Lower Colorado River Multi-Species Conservation Program

Balancing Resource Use and Conservation

Demographics and Monitoring of Repatriated Razorback Suckers in Lake Mohave

2018 Annual Report

April 2019

Work conducted under LCR MSCP Work Task D08

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National Park Service
Bureau of Land Management
Bureau of Indian Affairs
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Lower Colorado River Multi-Species Conservation Program

Demographics and Monitoring of Repatriated Razorback Suckers in Lake Mohave

2018 Annual Report

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ACRONYMS AND ABBREVIATIONS

AIC	Akaike's information criterion
AICc	Akaike's information criterion adjusted for small sample sizes
CI	confidence interval
FY	fiscal year
kHz	kilohertz
LCR MSCP	Lower Colorado River Multi-Species Conservation Program
M&A	Marsh & Associates, LLC
MARK	computer program MARK
M, C, R	mark, capture, recapture
m	meter(s)
mm	millimeter(s)
PIT	passive integrated transponder
PVC	polyvinyl chloride
QAICc	quasi-likelihood
Reclamation	Bureau of Reclamation
rkm	reservoir kilometer(s)
SY	sample year
TL	total length
USFWS	U.S. Fish and Wildlife Service
Willow Beach NFH	Willow Beach National Fish Hatchery

Symbols

n	number
$\hat{c}$	c-hat, variance inflation factor
p	capture
γ	gamma
$>$	greater than
$\geq$	greater than or equal to
$<$	less than
%	percent
$\pm$	plus or minus
c	recapture

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EXECUTIVE SUMMARY

Repatriated razorback suckers (*Xyrauchen texanus*) in Lake Mohave have been monitored for more than 20 years, but low recapture rates have inhibited evaluation of factors contributing to highly variable post-stocking survival. In 2010, deployment of remote passive integrated transponder (PIT) scanners able to detect 134.2-kilohertz (kHz) PIT tags was initiated to increase the number of encounters with marked fish. The program was expanded in 2012 and 2013, while traditional capture methods (i.e., trammel nets) continued to be employed to collect comparable long-term monitoring data and estimate abundance of all repatriated and wild razorback suckers marked with either 400- or 134.2-kHz PIT tags.

Twenty-one razorback suckers were handled by Marsh & Associates, LLC, during fiscal year (FY) 2018; 8 fish on November 28–29, 2017, with assistance from the Arizona Fish and Wildlife Conservation Office, and 13 fish during March 12–16, 2018, multi-agency monitoring activities. PIT tags were undetected in 3 of the 21 captures, and their histories were recorded as unknown in the database. These three unknown fish plus one other PIT-tagged capture with no rearing history were omitted from further consideration, leaving 17 fish for analysis. Sex was determined at both events, and captures included 17 females and 4 males. Based on monitoring data from March 2017 and 2018, there is no effective wild razorback sucker population remaining in Lake Mohave. The repatriated razorback sucker population estimate in 2017, based on March 2017 and 2018 capture data, was 841 (95% confidence interval [CI] from 694 to 4,487).

Total deployment time for remote PIT scanners from October 1, 2017, through August 31, 2018, was 37,903 scan-hours, resulting in 131,131 PIT tag contacts, representing 3,835 unique PIT tags for which 3,652 had a razorback sucker marking record (i.e., implanted with a PIT tag and associated data recorded) in the Lower Colorado River Native Fish Database (as of August 31, 2018). Among fish with a marking record, 3,615 were repatriates, 9 were wild, and 28 were of unknown origin.

Based on 2017 and 2018 remote PIT scanning, the 134.2-kHz tagged repatriate population in 2017 was 3,471 (95% CI from 3,365 to 3,576). The Basin and River zone subpopulation estimates based on zone-specific scanning in 2017 and 2018 also were calculated. The Basin zone subpopulation was estimated at 1,872 (95% CI from 1,804 to 1,940) and the River zone at 2,093 (95% CI from 1,966 to 2,220). The subpopulation in the Liberty zone was not estimated because there were no recaptures there. Too few wild fish were contacted to estimate the Basin and River zone subpopulations separately (six and three contacts, respectively). The lake-wide estimate of the wild population based on PIT scanning in 2017 and 2018 was 9 fish (95% CI from 4 to 23).

A robust mark-recapture model was applied to a subset of razorback suckers contacted by remote PIT scanning. This population was known to be at large during a 6-year period (FY12–FY18), allowing survival estimation to be removed from the analysis. This analysis was used to assess temporary emigration and to determine if capture parameters could be accurately assessed from PIT scanning data within the robust model framework. Temporary emigration was estimated at up to 8.1% of the known population (sample years 2014 to 2015), and estimates of razorback suckers able to be detected peaked at 54.9% for the last estimable period (2015 to 2016 and 2016 to 2017 combined). Temporary emigration could represent "skip" spawning or the existence of additional spawning areas that are not currently covered by remote PIT scanning deployments.

Stocking displacement was examined to determine the distance traveled from stocking locations and to identify movement between zones. In the River and Basin zones, most fish were contacted within their zone of release, and this result was consistent across years. Razorback suckers stocked into the Liberty zone were contacted in the River zone or downstream in the Basin zone, and fish stocked into the Katherine zone all were contacted upstream of their release locations. The results are congruent with 2016 and 2017 cohort analyses (Leavitt et al. 2017; Wisenall et al. 2016) but provide a more spatially explicit illustration of movement patterns among years.

Deployment of remote PIT scanners to monitor the two known subpopulation centers (River and Basin zones) will continue to be an effective means of contacting razorback sucker aggregates. Additional scanning efforts have continued in the Liberty zone to determine if other aggregations exist and to further evaluate the dynamics of razorback sucker dispersal and distribution. Biannual routine monitoring efforts in the Basin zone continue to collect essential growth, health, census, and genetic data for razorback suckers. These data continue to provide long-term insight into population dynamics and demographics. Additionally, larval collection efforts provide a means for population augmentation to ensure long-term persistence of razorback suckers in Lake Mohave. Together, these efforts continue to contribute to the maintenance of this endangered species.

INTRODUCTION

Lake Mohave in the latter half of the twentieth century was home to the largest known population of wild razorback suckers (*Xyrauchen texanus*), an endangered "big river" fish endemic to the Colorado River basin. This population contained more than 73,000 fish from 1980 to 1993 (Marsh 1994), but numbers declined to fewer than 50 wild individuals by 2010 (Dowling et al. 2014). Since 2010, wild razorback suckers are rarely encountered, and the population is functionally extirpated.

Although wild fish are gone, a genetically diverse adult razorback sucker population is maintained in Lake Mohave because of a repatriation program initiated by the Native Fishes Workgroup in the early 1990s (Dowling et al. 2005; Marsh et al. 2015). The program gradually developed into a system of wild larvae collection, protective rearing, and repatriation to the reservoir after growing to a minimum size of 300 millimeters (mm) in total length (TL) or more (Mueller 1995). There have been several adjustments to the program that incorporate new information to increase survival of stocked fish, primarily an increased size of stocked fish to reduce predation mortality, but results thus far have not met expectations (Marsh et al. 2005, 2015).

In 2006, management of the Lake Mohave repatriation program shifted to the Lower Colorado River Multi-Species Conservation Program (LCR MSCP), which currently oversees and funds stocking and monitoring of razorback suckers in Lake Mohave. Stocking razorback suckers into Lake Mohave from the Willow Beach National Fish Hatchery (Willow Beach NFH) (LCR MSCP 2015b, 2018, Work Task B2), Achii Hanyo Native Fish Rearing Facility (LCR MSCP 2015b, 2018, Work Task B3), Lake Mead Fish Hatchery (LCR MSCP 2015b, 2018, Work Task B6), and from lakeside ponds (LCR MSCP 2015b, 2018, Work Task B7) is conducted under the Fish Augmentation component of the program (LCR MSCP 2006, 2015a). The Lake Mohave repatriation program is one element of an overall conservation plan for razorback suckers within the LCR MSCP. This program, and other conservation plans upon which it was based (Minckley et al. 2003; U.S. Fish and Wildlife Service [USFWS] 2005), incorporates a population component that will occupy the lower Colorado River main stem; however, absent changes in the non-native fish community, it may be impractical or impossible to accommodate that component.

Efforts to enhance the population size of razorback suckers have included assessing the relationship between size and survival, which has led to a recommended minimum stocking TL of 500 mm (Kesner et al. 2008, 2012; Marsh et al. 2005). However, increasing individual size while maintaining sufficient stocking numbers had proven difficult (M. Olson 2009, personal communication), which led to a change in rearing strategy at the Willow Beach NFH in February 2015. About 8,000 to 10,000 fish were to be held on station for

5 years and then released as one cohort regardless of size (smaller fish will not be culled). The goal was to increase mean fish size, likely to be > 400 mm TL. The decrease in number of fish stocked per year also reduces the larval collection goal, which was updated to 18,000 per year, but will be subject to change dependent on program needs (LCR MSCP 2015a, 2018, Work Task B1). Unfortunately, in November 2016, approximately 30,000 razorback suckers at the Willow Beach NFH were lost due to a catastrophic outbreak of the parasitic protozoan *Ichthyophthirius multifiliis* ("ich"). Due to this loss, the number of fish available to be stocked into Lake Mohave over the next several years, especially those of a larger size, has dramatically decreased, and the larval goal was increased to 33,000 and 30,600 individuals in 2017 and 2018, respectively.

Traditionally, management of the Lake Mohave razorback sucker population relied entirely on data acquired during trammel net surveys to derive population and survivorship estimates (Marsh et al. 2005), but in 2010, the use of portable remote passive integrated transponder (PIT) scanners was implemented. This technological advance has expanded the study area into riverine portions (i.e., River and Liberty zones), while traditional capture methods in the Basin zone continue to provide important comparative health and dispersal information, samples for genetics monitoring, data on untagged or older 400-kilohertz (kHz) tagged fish, and temporal dynamics of the non-native fish community.

Overall, the objective of ongoing monitoring and research of razorback suckers in Lake Mohave is to provide information needed to determine how the repatriation program should contribute to the maintenance of this endangered species in Lake Mohave and throughout the lower Colorado River. Moreover, results of this research provide critical demographic information and inform management to help ensure long-term persistence of a genetically viable stock of adult razorback suckers in Lake Mohave.

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

1. Locating and capturing adult razorback suckers.

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

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

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

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

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

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

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

9. Providing monthly progress reports summarizing all field, laboratory, or office work completed during this effort.

10. Providing copies of all datasets generated during this work to the designated Bureau of Reclamation (Reclamation) Contracting Officer's Technical Representative.

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

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

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

This report summarizes the fourth year of data collected under the current 5-year contract as part of ongoing demographic and post-stocking survival studies of repatriated razorback suckers in Lake Mohave. Population estimates for wild and repatriate populations were updated based on results from standard monitoring. Repatriate population estimates include remote PIT scanning data collected across all years available in the basin and riverine portions of the lake. Lastly, a robust mark-recapture model was developed to examine temporary emigration and to determine if capture parameters could be accurately assessed from PIT scanning data within the robust model framework.

METHODS

For the purposes of this study, Lake Mohave (LCR MSCP Reach 2) was divided into four distinct zones (i.e., River, Liberty, Basin, and Katherine – listed from upstream to downstream) based on geographic features of the river system and razorback sucker demographics as determined from previous studies (figure 1; Kesner et al. 2012). Remote PIT scanning was conducted in the River, Liberty, and Basin zones.

Annual sampling followed the Federal fiscal year (FY), October 1, 2017, to September 30, 2018, which coincides with annual spawning behavior (i.e., the annual sampling event in autumn is reported together with the following March monitoring data each year, representing a single spawning season). Sample year (SY) refers to the calendar year based on the FY schedule (e.g., October 1, 2017, to September 30, 2018, is SY 2018). Unless otherwise stated, previous SY data in this report represent the entire SY, and current SY data were restricted to the active sampling period, through August 2018, to allow adequate time for data analyses.

Routine Monitoring

Objectives 1, 2, 3, 4, and 6 were accomplished through participation in the December and March multi-agency survey events. During both events, December 2017 and March 2018, Marsh & Associates, LLC (M&A) personnel occupied a field camp for 5 days on Lake Mohave at Carp Cove, Arizona (Basin zone), near River Mile 298 (miles upstream of the Southern International Boundary). For each sampling event, up to six trammel nets (91.4 meters [m] long x 1.8 m high, with 3.8 centimeter stretch mesh) were fished continuously along the Arizona shoreline from the Cottonwood Cove East Area upstream to Carp Cove. One net was placed inside Carp Cove, one at the point of the Carp Cove entrance, and four along the Arizona shoreline in the Cottonwood Cove East Area.

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

Figure 1.—Map of Lake Mohave, Arizona and Nevada, illustrating the zoning scheme used.

Remote Monitoring

Remote PIT scanning systems were deployed 1 week of every month during the FY18 sampling season on shallow gravel bars that extend into the Colorado River upstream of Willow Beach (River zone; objective 5) and throughout the Liberty zone. Three models of sinking submersible PIT scanning units were employed (0.8 x 0.8 m and 1.2 x 0.8 m [standard power] and 1.2 x 0.8 m [decreased power consumption]). PIT scanning units were comprised of a polyvinyl chloride (PVC) frame that housed a scanner and logger. Power to the submersible units was provided by a 20.8 or 28 ampere-hour lithium-ion battery pack contained in a watertight, 2-inch (5.08-centimeter) PVC pipe. Submersible units scanned continuously for up to 386 hours, but batteries generally were changed as needed. Five to 19 submersible units were employed throughout the monitoring season.

Five locations established in 2013 as fixed sites listed from downstream to upstream were Gio's Point, Black Bar, Ringbolt Rapids, Boy Scout Canyon, and Sauna Cave. Fixed sites were scanned continuously each sampling trip. These locations were initially examined and evaluated in 2011, PIT scanned periodically in 2011 and 2012, and determined to be used by razorback suckers at different times of the year. Fixed sites at these five locations were established to test the hypothesis that razorback sucker aggregation sites change temporally (i.e., seasonally), with large aggregates on Black Bar during spawning, then shifting upstream toward Hoover Dam as the spawning season ends. Thus far, results have not supported any directed movement of razorback sucker aggregations (Wisenall et al. 2015), but year-round data collected since 2015 continue to show seasonal variation in site contact rates (Leavitt et al. 2017; Wisenall et al. 2016). Due to seasonal variation in contact rates, deployment of scanners varied between trips depending on observed or reported fish concentrations.

One submersible unit with decreased power consumption was deployed throughout the 2018 sample season at Black Bar. This unit had twice the wire turns as standard units, which resulted in lower power consumption. The unit was deployed during scanning trips and retrieved the next month as a replacement of the shore-based continuous scanner deployed at Boy Scout Canyon in previous years.

Additional PIT scanning was conducted this year downstream from Willow Beach to determine if any additional aggregates exist and to assess spatiotemporal movement. M&A deployed up to 10 submersible PIT scanners per trip within a section of the reservoir between Willow Beach and Burny Cove (figure 2). Each month a different reservoir section was targeted subjectively. In addition, submersible units were deployed in Liberty Cove (Liberty zone) every month except August to assess temporal patterns. Reclamation deployed up to 10 additional submersible units per trip working in 1- to 2-mile increments moving

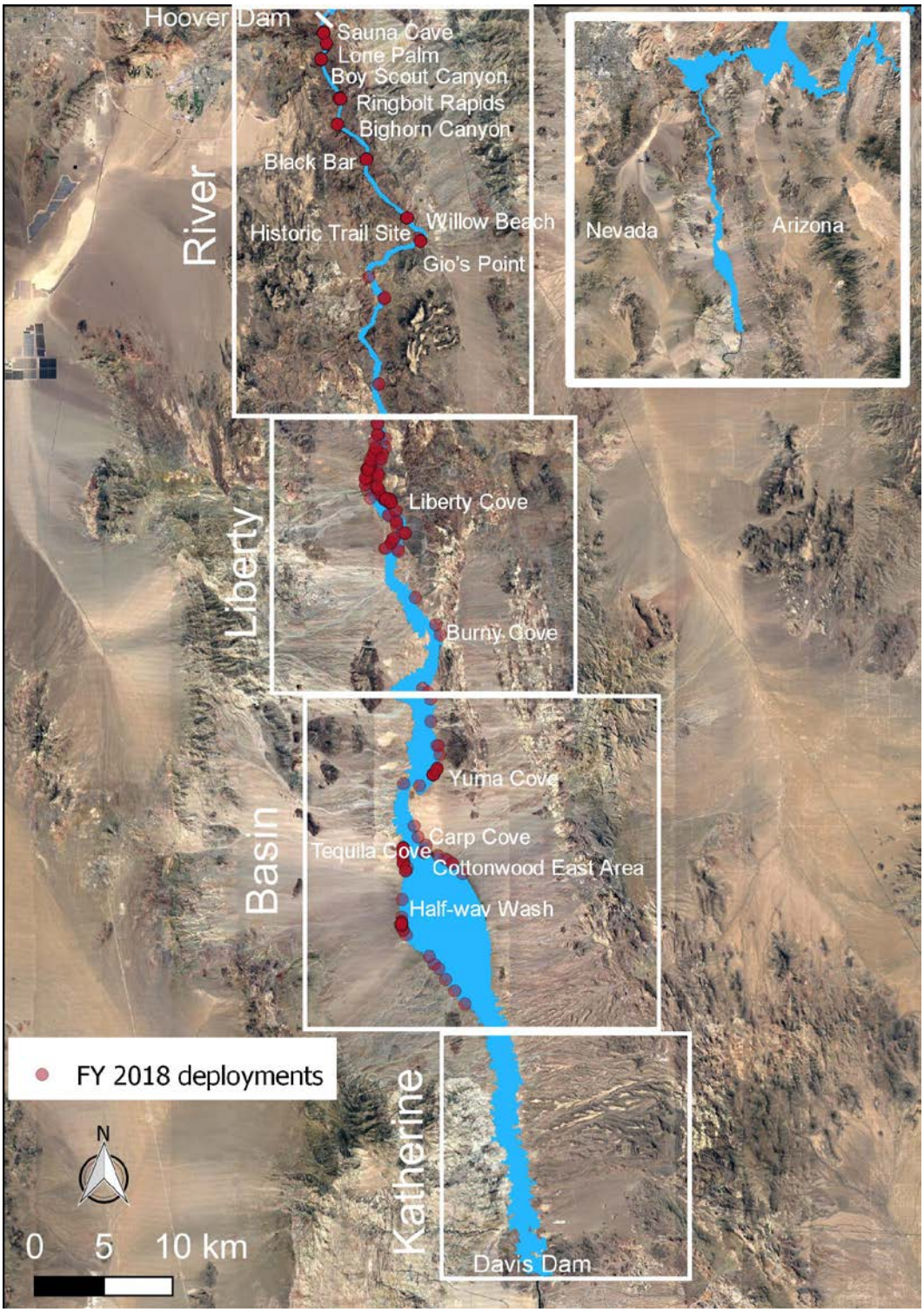

Figure 2.—Location of M&A and Reclamation remote PIT scanners in the River, Liberty, and Basin zones of Lake Mohave, Arizona and Nevada, FY18.

upstream each sample trip from the Basin zone to the Liberty zone at Liberty Cove. The general location of deployments for each trip was determined by subjectively targeting suspected razorback sucker habitat. These areas included shallow gravel bars and cobble substrates as well as cattail stands where razorback suckers have been observed in the past (J. Stolberg 2016, personal communication). Scanning did not take place in the Katherine zone during FY18.

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

Remote PIT scanning in the Basin zone (see figures 1 and 2) was conducted by Reclamation with support from M&A (objective 5). Semipermanent shore-based units were deployed in the Basin zone for continuous scanning from 2017 to 2018. Shore-based PIT scanners were deployed at Tequila Cove, Yuma Cove, and Half-Way Wash. The units operated continuously from December 2017 to May 2018 and were powered by a deep-cycle marine battery and a 60-watt solar panel. A shore-based unit deployed at Yuma Cove was attached to a solar panel for power.

All sites with semipermanent shore-based units are known spawning aggregation sites and have been collection sites for March monitoring since collections began in 1974 (Minckley 1983). Remote PIT scanning data and associated deployment information were provided by Reclamation, and all data acquired from PIT scanning on Lake Mohave were incorporated into a MySQL database, maintained by M&A, and hosted by Hostgator.com (http://www.hostgator.com/). Access to summary reports of scanning data as well as all raw data files are available through a password-protected section of the M&A website (http://www.nativefishlab.net; objective 10).

Population Estimates

The razorback sucker population in Lake Mohave was estimated from two data sources (objective 7). First, netting data[1] from all agencies participating in the spring survey were used to estimate overall populations of wild and repatriated fish in Lake Mohave using mark-recapture (objective 8). Second, remote PIT scanning data were used to estimate the population size for the lake-wide population as well as the River and Basin zone subpopulations of repatriated and

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

wild razorback suckers with 134.2-kHz PIT tags in 2017. Remote PIT scanning and routine monitoring data were treated separately for repatriate estimates because some repatriate razorback suckers contain only a 400-kHz tag, which is rarely detected by remote PIT scanners. Combining the two sources would not accurately estimate the repatriate population.

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

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

Capture data for population estimates were restricted to encounters in March of each SY because the highest number of encounters with razorback suckers occurs then, and the marking event must be short relative to the interval between marking and capturing events to meet assumptions of the estimate (Ricker 1975). For population estimates based on remote PIT scanning, the number of individual PIT tags contacted in a 2-month scanning period encompassing the peak of razorback sucker spawning (January 1 through the end of February) in the previous SY was the mark (*M*), the number contacted between the first of October and the end of April in the current SY was the capture (*C*), and the number in common between both years the recaptures (*R*). Any contacts with PIT tags released after May 31 of the year prior to the marking year were removed from population estimates. Confidence intervals (CIs) were derived using Poisson approximation tables with *R* as the entering variable when recaptures were 50 or less, or they were based on the normal distribution for 51 or more recaptures (Seber 1973). The Chapman estimate of large sample variance (Ricker 1975) was used for normal-based CIs.

In an effort to standardize razorback sucker population estimates based on remote PIT scanning data throughout the reservoirs in the Lower Colorado River Basin, the date ranges of marking and capture periods used to estimate the population in this report are different compared to previous annual reports (see Kesner et al. 2012, 2014; Leavitt et al. 2017; Wisenall et al. 2015, 2016). This change would likely result in slight changes to population estimates for all years that have previously been reported. Therefore, population estimates based on the new criteria are provided in this report for SY 2010 through 2017 (see figure 6).

Survival – Robust Model

Previous reports have provided mark-recapture estimates of survival and transition rates for subpopulations in the River and Basin zones, based on remote PIT scanning data and multi-site mark-recapture models (Kesner et al. 2012, 2014; Leavitt et al. 2017; Wisenall et al. 2015, 2016). These results have been informative, but two issues were apparent. One, information had to be removed from the data to conform to the model (e.g., multiple contacts with a fish within a

year were reduced to one contact) and estimates of ĉ (variance inflation factor) indicated significant overdispersion. In 2018, a robust mark-recapture model was developed to address these issues. The robust mark-recapture model can increase the amount of information included in the mark-recapture analysis by treating monthly PIT scanning trips as closed trapping occasions. Robust models also allow for temporary emigration, which may account for overdispersion in the multi-site model. Multi-site robust models are available but were not considered in 2018. There is continued interest in refining our understanding of movement between subpopulations, but the focus of the analysis in 2018 was to assess temporary emigration and to determine if capture parameters could be accurately assessed from PIT scanning data within the robust model framework.

Robust models combine closed sessions, repeated sampling occasions during which no mortality or migration occurs, with open periods between sessions with mortality and temporary migration (Kendall et al. 1997). Capture and recapture rates are estimated from the demographically closed sampling occasions within each session. Survival and temporary emigration rates are estimated from data collected over multiple sessions. There are 13 different parameterizations of the robust model in the computer program MARK (MARK) (Cooch and White 2016). Most of these are based on variations in closed mark-recapture parameterizations (see Otis et al. 1978). The "Huggin's p and c" model was selected for this analysis. This model removes population estimation from the likelihood and allows for differences in capture probabilities within a session (i.e., study year). The model also includes separate parameters for first time capture (p) and recapture (c). The gamma' (γ') and gamma" (γ'') parameters in the model allow for individuals to temporarily emigrate out of and immigrate back into the scanning area between sessions. γ'' is the probability a fish emigrates away from the scanning area, and γ' is the probability a fish remains out of the study area once it has emigrated. The probability of a fish surviving from one session to the next is estimated by the parameter S.

Sampling occasions for Lake Mohave PIT scanning were based on monthly PIT scanning trips conducted on behalf of this contract by M&A. These trips were typically 4 to 5 days long and were conducted monthly since 2011, between January and August prior to 2015 and year-round since 2015. PIT scanning deployments on these trips were focused on razorback sucker aggregation sites upstream of Willow Beach (River zone). PIT scanning data in the Basin zone were predominately collected with shore-based PIT scanners running continuously through the spawning season (typically November through April). To establish discrete capture (scanning) occasions for the robust model, contacts recorded outside the week of River zone scanning trips were removed from capture histories (i.e., regardless of contact location, only contacts collected during the date range of monthly River zone PIT scanning trips were included). Scanning occasions were grouped by SY (based on the FY, October through

September) to represent a sample session. To allow enough time between sessions for mortality and migration, only PIT scanning occasions between December and May of each SY (session) were included.

A "known" population of PIT-scanned razorback suckers was used to evaluate temporary emigration within the robust design mark-recapture model. The known population included razorback suckers released prior to January 1, 2010, and contacted in SY 2018 (between November 1, 2017, and August 31, 2018). A total of 1,107 razorback suckers met the criteria. PIT scanning contacts with these fish in Lake Mohave between SY 2012 and 2017 were used to develop contact histories. Restricting data in this way allowed us to assume the fish were adults (at large for more than 2 years) that survived the entire study period (scanned after 2017). Model complexity was therefore reduced (e.g., no mortality and no differences in contact rates due to immaturity). The analysis was focused on the presence and form of temporary emigration. Thirty-one scanning occasions were assessed (four in 2014; five in 2012, 2013, and 2015; and six in 2016 and 2017). Out of the 1,107 fish that met the criteria, 51 were never contacted during the 31 scanning occasions. These capture histories were removed from the MARK input file because they contained no relevant data (a capture history of zeros).

Model parameterizations were limited for the known population analysis (table 1). Survival (S) was fixed at one for all models (no mortality). Capture (p) and recapture (c) rates were set equal for any given sample occasion (hereon referred to as contact rates) because the likelihood of either is equivalent when both are represented by PIT scanning contacts. Contact rates varied with time (occasion) in all models because PIT scanning effort varied from month to month, and contact rates were higher during peak spawning months (January through March) compared to other sampling months. Different migration parameterizations were modeled to represent three potential temporary emigration patterns: no temporary emigration (γ'' and γ' fixed at 0), random emigration (γ'' equals γ' for each between session period), and Markovian emigration (γ'' and γ' independent and time varying) (see Kendall et al. [1997] for further explanation). The global model included time varying contact rates (p and c), no mortality (S fixed at one), and time varying migration rates (γ'' and γ'). Model parameterizations with one or both migration rates as constants also were assessed. In all models with time varying migration, the last parameter values of both migration rates (γ'' and γ') were constrained to equal values from the penultimate period to eliminate confounding of parameters (Kendall et al. 1997).

Models were ranked within MARK based on an Akaike's information criterion (AIC) score (Akaike 1974). This value reported in MARK is a modified value (AICc) that adjusts for small sample sizes (Burnham and Anderson 2002). AICc was adjusted for overdispersion with the Fletcher estimate of $\hat{c}$ (Fletcher 2012). Reported parameter values were based on the highest ranked model (lowest AICc

Table 1.—Complete list of robust model parameterizations used in MARK (S = survival, p = capture, c = recapture, γ" = probability fish emigrates from study area, and γ' = probability fish remains out of study area after emigrating. Characters within parentheses indicate variation within the parameter group: t = time varying, c = constant, 0 = all values set to 0, and 1 = all values set to 1).

Survival	Encounter rates	Emigration rates	Description
S(1)	p(t) = c(t)	γ"(0), γ'(0)	No temporary emigration (null model)
S(1)	p(t) = c(t)	γ"(t) = γ'(t)	Time varying migration, random
S(1)	p(t) = c(t)	γ"(c) = γ'(c)	Constant migration, random
S(1)	p(t) = c(t)	γ"(t), γ'(t)	gGobal model, Markovian
S(1)	p(t) = c(t)	γ"(c), γ'(t)	γ" constant, Markovian
S(1)	p(t) = c(t)	γ"(t), γ'(c)	γ' constant, Markovian
S(1)	p(t) = c(t)	γ"(c), γ'(c)	Migration constant, Markovian

or quasi-likelihood [QAICc]) when QAICc weight for the top model was > 0.9 (Johnson and Omland 2004). Otherwise estimates were based on model averaging.

Stocking Displacement

Stocking displacement was examined to determine the distance traveled from stocking locations and to identify movement between zones. The analysis included individuals stocked from October 1, 2008, through September 30, 2012, that were implanted with a 134.2-kHz PIT tag. The beginning of this interval marks the year when all razorback suckers being repatriated into Lake Mohave contained a 134.2-kHz PIT tag. Individuals with < 10 contacts were removed from analyses because fish with few contacts do not provide a reliable measure of displacement. FY13 was removed from analyses due to a limited number of contacts. Analyses were performed separately for fish stocked in each zone (i.e., River, Liberty, Basin, and Katherine) by pooling data across all stocking locations within each zone (figure 3). Stocking displacement was calculated by measuring the distance traveled in reservoir kilometers (rkm; from the locality of contact to Davis Dam [i.e., river mouth]) for every individual. A combination of QGIS version 2.18.16 (QGIS Development Team 2017) and R version 3.4.3 (R Development Core Team 2017) was used to calculate displacement. First, polyline data were obtained from the National Hydrography Dataset Plus, which represented the river network and allowed calculating distance as the path along the watercourse instead of a straight-line distance (i.e., Euclidean). Next, the river was clipped to the extent of the study area, and a dissolve was performed to expedite calculations in R. The "mouthdistbysurvey" function in the "riverdist" package was used to calculate the distance between subsequent dates of contact

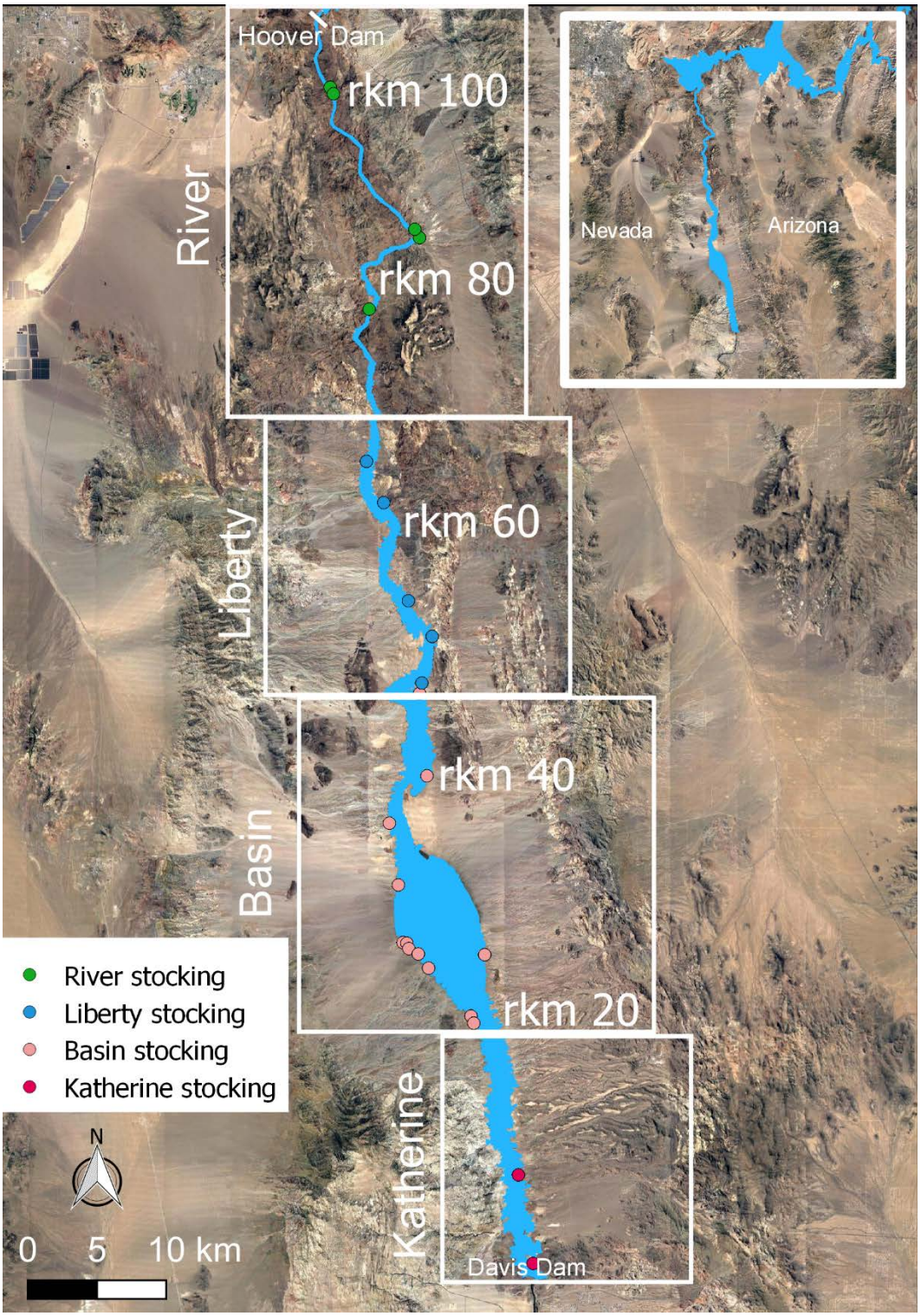

Figure 3.—Stocking locations of razorback suckers from October 1, 2008, to September 30, 2012, in the River, Liberty, Basin, and Katherine zones of Lake Mohave, Arizona and Nevada.

for every individual (Tyers 2017). By default, the "mouthdistbysurvey" function only allowed distance computation when an individual moved between two different locations (i.e., unique coordinates). Stocking displacement was visualized by plotting the distance contacted from Davis Dam across all individuals for each year with violin plots. Violin plots are similar to box plots but incorporate a rotated kernel density plot on each side to illustrate the abundance of contacts, thus providing a spatially explicit illustration.

RESULTS

Routine Monitoring

Twenty-one razorback suckers were handled at two different M&A monitoring events during FY18: eight during November 28–29, 2017, with assistance from the Arizona Fish and Wildlife Conservation Office, and 13 during March 12–16, 2018, monitoring activities (table 2). No PIT tag was detected in 3 of the 21 captures; their stocking history was unknown. The remaining 18 fish were PIT-tagged repatriates with original stocking data in the database. No rearing information was available for 1 of the 18 repatriates, and that fish was omitted from further analysis. Sex was determined at both events, and captures included 17 females and 4 males.

Table 2.—Adult razorback sucker monitoring summary by capture month, PIT tag, history, and sex during the FY18 monitoring events, Lake Mohave, Arizona and Nevada
(n = number of fish.)

Capture date	n	PIT tag?		History			Sex		
		Yes	No	Repatriate	Wild	Unknown	Female	Male	Unknown
November 28–29, 2017	8	8	0	8	0	0	8	0	0
March 12–16, 2018	13	10	3	10	0	3	9	4	0
Total	**21**	**18**	**3**	**18**	**0**	**3**	**17**	**4**	**0**

Of the 17 PIT-tagged repatriate razorback suckers with stocking and rearing information, only 1 was < 350 mm TL at stocking (table 3). Mean TL at stocking was 438 mm, and mean TL at capture was 611 mm, with 14 fish ≥ 620 mm TL at capture. Fish at large for more than 1 year exhibited similar growth rates, which ranged from 1 to 3 mm per month at large. One fish, at large for 10 months, grew at a rate of 9 mm per month while another fish at large for only 3 months appeared to have "lost" length for a rate of -15 mm per month at large (the latter likely representing TL measurement error). The mean growth rate was approximately 2 mm per month at large (including all fish). Years at large for all fish ranged from < 1 to 22 with mean time at large of 8 years. Fourteen fish were

Table 3.—Adult razorback sucker monitoring summary for nine paired stocking-capture data for each fish

PIT tag	Date		Capture history			TL (mm)		Growth rate (mm/months at large)
	Stocking	Capture	Sex[1]	Days at large	Number of captures	Stocking	Capture	
1B796EE3DB[a]	5/22/2013	11/28/2017	F	1,651	1	492	643	3
1C2D6C6741[b]	11/4/2011	11/28/2017	F	2,216	1	435	634	3
1C2D25D516[c]	10/23/2009	11/28/2017	F	2,958	1	470	624	2
5335245B2C[d]	6/18/2004	11/28/2017	F	4,911	1	355	624	2
1B796EEC75[e]	10/21/2013	11/29/2017	F	1,500	1	492	620	3
1C2D06BA6D[f]	5/11/2011	11/29/2017	F	2,394	1	405	628	3
1C2D6188C7[g]	12/3/2009	11/29/2017	F	2,918	1	435	634	2
003C06CAA5[h]	12/15/2017	3/12/2018	M	87	1	445	401	-15
36F2B263D5[b]	10/23/2012	3/14/2018	M	1,968	1	500	548	1
1C2D642F9E[i]	12/17/2009	3/14/2018	F	3,009	1	430	635	2
2037246223[b]	11/20/1995	3/14/2018	F	8,150	1	345	660	1
1C2D61A3F9[c]	10/23/2009	3/15/2018	F	3,065	1	455	627	2
1C2D635C66[i]	1/6/2010	3/15/2018	F	2,990	1	390	655	3
003BEA19E8[j]	5/2/2017	3/15/2018	M	317	1	434	525	9
1C2D26933A[c]	10/23/2009	3/15/2018	F	3,065	2	425	650	2
1C2D698C52[g]	12/3/2009	3/16/2018	F	3,025	2	425	640	2
1B796ED720[k]	10/31/2013	11/28/2017	F	1,489	5	510	643	3
			Average	2,689	–	438	611	2

[1] F = female, and M = male.
[a] 2009 year class; reared at the Arizona Juvenile lakeside backwater.
[b] No year class; reared at the Yuma Cove lakeside backwater.
[c] 2005 year class; reared at the Bubbling Ponds Fish Hatchery.
[d] No year class; reared at the Willow Beach NFH.
[e] 2009 year class; reared at the Dandy Cove lakeside backwater.
[f] 2007 year class; reared at the Willow Backwater, lakeside.
[g] 2008 year class; reared at the Achii Hanyo Native Fish Rearing Facility.
[h] 2015 year class; reared at the Lake Mead Fish Hatchery.
[i] 2006 year class; reared at the Willow Beach NFH.
[j] 2014 year class; reared at the Dandy Cove lakeside backwater.
[k] 2009 year class; reared at the North Chemehuevi Cove lakeside backwater.

captured during FY18 monitoring for the first time since their stocking into Lake Mohave, with one fish at large for 22 years prior to its first capture. Thirteen fish had year-class information, and these ranged from 1 to 4 years old at stocking.

Lakeside backwaters and offsite facilities contributed eight and nine fish to the PIT-tagged repatriates with paired data, respectively (table 4). Of the lakeside backwaters, Arizona Juvenile, Dandy Cove, North Chemehuevi Cove, Willow Backwater, and Yuma Cove were all represented, and all fish from these sites were stocked into the main channel adjacent to their rearing locations. Offsite rearing facilities included the Achii Hanyo Native Fish Rearing Facility, Bubbling Ponds Fish Hatchery, Lake Mead Fish Hatchery, and the Willow Beach NFH. Fish reared in lakeside backwaters traveled a mean distance of 7 kilometers (km) from stocking to capture site (5–11 km minimum-maximum), while the fish reared in offsite facilities traveled a mean distance of 25 km (2–54 km minimum-maximum). Notably, the three fish that traveled the greatest distances were hatchery reared, released into the River zone at Willow Beach, and contacted in the Basin zone (table 4).

Remote Monitoring

Remote PIT scanners were deployed in Lake Mohave for a total scan time of 37,903 hours; figures 3 and 4): 12,414 hours using shore-based devices and 25,489 hours with submersible units. The FY18 scanning year resulted in 131,131 total contacts, 3,835 of which were unique PIT tags, with 3,652 of those having a marking history in the Lower Colorado River Native Fish Database (i.e., have a marking record). Among fish with a marking record, 3,615 were repatriates, 9 were wild, and 28 were of unknown origin.

Remote PIT scanning in the River zone resulted in a total scan time of 9,280 hours, all with submersible units. The mean deployment time for submersible units was 39 hours. Among 33,781 contacts, 2,118 were unique PIT tags, and 2,032 of those were in the Lower Colorado River Native Fish Database. This excludes fish that are in the database, but do not have a proper marking record, and fish that were marked and released in a backwater but do not have a record of release into the reservoir. Repatriated razorback suckers accounted for 2,019 tags with a marking record, 7 were noted as wild individuals, and 6 had unknown histories.

Contacts at fixed sites in the River zone were compared during the entire duration of scanning from January 2013 to August 2018. The spawning period was evident, as most contacts were recorded at Black Bar from November through April, becoming fewer in subsequent months and scattered at different locations (figure 5). The next largest spawning aggregation site was at Boy Scout Cove. After the spawning season, razorback suckers appeared to shift upstream of or downstream from Black Bar, with fewer contacts.

Table 4.—Adult razorback sucker monitoring summary, March 2018
(Data are paired stocking-capture data by rearing type and location, and stocking and capture locations. Data are in alphabetical order of rearing type and location. n = number of fish.)

Rearing		Stocking			Capture			Distance traveled (change in rkm)	n
Type	Location	Location	rkm	Zone	Location	rkm	Zone		
Lakeside backwater	Arizona Juvenile	Arizona Cove	24	Basin	Cottonwood Cove East	32	Basin	8	1
Lakeside backwater	Dandy Cove	Dandy Cove	27	Basin	Cottonwood Cove East	32	Basin	5	1
Lakeside backwater	Dandy Cove	Dandy Cove	27	Basin	Waterwheel Cove	32	Basin	5	1
Lakeside backwater	North Chemehuevi	North Chemehuevi Cove	21	Basin	Cottonwood Cove East	32	Basin	11	1
Lakeside backwater	Willow backwater	Willow Cove	27	Basin	Carp Cove	34	Basin	6	1
Lakeside backwater	Yuma Cove	Yuma Cove	39	Basin	Cottonwood Cove East	32	Basin	7	1
Lakeside backwater	Yuma Cove	Yuma Cove	39	Basin	Waterwheel Cove	32	Basin	7	2
Offsite facility	Achii Hanyo Native Fish Rearing Facility	Cottonwood Cove	36	Basin	Carp Cove	34	Basin	2	1
Offsite facility	Achii Hanyo Native Fish Rearing Facility	Cottonwood Cove	36	Basin	Cottonwood Cove East	32	Basin	4	1
Offsite facility	Bubbling Ponds Fish Hatchery	Willow Beach boat ramp	87	River	Carp Cove	34	Basin	53	1
Offsite facility	Bubbling Ponds Fish Hatchery	Willow Beach boat ramp	87	River	Cottonwood Cove East	32	Basin	54	1
Offsite facility	Bubbling Ponds Fish Hatchery	Willow Beach boat ramp	87	River	Waterwheel Cove	32	Basin	54	1
Offsite facility	Lake Mead Fish Hatchery	Half-way Wash	30	Basin	Carp Cove	34	Basin	3	1
Offsite facility	Willow Beach NFH	North Nine Mile Coves	28	Basin	Carp Cove	34	Basin	6	1
Offsite facility	Willow Beach NFH	Liberty Cove	63	Basin	Waterwheel Cove	32	Basin	31	1
Offsite facility	Willow Beach NFH	Wrong Cove	52	Basin	Cottonwood Cove East	34	Basin	18	1
							Average distance traveled	25	-

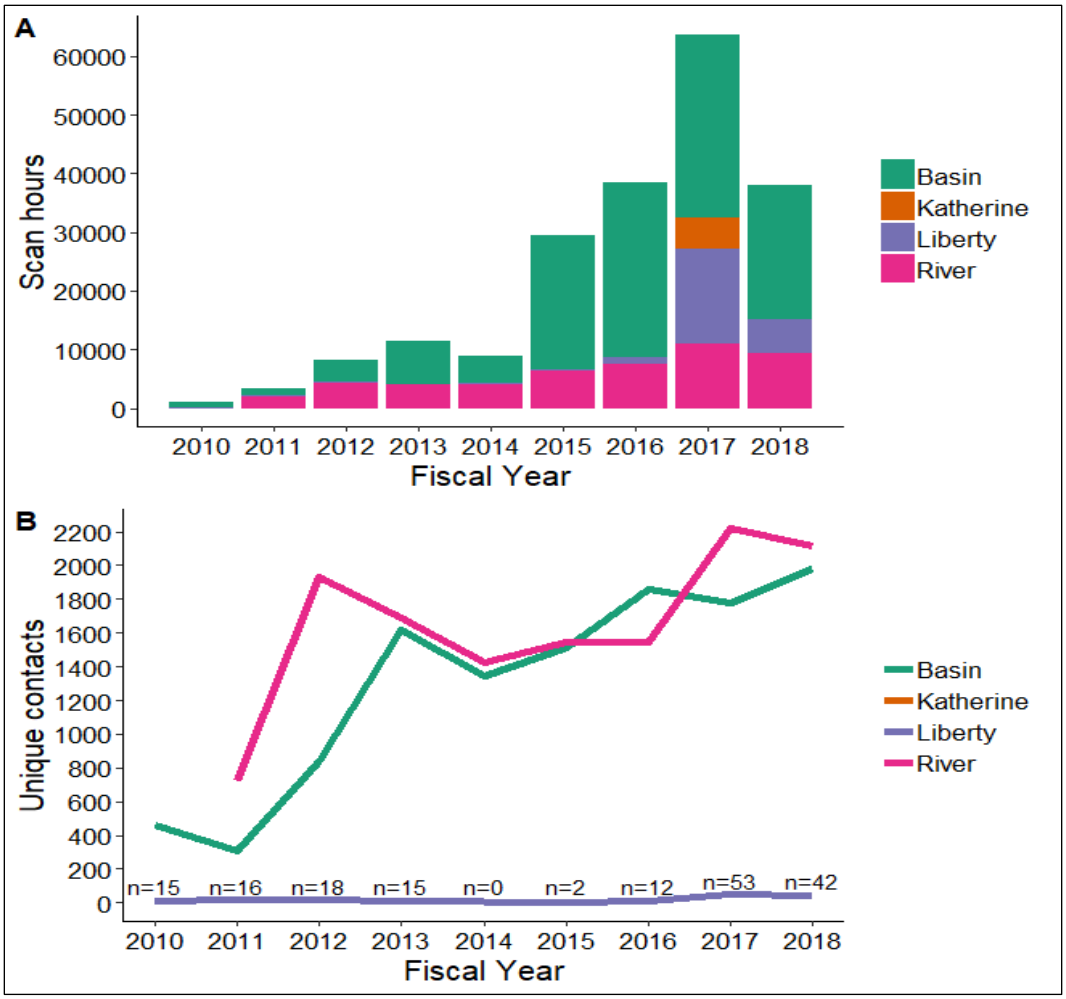

Figure 4.—Relationship between total scan-hours for submersible and shore-based PIT scanners for each zone (A) and total number of unique contacts (B) from FY10 to FY18 in Lake Mohave, Arizona and Nevada.
N = the number of unique contacts in the Liberty zone; the Katherine zone is overlapping with the Liberty zone in 2017; and the total number of unique contacts (n = 59) is not visible.

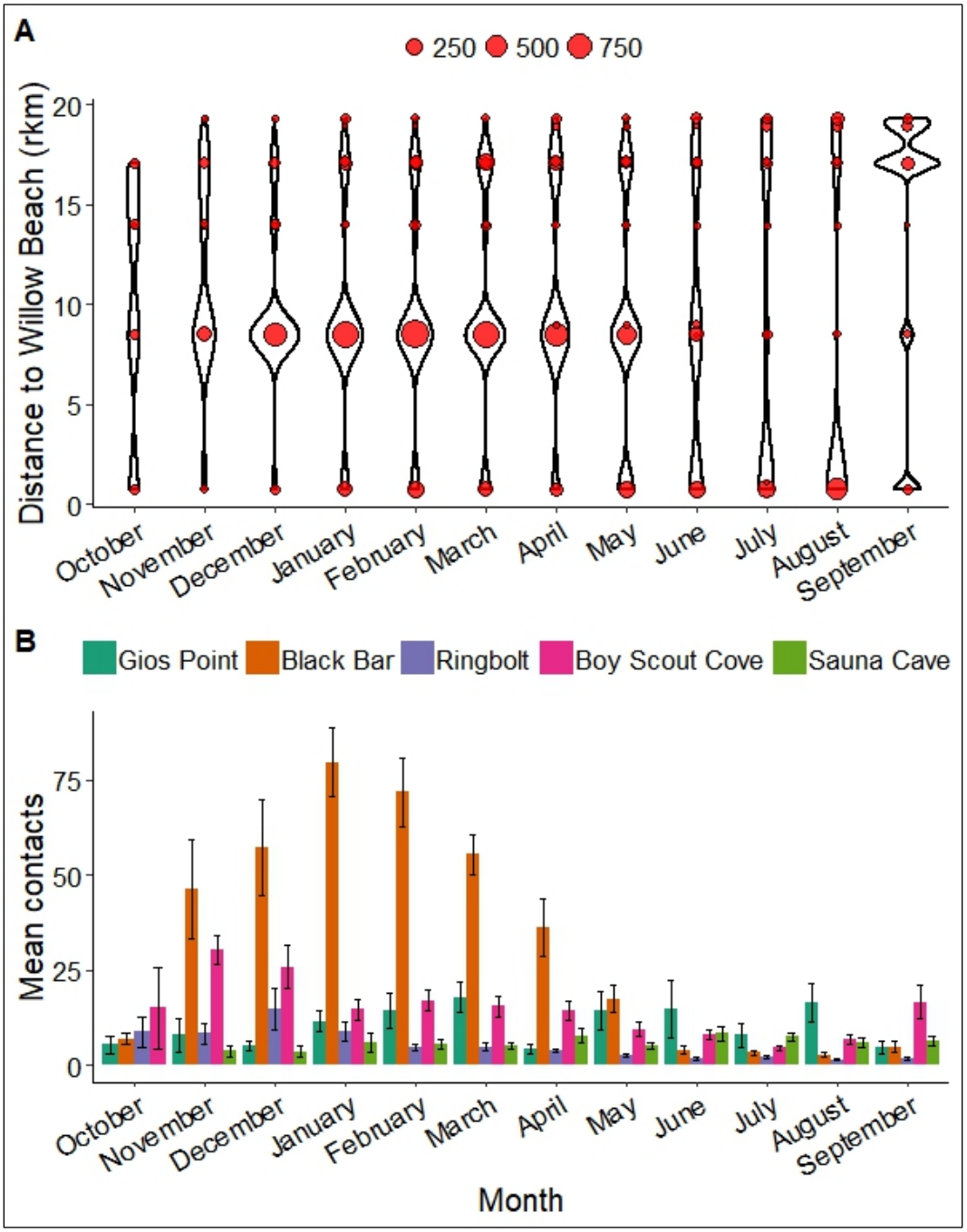

Figure 5.—Spatial distribution of contacts (red circles; A) and mean unique razorback sucker PIT tag contacts (B) recorded from January 2013 to August 2018 at five fixed stations in the River zone, Lake Mohave, Arizona and Nevada.
Error bars represent ±1 standard error.

Remote submersible scanners in the Liberty zone were deployed for a total scan time of 5,885 hours. The mean deployment time for submersible scanners was 40 hours. Seventy-six PIT tag contacts were recorded, representing 42 unique razorback suckers, of which 26 tags had a marking history. All tags with a marking history were repatriates.

Both shore-based and submersible units were deployed in the Basin zone and accumulated 22,737 total hours of scanning: 12,414 hours with shore-based and 10,323 hours with submersible units. The mean deployment times for shore-based and submersible units were 222 and 129 hours, respectively. A total of 97,274 contacts were recorded representing 1,976 unique PIT tags for which 1,879 had a marking record in the Lower Colorado River Native Fish Database. Repatriated razorback suckers accounted for 1,851 of the unique encounters, 3 were wild, and 25 were of unknown origin.

Population Estimates

Based on routine monitoring data from March 2017 and 2018, there is no effective wild razorback sucker population remaining in Lake Mohave. Based on March 2017 and 2018 capture data, the repatriated razorback sucker population estimate in 2017 was 841 (95% CI from 694 to 4,487), representing only a very small fraction of the total number of repatriates released into Lake Mohave since stocking began.

Based on 2017 and 2018 remote PIT scanning, the 134.2-kHz PIT-tagged Lake Mohave repatriate population for 2017 was estimated at 3,471 individuals (figure 6; 95% CI from 3,365 to 3,576). Population estimates using zone-specific scanning for 2017 estimated the Basin zone population at 1,872 (figure 6; 95% CI from 1,804 to 1,940) and the River zone at 2,093 (figure 6; 95% CI from 1,966 to 2,220). Too few wild fish were contacted to estimate the Basin and River zone subpopulations separately (six and three contacts, respectively). The lake-wide estimate of the wild population based on PIT scanning in 2017 and 2018 was 9 fish (M = 4, C = 8, R = 4, 95% CI from 4 to 23).

Survival – Robust Model

The robust model with 95.7% of weighted AIC was the global model (table 5). The no emigration model and all random emigration models had model likelihoods of < 0.001. The Fletcher $\hat{c}$ estimate was 1.000, indicating no overdispersion in the global model. Estimates of contact rates ranged from a low of 0.028 in May of 2017 to 0.409 in February 2015 (table 6). All years had at least one occasion with contact rates above 0.250, with the highest value for a given SY in January or February. An estimated 8.1% of the known population

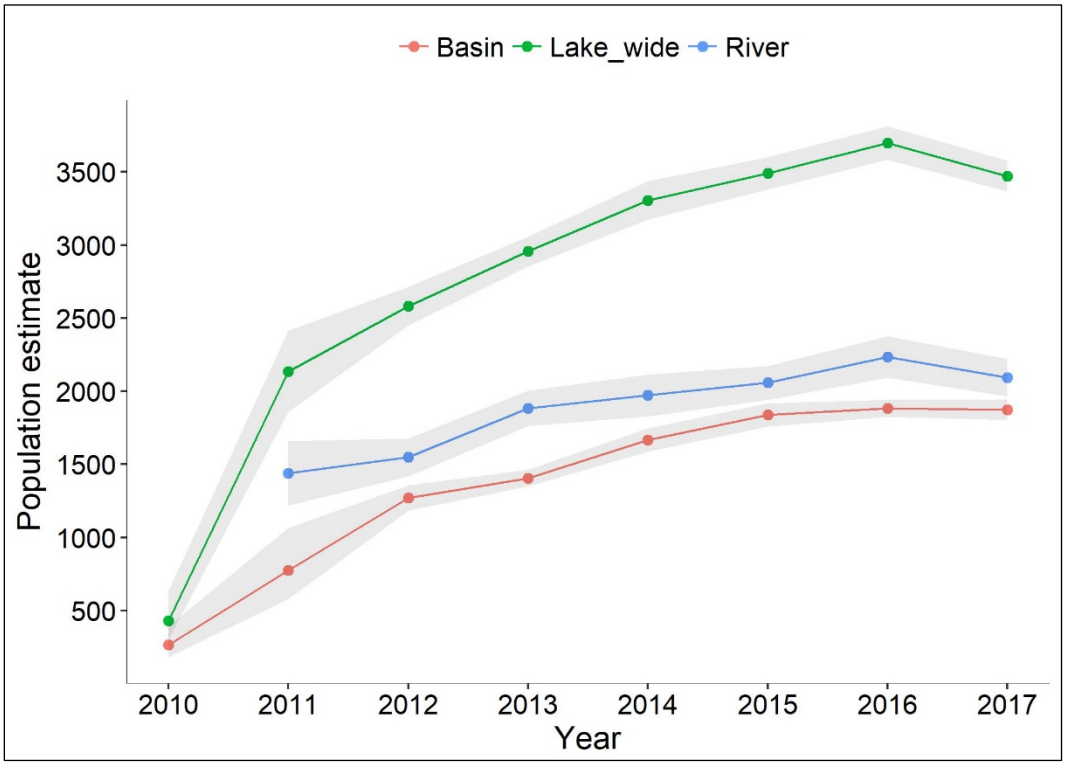

Figure 6.—Repatriate razorback sucker population estimates derived from PIT scanning data from 2010 to 2017 in Lake Mohave, Arizona and Nevada.
The lower and upper 95% CIs are represented by the shaded area.

Table 5.—Comparison of robust model results in MARK for Lake Mohave razorback sucker remote PIT scanner contacts between 2012 and 2017

Model	AICc	AICc weights	Model likelihood	Number of parameters	Deviance
S(1), γ”(t), γ’(t), pc(t)	24010.82	0.957	1.000	38	51165.67
S(1), γ”(t), γ’(c), pc(t)	24017.97	0.027	0.028	36	51176.88
S(1), γ”(c), γ’(t), pc(t)	24019.00	0.016	0.017	35	51179.93
S(1), γ”(c), γ’(c), pc(t)	24029.55	0.000	0.000	33	51194.54
S(1), γ”(t)=γ’(t), pc(t)	24072.73	0.000	0.000	35	51233.66
S(1), γ”(c)=γ’(c), pc(t)	24085.34	0.000	0.000	32	51252.36
S(1), γ”(0), γ’(0), pc(t)	24085.98	0.000	0.000	31	51255.02

that was available for PIT scanning in SY 2014 emigrated between SY 2014 and SY 2015 (table 7), and estimates of temporary emigration were > zero for three of four estimated parameters (the last two estimates were constrained to be equal). Initial estimates of razorback suckers returning to the population (1-γ') were zero when few fish had emigrated (table 7) but peaked at 54.9% of emigrants for the last estimable period (2015 to 2016 and 2016 to 2017 combined).

Table 6.—Monthly remote PIT scanner contact rate estimates for razorback suckers in Lake Mohave based on the "best fit" robust mark-recapture model

(Contacts are the number of unique PIT tags recorded by all remote PIT scanners deployed in Lake Mohave between “Trip start” and “Trip end.”)

SY	Occasion	Trip start	Trip end	Contacts	Contact rate (95% CI)
2012	1	1/24/2012	1/27/2012	163	0.165 (0.139 – 0.195)
2012	2	2/21/2012	2/24/2012	258	0.262 (0.226 – 0.3)
2012	3	3/12/2012	3/15/2012	101	0.102 (0.083 – 0.126)
2012	4	4/10/2012	4/13/2012	178	0.18 (0.153 – 0.212)
2012	5	5/7/2012	5/10/2012	88	0.089 (0.071 – 0.111)
2013	6	1/29/2013	2/1/2013	342	0.369 (0.335 – 0.404)
2013	7	2/25/2013	2/28/2013	263	0.284 (0.253 – 0.316)
2013	8	3/11/2013	3/14/2013	232	0.25 (0.222 – 0.281)
2013	9	4/9/2013	4/12/2013	100	0.108 (0.089 – 0.13)
2013	10	5/20/2013	5/23/2013	52	0.056 (0.043 – 0.073)
2014	11	1/21/2014	1/24/2014	219	0.252 (0.221 – 0.287)
2014	12	2/18/2014	2/21/2014	223	0.257 (0.225 – 0.292)
2014	13	3/10/2014	3/13/2014	183	0.211 (0.182 – 0.243)
2014	14	5/5/2014	5/8/2014	49	0.056 (0.043 – 0.074)
2015	15	1/20/2015	1/23/2015	147	0.173 (0.147 – 0.202)
2015	16	2/16/2015	2/20/2015	347	0.409 (0.368 – 0.451)
2015	17	3/2/2015	3/6/2015	208	0.245 (0.214 – 0.279)
2015	18	4/6/2015	4/10/2015	65	0.077 (0.06 – 0.097)
2015	19	5/4/2015	5/8/2015	39	0.046 (0.034 – 0.063)
2016	20	12/7/2015	12/11/2015	147	0.151 (0.129 – 0.175)
2016	21	1/19/2016	1/22/2016	279	0.286 (0.258 – 0.316)
2016	22	2/15/2016	2/19/2016	376	0.385 (0.354 – 0.417)
2016	23	3/21/2016	3/25/2016	152	0.156 (0.134 – 0.18)
2016	24	4/25/2016	4/29/2016	45	0.046 (0.035 – 0.061)
2016	25	5/9/2016	5/13/2016	30	0.031 (0.022 – 0.044)
2017	26	12/9/2016	12/13/2016	184	0.177 (0.155 – 0.202)
2017	27	1/9/2017	1/13/2017	242	0.233 (0.208 – 0.26)
2017	28	2/6/2017	2/10/2017	327	0.315 (0.287 – 0.344)
2017	29	3/6/2017	3/10/2017	231	0.222 (0.198 – 0.249)
2017	30	4/17/2017	4/21/2017	51	0.049 (0.038 – 0.064)
2017	31	5/15/2017	5/19/2017	29	0.028 (0.019 – 0.04)

Table 7.—Estimates of temporary emigration (γ") and probability of returning after temporary emigration (1-γ') based on the "best fit" mark-recapture robust model (95% CIs are in parentheses.)

Interval	γ"	1-γ'
2012 to 2013	0.061 (0.031 – 0.115)	NA
2013 to 2014	0.070 (0.033 – 0.142)	0.000 (0.000 – 0.000)
2014 to 2015	0.081 (0.037 – 0.170)	0.053 (0.000 – 0.998)
2015 to 2016	0.000 (0.000 – 0.000)	0.549 (0.413 – 0.679)
2016 to 2017[a]	0.000 (0.000 – 0.000)	0.549 (0.413 – 0.679)

[a] Estimate constrained to equal estimate from previous interval to avoid confounding parameters.

Stocking Displacement

A total of 37,591 hatchery-reared razorback suckers were stocked into Lake Mohave from October 2008 to September 2012. A total of 64,001 contacts were recorded from 2014 to 2018, of which 2,890 were unique. After removal of individuals with < 10 contacts, 1,889 unique fish were included in analyses with a total of 59,064 contacts. Of the 1,889 unique fish contacted, 1,423 (75.3%) were contacted in 1 zone, 447 (23.6%) were contacted in 2 zones, 19 (1.0%) were contacted in 3 zones, and 0 were contacted in four zones.

In the River zone, there were 5 stocking locations with 16,820 fish released from 2009 to 2012 (see figure 3). A total of 25,031 contacts were recorded from fish released into the River zone, of which 1,079 were unique. Of the 25,031 contacts, 18,804 (1,022 unique) were in the River zone, 32 (30 unique) were in the Liberty zone, 6,193 (349 unique) were in the Basin zone, and 2 unique contacts were in the Katherine zone (figure 7). A more detailed summary of contact histories for unique razorback suckers stocked into the River zone is provided in table 8.

Table 8.—Summary of contact histories for unique razorback suckers stocked into the River zone from 2008 to 2012 in Lake Mohave, Arizona and Nevada (Combination refers to each scenario for contact histories, and contacts are denoted [X] for each zone and summarized by number [n] and percent.)

Combination	River	Liberty	Basin	Katherine	n	Percent
1	–	–	X	–	56	5.2
2	–	X	X	–	1	0.1
3	X	–	-	–	712	66.0
4	X	–	X	–	279	25.9
5	X	–	X	X	2	0.2
6	X	X	–	–	18	1.7
7	X	X	X	–	11	1.0
				Total	**1,079**	**100**

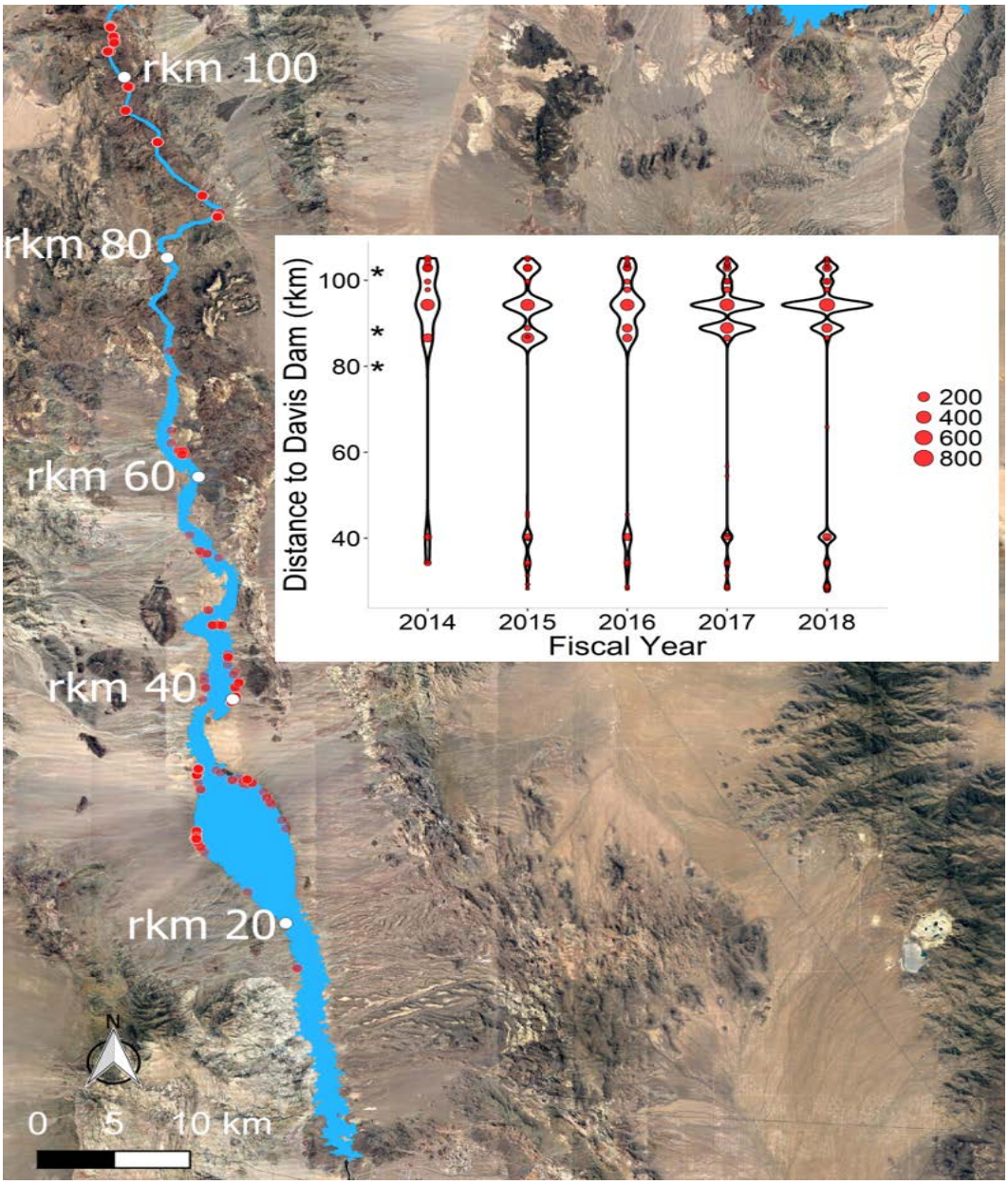

Figure 7.—Relationship between number of contacts (red circles) and distance to Davis Dam (rkm) for razorback suckers stocked into the River zone from 2008 to 2012, Lake Mohave, Arizona and Nevada.
Asterisks along the y-axis represent stocking locations.

In the Liberty zone, there were 5 stocking locations with 8,667 fish released from 2008 to 2012 (see figure 2). A total of 3,748 contacts were recorded from fish released into the Liberty zone, of which 113 were unique. Of the 3,748 contacts, 792 (62 unique) were only in the River zone, 7 (3 unique) were in the Liberty zone, 2,949 (82 unique) were in the Basin zone, and none were contacted in the Katherine zone. A more detailed summary of contact histories for unique razorback suckers stocked into the Liberty zone is provided in table 9. Stocking displacement showed consistent patterns across years, with fish dispersing away from stocking localities either upstream or downstream (figure 8).

Table 9.—Summary of contact histories for unique razorback suckers stocked into the Liberty zone from 2008 to 2012 in Lake Mohave, Arizona and Nevada
(Combination refers to each scenario for contact histories, and contacts are denoted [X] for each zone and summarized by number [n] and percent.)

Combination	River	Liberty	Basin	Katherine	n	Percent
1	–	–	X	–	50	44.2
2	–	X	-	–	1	0.9
3	X	–	-	–	29	25.7
4	X	–	X	–	31	27.4
5	X	X	–	–	2	1.8
				Total	**113**	**100**

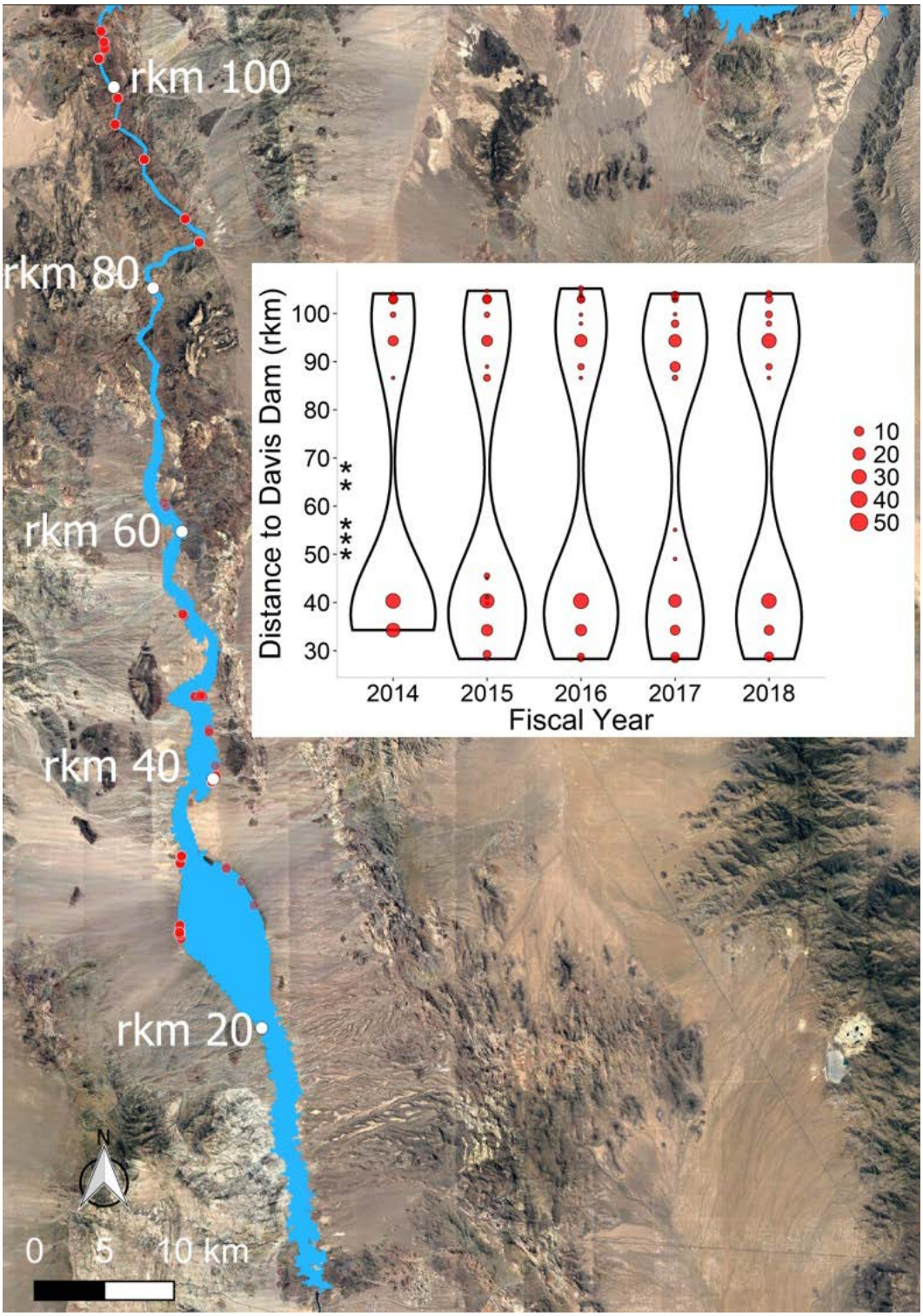

Figure 8.—Relationship between number of contacts (red circles) and distance to Davis Dam (rkm) for razorback suckers stocked into the Liberty zone from 2008 to 2012, Lake Mohave, Arizona and Nevada.
Asterisks along the y-axis represent stocking locations.

In the Basin zone, there were 12 stocking locations with 10,261 fish released from 2008 to 2012 (see figure 2). A total of 29,463 contacts were recorded from fish released into the Basin zone, of which 680 were unique. Of the 29,463 contacts, 1,340 (132 unique) were in the River zone, 8 (7 unique) were in the Liberty zone, 28,480 (655 unique) were in the Basin zone, and 18 (10 unique) were in the Katherine zone. A more detailed summary of contact histories for unique razorback suckers stocked into the Basin zone is provided in table 10. Stocking displacement indicated most fish stayed within the Basin zone and was consistent across years, while a small portion of fish dispersed into the River, Liberty, and Katherine zones (figure 9).

Table 10.—Summary of contact histories for unique razorback suckers stocked into the Basin zone from 2008 to 2012 in Lake Mohave, Arizona and Nevada

(Combination refers to each scenario for contact histories, and contacts are denoted [X] for each zone and summarized by number [n] and percent.)

Combination	River	Liberty	Basin	Katherine	n	Percent
1	–	–	X	–	537	79.0
2	–	–	X	X	8	1.2
3	–	X	X	–	3	0.4
4	X	–	–	–	25	3.7
5	X	–	X	–	101	14.9
6	X	–	X	X	2	0.3
7	X	X	X	–	4	0.6
				Total	**680**	**100**

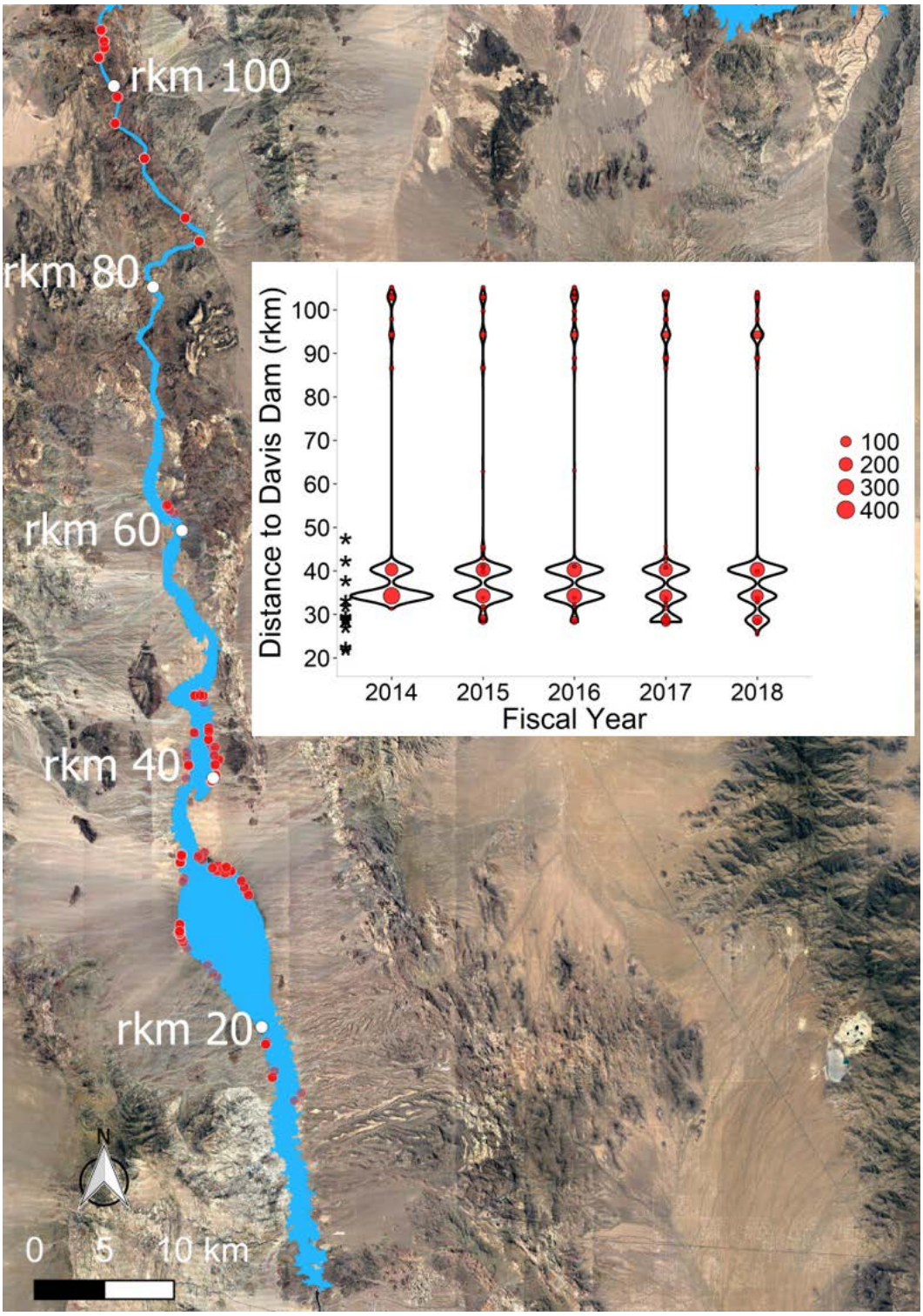

Figure 9.—Relationship between number of contacts (red circles) and distance to Davis Dam (rkm) for razorback suckers stocked into the Basin zone from 2008 to 2012, Lake Mohave, Arizona and Nevada.
Asterisks along the y-axis represent stocking locations.

In the Katherine zone, there were 2 stocking locations with 1,843 fish released from 2009 to 2012 (see figure 2). A total of 439 contacts were recorded from fish released into the Katherine zone, of which 17 were unique. Of the 439 contacts, 40 (4 unique) were in the River zone, 0 were in the Liberty zone, 397 (15 unique) were in the Basin zone, and 1 was in the Katherine zone. A more detailed summary of contact histories for unique razorback suckers stocked into the Katherine zone is provided in table 11. Stocking displacement showed most fish stocked into the Katherine zone were contacted in either the Basin or River zones across all years (figure 10).

Table 11.—Summary of contact histories for unique razorback suckers stocked into the Katherine zone from 2008 to 2012 in Lake Mohave, Arizona and Nevada
(Combination refers to each scenario for contact histories, and contacts are denoted [X] for each zone and summarized by number [n] and percent.)

Combination	River	Liberty	Basin	Katherine	n	Percent
1	-	-	X	-	12	70.6
2	-	-	X	X	1	5.9
3	X	-	-	-	2	11.8
4	X	-	X	-	2	11.8
				Total	**17**	**100**

The distribution of PIT scanners was greatest in FY17, with deployments in all zones (figure 11). In 2010, the technology was in its infancy, and scanning only occurred in the Basin and Liberty zones. Since then, deployment distribution expanded into the River and Liberty zones. Deployment distribution of PIT scanners in the Liberty zone was greatest in FY17 and FY18.

DISCUSSION

Long-term monitoring and research have provided invaluable information to inform management of the last remaining endemic “big river” fish in the lower Colorado River. Since routine monitoring began in 1974, the program continues to evolve as long-term data provide new information and insight on population dynamics and demographics. Development of portable remote PIT scanning units has increased the spatial extent of the study area from the Basin zone to riverine portions, where traditional methods were ineffective, allowing managers to understand large-scale patterns. Additionally, the temporal scale of PIT scanning data has allowed multi-year subpopulation estimates, assessment of factors influencing survival using mark-recapture models, and analysis of dispersal and movement patterns.

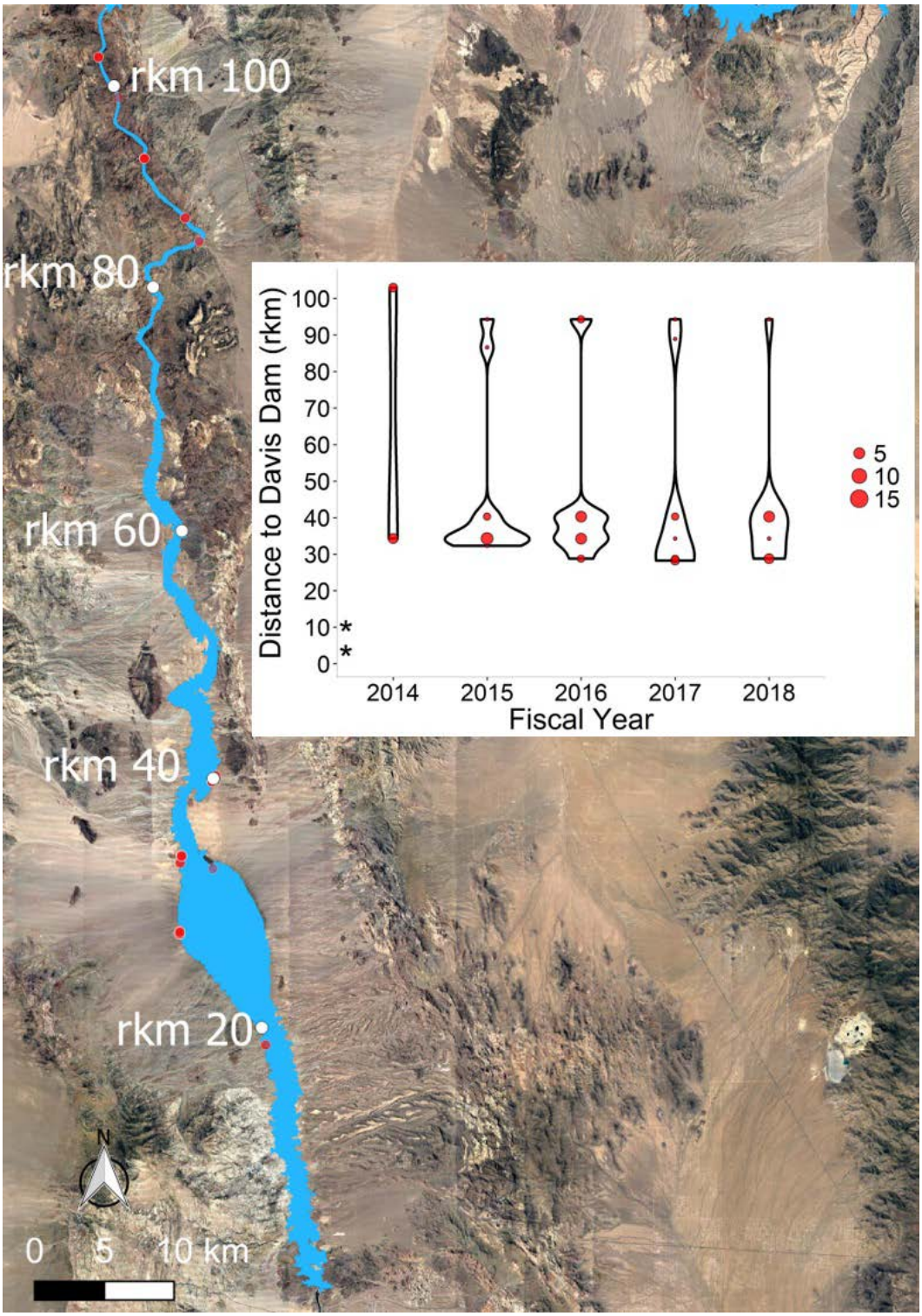

Figure 10.—Relationship between number of contacts (red circles) and distance to Davis Dam (rkm) for razorback suckers stocked into the Katherine zone from 2009 to 2012, Lake Mohave, Arizona and Nevada.
Asterisks along the y-axis represent stocking locations.

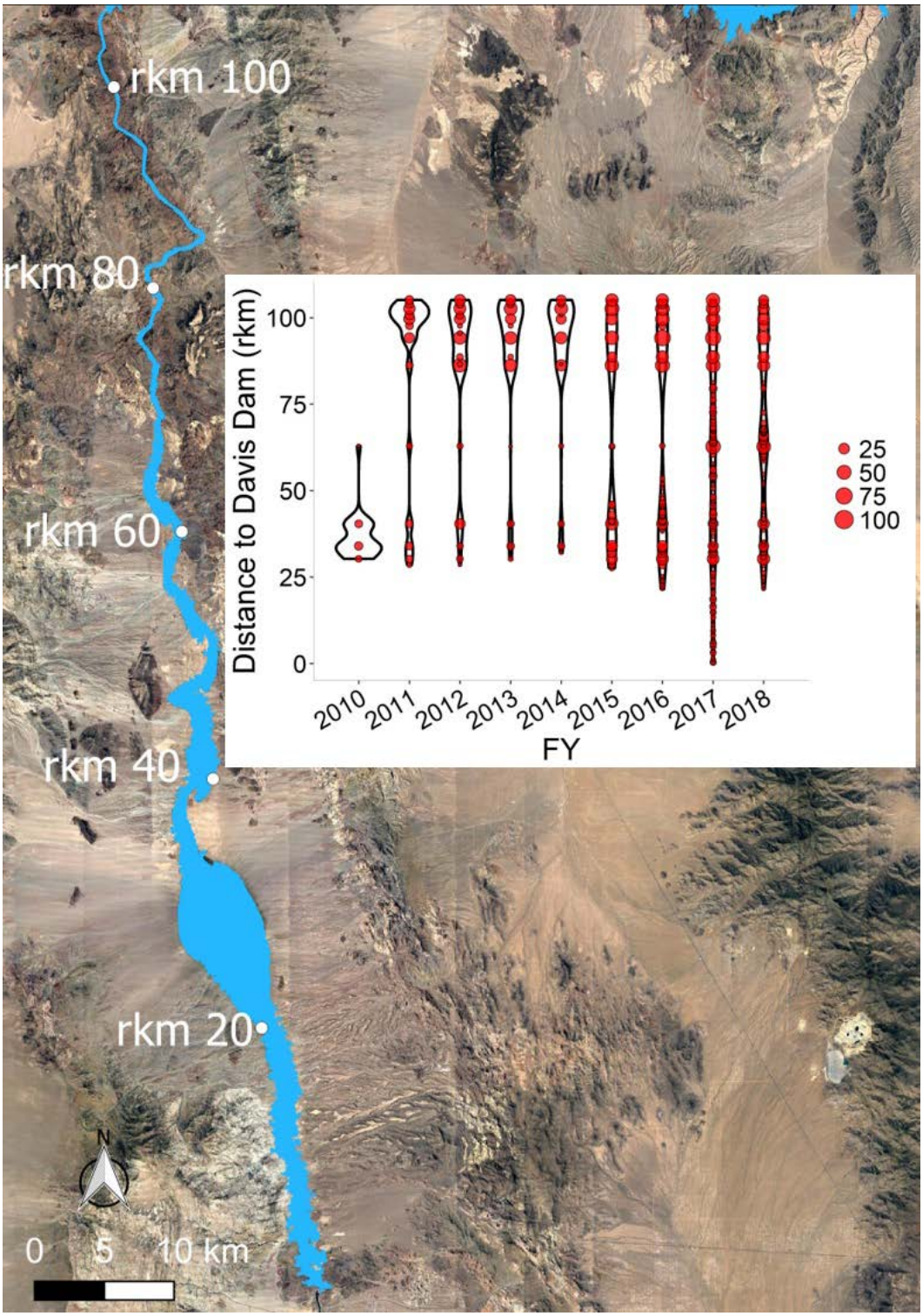

Figure 11.—Relationship between number of submersible and shore-based PIT scanners deployed (red circles) and distance to Davis Dam (rkm) from FY10 to FY18 in Lake Mohave, Arizona and Nevada.

Methods to derive population estimates were adjusted in 2018 to standardize definitions of mark and capture periods across reservoirs in the lower Colorado River, resulting in slightly different population estimates compared to previous years (see Leavitt et al. 2017; Wisenall et al. 2015, 2016). For example, subpopulation estimates derived from remote PIT scanning were significantly higher in the River zone compared to the Basin zone across all years as indicated by non-overlapping CIs (see figure 6). Previous subpopulation estimates for the same years found no significant difference. Lake-wide population estimates derived from remote PIT scanning were lowest in 2010 due to low effort and limited spatial distribution of scanner deployments (see figure 4A and figure 11) and, thus, do not provide accurate estimates. Across all spatial scales, population estimates increased through time and reached an asymptote in 2016 (see figure 5), which is congruent with previous estimates (Leavitt et al. 2017; Wisenall et al. 2016). Future monitoring will better determine whether populations can continue to grow or are inhibited by contemporary ecological constraints. The estimate derived from March monitoring data in 2017 (841 [95% CI from 694 to 4,487]) continues to reflect a population size more representative of the Basin zone estimate derived from remote PIT scanning in 2017 (1,872 [95% CI from 1,804 to 1,940] and, thus, does not appear to provide a lake-wide estimate across all years (Leavitt et al. 2017; Wisenall et al. 2016). Additionally, estimates derived from March monitoring data have low precision as indicated by broad CIs.

Long-term PIT scanning data have allowed the use of mark-recapture models for addressing different aspects of demographics and population dynamics (see Kesner et al. 2012; Leavitt et al. 2017; Wisenall et al. 2015, 2016). In 2018, a preliminary robust model was used to assess temporary emigration and to determine if contact rates could be accurately assessed from PIT scanning data within the robust model framework. Results from the robust model indicate significant levels of temporary emigration. In addition, once temporary emigration is included in estimates of available fish, there is no indication of overdispersion ($\hat{c}$ equal to one). The results strongly support the inclusion of temporary emigration in mark-recapture models based on razorback sucker remote PIT scanning data collected on Lake Mohave.

Temporary emigration rates significantly > 0 may indicate a tendency for razorback suckers to “skip spawn” (i.e., a portion of the population does not spawn every year), or it could reflect a lack of spatial coverage in sampling (i.e., there are other spawning locations that are not PIT scanned). Regardless of the mechanism, estimates of survival and population size will be accurate if this behavior is accounted for in the mark-recapture model and as long as a portion of the population does not solely visit spawning sites not accounted for in the current sampling scheme.

A major goal of this program is to enhance the population size of razorback suckers. Increasing the population size requires understanding factors that limit survival in addition to spatial processes that govern population structure

(e.g., dispersal). A multi-state mark-recapture model analyzed in 2016 and 2017 estimated about 6% of razorback suckers transitioned from the Basin to the River zone from 2015 to 2016 and about 4% transitioned from the River to the Basin zone (Leavitt et al. 2017; Wisenall et al. 2016). Therefore, results indicated minimal movement of razorback suckers between zones. In addition, analysis of cohorts stocked into different zones found fish stocked in the River and Basin zones primarily stayed within their zone of release, whereas cohorts stocked into the Liberty and Katherine zones were contacted in either the River or Basin zone. However, the reservoir distance traveled from stocking locations was unknown.

In 2018, an analysis of stocking displacement was examined to determine the distance traveled from stocking locations and to identify movement between zones to guide stocking endeavors. Stocking displacement analyses were congruent with cohort analyses (Leavitt et al. 2017; Wisenall et al. 2016) but provided a more spatially explicit illustration across years. Ultimately, the current data suggest stocking razorback suckers in the Liberty or Katherine zones contributes little to the lake-wide population because of displacement from stocking locations, and only a fraction are contacted. For example, 1 and 0.9% of fish stocked into the Liberty and Katherine zones, respectively, were contacted at least once compared to 16 and 7% in the River and Basin zones, respectively. This may not be the only reason razorback suckers are not contacted in the Liberty or Katherine zones. Increased scanning effort of these zones in 2017 and 2018 did not result in locating additional spawning aggregations. There are limited sites to deploy scanners in these zones due to depth (i.e., scanners are depth limited) and unfavorable habitat. Telemetry or trammel netting may be a more appropriate methodology to determine if these zones are used by razorback suckers. If it is determined that razorback suckers are using these zones in adequate numbers, this would argue for continuing stocking efforts and attempting to estimate subpopulation size; otherwise, stocking into the Basin and River zones are preferred.

The relationship between size at release and survival of razorback suckers has been supported by numerous lines of evidence (e.g., Marsh et al. 2005; Minckley et al. 2003; Zelasko et al. 2010). The rearing strategy at the Willow Beach NFH hatchery was modified in 2015 to increase the size at release (albeit fewer fish), with the intention of improving post-stocking survival. Unfortunately, a fish die-off at the Willow Beach NFH in 2016 has delayed this program, and stocking efforts over the next few years will rely on Lake Mead Fish Hatchery and backwater releases. Backwater-released fish are given an extra growing season and are on average longer than 400 mm TL at the time of release (Leavitt et al. 2017; Wisenall et al. 2016). These fish continue to contribute disproportionately to the Basin zone subpopulation compared to hatchery-reared fish based on their stocking numbers (Leavitt et al. 2017; Wisenall et al. 2016). Despite the catastrophic loss of repatriates at the Willow Beach NFH, razorback sucker population estimates should remain stable due to the contribution of backwater and Lake Mead Hatchery releases.

As of this writing, 224,137 razorback suckers have been repatriated into Lake Mohave (Lower Colorado River Native Fish Database), and that effort has maintained a population of a few thousand fish. This repatriation program is a primary facet of a broader conservation strategy, and it plays a critical role in maintaining Lake Mohave as the only genetic reservoir for the species throughout its range (Dowling et al. 1996a, 2005); thus, it requires continuation. While the stocking program has changed little over the past decade, additional data-based adjustments are being implemented to increase size at release (and thus survival) and maintain genetic diversity. The genetic legacy of razorback suckers embodied in the Lake Mohave population represents the "cornerstone for razorback sucker conservation" (Marsh et al. 2015) and, as such, it must be maintained until a successful backwater conservation strategy (Minckley et al. 2003; USFWS 2005) or an alternative can be realized, and long thereafter.

CONCLUSION

Population estimates derived from routine monitoring have proven to underestimate the lake-wide population size. However, the routine monitoring estimate is the only estimate available for repatriated razorback suckers that goes back to the beginning of the repatriation program, and routine monitoring continues to provide information on growth, health, fish without 134.2-kHz PIT tags, and genetics for wild and repatriate razorback suckers in Lake Mohave. There is currently no other mechanism to acquire these critical data.

Monthly remote PIT scanning in the River zone continues to be an effective method for monitoring this subpopulation of razorback suckers. In 2017, remote PIT scanning was expanded in the Liberty zone, but no additional aggregates of razorback suckers were detected after 2 years despite considerable effort and scanning distribution. To identify if razorback suckers are using this zone, other sampling methods (e.g., trammel nets, telemetry, etc.) or modified remote PIT scanning deployments (e.g., using block nets to guide fish over PIT scanners) could be used. If alternative methods confirm razorback suckers are not using this zone, efforts may be concentrated upstream in the River zone by deploying multiple units at fixed sites to maximize contacts. Deploying multiple units at fixed sites would also provide an opportunity to examine fine-scale movement patterns.

A preliminary assessment of the robust mark-recapture model supports temporary emigration of razorback suckers between sampling years. Therefore, a robust mark-recapture model may be used in the final report to reevaluate post-stocking and adult survival of razorback suckers in Lake Mohave.

Stocking razorback suckers into Lake Mohave at the largest individual size and in the greatest number possible is suggested. If there is a choice between a smaller

number of larger fish and a larger number of smaller fish, all available data indicate the former strategy will best further the goals of the program. Stocking cohorts in each zone (Basin and River) at approximately the same time (within days to a few weeks at most) and mean TL will support the goal of assessing razorback sucker metapopulation dynamics and the effect of stocking location on these dynamics. Based upon results of this study, releases of at least 500 fish per location and stocking event should result in adequate future PIT scanning contacts to support sound analyses.

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