Lower Colorado River
Multi-Species Conservation Program

Balancing Resource Use and Conservation

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

2015 Annual Report

U.S. Department of the Interior
Bureau of Reclamation

January 2016

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Lower Colorado River Multi-Species Conservation Program

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ACRONYMS AND ABBREVIATIONS

amp-hr	ampere-hour(s)
Bill Williams River NWR	Bill Williams River National Wildlife Refuge
CI	confidence interval
cm	centimeter(s)
ft	feet
g	gram(s)
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
mm	millimeter(s)
PIT	passive integrated transponder
PVC	polyvinyl chloride
Reclamation	Bureau of Reclamation
RKM	river kilometer
RM	river mile
TL	total length
UTM	Universal Transverse Mercator

Symbols

$>$	greater than
$\geq$	greater than or equal to
$<$	less than
$\leq$	less than or equal to
%	percent

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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 now listed as endangered. Under guidance of the Lower Colorado River Multi-Species Conservation Program, more than 60,000 razorback suckers have been stocked into Reach 3 (between Davis and Parker Dams) since 2006. Contact rates of stocked fish have been low using traditional fisheries sampling methods (i.e., electrofishing and trammel netting). However, the use of remote passive integrated transponder (PIT) scanning technology has proven effective at contacting hundreds of razorback suckers with minimal effort; 1 week of deployments with five PIT scanners during the peak of spawning (February – March).

Remote PIT scanners were deployed in Reach 3 for 4 months (with one additional trip in November 2014) from January to April 2015 from Davis Dam downstream to Park Moabi Regional Park, California, to target spawning aggregates of razorback suckers. In addition, data were compiled from other projects and from entities that scanned in Reach 3 from November 2014 to August 2015. These collective efforts resulted in the contact of 4,611 individual PIT tags. A total of 4,773 PIT tags were contacted through a combination of remote PIT scanning and standard sampling methodologies in 2015. Of these 2,232 individual razorback suckers were included in a 2014 population estimate of 4,795 (4,491–5,119; 95-percent confidence interval) individuals.

Relative contact rates of razorback suckers (number of fish contacted/number of fish released) were directly related to the size of fish at release. Contact rates (95-percent confidence interval) were lowest at 0.010 (0.001–0.019) for fish released at less than 11.8 inches (300 millimeters), increased at each size class, and were highest at 0.176 (0.140–0.213) for fish released at greater than 19.7 inches (500 millimeters). Differences in contact rates were statistically significant between stocking location, and the contact rate was lowest in zone 3-4 (between Copper Canyon and Parker Dam) at 0.006 (0.004–0.008) and highest for fish stocked in zone 3-2 (between Park Moabi and Lake Havasu Delta) at 0.069 (0.066–0.073). Contact rates were second highest for zone 3-1 (between Davis Dam and Park Moabi) and slightly lower for zone 3-3 (between Lake Havasu Delta and Copper Canyon) at 0.044 (0.041–0.047) and 0.027 (0.023–0.030), respectively. Contact rates were higher for fish released in the spring months, slightly lower for fish released in winter months, and lowest for the autumn months at 0.071 (0.067–0.075), 0.050 (0.048–0.053), and 0.010 (0.008–0.012), respectively.

PIT scanning continues to provide increased contacts of tagged fish compared to traditional means such as electrofishing and trammel netting. Monitoring of razorback suckers in LCR MSCP Reach 3 should continue with both remote PIT scanning and biannual netting trips. As more data are collected, a more in depth analysis of post-stocking dynamics will provide additional information to assess post-stocking survival of razorback suckers in Reach 3.

INTRODUCTION

The razorback sucker (*Xyrauchen texanus*) is a fish endemic to the Colorado River that was once abundant and widespread throughout the drainage (Minckley 1973). Its distribution and numbers have declined, and the species currently is 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).

The Lower Colorado River Multi-Species Conservation Program (LCR MSCP) 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). The lower Colorado River has been subdivided into designated planning areas and river reaches to address these goals. LCR MSCP 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) hypothesized 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 adults 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, over 60,000 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 netting) have remained low (less than 3 percent [%]) (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.

Razorback suckers have been found to aggregate in major spawning areas from Laughlin, Nevada, downstream to Needles, California (Wydoski and Mueller 2006; Wydoski and Lantow 2012). Remote passive integrated transponder (PIT) scanning of spawning aggregates has proven successful in Reach 3 as well as in Lake Mohave, which occupies LCR MSCP Reach 2 (Wisenall et al. 2015; Patterson et al. 2014). Because of the success of these previous studies, we continued with remote PIT scanning in Reach 3 from January to April 2015. In addition, we compiled PIT scanning data and capture data collected from other projects from November 2014 to August 2015 to be used in the analysis.

Here we report the results and conclusions of remote PIT scanning, 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 razorback sucker 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

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

3. Estimate the current repatriated razorback sucker population

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

5. Participate in the annual multi-agency native fish survey

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

METHODS

Study Area

Lake Havasu is impounded by Parker Dam, which was closed in 1938. The reservoir has a 658,000 acre-foot (7.98 x 10^8 cubic meter) 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 (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).

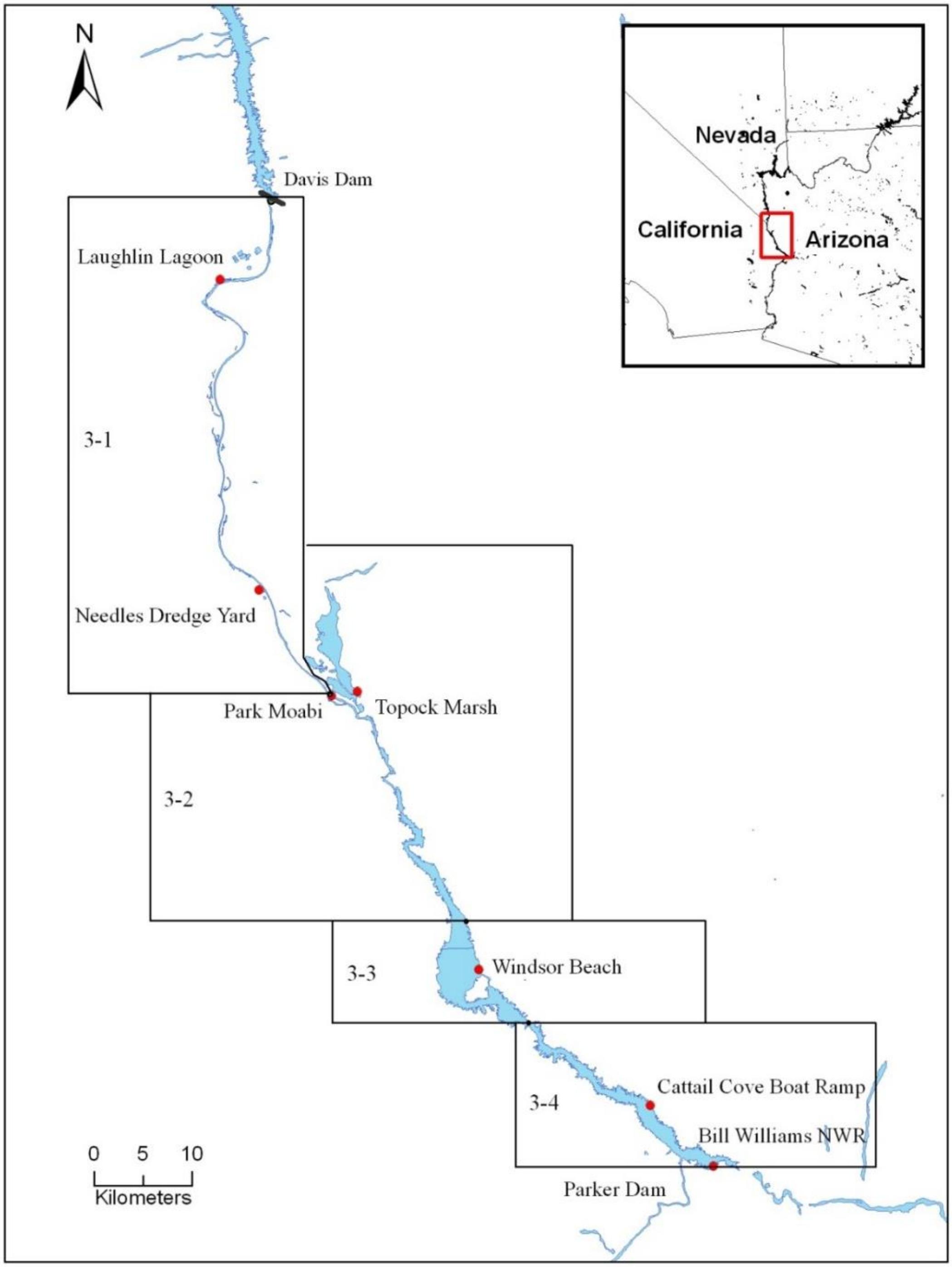

Figure 1.—Overview map of the study area depicting LCR MSCP Reach 3, including general remote PIT scanning and stocking locations, and general zones 3-1 to 3-4 established in the "Methods" section, lower Colorado River, Arizona-California-Nevada.

The shoreline is low lying and relatively well developed. Zone 3-2 is characterized by slower waters, rocky canyon-like shoreline, and 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 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 (Bill Williams River NWR).

Remote PIT Scanning

Remote PIT scanning units were deployed from January 5 to April 9, 2015, between Davis Dam and Needles, California. One additional trip was also conducted at an earlier date from November 17–20, 2014. Four models of PIT scanners were utilized: one large shore-based unit, two large submersible units, eight large neutrally buoyant submersible units, and 14 small submersible units. 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) antennae 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-hour) battery. This unit was deployed and maintained for the length of the field season. The large 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-hour battery contained in watertight PVC piping. The large submersible units were equipped with a sandbag and laid flat on substrate. The 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 deployed the first afternoon of a sampling trip and left to run until retrieved the last morning of sampling before departing the field site, with the exception of one trip in April. On this trip, units were retrieved approximately every 24 hours and downloaded onsite and redeployed. 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-hour or 20.8 amp-hour battery contained in PVC/acrylonitrile butadiene styrene piping. A sandbag was attached to each unit to keep it in place under water. The units were retrieved approximately every 24 hours and 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 four-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 nine different general areas in the Needles Reach, moving downstream: Palms, Cliffs, Cabana, Tower, White Wall, Power Lines, Lone Palm Beach, U.S. 95 bridge, Mesquite Wash, and Airport Wash near Needles, California (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 (figure 2). The shore-based unit was deployed and maintained at one location, Park Moabi in the Needles Reach (figure 2). Locations monitored varied from trip to trip based on fish concentrations, but each trip consisted of 3 nights and 2 days of continuous scanning.

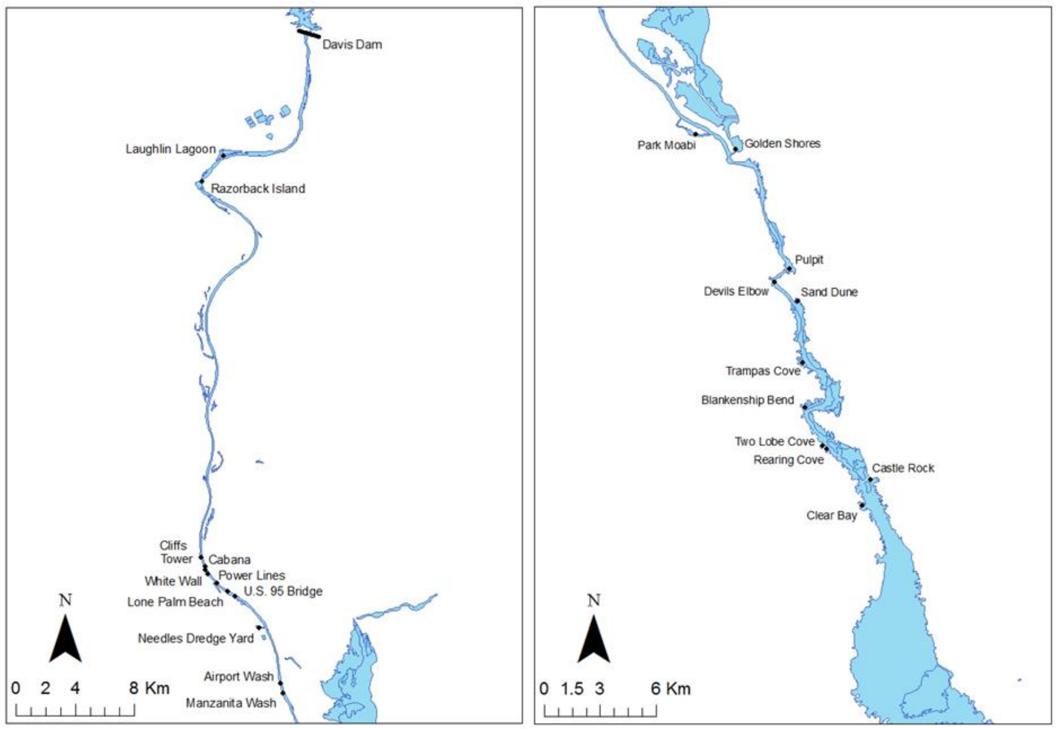

Figure 2.—Location of remote PIT scanning deployment by any entity in LCR MSCP Reach 3, zone 3-1 (left) and zone 3-2 (right) between November 1, 2014, and August 31, 2015, lower Colorado River, Arizona-California-Nevada.

Remote PIT scanning information for each individual deployment was recorded on waterproof data sheets 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 (S), end time or run interval of scanner (E), stop interval (I), scan time (min), 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.

Electrofishing and Routine Monitoring

Potential razorback sucker habitat was electrofished on the nights of March 10 and 11, 2015, at Laughlin Lagoon, Razorback Island, and the Needles reach from the Cliffs downstream to Airport Wash (see figure 2) to seek out potential sub-populations for scanning in those areas. 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 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 analysis. 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 on February 9–12, 2015 (see figure 3). Multi-filament trammel nets (150 or 300 ft x 6 ft [45.7 or 91.4 m x 1.8 m], 1.5 in [3.8 centimeter {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, bonytail (*Gila elegans*), and flannelmouth suckers (*Catostomus latipinnis*) captured were processed as described above. Non-native fish were identified to species and enumerated. All fish were then returned to their point of capture. Electrofishing and monitoring data were entered into the comprehensive lower Colorado River Native Fish Work Group PIT tag and stocking database.

Population Estimate

We employed the modified Petersen formula (Ricker 1975) on paired census data (November 1 through August 31) to calculate a single census population estimate (N^*) for razorback suckers in 2014.

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

Fish to be included in the estimate (M, C, and R) must have been released or tagged prior to the sampling year, before January 1, 2014, for the 2014 estimate. Only fish with a 134-kHz PIT tag release or capture record in the Native Fish

Work Group PIT tag database were included in the estimate (i.e., fish tagged with a 125- 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 not the number of fish tagged and placed into a water body, but the number of fish contacted in the designated mark period (January 1 to April 30, 2014). Catch, C, is the number of fish contacted in the second period of the paired data (January 1 to April 30, 2015), extended to include all scanning data from November 2014 to August 2015. Recapture, R, is the number of fish contacted in both mark and catch periods for the 2014 estimate. 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 greater than 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 PIT tag and had one implanted before January 1, 2014. 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.

The equal catchability assumption is influenced by the geographic and temporal distribution of the fish and the effort used to contact them as well as the

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[1] Due to previous data management practices, the date a fish was double tagged (given a 134-kHz PIT tag in addition to a 125-kHz PIT 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.

[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.

catchability (or contactability) of the fish to the gear used. In order to assess whether PIT scanning alone can provide accurate population estimates, three different population estimates were calculated. The first estimate was calculated with combined PIT scanning data from all entities in Reach 3 from January 1 to April 30, 2014, for the marking period and January 1 to April 30, 2015, for the capture period. This estimate included no capture data. The second estimate included the same PIT scanning data as well as capture data from trammel netting and electrofishing efforts. A third estimate covered the same marking and capture period but only included PIT scanning data collected by M&A specifically for this study. This third estimate was used to determine if PIT scanning conducted for this contract was spatially and temporally distributed adequately to accurately estimate the population.

Post-Stocking Survival

Remote PIT scanning contact rates were used as an index to post-stocking survival. Size at release for this report was assessed by dividing up the stocked fish and the contacted fish (by remote PIT scanning, trammel netting, and electrofishing) into six size classes, or cohorts, based on TL at release: one (≤ 11.7 in [299 mm]), two (11.8–13.7 in [300–349 mm]), three (13.8–15.7 in [350–399 mm]), four (15.8–17.6 in [400–449 mm]), five (17.7–19.6 in [450–499 mm]), and six (≥ 19.7 in [500 mm]). Only fish with a TL measurement at stocking were included in the analysis. Cohorts and number of fish scanned in each cohort were tabulated by year. Relative capture rates (number contacted/number released) were evaluated for each size class. Ninety-five percent binomial CIs were calculated for each contact rate using the normal approximation. CIs that did not overlap were determined as statistically significant.

The location and season of release were evaluated by dividing the location of release into four zones (3-1, 3-2, 3-3, and 3-4) as well as further dividing the zones into individual locations and the seasons into spring (March – May), autumn (October and November) and winter (December – February). The summer months were excluded, as less than 20 fish had been stocked between June and September. Individual locations that had less than 10 fish stocked were omitted. The number of fish stocked in each zone and season as well as the number of fish contacted from each stocking and the relative capture rates were tabulated. Only fish with a location or date of stocking were used in the analysis. Ninety-five percent binomial CIs were calculated for each contact rate using the normal approximation. CIs that did not overlap were determined as statistically significant.

RESULTS

Remote PIT Scanning

Remote PIT scanning in Reach 3 was performed by two entities in 2014–15, M&A and Reclamation. M&A scanning was implemented in Reach 3, zones 3-1 and 3-2. Eight trips were conducted in zone 3-1 and Park Moabi in zone 3-2 (see figure 2) from November 2014 to April 2015 and primarily focused on razorback sucker scanning directly related to this project. Eleven trips were conducted for a separate project in the Bill Williams River NWR in zone 3-4 and Park Moabi in zone 3-2 (see figure 2) from November 2014 to June 2015 and primarily focused on bonytail scanning. Efforts in zone 3-1 and Park Moabi in zone 3-2 resulted in 6,194.7 hours of scanning and 2,369 individual fish contacted. Efforts in the Bill Williams River NWR in zone 3-4 and Park Moabi in zone 3-2 resulted in 15,550.7 hours of scanning and 1,190 individual fish contacted. Reclamation scanning was done over 16 trips from November 2014 to August 2015 in Reach 3, zones 3-1 and 3-2, with the majority of efforts in zone 3-2 (see figure 2). Their efforts resulted in 21,832.9 hours of scanning and 2,202 individual fish contacted. Razorback sucker data collected from both the bonytail and Reclamation efforts were incorporated into the analyses for this report. Overall, 4,661 individual PIT tags were contacted. Of these, 4,331 have a fish tagging record. The majority of the fish (4,139) were razorback suckers; however, 188 bonytail and 4 flannelmouth suckers were scanned as well. Of the 4,139 razorback suckers, 4,089 were released with a 134-kHz PIT tag.

Electrofishing and Routine Monitoring

On the nights of March 9 and 10, 2015, four general locations were electrofished: Laughlin Lagoon, Razorback Island, Needles reach above the US 95 bridge, and Airport and Manzanita washes downstream from Jack Smith Park. Efforts in Laughlin Lagoon resulted in 2,807 seconds of electrofishing and the capture of 18 razorback suckers. Efforts at Razorback Island resulted in 505 seconds of electrofishing and the capture of 12 razorback suckers and 1 flannelmouth sucker. Efforts in the Needles reach resulted in 1,949 seconds of electrofishing and the capture of 18 razorback suckers. Efforts at the Airport and Manzanita washes resulted in 861 seconds of electrofishing and the capture of 16 razorback suckers. 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 analysis, and a total of eight razorback suckers were untagged and were implanted with a 134-kHz PIT tag. An older 125-kHz PIT tag was present in one razorback sucker, and a 134-kHz PIT tag was implanted into that fish. The one flannelmouth sucker had a TL of 22.4 in (568 mm).

A total of 947 fish 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 in (305–640 mm), with an average length of 16 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 in (494 mm) and was implanted with a 134-kHz PIT tag.

Population Estimate

Population estimates for Reach 3 were calculated with all scanning data combined, scanning data combined with capture data, and scanning only conducted by M&A. For scanning alone, the estimated 134-kHz PIT tagged razorback sucker population in 2014 for Reach 3 was 4,758 individuals (4,450–5,087, 95% CI) (figure 3); 1,852, 2,202, and 857 for mark, capture, and recapture, respectively. Combining scanning and capture data resulted in an estimated population of 4,795 (4,491–5,119) (figure 3; table 1); 1,925, 2,232, and 896 for mark, capture, and recapture, respectively. For scanning only conducted by M&A, the estimated population was 4,131 (3,793–4,499) (figure 3); 1,294, 1,677, and 525 for mark, capture, and recapture, respectively.

Post-Stocking Survival

A total of 57,201 razorback suckers with 134-kHz PIT tags were released into Reach 3 between January 1, 2006, and December 31, 2014. The majority of fish (94%) were released in size classes two, three, and four (11.8–17.6 in [300–449 mm]) (table 2). Of these stocked fish, a combined total of 2,739 individual repatriated fish were contacted by scanning, netting, and electrofishing from November 1, 2014, to August 31, 2015. A portion of the contacts are fish contacted in electrofishing and trammel netting efforts in which M&A did not participate, and therefore, those individual numbers are not stated in this report. The majority of contacts (87%) were fish released in size classes two, three, and four (table 2). Relative contact rates (95% CI) were significantly lowest for fish released at ≤ 11.8 in (299 mm) at 0.01 (0.001–0.019), and fish

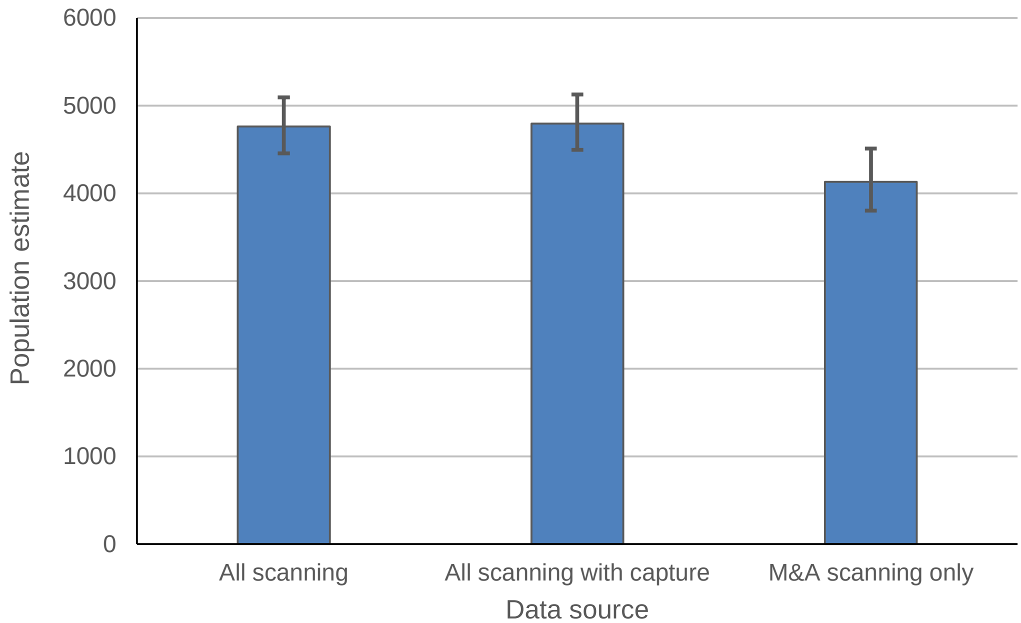

Figure 3.—Population estimates for 2014.
"All scanning" represents the population estimate derived from all scanning by any entity in Reach 3, "All scanning with capture" represents the population estimate derived from all scanning by any entity as well as capture data in Reach 3, and "M&A scanning only" represents the population estimate derived from only those scanning efforts by M&A in Reach 3. Error bars represent 95% CIs.

Table 1.—Population estimates of razorback suckers over three years in LCR MSCP 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	1,925	2,232	896	4,795 (4,491–5,119)

Table 2.—Number and proportion of 134-kHz PIT tagged razorback suckers released between January 1, 2006, and December 31, 2014, by year and size class (top) and individuals contacted by any means between November 1, 2014, to August 31, 2015 (bottom), LCR MSCP Reach 3, lower Colorado River, Arizona-California-Nevada (Fish were divided into the following six size classes based on TL at release: one (≤ 11.7 in [299 mm]), two (11.8–13.7 in [300–349 mm]), three (13.8–15.7 in [350–399 mm]), four (15.8–17.6 in [400–449 mm]), five (17.7–19.6 in [450–499 mm]), and six (≥ 19.7 in [500 mm])).

Stocked individuals							
Year	**One**	**Two**	**Three**	**Four**	**Five**	**Six**	**Proportion**
2006	109	2,122	1,738	77	0	0	0.07
2007	18	3,279	2,603	690	128	0	0.12
2008	64	2,707	334	10	4	19	0.05
2009	25	4,456	1,278	94	1	4	0.10
2010	10	2,032	2,686	677	58	2	0.10
2011	0	4,605	4,396	1,360	318	161	0.19
2012	111	3,599	3,073	1,080	286	89	0.14
2013	1	1,047	2,209	2,443	967	65	0.12
2014	160	741	2,117	2,340	723	85	0.11
Proportion	0.01	0.43	0.36	0.15	0.04	0.01	1.00
Individuals contacted by any means							
Year	**One**	**Two**	**Three**	**Four**	**Five**	**Six**	**Proportion**
2006	1	16	55	1	0	0	0.03
2007	0	16	58	17	3	0	0.03
2008	3	101	22	1	0	0	0.05
2009	1	147	94	10	0	0	0.09
2010	0	24	42	17	0	0	0.03
2011	0	193	258	133	37	43	0.24
2012	0	174	271	146	33	9	0.23
2013	0	27	101	165	106	10	0.15
2014	0	41	110	148	92	13	0.15
Proportion	0.00	0.27	0.37	0.23	0.10	0.03	1.00

released at 11.8–13.7 in (300–349 mm) at 0.03 (0.028–0.032) (figure 4; table 3). Relative contact rates increased as size increased. Fish released at 13.8–15.7 in (350–399 mm) had a contact rate of 0.05 (0.047–0.052), and fish released at 15.8–17.6 in (400–449 mm) had a contact rate of 0.07 (0.067–0.078) (figure 4; table 3). The relative contact rate was significantly highest for fish released at 17.7–19.6 in (450–499 mm) and fish released at greater than 19.7 in (500 mm) at 0.11 (0.097–0.121) and 0.18 (0.140–0.213), respectively (figure 4; table 3).

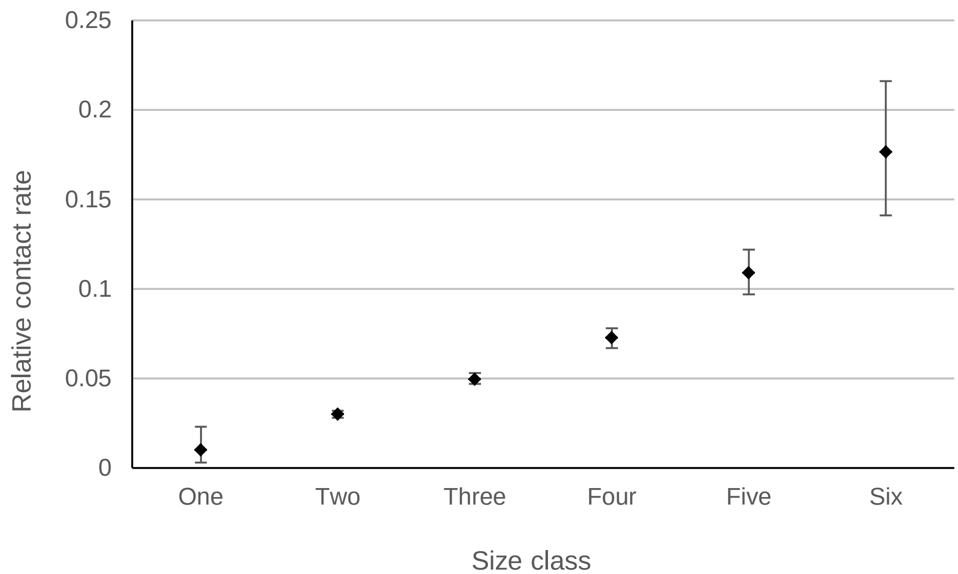

Figure 4.—Relative capture proportion of repatriated razorback suckers released between January 1, 2006, and December 31, 2014, and contacted between November 1, 2014, and August 31, 2015, LCR MSCP Reach 3, lower Colorado River, Arizona-California-Nevada.
Fish were divided into the following six size classes based on TL at release: one (≤ 11.7 in [299 mm]), two (11.8–13.7 in [300–349 mm]), three (13.8–15.7 in [350–399 mm]), four (15.8–17.6 in [400–449 mm]), five (17.7–19.6 in [450–499 mm]), and six (≥ 19.7 in [500 mm]). Error bars represent 95% binomial CIs.

The majority of fish were stocked into zones 3-1 (41%) and 3-2 (37%) (table 3). The relative contact rate (95% CI) was highest for fish stocked in zone 3-2 at 0.069 (0.066–0.073) (table 3). The contact rate was lowest for fish stocked in zone 3-4 at 0.006 (0.004–0.008) (table 3). Zone 3-1 had the second highest contact rate at 0.044 (0.041–0.047). Zone 3-3 had a lower contact rate at 0.027 (0.023–0.030) (table 3). When further divided into individual locations, 31% of fish were stocked in Laughlin Lagoon in zone 3-1 and Park Moabi in zone 3-2, yet half (18% from Laughlin Lagoon and 32% from Park Moabi) of these fish have been scanned (table 4).

Table 3.—Number, proportion, and relative contact rate of 134-kHz PIT tagged razorback suckers released and scanned between January 1, 2006, and December 31, 2014, by size class, zone, and season and the number and proportion of these fish that were scanned between November 1, 2014, and August 31,2015
(Relative contact rate (95% CI) is the number contacted/number stocked.)

	Number Stocked	Proportion stocked	Number contacted	Proportion of contacts	Relative contact rate
Size class					
One	498	0.01	5	0.00	0.01 (0.001–0.019)
Two	24,588	0.43	739	0.27	0.03 (0.028–0.032)
Three	20,434	0.36	1,011	0.37	0.05 (0.047–0.052)
Four	8,771	0.15	638	0.23	0.07 (0.067–0.078)
Five	2,485	0.04	271	0.10	0.11 (0.097–0.121)
Six	425	0.01	75	0.03	0.18 (0.140–0.213)
Zone					
3-1	23,392	0.41	1,032	0.38	0.04 (0.041–0.047)
3-2	21,003	0.37	1,457	0.53	0.07 (0.066–0.073)
3-3	8,270	0.14	222	0.08	0.03 (0.023–0.030)
3-4	4,536	0.08	28	0.01	0.01 (0.004–0.008)
Season					
Winter	29,089	0.51	1,459	0.53	0.05 (0.048–0.053)
Spring	16,431	0.29	1,160	0.42	0.07 (0.067–0.075)
Autumn	11,664	0.20	120	0.04	0.01 (0.008–0.012)

By season, the majority of fish (51%) were stocked in the winter months, and the majority of scanned fish (53%) came from winter stockings (see table 3). Fish stocked in spring accounted for only 29% of the stocking effort and 42% of scanning effort (see table 3). Relative contact rates (95% CIs) were higher in spring at 0.07 (0.067–0.075) than winter at 0.05 (0.048-0.053) (see table 3). Autumn months only accounted for 20% of the stocking and 4% of the scanning and had contact rates (95% CIs) of 0.01 (0.008–0.012) (see table 3).

Table 4.—Number and proportion of 134-kHz PIT tagged razorback suckers released between January 1, 2006, and December 31, 2014, in individual locations throughout Reach 3 and the number and proportion of these fish that were scanned between November 1, 2014, to August 31, 2015

Zone	Location	Number stocked	Proportion stocked	Number contacted	Proportion contacted
3-1	RM	83	0.001	4	0.001
	Big Bend State Park	2,425	0.042	86	0.032
	Jack Smith State Park	4,035	0.071	226	0.084
	Laughlin Lagoon	10,263	0.179	488	0.182
	Laughlin Lagoon and Needles Dredge Yard	3,227	0.056	108	0.040
	Laughlin Ramp	165	0.003	0	0.000
	Needles	36	0.001	2	0.001
	Needles Dredge Yard	4,214	0.074	169	0.063
3-2	Blankenship Bend	1,455	0.025	98	0.036
	Castle Rock Cove	721	0.013	84	0.031
	Catfish Paradise in Topock Marsh	3,243	0.057	32	0.012
	Clear Bay Cove	1,107	0.019	68	0.025
	Park Moabi	7,390	0.129	869	0.324
	Pulpit Rock Cove	739	0.013	32	0.012
	Rearing Cove	335	0.006	15	0.006
	Sand Dunes Cove	505	0.009	31	0.012
	Topock boat launch	4,245	0.074	117	0.044
	Tulobe	201	0.004	8	0.003
3-3	BLM Partner's Point Work Camp	16	< 0.001	0	0.000
	Windsor Beach State Park	8,253	0.144	222	0.083
3-4	Bill Williams River NWR	2,560	0.045	14	0.005
	Cattail Cove Boat Ramp	1,971	0.034	13	0.005

DISCUSSION

The majority of the fish released and scanned in this study were between 11.8 in (300 mm) and 17.7 in (450 mm) long (see table 3). Although fewer fish are stocked at larger sizes (> 17.7 in [450 mm]), relative contact rates have shown that potential survival of the larger fish is greater than that of smaller fish (see figure 4). The size-survival relationship has been documented in other portions of the river. Marsh et al. (2005) stated that TL at release was the most important determinant of post-stocking survival of razorback suckers in Lake Mohave. The effect of size at release on survival for razorback suckers in Lake Havasu was assessed in a previous report as well (Patterson et al. 2014). Although size at release was found to be a significant contributor to survival, it does not appear to be as major a factor to survival as for other populations of razorback suckers in the lower river such as the Lake Mohave population or in the Upper Colorado River Basin (Zelasko et al. 2011). In Lake Mohave, few fish below 13.8 in (350 mm) are contacted after release (Wisenall et al. 2015), whereas 27% of the contacts in Reach 3 are made up of fish that are less than 13.8 in (350 mm). In turn, fewer larger fish are scanned in Reach 3 than in Lake Mohave, as only 13% of the contacts are made up of fish over 17.7 in (450 mm). Complexity of habitat, presence and abundance of large predaceous fishes, and other environmental factors may contribute to the disparity. Regardless of the causes, 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. However, relative contacts and subsequent survival were significantly higher in zone 3-2. In the previous report, it was hypothesized that this was because the zone is characterized by numerous backwaters and side channels (Ehlo et al. 2015). However, the majority of fish scanned were stocked in Park Moabi. Park Moabi is just a single backwater in an area encompassed by the most complex habitat in Reach 3. Another significant portion of the scanning data came from fish stocked in Laughlin Lagoon in zone 3-1, which is approximately 30 RM (48 RKM) upstream of Park Moabi. Contact rates and subsequent survival estimates continue to be lowest for those fish stocked in zone 3-4 as stated in previous reports (Patterson et al. 2014; Ehlo et al. 2015). Relatively few fish have been stocked in zone 3-4 compared to other zones. Given sufficient time, telemetry studies have shown that fish stocked into the lower reaches of Lake Havasu can move upstream to spawning areas in zone 3-1 (Wydoski and Lantow 2012). Even though adults will move upstream to the spawning area, the combination of fewer fish stocked and a greater distance to the known spawning areas may account for the lack of contacts of fish stocked in zone 3-4.

Stocking season may also play an important role in razorback sucker survival. Contact rates were significantly higher for fish stocked in spring rather in winter or autumn. However, contact rates in winter were only slightly lower. This pattern has also been observed with razorback sucker stockings in the Green and San Juan Rivers (Bestgen et al. 2009; Zelasko et al. 2011). In past reports, stocking was divided into two seasons: spring (January – May) and winter (October – December) (Patterson et al. 2014; Ehlo et al. 2015). The data suggest that dividing stockings into three seasons rather than just two provides more insight into the best time to stock fish into the water. However, there may not be enough disparity between spring and winter stockings to justify only stocking in the spring months.

The relationship of general release location, season of release, and size at release are being re-evaluated in a mark-recapture model and will be presented in the final report. The additional PIT scanning data have increased the potential for precise survival estimates. However, the acquisition of PIT scanning data does not occur in discrete time intervals that are the hallmark of traditional mark-recapture models (Cormack-Jolly-Seber). Recently, the Barker model, which allows for continuous re-sighting events between discrete sampling events, has been proposed as a way to incorporate continuous remote sensing data into a mark-recapture model (Conner et al. 2015; Barbour et al. 2013). However, the models used as examples in both publications were simplified models without age structure or individual covariates. An unpublished working model for Lake Havasu with age structure, an individual covariate (size at release), and a season of release factor results in a global model with more than 100 parameters. Preliminary attempts to estimate the parameters of this model resulted in a lack of numerical convergence. The development of a workable model (reduced parameter space from the global model) is ongoing.

Population estimates slightly increased from subsequent years but still have overlapping CIs, with the exception of the 2011 estimate (Patterson et al. 2014; Ehlo et al. 2015; see table 1). The discrepancy between 2011 and other years is likely due to sampling bias related to the shift from traditional methods (i.e., electrofishing and trammel netting) to PIT scanning. Utilization of PIT scanning technology began in 2012, which increased the detectability of fish and therefore increased the number of captures for the 2011 estimate. Contact rates will continue to increase, and population estimates will become more precise in subsequent years as remote PIT scanning technology evolves and more spawning aggregates are identified and sampled.

The population estimate derived from all scanning efforts was nearly identical to the one based on scanning and capture efforts, while the one derived from M&A scanning efforts was lower (see figure 4). This indicates that M&A scanning alone does not contact a representative sample of razorback suckers in Reach 3. However, this does not appear to be related to differences in scanning location between the two main scanning efforts (M&A and Reclamation). Although there was some overlap (i.e., Park Moabi scanning) between scanning locations for the two different entities, the majority of M&A scanning occurred in zone 3-1, and the majority of Reclamation scanning occurred in zone 3-2. Out of the total number contacted by M&A and Reclamation, only 1,677 and 814, respectively, met the criteria for use in the 2014 population estimate. These values represent 35.2 and 17.1% (respectively) of the estimated 4,758 PIT-tagged razorback suckers (estimated from scanning data alone) in 2014. If we use these percentages as the expected probability of an individual being contacted by each technique, then we would expect about 6% (17.1% X 35.2% = 6.0%) of the population to have been contacted by Reclamation and M&A efforts (285 fish). The actual number that was contacted by both Reclamation and M&A was 289. This suggests that there is no demographic isolation between razorback suckers in zones 3-1 and 3-2.

Overall, the use of remote PIT scanning continues to provide increased contacts of fish compared to traditional means such as electrofishing and trammel netting. The majority of trammel netting occurs in backwater habitats with little to no flow and requires substantial equipment and many man-hours (Wydoski and Mueller 2006). Moreover, remote PIT scanning allows two biologists to efficiently sample fast-flowing riverine habitats where trammel netting is not feasible and electrofishing is relatively inefficient. While netting and electrofishing are ideal to collect such information as growth, health, and genetic information, remote PIT scanning provides a non-invasive method to monitor the population as a whole and continues to help meet the goals of this and other projects.

RECOMMENDATIONS

We recommend that remote PIT scanning continue to be utilized and expanded in Reach 3. While this technology is not perfect, it provides a more comprehensive look at the razorback sucker population in the lower Colorado River than traditional methods. However, netting and electrofishing efforts should continue in order to collect health, growth, and genetic data from repatriated razorback suckers.

Contact rates are highest in zones 3-1 and 3-2, particularly from fish stocked in Laughlin Lagoon and Park Moabi. Contact rates are higher from fish stocked in the winter and spring months. Therefore, we recommend that stocking efforts focus on Laughlin Lagoon, Park Moabi, and other locations within zones 3-1 and 3-2 from January – May.

Continued scanning will further build on the existing remote sensing database and will allow for a more complex analysis of the data using program MARK. With a more complex analysis in the final report we will be able to make more specific recommendations to enhance post-stocking survival of repatriated razorback suckers in Reach 3.

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