Lower Colorado River Multi-Species Conservation Program

Balancing Resource Use and Conservation

Demographics and Monitoring of Repatriated Razorback Suckers in Lake Mohave

2020 Annual Report

February 2021

Work conducted under LCR MSCP Work Task D8

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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

Demographics and Monitoring of Repatriated Razorback Suckers in Lake Mohave

2020 Annual Report

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ACRONYMS AND ABBREVIATIONS

C	capture
CI	confidence interval
kHz	kilohertz
km	kilometer(s)
LCR MSCP	Lower Colorado River Multi-Species Conservation Program
M	mark
m	meter(s)
M&A	Marsh & Associates, LLC
mm	millimeter(s)
n	number
NHDPlus	National Hydrography Dataset Plus
PIT	passive integrated transponder
PVC	polyvinylchloride
R	recapture
Reclamation	Bureau of Reclamation
rkm	reservoir kilometer(s)
SY	sample year
TL	total length
Willow Beach NFH	Willow Beach National Fish Hatchery

Symbols

≥	greater than or equal to
<	less than
%	percent
±	plus or minus

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EXECUTIVE SUMMARY

Repatriated razorback suckers (*Xyrauchen texanus*) in Lake Mohave have been monitored since the first releases in 1992. The most significant change to monitoring techniques occurred in 2010 with the advent of remote passive integrated transponder (PIT) scanners able to detect 134.2-kilohertz (kHz) PIT tags. Utilization of this technology was initiated to increase the number of fish encounters, and it has proven successful in that regard. 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 to estimate abundance of razorback suckers marked with either 400- or 134.2-kHz PIT tags. Monitoring methods remained relatively unchanged from 2015 to 2020, apart from the occasional addition or subtraction of remote PIT scanning efforts in certain areas or locations of the reservoir, which is split into four distinct zones, listed from up- to downstream, as River zone, Liberty zone, Basin zone, and Katherine zone (hereafter referred to as River, Liberty, Basin, and Katherine, respectively).

Trammel netting at Carp Cove in December 2019 and March 2020 resulted in capture of 80 razorback suckers – 57 females and 23 males. Seven of the fish captured had no detectable PIT tag, and one had a PIT tag but no previous record of tagging. The 72 razorback suckers captured with a tagging record represented 70 unique fish (2 were same-trip recaptures). All were repatriates. Overall total length (TL) at release ranged from 310–570 millimeters (mm), and TL at capture ranged from 355–695 mm, with an overall mean TL at release and capture of 453 and 553 mm, respectively. The shortest time at large, from stocking to capture, was 95 days, and years at large ranged from less than 1 to 12, with an overall mean of 3. Sixty-six fish had year-class information ranging from 2006 to 2016; most (52 fish) were from the 2014–16 year classes. The mean growth rate was 5 mm TL per month. Most captured fish were released into Basin (n = 62), the rest were released into River (n = 8); 11 were raised in lakeside backwaters and 59 in offsite facilities.

Total deployment time for PIT scanners (remote monitoring) from October 1, 2019, through September 30, 2020, was 27,330 scan-hours, resulting in 294,574 PIT tag contacts, representing 5,960 unique PIT tags for which 5,914 had a matching record in the Lower Colorado River Native Fish Database, including 43 double PIT tag contacts (2 tags in the same fish). Of the unique fish contacted, 5,870 were razorback suckers – 5,796 repatriate, 8 wild, and 66 unknown origin. One repatriate bonytail (*Gila elegans*) also was encountered.

Wild razorback suckers were not encountered during sample year (SY) 2020 routine monitoring events (i.e., trammel netting). The repatriated razorback sucker population in 2019, based on 2019 and 2020 March monitoring data, was estimated at 1,559 fish (95% confidence interval [CI] from 967 to 2,653). Based

on SY 2019 and SY 2020 remote PIT scanning, the 134.2-kHz PIT-tagged Lake Mohave population for 2019 was estimated at 3,906 individuals (95% CI from 3,789 to 4,022). Population estimates using zone-specific scanning for 2019 estimated the Basin population at 1,901 (95% CI from 1,856 to 1,945) and the River population at 2,014 (95% CI from 1,896 to 2,131).

Stocking displacement was examined to enumerate fish contacted in multiple zones (contact histories by zone) and to determine the farthest distance traveled from stocking locations (movement distance). Fish that were released into River or Basin mostly were contacted only within their zone of release (64.9 and 67.3% of contacted fish, respectively). However, a considerable portion of fish released into River or Basin were also detected in the other zone (31.9 and 31.6% of contacted fish, respectively). Razorback suckers released into Liberty were mostly contacted upstream in River or downstream in Basin in approximately equal proportions, and fish stocked into Katherine were mostly contacted upstream of their release location. Movement distance analysis results were comparable to those of previous evaluations in that the distribution of apparent range limits of fish stocked into River and Basin were bimodal, with peaks in both zones. Fish stocked into Liberty exhibited a more unimodal distribution of range limits, with fish traveling to join the River and/or Basin subpopulations.

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 PIT scanning efforts have continued in Liberty to determine if other aggregations exist. Biannual routine monitoring efforts in Basin continue to help with the collection of essential growth, health, census, and genetic data for razorback suckers. These data continue to provide long-term insight into population dynamics and demographics and contribute to the conservation of this endangered species.

INTRODUCTION

Lake Mohave in the latter half of the twentieth century was home to the largest known population of the wild razorback sucker (*Xyrauchen texanus*), an endangered "big river" fish endemic to the Colorado River Basin. The population was estimated at 60,000–75,000 in the 1980s, declining to fewer than 25,000 in the mid-1990s (Marsh et al. 2003), and fewer than 50 wild individuals by 2010 (Dowling et al. 2014). Since 2010, wild razorback suckers have rarely been encountered, and the population is functionally extirpated.

Although wild fish are nearly gone, a genetically diverse adult razorback sucker population persists in Lake Mohave, which is attributable to a repatriation program initiated by the Native Fishes Work Group 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) (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).

The razorback sucker population in Lake Mohave remains the most genetically diverse among razorback sucker populations (Dowling et al. 2020), and it acts as the primary broodstock for this species. This success has been due to a combination of the repatriation program itself and the demographic and genetic monitoring programs that inform the repatriation program currently funded through the Lower Colorado River Multi-Species Conservation Program (LCR MSCP). Changes in stocking size, age class structure, and geographic distribution of larvae collection activities are some of the adaptations that were derived directly from monitoring data (LCR MSCP 2015).

Monitoring techniques have also adapted to changes in technology. Remote sensing of repatriated and wild razorback suckers implanted with 134.2-kilohertz (kHz) passive integrated transponder (PIT) tags via deployment of PIT scanners has resulted in more than a tenfold increase in contact data compared to traditional capture and handling techniques (Wisenall et al. 2015). These data complement the handling data, which provide additional insights into the condition and growth rate of individuals. Continued monitoring of the Lake Mohave razorback sucker population through routine deployment of PIT scanners and annual sampling efforts will ensure the availability of suitable offspring for future LCR MSCP augmentation needs.

Overall, the objective of ongoing monitoring and research for 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.

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

1. Locating and capturing/contacting adult razorback suckers.

2. Locating and capturing larval razorback suckers.

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

4. Collecting tissue samples from captured adult razorback suckers for genetic analyses. (Samples may be provided to the designated Contracting Officer's Representative or shipped directly to a lab of the Bureau of Reclamation's (Reclamation) choosing. The contractor is not responsible for reporting results of these analyses.)

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

6. Using mobile, remote PIT tag scanning units capable of deployment in both the slack water and riverine sections of Lake Mohave.

7. Participating in a maximum of two annual, weeklong, multi-agency, survey events to take place in the spring (March) and fall (November or December) of each contract year. (In the event these surveys do not take place, the contractor may conduct additional remote scanning during these periods.)

8. Providing estimates for current repatriate, and if possible, wild razorback sucker populations.

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

10. Providing monthly progress reports summarizing all field, laboratory, and/or office work completed in the course of this effort.

11. Providing copies of all datasets generated in the course of this work to the designated Contracting Officer's Representative.

12. Providing a draft interim report during each contract year for review by the LCR MSCP.

13. Providing a final interim report for each completed contract year.

14. Providing a draft project report during the final option year.

15. Providing a final project report for the complete contract.

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

This report summarizes the first 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 routine monitoring. Population and subpopulation estimates were developed from remote PIT scanning data collected across all years available in the basin and riverine portions of the lake. In addition, remote PIT scanning data were used to illustrate post-stocking displacement patterns.

METHODS

For the purposes of this study, Lake Mohave (LCR MSCP Reach 2) was divided into four distinct zones: River zone, Liberty zone, Basin zone, and Katherine zone (listed from upstream to downstream), hereafter referred to as River, Liberty, Basin, and Katherine, respectively (figure 1; Kesner et al. 2012). These demarcations are based on geographic features of the river system and razorback sucker demographics as determined from previous studies.

Annual sampling followed the Federal fiscal year, October 1 to September 30, which coincides with annual spawning behavior (i.e., the annual sampling event in autumn is reported together with the following March monitoring data each year, representing a single spawning season). Sample year (SY) refers to a single 12-month period based on the fiscal year schedule (e.g., October 1, 2019, to September 30, 2020, is SY 2020). Unless otherwise stated, SY data in this report represent the entire sample year.

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

Routine Monitoring

Objectives 1, 3, 4, 5, and 7 were accomplished through participation in the December and March multi-agency survey events. During these events, Marsh & Associates, LLC (M&A) personnel occupied a field camp for 5 days on Lake Mohave at Carp Cove, Arizona (Basin), 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 East Area upstream to Carp Cove (figure 2).

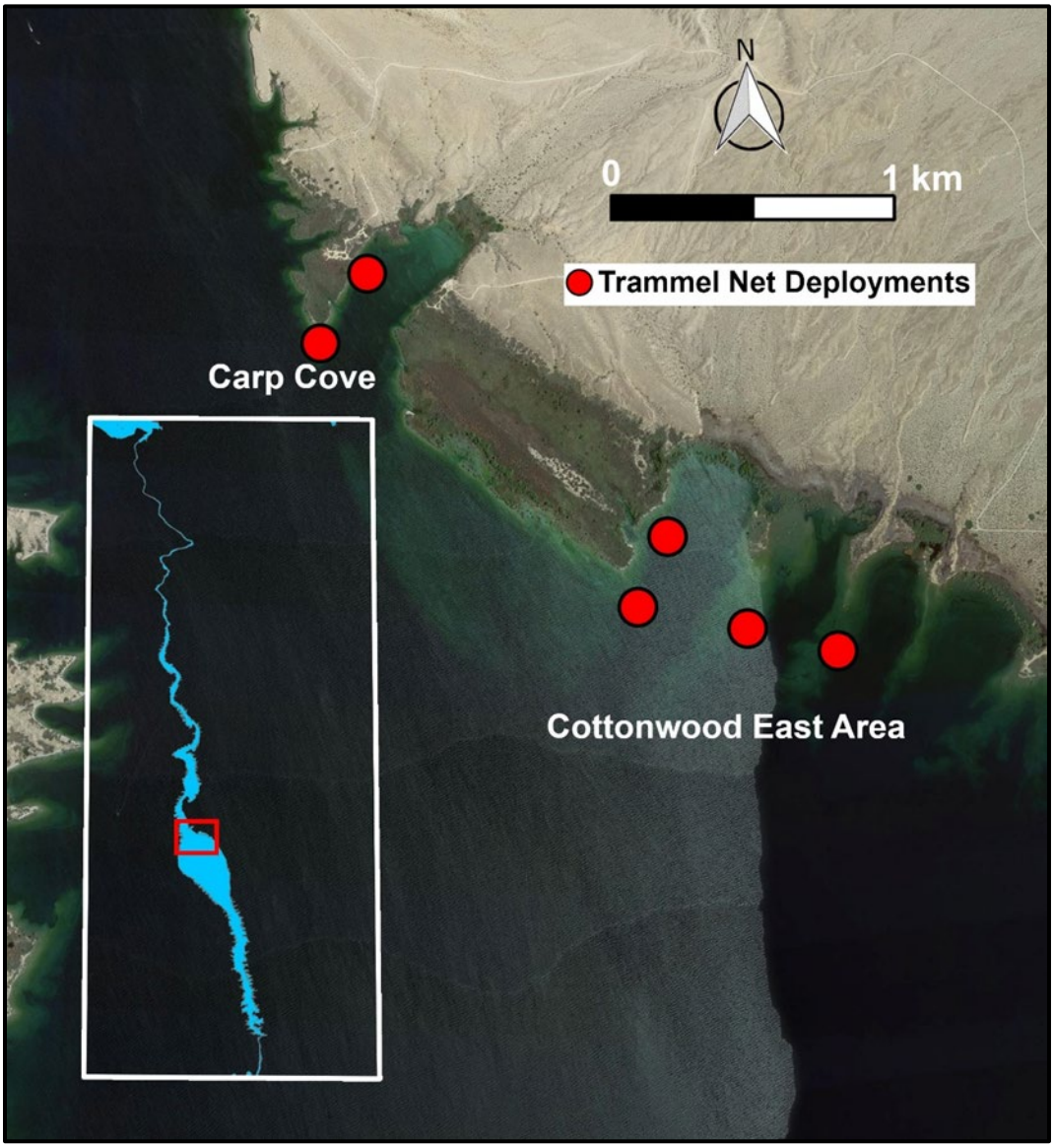

Figure 2.—General locations of trammel nets deployed by M&A during routine monitoring events at Lake Mohave, Arizona and Nevada.

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 (objectives 5), and examining the fish for general health and condition (objective 3). 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 analysis (objective 4; results reported elsewhere by others). All relevant data were entered into the comprehensive Lower Colorado River Native Fish Database maintained by M&A. Beginning in 2007, razorback suckers that were captured without a PIT tag were implanted with a 134.2-kHz PIT tag and labeled as "unknown" in the database to denote an unknown origin. PIT tags that do not have original capture or release data associated with them are also labeled as "unknown."

Remote Monitoring

Remote PIT scanning was conducted in River, Liberty, and Basin in SY 2020. Units were deployed 1 week of every month during the sample season on shallow gravel bars that extended into the Colorado River upstream of Willow Beach (River; objective 6). Two models of submersible PIT scanners 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]). Submersible 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, 28, or 30 ampere-hour lithium-ion battery pack contained in a watertight, 2-inch (5.08-centimeter) PVC pipe. Batteries were changed on a routine basis during sampling trips by checking battery voltage during daily downloads; typically, if a battery was at 7.2 volts or less, a new battery was installed. Generally, 15 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. These locations were initially examined and evaluated in 2011, PIT scanned periodically in 2011 and 2012, and determined to be utilized by razorback suckers at different times of year. These five locations were established as fixed sites to test the hypothesis that razorback sucker aggregation sites change temporally (i.e., seasonally), with large aggregates on Black Bar during spawning, shifting upstream toward Hoover Dam as the spawning season ends. Due to seasonal variation in contact rates, deployment of scanners not at fixed sites varied between trips depending on observed or reported fish concentrations. Fixed sites were scanned continuously each sampling trip and data typically downloaded daily. However, instances occurred when fixed sites

were scanned for multiple days without data being downloaded. For the purpose of analyses, these multi-day efforts were split into daily sub-efforts. PIT scanners were deployed five continuous days during every month of the year. Fixed site data were analyzed by summarizing contact proportions per site and month utilizing violin plots, which are similar to box plots but incorporate a rotated kernel density plot on each side to illustrate the abundance of contacts (more contacts equals wider plots). In addition, mean contacts per site and month were calculated and plotted as a grouped bar chart.

One PIT scanning unit was deployed between trips throughout the season in River above Willow Beach at the Black Bar site and scanned continuously for up to 241 hours. The model used for these deployments was a submersible unit with twice the wire turns as standard units, which resulted in lower power consumption and a longer runtime.

Additional PIT scanning was conducted downstream from Willow Beach to determine if any additional spawning aggregates existed 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 Plateau Cove. Each month, a different reservoir section was selected for PIT scanner deployments by subjectively targeting suspected razorback sucker habitat that was shallow enough for PIT scanner deployment (e.g., shallow wash fans or coves). These areas included shallow gravel bars, cobble substrates, and/or cattail (*Typha* spp.)/bulrush (*Scirpus* spp.) stands where razorback sucker have been observed in the past (J. Stolberg 2016, personal communication).

Reclamation conducted remote PIT scanning in Basin with support from M&A (objective 6). Semipermanent shore-based units were deployed December through early May for continuous scanning to coincide with the spawning season. Shore-based PIT scanners were deployed at Tequila and Yuma Coves. Continuous power was provided to these units using a combination of lead-acid batteries and solar panels. All sites with semipermanent shore-based units were known spawning aggregation sites and had been part of March monitoring efforts since collections began in 1974 (Minckley 1983). Reclamation deployed submersible units primarily at Half-way Wash, Yuma Cove, and Gold Cove.

Information downloaded from PIT 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 scanning interval. Narrative descriptions of weather, riverflows, etc., were recorded on field sheets or in data books.

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 website (http://www.ncreased.net; objective 10).

Maps for this document that used remote scanning data were made using QGIS, version 3.10.12 (QGIS.org 2020). Data manipulation, plotting, and statistical analyses were performed using program R, version 3.5.1 (R Core Team 2018).

In SY 2020, PIT scanners were deployed in Lake Mohave for a total scan time of 27,307 h (figure 3); 5,811 h using shore-based devices and 21,496 h with submersible units. Remote PIT scanning in River resulted in a total scan time of 9,012 h, all with submersible units. Mean deployment time for submersible units was 32.4 h. Remote scanners in Liberty were deployed for a total scan time of 4,009 h, all with submersible units, with a mean deployment time of 48 h. Both shore-based and submersible units were deployed in Basin and accumulated 14,286 total h of scanning: 5,811 h with shore-based and 8,475 h with submersible units with mean deployment times of 363 h and 233 h, respectively. SY 2020 PIT scanner deployments ranged from near Hoover Dam south to Half-way Wash, a range of approximately 78 river kilometers (rkm) (figures 4 and 5).

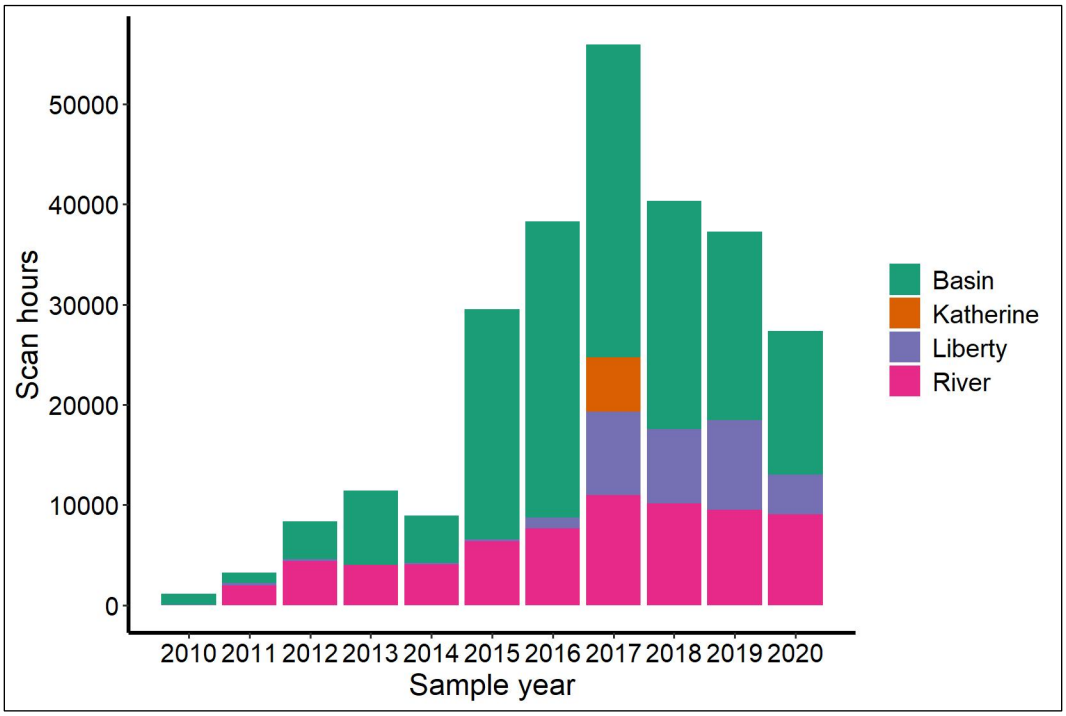

Figure 3.—Relationship between total scan-hours and sample year for submersible and shore-based PIT scanners for each zone, Lake Mohave, Arizona and Nevada.

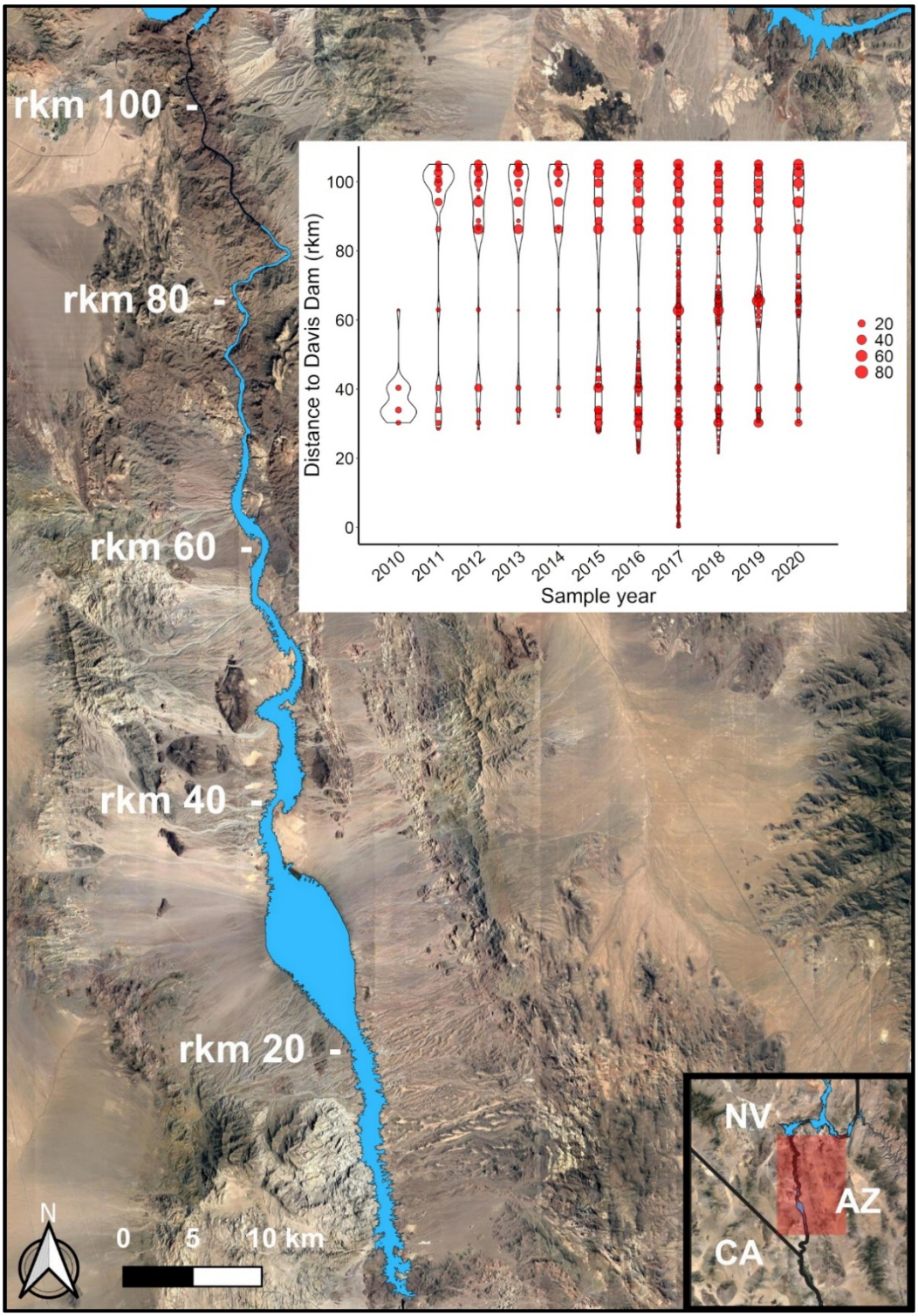

Figure 4.—Relationship between number of submersible and shore-based PIT scanners deployed per location (red circles) and distance to Davis Dam (rkm) from SY 2010 to SY 2020 in Lake Mohave, Arizona and Nevada.

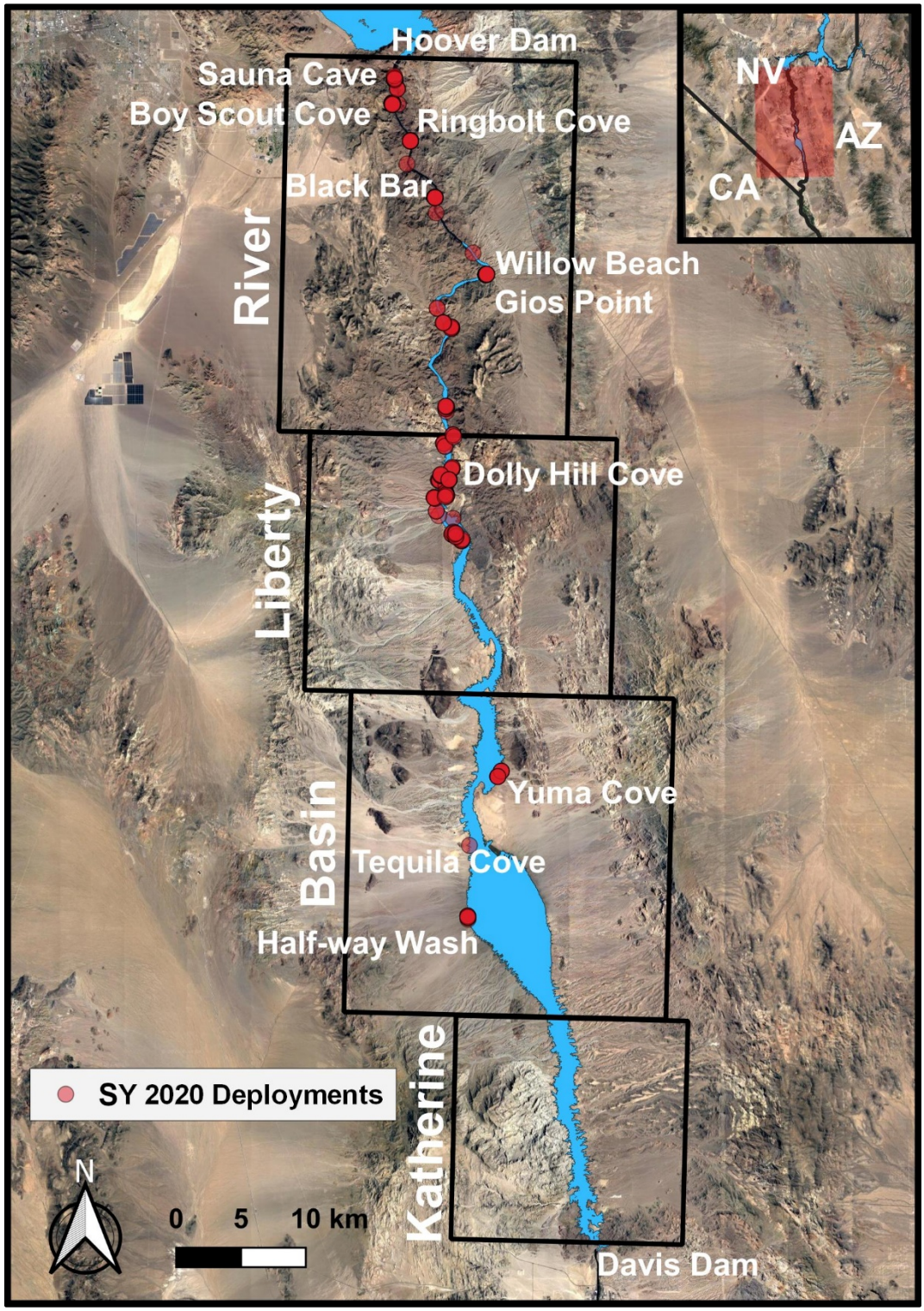

Figure 5.—Locations of M&A and Reclamation remote PIT scanners in River, Liberty, and Basin of Lake Mohave, Arizona and Nevada, SY 2020.

Population Estimates

The razorback sucker population in Lake Mohave was estimated from two data sources (objective 8). 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 9). Second, remote PIT scanning data were used to estimate population size for the lake-wide population as well as River and Basin subpopulations of razorback suckers with 134.2-kHz PIT tags. Remote PIT scanning and routine monitoring data were treated separately for population estimates because some razorback suckers contain only a 400-kHz tag, which is rarely detected by remote PIT scanners. There is also a growing number of "unknown" fish; labelled as "unknown" when they are captured without a detectable PIT tag. Most of these fish are likely repatriate fish that either lost their original PIT tag, or the tag was undetected and a new one was implanted. Separately estimating this population was not informative and sometimes confusing to the reader. Also, very few wild fish are captured or contacted via PIT scanners. Therefore, lake-wide and zone population estimates derived from PIT scanning data are no longer separated between repatriate, wild, and unknown. Wild fish contacted via PIT scanners are noted individually in the "Remote Monitoring" section within the "Results" section.

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 captures 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 sample year was the mark (*M*), the number contacted between October 1 and April 30 in the current sample year was the capture (*C*), and the number in common between both years the recapture (*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, using *R* as the entering variable when recaptures were 50 or less (Ricker 1975, Appendix II), or they were based on the normal distribution for

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

51 or more recaptures (Seber 1973). Estimates with fewer than four recaptures were not reported. The Chapman estimate of large sample variance (Ricker 1975) was used for normal distribution-based CIs.

Displacement

Contact Histories by Zone

Contact histories were examined by tallying contacts by zone. The analysis included hatchery-reared individual razorback suckers stocked from October 1, 2008, through September 30, 2014, 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 were injected with a 134.2-kHz PIT tag and the end of this interval denotes an "enlarging window" to allow enough time for fish to disperse. Razorback suckers stocked from lakeside backwaters were excluded from this analysis because these events occurred only in Basin. The inclusion of lakeside stockings would result in a confounding factor that could not be isolated from the effects of release zone. Individuals with less than 10 contacts were removed from analyses to reduce the probability that the zone of contact was due to chance alone.

Analyses were performed separately for fish stocked into each zone (i.e., River, Liberty, Basin, and Katherine) by pooling data across all stocking locations within each zone (figure 6) and then tabulating all contact history combinations. This same analysis was employed by Burgad et al. (2019) and Miller et al. (2020), and its annual utilization could prove useful in the assessment of displacement patterns through time.

Movement Distance

Maximum (detected) absolute movement distance from stocking location was determined for all available razorback suckers that were implanted with a 134.2-kHz PIT tag and contacted by remote PIT scanners more than 2 years (730 days) after their initial release into Lake Mohave to ensure sufficient time for dispersal. Analyses were performed separately for fish stocked into each zone by pooling data across all stocking locations within each zone. Katherine releases were not included in analysis due to a lack of remote PIT scanning effort there.

Few restrictions were imposed on which fish were included in analyses for several reasons, perhaps foremost of which is that most variables that may influence movement patterns have not been examined and are currently unknown or poorly understood. Therefore, a more comprehensive understanding of razorback sucker movement in Lake Mohave was desired for this preliminary examination. An analogous analysis that related the number of contacts to distance from

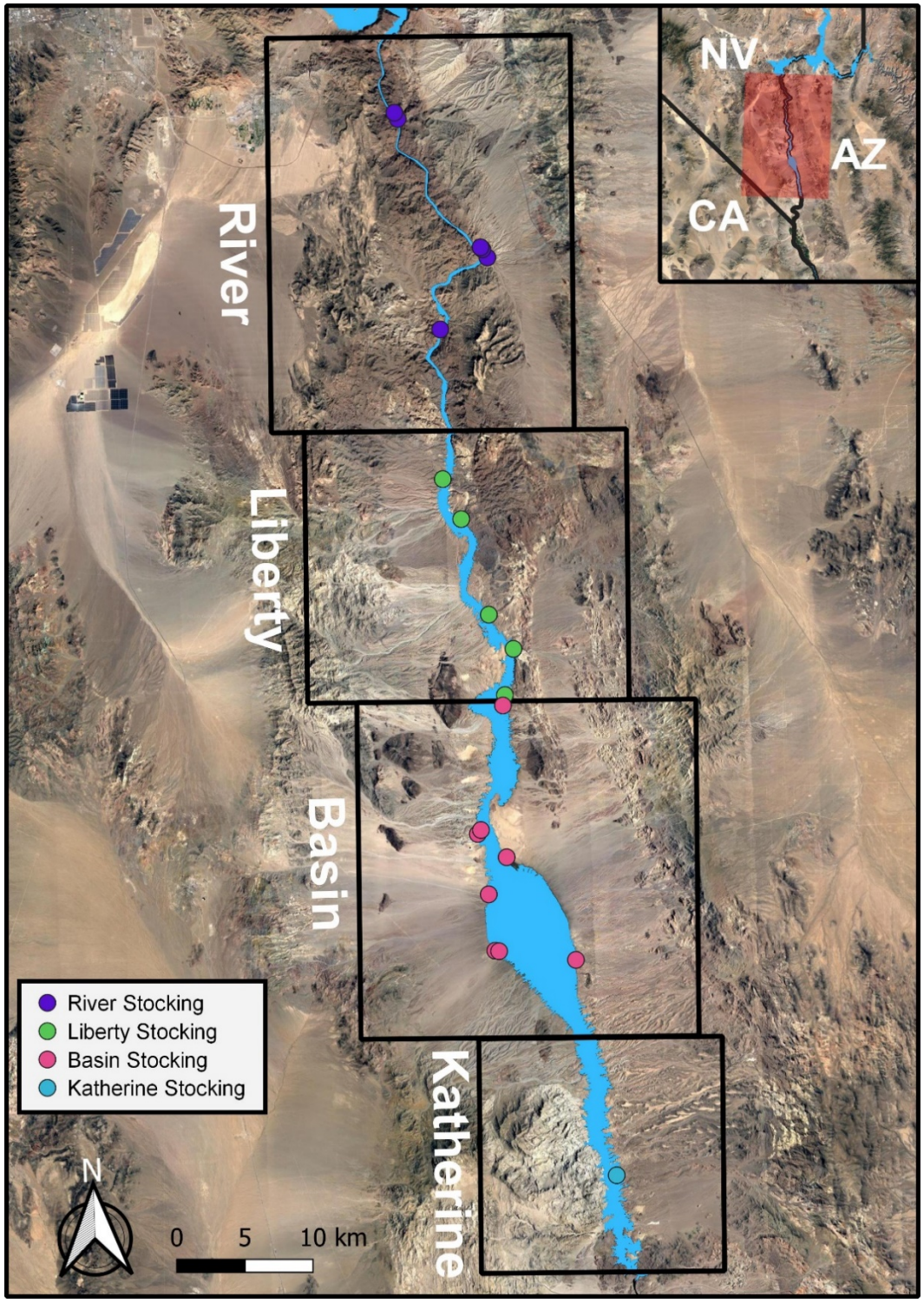

Figure 6.—Stocking locations of hatchery-reared razorback suckers from October 1, 2008, to September 30, 2014, in River, Liberty, Basin, and Katherine of Lake Mohave, Arizona and Nevada; location map inset.

Davis Dam for each stocking zone cohort and incorporated violin plots was performed by Burgad et al. (2019) and Miller et al. (2020). The current analysis significantly differs in that more fish are included in the analysis (all rearing types and broadened date ranges), contacts included in the analysis are deliberately chosen (contact of farthest movement distance), minimum time between stocking and inclusion in analysis (2 years) is calculated on an individual basis, and it is focused on illustrating the farthest extent of (detected) movement for individual razorback suckers.

Although, as stated earlier, most variables effecting displacement are unknown or poorly understood, previous work (e.g., Miller et al. 2020; Wisenall et al. 2015) has suggested that the zone of release has a significant effect on where fish will be found in the future. For this reason, release data were pooled by zone with the expected result that movement patterns would differ among zones.

A combination of QGIS and R was used to calculate movement distances. First, polyline data were obtained from National Hydrography Dataset Plus (NHDPlus), 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 (Tyers 2017) was used to calculate, for each fish, the rkm from Davis Dam for every date of contact made by remote PIT scanners. These values were then compared to stocking rkm values, and the farthest contact from stocking location was calculated for each fish. The maximum distance from a stocking location was plotted into histograms. To visualize contact proportions across the lake, proportional symbol maps of the source data (unique razorback suckers per date) were generated, with larger circles equating to more contacts.

RESULTS

Routine Monitoring

Eighty razorback suckers were captured at two different M&A monitoring events during SY 2020: 28 fish during December 3–6, 2019, and 52 fish during March 17–20, 2020, monitoring activities (table 1). Eight fish were excluded from further analyses because their tagging history was unknown; no PIT tag was detected in seven captures, and one fish had a PIT tag recorded but had no previous record in the database. The remaining 72 captures included two short-term recaptures of the same fish, leaving 70 PIT-tagged fish in total. All 70 fish were repatriated razorback suckers. Sex was determined at both events, and captures included 57 females and 23 males.

Table 1.—Adult razorback sucker monitoring summary by capture month, PIT tag, history, and sex during the SY 2020 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
December 3–6, 2019	28	25	3	24	0	4	23	5	0
March 17–20, 2020	52	48	4	48	0	4	34	18	0
Total	**80**	**73**	**7**	**72**	**0**	**8**	**57**	**23**	**0**

Of the 70 PIT-tagged repatriate razorback suckers with stocking and rearing information, only one was < 350 mm TL at stocking (table 2). Mean TL at stocking was 453 mm and mean TL at capture was 553 mm with 16 fish ≥ 620 mm TL at capture. Fish at large for more than 1 year (n = 30 fish) exhibited growth rates ranging from 1 to 11 mm/months at large. One fish at large for this timeframe appeared to have "lost" length with -6 mm/months at large; this likely represents a TL measurement error. The mean growth rate was approximately 5 mm/months at large. Years at large for all fish ranged from less than 1 to 12 years, with mean time at large of 3 years. Twenty-one fish were captured during SY 2019 monitoring for the first time since being stocked into Lake Mohave; these fish were at large for less than 1 to 10 years prior to their first capture. In SY 2020, 39 fish were captured during monitoring for the first time since being stocked into Lake Mohave; these fish were at large for less than 1 to 12 years prior to their first capture. Sixty-six fish had year-class information, and age at stocking for these fish ranged from approximately 2 to 5 years old.

Select backwaters and offsite facilities contributed 11 and 59 fish to the PIT-tagged repatriates with paired data, respectively (table 3). Of the select backwaters, Arizona Juvenile, Dandy, North Chemehuevi, and Yuma Coves all were represented, and all were stocked into the main channel adjacent to their rearing locations. Offsite facilities included the Achii Hanyo Native Fish Rearing Facility, Lake Mead Fish Hatchery, Overton Wildlife Management Area (Center Pond), and Willow Beach National Fish Hatchery (Willow Beach NFH). Fish reared in select backwaters traveled a mean distance of 8 rkm from the stocking site to the capture site (5–11 rkm minimum-maximum), while the fish reared in offsite facilities traveled a mean distance of 11 rkm (0–68 rkm minimum-maximum). Notably, the fish that traveled the greatest distance was hatchery-reared, released at Ringbolt Rapids in River, and was captured in Basin, having traveled 68 rkm.

Table 2.—Adult razorback sucker monitoring summary of paired stocking-capture data for each fish during the SY 2020 monitoring events, Lake Mohave, Arizona and Nevada
(TL is in mm, growth is in mm/month, and data are in order by capture date.)

PIT	Year class	Age at stocking	Release Date	Capture Date	Sex	Years at large	Captures	Release TL	Capture TL	Growth
36F2B5A70C	2010	2	12/6/2012	12/3/2019	F	7	1	385	598	2
003D4F6962	2015	4	4/18/2019	12/3/2019	F	1	1	488	542	7
003D4F421B	2015	4	4/17/2019	12/3/2019	M	1	1	450	510	8
003C072D27	2015	4	4/5/2019	12/3/2019	F	1	1	498	545	6
003C072D17	2015	4	4/5/2019	12/3/2019	F	1	2	493	565	9
003C06D3FD	2015	2	12/15/2017	12/3/2019	M	2	1	440	487	2
003BF3216A	2016	3	1/31/2019	12/3/2019	M	1	1	440	535	10
003BF31B85	2016	3	1/31/2019	12/3/2019	F	1	2	436	550	11
1C2D746B16	2005	5	1/7/2010	12/4/2019	F	10	1	475	649	1
003C06CC89	2014	4	5/9/2018	12/4/2019	F	2	1	457	575	6
003D4F41F4	2015	4	4/17/2019	12/4/2019	F	1	1	468	564	12
003D4F7689	2015	4	4/17/2019	12/4/2019	M	1	1	448	528	10
003C070259	2015	4	4/5/2019	12/4/2019	F	1	1	443	547	13
003C0736F7	2015	4	4/5/2019	12/4/2019	F	1	1	483	519	4
003C073A7A	2015	4	4/5/2019	12/4/2019	M	1	1	448	516	8
1B796EEE30	2009	4	5/22/2013	12/5/2019	F	6	1	445	646	2
003D4F6840	2015	4	4/17/2019	12/5/2019	F	1	1	452	500	6
003C0738DF	2015	4	4/5/2019	12/5/2019	F	1	1	510	567	7
003C073ADC	2015	4	4/5/2019	12/5/2019	F	1	1	512	587	9
003BF3189E	2016	3	1/31/2019	12/5/2019	F	1	1	446	565	12
003BF32045	2016	3	1/31/2019	12/5/2019	F	1	1	427	536	11
003C073A55	2015	4	4/5/2019	12/6/2019	F	1	1	413	568	19
003C06CAA8	2015	2	12/15/2017	12/6/2019	F	2	1	445	585	6
1B796EE6D4	2009	4	5/22/2013	3/17/2020	F	7	1	455	645	2
003D4F484E	2015	4	4/17/2019	3/17/2020	M	1	1	436	540	9
003C07023B	2015	4	4/5/2019	3/17/2020	F	1	1	487	570	7
003C07025B	2015	4	4/5/2019	3/17/2020	F	1	1	450	550	8
003C06D1C8	2015	2	12/8/2017	3/17/2020	F	2	1	471	620	5
003D7690F0	2016	3	12/13/2019	3/17/2020	M	0	1	354	355	0
003D4F52E5	2016	3	12/11/2019	3/17/2020	F	0	1	488	490	1
003D4F701F	2016	3	12/11/2019	3/17/2020	M	0	1	479	490	4
003D4F704D	2016	3	12/11/2019	3/17/2020	F	0	1	562	555	-2
36F2B2762C	-	-	5/23/2012	3/17/2020	F	8	2	383	625	2
1C2D67715E	2005	5	1/7/2010	3/18/2020	F	10	1	440	660	2
1C2D639AA1	2006	4	1/6/2010	3/18/2020	F	10	1	400	695	2
1C2D2647CD	2008	2	12/16/2010	3/18/2020	M	9	1	310	610	3

Table 2.—Adult razorback sucker monitoring summary of paired stocking-capture data for each fish during the SY 2020 monitoring events, Lake Mohave, Arizona and Nevada

(TL is in mm, growth is in mm/month, and data are in order by capture date.)

PIT	Year class	Age at stocking	Release Date	Capture Date	Sex	Years at large	Captures	Release TL	Capture TL	Growth
1B796EF281	2009	4	10/31/2013	3/18/2020	F	6	1	500	650	2
003BA653E9	2011	3	5/8/2014	3/18/2020	M	6	1	418	620	3
003D4F558D	2015	4	4/18/2019	3/18/2020	F	1	1	442	555	10
003C072941	2015	4	4/5/2019	3/18/2020	F	1	1	517	595	6
003C07332F	2015	4	4/5/2019	3/18/2020	F	1	1	460	550	8
003C0738D3	2015	4	4/5/2019	3/18/2020	F	1	2	490	570	7
003C06D20F	2015	2	12/15/2017	3/18/2020	F	2	1	465	625	6
003D76ECB6	2016	3	12/13/2019	3/18/2020	M	0	1	401	405	1
003D4F5316	2016	3	12/12/2019	3/18/2020	M	0	1	481	485	1
003D4F46C3	2016	3	12/11/2019	3/18/2020	F	0	1	478	480	1
003C07B2B6	2016	3	10/3/2019	3/18/2020	F	0	1	530	545	2
003BF318A5	2016	3	1/31/2019	3/18/2020	F	1	1	437	550	8
1C2D681706	2005	5	1/7/2010	3/19/2020	F	10	3	450	618	2
1C2D635C66	2006	4	1/6/2010	3/19/2020	F	10	2	390	660	2
003BA744B7	2011	3	5/14/2014	3/19/2020	M	6	1	419	610	3
003C06CFB1	2015	2	12/15/2017	3/19/2020	F	2	1	460	600	5
003D76E92F	2016	3	12/13/2019	3/19/2020	M	0	1	477	475	-1
003BF31AAA	2016	3	1/31/2019	3/19/2020	M	1	1	440	530	6
003BF32023	2016	3	1/31/2019	3/19/2020	M	1	1	421	525	7
003BA639B3	-	-	11/7/2014	3/19/2020	F	5	2	570	640	1
36F2B263D6	-	-	10/22/2012	3/19/2020	F	7	2	520	675	2
1C2D05BFB1	2007	4	5/11/2011	3/20/2020	F	9	2	450	675	2
003BCC6308	2012	3	1/12/2015	3/20/2020	F	5	1	410	615	3
003C06CDE3	2015	2	12/15/2017	3/20/2020	F	2	2	470	650	6
003D768D30	2016	3	12/13/2019	3/20/2020	F	0	1	430	435	2
003D76E516	2016	3	12/13/2019	3/20/2020	F	0	1	400	405	2
003D4F4929	2016	3	12/12/2019	3/20/2020	F	0	1	469	465	-1
003D4F5111	2016	3	12/12/2019	3/20/2020	M	0	1	430	430	0
003D4F703C	2016	3	12/11/2019	3/20/2020	M	0	1	485	475	-3
003D4F73E8	2016	3	12/9/2019	3/20/2020	M	0	1	381	390	3
003D4F7563	2016	3	12/9/2019	3/20/2020	M	0	1	387	395	3
003BF3207D	2016	3	1/31/2019	3/20/2020	F	1	1	423	580	11
003BF323FC	2016	3	1/31/2019	3/20/2020	M	1	1	465	385	-6
1C2C85193A	-	-	5/13/2008	3/20/2020	F	12	1	555	660	1

Table 3.—Stocking and capture location summary by rearing type of paired stocking-capture data from adult razorback sucker monitoring summary during the SY 2020 monitoring events, Lake Mohave, Arizona and Nevada

(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 = the number of fish.)

Rearing		Stocking			Capture			Distance (rkm)	n
Type	Location	Location	rkm	Zone	Location	rkm	Zone		
Offsite facilities	Achii Hanyo Native Fish Rearing Facility	Cottonwood Cove	36	Basin	Cottonwood Valley Cove	32	Basin	4	1
	Lake Mead Fish Hatchery	Cottonwood Cove	36	Basin	Carp Cove	34	Basin	2	2
	Lake Mead Fish Hatchery	Cottonwood Cove	36	Basin	Cottonwood Valley Cove	32	Basin	4	1
	Lake Mead Fish Hatchery	Cottonwood Cove	36	Basin	Waterwheel Cove	32	Basin	4	2
	Lake Mead Fish Hatchery	Half-way Wash	30	Basin	Waterwheel Cove	32	Basin	2	5
	Lake Mead Fish Hatchery	Placer Cove	64	River	Waterwheel Cove	32	Basin	32	2
	Lake Mead Fish Hatchery	Sandy Point Cove	33	Basin	Carp Cove	34	Basin	1	2
	Lake Mead Fish Hatchery	Sandy Point Cove	33	Basin	Tequila Cove	34	Basin	1	1
	Lake Mead Fish Hatchery	Sandy Point Cove	33	Basin	Waterwheel Cove	32	Basin	1	2
	Lake Mead Fish Hatchery	Tequila Cove	34	Basin	Waterwheel Cove	32	Basin	2	1
	Lake Mead Fish Hatchery	Yuma Cove	39	Basin	Carp Cove	34	Basin	5	2
	Lake Mead Fish Hatchery	Yuma Cove	39	Basin	Waterwheel Cove	32	Basin	7	6
	Overton Wildlife Management Area	Yuma Cove	39	Basin	Carp Cove	34	Basin	5	1
	Willow Beach NFH	Cottonwood Cove	36	Basin	Carp Cove	34	Basin	2	2
	Willow Beach NFH	Cottonwood Cove	36	Basin	Waterwheel Cove	32	Basin	4	1
	Willow Beach NFH	Dolly Hill Cove	66	River	Carp Cove	34	Basin	32	1
	Willow Beach NFH	Dolly Hill Cove	66	River	Waterwheel Cove	32	Basin	34	1
	Willow Beach NFH	Half-way Wash	30	Basin	Carp Cove	34	Basin	4	1
	Willow Beach NFH	Half-way Wash	30	Basin	Tequila Cove	34	Basin	4	1
	Willow Beach NFH	Half-way Wash	30	Basin	Waterwheel Cove	32	Basin	2	3
	Willow Beach NFH	Liberty Cove	63	Basin	Carp Cove	34	Basin	29	1
	Willow Beach NFH	Liberty Cove	63	Basin	Waterwheel Cove	32	Basin	31	1

Table 3.—Stocking and capture location summary by rearing type of paired stocking-capture data from adult razorback sucker monitoring summary during the SY 2020 monitoring events, Lake Mohave, Arizona and Nevada

(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 = the number of fish.)

Rearing		Stocking			Capture			Distance (rkm)	n
Type	Location	Location	rkm	Zone	Location	rkm	Zone		
Offsite facilities (continued)	Willow Beach NFH	North Nine Mile Coves	28	Basin	Waterwheel Cove	32	Basin	4	2
	Willow Beach NFH	Pot Cove	32	Basin	Carp Cove	34	Basin	2	1
	Willow Beach NFH	Pot Cove	32	Basin	Waterwheel Cove	32	Basin	0	4
	Willow Beach NFH	Ringbolt Rapids	100	River	Waterwheel Cove	32	Basin	68	1
	Willow Beach NFH	Tequila Cove	34	Basin	Carp Cove	34	Basin	0	1
	Willow Beach NFH	Tequila Cove	34	Basin	Tequila Cove	34	Basin	0	1
	Willow Beach NFH	Tequila Cove	34	Basin	Waterwheel Cove	32	Basin	2	1
	Willow Beach NFH	Willow Beach NFH	87	River	Waterwheel Cove	32	Basin	55	3
	Willow Beach NFH	Yuma Cove	39	Basin	Carp Cove	34	Basin	5	3
	Willow Beach NFH	Yuma Cove	39	Basin	Waterwheel Cove	32	Basin	7	2
Select backwaters	Arizona Juvenile	Arizona Juvenile	24	Basin	Waterwheel Cove	32	Basin	8	3
	Dandy Cove	Dandy Cove	27	Basin	Waterwheel Cove	32	Basin	5	2
	North Chemehuevi Cove	Chemehuevi Cove	21	Basin	Waterwheel Cove	32	Basin	11	2
	North Chemehuevi Cove	North Chemehuevi Cove	21	Basin	Waterwheel Cove	32	Basin	11	2
	Yuma Cove	Yuma Cove	39	Basin	Waterwheel Cove	32	Basin	7	2
Mean dispersal distance (kilometers)								**11**	

Remote Monitoring

SY 2020 PIT scanning efforts resulted in 294,574 total contacts (all species), 5,960 of which were unique PIT tags, with 5,914 of those having a record in the Lower Colorado River Native Fish Database. This includes 43 double PIT tag contacts (2 tags in the same fish). The 5,871 fish contacted in SY 2020

included 5,796[2] repatriates, 8 wild, and 66 unknown origin razorback suckers. One repatriate bonytail, released in May 2018, was contacted on January 21 and 22, 2020.

River PIT scanner deployments resulted in a total of 26,229 contacts from 2,590 unique PIT tags, of which 2,580 had a record in the Lower Colorado River Native Fish Database (figure 7). This total included 30 double PIT tag contacts. All fish contacted in River were razorback suckers; 2,535 repatriate, 6 wild, and 9 of unknown origin. In Liberty, 79 PIT tag contacts were recorded, representing 22 unique PIT tags, all of which had a record in the Lower Colorado River Native Fish Database. Of the unique fishes contacted in Liberty, 21 were razorback suckers, and 1 was a bonytail (all repatriates). In Basin, 268,266 contacts were recorded, representing 3,617 unique PIT tags for which 3,581 had a record in the Lower Colorado River Native Fish Database, including 14 double PIT tag contacts. One fish was included in River and Basin double tag contacts because both tag numbers, 003BA616F0 and 003BEA573A, were contacted in Basin and River during SY 2020. All fish contacted in Basin were razorback suckers (3,504 repatriates, 3 wild, and 60 of unknown origin).

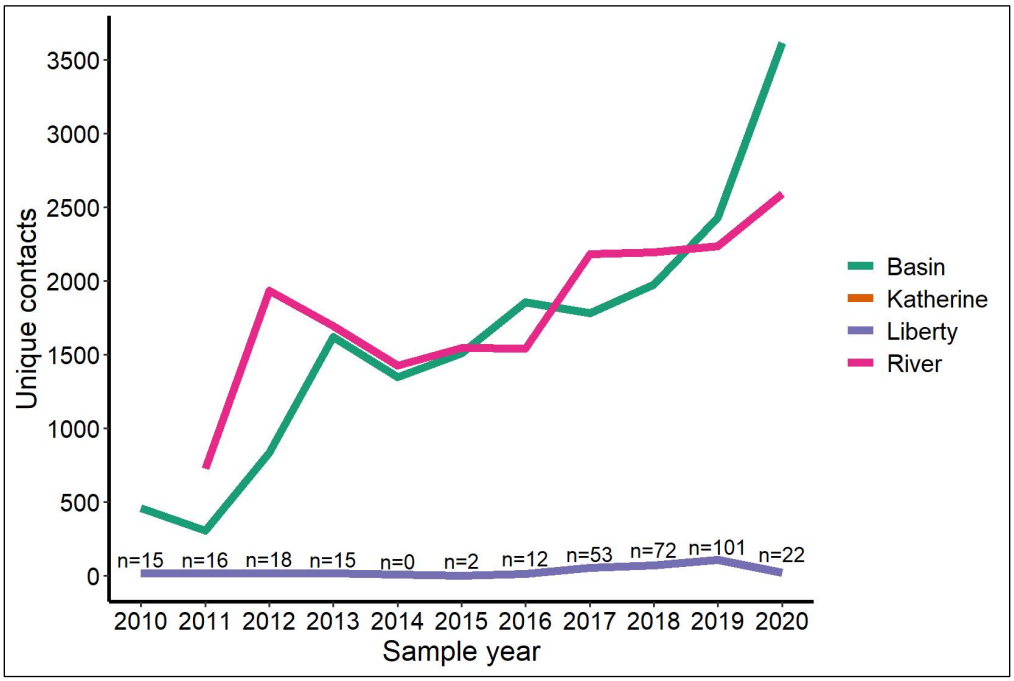

Figure 7.—Total number of unique razorback sucker contacts in each zone from SY 2010 to SY 2020 in Lake Mohave, Arizona and Nevada.
n = the number of unique contacts in Liberty; Katherine is overlapping with Liberty in 2017; the total number of unique contacts (n = 59) is not visible.

[2] The total number of razorback suckers contacted in a single sample year often exceeds the population estimate because a large number of fish are contacted within the first few months after release, and these fish are not included as part of the population estimate because their immediate post-release mortality is high. See the "Methods" section for specific criteria.

Fixed site analysis in River concluded that fish were contacted most prevalently during spawning (December, January, February, March), with fish gradually leaving afterward (figure 8). This pattern is most obvious in the Black Bar site, where most contacts in River occur, and is less obvious for the other sites.

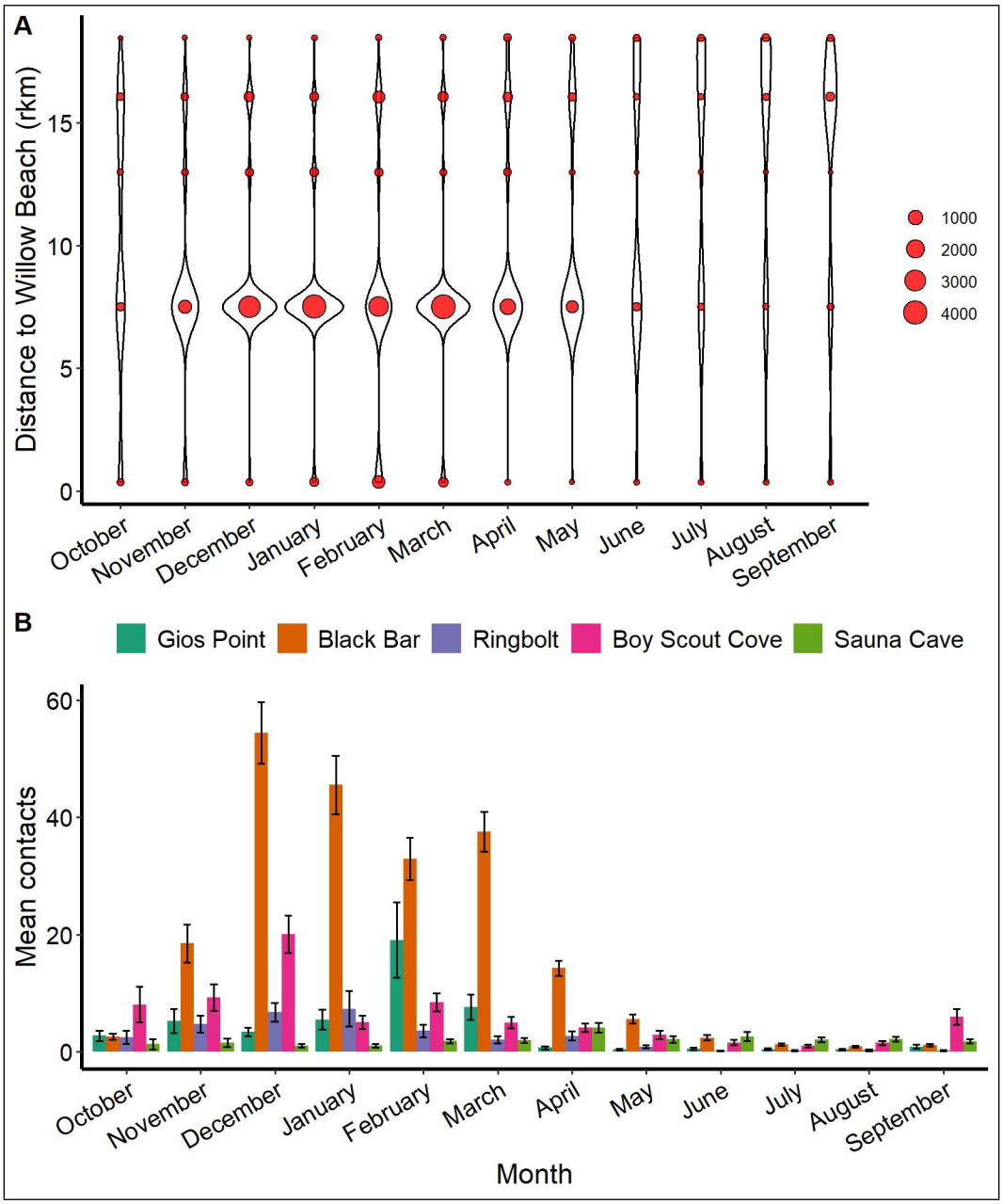

Figure 8.—Spatial distribution of contacts (red circles; A) and mean unique razorback sucker PIT tag contacts (B) recorded from January 2014 to September 2020 at five fixed stations in River, Lake Mohave, Arizona and Nevada. Error bars represent ±1 standard error.

Population Estimates

Routine Monitoring

Too few wild razorback suckers were encountered during routine monitoring in SY 2020 to estimate their abundance (n = 0). The repatriated razorback sucker population in 2019, based on 2019 and 2020 March monitoring data, was estimated at 1,559 fish (95% CI from 967 to 2,653).

Remote Monitoring

Based on SY 2019 and SY 2020 remote PIT scanning, the 134.2-kHz PIT-tagged Lake Mohave population for 2019 was estimated at 3,906 individuals (95% CI from 3,789 to 4,022; table 4; figure 9). Population estimates using zone-specific scanning for 2019 estimated the River population at 2,014 (95% CI from 1,896 to 2,131; table 5; figure 9) and the Basin population at 1,901 (95% CI from 1,856 to 1,945).

Table 4.—Lake-wide population estimates based on remote PIT scanning data

Year	*M*	*C*	*R*	Estimate (95% CI)
2010	110	141	29	525 (360–698)
2011	299	1,446	200	2,159 (1,882–2,435)
2012	1,139	2,006	872	2,620 (2,489–2,750)
2013	1,866	2,055	1,283	2,989 (2,888–3,089)
2014	1,669	2,495	1,243	3,350 (3,218–3,481)
2015	2,058	2,782	1,613	3,550 (3,437–3,662)
2016	2,171	3,072	1,775	3,758 (3,644–3,871)
2017	2,052	3,080	1,784	3,543 (3,436–3,649)
2018	2,403	3,116	2,078	3,604 (3,514–3,693)
2019	2,265	3,126	1,813	3,906 (3,789–4,022)

Table 5.—Subpopulation estimates based on remote PIT scanning data

Zone	Year	*M*	*C*	*R*	Estimate (95% CI)
River	2011	228	884	148	1,360 (1,161–1,558)
	2012	572	992	395	1,436 (1,326–1,545)
	2013	908	1,074	551	1,770 (1,667–1,872)
	2014	712	1,316	507	1,848 (1,722–1,973)
	2015	1,010	1,324	724	1,847 (1,756–1,937)
	2016	801	1,758	697	2,021 (1,904–2,137)
	2017	834	1,638	747	1,829 (1,732–1,925)
	2018	1,035	1,646	931	1,830 (1,752–1,907)
	2019	815	1,648	667	2,014 (1,896–2,131)
Basin	2010	110	80	29	299 (215–382)
	2011	62	574	50	710 (525–894)
	2012	568	1,092	507	1,224 (1,146–1,301)
	2013	993	1,030	774	1,322 (1,275–1,368)
	2014	972	1,282	793	1,572 (1,504–1,639)
	2015	1,084	1,569	985	1,727 (1,692–1,761)
	2016	1,411	1,487	1,254	1,674 (1,637–1,710)
	2017	1,237	1,675	1,198	1,730 (1,677–1,782)
	2018	1,468	1,722	1,464	1,727 (1,692–1,761)
	2019	1,536	1,627	1,315	1,901 (1,856–1,945)

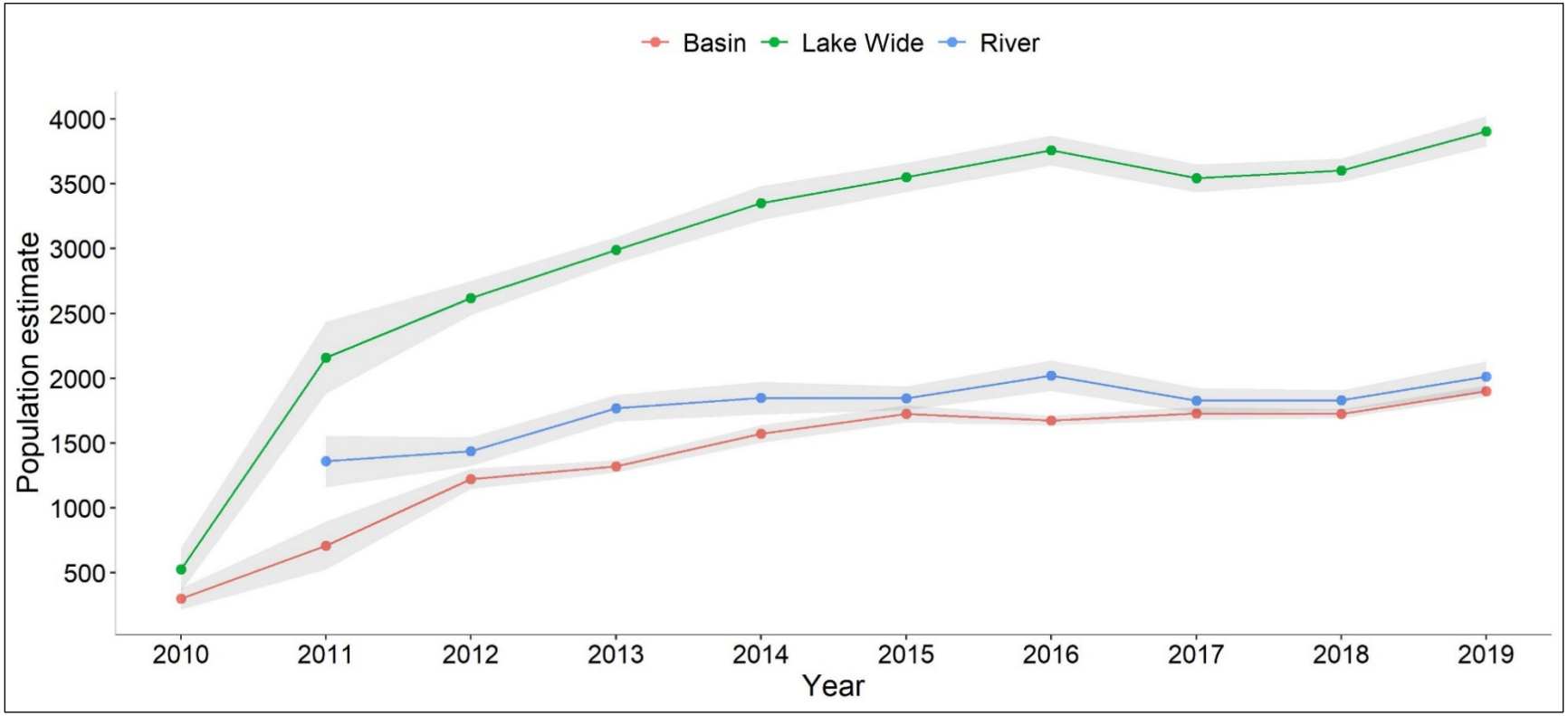

Figure 9.—Razorback sucker population estimates derived from PIT scanning data from 2010 to 2020 in Lake Mohave, Arizona and Nevada.
The shaded area represents lower and upper 95% CIs.

Displacement

Contact Histories by Zone

A total of 65,046 hatchery-reared razorback suckers were stocked into Lake Mohave from October 2008 to September 2014.[3] From these fish, 309,298 contacts were recorded from SY 2014 to SY 2020, representing 2,540 unique individuals. After removal of individuals with fewer than 10 contacts, 2,066 unique fish with a total of 306,871 contacts remained for use in zone-specific summaries. Of the 2,066 unique fish contacted, 1,430 (69.2%) were contacted in one zone, 600 (29.0%) were contacted in two zones, 36 (1.7%) were contacted in three zones, and none were contacted in all four zones.

In River, there were 6 stocking locations from which 25,904 razorback suckers were released from October 2008 to September 2014. A total of 102,300 contacts were recorded from fish released into River, representing 1,383 unique fish (table 6). Of the 102,300 contacts, 70,193 (1,324 fish) were in River, 117 (67 fish) were in Liberty, 31,986 (442 fish) were in Basin, and 4 (3 fish) were in Katherine. Most River releases were contacted only in River (64.9%; table 6); however, a substantial proportion of razorback suckers were detected in Basin (31.9%).

Table 6.—Summary of contact histories for unique razorback suckers stocked into River from October 2008 to September 2014 in Lake Mohave, Arizona and Nevada (Combination refers to each scenario for contact histories; if fish were contacted in a particular zone, it is denoted [X] and summarized by number contacted [n] and percent for each contact history combination.)

Combination	River	Liberty	Basin	Katherine	n	%
1	-	-	X	-	59	4.3
2	X	-	-	-	897	64.9
3	X	-	-	X	1	0.1
4	X	-	X	-	357	25.8
5	X	-	X	X	2	0.1
6	X	X	-	-	43	3.1
7	X	X	X	-	24	1.7
				Total	**1,383**	**100**

[3] Total releases are based on records of release in the Lower Colorado River Native Fish Database. These numbers may be lower than actual numbers released due to errors in data collection and/or data entry.

In Liberty, there were 5 stocking locations from which 12,912 razorback suckers were released from October 2008 to September 2014. A total of 34,475 contacts were recorded from fish released into Liberty, representing 217 individual razorback suckers (table 7). Of the total 34,475 contacts, 5,892 (153 fish) were in River, 56 (13 fish) were in Liberty, 28,522 (141 fish) were in Basin, and 5 (1 fish) were in Katherine. A small percentage of fish were detected exclusively in Liberty (0.5%; table 7), and most fish were not contacted in Liberty at all (94%). Detection of fish in River (31.8%), Basin (26.7%), and both River and Basin (35.0%) were analogous (table 7).

Table 7.—Summary of contact histories for unique razorback suckers stocked into Liberty from October 2008 to September 2014 in Lake Mohave, Arizona and Nevada (Combination refers to each scenario for contact histories; if fish were contacted in a particular zone, it is denoted [X] and summarized by number contacted [n] and percent for each contact history combination.)

Combination	River	Liberty	Basin	Katherine	n	%
1	-	-	X	-	58	26.7
2	-	-	X	X	1	0.5
3	-	X	-	-	1	0.5
4	-	X	X	-	4	1.8
5	X	-	-	-	69	31.8
6	X	-	X	-	76	35.0
7	X	X	-	-	6	2.8
8	X	X	X	-	2	0.9
				Total	**217**	**100**

In Basin, there were 9 stocking locations from which 16,413 fish were released from October 2008 to September 2014. A total of 157,021 contacts were recorded from fish released into Basin, representing 425 razorback suckers (table 8). Of the 157,021 total contacts, 3,857 (134 fish) were in River, 11 (10 fish) were in Liberty, 153,138 (398 fish) were in Basin, and 15 (3 fish) were in Katherine. Most Basin releases were contacted only in Basin (67.3%; table 8); however, a substantial proportion of razorback suckers were detected in River (31.6%).

Table 8.—Summary of contact histories for unique razorback suckers stocked into Basin from October 2008 to September 2014 in Lake Mohave, Arizona and Nevada

(Combination refers to each scenario for contact histories; if fish were contacted in a particular zone, it is denoted [X] and summarized by number contacted [n] and percent for each contact history combination.)

Combination	River	Liberty	Basin	Katherine	n	%
1	-	-	X	-	286	67.3
2	-	-	X	X	1	0.2
3	-	X	X	-	4	0.9
4	X	-	-	-	27	6.4
5	X	-	X	-	99	23.3
6	X	-	X	X	2	0.5
7	X	X	X	-	6	1.4
				Total	**425**	**100**

In Katherine, there was 1 stocking location from which 9,817 fish were released from October 2008 to September 2014. A total of 13,075 contacts were recorded from fish released into Katherine, representing 41 razorback suckers (table 9). Of the 13,075 contacts, 1,502 (10 fish) were in River, none were in Liberty, 11,562 (37 fish) were in Basin, and 11 (2 fish) were in Katherine. Most Katherine releases were detected in Basin (90%), but a significant proportion of fish were detected in River as well (24.4%). Only two (4.9%; table 9) fish were contacted in Katherine, although it should be noted that remote PIT scanning effort in this zone only occurred in SY 2017, potentially introducing a negative contact bias.

Table 9.—Summary of contact histories for unique razorback suckers stocked into Katherine from October 2008 to September 2014 in Lake Mohave, Arizona and Nevada (Combination refers to each scenario for contact histories; if fish were contacted in a particular zone it is denoted [X] and summarized by number contacted [n] and percent for each contact history combination.)

Combination	River	Liberty	Basin	Katherine	n	%
1	-	-	X	-	29	70.7
2	-	-	X	X	2	4.9
3	X	-	-	-	4	9.8
4	X	-	X	-	6	14.6
				Total	**41**	**100**

Movement Distance

Of 101,592[4] razorback suckers stocked with a 134.2-kHz PIT tag into Lake Mohave (excluding Katherine releases) from SY 2006 to SY 2020, 9,304 fish were contacted by remote PIT scanners from SY 2010 to SY 2020. After exclusion of contacts that were made less than 2 years after stocking (see the "Methods" section), 4,477 fish remained for analyses.

In River, there were 8 stocking locations from which 34,881 razorback suckers were stocked from SY 2006 to SY 2020; 2,220 fish were included in the analysis, with a total of 170,490 contacts. The majority (70.2%) of farthest movement distances occurred near the location of release (0 to 20 kilometers [km]), but a substantial proportion (25.6%) occurred farther away (40 to 60 km), resulting in a bimodal distribution (figures 10 and 11). Distances of 0 to 20 km and 40 to 60 km are generally representative of fish that were only contacted in River and fish that dispersed to Basin, respectively.

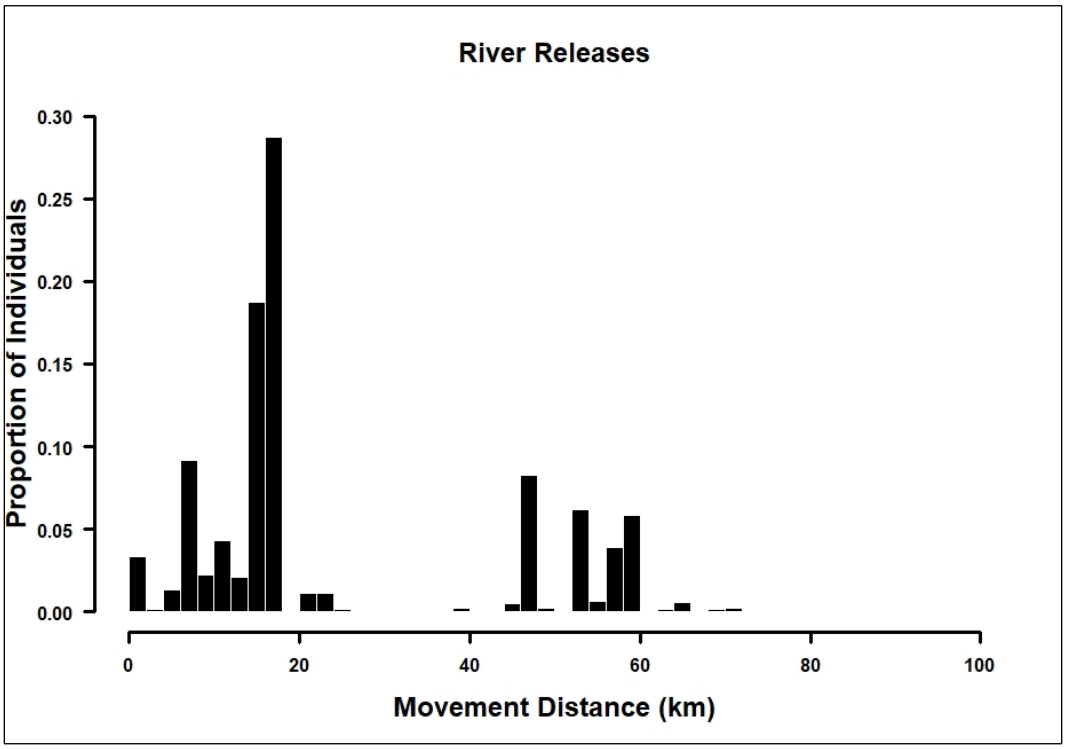

Figure 10.—Farthest absolute movement distance from release location of razorback suckers stocked into River as detected by remote PIT scanners in Lake Mohave, Arizona and Nevada.

[4] Total releases are based on records of release in the Lower Colorado River Native Fish Database. These numbers may be lower than actual numbers released due to errors in data collection and/or data entry.

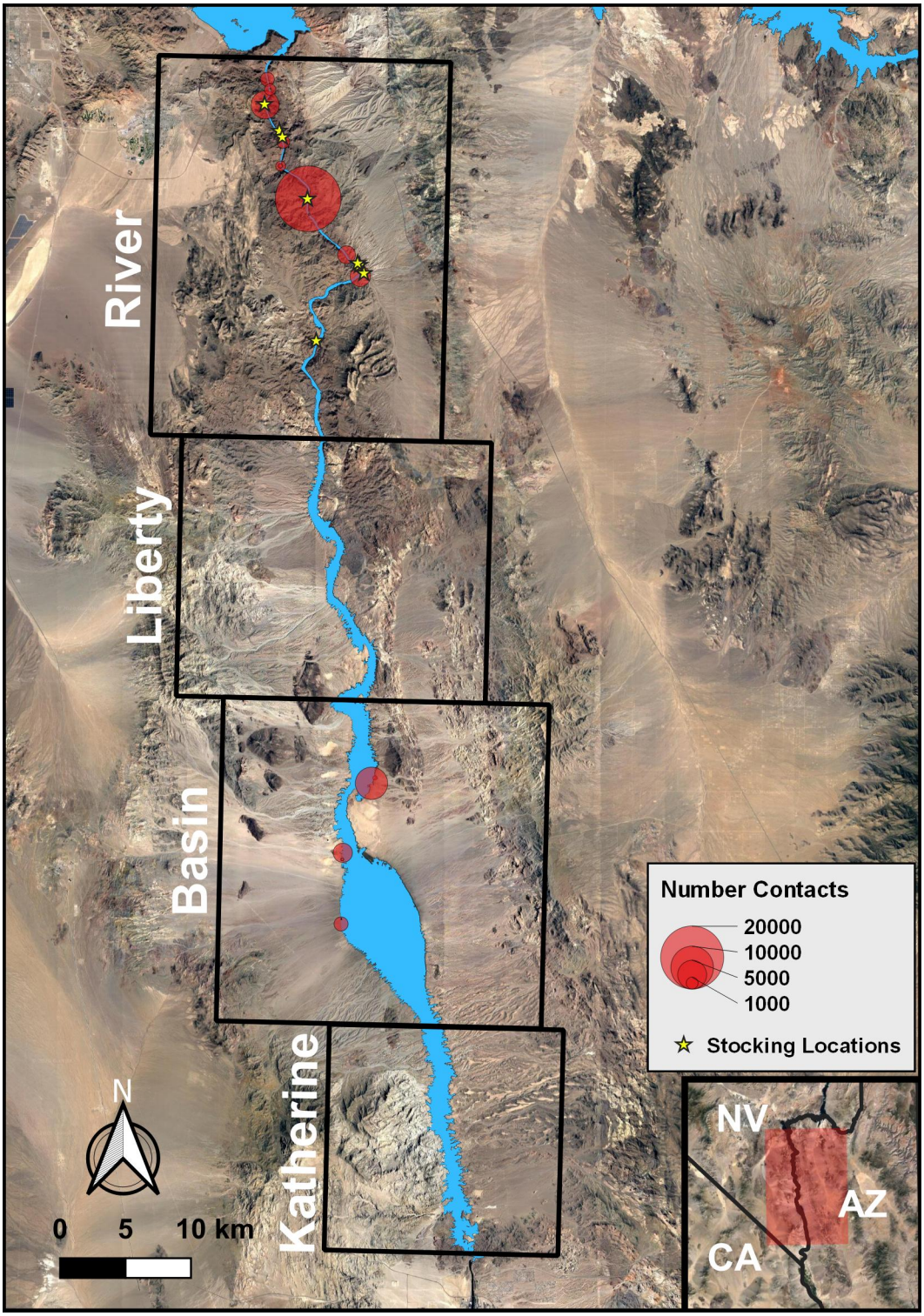

Figure 11.—Proportion of daily unique contacts made by remote PIT scanners (red circles) for razorback suckers stocked into River, Lake Mohave, Arizona and Nevada.

In Liberty, there were 8 stocking locations with 21,472 razorback suckers stocked from SY 2006 to SY 2020; 345 fish were included in the analysis, with a total of 67,807 contacts. Nearly all (93.9%) farthest movement distances occurred relatively far from location of release (20 to 60 km), resulting in a more unimodal distribution (figures 12 and 13), and is generally representative of fish dispersing to River and Basin.

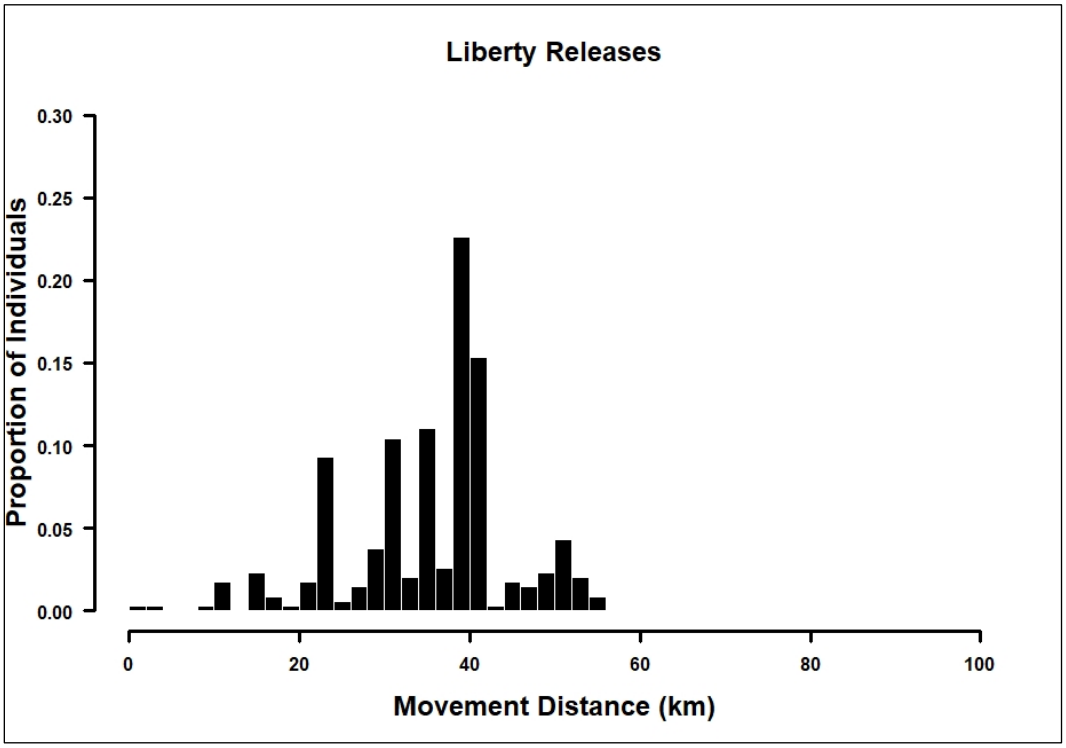

Figure 12.—Farthest absolute movement distance from release location of razorback suckers stocked into Liberty as detected by remote PIT scanners in Lake Mohave, Arizona and Nevada.

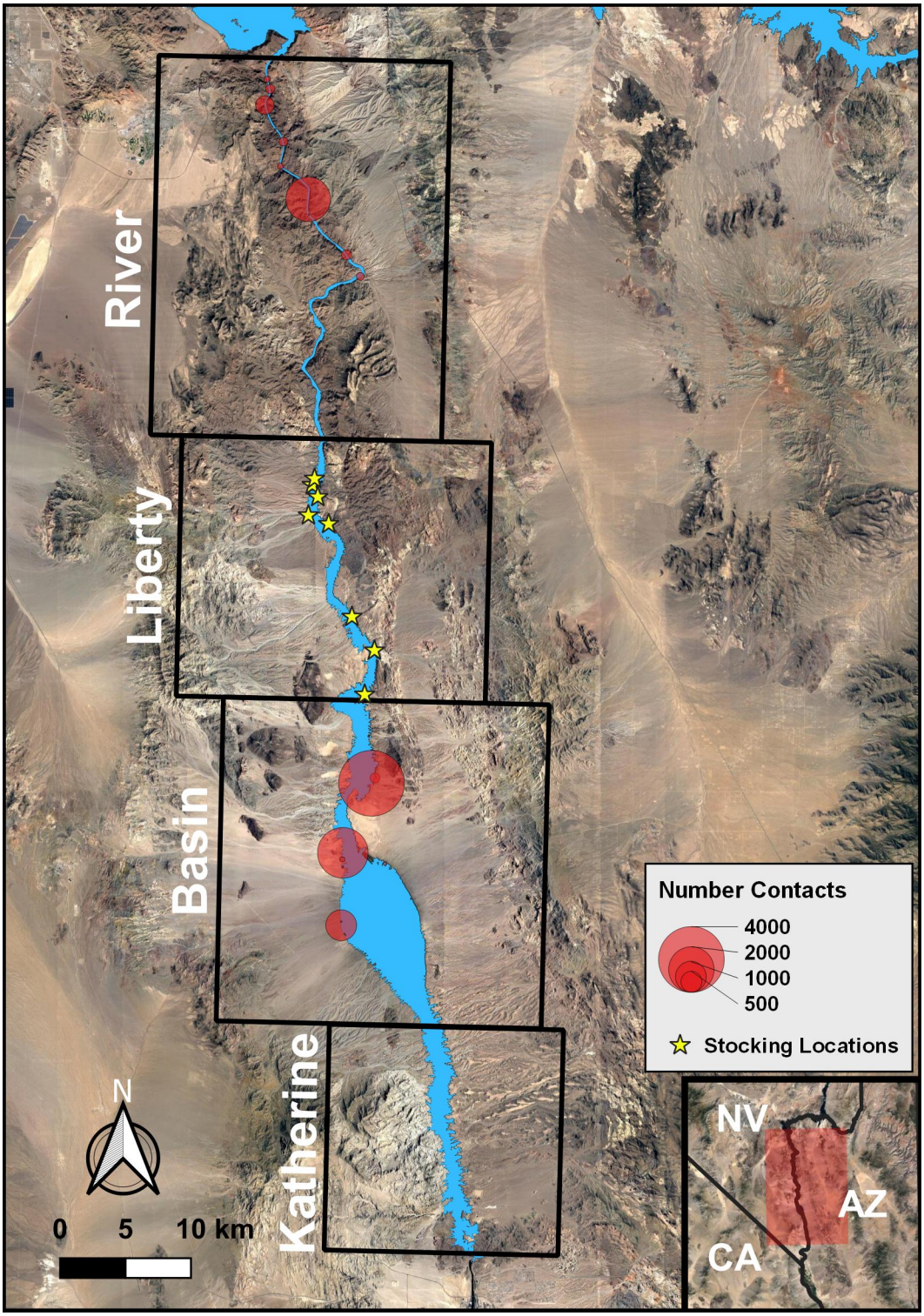

Figure 13.—Proportion of daily unique contacts made by remote PIT scanners (red circles) for razorback suckers stocked into Liberty, Lake Mohave, Arizona and Nevada.

In Basin, there were 25 stocking locations with 45,237 razorback suckers stocked from SY 2006 to SY 2020; 1,912 fish were included in the analysis, with a total of 886,775 contacts. The majority (61.3%) of farthest movement distances occurred near the location of release (0 to 20 km), but a substantial proportion (34.1%) occurred farther away (50 to 85 km), resulting in a bimodal distribution (figures 14 and 15). Distances of 0 to 20 km and 50 to 85 km are generally representative of fish that were only contacted in River and fish that dispersed to Basin, respectively.

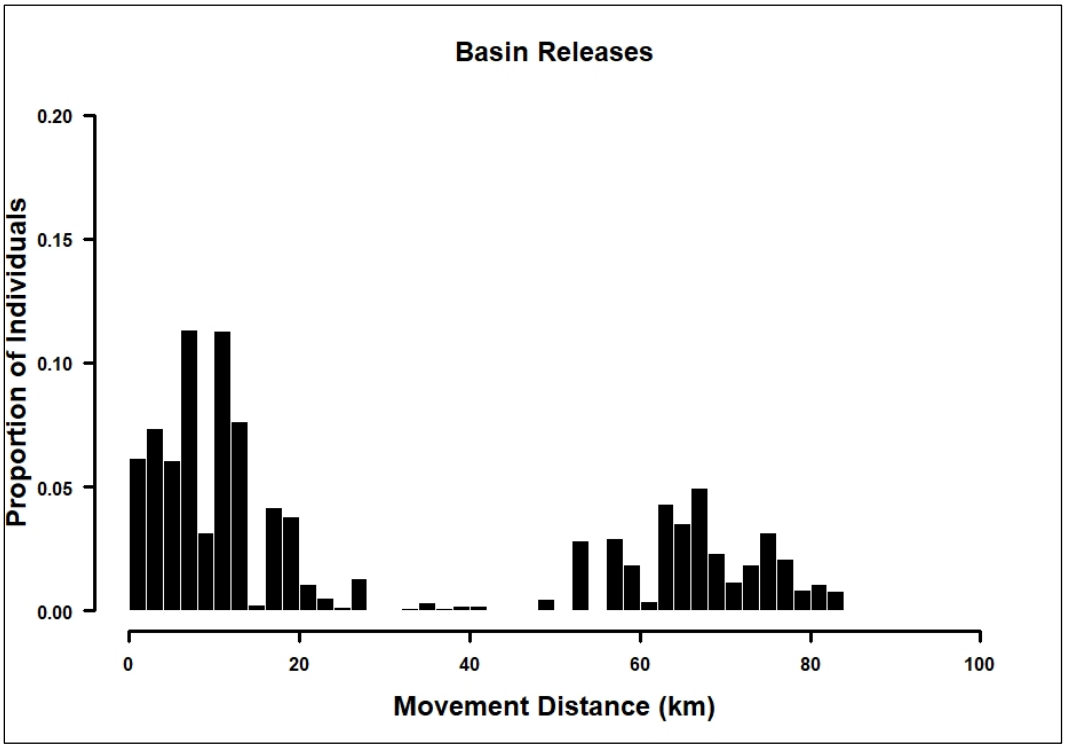

Figure 14.—Farthest absolute movement distance from release location of razorback suckers stocked into Basin as detected by remote PIT scanners in Lake Mohave, Arizona and Nevada.

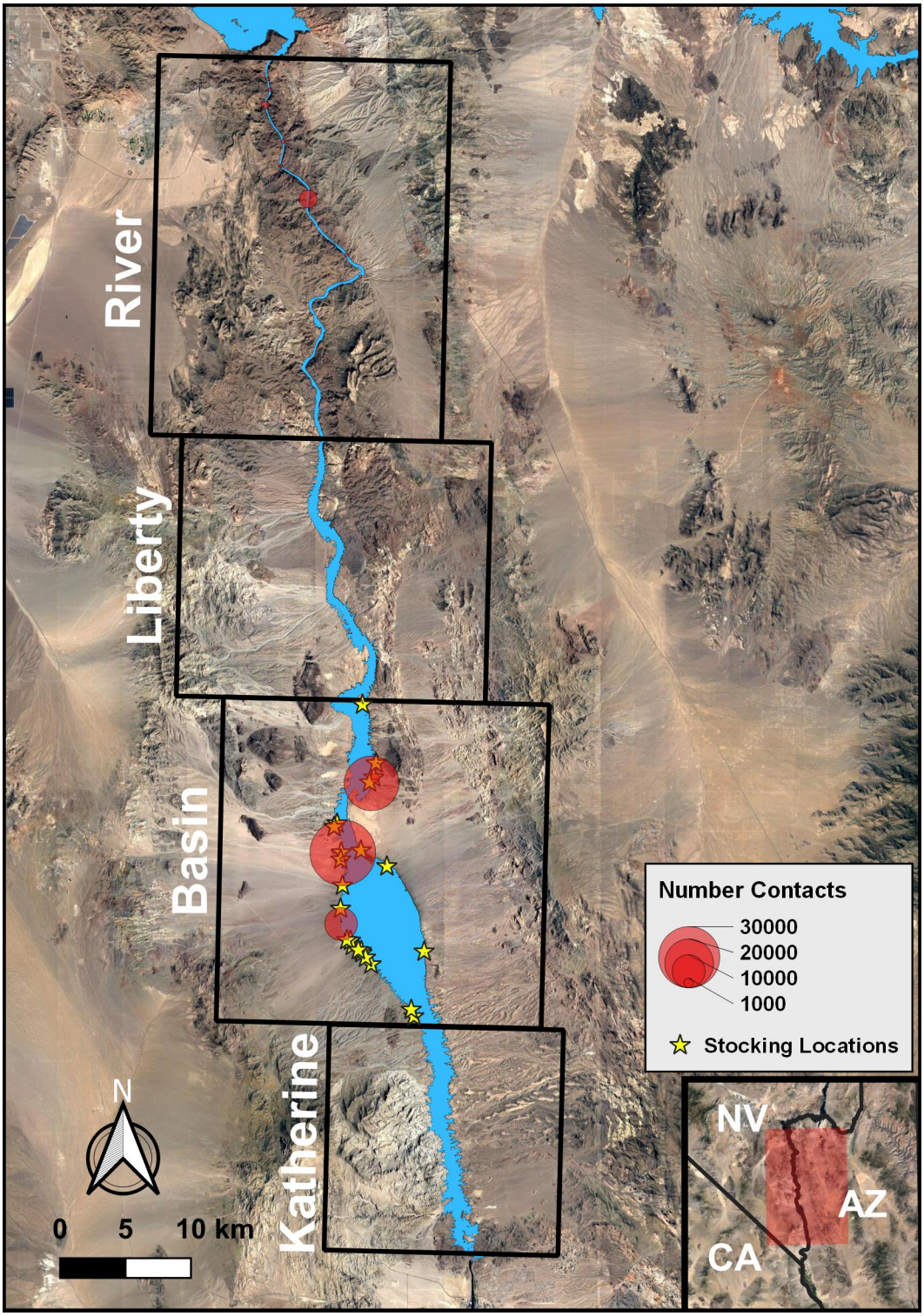

Figure 15.—Proportion of daily unique contacts made by remote PIT scanners (red circles) for razorback suckers stocked into Basin, Lake Mohave, Arizona and Nevada.

DISCUSSION

The population of razorback suckers in Lake Mohave appears stable but dependent on continued stocking. PIT scanning estimates of subpopulation abundance in River and Basin have remained stable over the last 5 years, while the routine monitoring estimate has varied by more than a factor of two (Miller et al. 2020). The population estimate based on routine monitoring for the last few years has been lower than the Basin subpopulation estimate based on PIT scanning. This is counter to expectations because the routine monitoring estimate includes additional fish that have older, 400-kHz PIT tags. We hypothesize that the difference is due to temporal constraints of the routine monitoring estimate, which is based on March data only.

Razorback suckers in the Lower Colorado River Basin historically spawned between November and May (Minckley 1983), but the younger, repatriate population that now occupies Lake Mohave typically reproduces from January through April only. As the population matures, the temporal window for active spawning may broaden or shift. Further analysis of PIT scanning data using "known" populations of razorback suckers that include shifting temporal windows to estimate population size would increase our understanding of this widening discrepancy. The known population would be a subset of the total population where the exact number of individuals was known to be alive and available to remote sensing during a set number of years based on release and contact data. By estimating this population while adjusting the size and timing of the mark and capture time windows, we can assess the impact of these changes on the accuracy of the estimate.

The hypothesis that fish contact rates at the five fixed sites in River would shift upstream toward Hoover Dam after peak spawning (Kesner et al. 2014) is not supported by the analysis employed in this report or the previous 5-year contract report (Miller et al. 2020). However, deployment of remote PIT scanners at these sites using the same protocol continues to provide high contact rates in River while maintaining broad geographical coverage (upstream of Willow Beach) and temporal consistency. These attributes assist in providing accurate population and/or survival estimates.

Results of the contact histories by zone analysis reported here remains analogous to those of Burgad et al. (2019) and Miller et al. (2020), with fish stocked into Liberty being detected outside their zone of release, and fish stocked into River and Basin being mostly contacted within their zone of release, but with a considerable proportion of fish stocked into River being contacted in Basin and vice versa. Going forward with this analysis in the future, it may be more informative if release data are kept as a constant (e.g., fish stocked from SY 2008 to SY 2014, and new scan data incorporated. In this manner, it may be

possible to observe a steady shift from fish being contacted solely in one zone to fish being contacted in more than one, or conversely where some fish never seem to move between zones.

The movement distance analysis introduced in this report, although broad in scope, has the potential to serve as a conceptual and mechanistic foundation for more focused analyses of movement in the future. The current movement analysis aimed to answer the basic question: Given a release zone and location, where do fish reach the limit of their detected range? For fish stocked into River, most range limits for fish seem to occur in River, but there was a considerable proportion of fish with range limits in Basin. A similar trend was detected for fish released into Basin, where most range limits were in Basin, but many were also in River. These results are comparable to findings of the contact history by zone analysis (although it included a narrower selection of fish) but provide spatially explicit and data visualization components.

It currently is unknown what factors influence this apparent heterogeneity in movement behavior for razorback suckers released into River and Basin in Lake Mohave. The future inclusion of temporal aspects may reveal presently unknown patterns. For example, it is currently unclear if fish remain in the subpopulation (River or Basin) they disperse to or if more complex patterns exist. Other variables that may help describe movement include age, duration of fish in the lake, age/size at release, rearing type (pond or hatchery), rearing location, seasonal shifts (e.g., spawning behavior, water temperatures), etc. Answering questions like these would improve our understanding of razorback sucker behavior in Lake Mohave and elsewhere, and also could inform the stocking program as to what factors are important for the long-term success of razorback suckers in Lake Mohave.

The first repatriations of razorback suckers to Lake Mohave were in 1992 when a few adults reared in the Yuma Cove backwater were transferred into the reservoir at Arizona Bay to augment a dwindling population of wild fish. The wild population is now gone, and in the nearly 30 years since its inception, the repatriation program has grown in size, scope, and complexity, and a population of several thousand stocked fish now exists only because of its implementation.

Important questions remain, but we now know many more details of razorback sucker population dynamics and factors that influence post-stocking and long-term survival. The return on stocking can be large, as represented by high long-term survival, when fish are repatriated at the appropriate size. The importance of the relationship between fish size at stocking and post-stocking survival is well understood and cannot be overemphasized, but logistical constraints to rearing large fish have proven difficult to overcome. Nonetheless, razorback suckers should benefit from future program enhancements informed by additional experience, data acquisition and population modelling, and implementation of novel strategies.

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