Lower Colorado River Multi-Species Conservation Program

Balancing Resource Use and Conservation

2016 ANNUAL REPORT
Demographics and Monitoring of Repatriated Razorback Sucker in Lake Mohave

January 2017

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Lower Colorado River
Multi-Species Conservation Program

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ACRONYMS AND ABBREVIATIONS

ABS – acrylonitrile butadiene styrene
AIC – Akaike's Information Criterion
amp-h – ampere hour
AZGFD – Arizona Game and Fish Department
CI – confidence interval
cm – centimeter(s)
FWS – U.S. 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 and 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 – U.S. 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 twenty 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.

Ten razorback sucker were handled at the Marsh & Associates camp during the March roundup from March 14 through March 18, 2016; no razorback sucker were captured at any other times of the reporting year. There were no original capture or stocking data in the Lower Colorado River (LCR) Native Fish Database for one 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, we determined there is no effective wild razorback sucker population remaining 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).

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 eight 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 (>85%) of fish released in River and Basin were contacted in their zone of release, regardless of release year. Razorback sucker 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 sucker between years with 96% of individuals (1,597 out of 1,668) contacted in the same zone 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 tagged Lake Mohave repatriate population was estimated at 3,656 (95% CI from 3,418 to 3,912). 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 River at 2,158 (95% CI from 1,960 to 2,377). The subpopulation in Liberty zone was not estimated due to a lack of scanning effort there during the sampling season. All ten wild razorback sucker contacted in 2016 were also contacted in 2015. Too few wild fish were contacted to estimate 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 sucker 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 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 could not be accurately estimated for 2015 to 2016 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 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 the Liberty zone 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 less than 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% CI from 4 to 250). In the early 1990s, a repatriation program to restore razorback sucker 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 mm in total length (TL) or more.

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). 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, Willow Beach National Fish Hatchery [Willow Beach NFH], January 2009, personal communication) and even fish of this size are subject to predation (Karam and Marsh 2010). 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 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 sucker in Lake Mohave. Stocking razorback sucker into Lake Mohave from Willow Beach NFH (LCR MSCP 2015, Work Task B2) 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 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, 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 sucker 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 one 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, potential to repeatedly capture the same individuals, and 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 population size and answer fundamental demographics questions that will improve ongoing conservation strategies (e.g., Kesner et al. 2008b).

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 adult 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 second 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, and Basin zones. 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.

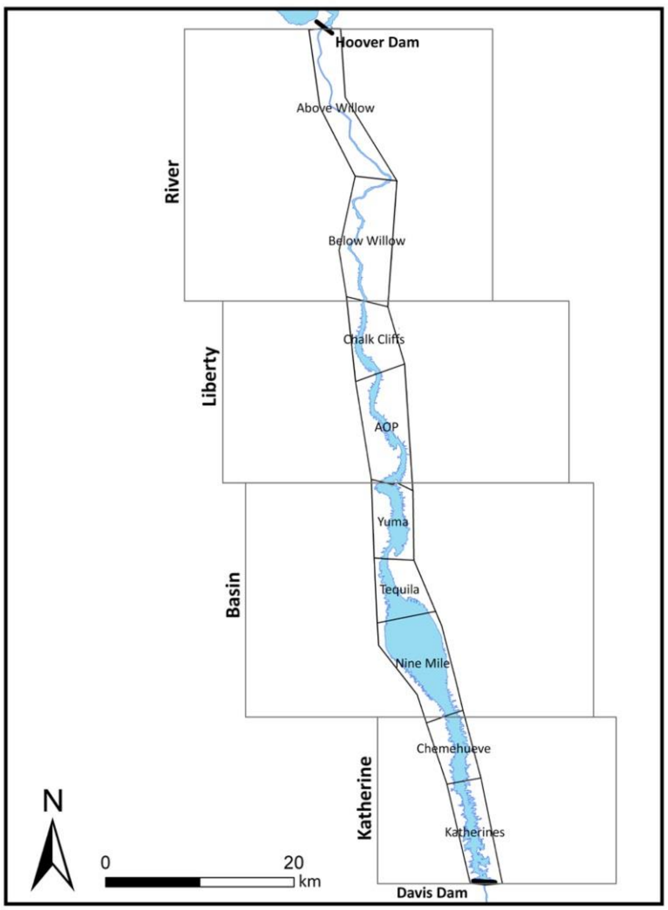

Figure 1. – Map of Lake Mohave, Arizona and Nevada, depicting two zoning schemes, general (large boxes) and specific (smaller boxes); only the former are used in this report.

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) 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 four to 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 and up to two 45.7 x 1.8 m, 3.8 cm stretch mesh) were fished continuously along the Arizona shoreline from Pot Cove upstream to Carp Cove.

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 LCR Native Fishes Database maintained by M&A.

Remote Monitoring

Remote PIT scanning systems were deployed one week of every month during the 2016 sampling season on shallow gravel bars that extend into the Colorado River upstream of Willow Beach (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 six volt, 12 ampere (amp)-hour (h) 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 1800 hours, ran for 24 hours, and stopped scanning for 24 hours. This cycle was repeated three 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 amp-h 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 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 sucker at different times of year. One shore based unit was deployed throughout the 2016 sample season at Boy Scout Canyon. 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 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 (m), 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 and Liberty (Figure 1) 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 2015 – 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 units were also deployed in Basin at both Half Way Wash and Yuma Cove and attached to a solar aeration system for power.

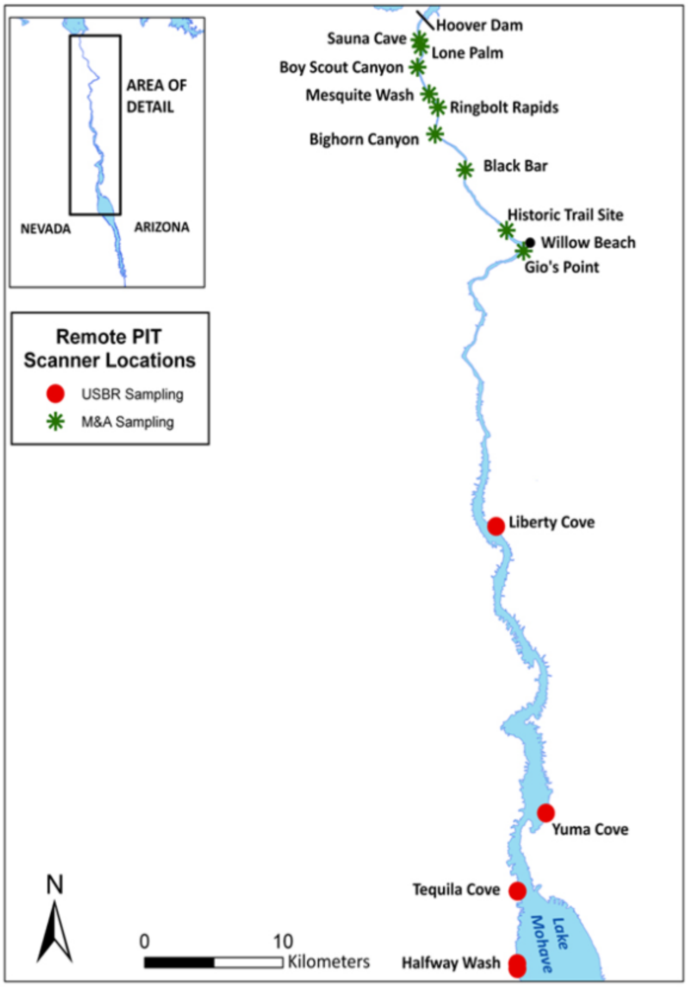

Figure 2. – Location of M&A and Reclamation remote PIT scanners in River, Liberty, and Basin zones Lake Mohave, Arizona and Nevada.

All sites with semi-permanent shore based units represent known spawning aggregation sites and have been collection sites for March monitoring since 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 are available through a password protected section of the M&A website (http://www.nativefishlab.net, Objective 10).

Post-stocking contact rates for PIT tagged repatriated razorback sucker 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 to ensure that an individual is a fully recruited member of the Lake Mohave population, only those fish that have been at large for one year prior to the beginning of the scanning year are included in analysis. Release records were grouped into "cohorts" based on location and date of release. Contact data within each cohort were tabulated for all fish contacted by remote PIT scanning for the 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 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[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 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 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 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 scanners. Combining the two sources would not accurately estimate the repatriate population.

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

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 roundup 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 (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 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 – 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 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 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). A total of 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 (four 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 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.

In 2016, an analysis of goodness-of-fit (GOF) was completed for the most general model with program U-CARE (Utilities- CApture-REcapture). For multi-state data, a time and state dependent JollyMoVe (JMV) model was used (Choquet et al. 2005). Primary assumptions of the JMV 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 JMV 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 JMV GOF tests is TEST M, which compares animals that are encountered at 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. Over-dispersion ($\hat{c}$) 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 over-dispersion when the $\hat{c}$ ratio is greater than one for all components and no $\hat{c}$ ratio exceeds the others for any one component (Choquet et al. 2009). This is generally accepted if the overall ratio is less than three, sometimes five (Burnham and Anderson 2002).

RESULTS

Routine Monitoring

We handled 10 razorback sucker during 2015 and 2016 monitoring events with March 2016 monitoring activities accounting for 100% of the captures (Table 1). Sex was determined for fish at capture and the majority captured were female (n=7). All ten fish captured were PIT tagged and nine were repatriates; one fish was captured with no original stocking or capture data in the database and was omitted from further analysis.

Of the nine PIT tagged repatriates with paired data (i.e., fish with both stocking and capture data), one fish was less than 350 mm TL at stocking, four fish were 350 to 450 mm TL at stocking, and four fish were greater than 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 greater than 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. Mean growth rate was approximately four mm/month. Years at large for all fish ranged from one to thirteen years with mean time at six 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 nine years prior to its first capture. Four fish with year class information were approximately one to four years old at stocking with an approximate mean of three years old at stocking.

Lakeside backwaters and off-site 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 the main channel adjacent to these locations. Off-site rearing facilities included Achii Hanyo Fish Hatchery and Willow Beach NFH. Fish reared in lakeside backwaters traveled an average of seven river km from stocking to capture site, while fish reared in off-site facilities traveled an average of 41 river km.

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

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

Capture month (year)	Total	PIT tag?		History		Sex		
		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 remaining table

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

PIT tag	Date		TL (mm)			Capture history					
	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
		Avg	428	611	4	-	1,986	66	5	2	-

[a]2008 year class, reared at Arizona Juvenile
[b]2013 year class, reared at WBNFH
[c]No year class, reared at Yuma Cove
[d]No year class, reared at Arizona Juvenile
[e]2010 year class, reared at Achii Hanyo Fish Hatchery

Table 3. – Adult razorback sucker monitoring summary. March 2016. Data are for nine paired release-capture data by rearing type and location and release and capture locations. 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 km)	n fish
Type	Location	Location	State	River km	Zone	Location	State	River km	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 Cove	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
									Avg distance traveled	7	7
Off-site 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
									Avg distance traveled	41	2

Remote Monitoring

PIT scanners were deployed in Lake Mohave for a total of 37,859 h of total scanning time; 10,363 h using shore based devices and 27,496 h 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 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 zone resulted in a total of 7,370 h of scanning; 946 h with shore based and 6,424 h with submersible units. Mean deployment times were 86 h and 22 h for shore based and submersible scanners, respectively. Among 10,862 total contacts, 1,544 were unique PIT tags and 1,524 of those were in the Native Fish Database. Repatriated razorback sucker accounted for 1,515 tags with a marking record, seven were noted as wild individuals, and two had unknown histories.

Contacts at fixed station sites in River were compared during the sampling season. Of a possible 240 fixed site replicates (twelve trips x five sites x four replicates[2]), 211 replicates were available for analysis. The January trip had only three nights of scanning, which accounts for five missing from the total number of replicates available. In October, November, and December of 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 a total of 915 h of scanning. The mean deployment time for submersible scanners was 76.2 h. A total of eight PIT tag contacts was recorded representing seven unique razorback sucker. Six of these individuals were repatriates and one was of unknown origin.

Both shore based and submersible units were deployed in Basin and accumulated 29,574 total h of scanning; 9,417 h with shore based and 20,157 h with submersible units. Mean deployment

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

times for shore based and submersibles were 214 h and 106.7 h 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 Native Fish Database, 1,760 of which were razorback sucker (21 bonytail). 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 1,750 of the unique encounters, three were wild, and seven were of unknown origin.

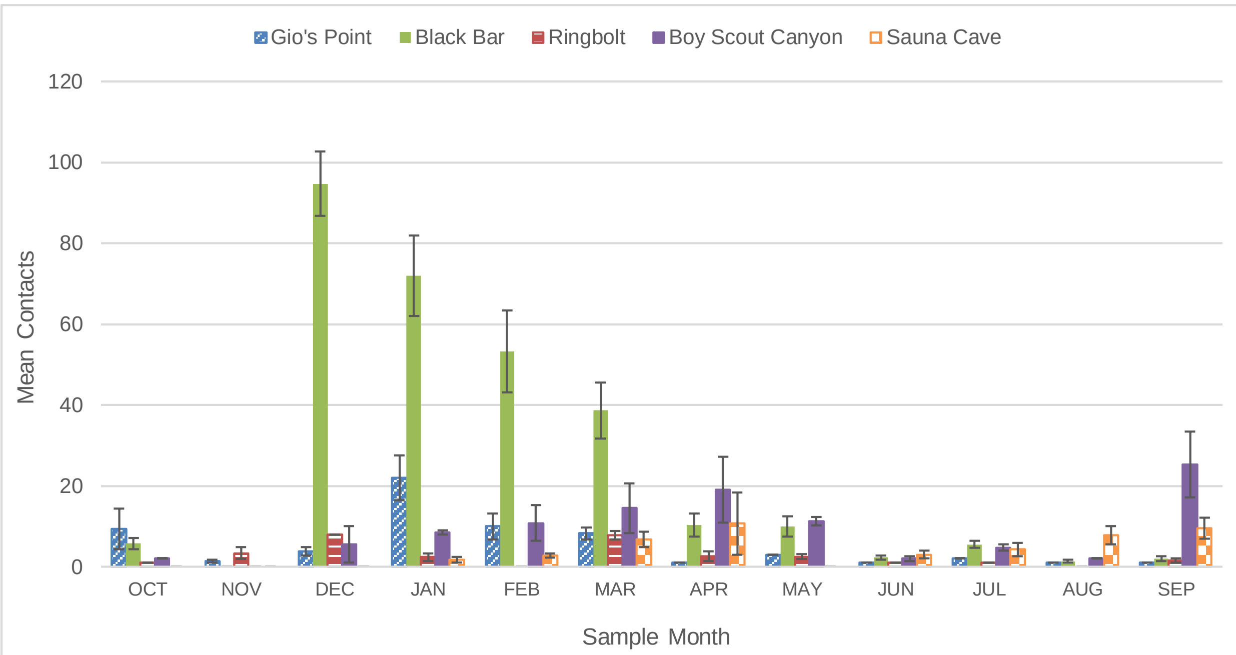

Figure 3. – Unique razorback sucker PIT tag contacts recorded October 1, 2015 to September 30, 2016 at five fixed stations in River zone, Lake Mohave, Arizona and Nevada. Error bars represent ±1 SE. n=4 except for all sites in January and Boy Scout Canyon and Sauna Cave October through December.

Post-stocking dispersal out of release zone was minimal for two of the three main stocking zones, excluding individuals that were stocked into Liberty (Figure 4). Of the 3,128 razorback sucker contacted in 2016 with a marking record, only 2,533 razorback sucker met the criteria for further analysis (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 zone of release regardless of release year (Figure 6). Basin released fish accounted for 41.2% (984) of razorback sucker contacted. PIT scanning was not conducted in Katherine in 2016, however 44 fish released there were contacted in Basin and six were contacted in River.

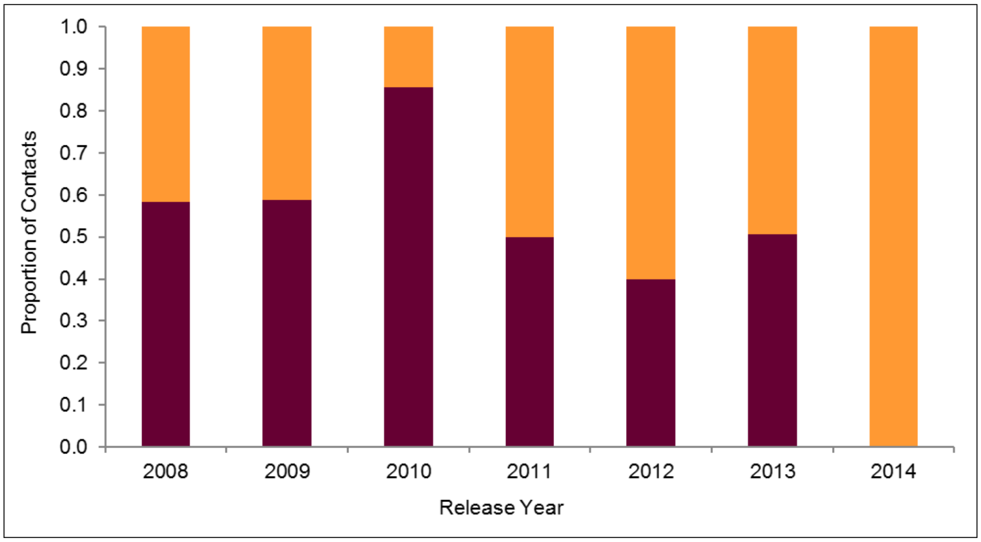

Figure 4. – Proportion of razorback sucker PIT tag contacts in 2016 among scanning zones in Lake Mohave; River (orange) and Basin (maroon), for fish released in Liberty; there were no contacts in Liberty. Fish were released between October 1, 2008 and October 1, 2014 and contacted during PIT scanning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

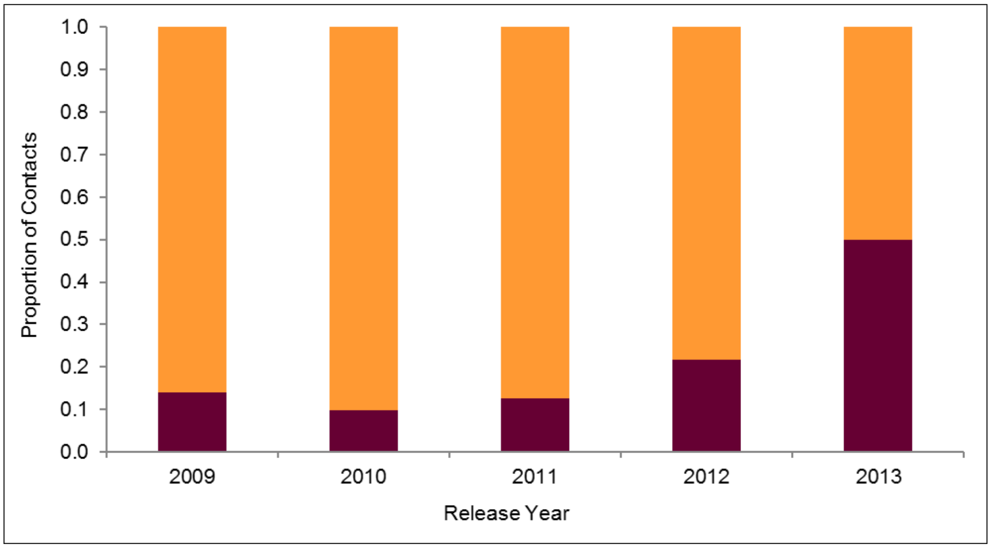

Figure 5. – Proportion of razorback sucker PIT tag contacts in 2016 among scanning zones in Lake Mohave; River (orange) and Basin (maroon), for fish released in River; there were no contacts in Liberty. Fish were released between October 1, 2008 and October 1, 2014 and contacted during PIT scanning activities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

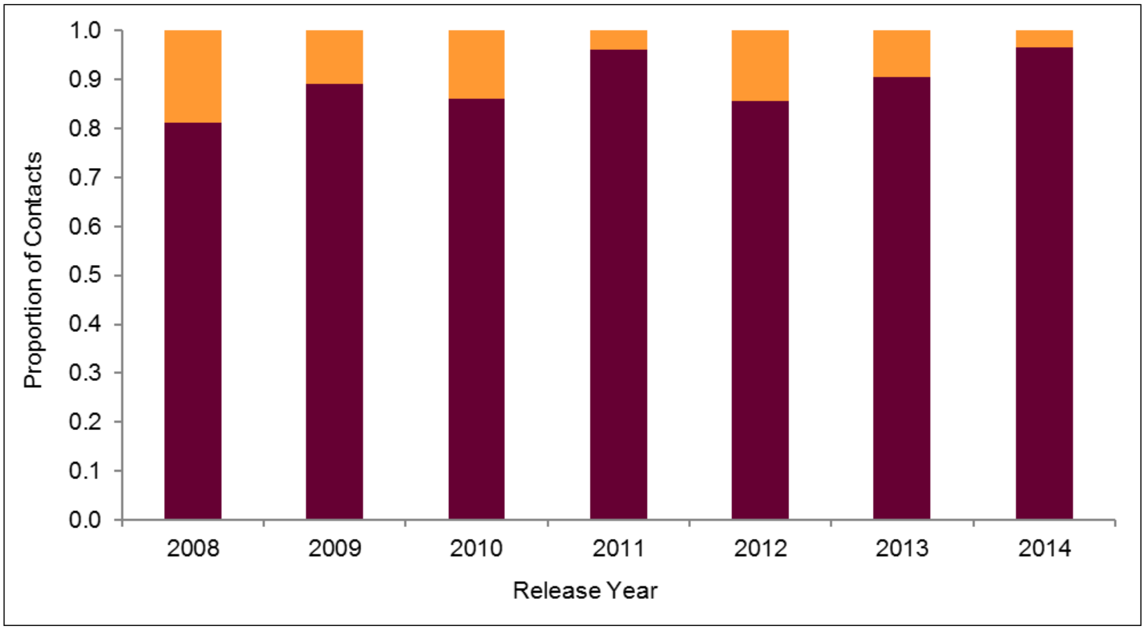

Figure 6. – Proportion of razorback sucker PIT tag contacts in 2016 among scanning zones in Lake Mohave; River (orange) and Basin (maroon), for fish released in Basin; there were no contacts in Liberty. Fish were released between October 1, 2008 and October 1, 2014 and contacted during PIT scanning activities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

Adult subpopulations in River, Liberty, and Basin zones exchanged few individuals from 2015 to 2016 (Table 4). Among 1,835 razorback sucker 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 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 2016 (Table 5). These five cohorts made up most 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 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 sucker released in March of 2011 with a mean TL of 414 mm at release.

For fish released in Basin, there were four cohorts that make up most of the fish scanned in 2016 (59%), but less than half of those released (31%) (Table 5). Mean sizes of fish in these four cohorts were longer than 450 mm TL at release and three of these 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 143 release cohorts that were released with less than 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. Mean TL for these smaller cohort (in number of released fish) was 445 mm. For comparison, 455 razorback sucker 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%).

Table 4. – Razorback sucker 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

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

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	2016 % Contacted
River	Willow Beach boat ramp	10/4/2011	500	441	106	21.2%
	Willow Beach boat ramp	10/23/2009	2234	421	391	17.5%
	Willow Beach boat ramp	1/7/2010	2077	423	275	13.2%
	Willow Beach boat ramp	12/8/2011	1594	394	207	13.0%
	Willow Beach boat ramp	10/13/2009	2588	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	1436	347	12	0.8%
	Willow Beach boat ramp	12/7/2012	1510	368	9	0.6%
	Ringbolt Rapids	2/13/2013	1725	330	5	0.3%
	Ringbolt Cove	1/6/2010	1493	334	4	0.3%
	Ringbolt Rapids	12/16/2010	1509	324	4	0.3%
	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%
	Willow Beach boat ramp	1/29/2014	1441	333	0	0.0%
	Ringbolt Rapids	1/30/2013	597	327	0	0.0%
	Ringbolt Rapids	1/30/2014	1541	331	0	0.0%
Liberty	Liberty Cove	3/16/2011	444	414	25	5.6%
	Liberty Cove	2/28/2013	1271	356	48	3.8%
	Wrong Cove	12/17/2009	917	374	31	3.4%
	Liberty Cove	1/29/2013	1186	326	29	2.4%
	Red Tail Cove	12/17/2009	897	382	19	2.1%
	Liberty Cove	12/17/2009	1521	379	24	1.6%
	Six Mile Coves	1/5/2010	1584	329	8	0.5%
	Liberty Cove	1/5/2011	1896	339	8	0.4%
	Liberty Cove	1/5/2012	1920	330	5	0.3%
	Liberty Cove	1/14/2014	1825	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	1019	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	1412	338	13	0.9%
	Cottonwood Cove East	1/24/2013	3206	336	27	0.8%
	Yuma Cove	12/18/2009	1611	329	7	0.4%
	Owl Point Cove	1/26/2012	1022	324	4	0.4%
	Lake Mohave at North Nine Mile Coves backwater	1/27/2014	2372	331	9	0.4%
	Nine Mile Coves (north of)	1/6/2011	1892	341	5	0.3%
	Yuma Cove	1/18/2012	693	328	1	0.1%
Katherine	Princess Cove ramp	12/5/2012	1073	380	11	1.0%
	Princess Cove ramp	1/14/2014	2725	335	9	0.3%
	Princess Cove ramp	1/23/2013	4330	336	11	0.3%
	Princess Cove ramp	1/18/2012	1689	335	4	0.2%

Population Estimates

Based on monitoring data from 2015 and 2016, there was no effective wild razorback sucker population remaining in Lake Mohave. We estimated that the repatriated razorback sucker population was 1,707 (95% CI from 603 to 3,897) representing less than one percent of the total number of repatriates released in the reach as of March 1, 2015.

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 Basin population at 1,947 (95% CI from 1,761 to 2,151) and River at 2,158 (95% CI from 1,960 to 2,377); no estimate was calculated for Liberty. All ten wild razorback sucker contacted in 2016 were also contacted in 2015. Too few wilds were contacted to estimate 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, $\hat{c}$ was significantly different than 1, estimated at 2.473 (95% CI from 1.946 to 2.982) based on median $\hat{c}$ estimation within MARK. This value was used to adjust AICc values (QAICc). Parameter estimates were based on model averaging since no model had more than 0.9 model weight (Table 6). The top six models all had QAICc weight greater than 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 between zones, but similar across years (2012-2015); 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 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).

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)	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 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 2016 and individuals released in Liberty due to limited scanning there

Zone	Period	Estimate	Lower CI	Upper CI
River	2012-2013	0.041	0.027	0.062
	2013-2014	0.041	0.029	0.059
	2014-2015	0.042	0.030	0.058
Basin	2012-2013	0.054	0.035	0.082
	2013-2014	0.052	0.036	0.074
	2014-2015	0.051	0.035	0.073

Table 8. – MARK model survival 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 2016 and individuals released in Liberty due to limited scanning there

Zone	Period	Estimate	Lower CI	Upper CI
River	2012-2013	0.883	0.847	0.911
	2013-2014	0.890	0.853	0.918
	2014-2015	0.883	0.847	0.912
Basin	2012-2013	0.939	0.911	0.958
	2013-2014	0.943	0.916	0.961
	2014-2015	0.938	0.912	0.957

Table 9. – MARK model recapture estimates (model averaged) for razorback sucker 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	2012-2013	0.733	0.664	0.792
	2013-2014	0.630	0.574	0.683
	2014-2015	0.742	0.689	0.789
Basin	2012-2013	0.933	0.873	0.966
	2013-2014	0.783	0.730	0.828
	2014-2015	0.822	0.775	0.860

Estimated $\hat{c}$ for the same general multi-state model in 2015 was significantly greater than one, 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 goodness-of-fit of the most general model. The first test, TEST 3G.SR a test for transience, yielded significant results (Table 10) and led us to reject the null hypothesis "there is no difference in the probability of being later reencountered between 'new' and 'old' individuals encountered simultaneously" (Choquet et al. 2009). P values were significant for all occasions and states except for Basin 2013. 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 reencounter among individuals previously encountered in the different states," except for River in 2013 (Choquet et al. 2009). The ĉ ratios calculated to determine over-dispersion for the transience model were all greater than one, and overall ĉ was greater than five 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 2009).

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

Zone	Occasion	χ^2 statistic	p value	DOF
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 JMV model for River and Basin. Index of test is Fisher exact test

Zone	Occasion	χ^2 statistic	p value	DOF
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 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 among the two subpopulations (Basin and River). Although estimates of monthly transition rates indicated a net migration upstream from Basin to River subpopulations (Wisenall et al. 2015), the difference in rate of exchange on an annual basis was very small and not statistically significant as indicated by overlapping confidence intervals. The estimate of the variance inflation factor ($\hat{c}$) was significantly greater than one, indicating over-dispersion in comparison to the multinomial expectation (Lebreton et al. 1992). Although it is generally accepted that values of $\hat{c}$ less than three are acceptable (Lebreton et al. 1992, Cooch & White 2016), the source of the deviance from expected is of critical importance. Values of $\hat{c}$ greater than one can indicate a structural problem with the model or additional residual variation that is unaccounted for in the multinomial model.

Additional goodness-of-fit diagnostics were performed to determine fit of the model and the source of over-dispersion. There was significant lack of fit to the general JMV model for both 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 over-dispersion is due to 'trap-happy' or 'trap-shy' behavior. One potential source for the lack of fit is that razorback sucker 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 sucker 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 Willow Beach NFH initiated a plan to rear larger razorback sucker while minimizing potential for loss in genetic integrity, which also meant lower stocking numbers and reduction in production of other species. In the plan, approximately 9,000 razorback sucker, most with a TL greater than 400 mm, will be stocked per year after being held on station for five years. The first cohort of this new size class of razorback sucker will be released in 2018 and fish are expected to have a mean TL of 450. 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, half of the larvae collected (9,000 individuals) should come from this zone. In 2016, FWS, 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 potentially possible with increased effort.

After a three-year absence from 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 sucker on station at Willow Beach, from overcrowding, etc., there is potential for an increase in predation in the reservoir. Rainbow trout provide a food source for

[3] In March collections over the last three years, 9.5% (99 out of 1046) were fish with a 400 kHz tag (unpublished data).

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.

Although razorback sucker abundance has been relatively stable, 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 zone, 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 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 (Table 5). The size at release of these fish (mean TL of 342 mm) was well below the Lake Mohave Native Fish Workgroup target size of 500 mm and post-stocking survival was likely very low. 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). Additional years of poor post-release survival could put this subpopulation at greater risk. The current program at the hatchery to release fewer but larger razorback sucker 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 sucker stocked into lakeside backwaters prior to release into Lake Mohave are given an extra growing season and are on average greater than 400 mm TL at release. This alone may account for their relatively high contribution to capture in M&A roundup data (7 of 9 fish captured with release data) as well as PIT scanning contacts. Cohort analysis has relied on cohorts with greater than 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. 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.

As of this writing, 236,200 razorback sucker have been repatriated to Lake Mohave (LCR Native Fishes 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. 1996 a, b; 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 stock size and maintain genetic diversity. 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 it must be maintained until a successful backwater conservation strategy (Minckley et al. 2003, FWS 2005) or an alternative can be realized, and long thereafter.

RECOMMENDATIONS

Bi-annual netting operations should continue during autumn and spring monitoring to collect growth, health, census, and genetic data from wild and repatriate razorback sucker in Lake Mohave. There currently is no other mechanism to acquire these critical data.

Razorback sucker stocked into Lake Mohave should 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. Stockings should be directed spatially and temporally with the goal of assessing razorback sucker metapopulation dynamics and effect of stocking location on these dynamics. In recent years, it was recommended to distribute fish equally between 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. Individual stocking cohorts repatriated to each zone (Basin and River) should 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 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.

Remote PIT scanning deployments in River should be conducted at least monthly. Marsh & Associates staff should continue to work with Reclamation biologists to ensure a similar scanning effort in Basin as well as Liberty. 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 of Willow Beach) and zones (i.e., Katherine) as time, equipment and weather permit.

Finally, we recommend 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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