# Lower Colorado River Multi-Species Conservation Program

*Balancing Resource Use and Conservation*

# Demographics and Monitoring of Repatriated Razorback Suckers in Lake Mohave

## 2015 Annual Report

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

**December 2018**

**Work conducted under LCR MSCP Work Task D8**

# Lower Colorado River Multi-Species Conservation Program Steering Committee Members

### Federal Participant Group

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

### Arizona Participant Group

Arizona Department of Water Resources
Arizona Electric Power Cooperative, Inc.
Arizona Game and Fish Department
Arizona Power Authority
Central Arizona Water Conservation District
Cibola Valley Irrigation and Drainage District
City of Bullhead City
City of Lake Havasu City
City of Mesa
City of Somerton
City of Yuma
Electrical District No. 3, Pinal County, Arizona
Golden Shores Water Conservation District
Mohave County Water Authority
Mohave Valley Irrigation and Drainage District
Mohave Water Conservation District
North Gila Valley Irrigation and Drainage District
Town of Fredonia
Town of Thatcher
Town of Wickenburg
Salt River Project Agricultural Improvement and Power District
Unit "B" Irrigation and Drainage District
Wellton-Mohawk Irrigation and Drainage District
Yuma County Water Users' Association
Yuma Irrigation District
Yuma Mesa Irrigation and Drainage District

### Other Interested Parties Participant Group

QuadState Local Governments Authority
Desert Wildlife Unlimited

### California Participant Group

California Department of Fish and Wildlife
City of Needles
Coachella Valley Water District
Colorado River Board of California
Bard Water District
Imperial Irrigation District
Los Angeles Department of Water and Power
Palo Verde Irrigation District
San Diego County Water Authority
Southern California Edison Company
Southern California Public Power Authority
The Metropolitan Water District of Southern California

### Nevada Participant Group

Colorado River Commission of Nevada
Nevada Department of Wildlife
Southern Nevada Water Authority
Colorado River Commission Power Users
Basic Water Company

### Native American Participant Group

Hualapai Tribe
Colorado River Indian Tribes
Chemehuevi Indian Tribe

### Conservation Participant Group

Ducks Unlimited
Lower Colorado River RC&D Area, Inc.
The Nature Conservancy

# Lower Colorado River Multi-Species Conservation Program

## Demographics and Monitoring of Repatriated Razorback Suckers in Lake Mohave

## 2015 Annual Report

*Prepared by:*

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

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

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

**December 2018**

Wisenall, J.B., B.R. Kesner, C.A. Pacey, and P.C. Marsh. 2018. Demographics and Monitoring of Repatriated Razorback Suckers in Lake Mohave, 2015 Annual Report. Submitted to the Lower Colorado River Multi-Species Conservation Program, Bureau of Reclamation, Boulder City, Nevada, by Marsh & Associates, LLC, Tempe, Arizona.

# ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| $AIC_c$ | Akaike's information criterion adjusted for small sample size |
| CI | confidence interval |
| cm | centimeter(s) |
| kHz | kilohertz |
| LCR MSCP | Lower Colorado River Multi-Species Conservation Program |
| m | meter(s) |
| M&A | Marsh & Associates, LLC |
| MARK | computer program MARK |
| *M, C, R* | mark, capture, recapture |
| mm | millimeter(s) |
| n | sample size |
| PIT | passive integrated transponder |
| PVC | polyvinylchloride |
| $QAIC_c$ | Akaike's information criterion adjusted for overdispersion |
| Reclamation | Bureau of Reclamation |
| RKM | river kilometer(s) |
| TL | total length |
| USFWS | U.S. Fish and Wildlife Service |
| Willow Beach NFH | Willow Beach National Fish Hatchery |

## Symbols

| | |
|---|---|
| $\varphi$ | apparent survival |
| $\hat{c}$ | c-hat, variance inflation factor |
| $\Delta$ | difference or change in quantity |
| $>$ | greater than |
| $<$ | less than |
| $\leq$ | less than or equal to |
| % | percent |
| $\pm$ | plus or minus |
| P | recapture |
| ™ | trademark |
| $\Psi$ | transition |

# CONTENTS

Page

Executive Summary ..... ES-1

Introduction ..... 1
Methods ..... 3
Routine Monitoring ..... 5
Remote Monitoring ..... 5
Population Estimates ..... 8
Movement and Survival ..... 9
Results ..... 10
Routine Monitoring ..... 10
Remote Monitoring ..... 11
Population Estimates ..... 19
Movement and Survival ..... 19
Discussion ..... 21
Conclusions ..... 23
Acknowledgements ..... 25
Literature Cited ..... 27

## Tables

Table Page

1 Adult razorback sucker monitoring summary by capture month, PIT tag, history, and sex during December 2014 and March 2015 monitoring events, Lake Mohave, Arizona and Nevada ..... 10
2 Adult razorback sucker monitoring summary for 34 paired stocking-capture data per fish PIT tag number with calculated growth rate (capture TL in mm minus stocking TL in mm then divided by months at large) and time at large (capture date minus stocking date then divided by 30 days for months at large or 365 days for years at large) and capture history ..... 12
3 Adult razorback sucker monitoring summary, December 2014 and March 2015 ..... 13
4 Razorback suckers contacted by remote PIT scanning in 2015 that were also contacted in 2014 broken down by zone of contact in Lake Mohave, Arizona and Nevada ..... 17
5 Razorback sucker repatriation cohorts (fish released at a given location on the same date) from October 1, 2008, to September 30, 2013, and their remote PIT scanning contact rates in 2015, Lake Mohave, Arizona and Nevada ..... 18

## Tables (continued)

Table Page


6 MARK movement and survival models for adult razorback suckers, Lake Mohave, Arizona and Nevada..... 20
7 MARK model transition estimates (model averaged) for razorback suckers released in River or Basin, at large for > 730 days, and scanned in River or Basin after 2011..... 20
8 MARK model survival estimates (model averaged) for razorback suckers released in River or Basin, at large for > 730 days, and scanned in River or Basin after 2011..... 21
9 MARK model recapture estimates (model averaged) for razorback suckers released in River or Basin, at large > 730 days, and scanned in River or Basin after 2011..... 21


## Figures

Figure Page


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..... 4
2 Location of M&A and Reclamation remote PIT scanners in the River, Liberty, and Basin zones, Lake Mohave, Arizona and Nevada. ..... 7
3 Unique razorback sucker PIT tag contacts recorded from January to September 2015 at five fixed stations in the River zone, Lake Mohave, Arizona and Nevada..... 15
4 Proportion of razorback sucker PIT tag contacts in 2015 among scanning zones in Lake Mohave – Basin (maroon) and River (orange) for fish released in Liberty; there were no contacts in Liberty..... 15
5 Proportion of razorback sucker PIT tag contacts in 2015 among scanning zones in Lake Mohave – Basin (maroon) and River (orange) for fish released in River; there were no contacts in Liberty..... 16
6 Proportion of razorback sucker PIT tag contacts in 2015 among scanning zones in Lake Mohave; Basin (maroon) and River (orange) for fish released in Basin – there were no contacts in Liberty..... 17

# EXECUTIVE SUMMARY

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

Forty-four razorback suckers were handled from December 2, 2014, through March 20, 2015, with 17 captures in December and 27 captures in March. Of the 44 captures, 1 fish was captured with no original capture or stocking data in the Lower Colorado River Native Fish Database, 4 fish were without tags, and 1 fish was a wild adult. There were also three fish that were short-term recaptures: one of these fish was captured twice by Marsh & Associates, LLC, and once by the Nevada Department of Wildlife in the same week. Of the 35 remaining individuals, all were PIT-tagged repatriates with paired stocking and capture data in the database. Based on monitoring data from 2014 and 2015, it is estimated that no effective wild razorback sucker population remains in Lake Mohave. The repatriated razorback sucker population for 2014, based on 2015 March roundup data, is estimated to number 2,230 (95% confidence interval [CI] from 922 to 5,933), representing < 1% of the total number of repatriates released into Lake Mohave as of March 1, 2014.

The total deployment time for remote PIT scanners from October 1, 2014, through September 30, 2015, was 29,394 scan-hours, resulting in 98,728 PIT tag contacts representing 2,928 unique PIT tags for which 2,872 had a razorback sucker marking record in the database (as of September 30, 2015). Among fish with a marking record, 2,859 were repatriates, 11 were wild, and 2 were of unknown origin.

Lake Mohave was subdivided for analytical purposes into four stocking zones, and up- to downstream these were River, Liberty, Basin, and Katherine. Post-stocking dispersal from zone to zone over the course of the study period was limited. The majority (> 90%) of fish released in River and Basin were contacted in their zone of release regardless of release year. Razorback suckers released in Liberty were generally contacted elsewhere (River and Basin). Among the three zones scanned in 2014 and 2015 (River, Liberty, and Basin), remote PIT scanning detected little movement of razorback suckers between years, with 94% of individuals (1,498 out of 1,593) contacted in the same zone in both years. Katherine had too few stockings and captures and no scanning to evaluate dispersal.

Based on 2014 and 2015 remote PIT scanning, the 134.2-kHz PIT-tagged Lake Mohave repatriate population was estimated at 3,572 (95% CI from 3,341 to 3,818). The Basin and River subpopulation estimates based on zone-specific scanning in 2014 and 2015 were also calculated. The Basin subpopulation was estimated at 1,854 (95% CI from 1,676 to 2,051) and the River subpopulation at 2,062 (95% CI from 1,880 to 2,261). The subpopulation in Liberty was not estimated due to a lack of scanning effort there during the sampling season. Although wild fish also were contacted in Basin and River, no estimate was calculated because a limited number of recaptures was recorded.

Based on a multi-state mark-recapture model assessment in the computer program MARK, an estimated 5.2% (95% CI from 1.9 to 13.6%) of razorback suckers transitioned from Basin to River from 2014 to 2015 and 3.9% (95% CI from 0.9 to 15.0%) from River to Basin. From 2012 to 2013, apparent annual survival in Basin was estimated at 91.0% (95% CI from 86.5 to 94.2%), and in River it was estimated at 88.3% (95% CI from 83.4 to 91.9%). Apparent survival was estimated at 90.8% (95% CI from 86.6 to 93.8%) in Basin from 2013 to 2014 and 88.1% (95% CI from 82.9 to 91.8%) in River during the same time period. Survival was confounded with recapture rates and could not be estimated for 2014 to 2015.

Biannual netting efforts continue to collect growth, health, census, and genetic data for razorback suckers. Combined larval collection efforts upstream of Willow Beach collected 2,685 larvae, indicating that it may be possible to collect an equal share of larvae from River and Basin if effort is increased. Deployment of remote PIT scanners to monitor the two known subpopulation centers (River and Basin) should continue with a nominal effort similar to that applied during the past year. Additional effort should be distributed throughout the lake in an effort to determine if other aggregations of razorback suckers exist and to further evaluate the dynamics of their dispersal and distribution.

# INTRODUCTION

Lake Mohave once was home to the largest known population of wild razorback suckers (*Xyrauchen texanus*), endangered "big-river" fish endemic to the Colorado River Basin. This population contained more than 73,000 fish from 1980 to 1993 (Marsh 1994), but numbers declined to < 100 individuals by 2010 (Dowling et al. 2014). The most recent estimates are fewer than 25 wild fish (Marsh et al. 2003; Turner et al. 2007, unpublished data), and today, too few individuals persist to reliably estimate their numbers. A repatriation program to restore razorback suckers in Lake Mohave was established in the early 1990s (Mueller 1995). The program utilizes wild larvae that are produced naturally in the lake, then harvested, reared in protective captivity, and repatriated to the reservoir after growing to a nominal size of 300 millimeters (mm) total length (TL) or more.

There have been a number of adjustments to the program that incorporate new information to increase the survival of stocked fish, primarily an increased size of stocked fish to reduce predation mortality, but results thus far have not met expectations (Marsh et al. 2005, 2015). A recommended minimum stocking TL of 500 mm to increase post-stocking survival and population size has proven difficult to produce in sufficient numbers (M. Olson 2009, personal communication), and even fish of this size are subject to predation (Karam and Marsh 2010).

The Lower Colorado River Multi-Species Conservation Program (LCR MSCP) currently oversees and funds stocking and monitoring of razorback suckers in Lake Mohave. Stocking razorback suckers into Lake Mohave from the Willow Beach National Fish Hatchery (Willow Beach NFH) (Bureau of Reclamation [Reclamation] 2015, Work Task B2) and from lakeside ponds (Reclamation 2015, Work Task B7) is conducted under the Fish Augmentation component of the program (Reclamation 2006). The Lake Mohave repatriation program is one element of an overall conservation plan for razorback suckers within the LCR MSCP. This program, and other conservation plans upon which it was based (Minckley et al. 2003; U.S. Fish and Wildlife Service [USFWS] 2005), incorporate a population component that will occupy the lower Colorado River main stem, but it may be impractical or impossible to accommodate that component. It is an objective of the research and monitoring portion of the Lake Mohave razorback sucker program, the subject of this report, to provide information needed to determine how such a strategy should contribute to maintenance of this endangered species both in Lake Mohave and throughout the lower Colorado River. Moreover, the results of this research provide critical demographic information and management recommendations to help ensure long-term persistence of a genetically viable stock of adult razorback suckers in Lake Mohave.

In prior years, 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, survival of subadult razorback suckers (mean TL 380 mm) varied from 7% (1 of 15 fish; Kesner et al. 2008a), to 67% (6 of 9 fish) (Kesner et al. 2012) for fish released just 1 year apart. Mark-recapture models that included annual variations in survival failed to provide accurate estimates due to the low recapture rate in annual March data (Marsh et al. 2005). Traditional sampling approaches, such as an increase in intensive trammel netting, are less than ideal strategies due to budget and personnel limitations, habitat constraints, the potential to repeatedly capture the same individuals, and the availability of a viable alternative. The repatriate population now is comprised primarily of individuals containing 134.2-kilohertz (kHz) passive integrated transponder (PIT) tags, so remote PIT scanning can be used to accurately estimate the population size and answer fundamental demographics questions that will improve ongoing conservation strategies (Kesner et al. 2008b).

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

1. Locating and capturing adult razorback suckers.

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

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

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

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

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

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

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

9. Providing monthly progress reports summarizing all field, laboratory, or office work completed in the course of this effort.

10. Providing copies of all datasets generated in the course of this work to the designated Reclamation Contracting Officer's Technical Representative.

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

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

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

This report summarizes the first year of data in behalf of a new agreement as part of ongoing demographic and post-stocking survival studies of repatriated razorback suckers in Lake Mohave. Population estimates for wild and repatriate populations were updated based on results from standard monitoring; repatriate population estimates include remote PIT scanning data collected in the Basin and lotic portions of the lake, and survival and transition were estimated for the Basin and lotic 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. 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).

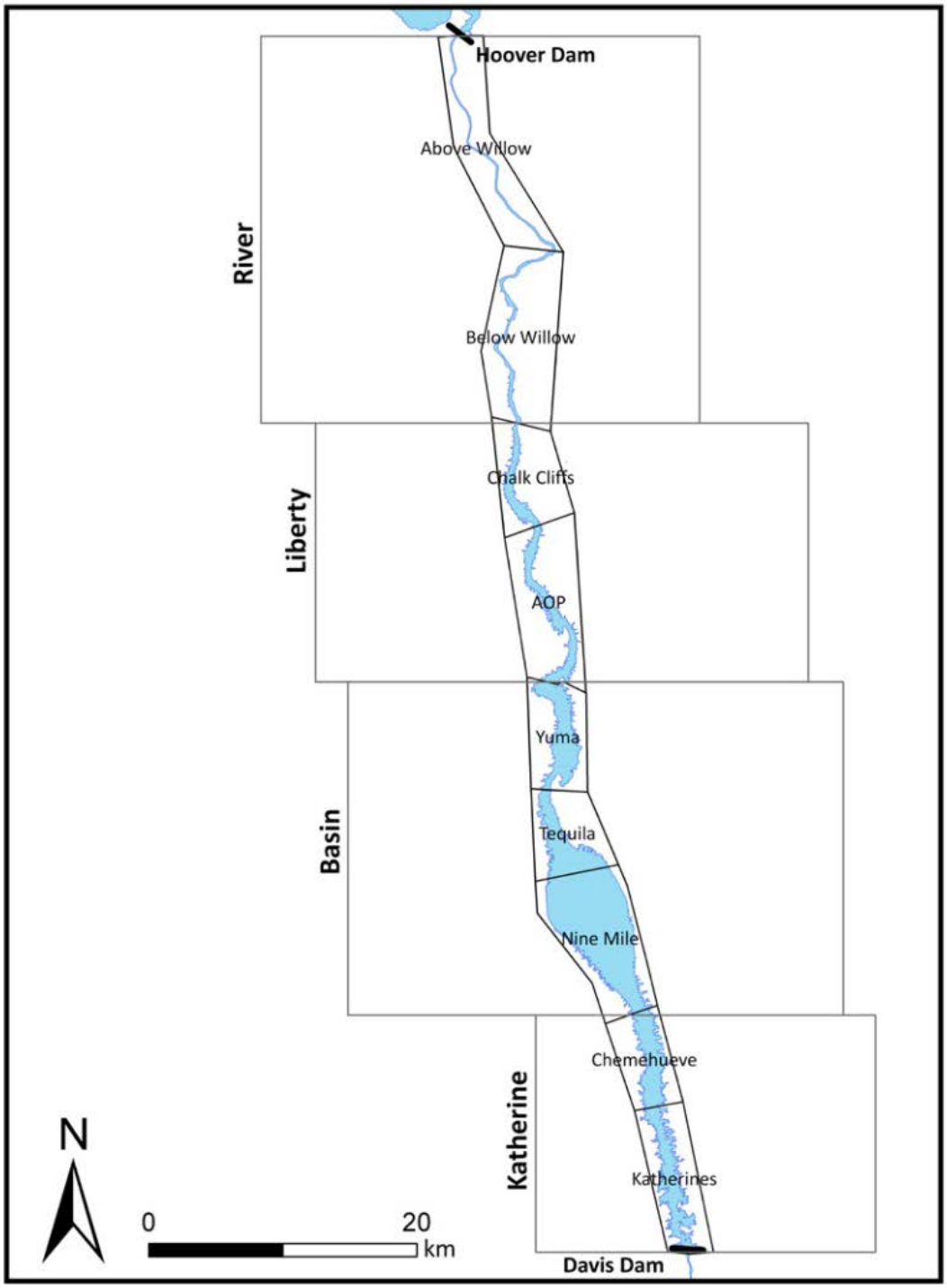


**Figure 1.—Map of Lake Mohave, Arizona and Nevada, depicting two zoning schemes, general (large boxes) and specific (smaller boxes); only the former are used in this report.**

# 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 2014 and March 2015, Marsh & Associates, LLC (M&A), occupied a field camp on Lake Mohave at Carp Cove, Arizona (the Basin zone), near River Mile 298 (miles upstream of the Southerly International Boundary with Mexico) for 4 to 5 days at a time. At each sampling event, as many as six trammel nets (four to six, 91.4 meters [m] long x 1.8 m wide with 3.8-centimeter [cm] stretch mesh and up to two 45.7 m long x 1.8 m wide with 3.8-cm stretch mesh) were fished continuously along the Arizona shoreline from Pot Cove upstream to Carp Cove.

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

# Remote Monitoring

Remote PIT scanning systems were deployed 1 week of every month during the 2015 sampling season on shallow gravel bars that extend into the Colorado River upstream of Willow Beach (the River zone; objective 5). Three models of PIT scanners were utilized. One type of unit (shore based) is comprised of an antenna and scanner housed in a 2.3 x 0.7 m polyvinylchloride (PVC) frame connected by 45.7 m of cable to a waterproof box that protected the logger and battery and was secured to shore. A 6-volt, 12 ampere-hour sealed lead acid battery and a solar panel provided power to the scanner, eliminating the need for manually removing and charging the battery more than once per month. The unit started scanning at 18:00 hours, ran for 24 hours, and stopped scanning for 24 hours. This cycle was repeated 3 weeks per month. During the week of active PIT scanning in River, this unit was allowed to scan continuously (24 hours per day). Two models of sinking submersible units were employed (0.8 x 0.8 m and 1.2 x 0.8 m) and were comprised of a PVC frame antenna attached to a scanner and logger contained in watertight PVC piping. Power to submersible units was provided by a 20.8 ampere-hour lithium-ion battery pack contained in a watertight, 2-inch (5.08-cm) PVC pipe. Submersible units scanned continuously for up to 96 hours, but the batteries were generally changed every 24 hours. Five to six submersible units were employed throughout the monitoring season.

Five locations established in 2013 as fixed sites were Gio's Point, Black Bar, Sauna Cave, Ringbolt Rapids, and Boy Scout Canyon (figure 2), and each received at least one submersible deployment per day each sampling trip. These fixed deployments were created to test the hypothesis that razorback sucker aggregation sites change over the course of the year, centering on Black Bar during spawning, but shifting upstream toward Hoover Dam as the spawning season ends. The sites were all initially examined and evaluated in 2011, PIT scanned periodically in 2011 and 2012, and determined to be utilized by razorback suckers at different times of the year. One shore-based device was deployed throughout the 2015 sample season at Boy Scout Canyon. The deployment locations of additional scanners not set at fixed sites varied between trips depending on observed or reported fish concentrations. Scanner units monitored fish presence monthly from January through September for 4 nights and 3 days (approximately 90 continuous hours) each trip.

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

Remote PIT scanning in Basin and Liberty (see figure 1) was conducted by Reclamation with support from M&A (objective 5). Semipermanent shore-based devices were deployed in Basin for continuous scanning from 2014 to 2015. One shore-based PIT scanner was deployed at Tequila Cove. The unit operated continuously from November 2014 to May 2015 and was powered by a deep-cycle marine battery and a 60-watt solar panel. Two shore-based devices were also deployed in Basin at Yuma Cove and attached to the solar aeration system for power.

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

Post-stocking contact rates for PIT-tagged repatriated razorback suckers that were released from October 1, 2008, through September 30, 2013, were summarized. The beginning of this interval marks the consistent use of 134.2-kHz PIT tags in Lake Mohave, and in order to ensure that an individual is a fully recruited member of the Lake Mohave population, only those fish that have been at large

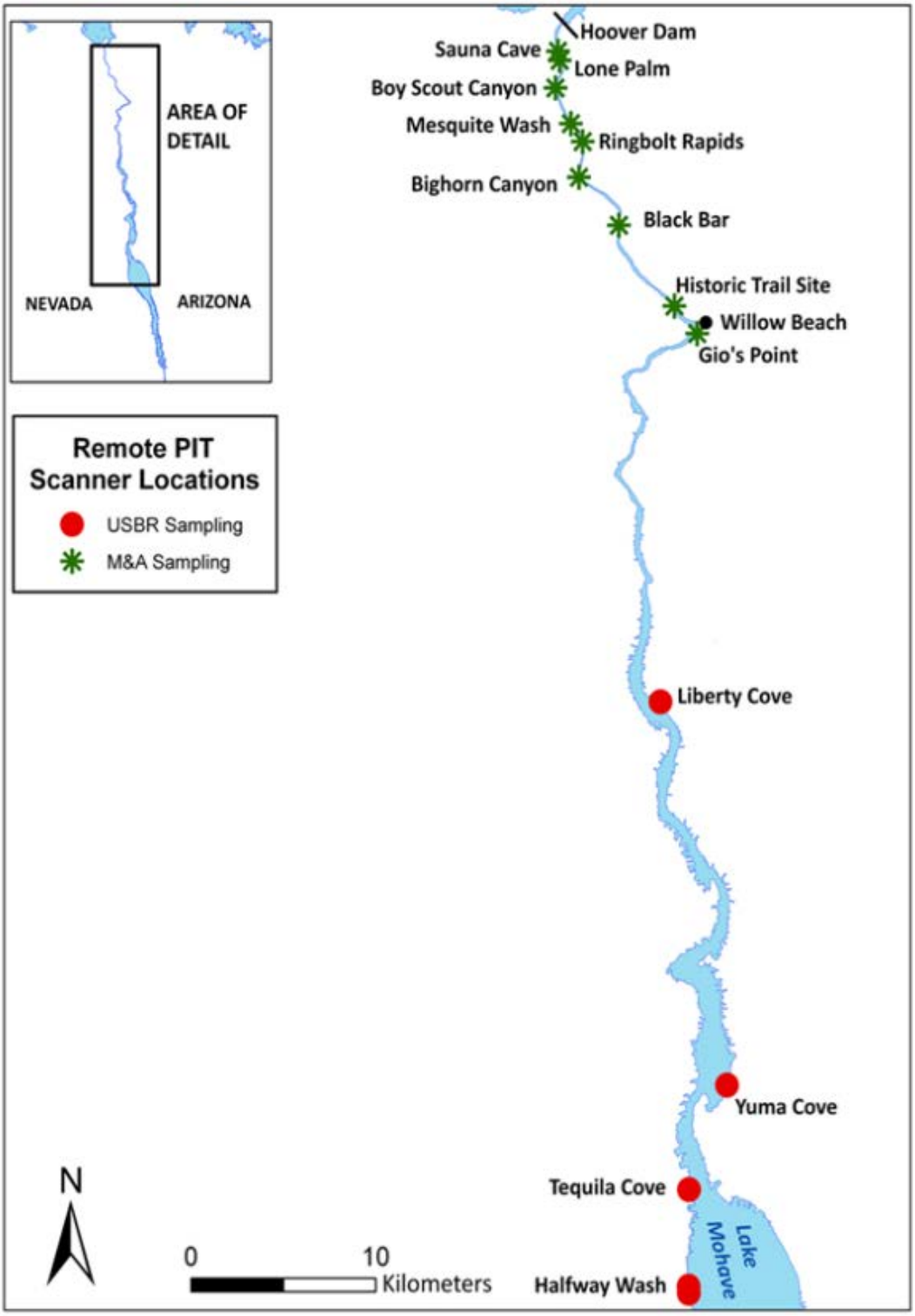


**Figure 2.—Location of M&A and Reclamation remote PIT scanners in the River, Liberty, and Basin zones, Lake Mohave, Arizona and Nevada.**

for 1 year prior the beginning of the scanning year are included in the analysis. Release records were grouped into "cohorts" based on the location and date of release. Contact data within each cohort were tabulated for all fish contacted by remote PIT scanning for the 2015 sample year. The sample year followed the same fiscal calendar as routine monitoring (October 1, 2014, through September 30, 2015) since scanning in Basin started as early as November. The proportion of each cohort that was contacted in 2015 was calculated as a relative index of long-term survival of each cohort. This comparison assumes that all razorback suckers alive in Lake Mohave with a 134.2-kHz PIT tag have an equal probability of encountering a PIT scanner over the course of the scanning year. These fish are considered "available" to PIT scanning equipment. Cohorts with fewer than 100 fish released were excluded from tabulation to reduce the probability that differences in contact proportion were due to chance alone.

## Population Estimates

The razorback sucker population in Lake Mohave was estimated from two data sources (objective 7). First, March monitoring data[1] were used to estimate overall populations of wild and repatriated fish in Lake Mohave using mark-recapture (objective 8). Data for population estimates from capture data were restricted to encounters in March because the highest number of encounters with razorback suckers occurs then, and the marking event must be short relative to the interval between marking and capturing events to meet assumptions of the estimate (Ricker 1975). Second, remote PIT scanning data were used to estimate the population size for the lake-wide population as well as the River, Basin, and Liberty subpopulations of repatriated and wild razorback suckers with 134.2-kHz PIT tags in 2014. PIT scanning data for the marking period were restricted to March, but the capture period was extended to include the entire scan year, with the assumption that only deletions (mortality and emigration) occur. Remote PIT scanning and routine monitoring data were treated separately for repatriate estimates because some repatriate razorback suckers contain only a 400-kHz tag, which is rarely detected by remote PIT scanners. Combining the two sources would not accurately estimate the repatriate population.

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

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

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

For each mark-recapture estimate, the number of individual PIT tags contacted in March of the previous population year was the mark (*M*), the number contacted in the current population year the capture (*C*), and the number in common between both years the recaptures (*R*). Any contacts with razorback suckers released after the initiation of the marking year (January 1 of the previous population year) were removed from the population estimates. 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 (CIs) were derived using Poisson approximation tables and *R* as the entering variable (Seber 1973).

## Movement and Survival

A multi-state mark-recapture model was developed within the computer program MARK (MARK) to estimate transition (movement) and survival of adult razorback suckers between the River and Basin zones of Lake Mohave. Included in the model were individuals at large for at least 730 days (2 years) and scanned in River or Basin from January through March from 2012 to 2015. Individuals that were scanned in 2015 only were removed from the model; to be included they must also have been scanned in a previous year. 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 ($\varphi$), recapture (P), and transition ($\Psi$). These parameters can vary with time, age, and state (zone). For this model, age was not considered a factor. Razorback suckers included in the model were at large for more than 2 years prior to being observed (PIT scanned), and all were assumed to be members of an adult age class.

The multi-state model included two states (zones) coded numerically depending on where fish were scanned: 1 – River and 2 – Basin. Capture histories were derived for fish scanned as a series of 0s, 1s, and 2s: 0 – not observed, 1 – observed in River, and 2 – observed in Basin. There were four encounter occasions, one per year from 2012 to 2015; 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., $\varphi$ state*time). Three time periods (2012 to 2013, 2013 to 2014, and 2014 to 2015) resulted in the maximum number of parameters in the most general model at 16 (3 time periods x 2 locations x 3 parameter groups minus 2 confounded survival estimates). Comparison models included additive and interactive effects of time and state

as well as models that constrain time and state to be constant. The recapture rate was consistently modeled to vary with time and state because PIT scanning efforts varied between both. Models were ranked within MARK based on an Akaike's information criterion score (Akaike 1974). This value reported in MARK is a modified value ($AIC_c$) that adjusts for small sample sizes (Burnham and Anderson 2002). $AIC_c$ was adjusted for overdispersion with the median estimate of the variance inflation factor ($\hat{c}$; c-hat) when appropriate ($QAIC_c$) (Cooch and White 2016). Reported parameter values were based on the highest ranked model (lowest $AIC_c$ or $QAIC_c$) when the $QAIC_c$ weight for the top model was > 0.9 (Johnson and Omland 2004); otherwise, the estimates were based on model averaging.

# RESULTS

## Routine Monitoring

Forty-four razorback suckers were handled during 2014 and 2015 monitoring events, with March 2015 and December 2014 monitoring activities accounting for 61% (n = 27) and 39% (n = 17) of the captures, respectively (table 1). Four captures were excluded from further analysis, including one capture in December that was a short-term recapture (i.e., captured again within 7 days of first capture), and three short-term recaptures in March. The sex was determined for fish at capture, and of the remaining individuals, the majority captured were female (n = 28), 10 were male, and 1 was a juvenile (table 1). Most of the fish captured were PIT tagged (n = 35), and all but 1 were repatriates (n = 38) (table 1). The 4 fish without PIT tags and the single wild adult were excluded, yielding 34 fish for further analyses.

Table 1.—Adult razorback sucker monitoring summary by capture month, PIT tag, history, and sex during December 2014 and March 2015 monitoring events, Lake Mohave, Arizona and Nevada

| | | PIT tag? | | History | | Sex | | |
|---|---|---|---|---|---|---|---|---|
| **Capture month (year)** | **Total** | **Yes** | **No** | **Repatriate** | **Wild** | **Female** | **Male** | **Juvenile** |
| December (2014) | 17[a] | 13 | 3 | 15 | 1 | 13 | 3 | 0 |
| March (2015) | 27[b] | 22 | 1 | 23 | 0 | 15 | 7 | 1 |
| **Total** | **44[c]** | **35** | **4** | **38[d]** | **1** | **28** | **10** | **1** |

[a] One short-term recapture included here in the number of fish but not in the remaining tables.
[b] Three short-term recaptures and one fish with no original capture or stocking data in the database included here in the number of fish but not in the remaining tables.
[c] Five fish included here in the number of fish as reported above but not in the remaining tables.
[d] Four fish captured without PIT tags were marked as a "repatriate" in the database.

Of the PIT-tagged repatriates with paired data (i.e., fish with both stocking and capture data, n = 34), 2 fish were < 350 mm TL at stocking, 23 fish were 350 to 450 mm TL at stocking, and 8 fish were > 450 mm TL at stocking (table 2); 1 fish had no TL at stocking. The average TL at stocking was 418 mm, while the average TL at capture was 580 mm, with 1 fish < 350 mm TL, 3 fish ≤ 475 mm TL, and 30 fish > 475 mm TL at capture. Males (n = 5) and females (n = 25) appeared to exhibit similar growth over their time at large, both ranging from < 1 to 11 mm/month. One fish was a juvenile, with no change in TL during its time at large of 72 days. Two males had no growth per month, as one was at large only 11 days, while the other's capture TL was 8 mm less than at stocking (reported as < 1 mm/month in the table). The single fish with no TL at stocking was female, and growth over time could not be determined. The average growth rate of the remaining 30 fish was approximately 4 mm/month. Years at large for all fish ranged from < 1 to 18 years, with an average time of 6 years. Five fish at large for < 1 year were at large < 1 to 10 months prior to their capture. Twenty-nine fish were captured during 2014/2015 monitoring for the first time since their stocking into Lake Mohave, with one fish at large for 18 years prior to its first capture. Twenty-one fish with year-class information were approximately 1 to 5 years old at stocking, with an approximate average of 3 years old at stocking; one fish was from a mixed batch of year-classes, and its approximate age at stocking was not considered.

Lakeside backwaters and offsite facilities each contributed 17 fish to the PIT-tagged repatriates with paired data (table 3). Fish were reared at four different backwaters, Arizona Juvenile, Dandy, North Chemehuevi, and Yuma, and all were stocked into the main channel adjacent to these locations. Offsite rearing facilities included the Achii Hanyo Fish Hatchery, Boulder City Wetlands Park, Bubbling Pond Fish Hatchery, Lake Mead Fish Hatchery, and the Willow Beach NFH. Fish reared in lakeside backwaters traveled an average of 8 river kilometers (RKM) from stocking to capture site, while fish reared in offsite facilities traveled an average of 19 RKM.

Based on monitoring data from 2014 and 2015, it is estimated that there is no wild razorback sucker population remaining in Lake Mohave. The estimated repatriate razorback sucker population is 2,230 (95% CI from 922 to 5,963).

# Remote Monitoring

Sampling units were deployed in Lake Mohave for 29,323 hours of scanning time: 12,916 hours using shore-based devices and 16,407 hours with submersible scanners. The 2015 scanning year resulted in 98,728 total contacts, 2,928 of which were unique PIT tags, with 2,872 of those having a marking history in the Lower Colorado River Native Fish Database. Among fish with a marking record, 2,859 were repatriates, 11 were wild, and 2 were of unknown origin.

Table 2.—Adult razorback sucker monitoring summary for 34 paired stocking-capture data per fish PIT tag number with calculated growth rate (capture TL in mm minus stocking TL in mm then divided by months at large) and time at large (capture date minus stocking date then divided by 30 days for months at large or 365 days for years at large) and capture history
(Data are in order by number of captures, then capture date, and include year-class information where available. The release date is when fish were stocked into Lake Mohave.)

| | Date | | TL (mm) | | | Capture history | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| PIT tag | Release | Capture | Release | Capture | Growth rate/month | Sex | Days at large | Months at large | Years at large | Number of captures | Comments |
| 003BA63ECB[a] | 1/14/14 | 12/2/14 | 350 | 475 | 11 | M | 322 | 11 | < 1 | 1 | First capture in 2014 |
| 36F2B5A1F3[b] | 12/6/12 | 12/2/14 | 430 | 541 | 5 | F | 726 | 24 | 2 | 1 | First capture in 2014 |
| 1C2D6CD55A[c] | 10/12/11 | 12/2/14 | 445 | 640 | 5 | F | 1,147 | 38 | 3 | 1 | First capture in 2014 |
| 36F2B5A66F[b] | 12/6/12 | 12/3/14 | 430 | 590 | 7 | F | 727 | 24 | 2 | 1 | First capture in 2014 |
| 1B796EECA8[c] | 10/28/11 | 12/3/14 | 440 | 589 | 4 | F | 1,132 | 38 | 3 | 1 | First capture in 2014 |
| 1B796EF477[d] | 5/6/13 | 12/3/14 | 455 | 585 | 7 | F | 576 | 19 | 2 | 1 | First capture in 2014 |
| 257C61D63E[c] | 5/19/10 | 12/3/14 | 470 | 625 | 3 | F | 1,659 | 55 | 5 | 1 | First capture in 2014 |
| 1B796ED99D[d] | 5/6/13 | 12/4/14 | 420 | 585 | 9 | F | 577 | 19 | 2 | 1 | First capture in 2014 |
| 1B796EE831[d] | 5/6/13 | 12/4/14 | 430 | 580 | 8 | F | 577 | 19 | 2 | 1 | First capture in 2014 |
| 1C2C840A18[e] | 3/16/11 | 12/4/14 | – | 645 | – | F | 1,359 | 45 | 4 | 1 | First capture in 2014 |
| 2241216911[c] | 10/23/96 | 3/17/15 | 306 | 625 | 1 | M | 6,719 | 224 | 18 | 1 | First capture in 2015 |
| 5216245249[f] | 8/13/99 | 3/17/15 | 360 | 574 | 1 | F | 5,695 | 190 | 16 | 1 | First capture in 2015 |
| 4646761253[g] | 3/29/05 | 3/17/15 | 390 | 675 | 2 | F | 3,640 | 121 | 10 | 1 | First capture in 2015 |
| 003BA7448C[h] | 5/13/14 | 3/17/15 | 420 | 525 | 10 | F | 308 | 10 | < 1 | 1 | First capture in 2015 |
| 1B796EEFF9[i] | 10/31/13 | 3/17/15 | 500 | 575 | 4 | F | 502 | 17 | 1 | 1 | First capture in 2015 |
| 003BCC5C34[j] | 1/5/15 | 3/18/15 | 390 | 390 | 0 | J | 72 | 2 | < 1 | 1 | First capture in 2015 |
| 1B796B41D9[k] | 10/16/12 | 3/18/15 | 430 | 579 | 5 | M | 883 | 29 | 2 | 1 | First capture in 2015 |
| 1C2D269177[l] | 10/23/09 | 3/18/15 | 435 | 560 | 2 | F | 1,972 | 66 | 5 | 1 | First capture in 2015 |
| 5333403056[m] | 6/17/04 | 3/19/15 | 330 | 642 | 2 | F | 3,927 | 131 | 11 | 1 | First capture in 2015 |
| 003BA62D97[n] | 3/9/15 | 3/19/15 | 350 | 342 | < 1 | M | 10 | <1 | < 1 | 1 | First capture in 2015 |
| 1C2D6C6905[c] | 10/12/11 | 3/19/15 | 450 | 641 | 3 | F | 1,254 | 72 | 3 | 1 | First capture in 2015 |
| 1C2D067132[o] | 5/11/11 | 3/19/15 | 465 | 625 | 3 | F | 1,408 | 47 | 4 | 1 | First capture in 2015 |
| 003BA62D65[n] | 3/9/15 | 3/20/15 | 355 | 360 | < 1 | M | 11 | <1 | < 1 | 1 | First capture in 2015 |
| 436478455A[m] | 4/14/04 | 3/20/15 | 355 | 570 | 2 | M | 3,992 | 133 | 11 | 1 | First capture in 2015 |
| 36F2B5A67A[b] | 12/6/12 | 3/20/15 | 390 | 520 | 5 | M | 834 | 28 | 2 | 1 | First capture in 2015 |
| 42403A6F62[f] | 5/22/01 | 3/20/15 | 420 | 670 | 1 | F | 5,050 | 168 | 14 | 1 | First capture in 2015 |
| 1B796ED90F[c] | 10/28/11 | 3/20/15 | 455 | 595 | 2 | F | 1,239 | 71 | 3 | 1 | First capture in 2015 |
| 1C2D8C9FEB[p] | 5/16/12 | 3/20/15 | 473 | 627 | 4 | F | 1,038 | 35 | 3 | 1 | First capture in 2015 |
| 46466C1A49[c] | 4/26/06 | 3/20/15 | 490 | 620 | 1 | F | 3,250 | 108 | 9 | 1 | First capture in 2015 |
| 46486F1069[q] | 6/8/05 | 12/3/14 | 365 | 620 | 2 | F | 3,465 | 115 | 9 | 2 | First capture in 2009, second in 2014 |
| 1C2D265EC1[l] | 10/23/09 | 12/3/14 | 430 | 595 | 3 | F | 1,867 | 62 | 5 | 2 | First capture in 2010, second in 2014 |
| 1C2C7FE9B4[l] | 3/26/09 | 3/19/15 | 450 | 640 | 3 | F | 2,184 | 72 | 6 | 2 | First capture in 2012, second in 2015 |
| 1C2D63A268[r] | 12/3/09 | 3/20/15 | 445 | 635 | 3 | F | 1,933 | 64 | 5 | 2 | First capture in 2014, second in 2015 |
| 1C2D69590E[s] | 9/29/10 | 3/20/15 | 480 | 645 | 3 | F | 1,633 | 54 | 4 | 3 | First capture in 2011, second in 2012, third in 2015 |
| | | **Average** | **418** | **580** | **4** | **–** | **1,814** | **66** | **6** | **1** | |

[a] 2011 year-class; reared at Willow Beach NFH.
[b] 2010 year-class; reared at Achii Hanyo Fish Hatchery.
[c] No year-class; reared at Yuma Cove.
[d] 2009 year-class; reared at Arizona Juvenile.
[e] 2007 year-class; reared at Willow Beach NFH.
[f] No year-class; reared at Boulder City Wetlands Park.
[g] 2001/2003 year-class; reared at Willow Beach NFH.
[h] 2011 year-class; reared at Arizona Juvenile.
[i] 2009 year-class; reared at North Chemehuevi Cove.
[j] 2012 year-class; reared at Willow Beach NFH.
[k] 2008 year-class; reared at North Chemehuevi Cove.
[l] 2005 year-class; reared at Bubbling Ponds Fish Hatchery.
[m] No year-class; reared at Willow Beach NFH.
[n] 2010 year-class; reared at Lake Mead Fish Hatchery.
[o] 2007 year-class; reared at Arizona Juvenile.
[p] 2008 year-class; reared at Arizona Juvenile.
[q] No year-class; reared at Dandy Cove.
[r] 2008 year-class; reared at Achii Hanyo Fish Hatchery.
[s] 2006 year-class; reared at Dandy Cove.

Table 3.—Adult razorback sucker monitoring summary, December 2014 and March 2015

(Data are for 34 fish with paired release-capture data by rearing type and location and release and capture locations. The release location is where fish were stocked into Lake Mohave. Data are in alphabetical order of rearing type and location.)

| Rearing | | Release | | | | Capture | | | | Distance traveled (change in RKM) | Fish (n) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Type | Location | Location | State[1] | RKM | Zone | Location | State[1] | RKM | Zone | | |
| Lakeside backwaters | Arizona Juvenile | Lakeside at Arizona Juvenile | AZ | 24 | Basin | Cottonwood Cove East (1st point south of north point) | AZ | 32 | Basin | 8 | 3 |
| | | | | | | Waterwheel Cove | | | | | 2 |
| | | | | | | Waterwheel Cove (north of) | | | | | 1 |
| | Dandy | Lakeside at Dandy | NV | 26 | | Cottonwood Cove East (1st point south of north point) | | | | 5 | 1 |
| | | | | | | Waterwheel Cove (north of) | | | | 6 | 1 |
| | North Chemehuevi | Lakeside at North Chemehuevi | | 19 | | Carp Cove | | 33 | | 14 | 1 |
| | | | | | | Waterwheel Cove | | 32 | | 13 | 1 |
| | Yuma | Lake Mohave at Yuma Cove | AZ | 39 | | Carp Cove | | 33 | | 6 | 1 |
| | | | | | | Cottonwood Cove East | | 32 | | 7 | 1 |
| | | | | | | Cottonwood Cove East (1st point south of north point) | | | | | 3 |
| | | | | | | Waterwheel Cove | | | | | 2 |
| **Average distance traveled** | | | | | | | | | | **8** | **17** |
| Offsite facilities | Achii Hanyo Fish Hatchery | Cottonwood Cove | NV | 37 | Basin | Carp Cove (north point) | AZ | 34 | Basin | 3 | 1 |
| | | | | | | Cottonwood Cove East | | 32 | | 5 | 1 |
| | | | | | | Cottonwood Cove East (1st point south of north point) | | | | | 2 |
| | Boulder City Wetlands Park | | | | | Carp Cove | | 33 | | 4 | 1 |
| | | Nelson's Landing | | 64 | River | Waterwheel Cove | | 32 | | 32 | 1 |
| | Bubbling Ponds Fish Hatchery | Cottonwood Cove | | 37 | Basin | | | | | 5 | 1 |
| | | Willow Beach boat ramp | AZ | 84 | River | Cottonwood Cove East (1st point south of north point) | | | | 52 | 1 |
| | | | | | | Waterwheel Cove | | | | | 1 |
| | Lake Mead Fish Hatchery | Valhalla Cove | NV | 26 | Basin | | | | | 6 | 2 |
| | Willow Beach NFH | Cottonwood Cove | | 35 | | Carp Cove | | 33 | | 2 | 1 |
| | | Liberty Cove | AZ | 62 | Liberty | Cottonwood Cove East (1st point south of north point) | | 32 | | 30 | 1 |
| | | Oro, Elizabeth, and Fortune Coves | NV | 66 | River | Carp Cove (north point) | | 34 | | 32 | 1 |
| | | | | | | Waterwheel Cove | | 32 | | 34 | 1 |
| | | Princess Cove | AZ | 8 | Katherine | Cottonwood Cove East (1st point south of north point) | | | | 24 | 1 |
| | | Red Tail Cove | | 53 | Liberty | Waterwheel Cove | | | | 21 | 1 |
| **Average distance traveled** | | | | | | | | | | **19** | **17** |

[1] AZ = Arizona, and NV = Nevada.

Remote PIT scanning in River resulted in 6,385 hours of scanning: 1,262 hours with shore-based devices and 5,123 hours with submersible units. Mean deployment times were 80.2 hours and 23.2 hours for shore-based devices and submersible scanners, respectively. Among 11,269 total contacts, 1,549 were unique PIT tags, and 1,534 of those were in the Lower Colorado River Native Fish Database. Repatriated razorback suckers accounted for 1,526 tags with a marking record, and 8 were noted as wild individuals.

Contacts at fixed station sites in River were compared during the sampling season. Of a possible 180 fixed site replicates (9 trips x 5 sites x 4 replicates[2]), 174 replicates were available for analyses. The January trip had only 3 nights of scanning, which accounts for five missing from the total number of replicates available. In April 2015, Ringbolt Rapids only had 3 overnight scanning deployments due to weather conditions and accounts for one replicate missing from the total. All other trip and location combinations had four replicates. The most contacts were observed at Black Bar during the first 4 months of sampling, becoming fewer in subsequent months (figure 3). Boy Scout Canyon had the most contacts in three of the remaining five sample periods.

Remote PIT scanners in Liberty were deployed for 179 hours of upscanning: 108 hours with submersible units and 71 hours with a single Destron Fearing™ (Destron) PIT scanner deployment. The mean deployment time for submersible scanners was 21.7 hours. Six PIT tag contacts were recorded, representing two unique razorback suckers, both of which had a marking history and were repatriates.

Both shore-based and submersible models were deployed for scanning in Basin and accumulated 22,829 hours of scanning: 11,654 hours with shore-based devices and 11,175 hours with submersible units. Mean deployment times for shore-based devices and submersible units were 215.8 hours and 90.9 hours, respectively. A total of 87,453 PIT tags were recorded, representing 1,510 unique PIT tags for which 1,468 had a marking record in the Lower Colorado River Native Fish Database. Repatriated razorback suckers accounted for 1,463 of the unique encounters, 3 were wild, and 2 were of unknown origin.

Post-stocking dispersal out of the zone of release was minimal for two of the three main stocking zones, excluding those that were stocked into Liberty (figure 4). Of the 2,872 razorback suckers contacted in 2015 with a marking record, only 2,322 razorback suckers met the criteria for further analyses (repatriate released between October 1, 2008, and September 30, 2013, with a 134.2-kHz tag). Eliminating an additional 107 fish contacted in multiple zones, 1,239 (53.4%) were released into River. The majority (> 80%) of these fish were contacted in River for all release years except 2013 (figure 5). Only 27 fish released in 2012 were contacted in 2015, and only 4 fish released in 2013 were contacted. The

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

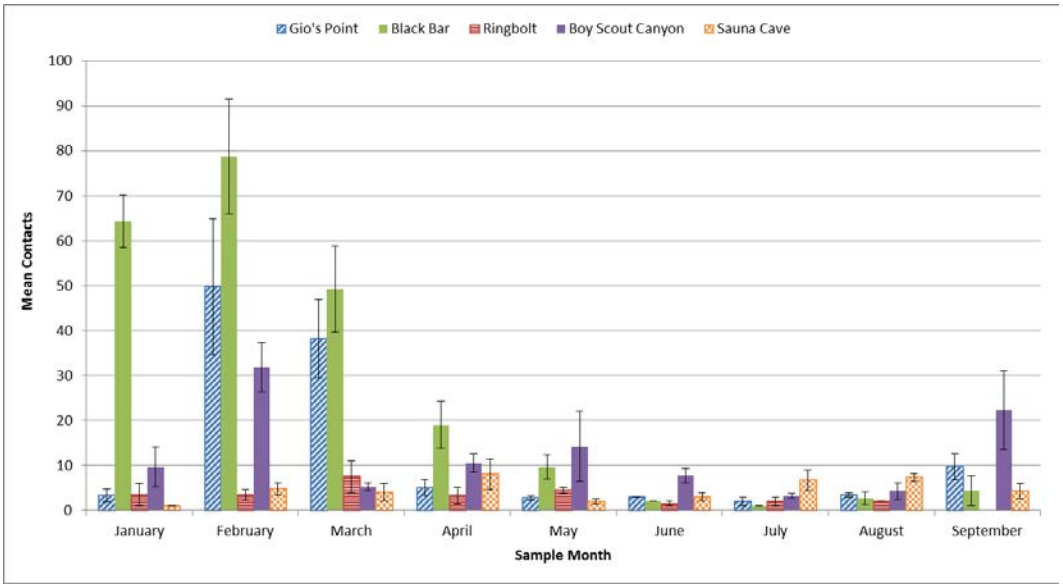


**Figure 3.—Unique razorback sucker PIT tag contacts recorded from January to September 2015 at five fixed stations in the River zone, Lake Mohave, Arizona and Nevada.**
Error bars represent ±1 standard error. n = 4 except for all sites in January and Ringbolt Rapids in April (n = 3).

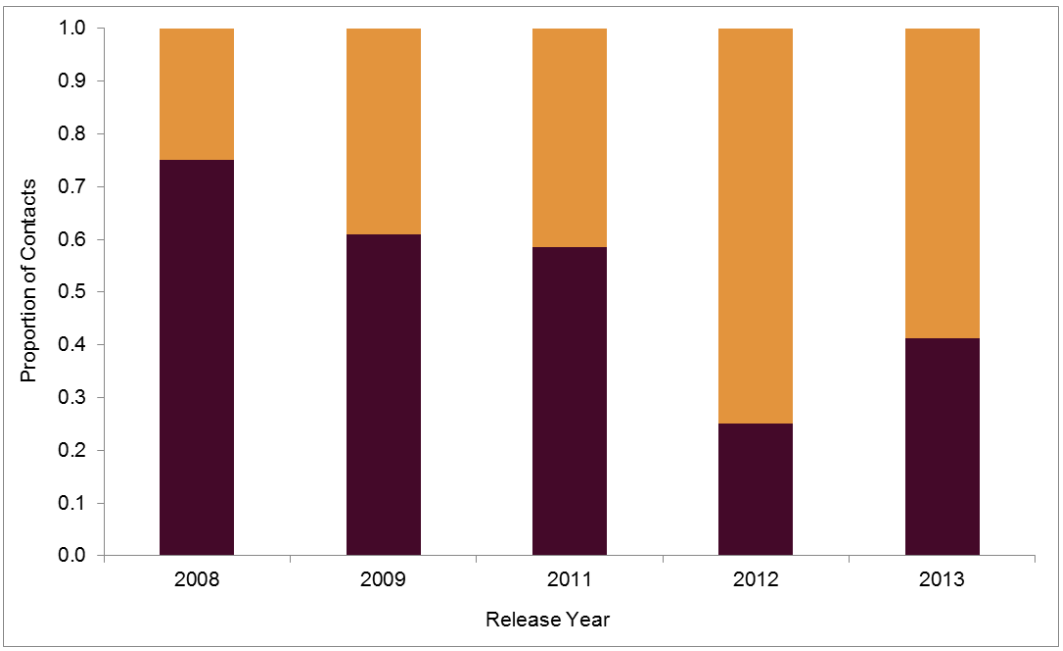


**Figure 4.—Proportion of razorback sucker PIT tag contacts in 2015 among scanning zones in Lake Mohave – Basin (maroon) and River (orange) for fish released in Liberty; there were no contacts in Liberty.**
Fish were released between October 1, 2008, and October 1, 2013, and contacted during PIT scanning activities from October 1, 2014, to September 30, 2015.

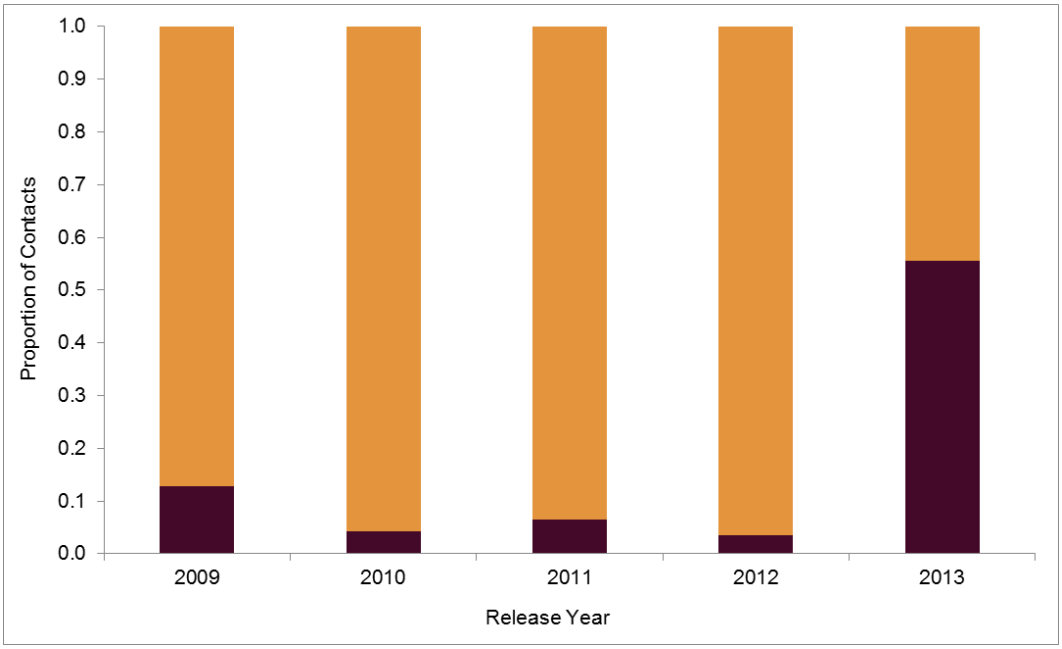


**Figure 5.—Proportion of razorback sucker PIT tag contacts in 2015 among scanning zones in Lake Mohave – Basin (maroon) and River (orange) for fish released in River; there were no contacts in Liberty.**
Fish were released between October 1, 2008, and October 1, 2013, and contacted during PIT scanning activities from October 1, 2014, to September 30, 2015.

same trend was also noted in Basin, where more than 80% of the individuals were contacted in their zone of release regardless of release year (figure 6). Basin-released fish accounted for 33.3% (738) of the razorback suckers contacted. PIT scanning was not conducted in Katherine in 2015; however, 69 fish released there were contacted in Basin, and 8 were contacted in River.

Adult subpopulations in River, Liberty, and Basin exchanged few individuals from 2014 to 2015 (table 4). Among 1,653 razorback suckers contacted in both years, 1,549 (93.7%) 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 (26 fish; 1.7%) from River to Basin as from Basin to River (25 fish; 1.6%). Remaining fish were contacted in multiple zones in a year; 31 fish were contacted in multiple zones in 2014, 60 in multiple zones in 2015, and 13 fish were contacted in multiple zones both years.

In River, five cohorts released at the Willow Beach boat ramp (October 13 and 23, 2009; January 7, 2010; October 4, 2011; and December 8, 2011) made up 93% of the fish contacted in 2015 (table 5). These five cohorts made up the majority of fish contacted but only account for 39% of fish released in River. Of 8,556 River-released fish in 2012 and 2013 (mean TL 344 mm), only 42 were contacted in 2015 (< 1%).

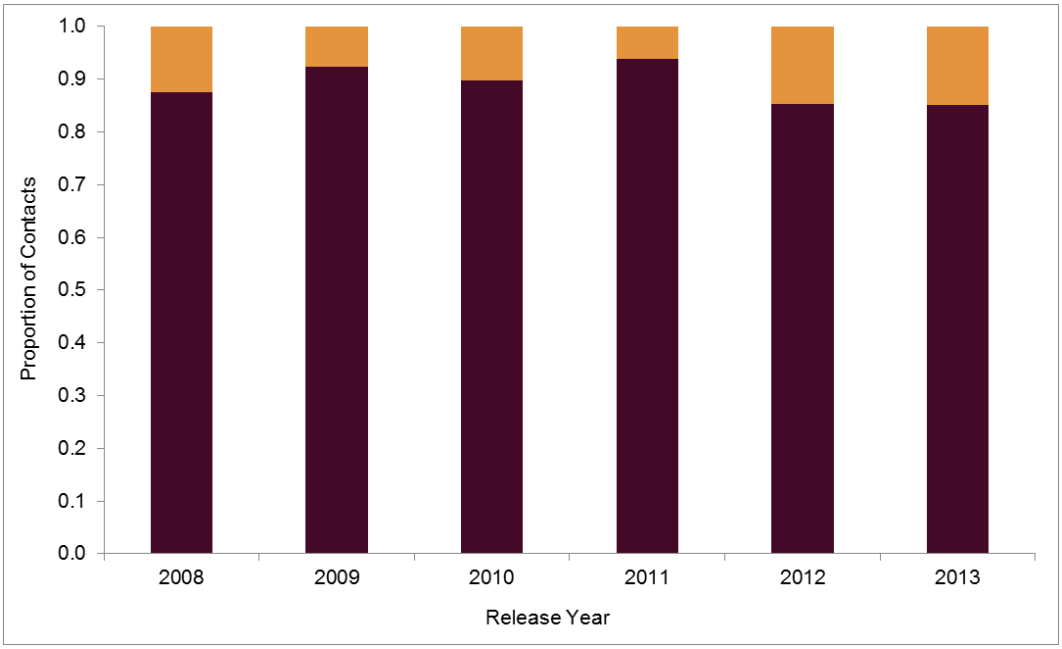


**Figure 6.—Proportion of razorback sucker PIT tag contacts in 2015 among scanning zones in Lake Mohave – Basin (maroon) and River (orange) for fish released in Basin; there were no contacts in Liberty.**
Fish were released between October 1, 2008, and October 1, 2013, and contacted during PIT scanning activities from October 1, 2014, to September 30, 2015.

Table 4.—Razorback suckers contacted by remote PIT scanning in 2015 that were also contacted in 2014 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.)

| 2014 | 2015 | | |
|---|---|---|---|
| | River | Liberty | Basin |
| **River** | 863 | 0 | 26 |
| **Liberty** | 0 | 0 | 0 |
| **Basin** | 25 | 0 | 635 |

Although little PIT scanning was conducted in Liberty, cohorts released there were scanned in similar proportions to releases elsewhere for fish of comparable size. Three to five percent of fish released into three coves in Liberty on December 17, 2009 (mean TL from 374 to 382 mm), were contacted in 2015, a proportion similar to that of Willow Beach released cohorts in March and April 2012 (mean TL of 375 and 373 mm). The cohort with the highest contact rate was 444 razorback suckers released in March 2011, with an average TL of 414 mm at release.

Table 5.—Razorback sucker repatriation cohorts (fish released at a given location on the same date) from October 1, 2008, to September 30, 2013, and their remote PIT scanning contact rates in 2015, Lake Mohave, Arizona and Nevada

| Release zone | Release location | Release date | Releases | Mean TL (mm) | 2015 | |
|---|---|---|---|---|---|---|
| | | | | | Contacted | Percent contacted |
| River | Willow Beach boat ramp | 10/4/2011 | 500 | 441 | 155 | 31.0 |
| | Willow Beach boat ramp | 10/23/2009 | 2,234 | 421 | 588 | 26.3 |
| | Willow Beach boat ramp | 1/7/2010 | 2,077 | 423 | 455 | 21.9 |
| | Willow Beach boat ramp | 12/8/2011 | 1,594 | 394 | 280 | 17.6 |
| | Willow Beach boat ramp | 10/13/2009 | 2,588 | 416 | 259 | 10.0 |
| | Willow Beach boat ramp | 12/7/2010 | 504 | 398 | 41 | 8.1 |
| | Willow Beach boat ramp | 3/8/2012 | 549 | 375 | 17 | 3.1 |
| | Willow Beach boat ramp | 4/4/2012 | 119 | 373 | 3 | 2.5 |
| | Willow Beach boat ramp | 12/12/2011 | 408 | 351 | 10 | 2.5 |
| | North Hatchery Cove | 4/19/2013 | 217 | 336 | 4 | 1.8 |
| | Painted 8 Cove | 12/18/2009 | 1,436 | 347 | 19 | 1.3 |
| | Willow Beach boat ramp | 12/7/2012 | 1,510 | 368 | 11 | 0.7 |
| | Ringbolt Rapids | 12/16/2010 | 1,509 | 324 | 8 | 0.5 |
| | Ringbolt Cove | 1/6/2010 | 1,493 | 334 | 7 | 0.5 |
| | Ringbolt Rapids | 2/13/2013 | 1,725 | 330 | 4 | 0.2 |
| | Ringbolt Rapids | 1/29/2013 | 575 | 326 | 1 | 0.2 |
| | Ringbolt Rapids | 1/5/2012 | 1,778 | 332 | 2 | 0.1 |
| | Ringbolt Rapids | 1/22/2013 | 1,486 | 331 | 0 | 0.0 |
| | Ringbolt Rapids | 1/30/2013 | 597 | 327 | 0 | 0.0 |
| Liberty | Liberty Cove | 3/16/2011 | 444 | 414 | 32 | 7.2 |
| | Wrong Cove | 12/17/2009 | 916 | 374 | 42 | 4.6 |
| | Red Tail Cove | 12/17/2009 | 897 | 382 | 28 | 3.1 |
| | Liberty Cove | 12/17/2009 | 1,521 | 379 | 44 | 2.9 |
| | Liberty Cove | 2/28/2013 | 1,271 | 356 | 34 | 2.7 |
| | Liberty Cove | 1/29/2013 | 1,186 | 326 | 17 | 1.4 |
| | Liberty Cove | 1/5/2011 | 1,896 | 339 | 10 | 0.5 |
| | Liberty Cove | 1/5/2012 | 1,920 | 330 | 6 | 0.3 |
| | Ow l Point Cove | 1/26/2012 | 1,022 | 324 | 1 | 0.1 |
| Basin | Yuma Cove | 5/19/2010 | 101 | 478 | 60 | 59.4 |
| | Cottonwood Cove | 3/20/2009 | 209 | 508 | 77 | 36.8 |
| | Cottonwood Cove | 3/26/2009 | 125 | 463 | 46 | 36.8 |
| | Cottonwood Cove | 12/3/2009 | 413 | 448 | 142 | 34.4 |
| | Lake Mohave at Dandy Cove | 10/8/2008 | 158 | 438 | 7 | 4.4 |
| | Nine Mile Coves | 1/6/2010 | 980 | 374 | 43 | 4.4 |
| | Cottonwood Cove | 12/6/2012 | 1,019 | 389 | 38 | 3.7 |
| | Carp Cove | 12/5/2012 | 400 | 391 | 9 | 2.3 |
| | Cottonwood Cove East | 1/24/2013 | 3,206 | 336 | 23 | 0.7 |
| | Six Mile Coves | 1/5/2010 | 1,584 | 329 | 11 | 0.7 |
| | Yuma Cove | 12/18/2009 | 1,611 | 329 | 7 | 0.4 |
| | Nine Mile Coves (north of) | 1/6/2011 | 1,892 | 341 | 7 | 0.4 |
| | Yuma Cove | 1/18/2012 | 693 | 328 | 2 | 0.3 |
| Katherine | Lake Mohave at North Chemehuevi Cove | 10/14/2008 | 176 | 451 | 10 | 5.7 |
| | Princess Cove | 12/5/2012 | 1,073 | 380 | 7 | 0.7 |
| | Princess Cove | 1/18/2012 | 1,689 | 335 | 6 | 0.4 |
| | Princess Cove | 1/23/2013 | 4,330 | 336 | 12 | 0.3 |

For fish released in Basin, there were four cohorts that made up most of the fish scanned in 2015 (69%) but less than one-half of those released (38%) (see table 5). The mean sizes of fish in these four cohorts were > 400 mm TL at release, and three of these were released at Cottonwood Cove in 2009 (two were reared at the Bubbling Ponds Fish Hatchery and the other at the Achii Hanyo Fish Hatchery) and contained 209, 125, and 413 individuals, respectively. The cohort with the highest contact rate in all three sample years was a group of 101 individuals reared at the Yuma Cove backwater and released at Yuma Cove with a mean TL at release of 478 mm (see table 5). Four other cohorts with the largest number of fish released (67%) were contacted the least (see table 5), and all four of these had a mean TL at release < 350 mm.

## Population Estimates

Based on monitoring data from 2014 and 2015, there was no effective wild razorback sucker population remaining in Lake Mohave. The repatriated razorback sucker population was estimated at 2,230 (95% CI from 922 to 5,963), representing < 1% of the total number of repatriates released in Reach 2 as of March 1, 2014.

Based on 2014 and 2015 remote PIT scanning, the 134.2-kHz tagged Lake Mohave repatriate population for 2014 was estimated at 3,572 individuals (95% CI from 3,341 to 3,818). Population estimates using zone-specific scanning for 2014 estimated the Basin zone population at 1,854 (95% CI from 1,676 to 2,051) and the River zone population at 2,062 (95% CI from 1,880 to 2,261); no estimate was made for the Liberty zone.

## Movement and Survival

For the "movement" and survival model, $\hat{c}$ was significantly different than 1, and the estimated $\hat{c}$, 2.869 (95% CI from 1.905 to 3.832), was used to adjust $AIC_c$ values ($QAIC_c$). Parameter estimates were based on model averaging since no model had more than a 0.9 model weight (table 6). The top five models all had $QAIC_c$ weights > 0.10. Based on the structure of these five models, there was little support for survival and transition to vary with time or state (zone). Estimates of yearly transition were slightly different among zones but similar across years: 5.2% (95% CI from 3.4 to 7.9%, 2.5 to 7.8%, and 1.9 to 13.6% in each year, respectively) of fish transitioned from Basin to River. An estimated 3.9% (95% CI from 2.6 to 5.8% and 0.9 to 15.0%) of fish transitioned from River to Basin each year (table 7).

Estimates of survival were lower in River than in Basin for any given year (table 8). Survival for both 2012 to 2013 and 2013 to 2014 was 88% in River

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

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

| Model | $QAIC_c$ | $\Delta QAIC_c$ | $QAIC_c$ weights | Model likelihood | Number of parameters |
|---|---|---|---|---|---|
| φ(state) P(state*t) Ψ(state) | 2734.0 | 0.0 | 0.251 | 1.000 | 10 |
| φ(.) P(state*t) Ψ(state) | 2734.3 | 0.3 | 0.218 | 0.869 | 9 |
| φ(state) P(state*t) Ψ(.) | 2734.5 | 0.4 | 0.202 | 0.807 | 9 |
| φ(state+t) P(state*t) Ψ(state) | 2735.4 | 1.4 | 0.127 | 0.505 | 11 |
| φ(.) P(state*t) Ψ(.) | 2735.5 | 1.5 | 0.120 | 0.477 | 8 |
| φ(state) P(state*t) Ψ(state+t) | 2738.1 | 4.0 | 0.034 | 0.134 | 12 |
| φ(state+t) P(state*t) Ψ(state+t) | 2739.4 | 5.4 | 0.017 | 0.068 | 13 |
| φ(state*t) P(state*t) Ψ(state+t) | 2739.9 | 5.9 | 0.013 | 0.053 | 14 |
| φ(state+t) P(state+t) Ψ(state+t) | 2740.6 | 6.5 | 0.010 | 0.038 | 12 |
| φ(state+t) P(state*t) Ψ(state*t) | 2741.9 | 7.9 | 0.005 | 0.020 | 15 |
| φ(state*t) P(state*t) Ψ(state*t) | 2743.7 | 9.6 | 0.002 | 0.008 | 16 |
| φ(state*t) P(state+t) Ψ(state*t) | 2743.7 | 9.6 | 0.002 | 0.008 | 15 |

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

(Models exclude fish scanned only in 2015 and individuals released in Liberty due to limited scanning there.)

| Zone | Period | Estimate | Lower CI | Upper CI |
|---|---|---|---|---|
| River to Basin | 2012–13 | 0.039 | 0.026 | 0.058 |
| | 2013–14 | 0.039 | 0.026 | 0.057 |
| | 2014–15 | 0.039 | 0.009 | 0.150 |
| Basin to River | 2012–13 | 0.052 | 0.034 | 0.079 |
| | 2013–14 | 0.052 | 0.035 | 0.078 |
| | 2014–15 | 0.052 | 0.019 | 0.136 |

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

**(**Models exclude fish scanned only in 2015 and individuals released in Liberty due to limited scanning there.)

| Zone | Period | Estimate | Lower CI | Upper CI |
|---|---|---|---|---|
| River | 2012–13 | 0.883 | 0.834 | 0.919 |
| | 2013–14 | 0.881 | 0.829 | 0.918 |
| Basin | 2012–13 | 0.910 | 0.865 | 0.942 |
| | 2013–14 | 0.908 | 0.866 | 0.938 |

compared to 91% for those same years in Basin. The most recent survival parameter for both zones, the 2014 to 2015 sample period, was confounded with the recapture rate and removed from the table. Recapture estimates in River varied between 64 and 74% of the marked population in a given year (table 9). Estimates were higher but just as varied for recapture in Basin (82–94%). Again, the last parameter in the recapture estimates was confounded with survival and was unreliable (removed from table).

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

(Models exclude fish scanned only in 2015 and individuals released in Liberty due to limited scanning there.)

| Zone | Period | Estimate | Lower CI | Upper CI |
|---|---|---|---|---|
| River | 2012–13 | 0.736 | 0.660 | 0.800 |
| | 2013–14 | 0.640 | 0.573 | 0.701 |
| Basin | 2012–13 | 0.939 | 0.873 | 0.972 |
| | 2013–14 | 0.824 | 0.763 | 0.872 |

# DISCUSSION

Remote sensing through deployment of PIT scanners in the Basin and River zones of the reservoir continues to be effective in contacting razorback sucker aggregates. A majority of the known population of 134.2-kHz tagged fish are 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 significantly higher than previously estimated, from 75% (Marsh et al. 2005) to about 90%. This discrepancy was likely due to the limited geographic scope of previous sampling activities and the limited exchange of individuals between the two subpopulations (River and Basin). Although estimates of monthly transition rates indicated a net migration upstream from the Basin to River subpopulations (Wisenall et al. 2015), the difference in the rate of exchange on an annual basis was very small and not significantly different (overlapping CIs). The estimate of $\hat{c}$ was significantly > 1, indicating overdispersion in comparison to the multi-nomial expectation (Lebreton et al. 1992). Although it is generally accepted that values of $\hat{c} < 3$ are acceptable (Lebreton et al. 1992; Cooch and White 2016), the source of the deviance from expected is of critical importance. Values of $\hat{c} > 1$ can indicate a structural problem with the model or additional residual variation that is unaccounted for in the multi-nomial model. Additional goodness-of-fit diagnostics will be performed within the next year to determine the source of overdispersion.

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 2014 population estimate based on remote PIT scanning data was the highest since scanning was initiated, and the estimate for Basin based on PIT scanning is similar to (23% below) the lake-wide estimate based on March monitoring data. 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. 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 always trend higher than PIT scanning estimates in the same subpopulation.

In 2015, Reclamation and the Willow Beach NFH developed a plan to begin to rear larger razorback suckers while minimizing the potential for loss in genetic integrity, low stocking numbers, and a reduction in the production of other species. In the plan, approximately 9,000 razorback suckers, most with a TL > 400 mm, will be stocked per year. The new yearly larval goal based on the stocking plan is 18,000. In order to accurately represent the River zone subpopulation, one-half of the larvae (9,000 individuals) should come from River. In 2015, the USFWS, Reclamation, and M&A collected 2,685 larvae above Willow Beach. It may be possible to collect an equal share of larvae from River and Basin if effort is increased upstream.

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

Although abundance has been relatively stable, a release cohort analysis based on PIT scanning in River presents some compelling data that new cohorts are not replacing declining older ones. In River, individual release cohorts from 2009 to 2011 dominate PIT scanning data in 2015. More recent releases in 2012 and 2013 were not scanned in similar numbers, indicating that these cohorts experienced lower survival. Of more than 8,500 individuals released in River in 2012 and 2013, only 42 were scanned in 2015 (see table 5). The size at release of these fish (mean TL of 344 mm) was well below the Lake Mohave Native Fish Work Group target size of 500 mm, and post-stocking survival was likely very low. The relationship between size at release and survival for razorback suckers has been supported by numerous lines of evidence (e.g., Minckley et al. 2003; Marsh et al. 2005; Zelasko et al. 2010). Additional years of poor post-release survival could put this subpopulation at greater risk. Currently, the River subpopulation does not contribute significantly to the repatriation program (i.e., few larvae are collected there), but with the ongoing effort to include this subpopulation into the program, the population size should be maintained.

As of this writing, 212,340 razorback suckers have been repatriated to Lake Mohave (Lower Colorado River Native Fish Database), and that effort has maintained a population of a few thousand fish. This repatriation program is a primary facet of a broader conservation strategy, and it plays a critical role in maintaining Lake Mohave as the only genetic reservoir for the species throughout its range (Dowling et al. 1996a, 1996b, 2005) and, thus, requires continuation. While the stocking program has changed little over the past decade, additional data-based adjustments are being implemented to increase stocking size and maintain genetic diversity. The genetic legacy of razorback suckers embodied in the Lake Mohave population represents the “cornerstone for razorback sucker conservation” (Marsh et al. 2015), and as such, it must be maintained until a successful backwater conservation strategy (Minckley et al. 2003; USFWS 2005) or an alternative can be realized, and long thereafter.

# CONCLUSIONS

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

Post-stocking survival of razorback suckers in Lake Mohave has been largely correlated to size at release. It is therefore suggested that razorback suckers stocked into Lake Mohave be at the largest individual size possible and in the greatest number possible. If there is a choice between a smaller number of larger fish and a larger number of smaller fish, all available data indicate the former

strategy will best further the goals of the program. Directing stockings both spatially and temporally will also provide opportunities to assess razorback sucker metapopulation dynamics and the effect of stocking location on these dynamics. In recent years, it was recommended to distribute fish equally among the three monitoring zones (River, Liberty, and Basin). Currently, there appears to be little utility in stocking fish at Liberty since fish do not seem to remain there long term. Also, given the current limitations of larval collections in River and the metapopulation dynamics of razorback suckers in Lake Mohave, it is suggested that stockings favor Basin over River when feasible for the next Federal fiscal year (fiscal year 2016 – October 2015 to September 2016). In order to adequately compare individual stocking cohorts repatriated to each zone (Basin and River), it is suggested that cohorts be as close as possible to the same mean size and total number, and releases should be within a few days to at most a few weeks of each other. Based upon the results of this study, releases of at least 500 fish per location and stocking event should result in adequate future PIT scanning contacts to support sound analyses.

Remote PIT scanning continues to be the most effective means of monitoring razorback sucker subpopulations in Lake Mohave. It is suggested that remote PIT scanning deployments in River be conducted at least monthly, and M&A will continue to work with Reclamation biologists to ensure a similar scanning effort in Basin. The locations of deployments would be based on past results and continued input from visual surveys as well as supplemental PIT scanner deployments in new locations and zones (i.e., Katherine) as equipment, personnel, and time permit.

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

# ACKNOWLEDGEMENTS

Collections were authorized under permits issued by the USFWS, National Park Service 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 and 13-1318R. 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 Giovanni Cappelli, Mark Olson, and other staff (Willow Beach NFH); Jeff Anderson, Trish Delrose, Gregg Garnett, Jeff Lantow, Jon Nelson, Jim Stolberg, and Ty Wolters (Reclamation – LCR MSCP); Lisa Osborn and Brandon Senger (Nevada Department of Wildlife); Sarah Taylor (Arizona Game and Fish Department Bubbling Ponds Fish Hatchery); Tom Dowling (Wayne State University, Detroit Michigan), and Melody Saltzgiver (U.S. Department of Agriculture, Wenatchee Washington). This work was supported by Reclamation Order No. R15PD00130 with assistance from Elizabeth Bailey, Reclamation Contract Officer, and Jim Stolberg, Contracting Officer's Representative.

# LITERATURE CITED

Akaike, H. 1974. A new look at the statistical model identification. IEEE Transactions on Automatic Control 19:716–723.

Bureau of Reclamation (Reclamation). 2006. Final Fish Augmentation Plan. Lower Colorado River Multi-Species Conservation Program, Bureau of Reclamation, Boulder City, Nevada. 15 p.

_____. 2015. Final Implementation Report, Fiscal Year 2016 Work Plan and Budget, Fiscal Year 2014 Accomplishment Report. Lower Colorado River Multi-Species Conservation Program, Bureau of Reclamation, Boulder City, Nevada. 458 p.

Burnham, K.P. and D.R. Anderson. 2002. Model Selection and Multimodel Inference: A Practical Information-Theoretic Approach. Springer, New York.

Cooch, E. and G.C. White. 2016. Program MARK: A Gentle Introduction. www.phidot.org/software/mark/docs/book/

Dowling, T.E., W.L. Minckley, and P.C. Marsh. 1996a. Mitochondrial DNA diversity within and among populations of razorback sucker (*Xyrauchen texanus*) as determined by restriction endonuclease analysis. Copeia 1996:542–550.

Dowling, T.E., W.L. Minckley, P.C. Marsh, and E. Goldstein. 1996b. Mitochondrial DNA diversity in the endangered razorback sucker (*Xyrauchen texanus*): analysis of hatchery stocks and implications for captive propagation. Conservation Biology 10:120–127.

Dowling, T.E., P.C. Marsh, A.T. Kelsen, and C.A. Tibbets. 2005. Genetic monitoring of wild and repatriated populations of endangered razorback sucker (*Xyrauchen texanus*, Catostomidae, Teleostei) in Lake Mohave, Arizona-Nevada. Molecular Ecology 14:123–135.

Dowling, T.E., T.F. Turner, E.W. Carson, M.J. Saltzgiver, D. Adams, B.R. Kesner, and P.C. Marsh. 2014. Time-series analysis reveals genetic responses to intensive management of razorback sucker (*Xyrauchen texanus*). Evolutionary Applications 3:339–354.

Johnson, J.B. and K.S. Omland. 2004. Model selection in ecology and evolution. TRENDS in Ecology and Evolution 19:101–108.

Karam, A.P. and P.C. Marsh. 2010. Predation of adult razorback sucker and bonytail by striped bass in Lake Mohave, Arizona-Nevada. Western North American Naturalist 70:117–120.

Kesner, B.R., A.P. Karam, C.A. Pacey, and P.C. Marsh. 2008a. Demographics and Post-Stocking Survival of Repatriated Razorback Sucker in Lake Mohave, Final Report. Prepared for the Bureau of Reclamation, Boulder City, Nevada, by Arizona State University, Tempe, Arizona, under Agreement No. 06-FC-300003. 41 p.

Kesner, B.R., J.R. Nelson, M.K. Fell, G. Ley, and P.C. Marsh. 2008b. The Development of Two Portable and Remote Scanning Systems for PIT Tagged Fish in Lentic Environments. Proceedings of the Colorado River Basin Science and Resource Management Symposium. U.S. Geological Survey Scientific Investigations Report 2010-5135.

Kesner, B.R., A.P. Karam, C.A. Pacey, K.A. Patterson, and P.C. Marsh. 2012. Demographics and Post-Stocking Survival of Repatriated Razorback Sucker in Lake Mohave, Final Report. Prepared for the Bureau of Reclamation, Boulder City, Nevada, by Marsh & Associates, LLC, Tempe, Arizona, under Agreement No. R09AP30002. 79 p.

Lebreton, J.D., K.P. Burnham, J. Clobert, and D.R. Anderson. 1992. Modeling survival and testing biological hypotheses using marked animals: a unified approach with case studies. Ecological Monographs 62:67–118.

Marsh, P.C. 1994. Abundance, movements, and status of adult razorback sucker, *Xyrauchen texanus*, in Lake Mohave, Arizona and Nevada. 1993. Proceedings of the Desert Fishes Council 25:35–36.

Marsh, P.C., C.A. Pacey, and B.R. Kesner. 2003. Decline of the razorback sucker in Lake Mohave, Colorado River, Arizona and Nevada. Transactions of the American Fisheries Society 132:1251–1256.

Marsh, P.C., B.R. Kesner, and C.A. Pacey. 2005. Repatriation as a management strategy to conserve a critically imperiled fish species. North American Journal of Fisheries Management 25:547–556.

Marsh, P.C., T.E. Dowling, B.R. Kesner, T.F. Turner, and W.L. Minckley. 2015. Conservation to stem imminent extinction: the fight to save razorback sucker *Xyrauchen texanus* in Lake Mohave and its implications for species recovery. Copeia 103:141–156.

Minckley, W.L., P.C. Marsh, J.E. Deacon, T.E. Dowling, P.W. Hedrick, W.J. Matthews, and G. Mueller. 2003. A conservation plan for native fishes of the lower Colorado River. Bioscience 53:219–234.

Mueller, G. 1995. A program for maintaining the razorback sucker in Lake Mohave. Pages 127–135 *in* H.R. Schramm, Jr., and R.G. Piper (editors). Uses and Effects of Cultured Fishes in Aquatic Ecosystems. American Fisheries Society Symposium 15, Bethesda, Maryland.

Olson, M. 2009. Willow Beach National Fish Hatchery, Willow Beach, Arizona, personal communication.

Ricker, W.E. 1975. Computation and Interpretation of Biological Statistics of Fish Populations. Bulletin of the Fisheries Research Board of Canada, No. 191. Department of the Environment Fisheries and Marine Service. 382 p.

Seber, G.A.F. 1973. The Estimation of Animal Abundance and Related Parameters. Griffin, London. 506 p.

Turner, T.F., T.E. Dowling, P.C. Marsh, B.R. Kesner, and A.T. Kelsen. 2007. Effective size, census size, and genetic monitoring of the endangered razorback sucker, *Xyrauchen texanus*. Conservation Genetics 8:417–425.

U.S. Fish and Wildlife Service (USFWS). 2005. Management Plan for the Big-River Fishes of the Lower Colorado River Basin: Amendment and Supplement to the Bonytail, Humpback Chub, Colorado Pikeminnow, and Razorback Sucker Recovery Plans. U.S. Fish and Wildlife Service Region 2, Albuquerque, New Mexico. 52 p.

Wisenall, J.B., B.R. Kesner, C.A. Pacey, and P.C. Marsh. 2015. Demographics and Monitoring of Repatriated Razorback Sucker in Lake Mohave, 2011 – 2014, Final Report. Submitted to the Bureau of Reclamation, Boulder City, Nevada, by Marsh & Associates, LLC, Tempe, Arizona. 54 p.

Zelasko, K.A., K.R. Bestgen, and G.C. White. 2010. Survival rates and movement of hatchery-reared razorback suckers in the Upper Colorado River Basin, Utah and Colorado. Transactions of the American Fisheries Society 139:1478–1499.