rapids	12/16/2010	1509	324	8	0.5%
	Willow Beach boat ramp	12/7/2012	1510	368	8	0.5%
	Black Bar	1/12/2015	1036	347	4	0.4%
	Ringbolt Rapids	2/13/2013	1725	330	5	0.3%
	Ringbolt Cove	1/6/2010	1493	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	1486	331	1	0.1%
	Ringbolt Rapids	1/5/2012	1778	332	1	0.1%
	Ringbolt Rapids	1/30/2013	597	327	0	0.0%
	Willow Beach boat ramp	1/29/2014	1441	333	0	0.0%
	Ringbolt Rapids	1/30/2014	1541	331	0	0.0%
	Ringbolt Rapids	1/5/2015	989	339	0	0.0%
	Ringbolt Rapids	1/12/2015	1000	339	0	0.0%
Liberty	Liberty Cove	3/16/2011	444	414	27	6.1%
	Liberty Cove	2/28/2013	1271	356	52	4.1%
	Wrong Cove	12/17/2009	917	374	34	3.7%
	Liberty Cove	1/29/2013	1186	326	31	2.6%
	Red Tail Cove	12/17/2009	897	382	20	2.2%
	Liberty Cove	12/17/2009	1521	379	33	2.2%
	Liberty Cove	1/14/2015	1000	346	16	1.6%
	Liberty Cove	1/21/2015	1070	341	13	1.2%
	Owl Point Cove	1/26/2012	1022	324	5	0.5%
	Owl Point Cove	1/6/2015	987	361	4	0.4%
	Liberty Cove	1/5/2011	1896	339	7	0.4%
	Liberty Cove	1/14/2014	1825	326	6	0.3%
	Owl Point Cove	1/13/2015	986	350	3	0.3%
	Liberty Cove	1/5/2012	1920	330	4	0.2%
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	1019	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	1004	372	15	1.5%
	Cottonwood Cove	12/12/2013	415	402	5	1.2%
	Nellis Cove	1/13/2015	1038	340	9	0.9%
	Cottonwood Cove East	1/24/2013	3206	336	25	0.8%
	Cottonwood Cove East	1/28/2014	1412	338	11	0.8%
	Lake Mohave at North Nine Mile Coves backwater	1/27/2014	2372	331	11	0.5%
	Lake Mohave at Yuma Cove backwater	12/18/2009	1611	329	7	0.4%
	Nellis Cove	1/20/2015	1015	337	4	0.4%
	Six Mile Coves	1/5/2010	1584	329	6	0.4%
	Nine Mile Coves (north of)	1/6/2011	1892	341	7	0.4%
	Lake Mohave at Yuma Cove backwater	1/18/2012	693	328	1	0.1%
Katherine	Princess Cove ramp	12/5/2012	1073	380	10	0.9%
	Princess Cove ramp	1/14/2014	2725	335	12	0.4%
	Princess Cove ramp	1/18/2012	1689	335	5	0.3%
	Princess Cove ramp	1/23/2013	4330	336	10	0.2%
	Princess Cove ramp	1/12/2015	1160	344	1	0.1%
	Princess Cove ramp	1/5/2015	1183	322	1	0.1%

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 Basin population at 2,008 (95% CI from 1,848 to 2,181) and River 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 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 MARK. This value was used to adjust AICc values (QAICc). 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 ΔQAICc ≤ 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 ΔQAICc in this range. Estimates of yearly transition were slightly different between zones, but similar across years (2012 – 2016); 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 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).

Table 6. – MARK movement and survival models for adult razorback sucker, 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. – MARK model transition estimates (model averaged) for razorback sucker released in 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 in Liberty due to limited scanning there

Zone	Period	Estimate	Lower CI	Upper CI
River	2012 - 2013	0.040	0.028	0.057
	2013 - 2014	0.040	0.029	0.055
	2014 - 2015	0.040	0.030	0.054
	2015 - 2016	0.043	0.033	0.055
Basin	2012 - 2013	0.059	0.042	0.081
	2013 - 2014	0.057	0.042	0.077
	2014 - 2015	0.057	0.042	0.077
	2015 - 2016	0.061	0.047	0.079

Table 8. – MARK model survival estimates (model averaged) for razorback released in 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 in Liberty due to limited scanning there

Zone	Period	Estimate	Lower CI	Upper CI
River	2012 - 2013	0.911	0.874	0.938
	2013 - 2014	0.925	0.891	0.949
	2014 - 2015	0.917	0.892	0.938
	2015 - 2016	0.912	0.875	0.939
Basin	2012 - 2013	0.933	0.904	0.953
	2013 - 2014	0.943	0.912	0.964
	2014 - 2015	0.937	0.915	0.954
	2015 - 2016	0.933	0.908	0.951

Table 9. – MARK model recapture estimates (model averaged) for razorback sucker released in 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 in 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

DISCUSSION

Remote sensing through deployment of PIT scanners in 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 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 confidence intervals.

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 confidence interval 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 the 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 sucker, 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 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 sucker 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

[4] In March collections over recent years, a 400 kHz tag was detected in 9.5% (99 out of 1046) of fish captured (unpublished data).

recent numerically large release cohorts are not replacing declining older ones (Wisenall et al. 2016). In 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 (Table 5). The size at release of these fish (mean TL of 347 mm) was well below the Lake Mohave Native Fish Workgroup 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 sucker 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 subpopulation is likely due to these releases. Total length 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 sucker 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 Willow Beach NFH hatchery to release fewer, but larger razorback sucker, should result in additional recruitment within a few years after releases begin. However, the fish kill at the hatchery in autumn 2016 has delayed this program, and harvest from lakeside backwaters and releases from Lake Mead Fish Hatchery will be the only sources of large razorback sucker 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 was increased in 2017 to 33,000 to account for the loss of razorback sucker at Willow Beach. To accurately represent the razorback sucker subpopulation residing upstream of Willow Beach, it is suggested that half of the larvae collected (9,000 individuals based on original harvest goal) come from this zone. In 2017, FWS, 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 three-year absence from 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 sucker at 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, which are one of the main predators of razorback sucker in the system. An increased abundance of larger striped bass, even with the advent of stocking larger razorback sucker, 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 sucker should be spatially and temporally separated to mitigate potential exacerbation of predation issues.

A substantial number of razorback sucker have been repatriated to Lake Mohave - 221,195 fish as of this writing (LCR Native Fishes 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, b; 2005). Adjustments to the 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 sucker 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, FWS 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 sucker in Lake Mohave. There currently is no other mechanism to acquire these critical data.

Efforts are ongoing to stock razorback sucker 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 program. Stocking cohorts in each zone (Basin and River) at approximately the same time (within days to a few weeks at most) and mean TL will support the goal of assessing razorback sucker metapopulation dynamics and 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 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 sucker and it is suggested that these efforts are maintained. Marsh & Associates staff will continue to work with Reclamation biologists to ensure a similar scanning effort in Basin as well as Liberty. Location 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 of Willow Beach) and in zones where past monitoring effort was minimal (i.e., Katherine) as time, equipment, and weather permit.

ACKNOWLEDGEMENTS

Collections were authorized under permits issued by FWS, NPS Lake Mead National Recreation Area, and the states of Arizona and Nevada. Care and use of fish used in this study was approved by the Institutional Animal Care and Use Committee, protocol numbers 11-1149R, 13-1318R, 15-1425R, and 16-1425R. All past and present members of the Lake Mohave Native Fish Work Group are thanked for their contributions to this work and the program. This project was made possible with cooperation from G. Cappelli, M. Olson, and other staff (Willow Beach NFH), J. Anderson, T. Delrose, G. Garnett, J. Lantow, E. Loomis, J. Nelson, J. Stolberg, R. Thomas, and T. Wolters (LCR MSCP Office), and T. Dowling (Wayne State University, Detroit, MI). This work was supported by Reclamation Order No. R15PD00130 with assistance from Elizabeth Bailey, Reclamation Contract Specialist and Jim Stolberg, Contracting Officer's Representative.

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