Lower Colorado River Multi-Species Conservation Program

Balancing Resource Use and Conservation

Demographics and Monitoring of Repatriated Razorback Suckers in Lake Mohave

2011–2014

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

January 2015

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

2011–2014

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

January 2015

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

ACRONYMS AND ABBREVIATIONS

Achii Hanyo SFH	Achii Hanyo State Fish Hatchery
AIC	Akaike's information criterion
Bubbling Ponds SFH	Bubbling Ponds State Fish Hatchery
CI	confidence interval
cm	centimeter(s)
kHz	kilohertz
km	kilometer(s)
LCR	lower Colorado River
LCR MSCP	Lower Colorado River Multi-Species Conservation Program
m	meter(s)
M&A	Marsh and Associates, LLC
mm	millimeter(s)
PIT	passive integrated transponder
PVC	polyvinylchloride
Reclamation	Bureau of Reclamation
RM	river mile
SFH	State Fish Hatchery
TL	total length
USFWS	U.S. Fish and Wildlife Service
Willow Beach NFH	Willow Beach National Fish Hatchery

Symbols

>	greater than
<	less than
%	percent
®	registered
™	trademark

CONTENTS

Tables

Tables (continued)

Tables (continued)

Figures

Figures (continued)

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 abundance of all repatriated and wild razorback suckers marked with either 400- or 134.2-kHz PIT tags.

Trammel netting efforts from October 1, 2011, to September 30, 2014, resulted in the capture of 94 razorback suckers. Sixty-four percent (%) (n = 60) of captures occurred during March "round-up" events and 36% (n = 34) during November routine monitoring. PIT tags were not detected in seven fish presumed to be repatriates that lost their tags, and one wild individual was collected during March 2014 monitoring; all remaining individuals were PIT-tagged repatriates. Based on monitoring data from the last 3 years, we estimate that there is no effective wild razorback sucker population remaining in Lake Mohave. The repatriated razorback sucker population in 2011, based on 2011 and 2012 monitoring data, was estimated to number 2,577 (95% confidence interval [CI] from 1,139 to 6,284). In 2012, repatriate population estimates from March data declined by over 700 individuals, totaling 1,854 (95% CI from 941 to 3,782). The current (2013) total population estimate for razorback suckers in Lake Mohave using March data is 2,525 (95% CI from 1,180 to 5,741).

Total deployment time for remote PIT scanners from October 2011 through September 2012 was 8,330 scan hours, resulting in 46,855 PIT tag contacts, representing 2,748 unique PIT tags for which 2,710 had a razorback sucker marking record in the Lower Colorado River Native Fish Database (as of August 1, 2014). Among fish with a marking record, 2,698 were repatriates, and 12 were wild. During the 2013 sampling season, remote antennas scanned for a total of 11,426 hours, recording 197,149 PIT tag contacts, more than four times as many as were observed in 2012. Of these total contacts, 3,222 were unique PIT tags, 3,147 of which had a marking history in the Lower Colorado River Native Fish Database. Almost all were repatriates (3,137), and 10 were recorded as wild individuals. Scanners were deployed for 8,955 hours from October 2013 through September 2014, almost 2,500 fewer hours than 2013, but resulted in 239,170 contacts, the most over the past three sampling seasons. These contacts represented 2,709 unique PIT tags for which 2,632 had a marking record in the Lower Colorado River Native Fish Database. Among razorback suckers with a marking record, 2,621 were repatriates, and 11 were wild.

Lake Mohave was subdivided into 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 the river and basin zones were contacted in their zone of release regardless of release year. Razorback suckers released in the Liberty zone were generally contacted elsewhere (river and basin zones); however, these fish accounted for 6.9% of the total number of fish contacted in only one zone (113 of 1,619). Remote PIT scanning detected little movement of razorback suckers among the three zones scanned in 2012 and 2013 (river, Liberty, and basin), with 92.4% of individuals (1,561 out of 1,689) contacted in the same zone both years. The same post-stocking dispersal trends were observed in 2013 and 2014; fish released in the river and basin zones tended to stay there, and fish released in the Liberty zone were contacted either up- or downstream. Individuals contacted in both 2013 and 2014 also exhibited minimal movement; more than 91% of the fish (1,528 of 1,674) were scanned in the same zone from year to year. The Katherine zone had too few stockings and captures and no scanning to evaluate dispersal.

Based on 2011 and 2012 remote PIT scanning, the 134.2-kHz tagged Lake Mohave repatriate population was estimated at 2,704 (95% CI from 2,437 to 3,001). Subpopulation estimates based on zone-specific scanning in 2011 and 2012 were also calculated. The basin zone population was estimated at 948 (95% CI from 795 to 1,130), and the river zone population was estimated at 1,851 (95% CI from 1,623 to2,111). Using 2012 and 2013 scanning data, Lake Mohave tagged repatriates were estimated to number 3,447 (95% CI from 3,142 to 3,783). Zone-specific scanning resulted in a subpopulation estimate for the basin zone of 1,509 (95% CI from 1,324 to 1,718), in the Liberty zone at 44 (95% CI from 13 to 80), and in the river zone at 2,169 (95% CI from 1,892 to 2,486). The river zone estimate was nearly identical to an estimate of 2,174 from a regression analysis conducted in 2012. With 2013 and 2014 PIT scanning contacts, the Lake Mohave population was estimated at 3,284 individuals (95% CI from 3,067 to 3,516). The basin zone subpopulation was estimated at 1,492 (95% CI from 1,357 to 1,640) and in the river zone at 2,053 (95% CI from 1,853 to 2,275). Subpopulations in the Liberty zone were not estimated in 2012 or 2014 due to a lack of scanning effort there during the sampling season. Although wild fish also were contacted in the basin and river zones, no estimate was calculated because a limited number of recaptures were recorded. Too few data were available to support a population estimate for the Katherine zone.

Based on a multi-strata mark-recapture model assessment in the computer program MARK, an estimated 6.0% (95% CI from 4.4 to 8.1%) of razorback suckers transitioned from the basin to the river zone post-release to January 2012 and 6.6% (95% CI from 4.3 to 10.0%) from the river to the basin zone. Monthly transition rates for adult razorback suckers were estimated at 0.6% (95% CI from 0.4 to 0.9%) for razorback suckers moving from the river to the basin zone and 2.3% (95% CI from 1.8 to 2.9%) from the basin to the river zone. Monthly survival was estimated at 99% for most of the year, declining for 1 or 2 months each year between January and April, with estimates as low as 74.1% (excluding parameter estimates that were confounded with recapture rates).

Biannual netting efforts should continue in order to collect growth, health, census, and genetic data for razorback suckers. Until an effective method to collect larvae upstream of Willow Beach is discovered, future repatriation efforts should be focused in the basin zone. Remote PIT scanners should be deployed to monitor the two known subpopulation centers (river and basin zones) with a nominal effort of 200 scanning hours per zone. Additional effort should be distributed throughout Lake Mohave in an effort to determine if other aggregations exist.

INTRODUCTION

Lake Mohave once was home to the largest known population of wild razorback suckers (*Xyrauchen texanus*), an endangered "big-river" fish endemic to the Colorado River Basin. Historically, this population contained more than 100,000 fish, but numbers have dwindled dramatically. 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 survival of stocked fish, 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 2012, personal communication), and even fish of this size are subject to predation (Karam and Marsh 2010).

Under the Lower Colorado River Multi-Species Conservation Program (LCR MSCP), the staff currently oversees, and funds are provided for, 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] 2013 – Work Task B2) and from lakeside ponds (Reclamation 2013 – 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), incorporates a population component that will occupy the lower Colorado River (LCR) 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 LCR. 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 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. 2012a). While telemetry results have generally been consistent with the mark-recapture model, survival for subadult razorback suckers (mean TL 380 mm) varied from

7 percent (%) (1 of 15 fish) (Kesner et al. 2008a), to 67% (6 of 9 fish) Kesner et al. 2012a) 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, 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 (Kesner et al. 2008b).

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

1. Locate and capture adult razorback suckers.

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

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

4. Record 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.

5. Use mobile remote PIT tag sensing units capable of deployment in both slack water and riverine sections of Lake Mohave (it is anticipated that remote sensing will occur 1 week per month between River Miles [RM] 290–305 in November and from January through May and for 1 week per month between RM 330–342 from June through August). An alternate monitoring schedule of equivalent time and effort may be proposed based on contractor expertise).

6. Estimate current repatriate and wild razorback sucker populations.

7. Participate in up to three annual, weeklong, multi-agency survey events to take place in November, March, and May (the majority of the effort related to these events will be restricted to RM 290–305).

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

9. Provide copies of all datasets to the designated Reclamation Contracting Officer's Technical Representative.

This report is the concluding document of a 3-year demographic and post-stocking survival study 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 were refined by including remote PIT scanning data collected in the basin and lotic portions of the lake, and survival and transition were estimated for basin and lotic subpopulations based on multi-state mark-recapture models. Multi-state models were developed due to the apparent dynamics of the population based on remote PIT scanning.

PIT scanning was initiated upstream of Willow Beach in 2011, and early results indicated that razorback suckers contacted there exchanged few individuals with razorback suckers in the basin zone (Kesner et al. 2012a); the basin zone has been the focus of sampling efforts and larval collections for more than 20 years. Previous mark-recapture analyses to assess survival and population size were potentially biased due to the exclusion of this other subpopulation. Although the addition of a second subpopulation adds to the overall abundance of razorback suckers in the reservoir, if there is a lack of exchange between the two subpopulations, the upstream subpopulation has been excluded from contributing to the repatriation program. Multi-state mark-recapture models extend the previously used Cormack-Jolly-Seber model to allow for individuals to move between "states" or locations between capture events (Lebreton and Pradel 2002). Besides estimating state-specific survival and recapture rates, the multi-state model allows for estimation of transition rates between states. Limited exchange (low transition rates) between Lake Mohave razorback sucker subpopulations or significant differences in subpopulation specific transition and survival rates would have important management implications (e.g., the repatriation program relies on larvae collected in the basin zone of Lake Mohave; if razorback suckers stocked in the Willow Beach area remain there, they cannot contribute to larval collections). Therefore, two multi-state mark-recapture models were developed to provide estimates of adult survival and transition for each subpopulation.

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. 2012a). 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 the river, Liberty, and basin zones. The Katherine zone was excluded due to a lack of known razorback sucker aggregation sites in that zone.

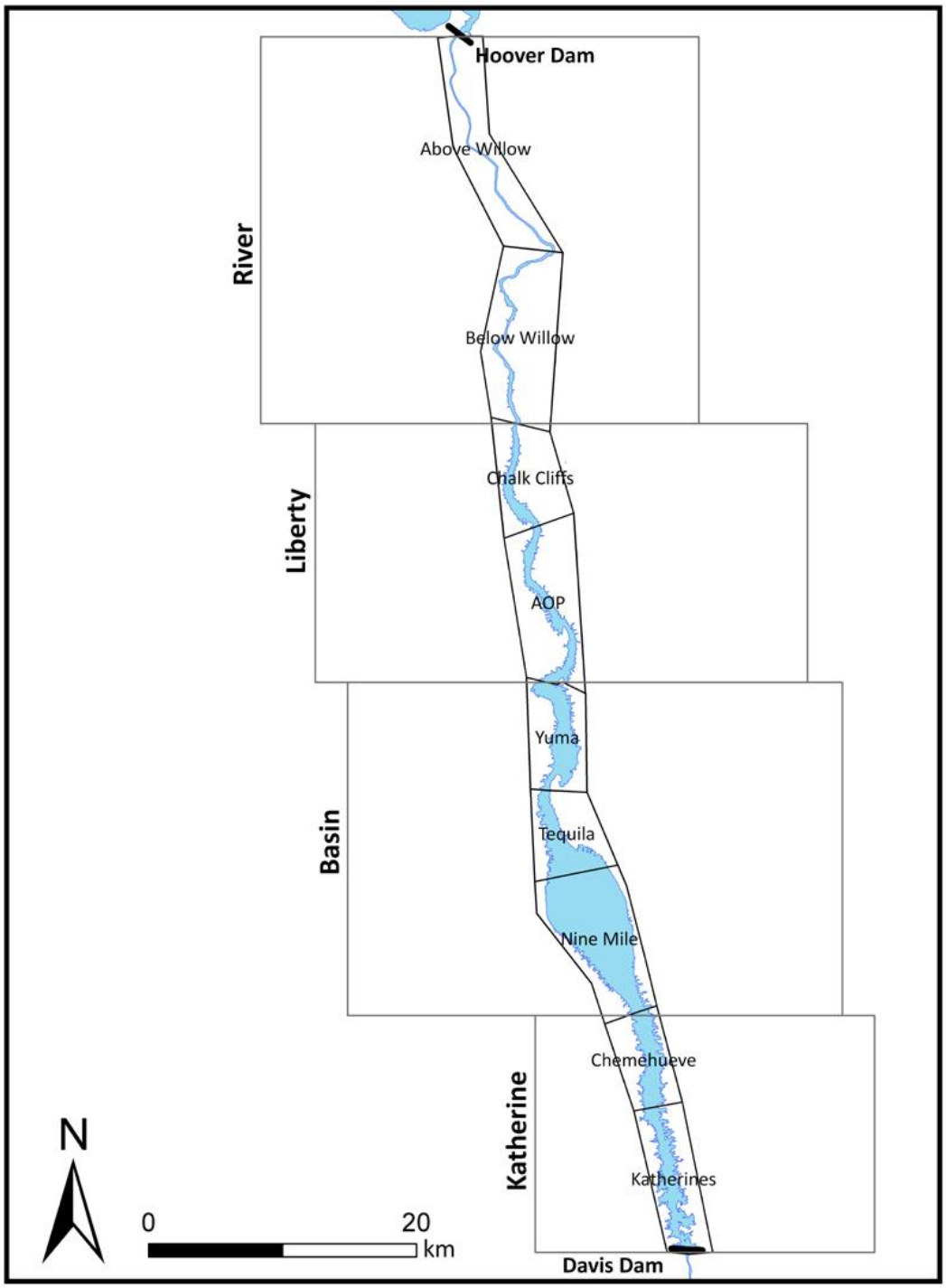

Figure 1.—Map of Lake Mohave, Arizona and Nevada, depicting two zoning schemes, general (large boxes) and specific (smaller boxes); only the former are used in this report.

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

Routine Monitoring

Objectives 1, 2, 3, 4, and 7 were accomplished through participation in the November or December and March multi-agency survey events. During all events from 2011 through 2014, Marsh & Associates, LLC (M&A) personnel occupied a field camp on Lake Mohave at Carp Cove, Arizona (basin zone), near RM 298 (miles upstream of the Southern International Boundary) for 4 to 5 days at a time. At each sampling event, as many as six trammel nets (four to six 91.4 x 1.8 meters [m], 3.8-centimeter [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 tags and tagging if none was present (objective 2), and examining the fish for general health and condition (objective 4). A fin clip was taken from a subsample[1] of razorback suckers, 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 Fishes Database maintained by M&A.

Remote Monitoring

Remote PIT scanning systems were deployed each sample year from January to September on shallow gravel bars that extend into the Colorado River upstream of Willow Beach (river zone) (objective 5). Two 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 polyvinyl chloride (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 55-ampere-hour battery provided power to the scanner continuously for 72 hours, eliminating the need for manually removing and charging batteries. The other unit (submersible) was comprised of a 0.8 x 0.8 m PVC frame antenna attached to a scanner and logger contained in watertight PVC piping. Power to

[1] Fin clips were not taken from some razorback suckers by inadvertent omission or because necessary supplies were exhausted or unavailable.

submersible units was provided either by an 8-ampere-hour sealed lead-acid battery contained in a waterproof "Otter Box®" or a 10.4-ampere-hour lithium-ion battery pack contained in a watertight, 2-inch (5.08 cm) acrylonitrile butadiene styrene pipe. Submersible units with either battery scanned continuously for up to 24 hours. Five to six submersible units were employed throughout the monitoring season.

The five locations established as fixed sites for sampling seasons 2013–14 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 years. One or two shore-based units were deployed in only a few locations, Black Bar, Boy Scout Canyon, and Sauna Cave. 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 3 nights and 2 days (approximately 65 continuous hours) each trip.

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

Remote PIT scanning in the basin and Liberty zones (see figure 1) was conducted by Reclamation with support from M&A personnel (objective 5). Semipermanent shore-based units were deployed in the basin zone for continuous scanning from November through May 2011–14. One shore-based PIT scanner was deployed at Tequila Cove. The unit operated continuously from November to May of each year and was powered by a deep-cycle marine battery and a 60-watt solar panel. Two shore-based units were also deployed in the basin zone at Yuma Cove and attached to the solar aeration system for power.

All sites with semipermanent, shore-based units represent known spawning aggregation sites and have been collection sites for March monitoring since collections began. 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

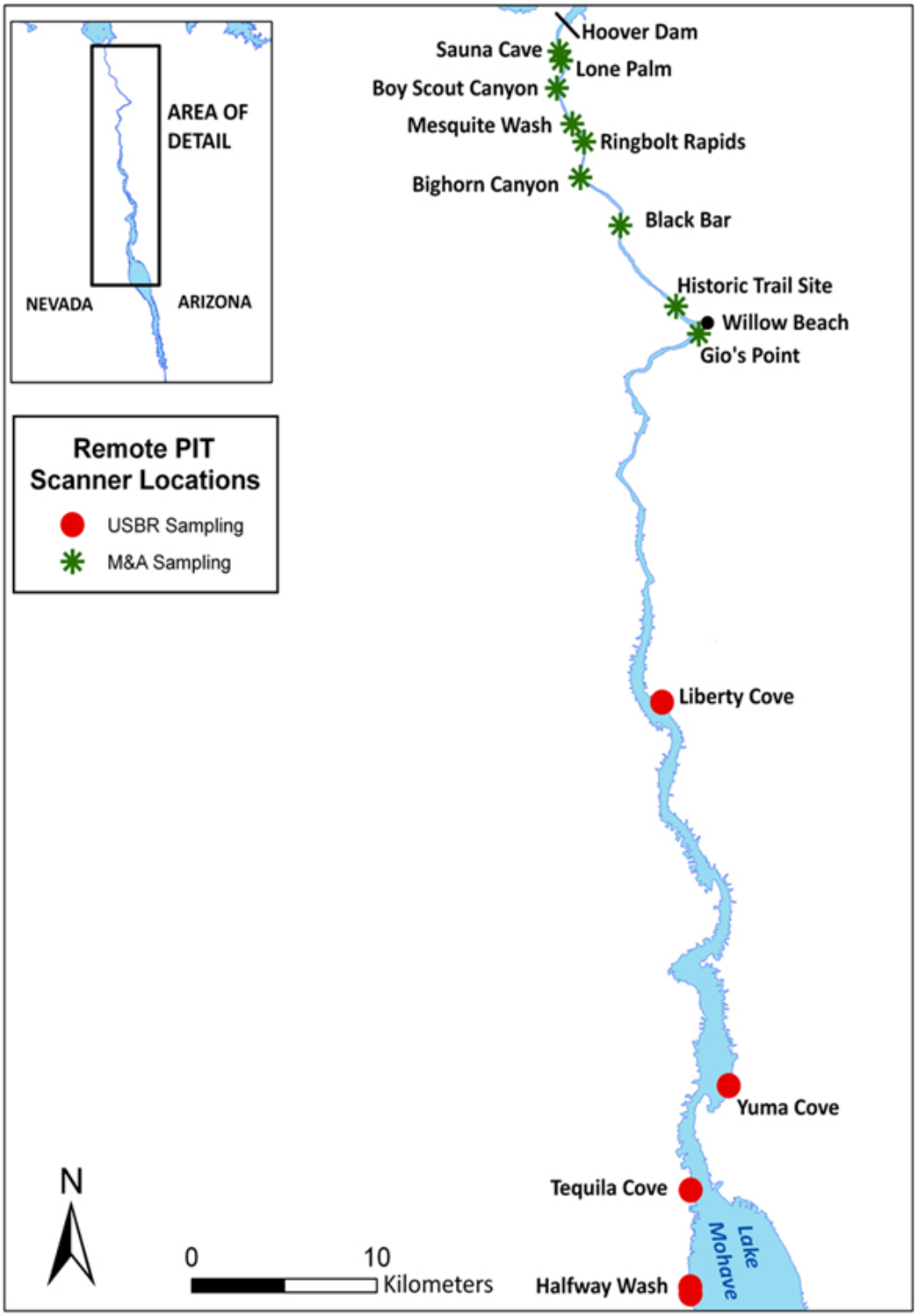

Figure 2.—Location of M&A and Reclamation remote PIT scanners during the 2012–14 razorback sucker sampling seasons in the river, Liberty, and basin zones of Lake Mohave, Arizona and Nevada.

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 9).

Post-stocking contact rates for PIT-tagged repatriated razorback suckers that were released from October 1, 2008, through September 30, 2013, were also summarized. 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 each sample year 2012–14. Sample years followed the same fiscal calendar as routine monitoring (October 1 through September 30) because scanning in the basin zone started as early as November. Cohorts must have been released at least one sample year prior to the sample year they were scanned. The proportion of each cohort that was contacted in each year 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 6). First, March monitoring data[2] were used to estimate the overall population 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 zone subpopulations of repatriated and wild razorback suckers with 134.2-kHz PIT tags in 2011 through 2013. 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 contained only a 400-kHz tag, which is rarely detected by remote PIT scanners. Combining the two sources would not accurately estimate the repatriate population.

[2] March data include the entire month of March although March round-up occurs during a single week.

Regardless of the 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 was the capture (*C*), and the number in common between both years was 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 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. CIs were derived using Poisson approximation tables, using *R* as the entering variable (Seber 1973).

Movement and Survival

A multi-state mark-recapture model was developed within the computer program 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 released in the river or basin zone from 2008 through 2010 that were also scanned in those zones from 2012 through 2014. This scanning period was selected because, during this period, there was consistent remote PIT scanning in both the river and basin zones, generally from January through April. By excluding fish that were released but not scanned, no estimate of post-stocking survival was estimated. If included, post-release survival would add unnecessary complexity to the model because it is known to be size dependent (Marsh et al. 2005). The multi-strata 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 suckers included in the model were at large for more than a year 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 the fish was released or scanned: 1 – river and 2 – basin. Capture histories were derived for fish released and scanned as a series of 0's, 1's, and 2's: 0 – not observed, 1 – observed in the river zone, and 2 – observed in the basin zone. All sampling periods were divided into weekly sampling trips, and data were used only when sampling occurred in both the river and basin zones in the same week. The time intervals for MARK modeling were standardized using a 30-day month and based on the difference between the start dates of sampling

trips. The time intervals between observation periods were not equal (e.g., monthly sampling trips were conducted on different dates each month, and time intervals between sample years were approximately 9 months apart [mid-April to mid-January]). Parameter estimates of apparent survival are therefore in unit months. Parameter estimates of transition are not adjusted in MARK because the estimated values are only valid for the entire time interval between sampling trips (Joe and Pollock 2002). Excluded from the model were 97 fish released in the Liberty zone, omitted due a limited amount of scanning that took place there.

Two sets of capture histories were developed separately to emphasize particular aspects of metapopulation dynamics in the mark-recapture model. The first set of capture histories included release state as the first value in the capture history, allowing for estimates of post-release transition rates (hereon referred to as the "movement" model). The first transition parameter is therefore representative of the entire period after release prior to initiation of PIT scanning. This post-release transition was treated separately (always estimated separately and denoted as Ψ 1) in the movement model to separate the post-release behavior from month to month transitions between zones of adult fish. Specifically, this "movement" model was testing the hypothesis that post-release and monthly transition rates differed between zones (basin and river). Because fish scanned between 2012 and 2014 must have survived the preceding post-stocking time interval, the first survival parameter (Φ1) was fixed at 1 (100% survival). This representation of the data excludes fish that were released between 2008 and 2010, survived to January 2012, and then either eluded detection from 2012 to 2014 and survived or eluded detection from 2012 until they perished. If these fish were included, they would have a negative influence on survival estimates during the period 2012 through 2014, but the number of fish with this history is unknowable, and therefore, survival estimates from this model will be positively biased. Therefore, a second set of capture histories was developed to reliably estimate adult survival. Capture histories for this "survival" model were exactly the same as for the previous model, except the first entry was excluded (first one or two signifying the release zone). Fish in this model were "marked" the first time they were scanned between 2012 and 2014, and post-release transition rates were not estimated.

The most general model contained different parameterizations across zone and time for all three parameters (e.g., Φ zone*time). A total of 11 time periods resulted in the maximum number of parameters in the most general "movement" model at 66 – 11 time periods x 2 locations x 3 parameter groups, and at 60 for the "survival" model – 10 time periods x 2 locations x 3 parameter groups. Comparison models included models with fixed parameter groups as well as shared parameter values between strata. A third set of models based on the differences in time intervals between sample years was also assessed. This "reduced time" model group constrained survival and transition parameters during a given sample year to be fixed, but different for each year, and an additional separate survival and transition parameter was used to represent the interval

between sample years. This model was developed because time intervals between sample years represent longer periods of time than the near monthly values during the sampling season. Models were ranked within MARK based on the 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). Reported parameter values were based on the highest ranked model (lowest AICc or QAICc) when the QAICc weight for the top model was greater than 0.9 (Johnson and Omland 2004). Otherwise, the estimates were based on model averaging.

RESULTS

Routine Monitoring

2012

Thirty-two razorback suckers were collected in November 2011 and March 2012 monitoring events; however, one fish was a short-term recapture and was therefore omitted from table 1 and any further analyses. Captures in November 2011 made up 35% (n = 11) of the total for that monitoring year, while individuals in March 2012 accounted for 65% (n = 20) of the captures (table 1). Five fish were captured with no PIT tags and were presumed to be repatriates. All remaining individuals (n = 26) were PIT-tagged repatriates. No wild adults were captured during our monitoring events. Sex was determined for all fish at time of capture; the majority of fish captured were female (27, 87%), and the remainder (4, 13%) were male.

Table 1.—Adult razorback sucker monitoring summary by capture month, PIT tag, history, and sex during November 2011 and March 2012 monitoring events, Lake Mohave, Arizona and Nevada
(One fish captured in March was a short-term recapture and omitted from analyses.)

Table 1 capture month (year)	Total (% of total)	PIT tag? (% of total)		History (% of total)		Sex (% of total)	
		Yes	No	Repatriate	Wild	Female	Male
November (2011)	11 (35)	7 (23)	4 (13)	11 (35)	0	10 (32)	1 (3)
March (2012)	20 (65)	19 (61)	1 (3)	20 (65)	0	17 (55)	3 (10)
Total (% of total)	31	26 (84)	5 (16)	31	0	27 (87)	4 (13)

Among 26 fish with paired capture data (i.e., fish with stocking and capture data), 3 were shorter than 30 cm TL at release (11%), 6 were 33 to 39 cm TL at release (23%), and 17 were greater than 41 cm TL at release (65%) (table 2). All fish were greater than or equal to 45 cm at capture. Average TL at release was 41 cm,

Table 2.—Adult razorback sucker monitoring summary, November 2011 and March 2012

(Data are for 26 paired release-capture data per fish PIT tag with calculated growth rate [capture TL in cm minus release TL in cm then divided by months at large], time at large [capture date minus release date then divided by 30 days for months at large or 365 days for years at large], and capture history. Data are in order by number of captures then capture date and include year class information where available. Release date is when fish were stocked into Lake Mohave.)

	Date		TL (cm)			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
257C60A898	10/2/2006	11/28/2011	43	65	< 1	F	1,883	63	5	1	First capture in 2011
1C2D679964[a]	1/5/2010	11/29/2011	37	60	1	F	693	23	2	1	First capture in 2011
1C2D6D0D48[b]	12/7/2010	11/29/2011	39	54	1	F	357	12	1	1	First capture in 2011
1B7969CE8C	10/13/2011	11/29/2011	43	45	1	F	47	2	< 1	1	First capture in 2011
1B7969CCAE	10/13/2011	11/30/2011	43	46	2	F	48	2	< 1	1	First capture in 2011
1B796ED9BB	10/14/2011	11/30/2011	43	45	1	M	47	2	< 1	1	First capture in 2011
257C60FCBA	4/3/2009	3/13/2012	53	61	< 1	F	1,075	36	3	1	First capture in 2012
1C2C843DE5[c]	5/11/2011	3/13/2012	45	52	1	F	307	10	1	1	First capture in 2012
1C2D060BDD[d]	5/11/2011	3/13/2012	47	55	1	F	307	10	1	1	First capture in 2012
1B7969DBC4	10/13/2011	3/13/2012	43	45	< 1	M	152	5	< 1	1	First capture in 2012
1C2C36F9E0	11/20/2007	3/14/2012	54	61	< 1	F	1,576	53	4	1	First capture in 2012
1C2C83C448[e]	3/20/2009	3/14/2012	49	59	< 1	F	1,090	36	3	1	First capture in 2012
1C2D696824[f]	5/18/2010	3/14/2012	45	48	< 1	F	666	22	2	1	First capture in 2012
1C2D6B300D	10/6/2010	3/14/2012	48	59	1	F	525	18	1	1	First capture in 2012
1C2D061AF3[g]	12/17/2009	3/15/2012	41	57	1	F	819	27	2	1	First capture in 2012
1C2D05AACB[h]	5/19/2010	3/15/2012	44	59	1	F	666	22	2	1	First capture in 2012
1B796ED22E	10/28/2011	3/15/2012	43	45	< 1	F	139	5	< 1	1	First capture in 2012
521C4F3432	11/15/2001	3/16/2012	33	57	< 1	F	3,774	126	10	1	First capture in 2012
1C2C2F7E5F	10/2/2007	3/16/2012	50	62	< 1	F	1,627	54	4	1	First capture in 2012
1C2D6D91E6[i]	1/6/2011	3/16/2012	39	50	1	F	435	15	1	1	First capture in 2012
1B7969EF1A[j]	1/26/2012	3/16/2012	35	46	7	M	50	2	< 1	1	First capture in 2012
1C2D74904B	1/13/2010	11/29/2011	48	64	1	F	685	23	2	2	First capture in March 2011, second capture in 2011
52081D0803	6/4/1999	3/13/2012	27	57	< 1	F	4,666	156	13	2	First capture in 2003, second capture in 2012
7F7A08103E	7/22/1997	3/16/2012	29	67	< 1	F	5,351	178	15	2	First capture in 2000, second capture in 2012
457178402F[k]	3/30/2005	3/14/2012	35	61	< 1	F	2,541	85	7	2	First capture in 2008, second capture in 2012
521621264F	6/11/1999	3/13/2012	27	62	< 1	M	4,659	155	13	4	First capture in 2001, second capture in 2002, third capture in 2004, fourth capture in 2012
		Average	41	56	1	–	1,315	44	4	–	–

[a] 2005 and 2006 mix of year class, reared at Willow Beach NFH.
[b] 2009 year class, reared at Achii Hanyo State Fish Hatchery.
[c] 2007 year class, reared at Arizona Juvenile, Lake Mohave.
[d] 2007 year class, reared at Dandy Cove, Lake Mohave.
[e] 2002, 2003, and 2004 mix of year class, reared at Bubbling Ponds State Fish Hatchery.
[f] 2006 year class, reared at Arizona Juvenile, Lake Mohave.
[g] 2006 year class, reared at Willow Beach NFH.
[h] 2006 year class, reared at Yuma Cove, Lake Mohave.
[i] 2007 year class, reared at Willow Beach NFH.
[j] 2008 year class, reared at Willow Beach NFH.
[k] 2000 and 2003 mix of year class, reared at Willow Beach NFH.

while average TL at capture was 56 cm. Sex was determined for all fish at the time of capture. Males (n = 4) appeared to exhibit faster growth over their time at large, ranging from less than 1 to 7 cm per month, while females (n = 22) appeared to have slower growth, ranging from less than 1 to 2 cm per month. Average growth rate of all fish was approximately 1 cm per month.

Years at large for all fish ranged from less than 1 to 15, with average time at large of 4 years. Fish at large for less than 1 year were at large 2 to 5 months prior to their capture. Twenty-one fish (81%) were captured during the 2011 or 2012 monitoring years for the first time since release. One fish was at large 10 years before its first capture, while another fish spent 12 years at large between captures. Three fish were tagged and released in the late 1990s, while 23 remaining fish were tagged since 2000. Twelve fish with year class information were approximately 1 to 7 years old at stocking.

Fifty-eight percent of captured fish (n = 15) originated from lakeside backwaters (table 3). Davis and Dandy Coves each contributed one fish, while most were from Arizona Juvenile and Yuma Cove. Offsite rearing facilities contributed more than 38% of the total fish captured; fish were reared at Achii Hanyo State Fish Hatchery (Achii Hanyo SFH), Boulder City Golf Course Ponds and Wetlands Park, Bubbling Ponds State Fish Hatchery (Bubbling Ponds SFH), Arizona, and Willow Beach NFH. One fish had unknown rearing information although available data suggested it may have originally been from Cibola High Levee Pond and moved to Davis Cove (unpublished data; Native Fish Work Group database). Fish reared in lakeside backwaters traveled an average of 9 kilometers (km) from release to capture sites, while fish reared in offsite facilities traveled an average of 17 km.

2013

We handled 22 razorback suckers during the 2012 and 2013 monitoring events, with November (2012) and March (2013) monitoring activities accounting for 23% (n = 5) and 77% (n = 17) of captures, respectively (table 4). Two fish captured in March were short-term recaptures by other agencies, with one's first capture by the Nevada Department of Wildlife and National Park Service on March 13, 2013, and recapture by M&A on March 15, and the other's first capture by the USFWS on March 13, 2013, and recapture by M&A on March 15; neither fish had any previous captures. Two fish had no PIT tag and were presumed to be repatriates that lost their tag; all remaining individuals (n = 20) were PIT-tagged repatriates. As in 2012, no wild adults were captured during our monitoring events. The majority of fish collected were female (16; 73%), and the other 6 (27%) were male. Both females and males were captured in March (n = 11 and 6, respectively), while only females were captured in November (n = 5).

Table 3.—Adult razorback sucker monitoring summary, November 2011 and March 2012

(Data are for 26 paired release-capture data by rearing type and location and release and capture locations. Data are in alphabetical order of rearing type and rearing location. Release location is where fish were stocked into Lake Mohave. One fish had unknown rearing information although available data suggested it may have originally been from Cibola High Levee Pond and moved to Davis Cove. This fish was omitted from analyses.)

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		Arizona	24	Basin	Pot Cove (north of, cove)	Arizona	31	Basin	7	1
			Arizona	24	Basin	Carp Cove (inside)	Arizona	32	Basin	8	1
			Arizona	24	Basin	Cottonwood Cove East	Arizona	32	Basin	8	1
			Arizona	24	Basin	Airport Cove (south of)	Arizona	34	Basin	10	1
	Dandy Cove		Nevada	26	Basin	Pot Cove (north of, cove)	Arizona	31	Basin	5	1
	Davis Cove		Arizona	0	Katherine	Carp Cove (north point)	Arizona	34	Basin	34	1
	North Chemehuevi Cove		Nevada	19	Basin	Pot Cove (north of, cove)	Arizona	31	Basin	12	1
			Nevada	19	Basin	Carp Cove (north point)	Arizona	34	Basin	15	1
	Yuma Cove		Arizona	39	Basin	Carp Cove (inside)	Arizona	32	Basin	5	2
			Arizona	39	Basin	Airport Cove (south of)	Arizona	34	Basin	7	2
			Arizona	39	Basin	Carp Cove (north point)	Arizona	34	Basin	5	1
			Arizona	39	Basin	Yuma Cove	Arizona	39	Basin	0	2
									Average distance traveled	9	15
Offsite facilities	Achii Hanyo SFH	Willow Beach boat ramp	Arizona	84	River	Cottonwood Cove East	Arizona	32	Basin	52	1
	Boulder City Golf Course Ponds	Cottonwood Cove	Nevada	37	Basin	Pot Cove (north of, cove)	Arizona	31	Basin	6	1
	Boulder City Wetlands Park	Placer Cove	Nevada	64	Liberty	Pot Cove (north of, cove)	Arizona	31	Basin	33	1
	Bubbling Ponds SFH	Princess Cove	Arizona	8	Katherine	Pot Cove (north of, cove)	Arizona	31	Basin	23	1
		Cottonwood Cove	Nevada	37	Basin	Carp Cove (inside)	Arizona	32	Basin	5	1
	Willow Beach NFH	Nine Miles Coves (north of)	Nevada	26	Basin	Pot Cove (north of, cove)	Arizona	31	Basin	5	1
		Yuma Cove	Arizona	39	Basin	Pot Cove (north of, cove)	Arizona	31	Basin	8	1
		Owl Point Cove	Arizona	47	Liberty	Pot Cove (north of, cove)	Arizona	31	Basin	16	1
		Wrong Cove	Arizona	50	Liberty	Pot Cove (north of, cove)	Arizona	31	Basin	19	1
		Six Mile Coves	Nevada	31	Basin	Carp Cove (inside)	Arizona	32	Basin	1	1
									Average distance traveled	17	10

Table 4.—Adult razorback sucker monitoring summary by capture month, PIT tag, history, and gender during November 2012 and March 2013 monitoring events, Lake Mohave, Arizona and Nevada (Two fish captured in March were short-term recaptures, and their capture data from other agencies were omitted from analyses.)

Capture month (year)	Total (% of total)	PIT tag? (% of total)		History (% of total)		Sex (% of total)	
		Yes	No	Repatriate	Wild	Female	Male
November (2012)	5 (23)	5 (23)	–	5 (23)	0	5 (23)	–
March (2013)	17 (77)	15 (68)	2 (9)	17 (22)	0	11 (50)	6 (27)
Total (% of total)	22	20 (91)	2 (9)	22	0	16 (73)	6 (27)

Among 20 fish with paired captured data, 2 were shorter than 350 mm TL at release (10%), 12 were less than 450 mm TL at release (60%), and 6 were 450 mm or greater TL at release (30%) (table 5). Average TL at release was 420 mm, and average TL at capture was 510 mm. At capture, one fish was shorter than 350 mm (5%), 6 were less than 450 mm TL (30%), and 13 were 450 mm TL or larger (65%; table 5).

Males (n = 5) appeared to exhibit less growth over their time at large, ranging from 0 to 7 mm per month, while females (n = 15) appeared to have more growth, ranging from 0 to 16 mm per month. The average growth rate of all fish was approximately 5 mm per month.

Years at large for all fish ranged from less than 1 to 14 years, with an average of almost 2 years (median = 0.6 year). Fish at large for less than 1 year were at large less than 1 to 7 months prior to capture. Eighteen fish (90%) were captured during 2012/2013 monitoring for the first time since release. One of these fish was at large for 7 years before its first capture. The two remaining fish had 1 and 2 years between release and first capture (as reported above), then it was almost 2 years and 12 years, respectively, until they were captured again. Seventeen fish with year class information were approximately 1 to 5 years old at stocking.

Thirty percent of fish (n = 6) captured originated from lakeside backwaters (table 6). Dandy Cove backwater contributed one fish, while Arizona Juvenile and Yuma Cove backwaters contributed two and three fish, respectively. Offsite rearing facilities, including Achii Hanyo SFH, Boulder City Wetlands Park, and Willow Beach NFH, contributed more than 70% of total fish captured (n = 14). Fish reared in lakeside backwaters traveled an average of 7 km from their release to their capture site, while fish reared in offsite facilities traveled an average of 22 km.

Table 5.—Adult razorback sucker monitoring summary, November 2012 and March 2013

(Data are for 20 paired release-capture data per fish PIT tag with calculated growth rate [capture TL, time at large [capture date minus release TL in cm then divided by months at large], time at large [capture date minus release date then divided by 30 days for months at large or 365 days for years at large], and capture history. Data are in order by number of captures then capture date and include year class information where available. Release date is when fish were stocked into Lake Mohave.)

	Date		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
1C2D6C6EBD	10/12/2011	11/29/2012	450	560	8	F	414	14	1	1	First capture in 2012
1C2D8DAFFA[a]	5/15/2012	11/29/2012	480	550	10	F	198	7	< 1	1	First capture in 2012
1C2D8C2AF6[b]	5/16/2012	11/29/2012	470	570	16	F	197	7	< 1	1	First capture in 2012
1C2D679787[c]	1/7/2010	11/30/2012	470	570	3	F	1,058	35	3	1	First capture in 2012
1C2D6D1839[b]	5/16/2012	11/30/2012	430	510	13	F	198	7	< 1	1	First capture in 2012
36F2B5A414[d]	12/5/2012	3/12/2013	370	370	0	M	97	3	< 1	1	First capture in 2013
36F2B5A7D6[d]	12/6/2012	3/12/2013	390	400	2	M	96	3	< 1	1	First capture in 2013
4646642132[e]	1/26/2006	3/12/2013	430	670	3	F	2,602	87	7	1	First capture in 2013
003B9F6612[f]	2/28/2013	3/12/2013	370	370	7	M	12	< 1	< 1	1	First capture in 2013
36F2B5A811[d]	12/6/2012	3/13/2013	380	380	0	M	97	3	< 1	1	First capture in 2013
36F2B59FC8[g]	12/5/2012	3/13/2013	450	450	0	F	98	3	< 1	1	First capture in 2013
003B9F6EC4[h]	1/24/2013	3/13/2013	330	330	2	M	48	2	< 1	1	First capture in 2013
1B796B4E44[d]	12/8/2011	3/13/2013	400	520	8	F	461	15	1	1	First capture in 2013
1C2D6CD9F6	10/12/2011	3/13/2013	420	570	9	F	518	17	1	1	First capture in 2013
36F2B5A693[d]	12/6/2012	3/14/2013	390	400	4	F	98	3	< 1	1	First capture in 2013
1B796B590E[d]	12/12/2011	3/14/2013	410	570	11	F	458	15	1	1	First capture in 2013
36F2B5A80A[d]	12/6/2012	3/15/2013	430	440	2	F	99	3	< 1	1	First capture in 2013
1C2C36A31C[i]	10/18/2010	3/15/2013	530	610	3	F	879	29	2	1	First capture in 2013
5210351932	11/10/1998	3/12/2013	330	700	2	F	5,236	175	14	2	First capture in 2001, second capture in 2013
1C2D685AB7[j]	12/3/2009	3/13/2013	430	600	4	F	1,196	40	3	2	First capture in 2011, second capture in 2013

Average	420	510	6	–	703	23	2	–	–

[a] 2008 year class, reared at Dandy Cove backwater.
[b] 2008 year class, reared at Arizona Juvenile backwater.
[c] 2005 year class, reared at Willow Beach NFH.
[d] 2010 year class, reared at Achii Hanyo SFH.
[e] 2003 year class, reared at Willow Beach NFH.
[f] 2010 year class, reared at Willow Beach NFH.
[g] 2007 year class, reared at Achii Hanyo SFH.
[h] 2009 year class, reared at Willow Beach NFH.
[I] 2006 year class, reared at Yuma Cove backwater.
[j] 2008 year class, reared at Achii Hanyo SFH.

Table 6.—Adult razorback sucker monitoring summary, November 2012 and March 2013

(Data are for 20 paired release-capture data by rearing type and location and release and capture locations. Data are in alphabetical order of rearing type and rearing location. Release location is where fish were stocked into Lake Mohave.)

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		Arizona	24	Basin	Waterwheel Cove	Arizona	32	Basin	8	2
	Dandy Cove		Nevada	26						6	1
	Yuma Cove		Arizona	39	Basin	Carp Cove (inside)				7	1
						Carp Cove (north point)		34		6	1
						Waterwheel Cove		32		7	1
									Average distance traveled	7	6
Offsite facilities	Achii Hanyo SFH	Cottonwood Cove	Nevada	37	Basin	Carp Cove (inside)	Arizona	32	Basin	4	1
						Carp Cove (north point)		34		3	1
						Cottonwood Cove East		32		5	2
						Cottonwood Cove East (100 m inside, north shore)				5	1
		Princess Cove	Arizona	8	Katherine	Cottonwood Cove East				24	1
						Cottonwood Cove East (100 m inside, north shore)				24	1
		Willow Beach boat ramp	Arizona	84	River	Cottonwood Cove East				51	1
						Cottonwood Cove East (100 m inside, north shore)				51	1
	Boulder City Wetlands Park	Placer Cove	Nevada	64	Liberty	Carp Cove (inside)				32	1
	Willow Beach NFH	Antelope Cove		50						18	1
		Cottonwood Cove East	Arizona	32	Basin	Cottonwood Cove East (100 m inside, north shore)				0	1
		Liberty Cove		62	Liberty	Cottonwood Cove East				30	1
		Willow Beach NFH		85	River	Waterwheel Cove				53	1
									Average distance traveled	22	14

2014

We handled 43 razorback suckers during 2013 and 2014 monitoring events, with December 2013 and March 2014 monitoring activities accounting for 42% (n = 18) and 58% (n = 25) of the captures, respectively (table 7); one fish had missing tag information, and one individual was a mortality, neither of which were included in table 7. Sex was determined for all fish when possible, and the majority of fish captured were female (68%), with 11 males (27%), one juvenile (2%), and one of unknown sex (2%). One fish captured in December was a short-term capture, with both of its captures by M&A, once on December 5 and again on December 6, 2013; this fish had no previous captures since its release. There was one wild adult captured, with all remaining individuals (n = 40 39) recorded as PIT-tagged repatriates; two fish were captured with no original capture or release data and presumed to be repatriates, and these two fish were excluded from further analyses.

Table 7.—Adult razorback sucker monitoring summary by capture month, PIT tag, history, and sex during December 2013 and March 2014 monitoring events, Lake Mohave, Arizona and Nevada
(One fish captured in December was a short-term recapture and is included in the analyses.)

Capture month (year)	Total (% of total)	PIT tag? (% of total)		History (% of total)		Sex (% of total)			
		Yes	No	Repatriate	Wild	Female	Male	Juvenile	Unknown
December (2013)	18 (44)	18 (44)	0	18 (45)	0	15 (53)	2 (18)	0	1 (100)
March (2014)	23 (56)	23 (56)	0	22 (55)	1 (100)	13 (46)	9 (82)	1 (100)	0
Total (% of total)	41	41	0	40 (98)	1 (2)	28 (68)	11 (27)	1 (2)	1 (2)

Among 37 fish with paired captured data (i.e., fish with stocking and capture data), 5 fish were less than 350 cm at release (13%), 24 fish were 350 to 450 cm TL at release (65%), and 8 fish were greater than 450 cm TL at release (22%; table 8). Average TL at release was 408 mm, while average TL at capture was 498 mm, with four fish less than 350 mm at capture (11%), 6 fish 350 to 499 mm TL at capture (16%), and 27 fish greater than 450 mm TL at capture (73%; table 8). Males (n = 11) appeared to exhibit less growth over their time at large, ranging from 0 to 9 cm per month while females (n = 24) appeared to have more growth, ranging from < 1 to 13 cm per month. Average growth rate of all fish was approximately 5 cm per month.

Years at large for all fish ranged from less than 1 to 4 years, with average time at large less than 2 years. Fish at large for less than 1 year were at large less than 1 to 10 months prior to capture. Thirty-five fish (95%) were captured during

Table 8.—Adult razorback sucker monitoring summary, December 2013 and March 2014

Data are for 37 paired release-capture data per fish PIT tag with calculated growth rate (capture TL, time at large (capture date minus release TL in cm then divided by months at large), time at large (capture date minus release date then divided by 30 days for months at large or 365 days for years at large), and capture history. Data are in order by number of captures then capture date and include year class information where available. Release date is when fish were stocked into Lake Mohave.

	Date		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
003B9F7006[a]	1/29/13	12/3/13	315	480	16	U	308	10	< 1	1	First capture in 2013
003B9F87DB[a]	1/23/13	12/3/13	370	450	8	M	314	10	< 1	1	First capture in 2013
1B796B58D1[b]	12/12/11	12/3/13	350	520	7	M	722	24	2	1	First capture in 2013
1B796ED660[c]	5/6/13	12/3/13	450	510	9	F	211	7	< 1	1	First capture in 2013
1C2D696720[d]	9/21/10	12/3/13	460	625	4	F	1,169	38	3	2	First capture in 2011, second capture in 2013
1C2D8DAFFA[e]	5/15/12	12/3/13	481	580	5	F	567	19	1	2	First capture in 2012, second capture in 2013
003B9F6663[a]	2/28/13	12/4/13	375	490	12	F	279	9	< 1	1	First capture in 2013
003B9F6DF6[g]	1/24/13	12/4/13	405	540	13	F	314	10	< 1	1	First capture in 2013
1C2C7EEB30[h]	10/15/10	12/4/13	516	590	2	F	1,146	38	3	1	First capture in 2013
003B9F700D[a]	1/29/13	12/5/13	405	490	8	F	310	10	< 1	1	First capture in 2013
1B796B3C34[i]	10/10/12	12/5/13	472	550	5	F	421	14	1	1	First capture in 2013
1C2D67CD28[j]	10/15/10	12/5/13	580	620	1	F	1,147	38	3	1	First capture in 2013
36F2B59FF3[b]	12/5/12	12/5/13	400	510	9	F	365	12	1	1	First capture in 2013
36F2B5A7B5[b]	12/6/12	12/5/13	420	540	10	F	364	12	1	1	First capture in 2013
003B9F5C05[g]	1/24/13	12/6/13	400	517	11	F	316	10	< 1	1	First capture in 2013
1B796EEA14[k]	10/31/13	12/6/13	500	498	< 1	F	36	1	< 1	1	First capture in 2013
1B796EEB57[c]	5/22/13	12/6/13	463	532	10	F	198	7	< 1	1	First capture in 2013
003B9F604B[g]	1/24/13	3/18/14	380	475	7	F	418	14	1	1	First capture in 2014
003BA69BF4[i]	1/28/14	3/18/14	360	356	< 1	M	49	2	< 1	1	First capture in 2014
003BA7483F[i]	1/28/14	3/18/14	370	370	0	M	49	2	< 1	1	First capture in 2014
1B796EE87Ff	5/6/13	3/18/14	428	480	5	M	316	10	< 1	1	First capture in 2014
1C2C3BDB0D[m]	10/13/09	3/18/14	390	615	4	F	1,617	54	4	1	First capture in 2014
1C2D63AA02[n]	1/6/10	3/18/14	390	647	5	F	1,532	51	4	1	First capture in 2014
36F2B5A75B[b]	12/6/12	3/18/14	400	500	6	M	467	16	1	1	First capture in 2014
003BA6A182[i]	1/27/14	3/19/14	350	340	< 1	M	51	2	< 1	1	First capture in 2014
003BA938EA[a]	1/27/14	3/19/14	335	325	< 1	M	51	2	< 1	1	First capture in 2014
1C2D63A268[o]	12/3/09	3/19/14	445	610	3	F	1,567	52	4	1	First capture in 2014
003B9F6318[g]	1/24/13	3/20/14	340	465	9	M	420	14	1	1	First capture in 2014
003BA69C47[i]	1/28/14	3/20/14	325	335	6	M	51	2	< 1	1	First capture in 2014
36F2B5A6EB[b]	12/6/12	3/20/14	390	415	2	M	469	16	1	1	First capture in 2014
003BA2F576[i]	1/28/14	3/21/14	305	315	6	J	52	2	< 1	1	First capture in 2014
003BA713BD[p]	12/12/13	3/21/14	435	440	1	F	99	3	< 1	1	First capture in 2014
003BA71A4A[a]	1/27/14	3/21/14	355	358	2	F	53	2	< 1	1	First capture in 2014
1B7969CDF0[j]	10/21/11	3/21/14	441	672	8	F	882	29	2	1	First capture in 2014
1C2C3C2270[m]	10/13/09	3/21/14	420	605	3	F	1,620	54	4	1	First capture in 2014
36F2B5A493[b]	12/5/12	3/21/14	430	525	6	F	471	16	1	1	First capture in 2014
36F2B5A7A7[b]	12/6/12	3/21/14	455	545	6	F	470	16	1	1	First capture in 2014
		Average	408	498	5	–	510	17	2	–	-

[a] 2010 year class, reared at Willow Beach NFH. [b] 2010 year class, reared at Achii Hanyo SFH. [c] 2009 year class, reared at Arizona Juvenile. [d] 2006 year class, reared at Arizona Juvenile.
[e] 2008 year class, reared at Dandy Cove. [f] 2009 year class, reared at Dandy Cove. [g] 2009 year class, reared at Willow Beach NFH. [h] 2006 year class, reared at Yuma Cove.
[i] 2008 year class, reared at North Chemehuevi Cove. [j] No year class, reared at Yuma Cove. [k] 2009 year class, reared at North Chemehuevi Cove. [l] 2 011 year class, reared at Willow Beach NFH.
[n] 2006 year class, reared at Willow Beach NFH. [o] 2008 year class, reared at Achii Hanyo SFH. [p] 2011 year class, reared at Achii Hanyo SFH.

Table 8.—Adult razorback sucker monitoring summary, December 2013 and March 2014

Data are for 37 paired release-capture data per fish PIT tag with calculated growth rate (capture TL, time at large (capture date minus release TL in cm then divided by months at large), time at large (capture date minus release date then divided by 30 days for months at large or 365 days for years at large), and capture history. Data are in order by number of captures then capture date and include year class information where available. Release date is when fish were stocked into Lake Mohave.

	Date		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

[m] 2006 year class, reared at Dexter NFH.

2013/2014 monitoring for the first time since their release into Lake Mohave. Four fish were at large 4 years before their initial captures. Thirty-five fish with year class information were approximately 1 to 4 years old at stocking, with an approximate average of 3 years old at stocking.

Twenty-seven percent of fish (n = 10) captured originated from lakeside backwaters (table 9). Fish were reared at four different coves: Arizona Juvenile, Dandy, North Chemehuevi, and Yuma, and were released into the main channel adjacent to these coves. Offsite rearing facilities, including Achii Hanyo SFH, Southwestern Native Aquatic Resources and Recovery Center , and Willow Beach NFH, contributed more than 73% of the total fish captured (n = 27). Fish reared in lakeside backwaters traveled an average of 8 river km from their release to their capture site, while fish reared in offsite facilities traveled an average of 12 river km.

In Lake Mohave, razorback suckers seem to exhibit rapid growth in the first 2 years post-release. For fish released between 300 and 350 mm, growth for the first year is rapid and then begins to plateau after 2.5 years, while individuals greater than 350 mm show slower growth 1 year after release. Since October 2008, 191 fish have been released at less than 300 mm TL, but none have been captured. Smaller-sized cohorts may not be fully grown yet; for example, we would expect to see fish released in 2012 in the 2015 March monitoring.

Remote Monitoring

2012

During the 2012 sampling season, remote PIT scanning from the river, Liberty, and basin zones resulted in 8,330 hours of scanning; 3,697 hours with shore-based units, 4,020 hours with submersible PIT units, and 613 hours with Destron (Destron Fearing^{TM}) scanners. In 2012, a total of 46,855 PIT tag contacts were recorded, representing 2,748 individual razorback suckers, 2,710 of which had a marking record in the Lower Colorado River Native Fish Database (as of August 1, 2014). Among fish with a marking record, 2,698 were repatriates, and 12 were wild. Thirty-eight unique contacts could not be assigned to a record of marking using the Native Fish Work Group PIT tag database and were removed from analyses. Data used for all further analyses are restricted to fish stocked with a 134.2-kHz tag.

Contact data from 2012 for abundance estimates were reduced further by removing contacts from fish released after March 1, 2011 (after the marking event).

In the river zone, remote PIT scanners were deployed for a total of 4,397 hours of scanning; 377 hours using shore-based units and 4,020 hours with the submersible model. Mean deployment times were 27.3 and 21.6 hours for shore-based and submersible scanners, respectively. Shore-based units were often downloaded on a daily basis, although they were left onsite for up to 3 days. River scanning

Table 9.—Adult razorback sucker monitoring summary, December 2013 and March 2014

Data are for 37 paired release-capture data by rearing type and location and release and capture locations. Release location is where fish were stocked into Lake Mohave.

Rearing		Release				Capture				Distance Traveled (change in km)	n fish
Type	Location	Location	State	River km	Zone	Location	State	River km	Zone		
Lakeside backwaters	Arizona Juvenile		AZ	24	Basin	Cottonwood Cove East	AZ	32	Basin	8	2
						Cottonwood Cove East (west side of north point of)				8	1
	Dandy Cove		NV	26		Cottonwood Cove East (100 m inside, north shore)				6	2
	North Chemehuevi Cove			19		Cottonwood Cove East (1st point south of north point)				13	2
						Cottonwood Cove East					
	Yuma Cove		AZ	39	Arizona Bay	Cottonwood Cove East (100 m inside, north shore)				7	1
						Cottonwood Cove East (back of)				7	1
						Cottonwood Cove East (west side of north point of)				7	1
									Avg distance traveled	8	10
Off-site facilities	Achii Hanyo	Carp Cove	AZ	33	Basin	Cottonwood Cove East (1st point south of north point)	AZ	32	Basin	1	1
						Cottonwood Cove East (west side of north point of)				1	1
		Cottonwood Cove	NV	37		Cottonwood Basin East				5	2
						Cottonwood Cove East (100 m inside, north shore)				5	2
						Cottonwood Cove East (1st point south of north point)				5	1
						Mile 20 Light				5	1
	SNARRC	Willow Beach boat ramp	AZ	84	River	Cottonwood Cove East				52	1
						27 RM Cove			Arizona Bay	41	1
	Willow Beach NFH					Cottonwood Basin East			Basin	52	1
										0	1
		Cottonwood Cove East		32	Basin	Cottonwood Cove East (100 m inside, north shore)				0	4
						Cottonwood Cove East (west side of north point of)				0	1
						Mile 20 Light				0	2
		Liberty Cove		62	Arizona Bay	Cottonwood Cove East				30	1
						Cottonwood Cove East (1st point south of north point)				30	1
						Cottonwood Cove East (2nd point south of north point)				30	1
		Nine Mile Coves	NV	26	Basin	Cottonwood Cove East (100 m inside, north shore)				6	1
						Mile 20 Light				6	3
		Princess Cove	AZ	8	Lower lake	Cottonwood Cove East				24	1
									Avg distance traveled	12	27

effort resulted in a total of 19,813 PIT tag contacts of which 1,934 were unique PIT tags and 1,923 had a marking record in the Lower Colorado River Native Fish Database. Eleven fish that were contacted with a marking history were wild individuals, and 1,912 were repatriates.

Remote PIT scanning in the Liberty zone was completed with Destron scanners and attributed a total of 188 hours of scanning, with a mean deployment time of 47 hours. A total of 27 PIT tags were contacted, representing 18 unique razorback suckers, all of which had a marking history and were repatriates.

Both shore-based and Destron scanning units were deployed in the basin zone in 2012 and accumulated 3,745 hours of scanning; 3,745 hours with shore-based units, and 425 hours with Destron scanners. Mean deployment times were 129.1 and 38.6 hours for shore-based and Destron scanners, respectively. Although there were fewer total scanning hours completed in the basin zone, the most contacts in 2012 occurred here, adding to 27,015 total PIT tag contacts. Of these, only 836 were unique contacts, more than 1,000 fewer than the number of unique encounters observed in the river zone. A total of 809 unique contacts in the basin zone had a marking record in the Lower Colorado River Native Fish Database, representing 808 repatriates and one wild razorback sucker.

Post-stocking dispersal between the three zones was limited mostly to the zone of stocking. Remote PIT scanners contacted a total of 1,073 fish that had been at large for at least 1 year and were released in the river zone after October 1, 2008. The majority of these fish, 93.4% (1,003 individuals), were scanned in the river zone (figure 3). Only 3 fish released in the river zone were contacted in the Liberty zone, and 67 were contacted in the basin zone. Only 113 fish released in the Liberty zone were contacted, with 55% (62 fish) contacted in the basin zone, 41% (47 fish) in the river zone, and 3% (4 fish) in the Liberty zone (figure 4). Finally, fish released in the basin zone were contacted in this zone 90% of the time (367 individuals out of 405), 9% (36 individuals) in the river zone, and 0.4% (2 individuals) in the Liberty zone (figure 5). Few fish have been released in the Katherine zone, and no PIT scanning was conducted there in 2012. However, 25 fish released in this zone were contacted in the basin zone and 3 in the river zone.

The adult subpopulations in the river, Liberty, and basin zones exchanged few individuals from 2011 to 2012 (table 10). Out of the 899 fish contacted in 2011 that were released with a 134.2-kHz tag after October 2008, 586 were contacted in 2012. Of these fish, 18 were contacted in more than one zone in either 2011 or 2012 and were excluded from analyses to remove repeated counting. Among the 568 that remained, 553 were contacted in the same zone as their initial contact in 2011. The greatest movement was eight fish (1.4%) that moved from the river zone to the basin zone.

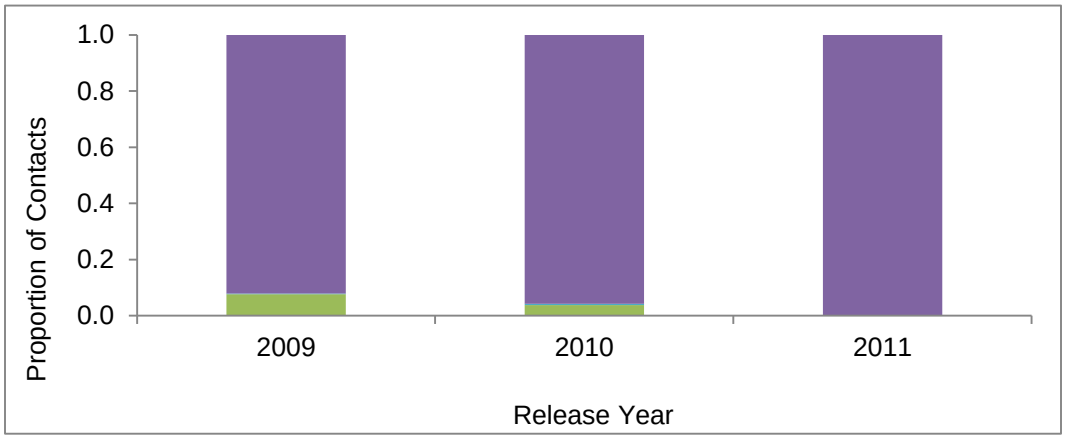

Figure 3.—Proportion of razorback sucker PIT tag contacts in 2012 among three scanning zones in Lake Mohave, basin (green), Liberty (blue), and river (purple), for fish released in the river zone.
Fish were released between October 1, 2008, and October 1, 2011, and contacted during PIT scanning activities from October 1, 2011, to September 30, 2012.

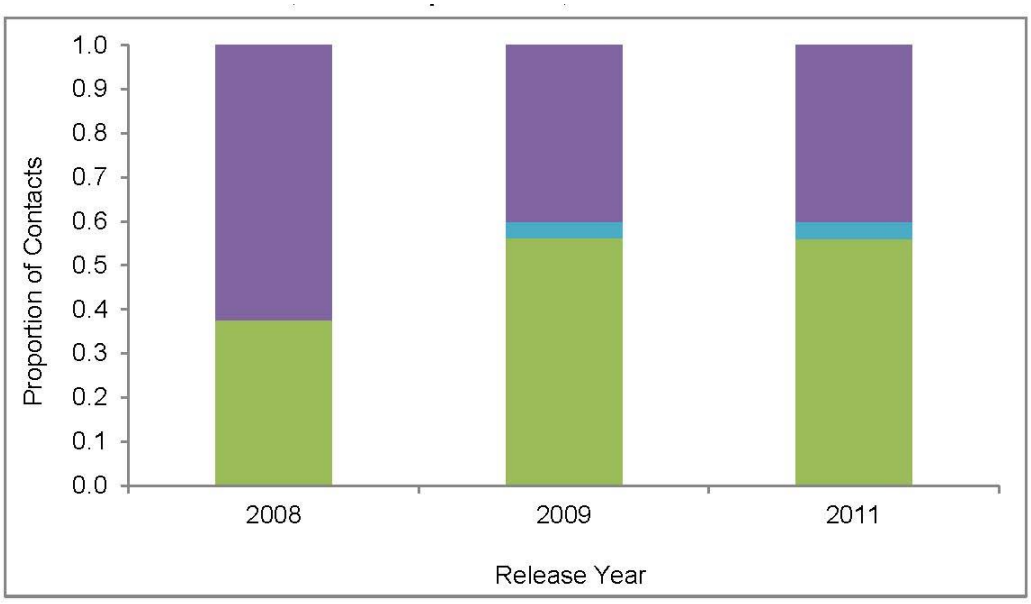

Figure 4.—Proportion of razorback sucker PIT tag contacts in 2012 among three scanning zones in Lake Mohave, basin (green), Liberty (blue), and river (purple), for fish released in the Liberty zone.
Fish were released between October 1, 2008, and October 1, 2011, and contacted during PIT scanning activities from October 1, 2011, to September 30, 2012.

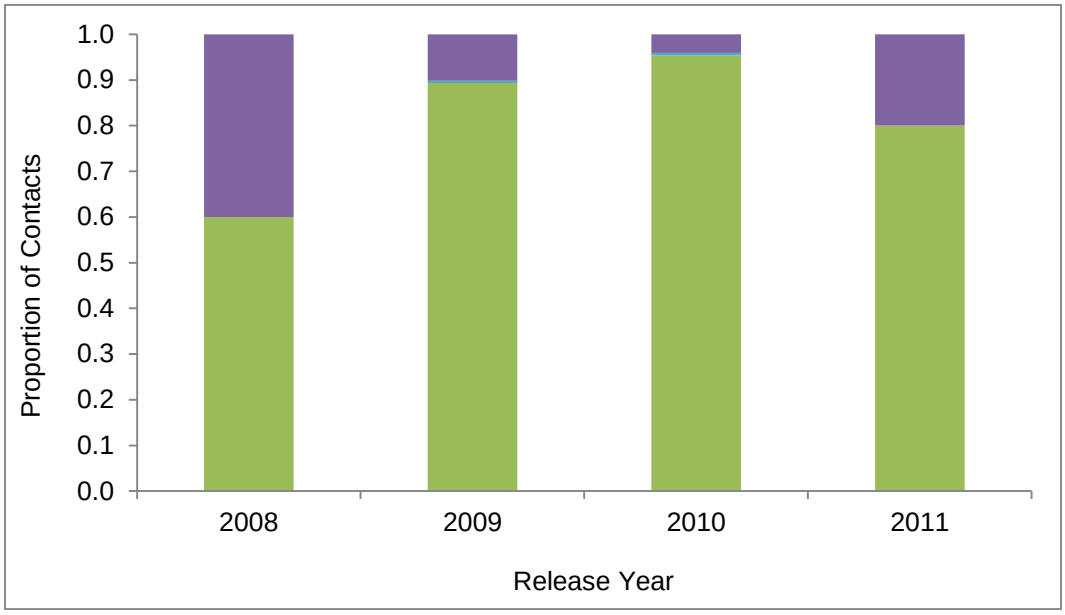

Figure 5.—Proportion of razorback sucker PIT tag contacts in 2012 among three scanning zones in Lake Mohave, basin (green), Liberty (blue), and river (purple), for fish released in the basin zone.
Fish were released between October 1, 2008, and October 1, 2011, and contacted during PIT scanning activities from October 1, 2011, to September 30, 2012.

Table 10.—Razorback suckers contacted by remote PIT scanning in 2012 that were also contacted in 2011 broken down by zone of contact, Lake Mohave, Arizona and Nevada
(Fish contacted in more than one zone in the same year were excluded from analyses.)

	2012		
2011	River zone	Liberty zone	Basin zone
River zone	402	0	8
Liberty zone	0	1	2
Basin zone	4	1	150

2013

Scanners deployed during the 2013 sampling season accounted for 11,426 total hours of scanning, more than 3,000 more hours than in 2012. Among total scan hours, 7,846 were with shore-based units, 3,430 with submersible scanners, and 150 with Destron scanning units. There also was a significant increase in the total number of contacts in 2013; more than four times the number observed in 2012.

The total number of PIT tag contacts in 2013 was 197,149. Of these 3,222 were unique, and 3,147 had a marking record. Among fish with a marking record, 3,137 were repatriates, and 10 were wild.

Remote PIT scanning in the river zone resulted in 3,974 hours of scanning – 544 hours with shore-based and 3,430 hours with submersible PIT scanning units. Mean deployment times were 27.2 and 21.5 hours for shore-based and submersible scanners, respectively. Although Lake Mohave contacts increased from 2012 to 2013, total contacts in the river zone decreased by approximately 8,000. A total of 11,576 PIT tag contacts were recorded, representing 1,693 unique contacts for which 1,680 had a marking record in the Lower Colorado River Native Fish Database. Repatriated razorback suckers accounted for 1,672 of the unique encounters, while 8 were wild individuals.

Most PIT scanning was conducted in the river zone at five fixed sampling locations. Contacts at these sites were compared in order to quantify spatial distribution across sample months. In 2013, 7 of a possible 120 river zone fixed site replicates (8 trips x 5 sites x 3 replicates per trip) were removed due to scanner error. All trip and location combinations had a minimum of two replicates. Fixed PIT scanners deployed at Black Bar detected the most unique PIT tags in three of eight sample periods (figure 6). In the other five sample periods, Gio's Point, the most downstream site, had the most contacts. Contacts at Black Bar were nearly double that observed in other fixed sites in January, February, and April, but few detections were made there after May.

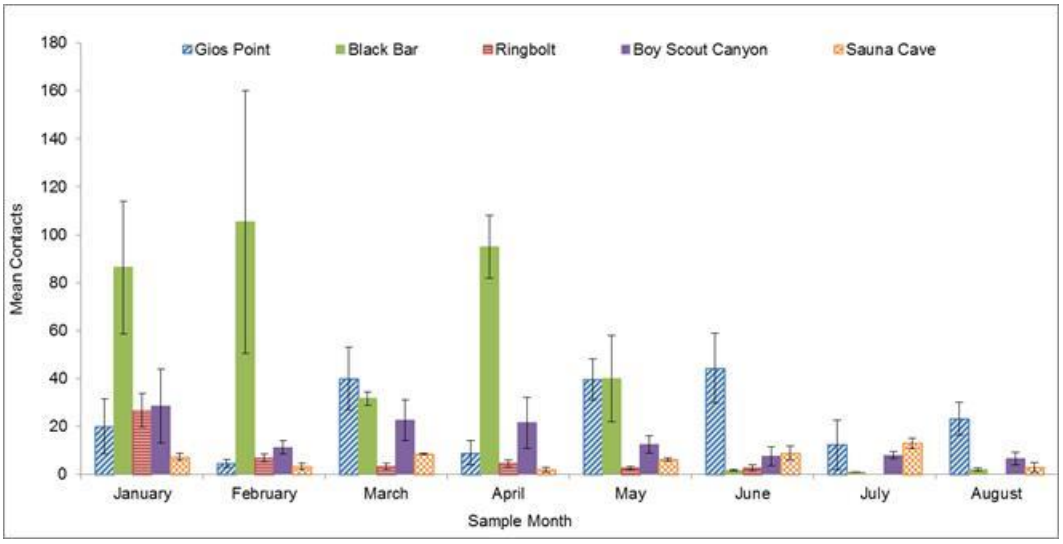

Figure 6.—Unique razorback sucker PIT tag contacts recorded in 2013 at five fixed stations in the river zone, Lake Mohave, Arizona and Nevada.
Error bars represent ±1 standard error.

Remote PIT scanning in the Liberty zone was completed with a single deployment of a Destron PIT scanner for 39 hours. A total of 82 PIT tags were recorded, representing 15 unique razorback suckers, all of which had a marking history and were repatriates. This is an increase in the number of contacts in the Liberty zone from 2012, but three fewer unique fish.

Remote PIT scanners in the basin zone were deployed for a total of 7,412 hours of scanning; 7,301 hours with shore-based and 111 hours with Destron units. Mean deployment times were 414.7 hours for shore-based and 55.5 hours for Destron scanners. A total of 185,491 PIT tags were contacted, representing 1,620[3] unique contacts for which 1,558 had a marking record in the Lower Colorado River Native Fish Database. Repatriated razorback suckers accounted for 1,556 of the unique encounters, and 3 were wild.

Post-stocking dispersal out of the zone of release was minimal for two of the three main stocking zones. Razorback suckers released into the river zone accounted for 61.3% (1,422) of the 2,319 fish contacted, excluding 90 fish (3.7% of total contacted in multiple zones). The majority (> 80%) of these fish were contacted in the river zone regardless of release year (figure 7). Razorback suckers released in the Liberty zone in 2012 were contacted in this zone (figure 8), but for other release years, they were contacted elsewhere (the river and basin zones). Basin zone released fish accounted for 30.4% (705) of razorback suckers contacted, and as with river zone released fish, more than 80% were contacted in their zone of release regardless of release year (figure 9). No PIT scanning was conducted in the Katherine zone because few fish have been released there between October 1, 2008, and September 30, 2013, and only 1 release cohort in that time period contained more than 100 fish (1,689 fish released at Princess Cove in 2012). However, 65 fish released in the Katherine zone were contacted in the basin zone, and 6 were contacted in the river zone.

Adult subpopulations in the river, Liberty, and basin zones exchanged few individuals from 2012 to 2013 (table 11). Among 1,689 fish contacted in both years, 1,561 (92.4%) were contacted in only one zone (no detectable movement between zones). For fish contacted in a different zone each year, but only one zone per year, the greatest detectable movement was 38 fish (2.4%) that moved from the river to the basin zone. Twelve fish moved from the basin to the river zone, and two fish moved from the Liberty to the basin zone. The remaining fish were contacted in multiple zones in a year; 18 fish were contacted in multiple zones in 2012, 53 in multiple zones in 2013, and 5 fish were contacted in multiple zones both years.

[3] Scanners contacted 1,620 unique tags; however, this number represents only 1,619 unique razorback suckers due to a double-tagged individual with a 400-kHz tag as well as a 134.2-kHz tag.

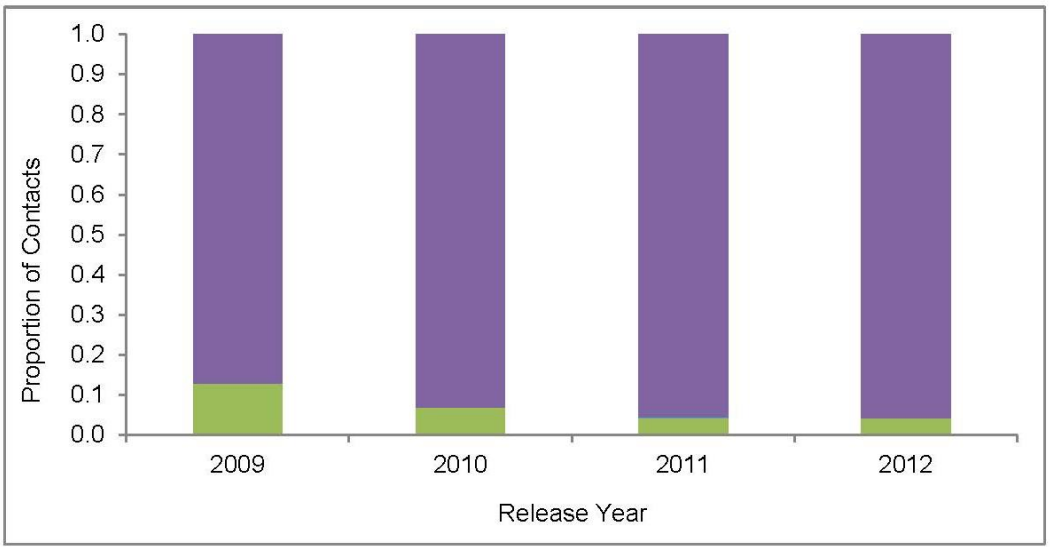

Figure 7.—Proportion of razorback sucker PIT tag contacts in 2013 among three scanning zones in Lake Mohave, basin (green), Liberty (blue), and river (purple), for fish released in the river zone.
Fish were released between October 1, 2008, and October 1, 2012, and contacted during PIT scanning activities from October 1, 2012, to September 30, 2013.

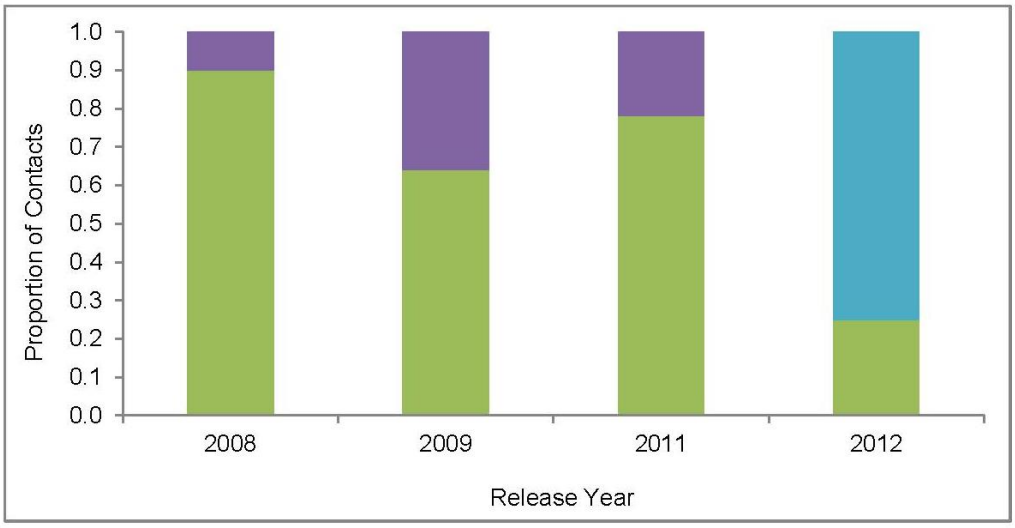

Figure 8.—Proportion of razorback sucker PIT tag contacts in 2013 among three scanning zones in Lake Mohave, basin (green), Liberty (blue), and river (purple), for fish released in the Liberty zone.
Fish were released between October 1, 2008, and October 1, 2012, and contacted during PIT scanning activities from October 1, 2012, to September 30, 2013.

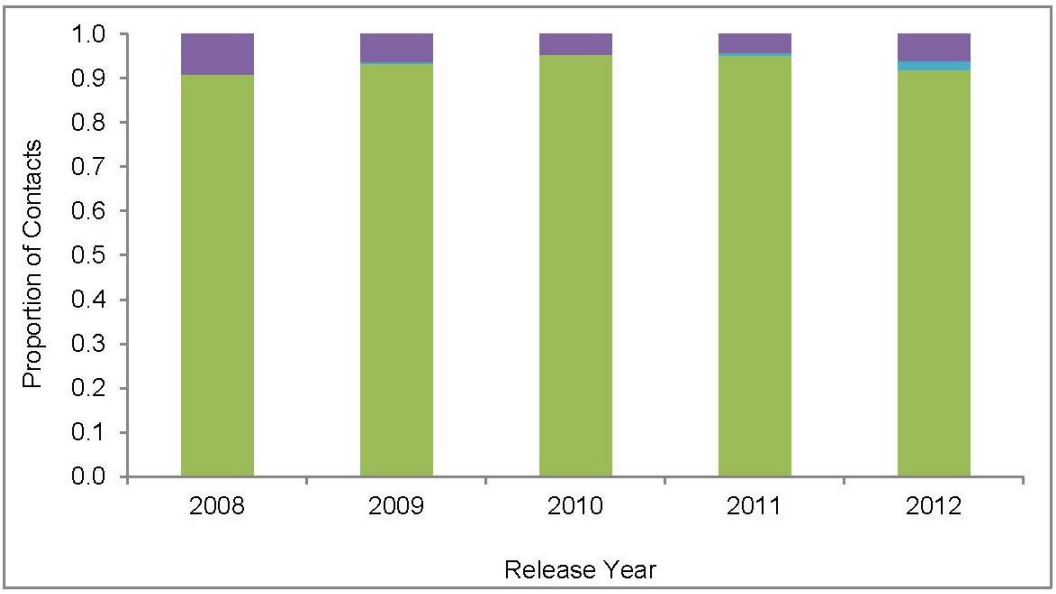

Figure 9.—Proportion of razorback sucker PIT tag contacts in 2013 among three scanning zones in Lake Mohave, basin (green), Liberty (blue), and river (purple), for fish released in the basin zone.
Fish were released between October 1, 2008, and October 1, 2012, and contacted during PIT scanning activities from October 1, 2012, to September 30, 2013.

Table 11.—Razorback suckers contacted by remote PIT scanning in 2013 that were also contacted in 2012 broken down by zone of contact, Lake Mohave, Arizona and Nevada
(Fish contacted in more than one zone in the same year were excluded from this table.)

2012	2013		
	River zone	Liberty zone	Basin zone
River zone	1,070	0	38
Liberty zone	0	1	2
Basin zone	12	0	490

2014

In 2014, sampling units were deployed in Lake Mohave for a total of 8,955 hours of total scanning time – 5,790 hours using shore-based and 3,165 hours with submersible scanners. In the past 3 years, 2014 exhibited the second lowest amount of scan hours, slightly more than numbers from 2012 and about 3,000 fewer hours than in 2013. Of the three sampling years, the highest number of PIT tag contacts was observed in 2014 despite fewer recorded scanning hours than the previous season. The 2014 sampling year resulted in 239,170 total

contacts, 2,709 of which were unique PIT tags, with 2,632 of those having a marking history in the Lower Colorado River Native Fish Database. Among fish with a marking record, 2,621 were repatriates, and 11 were wild.

Scanning in the river zone resulted in a total of 4,091 hours of scanning; 994 hours with shore-based and 3,097 hours with submersible scanners. Mean deployment times were 71.0 and 22.8 hours for shore-based and submersible scanners, respectively. Although the total number of contacts was much higher in 2014 than the past two years, mostly due to scanning in the basin zone, only 8,253 total contacts were recorded in the river zone, down about 3,300 from 2013 and 11,500 from 2012. Among 8,253 total contacts, 1,430 were unique PIT tags, and 1,414 of those were in the Lower Colorado River Native Fish Database. While the total number of river zone contacts was much less than past sampling years, the number of unique fish contacted is only slightly fewer than in 2012 and 2013. Repatriated razorback suckers accounted for 1,405 tags with a marking record, and 9 were noted as wild individuals.

As in 2013, contacts at fixed station sites in the river zone were compared during the 2014 sampling season. In 2014, 8 of a possible 105 fixed site replicates (7 trips x 5 sites x 3 replicates per trip) were removed due to scanner error. In August 2014, Boy Scout Canyon and Sauna Cave did not have any replicates due to scanner issues (figure 10). All other trip and location combinations had a minimum of two replicates. No sampling trip was conducted in April. Similar to 2013, the most contacts were observed at Black Bar during the first 4 months of sampling, dropping off in subsequent months. Gio's Point had the most contacts in two of the remaining three sample periods.

Liberty zone scanning was completed in 2014 using only shore-based units in Liberty Cove, resulting in a total of 112 hours scanned with an average deployment time of 55.8 hours. Zero contacts were recorded in the Liberty zone during the 2014 sampling season.

Both shore-based and submersible scanners were deployed for scanning in the basin zone and accumulated a total of 4,753 hours of scanning – 4,685 hours with shore-based and 68 hours with submersible scanners. Mean deployment times were 360.4 and 68.3 hours for shore-based and submersible scanners, respectively. A total of 230,917 PIT tags were contacted, representing 1,347 unique contacts. Total basin zone scan hours in 2014 were almost 3,000 fewer than in 2013; however, the number of basin zone contacts increased by about 45,000. Even with the increase in PIT tag contacts, the total observed unique individuals was higher in 2013. Among unique individuals, 1,284 had a marking history, comprised of only 2 wild fish and 1,282 repatriates.

As observed in the previous two seasons, fish tended to remain in two of the three zones in which they were stocked, excluding those that were stocked into the Liberty zone (figure 11). Of 2,185 razorback suckers contacted, eliminating

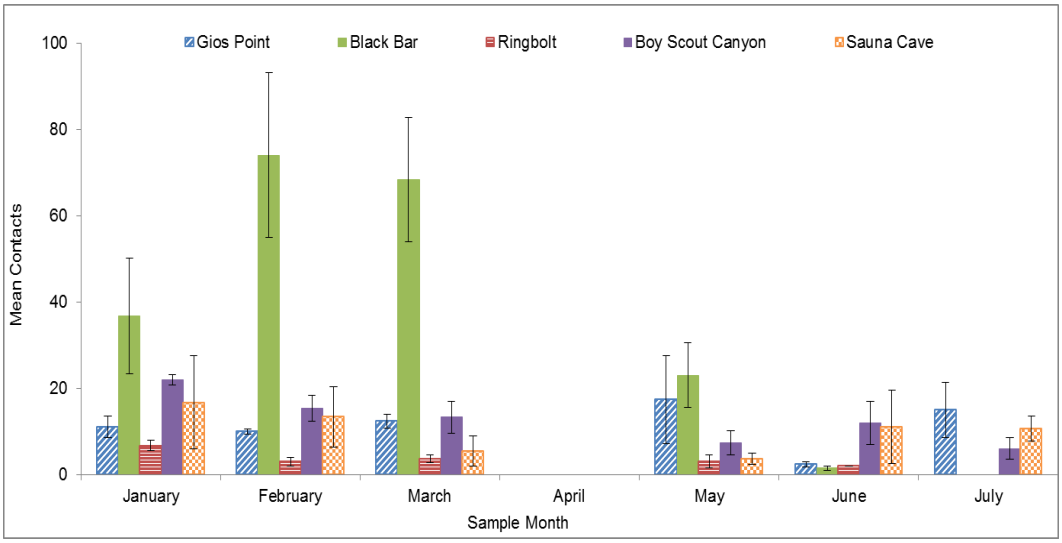

Figure 10.—Unique razorback sucker PIT tag contacts recorded in 2014 at five fixed stations in the river zone, Lake Mohave, Arizona and Nevada.
Error bars represent ±1 standard error.

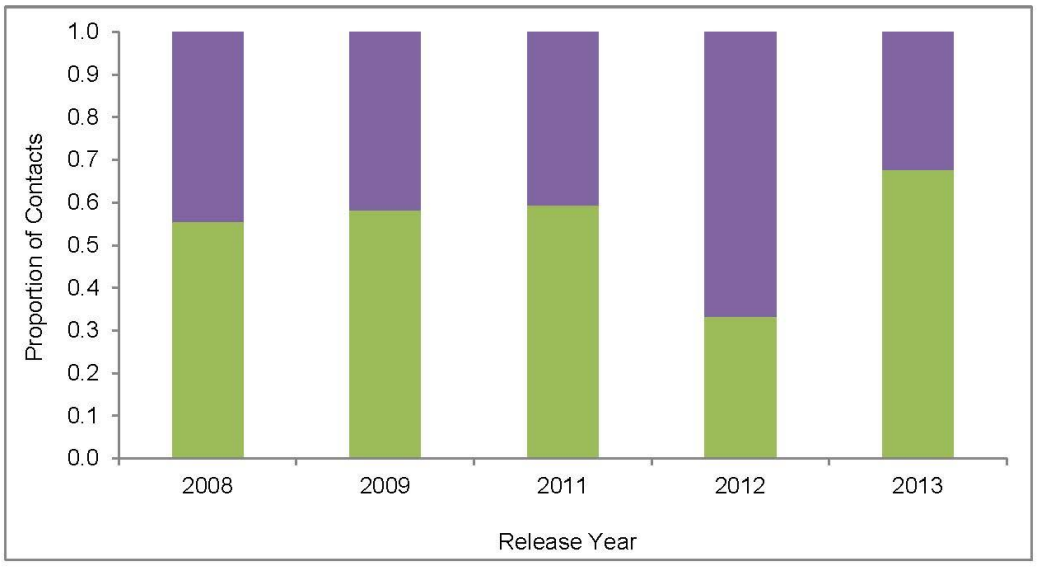

Figure 11.—Proportion of razorback sucker PIT tag contacts in 2014 among three scanning zones in Lake Mohave, basin (green), Liberty (blue), and river (purple), for fish released in the Liberty zone.
Fish were released between October 1, 2008, and October 1, 2013, and contacted during PIT scanning activities from October 1, 2013, to September 30, 2014.

63 fish contacted in multiple zones, 1,211 (55.4%) were released into the river zone. Regardless of release year, the majority (> 80%) of these fish were contacted in the river zone (figure 12). The same trend was also noted in the basin zone where more than 80% of individuals were contacted in their zone of release regardless of release year (figure 13). Basin zone released fish accounted for 34.5% (756) of razorback suckers contacted. PIT scanning was not conducted in the Katherine zone in 2014; however, 67 fish released there were contacted in the basin zone, and 6 were contacted in the river zone.

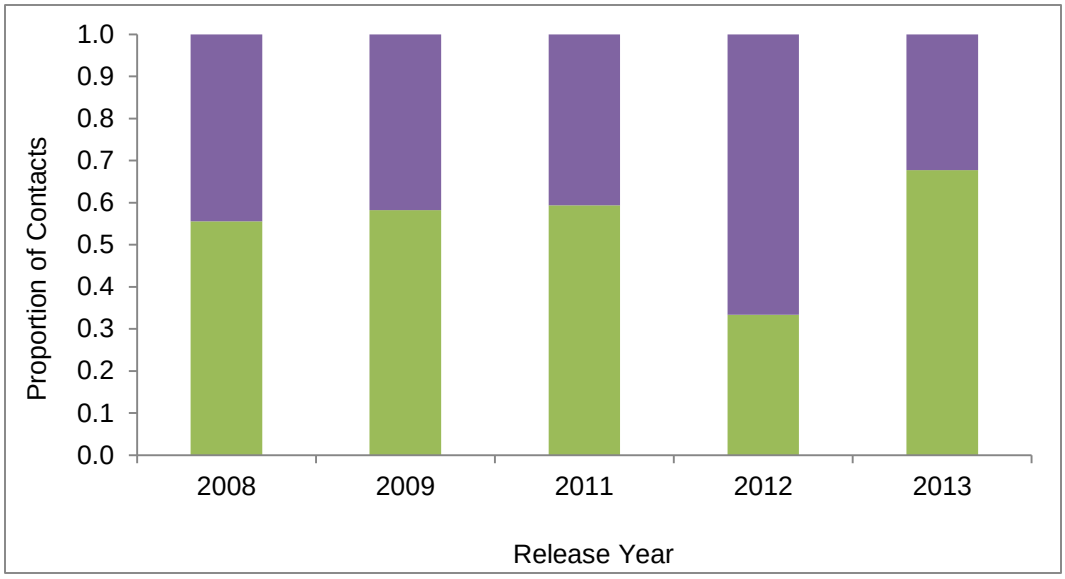

Figure 12.—Proportion of razorback sucker PIT tag contacts in 2014 among three scanning zones in Lake Mohave, basin (green), Liberty (blue), and river (purple), for fish released in the river zone.
Fish were released between October 1, 2008, and October 1, 2013, and contacted during PIT scanning activities from October 1, 2013, to September 30, 2014.

Similar to previous year comparisons, adult subpopulations in the river, Liberty, and basin zones exchanged few individuals from 2013 to 2014 (table 12). Among 1,674 razorback suckers contacted in both years, 1,528 (91.2%) were contacted in only one zone, slightly lower than the value for 2013/2012 evaluations. For individuals contacted in a different zone each year, but only one zone per year, the greatest detectable movement was 56 fish (3.6%) that moved from the basin to river zone. Thirty-seven fish moved from the river to the basin zone, three from the Liberty to the basin zone and one from the Liberty zone to the river zone. Remaining fish were contacted in multiple zones in a year; 49 fish were contacted in multiple zones in 2013, 44 in multiple zones in 2014, and 10 fish were contacted in multiple zones both years.

In the river zone, three cohorts released at Willow Beach NFH (October 13 and 23, 2009, and January 7, 2010) made up 95% of fish contacted in 2012 and continued to make up the majority of contacts through 2014 (65%) (table 13).

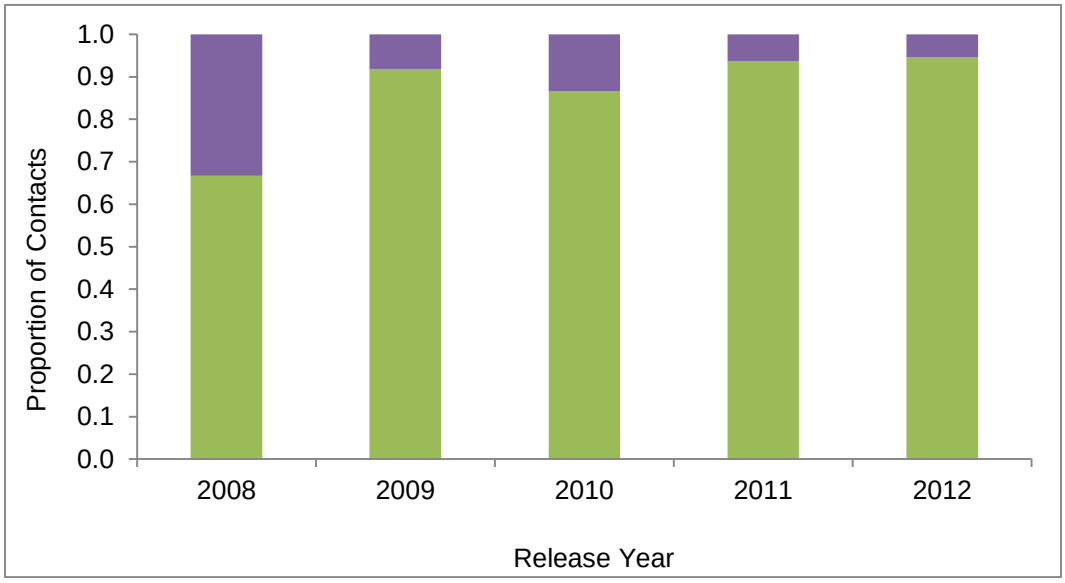

Figure 13.—Proportion of razorback sucker PIT tag contacts in 2014 among three scanning zones in Lake Mohave, basin (green), Liberty (blue), and river (purple), for fish released in the basin zone.
Fish were released between October 1, 2008, and October 1, 2013, and contacted during PIT scanning activities from October 1, 2013, to September 30, 2014.

Table 12.—Razorback suckers contacted by remote PIT scanning in 2014 that were also contacted in 2013 broken down by zone of contact, Lake Mohave, Arizona and Nevada
(Fish contacted in more than one zone in the same year were excluded from analyses.)

2013	2014		
	River zone	Liberty zone	Basin zone
River zone	893	0	37
Liberty zone	1	0	3
Basin zone	56	0	635

Two additional cohorts released at Willow Beach on October 4 and December 8, 2011, were contacted beginning in 2013. These five cohorts made up 94% of fish contacted in 2013 and 2014 but only account for 54% of fish released in the river zone. Of 2,446 river zone released fish in 2012, only 19 were contacted in 2014 (< 2%).

Although little PIT scanning was conducted in the Liberty zone, cohorts released there were scanned in similar proportions to releases elsewhere for fish of comparable size. Two to four percent of fish in cohorts released on December 17,

Table 13.—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 from 2012–14, Lake Mohave, Arizona and Nevada

Release zone	Release location	Release date	Releases	Mean TL (mm)	2012		2013		2014	
					Contacted	% contacted	Contacted	% contacted	Contacted	% contacted
River	Willow Beach boat ramp	10/13/2009	2,588	416	192	7.4%	187	7.2%	152	5.9%
	Willow Beach boat ramp	10/23/2009	2,234	421	475	21.3%	442	19.8%	357	16.0%
	Painted 8 Cove	12/18/2009	1,436	347	11	0.8%	16	1.1%	10	0.7%
	Ringbolt Cove	1/6/2010	1,493	334	7	0.5%	3	0.2%	4	0.3%
	Willow Beach NFH	1/7/2010	2,077	423	356	17.1%	338	16.3%	272	13.1%
	Willow Beach boat ramp	12/7/2010	504	398	36	7.1%	34	6.7%	24	4.8%
	Ringbolt Rapids	12/16/2010	1,508	324	3	0.2%	3	0.2%	6	0.4%
	Willow Beach NFH	10/4/2011	500	441	–	–	148	29.6%	125	25.0%
	Willow Beach boat ramp	12/8/2011	1,594	394	–	–	260	16.3%	233	14.6%
	Willow Beach boat ramp	12/12/2011	408	351	–	–	5	1.2%	8	2.0%
	Ringbolt Rapids	1/5/2012	1,778	332	–	–	0	0.0%	2	0.1%
	Willow Beach NFH	3/8/2012	549	375	–	–	21	3.8%	15	2.7%
	Willow Beach NFH	4/4/2012	119	373	–	–	1	0.8%	2	1.7%
Liberty	Wrong Cove	12/17/2009	916	374	29	3.2%	37	4.0%	30	3.3%
	Red Tail Cove	12/17/2009	897	382	26	2.9%	18	2.0%	17	1.9%
	Liberty Cove	12/17/2009	1,521	379	27	1.8%	27	1.8%	21	1.4%
	Liberty Cove	1/5/2011	1,896	339	4	0.2%	7	0.4%	7	0.4%
	Liberty Cove	3/16/2011	444		21	4.7%	26	5.9%	25	5.6%
	Liberty Cove	1/5/2012	1,920	330	–	–	3	0.2%	5	0.3%
	Owl Point Cove	1/26/2012	1,022	324	–	–	2	0.2%	1	0.1%
Basin	Dandy Cove	10/8/2008	158	438	4	2.5%	6	3.8%	5	3.2%
	Cottonwood Cove	3/20/2009	209	508	42	20.1%	72	34.4%	61	29.2%
	Cottonwood Cove	3/26/2009	125	463	26	20.8%	44	35.2%	40	32.0%
	Cottonwood Cove	12/3/2009	413	448	98	23.7%	119	28.8%	105	25.4%
	Yuma Cove	12/18/2009	1,611	329	5	0.3%	5	0.3%	3	0.2%
	Six Mile Coves	1/5/2010	1,584	329	9	0.6%	9	0.6%	9	0.6%
	Nine Mile Coves	1/6/2010	980	374	26	2.7%	36	3.7%	36	3.7%
	Yuma Cove	5/19/2010	101	478	44	43.6%	46	45.5%	35	34.7%
	Nine Mile Coves (north of)	1/6/2011	1,892	341	3	0.2%	7	0.4%	4	0.2%
	Yuma Cove	1/18/2012	693	328	–	–	1	0.1%	1	0.1%

2009 (mean TL of 374 and 382 mm) were contacted in 2014, a proportion similar to that of Willow Beach released cohorts in March and April 2012 (meal TL of 375 and 373 mm).

For fish released in the basin zone, there were five cohorts that make up the majority (93%) of fish scanned in 2014 but a minority (24%) of fish released (see table 13). The average sizes of fish in four of these five cohorts were longer than 400 mm TL at release, and three of these were released at Cottonwood Cove in 2009 (two were reared at Bubbling Ponds SFH and the other at Achii Hanyo SFH) 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 Yuma Cove Backwater and released at Yuma Cove with a mean TL at release of 477 mm (see table 13). The fifth cohort was comprised of 980 individuals reared at Willow Beach and released at Nine Mile Cove at a mean TL of 374 mm. Of the top five cohorts with the highest contact rates, only one, the Nine Mile Cove release, has a TL at release less than 400 mm. Four other cohorts with the largest number of fish released (74%) were contacted the least (see table 13), and all four of these had a mean TL at release shorter than 350 mm. The final cohort out of 10 examined for the basin zone was released at Dandy Cove in 2008; these fish were released at an average size of 438 mm TL but had very few contacts.

Population Estimates

2012

Monitoring data from 2011 and 2012 did not provide enough recaptures to estimate the size of the wild razorback sucker population in Lake Mohave. The repatriated razorback sucker population for 2011 was 2,577 (95% CI from 1,139 to 6,284) with a 2% estimated survival of all repatriates released as of March 1, 2011.

Based on remote PIT scanning data from 2011 and 2012, the 134.2-kHz tagged Lake Mohave repatriate population for 2011 was estimated at 2,704 individuals (95% CI from 2,437 to 3,001). Subpopulation estimates based on zone-specific scanning in 2011 and 2012 also were calculated. The basin zone population was estimated at 948 (95% CI from 795 to 1,130), and the river zone at 1,851 (95% CI from 1,623 to 2,111). No estimate was made for the Liberty zone due to a lack of scanning there.

2013

Similar to the 2011 population year, sample data from 2012 and 2013 did not provide enough recaptures to estimate the size of the 2012 wild razorback sucker population in Lake Mohave. The repatriated razorback sucker population

estimate for 2012 was 1,854 fish (95% CI from 941 to 3,782) with a 1% estimated survival of all repatriates released as of March 1, 2012.

The 2012 repatriate population in Lake Mohave based on 2012 and 2013 remote PIT scanning was estimated at 3,447 individuals (95% CI from 3,142 to 3,783), a significant increase since 2011, contrary to estimates made using routine monitoring data, which were actually lower in 2012 than in 2011. Lake Mohave subpopulation estimates also increased in number of individuals from 2011. The basin zone population was estimated at 1,509 (95% CI from 1,324 to 1,718), the Liberty zone at 44 (95% CI from 13 to 80; 1 recapture), and the river zone at 2,169 (95% CI from 1,892 to 2,486). The river zone estimate was nearly identical to an estimate of 2,174 from a regression analysis conducted in 2012 (Kesner et al. 2012b). Wild fish also were contacted in the basin and river zones, but no estimate was calculated because no recaptures was recorded in the basin zone and only one in the river zone.

2014

Based on monitoring data from 2013 and 2014, there was no effective wild razorback sucker population remaining in Lake Mohave. We estimated that the repatriated razorback sucker population was 2,525 (95% CI from 1,180 to 5,741) with a 1% estimated long-term survival of all repatriates released as of March 1, 2013.

Based on 2013 and 2014 remote PIT scanning, the 134.2-kHz tagged Lake Mohave repatriate population for 2013 was estimated at 3,284 individuals (95% CI from 3,067 to 3,516). Population estimates using zone-specific scanning for 2013 estimated the basin zone population at 1,492 (95% CI from 1,357 to 1,640) and the river zone population at 2,053 (95% CI from 1,357 to 1,640); no estimate was made for the Liberty zone.

Movement and Survival

For the "movement" model, $\hat{c}$ was significantly different than 1, and the estimated $\hat{c}$, 1.539 (95% CI from 1.521 to 1.557), was used to adjust AICc values (QAICc). Parameter estimates were based on model averaging because no model had more than 0.9 model weight (table 14). Estimates of post-release transition were slightly different between zones: 6.0% (95% CI from 4.4 to 8.1%) of fish post-release transitioned from the basin to the river zone and 6.6% (95% CI from 4.3 to 10.0%) from the river to the basin zone. Monthly transition rates for adult razorback suckers differed between the two zones in all supported models. In a given month, an estimated 0.6% (95% CI from 0.4 to 0.9%) of razorback suckers in the river zone transitioned to the basin zone, and 2.3% (95% CI 1.8 to 2.9%) were estimated to transition from the basin to the river zone monthly.

Table 14.—MARK movement models for adult razorback suckers, Lake Mohave, Arizona and Nevada (*P* [recapture] parameters were time varying and different among zones in all models.)

Model	QAICc	ΔQAICc	QAICc weights	Model likelihood	Number of parameters
Φtime(reduced), Ψzone, Ψ^1	14140.6	0.0	0.339	1.000	30
Φtime, Ψzone, Ψ^1	14140.9	0.2	0.304	0.896	34
Φtime(reduced), Ψzone, Ψ^1zone	14141.9	1.3	0.176	0.519	31
Φtime, Ψzone, Ψ^1zone	14142.2	1.6	0.154	0.455	35
Φtime(reduced), Ψtime(reduced)*zone, Ψ^1	14148.6	7.9	0.006	0.019	38
Φtime, Ψtime(reduced)*zone, Ψ^1	14148.7	8.1	0.006	0.018	42
Φtime(reduced)*zone, Ψzone, Ψ^1zone	14149.3	8.6	0.004	0.013	36
Φtime(reduced), Ψtime(reduced)*zone, Ψ^1zone	14149.5	8.9	0.004	0.012	39
Φtime, Ψtime(reduced)*zone, Ψ^1zone	14149.7	9.0	0.004	0.011	43
Φzone, Ψzone, Ψ^1	14153.8	13.1	0.000	0.001	27
Φ, Ψzone, Ψ^1zone	14154.7	14.1	0.000	0.001	27
Φtime(reduced)*zone, Ψtime(reduced)*zone, Ψ^1	14154.7	14.1	0.000	0.001	43
Φzone, Ψzone, Ψ^1zone	14155.1	14.4	0.000	0.001	28
Φtime(reduced)*zone, Ψtime(reduced)*zone, Ψ^1zone	14155.7	15.0	0.000	0.001	44

Estimates of survival indicated no measurable mortality in 2012 or in the period of April through January of any given year (table 15). However, in both 2013 and 2014, survival was lowest from January to February (90%), which coincides with the protracted spawning period from December to April. The last survival parameter, February through March 2014, was confounded with recapture rates and removed from the table. Recapture estimates varied between 4 and 45% of the marked population in a given month (table 16). Less variation occurred from month to month in the river zone (15–37%) than in the basin zone (4–45%). Again, the last parameter in the recapture estimates was confounded with survival and was unreliable (removed from table). The four highest ranked models with a combined model weight of 0.973 had fixed transition parameters (excluding post-stocking transition Ψ1); therefore, averaged parameter estimates were nearly constant for all periods (table 17).

For the "survival" model, ĉ was significantly different than 1, and the estimated ĉ, 1.318 (95% CI from 1.212 to 1.424), was used to adjust AICc values (QAICc). Parameter estimates were based on model averaging because no model had more than 0.9 model weight (table 18). As in the "movement" model, mortality (1-survival) was highest during the spawning season (table 19), and little mortality was estimated to occur between years. Recapture rates were similar to those estimated with the movement model and ranged from 3–58%, with less variation in the river zone estimates (20–57%) than in the basin zone (3–58%) (table 20). Lowest recapture rates in the basin zone occurred in April of both 2012 and 2013. Transition rates were similar to the previous model estimate and were again significantly higher for fish moving from the basin to the river zone (2.4 to 2.8%) than from the river to the basin zone (0.6%) (table 21).

Table 15.—MARK movement model survival estimates (model averaged) for razorback suckers released in the river or basin zone from 2008–10 that were also scanned in the river or basin zone from 2012–14

(Models exclude 97 fish released in the Liberty zone due to limited scanning there.)

Zone	Period	Estimate	Lower CI	Upper CI
River	Release to January 2012 (fixed)	1.000	1.000	1.000
	January 2012 to February 2012	1.000	1.000	1.000
	February 2012 to March 2012	1.000	1.000	1.000
	March 2012 to April 2012	1.000	1.000	1.000
	April 2012 January 2013	1.000	1.000	1.000
	January 2013 to February 2013	0.908	0.823	0.954
	February 2013 to March 2013	0.964	0.785	0.995
	March 2013 to April 2013	0.964	0.785	0.995
	April 2013 to January 2014	0.998	0.988	1.008
	January 2014 to February 2014	0.974	0.007	1.000
Basin	Release to January 2012 (fixed)	1.000	1.000	1.000
	January 2012 to February 2012	1.000	1.000	1.000
	February 2012 to March 2012	1.000	1.000	1.000
	March 2012 to April 2012	1.000	1.000	1.000
	April 2012 January 2013	1.000	1.000	1.000
	January 2013 to February 2013	0.908	0.823	0.954
	February 2013 to March 2013	0.964	0.785	0.995
	March 2013 to April 2013	0.964	0.785	0.995
	April 2013 to January 2014	0.998	0.988	1.008
	January 2014 to February 2014	0.972	0.008	1.000

Table 16.—MARK movement model recapture estimates (model averaged) for razorback suckers released in the river or basin zone from 2008–10 that were also scanned in the river or basin zone from 2012–14

(Models exclude 97 fish released in Liberty zone due to limited scanning there.)

Zone	Period	Estimate	Lower CI	Upper CI
River	January 2012	0.172	0.147	0.201
	February 2012	0.328	0.296	0.362
	March 2012	0.152	0.128	0.179
	April 2012	0.314	0.282	0.348
	January 2013	0.284	0.253	0.317
	February 2013	0.372	0.332	0.414
	March 2013	0.345	0.309	0.384
	April 2013	0.209	0.177	0.246
	January 2014	0.215	0.179	0.256
	February 2014	0.264	0.210	0.326
Basin	January 2012	0.215	0.176	0.261
	February 2012	0.255	0.212	0.302
	March 2012	0.120	0.090	0.158
	April 2012	0.049	0.031	0.077
	January 2013	0.449	0.397	0.502
	February 2013	0.257	0.209	0.312
	March 2013	0.167	0.129	0.215
	April 2013	0.041	0.024	0.071
	January 2014	0.313	0.255	0.379
	February 2014	0.292	0.220	0.376

Table 17.—MARK movement model transition estimates (model averaged) for razorback suckers released in the river or basin zone from 2008–10 that were also scanned in the river or basin zone from 2012–14
(Models exclude 97 fish released in Liberty zone due to limited scanning there.)

Zone	Period	Estimate	Lower CI	Upper CI
River	Release to January 2012	0.060	0.044	0.081
	January 2012 to February 2012	0.006	0.003	0.009
	February 2012 to March 2012	0.006	0.003	0.009
	March 2012 to April 2012	0.006	0.003	0.009
	April 2012 January 2013	0.006	0.003	0.010
	January 2013 to February 2013	0.006	0.003	0.009
	February 2013 to March 2013	0.006	0.003	0.009
	March 2013 to April 2013	0.006	0.003	0.009
	April 2013 to January 2014	0.006	0.003	0.010
	January 2014 to February 2014	0.006	0.003	0.010
	February 2014 to March 2014	0.006	0.003	0.010
Basin	Release to January 2012	0.066	0.043	0.100
	January 2012 to February 2012	0.022	0.016	0.032
	February 2012 to March 2012	0.022	0.016	0.032
	March 2012 to April 2012	0.022	0.016	0.032
	April 2012 January 2013	0.023	0.015	0.036
	January 2013 to February 2013	0.023	0.016	0.031
	February 2013 to March 2013	0.023	0.016	0.031
	March 2013 to April 2013	0.023	0.016	0.031
	April 2013 to January 2014	0.022	0.014	0.034
	January 2014 to February 2014	0.023	0.014	0.037
	February 2014 to March 2014	0.023	0.014	0.037

Table 18.—MARK survival models for adult razorback suckers, Lake Mohave, Arizona and Nevada (*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
Φtime(reduced)*zone, Ψzone	9518.7	0.0	0.76942	1.0000	33
Φtime(reduced), Ψzone	9521.7	3.0	0.17016	0.2212	27
Φtime(reduced)*zone, Ψtime(reduced)*zone	9524.0	5.4	0.05277	0.0686	42
Φtime, Ψzone	9528.9	10.2	0.00473	0.0061	31
Φtime(reduced), Ψtime(reduced)*zone	9531.1	12.4	0.00156	0.0020	37
Φtime(reduced)*zone, Ψtime*zone	9533.0	14.3	0.00061	0.0008	50
Φtime*zone, Ψzone	9533.4	14.8	0.00048	0.0006	41
Φtime(reduced)*zone, Ψ	9536.8	18.2	0.00009	0.0001	33
Φtime(reduced), Ψ	9538.2	19.6	0.00004	0.0001	26
Φtime, Ψtime(reduced)*zone	9538.3	19.6	0.00004	0.0001	41

Table 19.—MARK survival model repatriate adult survival estimates (model averaged) for razorback suckers released in the river or basin zone from 2008–10 that were also scanned in the river or basin zone from 2012–14

(Models exclude 97 fish released in the Liberty zone due to limited scanning there.)

Zone	Period	Estimate	Lower CI	Upper CI
River	January 2012 to February 2012	0.928	0.821	0.973
	February 2012 to March 2012	0.993	0.987	1.000
	March 2012 to April 2012	0.993	0.987	1.000
	April 2012 January 2013	0.993	0.987	1.000
	January 2013 to February 2013	0.855	0.762	0.915
	February 2013 to March 2013	0.989	0.965	0.997
	March 2013 to April 2013	0.989	0.965	0.997
	April 2013 to January 2014	0.989	0.965	0.997
Basin	January 2012 to February 2012	0.817	0.632	0.921
	February 2012 to March 2012	0.993	0.982	1.004
	March 2012 to April 2012	0.993	0.983	1.003
	April 2012 January 2013	0.993	0.983	1.003
	January 2013 to February 2013	0.762	0.624	0.861
	February 2013 to March 2013	0.999	0.994	1.005
	March 2013 to April 2013	0.999	0.994	1.005
	April 2013 to January 2014	0.999	0.994	1.005

Table 20.—MARK survival model recapture estimates (model averaged) for razorback suckers released in the river or basin zone from 2008–10 that were also scanned in the river or basin zone from 2012–14

(Models exclude 97 fish released in the Liberty zone due to limited scanning there.)

Zone	Period	Estimate	Lower CI	Upper CI
River	February 2012	0.569	0.482	0.651
	March 2012	0.217	0.177	0.264
	April 2012	0.256	0.215	0.301
	January 2013	0.307	0.265	0.352
	February 2013	0.429	0.383	0.475
	March 2013	0.357	0.318	0.399
	April 2013	0.197	0.168	0.229
	January 2014	0.224	0.183	0.270
	February 2014	0.278	0.233	0.329
Basin	February 2012	0.280	0.185	0.400
	March 2012	0.150	0.102	0.216
	April 2012	0.057	0.031	0.103
	January 2013	0.490	0.401	0.579
	February 2013	0.298	0.232	0.373
	March 2013	0.206	0.156	0.268
	April 2013	0.030	0.014	0.061
	January 2014	0.325	0.263	0.394
	February 2014	0.408	0.258	0.578

Table 21.—MARK survival model movement estimates (model averaged) for razorback suckers released in the river or basin zone from 2008–10 that were also scanned in the river or basin zone from 2012–14

(Models exclude 97 fish released in the Liberty zone due to limited scanning there.)

Zone	Period	Estimate	Lower CI	Upper CI
River	January 2012 to February 2012	0.006	0.002	0.010
	February 2012 to March 2012	0.006	0.003	0.010
	March 2012 to April 2012	0.006	0.003	0.010
	April 2012 January 2013	0.006	0.003	0.010
	January 2013 to February 2013	0.007	0.003	0.011
	February 2013 to March 2013	0.006	0.003	0.010
	March 2013 to April 2013	0.006	0.003	0.010
	April 2013 to January 2014	0.006	0.003	0.010
	January 2014 to February 2014	0.006	0.002	0.010
Basin	January 2012 to February 2012	0.024	0.014	0.040
	February 2012 to March 2012	0.024	0.016	0.036
	March 2012 to April 2012	0.024	0.016	0.036
	April 2012 January 2013	0.024	0.016	0.036
	January 2013 to February 2013	0.026	0.013	0.051
	February 2013 to March 2013	0.024	0.015	0.038
	March 2013 to April 2013	0.024	0.015	0.038
	April 2013 to January 2014	0.024	0.015	0.038
	January 2014 to February 2014	0.028	0.009	0.086

DISCUSSION

Three years of consistent remote PIT scanning in the basin and riverine sections of Lake Mohave have resulted in the identification of two demographically distinct razorback sucker subpopulations and estimates of their abundance, survival, and transition rates. Remote sensing through deployment of PIT scanners in the basin and river zones of the reservoir has proven effective in contacting razorback sucker aggregates with an estimated 80% or more of the known population of 134.2-kHz tagged fish being contacted over a sample year. Compared to the 10 to 15% rate of contact during annual March monitoring, PIT scanning has proven to provide the necessary level of contact for precise mark-recapture analyses without increasing handling. Nonetheless, there continues to be a strong need for adequate levels of handling to meet genetic and demographic needs beyond PIT tag contacts.

The mark-recapture model based on remote PIT scanning data indicates that stocking location determines subpopulation membership for the majority of repatriated fish; fish released in the river zone join the river zone subpopulation, and fish released in the basin zone join the basin zone subpopulation. Post-stocking transition rates (movement between subpopulations) did not significantly differ among zones, with approximately 6% transition to the other subpopulation, sometime after release. However, monthly transition rates for adult razorback suckers indicate a net upstream migration of fish from the basin to the river zone with a transition rate estimated at nearly three times the rate of river to basin zone transitions.

Although the size of the riverine subpopulation is known, it is not known how many larvae these fish produce. Current harvest from this region has been limited, either because larvae are few or unavailable to sample, or because of low and spatially restricted effort. Razorback sucker spawning has been documented in the Colorado River 4.8 km below Hoover Dam on gravel substrate presumably similar to spawning areas that would have been utilized in riverine areas historically (Minckley 1983). Mueller (1989) discovered and collected razorback sucker eggs and larvae from this spawning site and directly downstream (alleging a high degree of larval drift). Other "big-river" fish endemic to the Colorado, including the humpback chub (*Gila cypha*), have been known to successfully reproduce in warmer water tributaries to the perennially cold tailwater below Glen Canyon dam, and their larvae have been collected in association with warm springs along the river's edge (Valdez and Masslich 1999). Geothermal inflows are prevalent in the riverine section of Lake Mohave, and these may provide suitable razorback sucker spawning areas. If reproduction by these fish results in a seasonal abundance of larvae, and these young fish are available for harvest, then from a programmatic standpoint, developing a method of collecting tens of thousands of larvae from the riverine subpopulation should be a priority. Collecting razorback sucker larvae from both subpopulations will ensure that each subpopulation is contributing to the repatriation program and is represented in the genetic makeup of the repatriate population.

Adult survival had previously only been estimated on an annual basis at around 75% (Marsh et al. 2005). The use of PIT scanning data in the mark-recapture model allowed for monthly estimates of apparent survival for the period January through April. These estimates, along with the estimated apparent survival between sample years (April – January), indicate that survival for most months is near 100%. Nearly all mortality occurs sometime during the spawning period, peaking in different months depending on the year and zone. The timing of mortality is similar to what has been seen recently in the Yuma Cove backwater where continuous PIT scanning has allowed for the timing of mortality to be tracked almost daily (unpublished data). Mortality corresponding to the spawning period may indicate that razorback suckers are more vulnerable to predation during this period or that the stress of spawning increases mortality.

Population estimates for each subpopulation based on mark-recapture data derived from remote PIT scanning and March monitoring data were relatively stable for the 3 years of this study, except for the PIT scanning estimate for the basin zone from 2011 to 2012. This likely was due to the addition of a semipermanent PIT scanner at Tequila Cove in 2012, which scanned almost continuously from December to April and increased geographic coverage in the basin zone. Population estimates from traditional sampling versus PIT scanning for the basin zone also differed substantially in two of three years, 2011 and 2013. Differences may be due in part to the limited geographic coverage of PIT scanners relative to netting in the basin zone (90% of data are received from units deployed at Yuma and Tequila Coves). Also, capture records used in the traditional estimate continue to include fish with 400-kHz PIT tags,[4] or no tags at all prior to capture. These differences were not statistically significant, but the lack of significance is likely caused by low precision (wide CIs) of population estimates based on traditional sampling.

Although abundance has been relatively stable, release cohort analyses based on PIT scanning in the river zone present some compelling data that new cohorts are not replacing declining older ones. In the river zone, individual release cohorts in 2009 and 2010 dominate PIT scanning data in all three sample years, but the number contacted has declined each year. For example, in a cohort of 2,077 fish released from Willow Beach in 2010, 17.1% (356 unique) of the group were contacted in 2012, dropping to 16.3% (338 unique) in 2013, and falling again to 13.1% (272 unique) contacted in 2014 (see table 13). More recent releases in 2011 and 2012 were not scanned in similar numbers, indicating that these cohorts experienced lower survival. Additional years of poor post-release survival could put this subpopulation at greater risk. Currently, the river zone subpopulation does not contribute significantly to the repatriation program (i.e., few larvae are collected there. However, they contribute to the overall abundance of razorback suckers in the Colorado River system, a valuable contribution to the perpetuation of the species.

The relationship between size at release and survival for razorback suckers has been supported by numerous lines of evidence (Marsh et al. 2005; Minckley et al. 2003; Zelasko et al. 2010). In general, the size of an individual fish across taxa is inversely related to predation vulnerability (Fritts and Pearsons 2006; Krummrich and Heidinger 1973; Truemper and Lauer 2005). Additional factors often are highly correlated with size at release. Razorback suckers released from backwaters are larger (TL) than fish released from Willow Beach, and these are contacted at a higher rate than smaller (< 400 mm TL) fish. Most large fish released in the river zone were not raised at the Willow Beach NFH, but were reared at the Southwestern Native Aquatic Resources and Recovery Center, Achii Hanyo SFH, and Bubbling Ponds SFH. The only release from Willow Beach

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

NFH with a mean TL greater than 400 mm was a cohort of over 2,000 fish from January 1, 2010. This is also the only release from Willow Beach with a contact rate greater than 20%. Cohorts that have had the highest contact rates from the past several monitoring seasons seem to have peaked, and both numbers of remaining individuals and contact rates are declining. The really "good" cohorts – those comprised of relatively large fish at release and characterized by relatively high post-stocking survival – are fading. Few contacts have been made with fish released at a smaller size in 2012 and 2013.

The lack of river zone PIT scanning contacts for fish released in 2012 and 2013 could be attributed to those fish being immature and not visiting spawning areas, which typically yield the most contacts. However, fish released in 2009 have been contacted on spawning grounds since 2011, growth data (figures 14 and 15) indicate that 2 years post-release is enough time for most fish to achieve adult size, and most individuals captured a year after release are greater than 450 mm at capture. Lack of contact with release cohorts from 2012 is more likely due to poor post-stocking survival at least partially explained by their smaller average size at release compared to fish released from 2009–11.

The mark-recapture model used in these analyses required pooling of monthly remote PIT scanning data, and some data were excluded in an attempt to meet the model assumptions. Barbour et al. (2013) argued in a recent paper that the Barker model performed better with continuous PIT scanning data than pooling into a Cormack-Jolly-Seber model for time-dependent survival. However, these researchers assumed there was no movement or emigration in or out of their study area. Transition between the river and basin zones could be modeled as emigration in the Barker model, and therefore, emigration would be greater than zero. When assessing an equivalent model structure for Lake Mohave razorback sucker data, it was apparent that the same model structure with time varying re-sighting parameters resulted in undeterminable fidelity parameters (rates of emigration out of and immigration into a zone could not be estimated). Therefore, the multi-strata (recaptures only) model was chosen for this report. As PIT scanning becomes more and more prevalent, the development of more relevant mark-recapture models will improve data inclusion and model inferences.

For more than a decade, the repatriated population of razorback suckers in Lake Mohave has been maintained at a few thousand fish by stocking nearly 200,000 fish. This repatriation program is one facet of a broader strategy, but 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. The genetic legacy of razorback suckers embodied in the Lake Mohave population must be maintained while a backwater conservation strategy (Minckley et al. 2003; USFWS 2005) or an alternative is developed and implemented. The largest and most genetically diverse razorback sucker population resides in Lake Mohave, making it the "cornerstone for razorback sucker conservation" (Marsh et al. 2015).

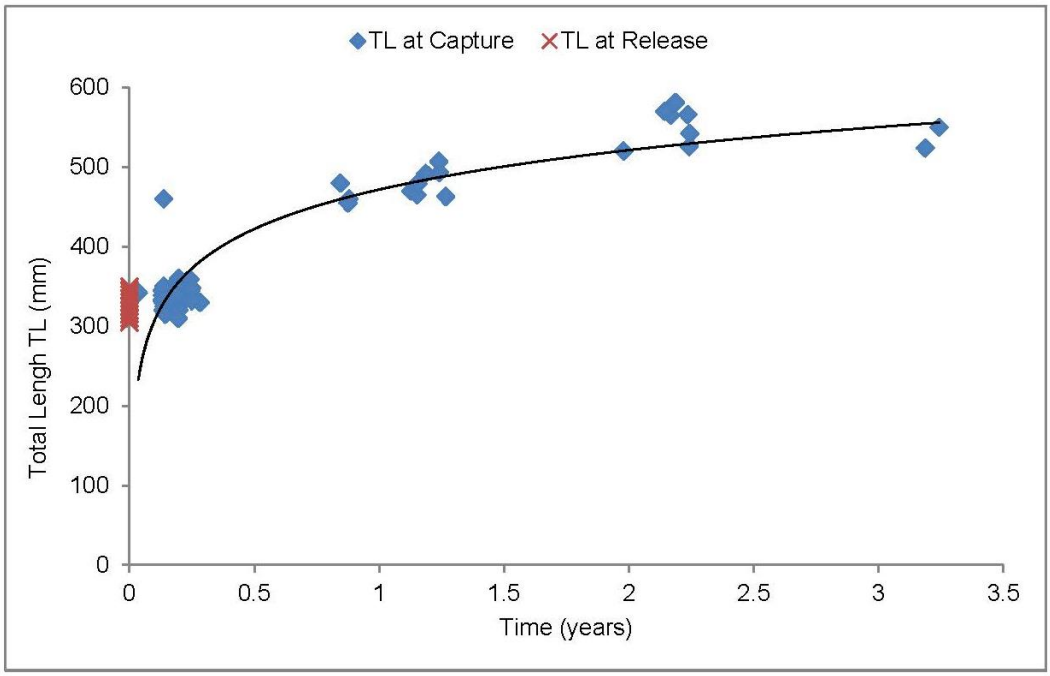

Figure 14.—Growth curve comparing TL at release for fish stocked between 300 and 350 mm after October 1, 2008, with TL at capture after January 1, 2009.

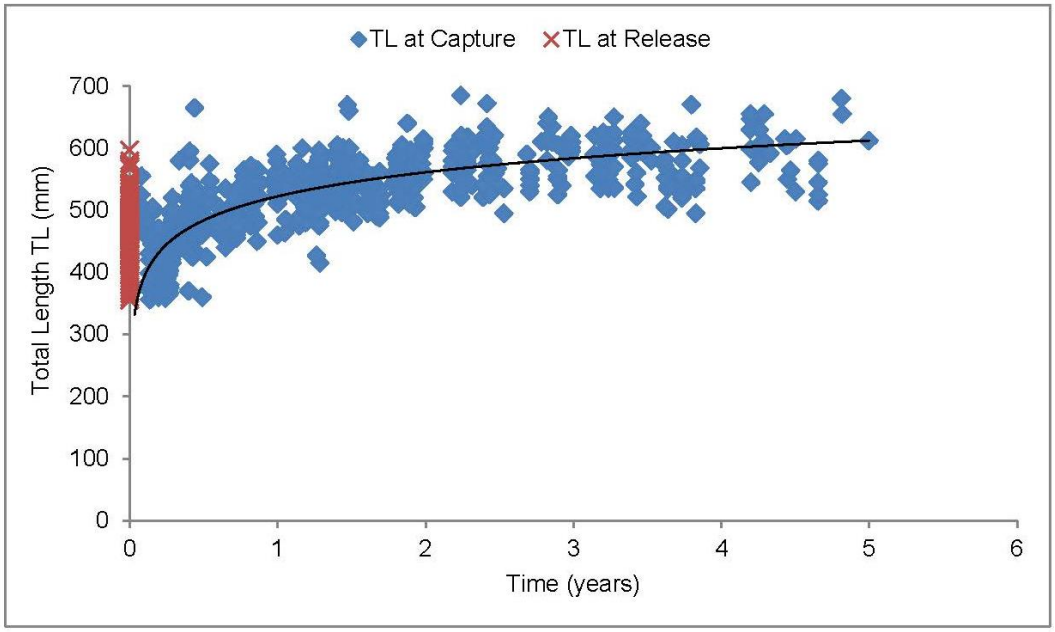

Figure 15.—Growth curve comparing TL at release for fish greater than 350 mm at release after October 1, 2008, with TL at capture after January 1, 2009.

RECOMMENDATIONS

Biannual 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 suckers 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 the Liberty zone because fish do not seem to remain there long term. Also, given the current limitations of larval collections in the river zone, and the metapopulation dynamics of razorback suckers in Lake Mohave, stocking should favor basin zone locations over the river zone when feasible for the next Federal fiscal year (fiscal year 2015 – October 2014 to September 2015). Fish 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 analyses.

The goal of the Lake Mohave razorback sucker repatriation program is to maintain or increase the genetic diversity of the adult population for the purpose of species conservation. Remote PIT scanning deployments in the river zone should be conducted at least monthly. M&A staff should continue to work with Reclamation biologists to ensure a similar scanning effort in the basin zone. The location 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, 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.

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 G. Cappelli, M. Olson, and other staff (Willow Beach NFH); J. Anderson, T. Burke (retired), T. Delrose, G. Garnett, J. Lantow, J. Nelson, J. Stolberg, and T. Wolters (LCR MSCP); M. Urban and M. Burrell (retired) (Nevada Department of Wildlife); F. Agyagos and D. Billingsly (Arizona Game and Fish Department Bubbling Ponds SFH); and D. Adams, T. Dowling, and M. Saltzgiver (Wayne State University). This work was supported by Reclamation Order No. R12PD30001.

LITERATURE CITED

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

Barbour, A.B., J.M. Ponciano, and K. Lorenzen. 2013. Apparent survival estimation from continuous mark-recapture/resighting data. Methods in Ecology and Evolution 4:846–853.

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

_____. 2013. Final Implementation Report, Fiscal Year 2014 Work Plan and Budget, Fiscal Year 2012 Accomplishment Report. Lower Colorado River Multi-Species Conservation Program, Bureau of Reclamation, Boulder City, Nevada. 410 p.

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

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.

Fritts, A.L. and T.N. Pearsons. 2006. Effects of predation by nonnative smallmouth bass on native salmonid prey: the role of predator and prey size. Transactions of the American Fisheries Society 135:853–860.

Joe, M. and K. H. Pollock. 2002. Separation of survival and movement rates in multi-state tag-return and capture-recapture models. Journal of Applied Statistics 29:373–384.

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. Bureau of Reclamation Agreement No. 06-FC-300003, Boulder City, Nevada. Arizona State University, Tempe. 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. 2012a. Demographics and Post-stocking Survival of Repatriated Razorback Sucker in Lake Mohave, Final Report. Bureau of Reclamation Agreement No. R09AP30002, Boulder City, Nevada. Marsh & Associates, LLC, Tempe, Arizona. 79 p.

Kesner, B.R., A.P. Karam, C.A. Pacey, J.W. Warmbold, and P.C. Marsh. 2012b. Lake Mohave Razorback Sucker Monitoring, 2012 Annual Report. Bureau of Reclamation Agreement No. R12PD30001, Boulder City, Nevada. Marsh & Associates, LLC, Tempe, Arizona. 35 p.

Krummrich, J.T. and R.C. Heidinger. 1973. Vulnerability of channel catfish to largemouth bass predation. Progressive Fish-Culturist 35:173–175.

Lebreton, J. D. and R. Pradel. 2002. Multistate recapture models: modelling incomplete individual histories. Journal of Applied Statistics 29:353–369.

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(1):141–156.

Minckley, W.L. 1983. Status of the razorback sucker, *Xyrauchen texanus* (Abbott), in the lower Colorado River basin. The Southwestern Naturalist 24:686–687.

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. 1989. Observations of spawning razorback sucker (*Xyrauchen texanus*) utilizing riverine habitat in the lower Colorado River Arizona-Nevada. The Southwestern Naturalist 34:147–149.

_____. 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. 2012. 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.

Truemper, H.A. and T.E. Lauer. 2005. Gape limitation and piscine prey size-selection by yellow perch in the extreme southern area of Lake Michigan, with emphasis on two exotic prey items. Journal of Fish Biology 66:135–149.

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.

Valdez, R.A. and W.J. Masslich. 1999. Evidence of reproduction by humpback chub in a warm spring of the Colorado River in Grand Canyon, Arizona. The Southwestern Naturalist 44:384–387.

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.