Lower Colorado River
Multi-Species Conservation Program

Balancing Resource Use and Conservation

Comparative Survival of Repatriated Razorback Suckers in Lower Colorado River Reach 3

2014–2016

U.S. Department of the Interior
Bureau of Reclamation

April 2017

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Lower Colorado River Multi-Species Conservation Program

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ACRONYMS AND ABBREVIATIONS

AIC_c	Akaike's information criterion adjusted for small sample size
amp-h	ampere-hour(s)
CI	confidence interval
cm	centimeter(s)
g	gram(s)
ft	foot/feet
in	inch(es)
kHz	kilohertz
km	kilometer(s)
LCR MSCP	Lower Colorado River Multi-Species Conservation Program
m	meter(s)
M&A	Marsh & Associates, LLC
MARK	computer program MARK
mm	millimeter(s)
PIT	passive integrated transponder
PVC	polyvinyl chloride
$QAIC_c$	Akaike's information criterion corrected for overdispersion
Reach 3	Lower Colorado River Reach 3
Reclamation	Bureau of Reclamation
RKM	river kilometer
RM	reservoir mile
TL	total length
UTM	Universal Transverse Mercator

Symbols

Δ	change, difference between models
$>$	greater than
$<$	less than
%	percent
$\hat{c}$	c-hat, variance inflation factor

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EXECUTIVE SUMMARY

The razorback sucker (*Xyrauchen texanus*) is a fish endemic to the Colorado River drainage. It was once abundant throughout its range, but populations have steadily declined, and the species is listed as endangered. Under guidance of the Lower Colorado River Multi-Species Conservation Program), more than 75,000 razorback suckers have been stocked into Lower Colorado River Reach 3 (between Davis and Parker Dams) (Reach 3) since 2006. Contact rates of stocked fish have been low using traditional fisheries sampling methods (i.e., electrofishing and trammel nets); however, the use of remote passive integrated transponder (PIT) scanning technology has proven effective at contacting thousands of razorback suckers.

Remote PIT scanners were deployed in Reach 3 for 1 week per month for 4 months during the razorback sucker spawning season (January to April) from Davis Dam downstream to Park Moabi Regional Park, California, to target aggregations of razorback suckers. In addition, data were compiled from other projects and entities that scanned or captured razorback suckers in Reach 3. These annual collective efforts resulted in the contact of 1,972, 4,142, and 3,027 individual razorback suckers in 2014, 2015, and 2016, respectively. The razorback sucker population in Reach 3 was estimated at 4,935 (4,629–5,262; 95% confidence interval in 2014 and 4,923 (4,652–5,209; 95% confidence interval) in 2015.

Post-stocking survival appears to be higher for relatively small razorback suckers, with contact proportions as high as 10% for fish released at 13.8 inches (350 millimeters) compared to a 1.8% contact rate in Lake Mohave for similar-sized fish. The season of release had a minimal impact on apparent survival. Population estimates for razorback suckers in Reach 3 are consistently higher than Lake Mohave. However, maintenance of both populations is wholly dependent on their respective stocking programs. PIT scanning continues to provide increased contacts of tagged fish compared to traditional means such as electrofishing and trammel netting, but the latter provides information not otherwise available. Monitoring of razorback suckers in Reach 3 should continue with both remote PIT scanning and biannual netting trips. The stocking regime should be coordinated with a sampling regime to test specific hypotheses about factors affecting post-stocking survival.

INTRODUCTION

The razorback sucker (*Xyrauchen texanus*) is a long-lived catostomid fish endemic to the Colorado River Basin. It was once abundant and widespread throughout the drainage (Minckley 1973). Its distribution and numbers have declined range-wide, and the species is currently listed as endangered under the Endangered Species Act (U.S. Fish and Wildlife Service 1991). The population decline is largely attributed to habitat alterations associated with dam construction and direct and indirect interactions with introduced non-native fish species (Joseph et al. 1977; Minckley 1979; Bestgen 1990; Minckley et al. 1991; Mueller and Marsh 2002). Stocking of subadult to adult fish has been the focus of management actions in the Lower Colorado River Basin (U.S. Fish and Wildlife Service 2005). Adult razorback suckers have relatively high survival, greater than 75% annually (Marsh et al. 2005; Wisenall et al. 2015), and established populations spawn annually throughout the Lower Colorado River Basin. However, evidence of natural recruitment is limited to a single population in Lake Mead (Kegerries et al. 2009; Albrecht et al. 2010), and all other populations are contingent on continued stocking.

Current management of razorback suckers in the Lower Colorado River Basin is under the direction of the Lower Colorado River Multi-Species Conservation Program (LCR MSCP). This program was implemented in 2005 to balance the use of the water resources and conservation of native species and their habitat in compliance with the Endangered Species Act (Bureau of Reclamation [Reclamation] 2004). Under this program, the lower Colorado River is subdivided into designated planning areas and river reaches to address these goals. Lower Colorado River Reach 3 (Reach 3) is the 84-mile (135-kilometer [km]) section along the Arizona-Nevada and Arizona-California borders between Davis and Parker Dams. The reach includes the 54-mile (87-km) riverine section immediately downstream from Davis Dam and the entirety of Lake Havasu proper, which is impounded by Parker Dam.

Minckley (1983) hypothesizes that razorback sucker populations experienced highly successful recruitment events immediately following impoundment of reservoirs in the Lower Colorado River Basin. Lake Havasu was impounded in 1938, but recruitment events became rare due to negative interactions with non-native sport fishes. As a result, populations began to decline, and the last documented capture of wild adult razorback suckers was in Laughlin Lagoon in 1986 (Marsh and Minckley 1989). A population persists today only because of annual stocking efforts that began with larval stocking in 1986 (Marsh and Minckley 1989) and continued with nearly 500,000 mostly small razorback suckers stocked between 1986 and 2005 (Schooley and Marsh 2007, unpublished data).

Under guidance of the LCR MSCP, more than 75,000 larger razorback suckers (> 11.8 inches [in] or 300 millimeters [mm]) have been stocked into Reach 3 since 2006. Post-stocking research and monitoring activities have resulted in the capture of very few fish from early stockings, and while individuals from more recent stockings have comparatively higher contact rates, absolute capture rates using standard fisheries gear (i.e., electrofishing and trammel nets) have remained low (< 3%) (Patterson et al. 2014). Therefore, calculating accurate population estimates and isolating specific factors affecting survival of repatriated razorback suckers in Reach 3 presents a challenge.

Historically, traditional capture methods, including electrofishing and trammel netting, were the only avenues for contacting fishes in reservoirs. However, with the advent of passive integrated transponder (PIT) tags and remote scanning units able to detect these tags, contacts with razorback suckers have increased greatly. Since a remote PIT scanning program was initiated in 2011 in Lake Mohave (Lower Colorado River Reach 2), encounters with marked fish has increased remarkably, allowing for more accurate estimates of population and post-stocking survival.

Razorback suckers in Reach 3 have been found to aggregate in major spawning areas like those observed in Lake Mohave, from Laughlin, Nevada, downstream to Needles, California (Wydoski and Mueller 2006; Wydoski and Lantow 2012). Remote PIT scanning of spawning aggregates has proven successful in Reach 3 as well as in Lake Mohave (Patterson et al. 2014; Wisenall et al. 2015). Because of the success of these previous studies, remote PIT scanning was continued in Reach 3 from January 2014 to April 2016. In addition, PIT scanning data and capture data collected from other projects from December 2011 to August 2016 to be used in the analysis were compiled.

Reported here are the final results and conclusions on the use of a combination of remote PIT scanning and capture data to assess the current Reach 3 razorback sucker population and evaluate the effects of size, location, and timing of release on post-stocking survival. This information is integral in formulating a cost-effective, efficient method to restore the population in Reach 3. Specific objectives from the study period include:

1. Contact razorback suckers using remote PIT scanning units in Zones 3-1, 3-2, and 3-4 (figure 1)

2. Assimilate all Reach 3 razorback sucker release and capture data collected by any entity

3. Estimate the current repatriate razorback sucker population

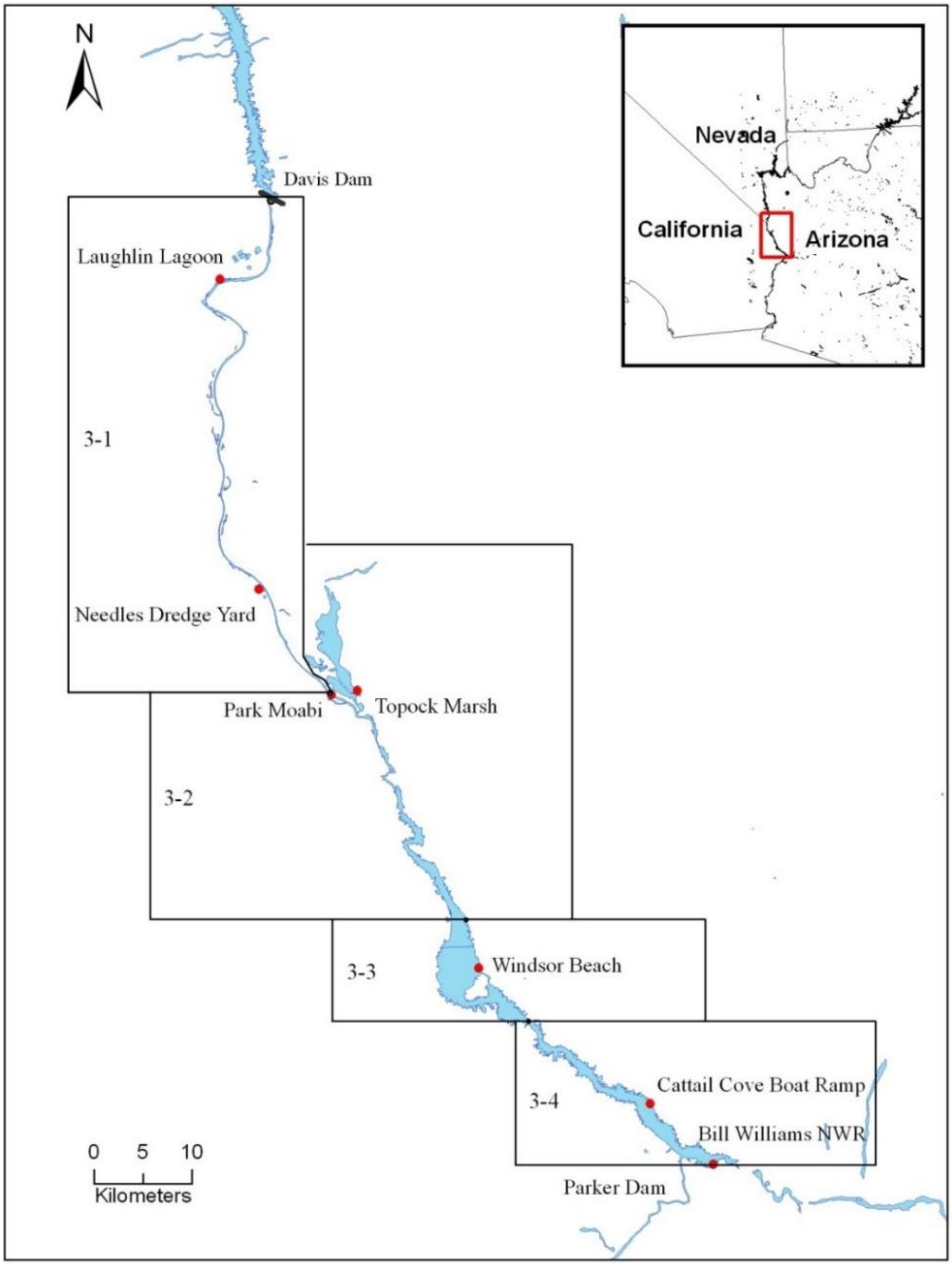

Figure 1.—Overview map of the study area depicting Reach 3, including general remote PIT scanning and stocking locations, and general Zones 3-1 to 3-4 established in the "Methods" section, lower Colorado River, Arizona-California-Nevada.

4. Estimate the survival of razorback suckers released in Reach 3 based on size, location, and season of release since 2005

5. Participate in annual multi-agency native fish surveys

This information will aid in completion of LCR MSCP Work Task D8 (formerly Work Task C33): comparative survival of > 11.8-in (300-mm) razorback suckers released in Reach 3.

METHODS

Study Area

Lake Havasu is formed by the impoundment of Parker Dam, which was constructed by Reclamation in 1938. The reservoir has a 658,000 acre-foot (7.98 x 10^8 cubic meters) storage capacity regulated by releases at the upstream terminus (Davis Dam), downstream terminus (Parker Dam), and less significantly through releases into the Bill Williams River from Alamo Dam. For this work, Reach 3 (including Lake Havasu) has been separated into four distinct zones based largely on habitat types (see figure 1). Moving downstream from Davis Dam, the first zone, Zone 3-1, encompasses clear, fast-flowing waters of the riverine section from the dam downstream to reservoir mile (RM) 43.9 (reservoir kilometer [RKM] 70.6). The shoreline is low lying and relatively well developed. Zone 3-2 is characterized by slower waters and rocky canyon-like shoreline, and it contains the highest concentration of backwater habitat in Reach 3. It encompasses Park Moabi, Topock Marsh, and the Lake Havasu delta region from RM 43.9 (RKM 70.6) downstream to RM 24.7 (RKM 39.7). Zone 3-3 has a gently sloping surrounding shoreline and is the open water portion of the reservoir from the bottom of the delta, RM 24.7 (RKM 39.7) to immediately upstream of Copper Canyon where the reservoir once again narrows at RM 14.5 (RKM 23.3). The fourth zone, Zone 3-4, extends from Copper Canyon downstream to Parker Dam and includes the Bill Williams River National Wildlife Refuge.

Remote PIT Scanning

Remote PIT scanning units were deployed 1 week per month from January to April each year from 2014 through 2016 between Davis Dam and Needles, California. One additional trip was conducted in November 2014. Four models of PIT scanners were utilized during the 3-year study: large shore-based units, large submersible units (both negative and neutrally buoyant), and small submersible units (all negatively buoyant). The shore-based unit was comprised of a 6.2 x 2.6 feet (ft) (1.9 x 0.8 meter [m]) polyvinyl chloride (PVC) antenna with a built-in scanner connected to a shore-based, waterproof housing. The waterproof housing was equipped with a "grey box logger" and a 55 ampere-hour (amp-h) battery. The large submersible units were comprised of a 3.9 x 2.6 ft (1.2 x 0.8 m) PVC frame antenna attached to a scanner, "mini logger," and a 20.8 amp-h battery contained in watertight PVC piping. The large negatively buoyant submersible units were equipped with a sandbag and laid flat on substrate. The large neutrally buoyant units could be equipped with weights and oriented to lie flat along the substrate (bottom flat) or stand upright in the water column (bottom long). Both large units were generally deployed the first afternoon of a sampling trip and left to run until retrieved the last morning of sampling before departing. The small submersible units consisted of a 2.6 x 2.6 ft (0.8 x 0.8 m) PVC antenna frame with a scanner, "mini logger," and 10.4 amp-h or 20.8 amp-h battery contained in PVC/acrylonitrile butadiene styrene piping. A sandbag was attached to each unit to keep it in place under water. Units were retrieved approximately every 24 hours and data downloaded onsite; the battery was replaced before redeployment. Nine to 15 of these units were deployed throughout the scanning season; each unit was assigned and labeled with a 4-character alpha-numeric code (unit ID, e.g., RT03) for individual identification. This allowed data downloads to be matched with deployment locations.

Small submersible units were deployed at the following general areas in the Needles and Laughlin reaches, moving downstream: Laughlin Lagoon, Palms, Cliffs, Cabana, Tower, White Wall, Power Lines, Lone Palm Beach, U.S. 95 Bridge, Needles Dredge Yard, Airport Wash, and Manzanita Wash near Needles, California, and Topock Marsh (figure 2). Neutrally buoyant large units were deployed at three locations: Laughlin Lagoon in the Laughlin reach and Needles Dredge Yard and Topock Bay (Golden Shores) in the Needles reach (figure 2). Large submersible units were deployed at one location, Razorback Riffle in the Laughlin reach. Across all study years, shore-based units were deployed and maintained at Razorback Island, Laughlin Lagoon, Topock Marsh, and Park Moabi. The locations monitored varied from trip to trip based on fish concentrations, but each trip consisted of 3 nights and 2 days of continuous scanning.

Remote PIT scanning information for each individual deployment was recorded on waterproof datasheets as follows: location, river right or river left, unit deployed, battery deployed, Universal Transverse Mercator (UTM) zone, UTM easting, UTM northing, depth (m) of deployed unit, date and time deployed, date and time retrieved, start time of scanner, end time or run interval of scanner, stop interval, scan time (minutes), unit orientation in water, purpose of scanning, comments, and a check box to indicate if any equipment malfunctioned. All information, including downloaded contact data, was incorporated into a MySQL database maintained by Marsh & Associates, LLC (M&A), and hosted by Hostmonster.com (http://www.hostmonster.com/) using an online form within a password-protected section of the M&A Web site (http://www.nativefishlab.net). Microsoft® Access 2010 was used for data management.

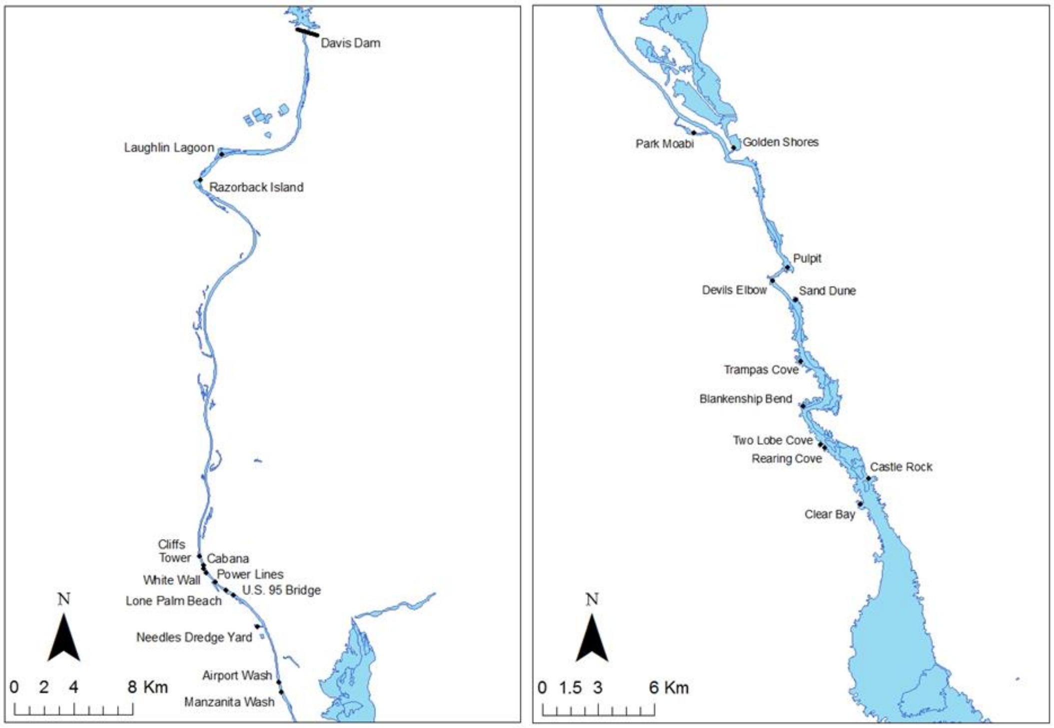

Figure 2.—Location of remote PIT scanning deployment by any entity in Reach 3, Zone 3-1 (left) and Zone 3-2 (right), between November 1, 2014, and August 31, 2015, lower Colorado River, Arizona-California-Nevada.

Electrofishing and Routine Monitoring

Boat electrofishing was conducted during all three sample years to seek out potential subpopulations for scanning. Sampling was conducted from Clear Bay upstream to Park Moabi from February 10–14, 2014. In 2015, electrofishing took place on March 9 and 10 near Laughlin Lagoon, Razorback Island, and the Needles reach from Cliffs downstream to Airport Wash (figure 2). In 2016, two separate efforts were conducted: January 25–27, 2016, near Laughlin, Nevada; the Avi Resort; and Needles, California; and February 29 – March 3, 2016, near Big Bend State Park, Blankenship Bend, Mesquite Bay, and Castle Rock. These efforts occurred at night with three netters present. All razorback suckers captured were measured for total length (TL, mm) and weight (grams [g]), sexed, assessed for sexual ripeness, scanned for a wire tag, scanned for a 125-, 400-, or 134.2- (hereafter 134-) kilohertz (kHz) PIT tag, and tagged with a 134-kHz PIT tag if no tag or an older tag (125-kHz or 400-kHz) was detected. A right pectoral fin clip was taken from each individual, preserved in a 1 milliliter snap-cap tube with 95% ethanol, and sent to the Conservation Genetics Laboratory at Wayne State University), Detroit, Michigan, for analyses. All fish were then returned to their point of capture.

Biologists from M&A assisted with trammel netting in Zone 3-2 from Clear Bay upstream to Park Moabi each year. Multifilament trammel nets (150 or 300 ft x 6 ft [45.7 or 91.4 m x 1.8 m], 1.5-in [3.8 cm] square mesh, 12-in [30.5 cm] bar outer wall) were deployed each afternoon and retrieved the following morning and redeployed for three consecutive nights. All razorback suckers, bonytail (*Gila elegans*), and flannelmouth suckers (*Catostomus latipinnis*) captured were processed as described above. Non-native fishes were identified and enumerated by species, and all except carp (*Cyprinus carpio*) and gizzard shad (*Dorosoma cepedianum*) were measured for TL. All fishes were then returned to their point of capture. All electrofishing and monitoring records were added to the comprehensive Lower Colorado River Native Fish Work Group PIT tag and stocking database.

Population Estimate

A single census population estimate ($\widehat{N}$) for razorback suckers for each year (estimates valid for 2013, 2014, and 2015) was calculated using the modified Petersen formula (Ricker 1975) on paired census data from each scan-year (November 1 through August 31).

$$N^{\wedge *} = \frac{(M+1)(C+1)}{(R+1)}$$

Fish to be included in the estimate (*M*, *C*, and *R*) must have been released or tagged prior to the sampling year (e.g., before January 1, 2014, for the 2014 estimate). Only fish with a 134-kHz PIT tag release or capture record in the Colorado River Native Fish Work Group PIT tag database were included in the estimate (i.e., fish tagged with a 125-kHz and 134-kHz PIT tag were not included.)[1] All releases were into the main stem or reservoir, or into backwaters connected to the river; none were released into habitats permanently isolated from the river.

Definitions for *M*, *C*, and *R* from Ricker (1975) have been modified for our purposes. *M* is the number of fish contacted in the designated mark period (January 1 to April 30 of each marking year) and not the number of fish tagged and placed into a water body. Catch, *C*, is the number of fish contacted in the scan-year following the marking year. The catch data are extended to include all scanning data from November of the marking year to August of the subsequent year (e.g., for the 2014 estimates, from November 2014 through August 2015).

[1] Due to previous data management practices, the date a fish was double tagged (given a 134-kHz in addition to a 125-kHz tag) cannot be determined. Without this determination, the fish’s availability to PIT scanning equipment during both the marking and capture periods cannot be verified.

The data were cutoff at the end of April to provide adequate time for report writing. Recapture, *R*, is the number of fish contacted in both mark and catch periods. Fish contacted more than once in mark or catch periods were only included in the analysis for their first encounter event in each timeframe. Confidence intervals (CIs) were derived using the normal distribution, valid when recaptures are > 30 (Seber 1973).

To be unbiased, the model should meet three assumptions when applying the Chapman modified Petersen estimate (Pollock et al. 1990): (1) the population is closed to both deletions and additions, (2) no tags are lost or omitted, and (3) equal catchability of all individuals.[2] This project only includes known individuals added to the system with a 134-kHz PIT tag before the period of the mark (*M*) and individuals that were captured without a 134-kHz tag and had one implanted before January 1 of the marking year. Emigration out of Lake Havasu by passing through Parker Dam or deletion of fish through water intake structures is negligible in this system because razorback suckers have only been found to occupy regions of the reservoir upstream of these structures (Wydoski et al. 2010). PIT tags are considered a permanent tag (Zydlewski et al. 2003); thus, deletion due to natural mortality is the only factor present, and this does not bias the estimate. Efforts employed to sample razorback suckers are diverse both methodologically and geographically, which imparts equal catchability of individuals. Estimates based on PIT scanning alone and PIT scanning combined with capture data were compared in 2014, and the combined estimate provided a slightly higher estimate (approximately 6%). The combined estimate based on remote PIT scanning and capture data was therefore used for this final report.

Post-Stocking Survival

Contact Rates

Remote PIT scanning contact rates were used as an index to post-stocking survival. Razorback sucker releases from January 1, 2011, through April 30, 2015, were compiled into daily release “cohorts” based on date and location of release within Reach 3. Only fish with a recorded TL at release were included in the analysis. The number of fish released in each cohort, mean TL at release, and number of razorback suckers from that cohort that were contacted at least 120 days (4 months) after release were tabulated. The minimum number of days between release and contact was chosen to be representative of minimum inclusion into the mark-recapture model (see next paragraph) because the minimal

[2] Tag loss and emigration are distinct possibilities, but they both can be considered losses to the population just as natural mortality. The lost tag issue is only important if fish that lost tags were improperly counted as part of *C* and not *R* when they actually were recaptures. Because we do not include fish without tags in either *M* or *C*, if a fish loses a tag between mark and capture, it would be the same as if the fish died between *M* and *C*. These factors all have the same effect on the population estimate and make no difference except to validate the estimate for the marking period.

time at large between release and contact for inclusion into the mark-recapture model was 4 months (July 1 to November 1). Relative contact rates (number contacted/number released) were compared to size at release, season, and location.

Mark-Recapture Model

A multi-state, age-structured mark-recapture model was developed to assess factors influencing first-year and adult post-stocking survival of razorback suckers in Reach 3. The multi-state model was chosen to provide an "unobservable state" for razorback suckers not located near the focus of remote PIT scanning efforts in any given year. The estimated parameters were apparent survival (Φ), recapture rate (p), and transition rate (ψ) (Cooch and White 2016). For all parameters to be identifiable, the model was constrained to the even flow movement model; the transition rate from observable to unobservable (ψ_{ou}) was constrained to equal transition rate from unobservable to observable (ψ_{uo}). All razorback suckers in the unobservable state cannot be encountered, so a single transition rate was estimated in all models (ψ). Also, survival in observed and unobserved state were constrained to be equal.

A capture history was derived for each razorback sucker released in Reach 3 with a 134-kHz PIT tag and a recorded TL at release from January 1, 2011, through April 30, 2015. Each capture history was six characters long and contained either the letter "A: to indicate a release or PIT scanning contact (in state A – observable) within the scan-year, or a "0" to indicate no contact or release. Three individual covariates were provided: TL at release, release season, and years prescan. TL at release was calculated in meters to ensure all values were between 0 and 1. Release season was separated into two main seasons, spring or autumn. Fish released between January and June were considered spring releases, and fish released between July and December were considered autumn releases. This was coded in the capture history as a dummy variable (binary coded as a "1" for spring and "0" for autumn). A dummy covariate was preferred over a grouping variable because season was modeled to only impact first year survival, and a grouping variable doubles the number of parameters to be modeled. The two seasons were chosen to simplify the condition for when a razorback sucker was available for detection after release. If a razorback sucker was released in spring, it could be scanned in the scan-year starting in November (e.g., a razorback sucker released in June 2014 was available for scanning in November 2014). Autumn releases were not available for detection (any PIT scanning contacts were removed from capture histories) until the following scan-year after release (contacts before November 2015 would not be included in the capture history for a fish released in November 2014).

The third covariate accounted for the difference in time between release and availability for detection among razorback suckers released in different months, labeled as "prescan." This was calculated based on the difference between the month of release and the first month of the scan-year (November) in which the fish was made available to PIT scanning. For spring releases, this was simply the difference between the two months. For autumn releases, the value was calculated as the difference between months plus 12 months. All values were converted to decimal years, spring releases were less than 1, autumn releases were near 1.

The most general model was a full interaction two-age (age modeled for first-year and adult survival only, φ1 and φ2) time-varying (t) model with all three individual covariates included in separate linear models of first-year survival ($\varphi1_{t+TL+season+prescan+t*TL+t*season+t*prescan}$, $\varphi2_t$, p_t, ψ_t). Comparison models included additive and interactive effects of time and all three covariates as well as models that constrained time and transition to be constant. Also, a "no movement" model ($\psi = 0$) was assessed to evaluate the effect of the transition parameter on age-1 and age-2 survival. The recapture rate was consistently modeled to vary with time because PIT scanning efforts varied from year to year. Models were ranked within the computer program MARK (MARK) based on an Akaike's information criterion score (Akaike 1974). This value reported in MARK is a modified value (AIC_c) that adjusts for small sample sizes (Burnham and Anderson 2002). AIC_c was adjusted for overdispersion with the median estimate of $\hat{c}$ (c-hat from the general model) when appropriate ($QAIC_c$) (Cooch and White 2016). Reported parameter values were based on the highest ranked model (lowest AIC_c or $QAIC_c$) when the $QAIC_c$ weight for the top model was > 0.9 (Johnson and Omland 2004). Otherwise, the estimates were based on model averaging.

RESULTS

Remote PIT scanning

2014

During the 2014 sample year (November 2013 to August 2014), remote PIT scanning in Reach 3 was performed by two entities, M&A and Reclamation. Seven trips were conducted by M&A in Zone 3-1 (Laughlin and Needles) and Zone 3-2 (Park Moabi) (see figure 2) from January to April 2014 and primarily focused on razorback sucker scanning directly related to this project. From October 2013 to February 2014, M&A completed seven scanning trips for a separate bonytail project (Humphrey et al. 2016) in Zone 3-2 (see figure 2). Efforts in Zones 3-1 and 3-2 resulted in 3,820 scan-hours and 1,518 individual fish contacted and 6,958.4 scan-hours and 463 individual fish contacted, respectively. From November 2013 to May 2014, Reclamation conducted seven trips in Zones 3-1 and 3-2, with the majority of efforts in Zone 3-2 (see figure 2). Reclamation contacted 414 individual fish over 2,599.3 scan-hours. Data from all sampling efforts were incorporated into the analyses for this report. Overall, 2,324 individual PIT tags were contacted, of which 2,291 have a tagging record in the Lower Colorado River Native Fish Database. The majority of fish (1,972) were razorback suckers, 314 were bonytail, and 5 were flannelmouth suckers. Of the 1,972 razorback suckers, 1,923 were released with a 134-kHz tag.

2015

M&A and Reclamation conducted remote PIT scanning activities in Reach 3 during the 2015 sample year (November 2014 to August 2015). M&A completed eight scanning trips in Reach 3 Zones 3-1 and 3-2 (see figure 2) from November 2014 to April 2015 and primarily focused on razorback sucker scanning. A separate M&A project (Humphrey et al. 2016) focused on bonytail scanning in Zone 3- 4 (Bill Williams River National Wildlife Refuge) and Zone 3-2 (see figure 2) and consisted of 11 sampling trips from November 2014 to June 2015. M&A efforts in Zones 3-1 and 3-2 resulted in 6,194.7 scan-hours and 2,369 individual fish contacted. M&A bonytail scanning in Zones 3-4 and 3-2 resulted in 15,550.7 scan-hours and 1,190 individual fish contacted. Reclamation conducted 20 scanning trips from November 2014 to August 2015 in Zones 3-1 and 3-2, with most of the effort in Zone 3-2 (see figure 2). Reclamation scanning resulted in 22,172.7 total scan-hours and 2,205 individual fish contacted. Razorback sucker data collected from both the bonytail and Reclamation efforts were incorporated into the analyses for this report. Overall, 4,663 individual PIT tags were contacted; of these, 4,621 have a fish tagging record. Most of the fishes (4,142) were razorback suckers; however, 475 were bonytail, and 4 were flannelmouth suckers. Of the 4,142 razorback suckers, 4,091 were released with a 134-kHz tag.

2016

Remote PIT scanning in Reach 3 was performed by M&A and Reclamation from November 2015 to April 2016. M&A conducted seven razorback sucker scanning trips in Zone 3-1 (see figure 2) from January to April 2016. From December 2015 to January 2016, M&A completed two bonytail sampling trips in Zone 3-1 (see figure 2). Efforts in Zone 3-1 resulted in 4,705.9 scan-hours and 1,611 individual fish contacted. Laughlin Lagoon bonytail sampling resulted in 6,584.9 scan-hours and 484 individual fish contacted. Reclamation conducted 21 sampling trips, mostly in Zone 3-2 (see figure 2) from November 2015 to April 2016. Reclamation efforts resulted in 12,980.8 scan-hours and 1,705 individual fish contacted. Sampling from all entities were incorporated into the analyses for this report. Overall, 3,384 individual PIT tags were contacted, of which 3,330 have a fish tagging record. The majority of fish scanned were razorback suckers (3,027), 292 were bonytail, and 11 were flannelmouth suckers. Of the 3,027 razorback suckers, 2,985 were released with a 134-kHz tag.

Electrofishing and Routine Monitoring

2014

In 2014, electrofishing efforts in Laughlin Lagoon and Razorback Island resulted in 1,926 seconds of electrofishing and the capture of 37 razorback suckers and 500 seconds of electrofishing and the capture of 13 fish, respectively. TLs ranged from 16.9–27.5 in (431–700 mm), with an average length of 20.7 in (528 mm). Eleven of the fish in Laughlin Lagoon were untagged, and each was implanted with a 134-kHz PIT tag; four of these untagged fish were missing the distal portion of one pectoral fin, presumably from fin clipping to obtain a sample for genetic characterization. The untagged razorback suckers were likely small fish harvested from Lake Mohave backwaters and were not implanted with PIT tags prior to being stocked into Laughlin Lagoon (J. Lantow, Reclamation 2014, personal communication). All recaptured fish had 134-kHz PIT tags.

A total of 614 fishes of all species were captured in trammel nets during the routine annual monitoring. Of these, 27 were razorback suckers and 5 were bonytail. TLs of razorback suckers ranged from 15.2–23.6 in (385–600 mm), with an average of 20.2 in (512 mm). Sixteen of the razorback suckers were sexed as female, and nine were male.

2015

On the nights of March 9 and 10, 2015, four general locations were electrofished: Laughlin Lagoon, Razorback Island, Needles reach above the U.S. 95 bridge, and Airport and Manzanita Washes downstream from Jack Smith Park. The following efforts (seconds of electrofishing) and catch were recorded at each sampling location: 2,807 seconds and 18 razorback suckers in Laughlin Lagoon; 505 seconds, 12 razorback suckers, and 1 flannelmouth sucker at Razorback Island; 1,949 seconds and 18 razorback suckers in the Needles reach; and 861 seconds and 16 razorback suckers at the Airport and Manzanita Washes. The mean TL for all razorback suckers captured was 22.1 in (561 mm) and ranged from 12.6–28.4 in (319–721 mm). Fin clips were taken from all fish and fixed in 95% ethanol for genetic analyses, and eight razorback suckers were untagged, and each was implanted with a 134-kHz tag. An older 125-kHz tag was present in one razorback sucker, and a 134-kHz tag was implanted into that fish. The one flannelmouth sucker had a TL of 22.4 in (568 mm).

A total of 947 fishes of all species were captured in trammel nets during routine annual monitoring in February 2015. Of these, 55 were razorback suckers and 1 was a flannelmouth sucker. The TL of razorback suckers ranged from 12–25.2 in (305–640 mm), with an average length of 16.1 in (408 mm). Twelve razorback suckers were female, 10 were male, 21 were labeled as juveniles, and 12 were not sexed. Three razorback suckers were untagged, and each was implanted with a 134-kHz PIT tag. All recaptured fish had 134-kHz PIT tags. The flannelmouth sucker had a TL of 19.4 in (494 mm) and was implanted with a 134-kHz PIT tag.

2016

Two separate electrofishing trips were conducted in 2016. The first trip took place on the nights of January 25, 26, and 27, 2016, near Laughlin, the Avi Resort, and Needles. The second trip was near Big Bend State Park, Blankenship Bend, Mesquite Bay, and Castle Rock on the nights of February 29 and March 1, 2, and 3, 2016. During the January trip, effort (in seconds of electrofishing) was not recorded, but catch was noted as follows: 66 razorback suckers and 10 flannelmouth suckers were captured near Laughlin, 7 razorback suckers and 4 flannelmouth suckers were captured near the Avi Resort, and 124 razorback suckers and 2 flannelmouth suckers were sampled in the Needles reach. The mean TL for all razorback suckers captured was 24.6 in (624 mm) and ranged from 14.2–30 in (360–760 mm). Fin clips were taken from all fish and fixed in 95% ethanol for genetic analyses, and eight razorback suckers were untagged, and each was implanted with a 134-kHz tag. An older 125-kHz tag was present in one razorback sucker, and a 134-kHz tag was implanted into that fish. The mean TL for all flannelmouth suckers captured was 23.2 in (590 mm) and ranged from 21.2–25 in (538–630 mm).

During the February trip, the following effort (in seconds of electrofishing) and catch was recorded at each sampling location: 9,551 seconds, 74 razorback suckers, and 30 flannelmouth suckers near Big Bend; 19,102 seconds and 12 razorback suckers at Blankenship Bend; 1,473 seconds and 3 razorback suckers near Mesquite Bay; and 2,472 seconds and two razorback suckers near Castle Rock. The mean TL for all razorback suckers captured was 23.8 in (605 mm) and ranged from 13.4–28.1 in (341–715 mm). Fin clips were taken from all fish and fixed in 95% ethanol for genetic analyses, and eight razorback suckers were untagged, and each was implanted with a 134-kHz tag. An older 125-kHz tag was present in one razorback sucker, and a 134-kHz tag was implanted into that fish. The mean TL for all flannelmouth suckers captured was 23 in (583 mm) and ranged from 20.1–25.6 in (510–650 mm).

A total of 595 fish of all species were captured in trammel nets during the routine annual monitoring in February 2016. Of these, 66 were razorback suckers, and 1 was a flannelmouth sucker. The TL of razorback suckers ranged from 12.4–24.4 in (314–620 mm), with an average length of 17.4 in (442 mm). Twenty razorback suckers were female, 25 were male, 17 were labeled as juveniles, and 4 were not sexed. Two razorback sucker were untagged, and each was implanted with a 134-kHz PIT tag. All recaptured fish had 134-kHz PIT tags. The flannelmouth sucker had a TL of 16.5 in (419 mm) and was implanted with a 134-kHz PIT tag.

Population Estimate

Population estimates for Reach 3 were calculated with scanning data combined with capture data, and the most recent (2015) estimate is 4,923 individuals (table 1). Population estimates for the 4 years after 2011 have overlapping CIs and are relatively stable (table 1). Each estimate after 2011 is about twice the 2011 estimate (2,454), and none has an overlapping CI with that of the first year.

Table 1.—Population estimates of razorback suckers in Reach 3, lower Colorado River, Arizona-California-Nevada
(Population estimates for 2011 and 2012 were derived from Patterson et al. (2014), and the population estimate from 2013 was derived from Ehlo et al. (2015). Estimates are based on all available data from each sample year.)

Year	Number marked	Number captured	Number recaptured	Population estimate (95% CI)
2011	228	642	59	2,454 (1,910–3,150)
2012	934	1,373	284	4,508 (4,015–5,061)
2013	1,335	1,730	518	4,456 (4,089–4,856)
2014	1,931	2,385	933	4,935 (4,629–5,262)
2015	2,674	2,211	1,201	4,923 (4,652–5,209)

Post-Stocking Survival

A total of 38,464 razorback suckers with 134-kHz PIT tags and a recorded TL at release were released into Reach 3 between January 1, 2011, and April 30, 2015, (table 2). The index of survival (proportion contacted) was highly variable, from 0 to 0.583, but cohorts with > 0.300 proportion contacted were generally released in small batches (< 200 fish), at TL > 15 in (400 mm), in the Park Moabi area (Zone 3-2). The most notable exception is the release of a cohort of 465 razorback suckers at Park Moabi on February 12, 2015, that had a mean TL at release of 13 in (335 mm), smaller than the overall mean of 14.7 in (374 mm); the proportion of this cohort that has been contacted at least 120 days after release is 0.434, much higher than the overall mean of 0.112, and the fifth highest capture proportion overall. Zone 3-2 had 9 of the 10 highest contact proportions, and Park Moabi had 8 of the 10 highest contact proportions within that zone.

Model $\hat{c}$ was near 1 for the general model and no adjustment to AIC_c values was made. All models with AIC_c weights > 0 contained all three covariates (TL, season, and prescan) and their interaction terms (table 3). The top two models combined have an AIC_c weight of 0.959. The difference between the first and second ranked model is the presence or absence (fixed at 0) of a transition rate between being observable and unobservable. The weight given to models of no transition indicates that a model without an unobservable state (i.e., Cormack-Jolly-Seber model type) would fit nearly as well as the multi-state model used here. However, the inclusion of an unobservable state significantly impacts the estimate of age-2 survival (table 4).

Table 2.—Number and proportion of 134-kHz PIT tagged razorback suckers released between January 1, 2011, and April 30, 2015, by date and location and individuals contacted by remote PIT scanning, Reach 3, lower Colorado River, Arizona-California-Nevada

Date	Location	Number released	Mean TL	Number contacted	Proportion contacted
Zone 3-1					
1/5/2012	46 RM	33	500	12	0.364
3/23/2012	Laughlin Lagoon	4,125	365	741	0.180
2/1/2013	Jack Smith State Park (inlet)	1,603	402	151	0.094
5/3/2012	Needles	36	335	3	0.083
1/17/2014	Jack Smith State Park (inlet)	2,431	403	188	0.077
1/31/2013	Big Bend National Park	1,989	406	143	0.072
11/1/2013	Big Bend National Park	29	315	2	0.069
1/27/2011	Laughlin Lagoon to Needles Dredge Yard	3,227	366	221	0.068
1/15/2015	Jack Smith State Park (inlet)	686	329	37	0.054
2/27/2014	Big Bend National Park boat ramp	299	355	15	0.050
1/7/2015	Laughlin Ramp	791	353	22	0.028
10/23/2014	Laughlin Ramp	49	231	1	0.020
1/27/2015	Laughlin Lagoon	249	367	5	0.020
10/24/2014	Laughlin Ramp	65	238	1	0.015
11/15/2013	Big Bend National Park	66	327	1	0.015
10/22/2014	Laughlin Ramp	7	235	0	0.000
10/16/2014	Laughlin Ramp	44	284	0	0.000
10/25/2013	Big Bend National Park	42	310	0	0.000
Zone 3-2					
2/24/2011	Park Moabi	12	502	7	0.583
2/23/2011	Park Moabi	184	509	93	0.505
12/7/2012	Park Moabi Marina	14	465	7	0.500
4/8/2014	Blankenship Bend	2	480	1	0.500
2/12/2015	Park Moabi	465	335	202	0.434
3/22/2011	Park Moabi	40	442	15	0.375
4/5/2012	Topock Marina boat launch	36	487	13	0.361
12/5/2012	Park Moabi Marina	20	449	6	0.300
2/8/2013	Park Moabi	465	420	120	0.258
2/22/2011	Park Moabi	176	445	43	0.244
2/10/2011	Park Moabi	3,124	355	689	0.221
12/6/2012	Park Moabi Marina	15	470	3	0.200
4/6/2012	Topock Marina boat launch	35	492	7	0.200
2/27/2014	Castle Rock Cove	360	357	69	0.192
3/24/2013	Blankenship Cove	724	390	138	0.191
1/15/2015	Golden Shores launch ramp	669	372	112	0.167

Table 2.—Number and proportion of 134-kHz PIT tagged razorback suckers released between January 1, 2011, and April 30, 2015, by date and location and individuals contacted by remote PIT scanning, Reach 3, lower Colorado River, Arizona-California-Nevada

Date	Location	Number released	Mean TL	Number contacted	Proportion contacted
Zone 3-2 (continued)					
3/28/2013	Clear Bay Cove	539	388	72	0.134
3/28/2013	Castle Rock Cove	361	384	47	0.130
3/28/2013	Two Lobe backwater	100	386	13	0.130
2/22/2013	Sand Dunes Cove	269	394	34	0.126
11/30/2011	Topock Marina boat launch	250	420	31	0.124
4/1/2012	Topock Marina boat launch	176	469	19	0.108
2/16/2012	Topock Marina boat launch	2,885	344	310	0.107
3/27/2013	Rearing Cove	169	389	17	0.101
2/13/2014	Park Moabi	475	408	42	0.088
2/22/2013	Pulpit Rock Cove	376	393	32	0.085
4/16/2012	Topock Marina boat launch	340	334	25	0.074
2/13/2014	Blankenship Bend	729	414	53	0.073
2/13/2014	Clear Bay Cove	568	415	38	0.067
2/13/2014	Rearing Cove	166	407	11	0.066
4/12/2012	Topock Marina boat launch	400	343	25	0.063
2/13/2014	Sand Dunes Cove	236	404	14	0.059
2/13/2014	Pulpit Rock Cove	363	407	16	0.044
1/15/2015	Trampas Cove	543	336	23	0.042
2/25/2015	Castle Rock Cove	362	387	15	0.041
2/13/2014	Two Lobe backwater	101	415	4	0.040
2/25/2015	Rearing Cove	171	385	6	0.035
2/26/2015	Blankenship Bend	727	388	23	0.032
2/26/2015	Sand Dunes Cove	245	382	7	0.029
2/26/2015	Clear Bay Cove	568	385	12	0.021
2/26/2015	Pulpit Rock Cove	350	384	7	0.020
5/11/2012	Topock Marina boat launch	123	345	0	0.000
Zone 3-3					
2/27/2014	Windsor Beach State Park	270	358	42	0.156
3/3/2011	Windsor Beach State Park	2,192	343	242	0.110
1/15/2015	Windsor Beach State Park	663	374	32	0.048
2/17/2011	Windsor Beach State Park	1,308	361	29	0.022
10/24/2011	Windsor Beach State Park	327	324	0	0.000
	Total or mean*	**38,464**	**374***	**4,309**	**0.112***

Table 3.—MARK multi-state models for released razorback suckers in Reach 3
(φ = apparent survival, p = recapture, and Ψ = transition. All models were two-age structured models with three potential first year survival covariates; TL, season (spring or autumn binary coded as 1 and 0, respectively), and prescan time (decimal year between release and first opportunity to be encountered). p(recapture) parameters were time varying in all models. Thirty-five models were assessed; all models not in this table had 0 AIC_c weights.)

Model	AIC_c	ΔAIC_c	AIC_c weight	Model likelihood	Number of parameters
$\varphi1_{t+TL+season+prescan+t*TL+t*season+t*prescan}$, $\varphi2_t$, p_t, $\psi.$	40131.62	0.000	0.563	1.000	29
$\varphi1_{t+TL+season+prescan+t*TL+t*season+t*prescan}$, $\varphi2_t$, p_t, ψ=0	40132.32	0.704	0.396	0.703	27
$\varphi1_{t+TL+season+prescan+t*TL+t*season+t*prescan}$, $\varphi2.$, p_t, $\psi.$	40137.24	5.620	0.034	0.060	26
$\varphi1_{t+TL+season+prescan+t*TL+t*season+t*prescan}$, $\varphi2.$, p_t, ψ=0	40140.34	8.717	0.007	0.013	25
$\varphi1_{t+TL+season+prescan+t*TL+t*prescan}$, $\varphi2_t$, p_t, $\psi.$	40164.77	33.154	0.000	0.000	25
$\varphi1_{t+TL+season+prescan+t*TL+t*prescan}$, $\varphi2_t$, p_t, ψ=0	40169.44	37.818	0.000	0.000	25
$\varphi1_{t+TL+season+prescan+t*TL+t*prescan}$, $\varphi2.$ p_t, $\psi.$	40172.44	40.824	0.000	0.000	23
$\varphi1_{t+TL+prescan+t*TL+t*prescan}$, $\varphi2_t$, p_t, $\psi.$	40174.47	42.847	0.000	0.000	25

Table 4.—Second year survival (φ2) estimates based on MARK
("Model averaged" estimates are weighted averages (based on AIC_c weights) from all assessed models, "With transition" are estimated from the top ranked model, and "Without transition" are estimated from the second ranked model.)

Survival period	Estimate	95% CI	
		Lower limit	Upper limit
Model averaged			
2012–13	0.901	0.580	0.984
2013–14	0.793	0.680	0.873
2014–15	0.743	0.642	0.823
2015–16	0.505	0.365	0.644
With transition			
2012–13	0.944	0.527	0.996
2013–14	0.825	0.752	0.881
2014–15	0.773	0.720	0.820
2015–16	0.523	0.474	0.573
Without transition			
2012–13	0.851	0.669	0.942
2013–14	0.746	0.687	0.797
2014–15	0.694	0.654	0.731
2015–16	0.448	0.427	0.469

Although the season was included in first year survival estimates, the impact on apparent first year survival is undetectable (figure 3). First year survival was significantly impacted by size at release and years prior to scanning (figures 3–5). The relationship of size and survival varied over time but was generally a positive relationship except for first year survival in 2015. Adjusting the time before first scanning from 1 year to 0.5 year increased estimated first year survival for all years.

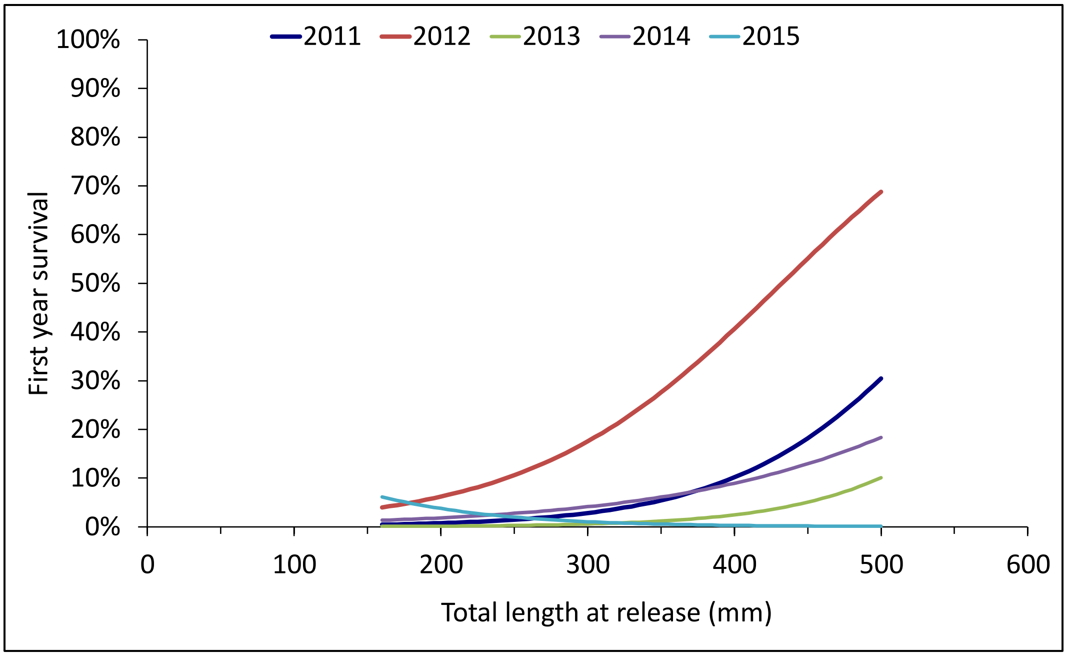

Figure 3.—First year survival as a function of size at release for razorback suckers released in Reach 3 in spring (January through June).
Separate lines are representative of release year and based on the top ranked model from MARK with the covariate "prescan" set to 1 (1 year between release and availability to PIT scanners).

Discussion

The razorback sucker population in Reach 3 has remained stable for the entire period of this study. This is a direct result of the LCR MSCP stocking program, which has released nearly 40,000 PIT tagged razorback suckers since 2011. Size at release appears to be the most important factor impacting post-release survival, and post-release survival for smaller (< 15 in [400 mm] TL) razorback suckers is higher in Reach 3 than in Lake Mohave. In Lake Mohave, few fish smaller than 13.8 in (350 mm) are contacted after release, with the highest proportion of any cohort at 1.8% (Wisenall et al. 2015); in Reach 3, the mean contact rate for fish at 13.8 in (350 mm) is near 10%.

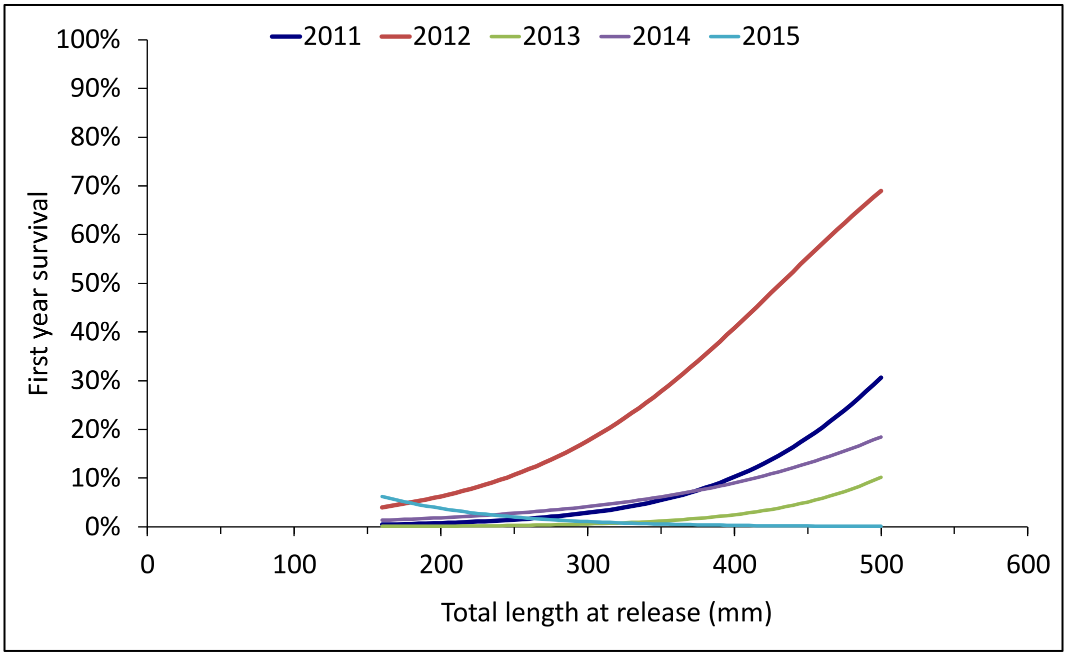

Figure 4.—First year survival as a function of size at release for razorback suckers released in Reach 3 in autumn (July through December).
Separate lines are representative of release year and based on the top ranked model from MARK with the covariate “prescan” set to 1 (1 year between release and availability to PIT scanners).

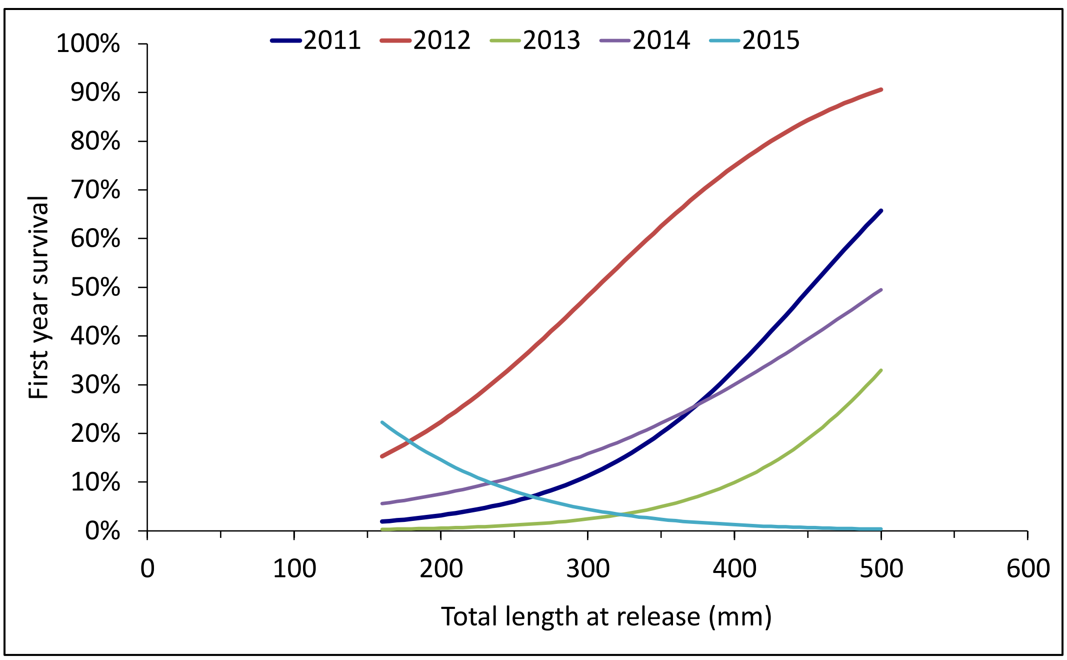

Figure 5.—First year survival as a function of size at release for razorback suckers released in Reach 3 in autumn (July through December).
Separate lines are representative of release year and based on the top ranked model from MARK with the covariate “prescan” set to 0.5 (6 months between release and availability to PIT scanners).

Complexity of habitat, presence and abundance of large predaceous fishes, and other environmental factors may contribute to the differences in contact rates between size classes in the two reservoirs. In Lake Mohave, low (< 10%) survival of razorback suckers released at TL less than 15 in (380 mm) has been attributed to striped bass (*Morone saxatilis*) predation (Karam et al. 2008, Karam and Marsh 2010). Razorback suckers released at > 19.7 in (500 mm) are less vulnerable to striped bass predation, and survival is high (about 80%). Lake Havasu has an additional fish predator, flathead catfish (*Pylodictis olivaris*), which has a larger gape per TL than striped bass and is likely able to ingest razorback suckers of sizes exceeding 27.6 in (700 mm). Regardless of the causes of differences in contact rates in the two reservoirs, it is important to recognize that best management practices may differ among different populations of the same species.

It is unclear if there is any significant effect of stocking location on survival. Although the highest contact proportion was for fish released in Zone 3-2, this is also where the largest razorback sucker spawning aggregation is found and where remote PIT scanning effort is highest. Most of the razorback suckers scanned were stocked in Park Moabi, also a focal point of PIT scanning effort. Telemetry studies have shown that fish stocked into the lower reaches of Lake Havasu (Zone 3-4), given sufficient time, can move upstream to spawning areas in Zones 3-1 and 3-2 (Wydoski and Lantow 2012). However, the combination of fewer fish stocked in lower Lake Havasu, and the greater distance from there to known spawning areas (and thus potentially increased exposure to piscivores), may account for the lack of contacts of fish stocked in Zone 3-4.

Stocking season had previously been indicated as a potential important factor in post-stocking survival. This may have been due to the lack of accounting for the difference in time at large prior to the first scanning period. Razorback suckers released in spring were generally at large for less than 6 months prior to the initiation of PIT scanning each year, whereas razorback suckers released in autumn were at large for nearly a year prior to being available for scanning. Although the previously applied model divided scanning as well as stocking between spring and autumn, razorback suckers released immediately prior to the spawning season are unlikely to participate in spawning and would not be available to PIT scanners until the following year. Once this disparity in time at large was accounted for as an individual covariate, the effect of release season was undetectable (see figures 4 and 5).

No specific mark-recapture models have been developed for data like those available through remote PIT scanning. Robust, multi-state, open Robust multi-state, and Barker models all have potential uses depending on need. The Barker model, which allows for continuous resighting events between discrete sampling events, has been proposed to incorporate continuous remote sensing data into a mark-recapture model (Barbour et al. 2013; Conner et al. 2015). This works best when the sampling regime is designed for this specific model because it was developed for cases when discrete random sampling is supplemented with continuous resighting data between discrete periods. Robust designs allow for closed "sessions" followed by open periods. These models allow for all closed model types, and they deal well with differences in probabilities of first capture and recapture. This model may fit well with Reach 3 PIT scanning data if each sampling trip is treated as a closed "session." Each trip would need to be conducted on a broad enough spatial scale to cover the extent of the razorback sucker population range in the reach. This group of models also is concerned with estimating population size. These models contain additional complexity that is unnecessary when assessing razorback sucker post-stocking survival because all fish are PIT tagged at release (first time capture probability is not needed and is best if not included in the model), and estimating survival is more important than population size.

Standard Cormack-Jolly-Seber and multi-state models both ignore first capture, have few nuisance parameters (recapture rates only), and appear to be the best models available as of this report. The advantage of using a multi-state approach is in the flexibility of assessing both a model with and without the unobserved state; a thorough description of the flexibility of this modeling approach is provided in Lebreton et al. (2009). In the case of razorback suckers in Reach 3, the more complex model with unobservable state did not fit significantly better than models in which transition rates were fixed at zero. The lack of resolution between models with or without transition may be the result of poor study design, the variability in individual stocking cohort survival, or structural issues with the general model used in this study. Contact rates among stocking cohorts (see table 2) provide evidence of highly variable survival among stocking cohorts. A more structured stocking program with replicate cohorts of similar sizes within the same year would likely improve model resolution, and a broader selection of potential multi-state mark recapture models should be assessed.

The primary goal of this monitoring program was to assess the impact of size, location, and season of release on post-stocking survival of razorback suckers in Reach 3. Mark-recapture modeling of remote PIT scanning data collected during the 5 years of this project provided statistical comparisons for size and season but not location. The lack of consistency in stocking protocols across locations and seasons made analyses problematic. Remote PIT scanning has increased precision of demographic parameters, and it is likely that remote PIT scanning will continue to provide significantly more contact data than routine netting and electrofishing. The increase in data will only be useful to the program if temporal and spatial factors are an integral part of the sampling design and stocking plan.

Remote PIT scanning has proven effective at monitoring the population of razorback suckers in Reach 3. In order to continue this assessment and to evaluate post-stocking survival, remote PIT scanning should be coordinated with dates and locations of future stockings. Remote PIT scanning is unable to provide data on health, growth, and genetics. If this information is desired, then netting and electrofishing efforts should also continue.

Contact rates for razorback suckers in Reach 3 are highest for fish stocked in Laughlin Lagoon and Park Moabi. To get adequate recontact rates for population estimates, coordinated stocking and scanning efforts should be continued in these areas. If other spawning sites are identified, similar coordinated efforts of stocking and scanning should be employed to avoid bias in population estimates.

Continued PIT scanning will further build on the existing remote sensing database, and population and post-stocking survival estimates can be updated on a regular basis. The current mark-recapture model should be reassessed on a routine basis in case additional complexity can improve precision.

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ATTACHMENT 1

Complete List of Program MARK Multi-State Models for Released Razorback Suckers (*Xyrauchen texanus*) in Lower Colorado River Reach 3

(φ = apparent survival, p = recapture, and Ψ = transition. All models were two-age structured models with three potential first year survival covariates: TL, season (spring or autumn binary coded as “1” and “0,” respectively), and prescan time (decimal year between release and first opportunity to be encountered). p(recapture) parameters were time varying in all models. A total of 35 models were assessed.)

Model	**AIC$_c$[1]**	**ΔAIC$_c$[2]**	**AIC$_c$ weights**	**Model likelihood**	**Number of parameters**
$\varphi1_{t+TL+season+prescan+t*TL+t*season+t*prescan}$, $\varphi2_t$, p_t, $\psi.$	40131.62	0.000	0.563	1.000	29
$\varphi1_{t+TL+season+prescan+t*TL+t*season+t*prescan}$, $\varphi2_t$, p_t, ψ=0	40132.32	0.704	0.396	0.703	27
$\varphi1_{t+TL+season+prescan+t*TL+t*season+t*prescan}$, $\varphi2.$, p_t, $\psi.$	40137.24	5.620	0.034	0.060	26
$\varphi1_{t+TL+season+prescan+t*TL+t*season+t*prescan}$, $\varphi2.$, p_t, ψ=0	40140.34	8.717	0.007	0.013	25
$\varphi1_{t+TL+season+prescan+t*TL+t*prescan}$, $\varphi2_t$, p_t, $\psi.$	40164.77	33.154	0.000	0.000	25
$\varphi1_{t+TL+season+prescan+t*TL+t*prescan}$, $\varphi2_t$, p_t, ψ=0	40169.44	37.818	0.000	0.000	25
$\varphi1_{t+TL+season+prescan+t*TL+t*prescan}$, $\varphi2.$ p_t, $\psi.$	40172.44	40.824	0.000	0.000	23
$\varphi1_{t+TL+prescan+t*TL+t*prescan}$, $\varphi2_t$, p_t, $\psi.$	40174.47	42.847	0.000	0.000	25
$\varphi1_{t*TL+t*season+t+prescan}$, $\varphi2_t$, p_t, $\psi.$	40273.914	142.2947	0	0	25
$\varphi1_{t+TL+prescan+t*TL}$, $\varphi2_t$, p_t, $\psi.$	40284.088	152.4689	0	0	20
$\varphi1_{t+TL+season+prescan+t*TL}$, $\varphi2_t$, p_t, $\psi.$	40285.372	153.7529	0	0	21
$\varphi1_{t+TL+t*season+t*prescan}$, $\varphi2_t$, p_t, $\psi.$	40386.368	254.7487	0	0	25
$\varphi1_{t+TL+season+prescan+t*season+t*prescan}$, $\varphi2.$, p_t, $\psi.$	40397.704	266.0849	0	0	22
$\varphi1_{t+TL+season+prescan+t*season+t*prescan}$, $\varphi2_t$, p_t, ψ=0	40409.644	278.0247	0	0	25
$\varphi1_{t+TL+season+prescan+t*prescan}$, $\varphi2_t$, p_t, $\psi.$	40420.226	288.6069	0	0	20
$\varphi1_{TL+season+t*TL+t*season}$, $\varphi2_t$, p_t, $\psi.$	40427.366	295.7467	0	0	25
$\varphi1_{t+TL+prescan+t*prescan}$, $\varphi2_t$, p_t, $\psi.$	40430.065	298.4459	0	0	21
$\varphi1_{TL+season+t*TL}$, $\varphi2_t$, p_t, $\psi.$	40445.705	314.0859	0	0	21
$\varphi1_{t+TL+season+prescan+t*season}$, $\varphi2_t$, p_t, $\psi.$	40472.68	341.061	0	0	19
$\varphi1_{t+TL+season+prescan}$, $\varphi2_t$, p_t, $\psi.$	40474.987	343.3679	0	0	16
$\varphi1_{t+TL+prescan}$, $\varphi2_t$, p_t, $\psi.$	40477.01	345.3909	0	0	16
$\varphi1_{t+TL+t*TL}$, $\varphi2_t$, p_t, $\psi.$	40503.573	371.9539	0	0	20
$\varphi1_{TL+season+t*season}$, $\varphi2_t$, p_t, $\psi.$	40589.784	458.165	0	0	19
$\varphi1_{TL+season}$, $\varphi2_t$, p_t, $\psi.$	40599.898	468.2794	0	0	15
$\varphi1_{t+TL}$, $\varphi2_t$, p_t, $\psi.$	40635.462	503.8434	0	0	15
$\varphi1_{t+season+prescan+t*season+t*prescan}$, $\varphi2_t$, p_t, $\psi.$	40923.818	792.1993	0	0	24
$\varphi1_{t+season+prescan+t*prescan}$, $\varphi2_t$, p_t, $\psi.$	40958.332	826.7129	0	0	21
$\varphi1_{t+prescan+t*prescan}$, $\varphi2_t$, p_t, $\psi.$	40960.009	828.3899	0	0	21
$\varphi1_{t+season+prescan+t*season}$, $\varphi2_t$, p_t, $\psi.$	40985.078	853.4589	0	0	22
$\varphi1_{t+prescan}$, $\varphi2_t$, p_t, $\psi.$	40998.058	866.4389	0	0	16
$\varphi1_{t+season+prescan}$, $\varphi2_t$, p_t, $\psi.$	40998.485	866.8665	0	0	17
$\varphi1_{t+season+t*season}$, $\varphi2_t$, p_t, $\psi.$	41082.823	951.2039	0	0	20
$\varphi1_{t+season}$, $\varphi2_t$, p_t, $\psi.$	41106.638	975.0189	0	0	16
$\varphi1_t$, $\varphi2_t$, p_t, $\psi.$	41142.818	1011.199	0	0	15

[1] AIC$_c$ = Akaike’s information criterion adjusted for small sample size.
[2] ΔAIC$_c$ = change, difference between models.