Lower Colorado River Multi-Species Conservation Program

Balancing Resource Use and Conservation

2018 ANNUAL REPORT
Demographics and Monitoring of Repatriated Razorback Suckers in Lake Mohave

January 2019

Work conducted under LCR MSCP Work Task D8

Lower Colorado River Multi-Species Conservation Program Steering Committee Members

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National Park Service
Bureau of Land Management
Bureau of Indian Affairs
Western Area Power Administration

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Lower Colorado River Multi-Species Conservation Program

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ACRONYMS AND ABBREVIATIONS

AIC – Akaike's Information Criterion
amp-h – ampere hour
AZFWCO – Arizona Fish and Wildlife Conservation Office
CI – confidence interval
cm – centimeter(s)
FY – fiscal year
FWS – Fish and Wildlife Service
h – hour(s)
kHz – kilohertz
km – kilometer(s)
LCR – Lower Colorado River
LCR MSCP – Lower Colorado River Multi-Species Conservation Program
M&A – Marsh & Associates, LLC
m – meter(s)
M, C, R – mark, capture, recapture
mL – milliliter(s)
mm – millimeter(s)
NFH – National Fish Hatchery
PIT – passive integrated transponder
PVC – polyvinylchloride
QAICc – quasi-likelihood
Reclamation – Bureau of Reclamation
RM – river mile(s)
rkm – reservoir kilometer(s)
SY – sample year
TL – total length
UTM – Universal Transverse Mercator

Symbols

c – recapture
n – number
p – capture
% – percent
ĉ – c-hat, variance inflation factor
γ – gamma

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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 (M&A) during FY18; eight fish on November 28-29, 2017 with assistance from Arizona Fish and Wildlife Conservation Office (AZFWCO), and 13 fish during March 12-16, 2018 multi-agency monitoring activities. PIT tags were undetected in three 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 four 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 Native Fish Database (as of August 31, 2018). Among fish with a marking record, 3,615 were repatriates, nine 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). Basin and River subpopulation estimates based on zone specific scanning in 2017 and 2018 also were calculated. The Basin subpopulation was estimated at 1,872 (95% CI from 1,804 to 1,940) and River at 2,093 (95% CI from 1,966 to 2,220). The subpopulation in Liberty zone was not estimated because there were no recaptures there. Too few wild fish were contacted to estimate Basin and River subpopulations separately (six and three contacts, respectively). The lake-wide estimate of the wild population based on PIT scanning in 2017 and 2018 was nine 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 six year period (FY12 through 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 sucker returning to availability 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 distance traveled from stocking locations and to identify movement between zones. In River and Basin zones, most fish were contacted within their zone of release and this result was consistent across years. Razorback suckers stocked in Liberty zone were contacted in River or downstream in Basin and fish stocked in Katherine zone all were contacted upstream of their release locations. Results are congruent with

2016 and 2017 cohort analyses (Wisenall et al. 2016; Leavitt et al. 2017) 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) will continue to be an effective means of contacting razorback sucker aggregates. Additional scanning efforts have continued in Liberty zone to determine if other aggregations exist and to further evaluate the dynamics of razorback sucker dispersal and distribution. Bi-annual routine monitoring efforts in Basin continue to collect essential growth, health, census, and genetic data for razorback sucker. 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 sucker 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 – 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 1990's (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 sucker in Lake Mohave. Stocking razorback suckers into Lake Mohave from the Willow Beach National Fish Hatchery (NFH) (LCR MSCP 2015, 2018, Work Task B2), Achii Hanyo Native Fish Rearing Facility (LCR MSCP 2015, 2018, Work Task B3), Lake Mead Fish Hatchery (LCR MSCP 2015, 2018, Work Task B6), and from lakeside ponds (LCR MSCP 2015, 2018, Work Task B7) is conducted under the Fish Augmentation component of the program (LCR MSCP 2006, 2015). The Lake Mohave repatriation program is one element of an overall conservation plan for razorback sucker 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 [FWS] 2005), incorporate a population component that will occupy the lower Colorado River mainstem; 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 sucker have included assessing the relationship between size and survival, which has led to a recommended minimum stocking TL of 500 mm (Marsh et al. 2005, Kesner et al. 2008, Kesner et al. 2012). However, increasing individual size while maintaining sufficient stocking numbers had proven difficult (M. Olson, Willow Beach NFH, January 2009, personal communication), which led to a change in rearing strategy at Willow Beach NFH in February 2015. About 8,000 to 10,000 fish were to be held on station for five years and then released as one cohort, regardless of size (smaller fish will not be culled). The goal is to increase mean fish size, likely to greater than 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 2015, 2018, Work Task B1). Unfortunately, in November 2016, approximately 30,000 razorback suckers at 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 kHz tagged fish, and temporal dynamics of the non-native fish community.

Overall, the objective of ongoing monitoring and research for razorback sucker 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 sucker in Lake Mohave.

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

1. Locating and capturing adult razorback sucker
2. Recording biological data (e.g., sex, TL, weight), documenting the PIT tag number, and examining the general health and condition of captured razorback sucker
3. Collecting tissue samples from adult razorback sucker for genetic analysis
4. Marking of captured adult razorback sucker 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 one 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 the 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 nonfederal 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 data sets generated during this work to the designated Reclamation Contracting Officer's Technical Representative

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

12 Providing a final annual report for each completed contract year

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

This report summarizes the fourth year of data collected under the current five-year contract as part of ongoing demographic and post-stocking survival studies of repatriated razorback sucker 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 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 fiscal year 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 five days on Lake Mohave at Carp Cove, Arizona (Basin zone), near River Mile (RM) 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 [cm] stretch mesh) were fished continuously along the Arizona shoreline from Cottonwood 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 .

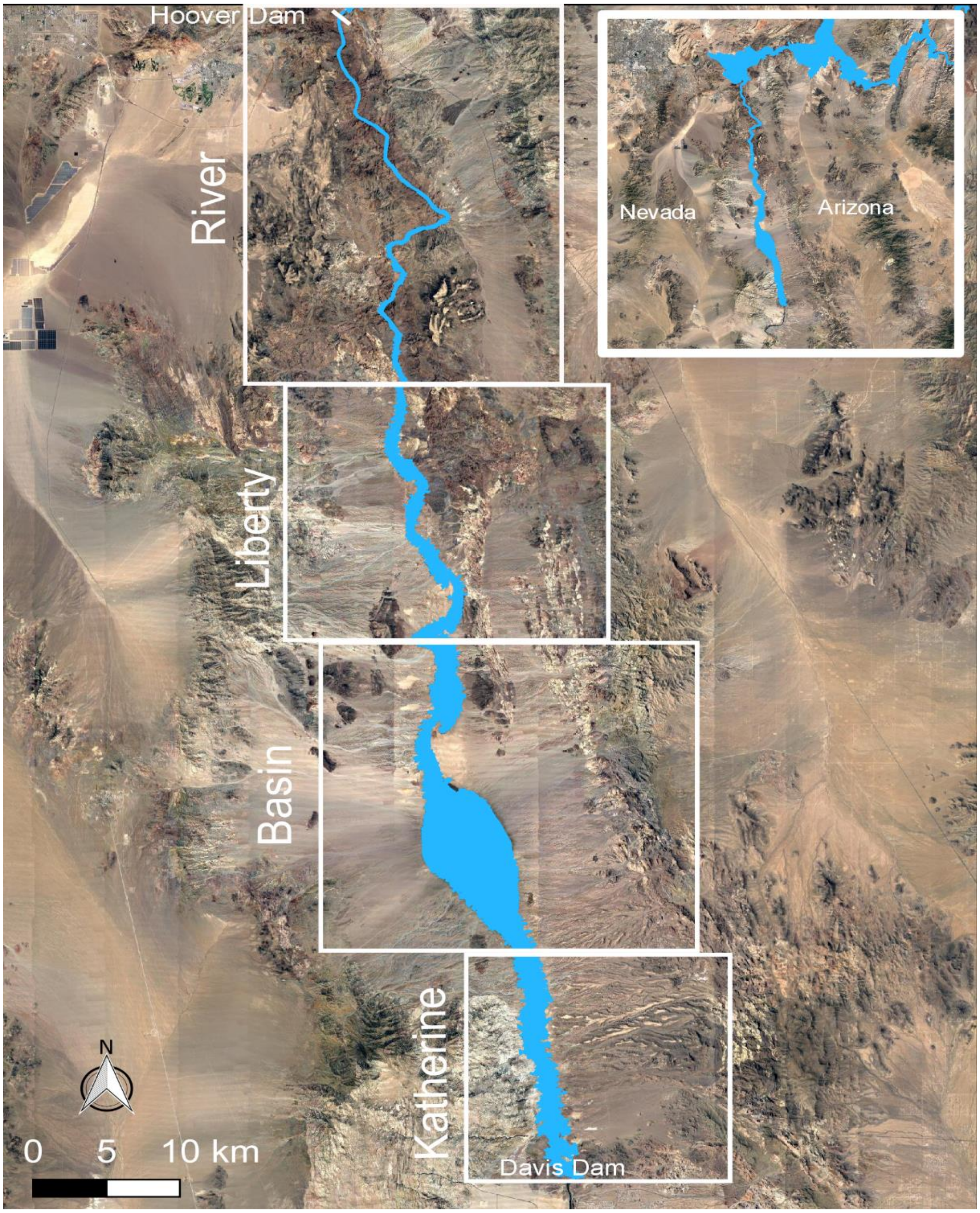

Figure 1.—Map of Lake Mohave, Arizona and Nevada, illustrating the zoning scheme used.

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 (mL) of 95% ethanol in a labeled snap-cap tube, and returned to the laboratory for genetic analysis (Objective 3; results reported elsewhere by others). All relevant data were entered into the comprehensive Lower Colorado River (LCR) Native Fish Database maintained by M&A.

Remote Monitoring

Remote PIT scanning systems were deployed one 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 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 submersible units was provided by a 20.8 or 28 ampere (amp)-hour (h) lithium-ion battery pack contained in a watertight, 2-inch (5.08 cm) 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 utilized by razorback sucker at different times of 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 (Wisenall et al. 2016; Leavitt et al. 2017). 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 of Willow Beach to determine if any additional aggregates exist and 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 one to two-mile increments moving upstream each sample trip from Basin zone to the Liberty zone at Liberty Cove. 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 sucker have been observed in the past (J. Stolberg, Bureau of Reclamation, July 2016, personal communication). Scanning did not take place in Katherine zone during FY18.

Information downloaded from scanning units was recorded as follows: general location or site name, Universal Transverse Mercator (UTM) 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, river flows, etc. were recorded on field sheets or data books.

Remote PIT scanning in Basin zone (figures 1 and 2) was conducted by Reclamation with support from M&A personnel (Objective 5). Semi-permanent shore-based units were deployed in Basin 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 semi-permanent 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).

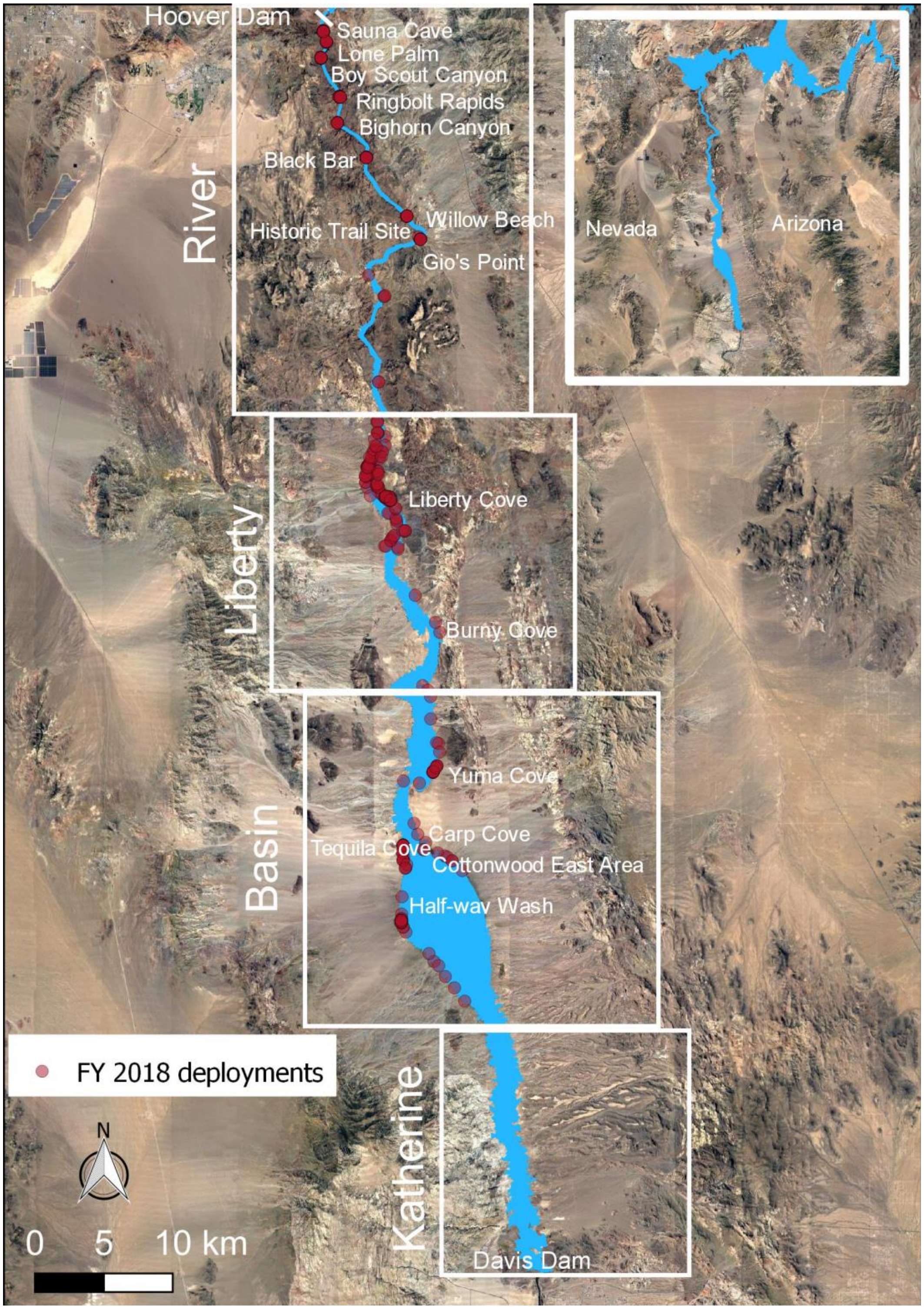

Figure 2.—Location of M&A and Reclamation remote PIT scanners in River, Liberty, and Basin zones of Lake Mohave, Arizona and Nevada, FY2018.

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 population size for the lake-wide population as well as River and Basin subpopulations of repatriated and 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 sucker 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,

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

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 two-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

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

population estimates. Confidence intervals (CIs) were derived using Poisson approximation tables using *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 confidence intervals.

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, Kesner et al. 2014, Wisenall et al. 2015, Wisenall et al. 2016, and Leavitt et al. 2017). 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 River and Basin, based on remote PIT scanning data and multi-site mark-recapture models (Kesner et al. 2012 Kesner et al. 2014, Wisenall et al. 2015, Wisenall et al. 2016, and Leavitt et al. 2017). 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 $\hat{c}$ (variance inflation factor) indicated significant over-dispersion. 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 over-dispersion 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 (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 four to five 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 Basin 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 scanning trips were removed from capture histories (i.e., regardless of contact location, only contacts collected during the date range of monthly River PIT scanning trips were included). Scanning occasions were grouped by SY (based on the fiscal year 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 two 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. A total of 31 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 Akaike's Information Criterion (AIC) score (Akaike 1974). This value reported in MARK is a modified value (AICc) that adjusts for small sample sizes (Burnham and Anderson 2002). AICc was adjusted for over-dispersion with the Fletcher estimate of $\hat{c}$ (Fletcher 2012). Reported parameter values were based on the highest ranked model (lowest AICc or quasi-likelihood [QAICc]) when QAICc weight for the top model was greater than 0.9 (Johnson and Omland 2004). Otherwise estimates were based on model averaging.

Table 1.—Complete list of robust model parameterizations used in Program MARK.
(S = survival; p = capture; c = recapture; γ” = probability fish emigrates from study area; 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; 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)	global 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

Stocking Displacement

Stocking displacement was examined to determine 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 to Lake Mohave contained a 134.2 kHz PIT tag. Individuals with less than ten 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 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 distance between subsequent dates of contact 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.

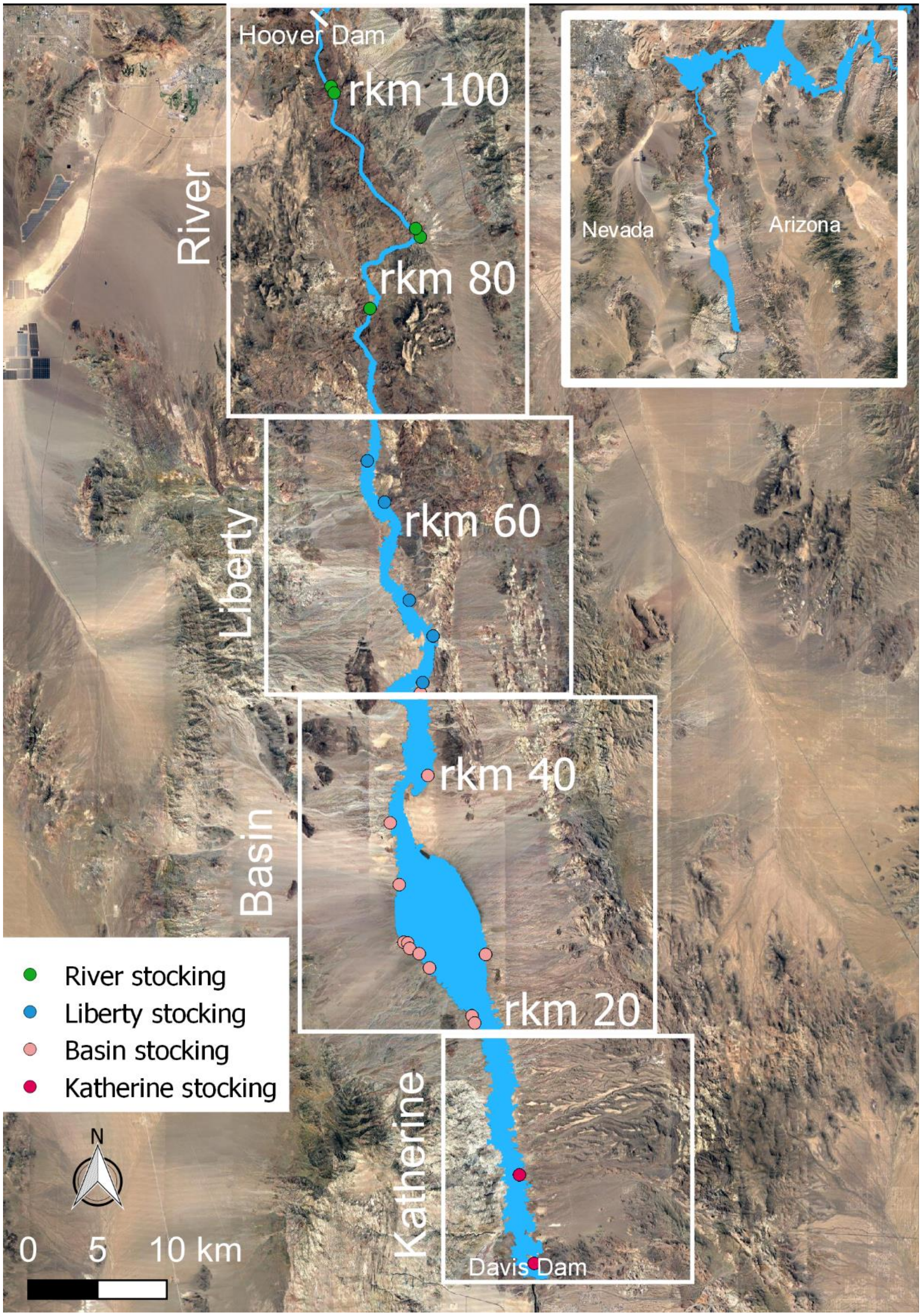

Figure 3.—Stocking locations of razorback sucker from October 1, 2008 to September 30, 2012 in River, Liberty, Basin, and Katherine zones of Lake Mohave, Arizona and Nevada.

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 AZFWCO and 13 during March 12-16, 2018 monitoring activities (table 2). No PIT tag was detected in three 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 one of the 18 repatriates and that fish was omitted from further analysis. Sex was determined at both events, and captures included 17 females and four males.

Of the 17 PIT tagged repatriate razorback suckers with stocking and rearing information, only one was less than 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 greater than or equal to 620 mm TL at capture. Fish at large for more than one year exhibited similar growth rates, which ranged from 1 to 3 mm/month at large. One fish, at large for 10 months, grew at a rate of 9 mm/month while another fish at large for only three months appears to have “lost” length for a -15 mm/month at large (the latter likely representing TL measurement error). Mean growth rate was approximately 2 mm/months at large (including all fish). Years at large for all fish ranged from less than one to 22 with mean time at large of eight years. Fourteen fish were 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 one to four years old at stocking.

Table 2.—Adult razorback sucker monitoring summary by capture month, PIT tag, history, and sex during the FY2018 monitoring events, Lake Mohave, Arizona and Nevada
(n is number of fish.)

		PIT tag?		History			Sex		
Capture date	**n**	**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

Lakeside backwaters and off-site 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. Off-site rearing facilities included Achii Hanyo Native Fish Rearing Facility, Bubbling Ponds Fish Hatchery, Lake Mead Fish Hatchery, and Willow Beach NFH. Fish reared in lakeside backwaters traveled a mean distance of 7 km from stocking to capture site (5-11 km min-max), while the fish reared in off-site facilities traveled a mean distance of 25 km (2-54 km min-max). Notably, the three fish that traveled the greatest distances were hatchery reared, released in the River zone at Willow Beach, and contacted in the Basin zone (table 4).

Table 3.—Adult razorback sucker monitoring summary for nine paired stocking-capture data for each fish
(Table 3 is continued on the next page.)

PIT tag	Date		Capture history			TL (mm)		Growth rate (mm/months at large)
	Stocking	Capture	Sex	Days at large	Number of captures	Stocking	Capture	
1B796EE3DB[a]	22-May-13	28-Nov-17	F	1,651	1	492	643	3
1C2D6C6741[b]	04-Nov-11	28-Nov-17	F	2,216	1	435	634	3
1C2D25D516[c]	23-Oct-09	28-Nov-17	F	2,958	1	470	624	2
5335245B2C[d]	18-Jun-04	28-Nov-17	F	4,911	1	355	624	2
1B796EEC75[e]	21-Oct-13	29-Nov-17	F	1,500	1	492	620	3
1C2D06BA6D[f]	11-May-11	29-Nov-17	F	2,394	1	405	628	3
1C2D6188C7[g]	03-Dec-09	29-Nov-17	F	2,918	1	435	634	2
003C06CAA5[h]	15-Dec-17	12-Mar-18	M	87	1	445	401	-15

(Table 3 continued)

PIT tag	Date		Capture history			TL (mm)		Growth rate (mm/months at large)
	Stocking	Capture	Sex	Days at large	Number of captures	Stocking	Capture	
36F2B263D5[b]	23-Oct-12	14-Mar-18	M	1,968	1	500	548	1
1C2D642F9E[i]	17-Dec-09	14-Mar-18	F	3,009	1	430	635	2
2037246223[b]	20-Nov-95	14-Mar-18	F	8,150	1	345	660	1
1C2D61A3F9[c]	23-Oct-09	15-Mar-18	F	3,065	1	455	627	2
1C2D635C66[i]	06-Jan-10	15-Mar-18	F	2,990	1	390	655	3
003BEA19E8[j]	02-May-17	15-Mar-18	M	317	1	434	525	9
1C2D26933A[c]	23-Oct-09	15-Mar-18	F	3,065	2	425	650	2
1C2D698C52[g]	03-Dec-09	16-Mar-18	F	3,025	2	425	640	2
1B796ED720[k]	31-Oct-13	28-Nov-17	F	1,489	5	510	643	3
Avg				2,689	-	438	611	2

[a] 2009 year class, reared at Arizona Juvenile lakeside backwater

[b] No year class, reared at Yuma Cove lakeside backwater

[c] 2005 year class, reared at Bubbling Ponds Fish Hatchery

[d] No year class, reared at Willow Beach NFH

[e] 2009 year class, reared at Dandy Cove lakeside backwater

[f] 2007 year class, reared at Willow Backwater, lakeside

[g] 2008 year class, reared at Achii Hanyo Native Fish Rearing Facility

[h] 2015 year class, reared at Lake Mead Fish Hatchery

[i] 2006 year class, reared at Willow Beach National Fish Hatchery

[j] 2014 year class, reared at Dandy Cove lakeside backwater

[k] 2009 year class, reared at North Chemehuevi Cove lakeside backwater

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 is 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
Off-site facility	Achii Hanyo Native Fish Rearing Facility	Cottonwood Cove	36	Basin	Carp Cove	34	Basin	2	1
Off-site facility	Achii Hanyo Native Fish Rearing Facility	Cottonwood Cove	36	Basin	Cottonwood Cove East	32	Basin	4	1
Off-site facility	Bubbling Ponds Fish Hatchery	Willow Beach boat ramp	87	River	Carp Cove	34	Basin	53	1
Off-site facility	Bubbling Ponds Fish Hatchery	Willow Beach boat ramp	87	River	Cottonwood Cove East	32	Basin	54	1
Off-site facility	Bubbling Ponds Fish Hatchery	Willow Beach boat ramp	87	River	Waterwheel Cove	32	Basin	54	1
Off-site facility	Lake Mead Fish Hatchery	Half-way Wash	30	Basin	Carp Cove	34	Basin	3	1
Off-site facility	Willow Beach NFH	North Nine Mile Coves	28	Basin	Carp Cove	34	Basin	6	1
Off-site facility	Willow Beach NFH	Liberty Cove	63	Basin	Waterwheel Cove	32	Basin	31	1
Off-site facility	Willow Beach NFH	Wrong Cove	52	Basin	Cottonwood Cove East	34	Basin	18	1
Avg distance traveled								25	-

Remote Monitoring

Remote PIT scanners were deployed in Lake Mohave for a total scan time of 37,903 hours ([h]; figures 3 and 4); 12,414 h using shore-based devices and 25,489 h 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 Native Fish Database (i.e., have a marking record). Among fish with a marking record, 3,615 were repatriates, nine were wild, and 28 were of unknown origin.

Remote PIT scanning in River zone resulted in a total scan time of 9,280 h, all with submersible units. Mean deployment time for submersible units was 39 h. Among 33,781 contacts, 2,118 were unique PIT tags and 2,032 of those were in the 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, seven were noted as wild individuals, and six had unknown histories.

Contacts at fixed sites in River 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 sucker appeared to shift upstream or downstream of Black Bar with fewer contacts.

Remote submersible scanners in Liberty were deployed for a total scan time of 5,885 h. The mean deployment time for submersible scanners was 40 h. A total of 76 PIT tag contacts were recorded representing 42 unique razorback sucker, 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 Basin and accumulated 22,737 total h of scanning; 12,414 h with shore-based and 10,323 h with submersible units. Mean deployment times for shore-based and submersibles were 222 h and 129 h, 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 Native Fish Database. Repatriated razorback sucker accounted for 1,851 of the unique encounters, three were wild, and 25 were of unknown origin.

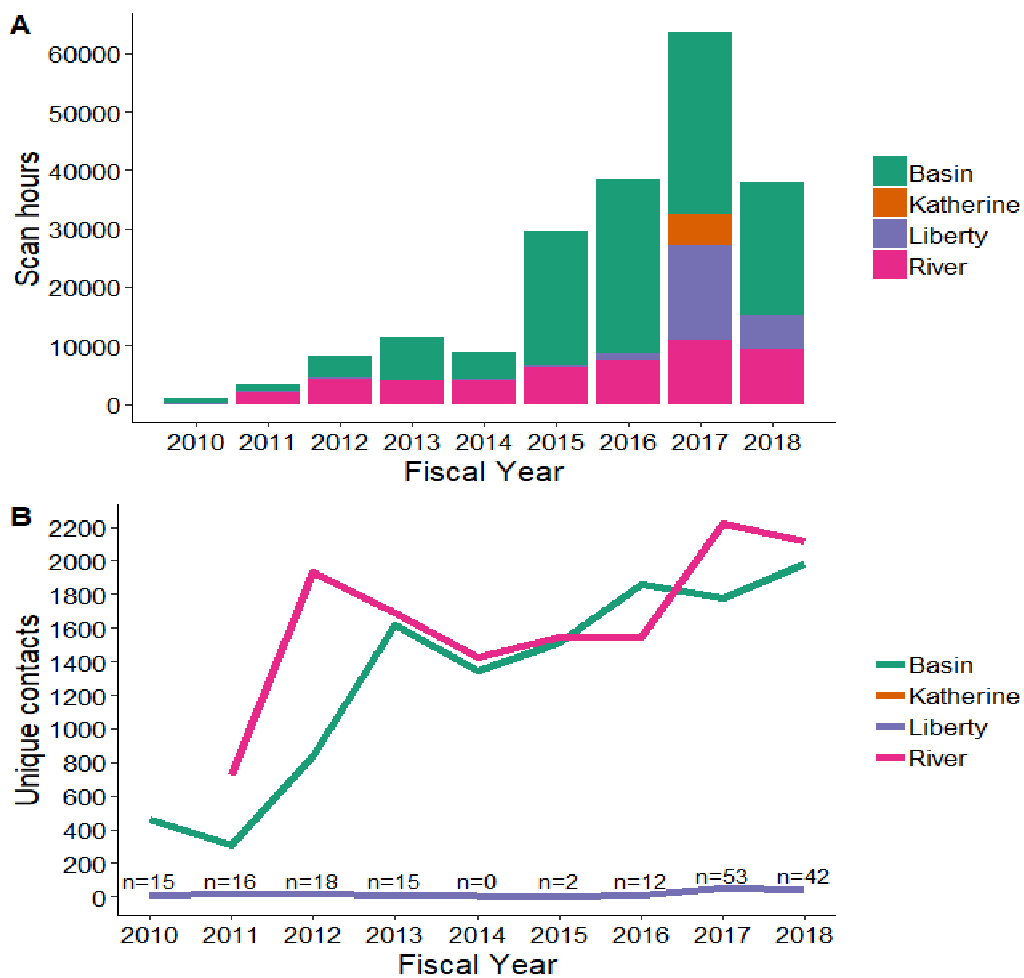

Figure 4.—Relationship between total scan hours for submersible and shore-based PIT scanners for each zone (A) and total number of unique contacts (B) from FY2010-2018 in Lake Mohave, Arizona and Nevada.
N is the number of unique contacts in Liberty; Katherine is overlapping with Liberty in 2017 and the total number of unique contacts (n=59) is not visible.

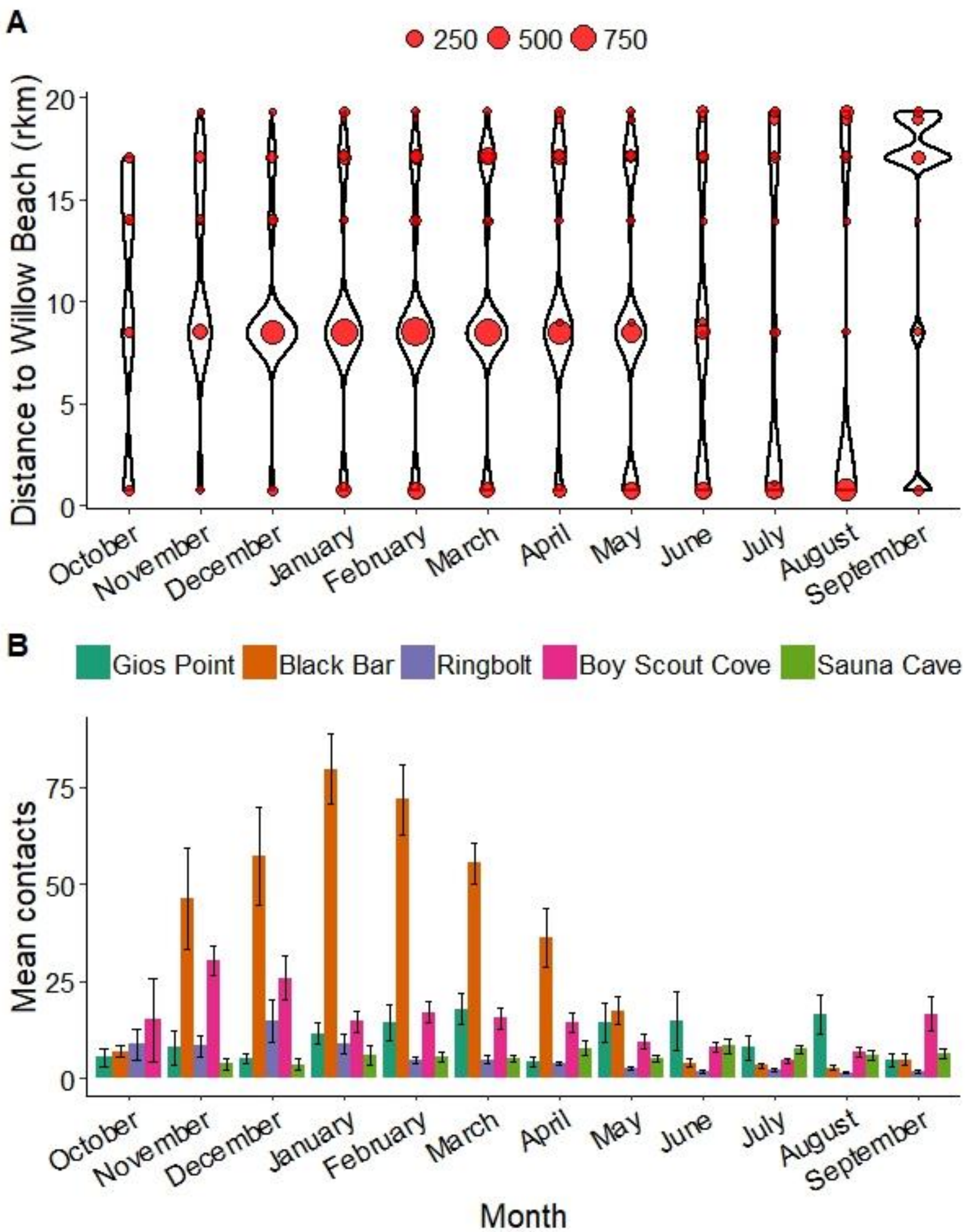

Figure 5.—Spatial distribution of contacts (red circles; A) and mean unique razorback sucker PIT tag contacts (B) recorded January 2013 to August 2018 at five fixed stations in River zone, Lake Mohave, Arizona and Nevada.
Error bars represent ±1 SE.

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 Basin population at 1,872 (see figure 6; 95% CI from 1,804 to 1,940) and River at 2,093 (see figure 6; 95% CI from 1,966 to 2,220). Too few wild fish were contacted to estimate Basin and River subpopulations separately (six and three contacts, respectively). The lake-wide estimate of the wild population based on PIT scanning in 2017 and 2018 was nine fish (M=4, C=8, R=4, 95% CI from 4 to 23).

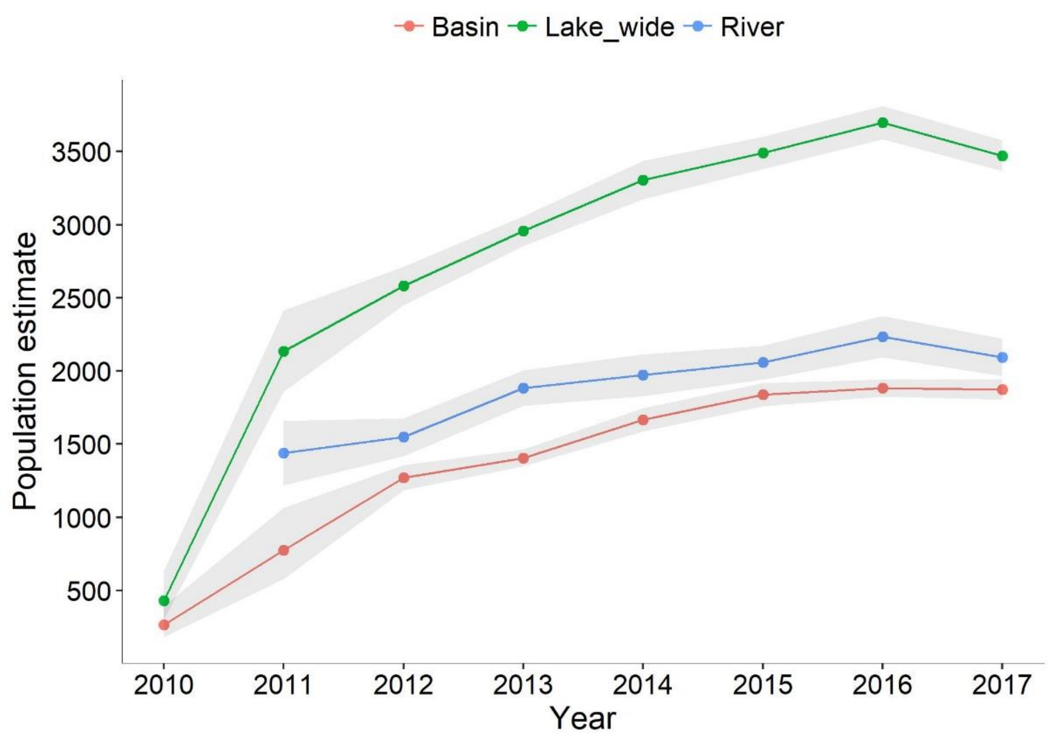

Figure 6.—Repatriate razorback sucker population estimates derived from PIT scanning data from 2010 to 2018 in Lake Mohave, Arizona and Nevada.
The lower and upper 95% confidence intervals are represented by the shaded area.

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 less than 0.001. The Fletcher $\hat{c}$ estimate was 1.000 indicating no over-dispersion 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 that was available for PIT scanning in SY 2014 emigrated between SY 2014 and SY 2015 (table 7) and estimates of temporary emigration were greater than 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 ($1-\gamma'$) 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 5.—Comparison of robust model results in Program Mark for Lake Mohave razorback sucker remote PIT scanner contacts between 2012 and 2017.

Model	AICc	AICc Weights	Model likelihood	No. 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

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% confidence intervals 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 sucker 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 less than 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 one zone, 447 (23.6%) were contacted in two zones, 19 (1.0%) were contacted in three zones, and none were contacted in four.

In River zone, there were five 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 in River zone, of which 1,079 were unique. Of the 25,031 contacts, 18,804 (1,022 unique) were in River zone, 32 (30 unique) were in Liberty zone, 6,193 (349 unique) were in Basin zone, and two unique were in Katherine zone. A more detailed summary of contact histories for unique razorback suckers stocked in River zone is provided in table 8.

Table 8.—Summary of contact histories for unique razorback suckers stocked in 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

In Liberty zone, there were five 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 in Liberty zone, of which 113 were unique. Of the 3,748 contacts, 792 (62 unique) were only in River zone, seven (3 unique) were in Liberty zone, 2,949 (82 unique) were in Basin zone, and none were contacted in Katherine zone. A more detailed summary of contact histories for unique razorback suckers stocked in 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 in 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

In 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 in Basin zone, of which 680 were unique. Of the 29,463 contacts, 1,340 (132 unique) were in River zone, eight (seven unique) were in Liberty zone, 28,480 (655 unique) were in Basin zone, and 18 (10 unique) were in Katherine zone. A more detailed summary of contact histories for unique razorback suckers stocked in 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 River, Liberty, and Katherine zones (figure 9).

Table 10.—Summary of contact histories for unique razorback suckers stocked in 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

In Katherine zone, there were two stocking locations with 1,843 fish released from 2009 to 2012 (see figure 2). A total of 439 contacts were recorded from fish released in Katherine zone, of which 17 were unique. Of the 439 contacts, 40 (4 unique) were in River zone, none were in Liberty zone, 397 (15 unique) were in Basin zone, and one was in Katherine zone. A more detailed summary of contact histories for unique razorback suckers stocked in Katherine zone is provided in table 11. Stocking displacement showed most fish stocked in Katherine were contacted in either Basin or River zones across all years (figure 10).

Table 11.—Summary of contact histories for unique razorback suckers stocked in 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 Basin and Liberty. Since then, deployment distribution expanded into the River and Liberty zones. Deployment distribution of PIT scanners in Liberty was greatest in FY17 and FY18.

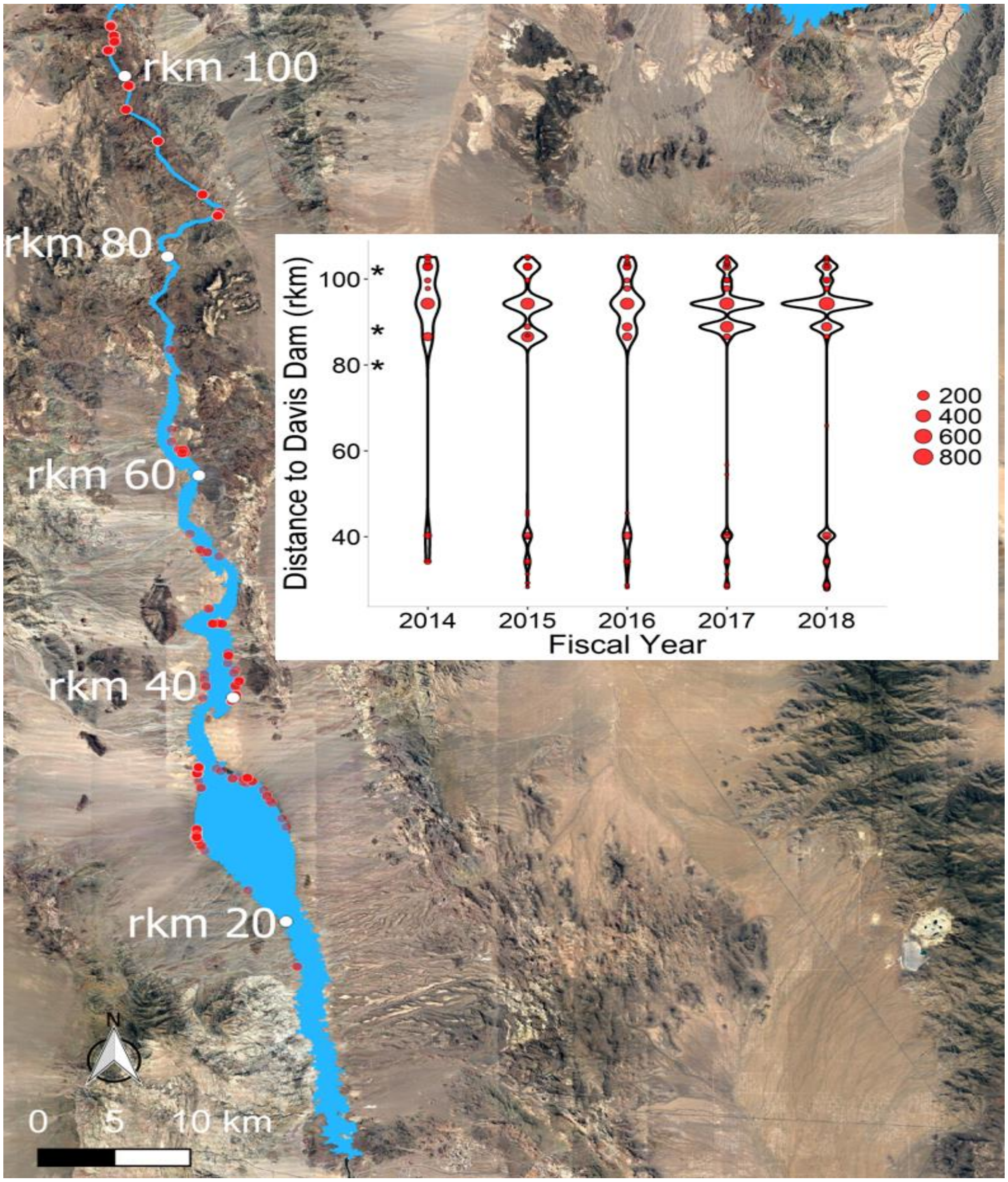

Figure 7.—Relationship between number of contacts (red circles) and distance to Davis Dam (rkm) for razorback suckers stocked in River zone from 2008 to 2012, Lake Mohave, Arizona and Nevada.
Asterisks along y-axis represent stocking locations.

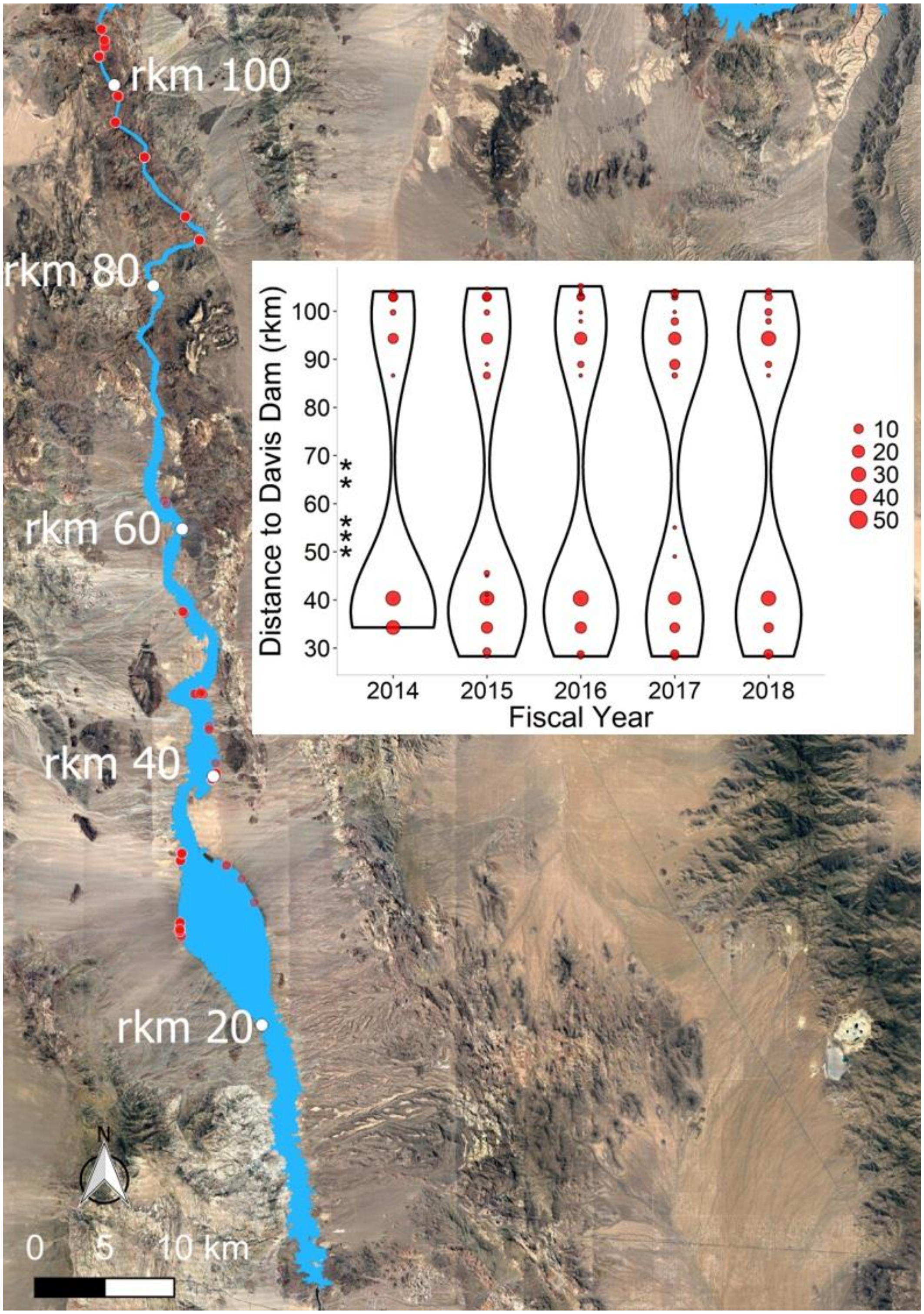

Figure 8.—Relationship between number of contacts (red circles) and distance to Davis Dam (rkm) for razorback suckers stocked in Liberty zone from 2008 to 2012, Lake Mohave, Arizona and Nevada.
Asterisks along y-axis represent stocking locations.

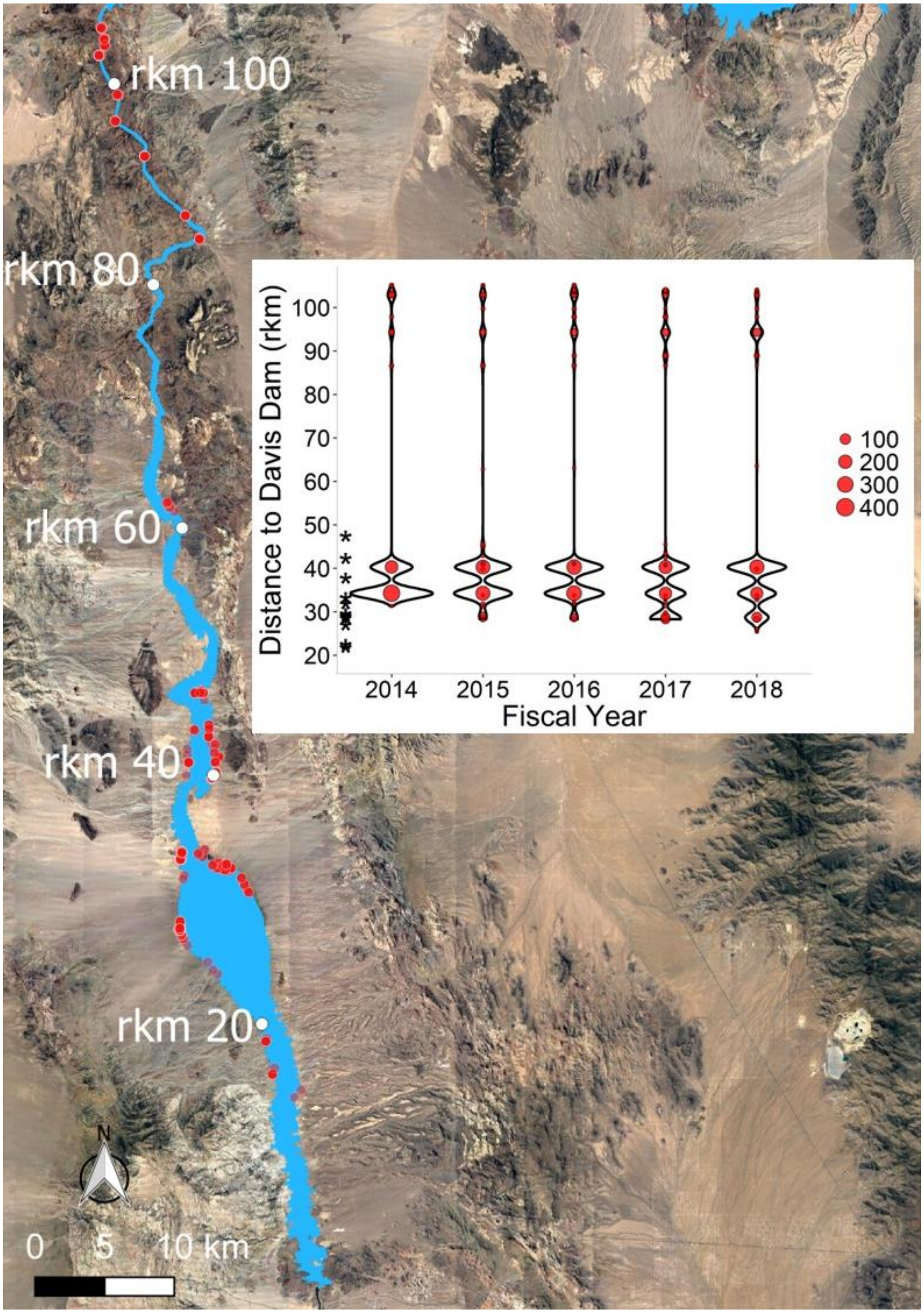

Figure 9.—Relationship between number of contacts (red circles) and distance to Davis Dam (rkm) for razorback suckers stocked in Basin zone from 2008 to 2012, Lake Mohave, Arizona and Nevada.
Asterisks along y-axis represent stocking locations.

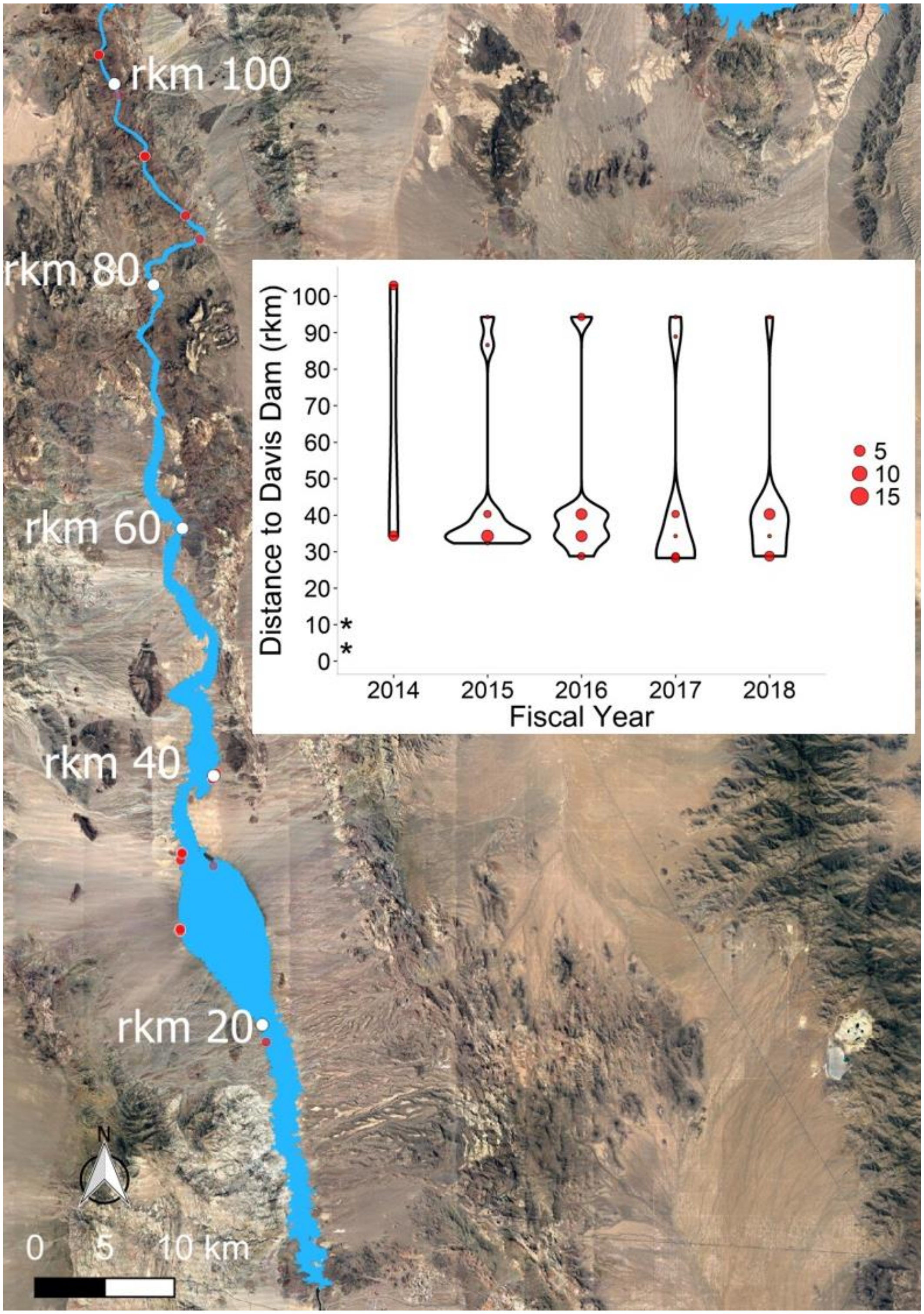

Figure 10.—Relationship between number of contacts (red circles) and distance to Davis Dam (rkm) for razorback suckers stocked in Katherine zone from 2009 to 2012, Lake Mohave, Arizona and Nevada.
Asterisks along y-axis represent stocking locations.

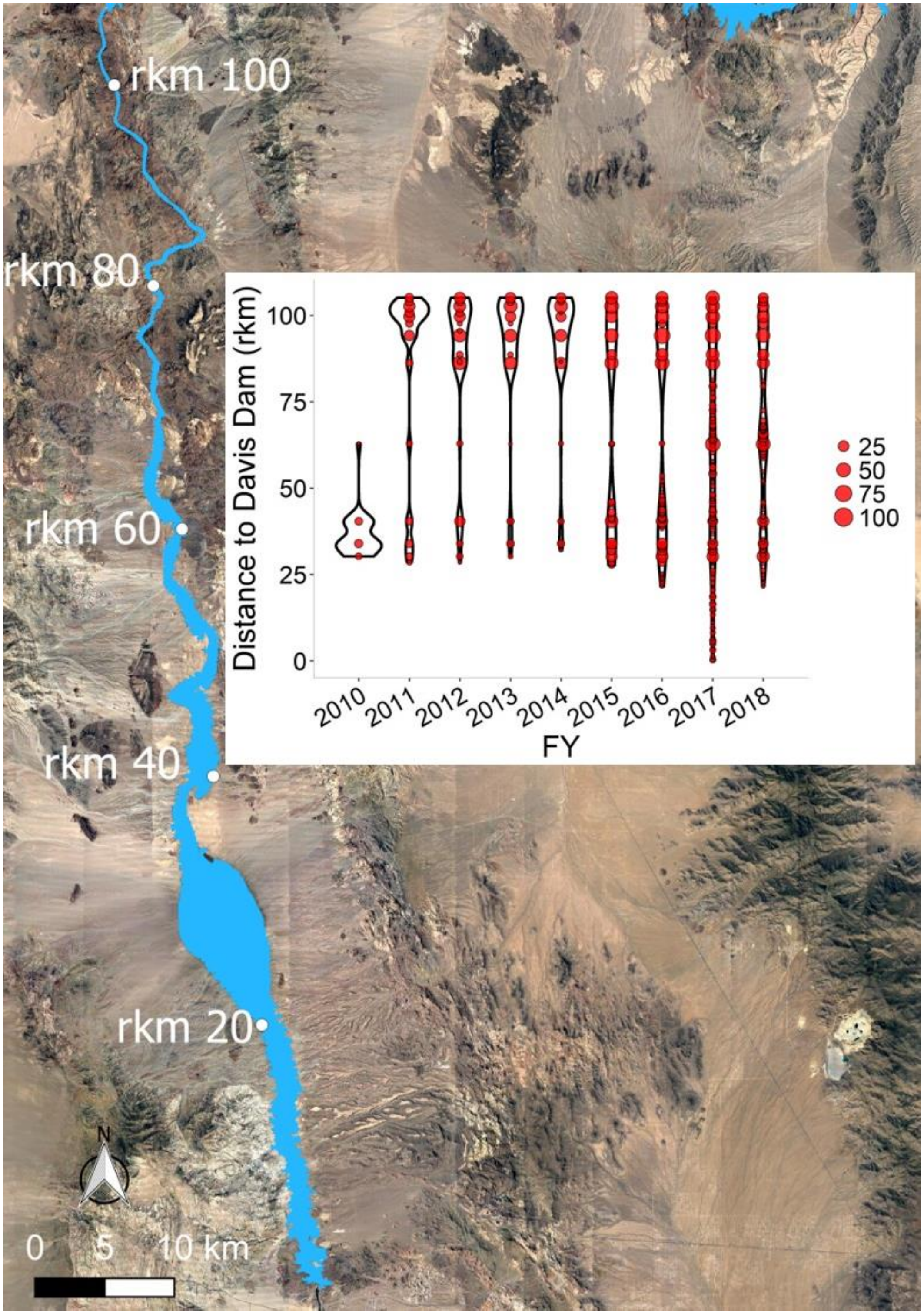

Figure 11.—Relationship between number of submersible and shore-based PIT scanners deployed (red circles) and distance to Davis Dam (rkm) from FY2010-2018 in Lake Mohave, Arizona and Nevada.

DISCUSSION

Long-term monitoring and research have provided invaluable information to guide 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 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.

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 Wisenall et al. 2015, Wisenall et al. 2016, Leavitt et al. 2017). For example, subpopulation estimates derived from remote PIT scanning were significantly higher in River compared to Basin across all years as indicated by non-overlapping confidence intervals (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 (Wisenall et al. 2016, Leavitt et al. 2017). 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 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 (Wisenall et al. 2016, Leavitt et al. 2017). Additionally, estimates derived from March monitoring data have low precision as indicated by broad confidence intervals.

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, Wisenall et al. 2015, Wisenall et al. 2016, Leavitt et al. 2017). 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 over-dispersion ($\hat{c}$ 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 greater than zero 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 Basin to River from

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

In 2018, an analysis of stocking displacement was examined to determine distance traveled from stocking locations and to identify movement between zones to guide stocking endeavors. Stocking displacement analyses were congruent with cohort analyses (Wisenall et al. 2016, Leavitt et al. 2017), but provided a more spatially explicit illustration across years. Ultimately, the current data suggest stocking razorback suckers in Liberty or Katherine 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 in Liberty and Katherine, respectively, were contacted at least once compared to 16% and 7% in River and Basin, respectively. This may not be the only reason razorback suckers are not contacted in Liberty and Katherine. 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 utilized by razorback suckers. If it is determined razorback suckers are utilizing these zones in adequate numbers, this would argue for continuing stocking efforts and attempting to estimate subpopulation size. Otherwise, stocking in Basin and River are preferred.

The relationship between size at release and survival for razorback sucker has been supported by numerous lines of evidence (e.g., Minckley et al. 2003, Marsh et al. 2005, Zelasko et al. 2010). The rearing strategy at 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 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 (Wisenall et al. 2016, Leavitt et al. 2017). These fish continue to contribute disproportionately to the Basin subpopulation compared to hatchery-reared fish based on their stocking numbers (Wisenall et al. 2016, Leavitt et al. 2017). Despite the catastrophic loss of repatriates at 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 to Lake Mohave (LCR 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, Dowling et al. 2005) and thus requires continuation. While the stocking program has changed little over the past decade, additional data-based adjustments are being implemented to increase 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, FWS 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 sucker 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 River continues to be an effective method for monitoring this subpopulation of razorback suckers. In 2017, remote PIT scanning was expanded in Liberty, but no additional aggregates of razorback suckers were detected after two years despite considerable effort and scanning distribution. To identify if razorback suckers are utilizing 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 utilizing 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 sucker in Lake Mohave.

Stocking razorback sucker 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 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 analysis.

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