Lower Colorado River Multi-Species Conservation Program

Balancing Resource Use and Conservation

Population Status and Distribution of Razorback Suckers and Bonytail Downstream from Palo Verde Diversion Dam

2018 Interim Report

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

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Lower Colorado River
Multi-Species Conservation Program

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ACRONYMS AND ABBREVIATIONS

ABS	acrylonitrile butadiene styrene
Center	Southwestern Native Aquatic Resources and Recovery Center
CI	confidence interval
Cibola NWR	Cibola National Wildlife Refuge
DAL	days at large
kHz	kilohertz
km	kilometer(s)
LCR MSCP	Lower Colorado River Multi-Species Conservation Program
m	meter(s)
mg/kg	milligram(s) per kilogram
mg L^{-1}	milligram(s) per liter
mm	millimeter(s)
MS-222	tricaine methanesulfonate
PIT	passive integrated transponder
RM	river mile
SUR	submersible ultrasonic receiver
SY	study year
TL	total length
UTM	Universal Transverse Mercator

Symbols

≥	greater than or equal to
<	less than
%	percent
®	registered trademark

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EXECUTIVE SUMMARY

This is the second year of the current project to monitor the population status and distribution of razorback suckers (*Xyrauchen texanus*) and bonytail (*Gila elegans*) in the lower Colorado River downstream from Palo Verde Diversion Dam and upstream of Imperial Diversion Dam. A total of 5,950 razorback suckers and 6,779 bonytail were stocked into the backwaters and main channel of the study area in La Paz County, Arizona, and Riverside County, California, from October 2017 through April 2018. All fishes released were implanted with a 134.2-kilohertz passive integrated transponder (PIT) tag.

Up to 20 portable remote PIT tag sensing units were distributed throughout the backwaters and main channel for 5 days during each month from October to March. During the peak spawning season (January – February) PIT tag sensing units were deployed for 10 days each month. Effort in the river channel was increased during the active sample period (October 1, 2017, to April 30, 2018) to identify spawning sites outside of backwater habitat and to contact individuals during spawning. PIT tag sensing units were deployed for 12,597.1 hours in the second year of study and recorded 1,792 unique contacts: 1,234 razorback suckers, 535 bonytail, and 23 individuals with no database record. A total of 206 razorback suckers and one bonytail were contacted more than a year after release in study year (SY) 2018. Fifteen unique fishes, nine razorback suckers and six bonytail, were contacted in the main channel during SY 2018. No bonytail contacted during the marking period (October 1, 2016, to May 31, 2017) were contacted again in the capture period (October 1, 2017, to May 31, 2018); therefore, no population estimate was possible. The razorback sucker population estimate for 2017 was 169 (95% confidence interval = 157 to 180).

Eighteen subadult razorback suckers and 18 subadult bonytail were implanted with short-term (3-month) acoustic telemetry tags to examine dispersal patterns immediately following release. Twenty tags for each species was planned, but four tags were inoperable. Ten adult razorback suckers were implanted with longer-term (36-month) tags to examine dispersal over a longer period. One adult was electrofished from the main channel of the Colorado River – the first razorback sucker capture from the river channel during this study.

During this SY, nine submersible ultrasonic receivers (SURs) were deployed, three of which were replacements for SURs lost during the study, five of which were supplemental, and one of which was moved to a more secure location in A7 upper. At the end of the field portion of the current SY, 18 SURs were active in the study area.

Throughout the SY, manual acoustic tag tracking was conducted in backwaters to supplement dispersal data and identify stationary tags. During peak spawning months (January – February) and March, manual acoustic tracking was conducted

in the main river channel, and one juvenile razorback sucker released in November 2017 was contacted. The maximum dispersal distance of any acoustic-tagged fish was 80.9 kilometers by a subadult razorback sucker released in November 2017. Divers recovered three 36-month acoustic tags: One was implanted in an adult razorback sucker on January 18, 2018, and the other two were implanted in an adult razorback sucker on February 22, 2017.

The temporal and spatial limitations of the remote PIT tag sensing data in Reach 4 continue. Evidence of long-term persistence (more than 1 year post-release) of either razorback suckers or bonytail in the study area is lacking despite contacting thousands of razorback suckers and bonytail post-release. Most contacts with either species occur within 30 days post-release and are acquired from one backwater complex (A10 upper and A10 lower).

INTRODUCTION

Razorback suckers (*Xyrauchen texanus*) and bonytail (*Gila elegans*) are listed as endangered by the U.S. Fish and Wildlife Service. Wild populations are extirpated from the lowermost Colorado River, and the species remain in this portion of their native range only through intensive stocking. The Lower Colorado River Multi-Species Conservation Program (LCR MSCP) has been stocking fishes into Reaches 4 and 5 of the lower Colorado River (Parker Dam to Imperial Diversion Dam) since 2005. The program has a planned stocking goal of 6,000 razorback suckers and 4,000 bonytail per year into Reaches 4 and 5 for 45 years, with all fish ≥ 305 millimeters (mm). Beginning in 2018, an additional 4,000 bonytail per year will be stocked for a 10-year period of intense research and monitoring (Bureau of Reclamation 2015). An additional 6,000 razorback suckers will be stocked for a 10-year period starting in 2019. All fishes will be released with a full duplex 134.2-kilohertz (kHz) passive integrated transponder (PIT) tag.

Previous research and monitoring efforts in the study area (2006–08) estimated annual survival of razorback suckers at < 30%, and no estimate was available for bonytail due to low recapture rates (Schooley et al. 2008). Lack of physical and behavioral defense mechanisms and a prominence of piscivorous fishes and birds resulted in low post-stocking survival for both species. Results were based on trammel net and electrofishing data, and recapture rates were low (< 1% of total fishes released) outside of release backwaters. The current research and monitoring effort is based on remote PIT tag sensing, which may result in higher contact rates while eliminating stress and mortality due to handling.

The current project has six primary objectives:

1. Contact razorback suckers and bonytail using mobile remote PIT tag sensing units capable of detecting full duplex 134.2-kHz tags and deployable in backwater, slack water, and riverine sections of the Colorado River.

2. Conduct eight monitoring trips across multiple release sites and habitat types within Reach 4 (Parker Dam at River Mile [RM] 192 downstream to the southern end of the Cibola National Wildlife Refuge [Cibola NWR]) from October through March of each year.

3. Conduct broad-scale, multi-year telemetry monitoring on 10 resident adult razorback suckers per year to determine relative dispersal, seasonal movements, and preferred habitat types.

4. Conduct broad-scale telemetry monitoring of 20 subadult razorback suckers and 20 subadult bonytail each year to determine relative dispersal and preferred habitat types.

5. Assimilate and summarize all Reach 4 and 5 razorback sucker and bonytail contact data collected by other Federal and non-Federal entities into mark-recapture population estimates for each species with 95% confidence intervals (CIs).

6. If data are adequate, use mark-recapture modeling to provide estimates for adult survival (with 95% CIs) and assess its dependence on a variety of factors (i.e., size at release, location of release, and season of release) for all razorback suckers and bonytail released since 2005. If data are inadequate for a model-comparison assessment of all factors, use exploratory analyses to identify their potential relationship to scanning contact rates (e.g., with graphs and/or correlation analyses).

Study Area

Reach 4 extends from Parker Dam at RM 192 downstream to the southern end of the Cibola NWR (RM 88). Reach 5 continues from here downstream to Imperial Diversion Dam at RM 49.2 (figure 1). The focal area of this study is from the Palo Verde Diversion Dam north of Ehrenberg, Arizona, downstream approximately 45 river miles to Walters Camp, California. Fishes were released into one or more of the five focal backwaters within this zone: A7 upper, A10 upper, A10 lower, C7 McIntyre Park, and C10 Ehler's, or directly into the Colorado River (figure 2). All backwaters are connected to the main channel via culvert or a boat-accessible channel (figure 3).

METHODS

Passive and active remote sensing technologies were used to contact razorback suckers and bonytail in backwater, slack water, and riverine sections of the lower Colorado River. Passive sampling was achieved using an array of submersible ultrasonic receivers (SURs) and remote PIT tag sensing units, while active sampling was conducted by boat using a directional or towable omnidirectional hydrophone. Acoustic tags were surgically implanted into 18 hatchery-reared subadult razorback suckers and bonytail, and 10 adult razorback suckers; 9 of the last were from the Lake Mead Fish Hatchery, Nevada, and 1 was electrofished from the Colorado River at Universal Transverse Mercator (UTM) 11 S 722098 E 3705936 N (Mueller et al. 2000; Karam et al. 2008). Telemetry and remote PIT tag sensing data were grouped by study year (SY) based on the fiscal year

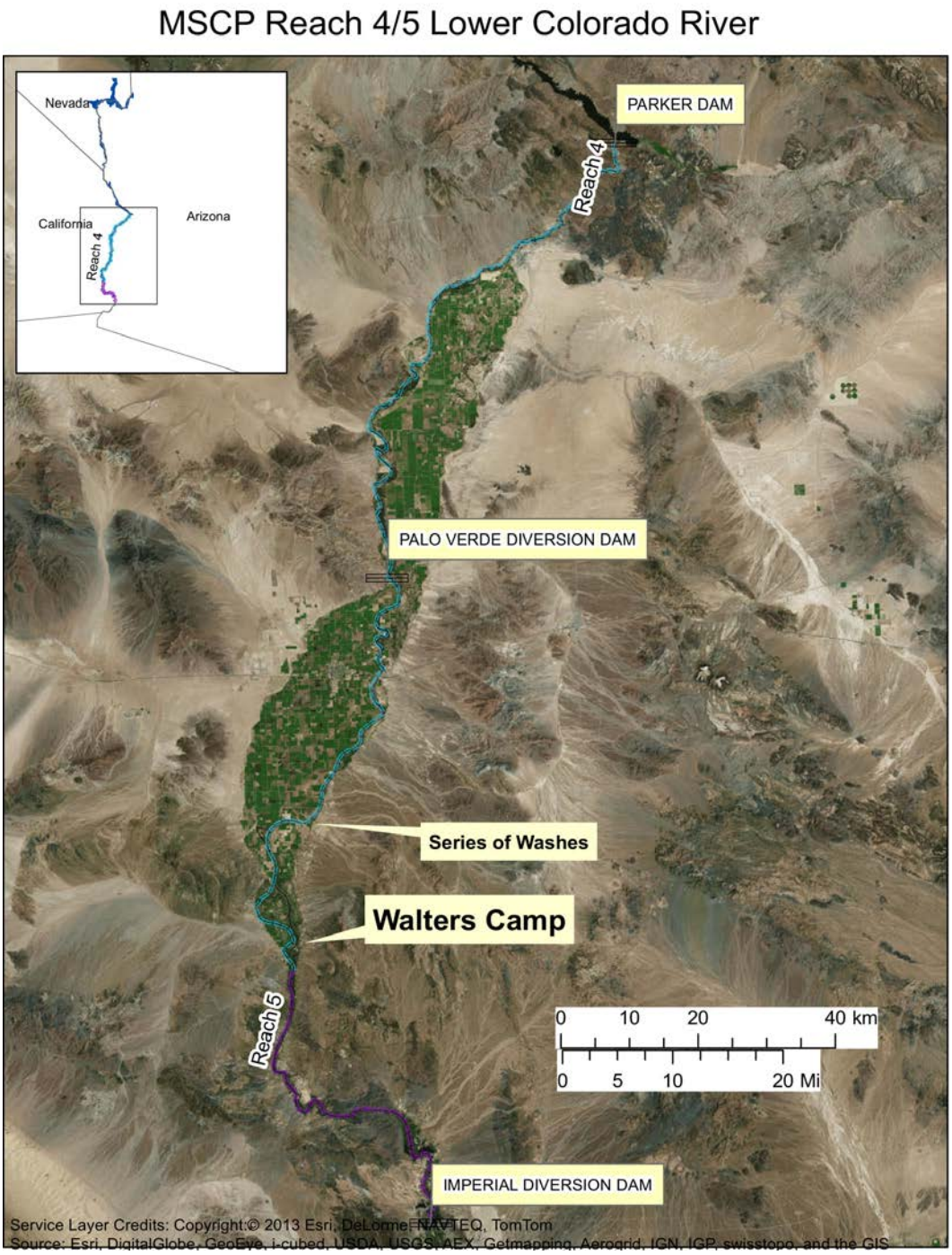

Figure 1.—Reaches 4 and 5 on the lower Colorado River, Arizona and California. Reach 4 (light blue) begins downstream from Parker Dam and continues downstream to the southern border of the Cibola NWR. Reach 5 (violet) begins at the adjoining northern border of the Imperial National Wildlife Refuge and continues downstream to Imperial Diversion Dam.

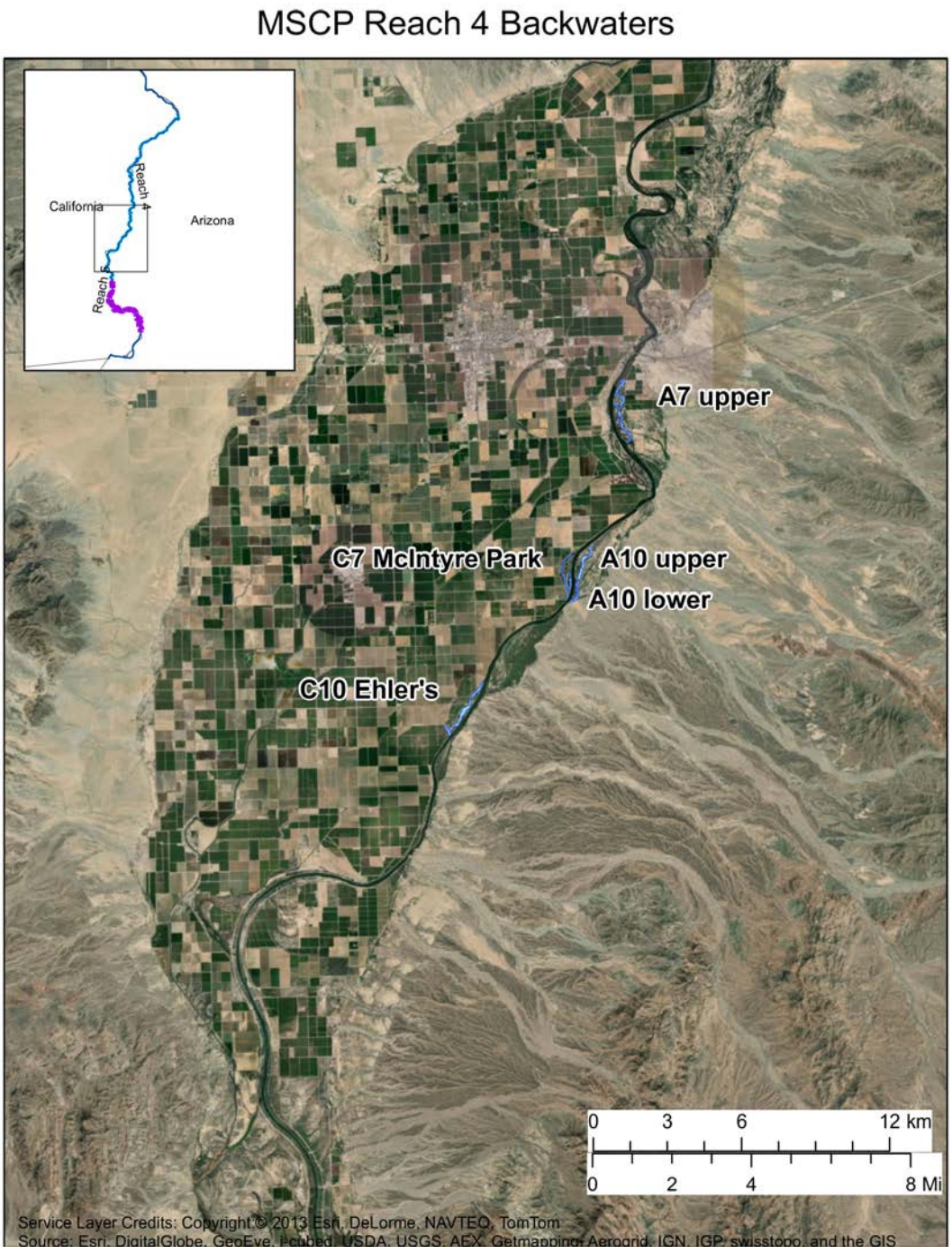

Figure 2.—Study backwaters in Reach 4 on the lower Colorado River, Arizona and California.

Figure 3.—Aerial imagery of five backwaters in Reach 4, lower Colorado River, Arizona and California.

These backwaters were the focal point of release and monitoring efforts during this study.

schedule (e.g., October 1, 2015, to September 30, 2016, is SY 2016). 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 April 2018, to allow adequate time for data analyses.

Releases

Releases of razorback suckers and bonytail during SY 2018 were distributed across spatial and temporal variables to accommodate an analysis of factors influencing post-stocking survival (objective 6). At least one stocking per season (autumn, winter, and spring) was anticipated, dependent on availability of hatchery fishes and crew for PIT tagging fishes prior to release. Five backwaters were identified as primary stocking locations: A7 upper, A10 upper, A10 lower, C7 McIntyre Park, and C10 Ehler's (see figures 2 and 3). Releasing hatchery-reared fishes into backwaters provides better access to immediate cover than what is available in the river channel, where the current is also faster. All backwaters provide access to the river channel. Release sites were moved upstream and further from the river connection point within each backwater where possible when compared to release sites in the first SY.

Telemetry

Throughout the course of SY 2017, 17 SURs were distributed throughout the study area. Of those, 12 were still active as of the end of SY 2018. Six additional SURs were added to the study area in SY 2018 to replace inactive units and improve coverage for telemetry data collection (figure 4). Sites were selected to segment the river channel as best as possible to most accurately determine movement and location. All SURs deployed throughout the study area were attached to a camouflaged rope and connected to a 6-meter (m) piece of galvanized cable that was connected to secure on-shore habitat (e.g., a tree root). Cable was used to mitigate abrasion caused by waves and current on rocks in the river. Weights were attached to the cable and SUR to ensure the SUR remained completely submerged in the water column. Each SUR has a battery life expectancy of 8 months and is programmed to scan continuously with a detection range of 200 m.

At least one SUR was deployed in each major backwater (A7 upper, A10 upper, A10 lower, C7 McIntyre Park, and C10 Ehler's). A10 upper, C7 McIntyre Park, and C10 Ehler's each had two SURs due to the size and number of acoustic-tagged fishes released in them. The remaining SURs were spaced out in the river from Palo Verde Dam downstream to Walter's Camp.

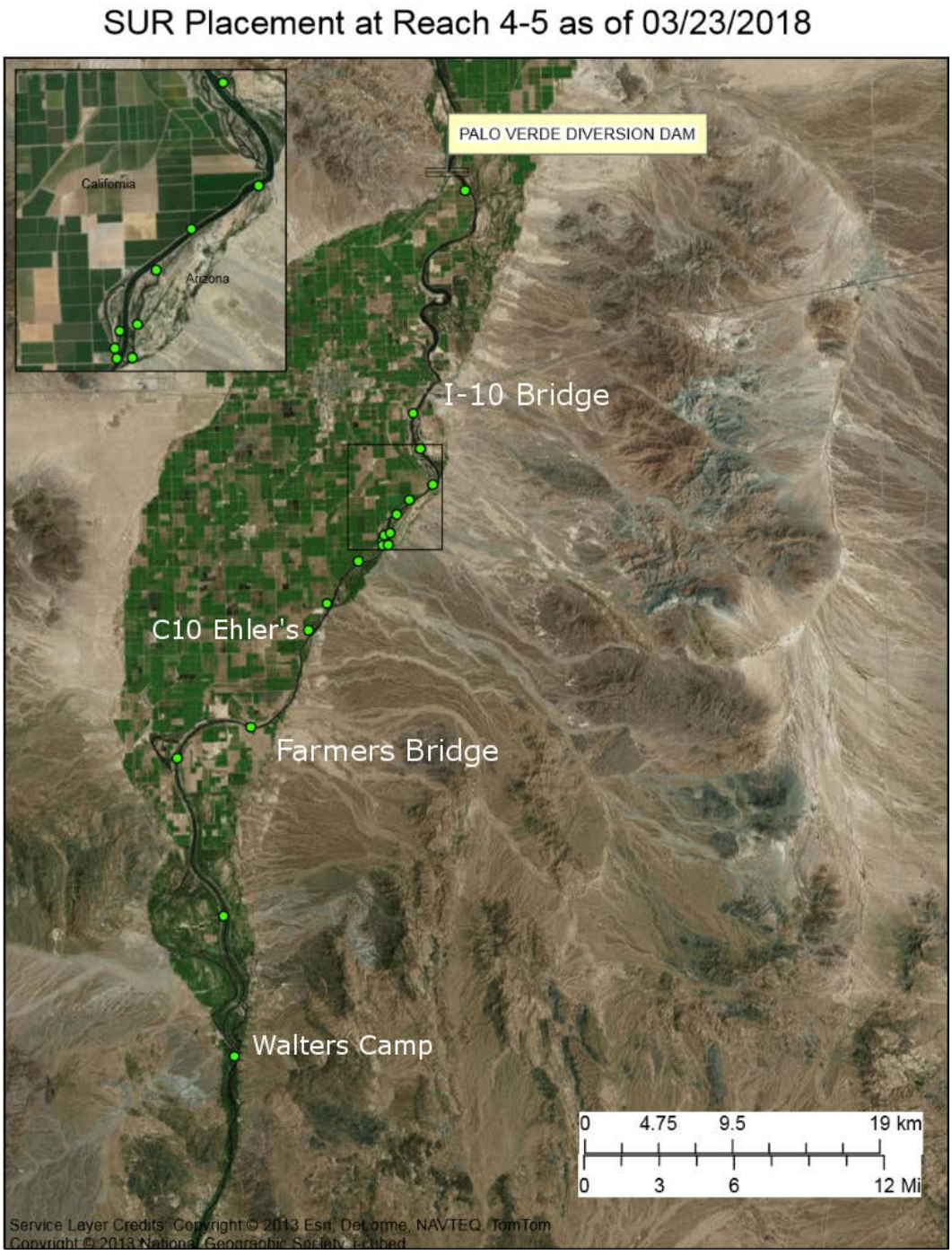

Figure 4.—Location of SURs deployed in the main channel and backwaters in Reach 4, lower Colorado River, Arizona and California.

All data from the SURs were downloaded once every trip. In months when two trips occurred in consecutive weeks, SUR data were downloaded once during the span of the 2 weeks. Confidence values defined by number of detections within a timed window were calculated using Sonotronics SURsoft Stand Alone Data Processing Center software. The software calculates a confidence level between 1 and 5 for each contact (1 designating the lowest level of confidence and 5 the highest). Two detections at the correct interval and frequency within an hour were given a confidence of 5. Only records from SURs with a confidence of 5 were included in the analysis; others were retained in the database but excluded from analyses. Some records with a confidence of 5 were removed from analyses when it was clear that background noise was the source of the acoustic signal and spurious record. In these isolated cases, multiple records across all frequencies with the same interval were recorded in the raw data file, which indicated that an environmental noise was present. In several cases, this was verified by a tag being recorded prior to release of the acoustic-tagged fish. Data were imported into a Microsoft Access® database used for managing fish contact histories and SUR locations.

Active tracking was conducted with a directional (Model DH-4, Sonotronics, Inc.) or omnidirectional towable (Model TH-2, Sonotronics, Inc.) hydrophone and receiver. The receiver was manually set to specific tag frequencies corresponding to each tagged fish. Active tracking took place in backwaters throughout the SY, when time permitted, with a special focus on the spawning season. This year, additional effort was made to manually track acoustically tagged fishes in the main channel.

When the towable hydrophone was used, boat speed was maintained at about 10 kilometers (km) per hour (6 miles per hour) or slower to reduce noise interference from the engine and to allow the device to scan for multiple frequencies within a signal's potential detection range. Once a fish was detected using the towable hydrophone, the directional hydrophone was used to triangulate its location; then, an underwater dive receiver was used to pinpoint, within 5 m based on previous dive recoveries, the location of the fish.

Surgery

All surgeries followed established procedures.. Fishes reared in hatcheries were implanted with PT-4 acoustic transmitters (Sonotronics Inc., Tucson, Arizona). This tag is small, reliable, and has a battery life of approximately 3 months. Adult razorback suckers captured from a backwater were implanted with CT-05-36 acoustic transmitters. This is a larger tag that has a battery life of approximately 36 months. A few Sonotronics, Inc., provided tag numbers were duplicated from the previous year's study, so all tags implanted this year have the prefix "Y2_" to differentiate SYs.

Before surgery, an individual fish was immersed into a dark container with approximately 16 liters of fresh water and tricaine methanesulfonate (MS-222) (125 mg L^{-1}) to anesthetize it. A successfully anesthetized fish was indicated by lack of operculation, weak muscular movements, and cessation of fin movements. Once these criteria were met, the fish was removed from the container, measured (total length [TL] in m), weighed (nearest gram), and scanned for a 134.2-kHz PIT tag. The fish was then placed on a surgery cradle, ventral side up, and covered in a wet towel to eliminate desiccation. Anesthesia was maintained by gently pumping MS-222 solution with a small tube (4.77 mm) via the mouth across the gills for the remainder of the surgical procedure. A short (< 2 centimeters) mediolateral incision was made slightly anterior and dorsal to the left pelvic fin, and an acoustic transmitter sanitized in 70% ethanol was inserted into the abdominal cavity. Fish absent of a PIT tag were implanted with a 134.2-kHz tag via the mediolateral incision. The incision was closed with 2–3 knots using a 4-0 absorbable braided, coated suture and an RB-1 (CV-23), 17 mm, ½ taper needle (AD Surgical, Sunnyvale, California). Post-surgery fishes received additional care to prevent infection (Martinsen and Horsberg 1995): The sutured wound was swabbed with Betadine, and a 10 mg/kg dosage of the antibiotic Baytril® (enrofloxacin) was injected into the dorso-lateral musculature to mitigate infection.

November

On November 16, 2017, 10 subadult razorback suckers and 9 subadult bonytail (1 tag was inoperable) (table 1) were surgically implanted with model PT-4 acoustic transmitters at the culvert connecting C7 McIntyre Park with the lower Colorado River (objective 4). Fishes were released into C7 McIntyre Park immediately post-surgery. The mean TL of razorback suckers was 407 mm (380–434 mm), and the mean TL of bonytail was 451 mm (412–476 mm).

January

Over the course of the study year, electrofishing on the main channel was conducted three times to capture adult fishes for acoustic tagging. Suitable habitat was targeted, and one fish was collected on January 18, 2018, at UTM 11S 722098 E, 3705936 N, 600 m upstream of the C10 Ehler's entrance. On January 18, 2018, 10 razorback suckers (table 2) were surgically implanted withCT-05-36 acoustic transmitters at the A10 lower ramp, including the fish captured from the river (objective 3). Fish were released into the A10 lower backwater immediately post-surgery. The mean TL of razorback suckers was 479 mm (445–540 mm).

Table 1.—Subadult razorback suckers and bonytail released into C7 McIntyre Park, lower Colorado River, Arizona, November 16, 2017

Tag ID	Frequency	Interval (milliseconds)	Code	TL (mm)	Weight (grams)	PIT tag number
Razorback sucker						
Y2_04	72	880	3-6-6	420	735	3DD.003C06C5FD
Y2_08	76	920	5-5-5	434	830	3DD.003C06C422
Y2_10	78	940	6-7-8	428	769	3DD.003C06C244
Y2_18	71	1050	3-5-4-6	390	678	3DD.003C06CDAS
Y2_20	73	1070	3-5-8-4	419	718	3DD.003C06C812
Y2_32	70	1200	5-5-7-8	380	556	3DD.003C06C80C
Y2_36	74	1240	6-6-8-8	389	710	3DD.003C06C622
Y2_38	76	860	3-4-5	388	523	3DD.003C06C7E7
Y2_44	82	920	5-6-8	394	636	3DD.003C06C3B8
Y2_48	71	990	3-3-6-8	431	814	3DD.003C06C408
Bonytail						
Y2_05	73	910	4-4-7	412	523	3DD.003BCBF71B
Y2_17	70	1040	3-5-4-5	469	946	3DD.003BCBF71F
Y2_21	74	1080	3-6-6-6	455	1,119	3DD.003BCBF73D
Y2_23	76	1100	3-7-7-4	431	590	3DD.003BCBF771
Y2_29	82	1160	4-7-4-7	476	1,065	3DD.003BCBF738
Y2_33	71	1230	5-7-6-7	461	894	3DD.003BCBF71D
Y2_41	79	910	4-6-5	468	945	3DD.003BCBF768
Y2_43	81	930	5-6-7	437	681	3DD.003BCBF731
Y2_47	70	980	3-3-6-5	446	909	3DD.003BCBF778

Table 2.—Adult razorback suckers released in A10 lower, lower Colorado River, Arizona, January 18, 2018

(Fish Y2_148 was captured by electrofishing in the Colorado River main channel.)

Tag ID	Frequency	Interval (milliseconds)	Code	TL (mm)	Weight (grams)	PIT tag number
Y2_148	81	970	3-3-5-6	540	1,680	3DD.003BEA6340
Y2_149	82	960	3-3-5-7	476	1,538	3D9.1C2D6C2CC7
Y2_150	83	990	3-3-8-8	500	1,680	3D9.1C2D6C0572
Y2_152	70	1020	3-4-6-5	486	1,653	3D9.1C2D6C0531
Y2_153	71	1030	3-4-6-6	504	1,663	3D9.1C2D6C3A87
Y2_154	72	1040	3-5-4-7	460	1,207	3D9.1C2D6C4324
Y2_155	73	890	3-6-7	479	1,349	3D9.1C2D6D0F67
Y2_156	74	1060	3-5-8-5	447	1,177	3D9.1C2D6C687A
Y2_158	73	1080	3-6-6-8	445	1,123	3D9.1C2D6C0CA3
Y2_159	77	1090	3-6-7-4	449	1,065	3D9.1C2D6C43F1

February

On February 7, 2018, eight subadult razorback suckers and nine subadult bonytail (three tags were inoperable) (table 3) were surgically implanted with PT-4 acoustic transmitters at C10 Ehler's boat ramp (objective 4). Fish were released into C10 Ehler's immediately post-surgery. The mean TL of adult razorback suckers was 457 mm (436–481 mm), and the mean TL of bonytail was 414 (376–446 mm).

Remote PIT Tag Sensing

Twenty portable remote PIT tag sensing units were deployed during six monthly field sampling trips between October 2, 2017, and March 19, 2018 (objectives 1 and 2). Two additional sampling trips were conducted to maximize remote PIT tag sensing contacts during peak spawning periods in January and February. Each sampling trip was 5 days. Each backwater, A7 upper, A10 upper, A10 lower, C7 McIntyre Park, and C10 Ehler's (see figure 2), received at least two remote PIT tag sensing units throughout the sampling trips, except for one occasion when A7 upper only received deployments on the first trip in January.

Table 3.—Subadult razorback suckers and bonytail released in C10 Ehler's, lower Colorado River, February 7, 2018

Tag ID	Frequency	Interval (milliseconds)	Code	TL (mm)	Weight (grams)	PIT tag number
Razorback sucker						
Y2_2	70	860	3-3-4	472	1,214	3DD.003BCBF725
Y2_6	74	900	4-4-8	449	1,258	3DD.003BCBF749
Y2_12	80	960	3-3-5-5	453	1,220	3DD.003BCBF770
Y2_14	82	980	3-3-8-7	436	980	3DD.003BCBF736
Y2_24	77	1110	3-7-7-5	467	1,371	3DD.003BCBF717
Y2_26	79	1130	4-4-6-8	481	1,187	3DD.003BCBF76C
Y2_28	81	1150	4-5-7-7	452	1,070	3DD.003BCBF728
Y2_40	78	880	3-7-7	442	1,021	3DD.003BCBF75A
B**onytail**						
Y2_3	71	890	3-6-5	421	678	3DD.003C06DF97
Y2_09	77	950	6-7-7	446	853	3DD.003C06DF45
Y2_13	81	99	3-3-8-6	440	866	3DD.003C06DF2C
Y2_15	83	1010	3-4-5-8	429	807	3DD.003C06DF4F
Y2_19	72	1060	3-5-7-8	391	594	3DD.003C06D927
Y2_25	78	1120	4-4-6-7	376	478	3DD.003C06E06E
Y2_35	73	1250	6-6-7-8	429	658	3DD.003C06DF27
Y2_39	77	890	3-7-6	412	606	3DD.003C06DF59
Y2_45	83	950	7-8-8	386	493	3DD.003C06DF4A

Remote PIT tag sensing unit deployments in the main channel were increased compared to the previous SY. Typically, between 8 and 10 units were placed in the channel compared to 3 to 5 last year. These deployments initially targeted locations of swift-moving water over gravel, based on habitat preference for spawning razorback suckers (Minckley 1983; Tyus 1987). Throughout the study area, this habitat type was scarce due to channelization and riprap levees on riverbanks. A series of washes between A10 lower and Farmer's Bridge was the most prevalent aggregation of this habitat type within the study reach and was the focus of unit deployments in the main channel. Throughout the year, locations of river-deployed units were expanded to include other areas with suitable habitat. Any deployment in the main channel that resulted in a new PIT tag contact received additional deployments on the subsequent trip.

In addition to standardized portable remote PIT tag sensing unit deployments, a semipermanent remote PIT tag sensing unit was placed inside the culvert connecting A10 upper and A10 lower on February 5, 2018. The antenna was made from 1-inch flexible polyvinyl chloride, and its diameter was custom fit to the inside of the acrylonitrile butadiene styrene (ABS) culvert. Three mounting holes were drilled into the culvert to secure the antenna inside the culvert with plastic hose clamps. A 5-conductor cable connected the antenna to the data logger and passed through an additional hole drilled into the side of the culvert. The data logger (mini-logger) and batteries (three, 7.4-volt 20 ampere-hour lithium-ion batteries) were secured inside an ABS drain pipe partially buried within 25 feet of the culvert.

Population Estimates

Population estimates for razorback suckers and bonytail were based on remote PIT tag sensing data when paired year-to-year sample data included four or more recaptures (objective 5). Data for population estimates were based on the scanning period from October 1 to May 31 of each SY, giving the fishes 4 months between mark and capture periods to randomly assort.

The mark-recapture estimate for each species was based on the modified Peterson formula:

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

For each mark-recapture estimate, the number of individual PIT tags contacted in the field season of the previous SY was the mark (*M*), the number contacted in the current SY the capture (*C*), and the number in common between both years the recaptures (*R*). Any contacts with PIT tags released after the initiation of the marking year (October 1 of the previous SY) were removed from population estimates. CIs were derived using Poisson approximation tables and R as the entering variable when recaptures were 50 or less (Ricker 1975), or they were based on the normal distribution for 51 or more recaptures (Seber 1973).

Post-Stocking Survival and Dispersal

A combination of QGIS (QGIS Development Team 2017) and R (R Core Development Team 2018) was used to calculate dispersal between SURs. First, polyline data from the National Hydrography Dataset Plus was used to represent the river network. Dispersal was calculated as the path along the river network instead of straight line distance (i.e., Euclidean). The river network was spatially constrained to the extent of the study area, and dispersal distance calculations

were performed in R. Dispersal distance (km) was calculated using point data (i.e., SUR locations) for all individuals. Dispersal was calculated between contacts only when an individual moved between SUR locations; therefore, a dispersal distance of zero was not possible. The "riverdistanceseq" function in the "riverdist" package (Tyers 2017) was used to calculate network distance between sequential SUR contacts of individuals.

If a tag was contacted multiple times via manual tracking in the same location, the fish was suspected dead, and the site was marked for tag retrieval via a scuba diver at the end of the field season. The date of first contact at the spot of retrieval was used as the day the fish was determined dead.

A third year of remote PIT tag sensing data is required to develop mark-recapture estimates of post-release survival (objective 6). However, release and remote PIT tag sensing contact totals among release sites, species, and size classes were tallied and provided in figures to illustrate relationships between contact availability, release size, and release location. All 134.2-kHz PIT tagged razorback suckers and bonytail released within the study area (Palo Verde Dam downstream to Imperial Diversion Dam) and recorded in the Lower Colorado River Native Fish Database with a TL at release and release location were grouped into size classes. Size classes were based around the minimum target release size of 305 mm TL as follows: size class 1 – < 305 mm TL, size class 2 – 305 to 354 mm TL, size class 3 – 355 to 404 mm TL, size class 4 – 405 to 454 mm TL, and size class 5 – ≥ 455 mm TL at release. Days at large (DAL) for each contact record was calculated as the difference between the most recent contact date within the SY and the release date.

RESULTS

Releases

Totals of 21,749 razorback suckers and 18,475 bonytail were released into the 5 focal backwaters, as well as some river locations, between 2007 and April 4, 2018 (tables 4 and 5), based on records in the Lower Colorado River Native Fish Database. For SY 2018 (from October 1, 2017, through April 30, 2018) 5,950 razorback suckers and 6,779 bonytail were released. Released fishes were reared at the Arizona Game and Fish Department's Bubbling Ponds State Fish Hatchery, Imperial Ponds Conservation Area, Southwestern Native Aquatic Resources and Recovery Center (Center) (previously the Dexter National Fish Hatchery), Lake Mead Fish Hatchery, and the Achii Hanyo Native Fish Rearing Facility. Release size ranged from 275–640 mm TL for razorback suckers and 223–535 mm TL for bonytail.

Table 4.—Razorback sucker releases (January 2007 through April 2018) downstream from Palo Verde Dam and their subsequent remote PIT sensing contacts, lower Colorado River, Arizona and California

(TL was measured in mm, and DAL was the maximum number of days between release and contact via remote PIT tag sensing. SY 2018 contacts refer to the number of unique fish in each release cohort contacted during this SY. Release locations listed as "A10" were not differentiated between lower and upper in release records.)

Release date	Release location	Rearing site	Releases	Contacts	SY 2018 contacts	TL mean (range)	DAL mean (range)
	Before September 2014		1959	22	4	364 (300–624)	2,510 (313–3801)
12/5/2014	A10	Imperial ponds	35	17	0	550 (275–640)	81 (11–161)
4/2/2015	A10 lower	Bubbling Ponds State Fish Hatchery	1,019	187	3	344 (305–440)	53 (0–1086)
4/2/2015	A10 upper	Bubbling Ponds State Fish Hatchery	778	172	53	347 (305–420)	673 (0–1086)
12/8/2015	A7 upper	Achii Hanyo Native Fish Rearing Facility	1,212	31	0	336 (305–460)	16 (0–94)
12/9/2015	Oxbow Campground Recreational Area	Achii Hanyo Native Fish Rearing Facility	1,160	160	0	347 (305–455)	3 (0–76)
2/18/2016	A10 lower	Bubbling Ponds State Fish Hatchery	518	11	0	338 (305–470)	198 (7–420)
2/18/2016	Oxbow Campground Recreational Area	Bubbling Ponds State Fish Hatchery	516	13	0	336 (305–445)	16 (5–119)
4/28/2016	A10 upper	Bubbling Ponds State Fish Hatchery	1,106	21	3	351 (305–450)	301 (46–693)
4/28/2016	Oxbow Campground Recreational Area	Bubbling Ponds State Fish Hatchery	981	8	0	351 (305–445)	184 (47–447)
10/27/2016	A10 lower	Bubbling Ponds State Fish Hatchery	629	48	0	358 (305–440)	16 (0–265)
10/27/2016	A10 upper	Bubbling Ponds State Fish Hatchery	628	26	4	356 (305–455)	118 (12–511)
10/27/2016	A7 upper	Bubbling Ponds State Fish Hatchery	630	17	0	353 (305–450)	20 (0–84)
10/27/2016	C10 Ehler's	Bubbling Ponds State Fish Hatchery	633	61	0	360 (305–465)	22 (0–321)
10/27/2016	C7 McIntyre Park	Bubbling Ponds State Fish Hatchery	625	45	1	359 (305–465)	42 (0–453)
11/17/2016	A10 upper	Bubbling Ponds State Fish Hatchery	600	18	2	356 (305–465)	72 (18–470)
11/17/2016	A7 upper	Bubbling Ponds State Fish Hatchery	574	3	0	354 (305–485)	35 (19–63)
11/17/2016	C10 Ehler's	Bubbling Ponds State Fish Hatchery	598	9	1	354 (305–485)	89 (18–490)
11/17/2016	C7 McIntyre Park	Bubbling Ponds State Fish Hatchery	467	13	1	358 (305–480)	65 (18–446)

Table 4.—Razorback sucker releases (January 2007 through April 2018) downstream from Palo Verde Dam and their subsequent remote PIT sensing contacts, lower Colorado River, Arizona and California

(TL was measured in mm, and DAL was the maximum number of days between release and contact via remote PIT tag sensing. SY 2018 contacts refer to the number of unique fish in each release cohort contacted during this SY. Release locations listed as "A10" were not differentiated between lower and upper in release records.)

Release date	Release location	Rearing site	Releases	Contacts	SY 2018 contacts	TL mean (range)	DAL mean (range)
12/14/2016	A10 upper	Lake Mead Fish Hatchery	10	3	2	456 (425–495)	319 (72–443)
1/25/2017	A10 lower	Lake Mead Fish Hatchery	215	0	0	447 (334–540)	(–)
1/25/2017	A7 upper	Lake Mead Fish Hatchery	322	3	0	455 (362–550)	22 (21–22)
5/4/2017	A10 lower	Lake Mead Fish Hatchery	202	26	12	419 (320–539)	153 (20–322)
5/4/2017	C7 McIntyre Park	Lake Mead Fish Hatchery	182	36	15	418 (312–509)	139 (21–315)
5/4/2017	Mayflower at Hidden Beaches Resort	Lake Mead Fish Hatchery	200	4	2	423 (318–530)	164 (131–197)
11/16/2017	A10 upper	Bubbling Ponds State Fish Hatchery	665	62	62	357 (305–465)	89 (0–127)
11/16/2017	C7 McIntyre Park	Bubbling Ponds State Fish Hatchery	594	38	38	353 (305–455)	62 (0–119)
11/16/2017	C10 Ehler's	Bubbling Ponds State Fish Hatchery	580	149	149	355 (305–455)	5 (0–105)
1/19/2018	A10 lower	Bubbling Ponds State Fish Hatchery	464	261	261	411 (335–485)	36 (4–62)
1/19/2018	A10 upper	Bubbling Ponds State Fish Hatchery	459	309	309	413 (335–480)	47 (5–63)
1/19/2018	A7 upper	Bubbling Ponds State Fish Hatchery	461	51	51	409 (325–515)	42 (18–62)
2/7/2018	C10 Ehler's	Lake Mead Fish Hatchery	16	0	0	448 (401–481)	(–)
2/15/2018	A10 lower	Bubbling Ponds State Fish Hatchery	506	105	105	360 (305–460)	14 (0–35)
2/15/2018	A10 upper	Bubbling Ponds State Fish Hatchery	510	105	105	360 (305–480)	22 (5–36)
2/15/2018	A7 upper	Bubbling Ponds State Fish Hatchery	501	11	11	364 (305–470)	16 (6–35)
2/15/2018	Colorado River downstream from Ehrenberg Bridge	Bubbling Ponds State Fish Hatchery	510	12	12	364 (305–465)	16 (4–35)
2/16/2018	C7 McIntyre Park	Bubbling Ponds State Fish Hatchery	384	22	22	358 (305–460)	15 (2–32)
2/16/2018	C10 Ehler's	Bubbling Ponds State Fish Hatchery	300	6	6	362 (305– 70)	15 (11–27)
		Totals	**21,749**	**2,085**	**1,234**		

Table 5.—Bonytail releases (January 2007 through April 2018) downstream from Palo Verde Dam and their subsequent remote PIT sensing contacts, lower Colorado River, Arizona and California

(TL was measured in mm, and DAL was maximum number of days between release and contact via remote PIT tag sensing. SY 2018 contacts refers to the number of unique fish in each release cohort contacted during this SY. Release locations listed as "A10" were not differentiated between lower and upper in release records.)

Release date	Release location	Rearing site	Releases	Contacts	SY 2018 contacts	TL mean (range)	DAL mean (range)
	Before September 2014		150	0	0	320 (275–405)	(–)
12/10/2014	A10	Center	1,996	113	0	346 (305–425)	30 (6–278)
9/23/2015	A10	Center	2,865	47	0	324 (305–429)	50 (20–548)
10/26/2016	A10 upper	Center	600	32	0	323 (305–392)	18 (0–44)
10/26/2016	A7 upper	Center	600	13	0	326 (240–401)	25 (12–149)
10/26/2016	C7 McIntyre Park	Center	600	19	0	325 (223–385)	13 (0–44)
11/16/2016	A10 upper	Center	800	3	0	326 (305–395)	22 (19–23)
11/16/2016	A7 upper	Center	456	0	0	324 (305–397)	(–)
11/16/2016	C10 Ehler's	Center	700	1	0	326 (305–535)	20 (20–20)
11/16/2016	C7 McIntyre Park	Center	700	3	0	326 (305–387)	21 (19–23)
12/14/2016	A10 upper	Lake Mead Fish Hatchery	14	0	0	415 (405–428)	(–)
1/25/2017	A10 lower	Lake Mead Fish Hatchery	5	0	0	402 (385–416)	(–)
1/25/2017	A7 upper	Lake Mead Fish Hatchery	15	0	0	401 (366–435)	(–)
3/20/2017	C7 McIntyre Park	Lake Mead Fish Hatchery	1,445	206	0	349 (305–444)	3 (0–91)
4/25/2017	A7 upper	Center	750	1	0	312 (305–431)	31 (31–31)
10/11/2017	A10 upper	Center	404	27	27	339 (305–419)	80 (34–130)
10/11/2017	A7 upper	Center	500	17	17	336 (305–461)	47 (35–123)
10/11/2017	C7 McIntyre Park	Center	500	24	24	333 (305–439)	75 (34–124)

Table 5.—Bonytail releases (January 2007 through April 2018) downstream from Palo Verde Dam and their subsequent remote PIT sensing contacts, lower Colorado River, Arizona and California

(TL was measured in mm, and DAL was maximum number of days between release and contact via remote PIT tag sensing. SY 2018 contacts refers to the number of unique fish in each release cohort contacted during this SY. Release locations listed as "A10" were not differentiated between lower and upper in release records.)

Release date	Release location	Rearing site	Releases	Contacts	SY 2018 contacts	TL mean (range)	DAL mean (range)
11/16/2017	C7 McIntyre Park	Lake Mead Fish Hatchery	15	0	0	447 (412–476)	(–)
12/5/2017	A10 lower	Center	600	48	48	343 (305–456)	67 (42–82)
12/5/2017	A10 upper	Center	600	85	85	343 (305–436)	35 (8–69)
12/5/2017	A7 upper	Center	600	5	5	345 (305–447)	20 (6–72)
12/5/2017	C10 Ehler's	Achii Hanyo Native Fish Rearing Facility	413	10	10	332 (305–440)	20 (6–52)
1/24/2018	A10 upper	Lake Mead Fish Hatchery	400	134	134	362 (305–466)	3 (0–19)
1/24/2018	C7 McIntyre Park	Lake Mead Fish Hatchery	300	78	78	361 (305–473)	4 (0–34)
1/24/2018	C10 Ehler's	Lake Mead Fish Hatchery	300	27	27	360 (305–458)	4 (1–36)
2/7/2018	A10 lower	Lake Mead Fish Hatchery	500	76	76	379 (305–475)	5 (0–39)
2/7/2018	A7 upper	Lake Mead Fish Hatchery	500	3	3	376 (305–510)	26 (12–43)
2/7/2018	C10 Ehler's	Lake Mead Fish Hatchery	350	1	1	359 (305–465)	23 (23–23)
4/4/2018	A10 upper	Lake Mead Fish Hatchery	390	0	0	355 (305–455)	(–)
4/4/2018	C7 McIntyre Park	Lake Mead Fish Hatchery	407	0	0	363 (305–480)	(–)
		Totals	**18,475**	**973**	**535**		

Remote PIT Tag Sensing

Throughout the entirety of the SY, Marsh & Associates, LLC, biologists took eight trips to the study area, each lasting 5 days and 4 nights. During these trips, 233 remote PIT tag sensing unit deployments were made, totaling 12,597.1 hours of scan time. Of these units, 123 were deployed in the 5 focal backwaters for 7,037.6 scan-hours. The remaining 110 were deployed in the main channel of the Colorado River for a total of 5,559.4 scan-hours.

Totals of 1,234 razorback sucker and 535 bonytail unique contacts were recorded in the backwaters and main channel during scanning activities in SY 2018 (see tables 4 and 5). All 1,131 razorback sucker contacts (91.6%) and all bonytail contacts were fishes stocked this SY. There were 103 razorback suckers stocked in previous SYs that were contacted this SY, 84 of which were stocked in A10 upper or A10 lower. Four razorback suckers released in the area prior to September 2014 were contacted in SY 2018, as were 56 fish from an April 2015 release. The semipermanent remote PIT tag sensing unit deployed in the culvert between A10 upper and A10 lower contacted 710 unique fishes during the 2 months it was in operation. The overall proportion of fishes released this SY that were contacted via remote PIT tag sensing units was 0.078 (535 of 6,779) and 0.19 (1,131 of 5,950) for razorback suckers and bonytail, respectively.

Remote PIT tag sensing units were deployed further downstream in SY 2018 compared to deployments in SY 2017 (figure 5). In SY 2018, more units were deployed in the main channel, which in turn produced more main channel contacts. Fifteen unique fishes, nine razorback suckers, and six bonytail were contacted in the main channel this SY (table 6).

Population Estimates

No bonytail contacted in SY 2018 were released prior to SY 2018 (October 1, 2017); therefore, no population estimate was possible. The razorback sucker population estimate for SY 2017 was 169 (95% CI = 157 to 180), with 155 encountered in SY 2017 (marking period October 2016 through May 2017), 65 encountered in SY 2018 (capture period October 2017 through May 2018), and 60 encountered in both periods (recaptures). For comparison, the estimated population of razorback suckers in A10 (upper and lower) for SY 2017 was 151 (95% CI = 142 to 161), with 141, 64, and 60 for marks, captures, and recaptures, respectively.

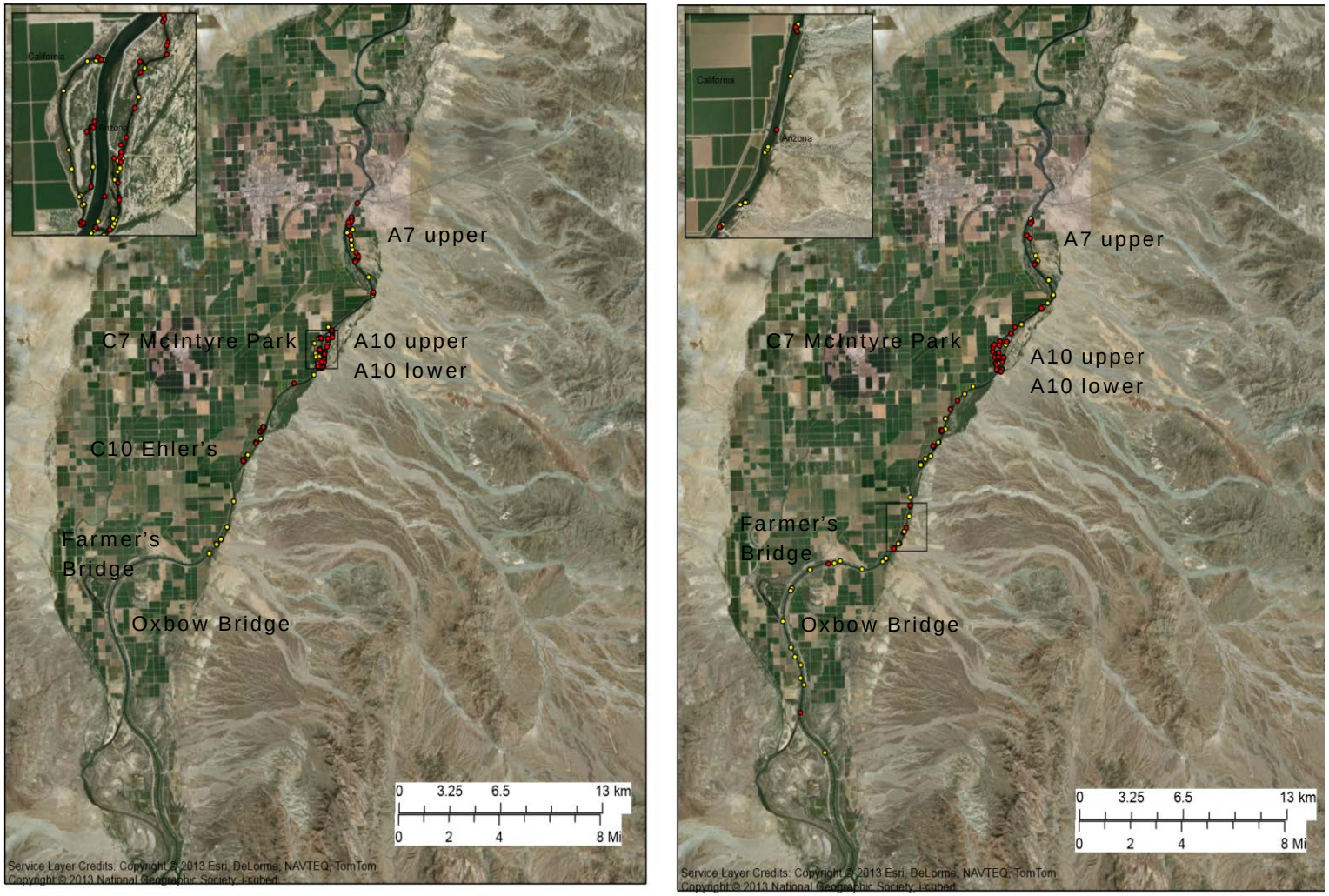

Figure 5.—Remote PIT tag sensing unit deployment locations for SY 2017 (left) and SY 2018 (right), lower Colorado River, Arizona and California.

A red dot represents a location where at least one PIT contact was recorded; a yellow dot represents a location where no PIT tags were contacted.

Table 6.—Razorback sucker and bonytail release and contact data for fishes contacted via remote PIT sensing in the main channel, lower Colorado River, Arizona and California

PIT tag	Release location	Release date	Scan location
Razorback sucker			
003BEA544F	Mayflower	5/4/2017	Farmers Bridge
003C06CF83	A10 lower	1/19/2018	Arroyo Wash
003C0797D4	A7 upper	2/15/2018	Riverside Wash
003C0790D3	C10 Ehler's	2/16/2018	Riverside Wash
003C079851	A10 lower	2/15/2018	Below Oxbow Bridge
003BF30C7C	A7 upper	1/19/2018	C10 Ehler's culvert (river side)
003C06C4EB	A10 lower	1/19/2018	C10 Ehler's culvert (river side)
003C06CF76	A10 lower	1/19/2018	C7 Riverside
003C06CF7D	A10 lower	1/19/2018	C7 Riverside
Bonytail			
2794E995C0	A10 upper	10/11/2017	C10 Ehler's culvert (river side)
003BC0075C	A7 upper	10/11/2017	Upriver of C7 McIntyre Park
2794E9874A	A10 upper	12/5/2017	Below Farmers Bridge
003C06D75D	C7 McIntyre Park	1/24/2018	Riverside C10 Ehler's seep
003BF30CD8	A10 upper	1/24/2018	Riverside above washes
003C06D50C	A7 upper	2/7/2018	Above C7 McIntyre Park powerlines
003C06D50C	A7 upper	2/7/2018	Above C7 McIntyre powerlines

Post-Stocking Survival and Dispersal

Dispersal distances were calculated for acoustic-tagged fishes contacted outside their release backwater (tables 7, 8, and 9). Of 46 fish that were tagged this year, 20 were contacted outside their release backwater, 24 were never contacted outside their release backwater, and 2 were never contacted. Of the 20 fish contacted outside their release backwater, 7 were subadult razorback suckers, 7 were adult razorback suckers, and 6 were subadult bonytail.

Results of acoustic-tagged fishes leaving release backwaters were mixed in SY 2018, with 24 of 46 (52%) contacted only in their release backwater. For the first two SYs (SY 2017 and SY 2018), 31 of 96 acoustic-tagged fishes (32%) were detected outside their release backwater, 21 of those were detected across the channel between A10 lower and C7 McIntyre Park. Three of these fishes

Table 7.—Dispersal statistics for acoustic-tagged razorback suckers released in SY 2018, lower Colorado River, Arizona and California

(DAL was calculated by the difference in days from the day of last contact and the day of release. Tags Y2_148 and above are adult fish.)

Tag ID	Dispersal distance (km)	DAL	Displacement/day (km)
Y2_10	8.94	124.43	0.07
Y2_12	36.73	41.14	0.89
Y2_14	36.54	34.9	1.05
Y2_20	80.96	118.92	0.68
Y2_24	12.23	31	0.39
Y2_32	9.75	70.8	0.14
Y2_44	6.84	114.75	0.06
Y2_148	6.66	62.91	0.11
Y2_149	21.56	63.05	0.34
Y2_150	2.56	62.89	0.04
Y2_152	2.19	63.32	0.03
Y2_154	3.15	60.82	0.05
Y2_155	66.24	59.83	1.11
Y2_156	8.12	38.27	0.21

Table 8.—Dispersal statistics for acoustic-tagged bonytail released in SY 2018, lower Colorado River, Arizona and California

(DAL was calculated by the difference in days from the day of last contact and the day of release. All fish are subadult.)

Tag ID	Dispersal distance (km)	DAL	Displacement/day (km)
Y2_5	2.4	99.39	0.02
Y2_17	4.99	108.3	0.05
Y2_21	2.91	113.43	0.03
Y2_29	34.82	122.67	0.28
Y2_33	9.75	104.49	0.09
Y2_47	17.14	103.85	0.17

Table 9.—Dispersal statistics for acoustic-tagged adult razorback suckers from SY 2017 outside of the release backwater after 4/15/2017 (last field day of SY 2017), lower Colorado River, Arizona and California

Tag ID	Dispersal distance (km)	Location of last contact	Date of last contact
137	138.17	C7 McIntyre Park	8/23/2017
141	166.448	Oxbow Bridge	7/29/2017
143	138.17	C10	2/7/2018
146	148.67	A10 lower	3/5/2018

were later detected downstream from the area. Of the remaining 10 fishes that were detected outside their release backwater, 8 were detected downstream. There were no detections at the upstream-most SUR at the Palo Verde Ecological Preserve.

The greatest calculated dispersal distance by an acoustic-tagged subadult bonytail (Tag ID Y2_29) was 34.82 km (see table 8). Released into C7 McIntyre Park on November 16, 2017, it was recorded on two SURs in C7 McIntyre Park until November 30, when it was contacted by a SUR in the river outside of C7 McIntyre Park and then by the Hart Mine Bridge SUR on December 9, 2017.

The greatest calculated dispersal distance for a subadult razorback sucker (Tag ID Y2_20) was 80.96 km (see table 7). This fish was released on November 16, 2017, into C7 McIntyre Park. It was recorded on SURs in C7 McIntyre Park and A10 lower from November 18, 2017, to January 8, 2018. It was subsequently recorded on a SUR in C10 Ehler's on January 9, 2018. From February 1 through March 16, 2018 (the last SUR contact downloaded), the fish was recorded multiple times downstream from and within C7 McIntyre Park and within A10 lower.

Of the 10 adult razorback suckers tagged in SY1, it is likely that 5 of them were alive at the end of the SY2 field season. All five were contacted in a backwater habitat in the month prior to the last data retrieval, with four of the five being in a different backwater than the release location. Going into SY3, their telemetry tags will have 1 year of battery life remaining.

Manual tracking effort resulted in one fish contacted in the main channel during SY 2018, which was the first acoustically tagged fish to be manually tracked in the main channel during this study.

On March 21, 2018, a diver recovered three acoustic tags from the study area. All three tags were CT-05-36 (36-month tags implanted into adult razorback suckers). One tag was implanted in a fish this SY on January 18, 2018, and the other two were implanted into fish on February 22, 2017 (SY 2017).

The majority of PIT tagged razorback suckers and bonytail released in the study reach were contacted by remote PIT tag sensing units within the first 60 days of release (figure 6). A total of 206 razorback suckers and one bonytail were contacted more than a year after release. Contact with razorback suckers released into A10 backwater complex more than 30 days after release was highest among all release sites for all release size classes (excluding size class 1 – < 305 mm TL, which has zero contacts among all locations and species). Razorback suckers released in size class 4 (405 to 454 mm TL) into the A10 backwater complex had the highest contact rate at 32.7% (375 out of 1,146). Among other release sites, size class 4 had the highest contact rate in A7 upper, and size class 5 (455 mm TL or longer) had the highest contact rate for releases into C7 McIntyre Park and the main channel. Contact with bonytail more than 30 days after release was < 5% across all locations and size classes (figure 7). Bonytail released into A10 backwater complex between 355 and 404 mm TL had the greatest percentage of contacts at 3.7% (37 out of 993 released).

Avian Predation Observations

Throughout the field season, October 2017 through March 2018, multiple species of predatory birds were seen within the study area. The most numerous species observed were double-crested cormorants (*Phalacrocorax auritus*), which were seen roosting throughout the area and swimming in each backwater. Other species observed included great blue herons (*Ardea Herodias*) and osprey (*Pandion haliaetus*). During the field season, dead fish were encountered floating in backwaters with wounds consistent with bird strikes – scratch marks and punctures (figure 8).

Similar to last year, a double-crested cormorant was observed regurgitating remains of an unidentifiable fish in a backwater. This year, for the first time, double-crested cormorants were observed at the downstream end of A10 upper. Razorback sucker aggregations are consistently observed in the same area.

DISCUSSION

This year there was an emphasis on contacting released fishes in the main channel. Nearly half of the remote PIT tag sensing unit deployments were in the river channel. This did not result in a large increase of river channel contacts; 15 fish were contacted in 110 deployments during SY 2018. In SY 2017, there were 25 PIT contacts in 41 main channel river deployments, but 21 of these contacts were with bonytail released less than a week before last contact.

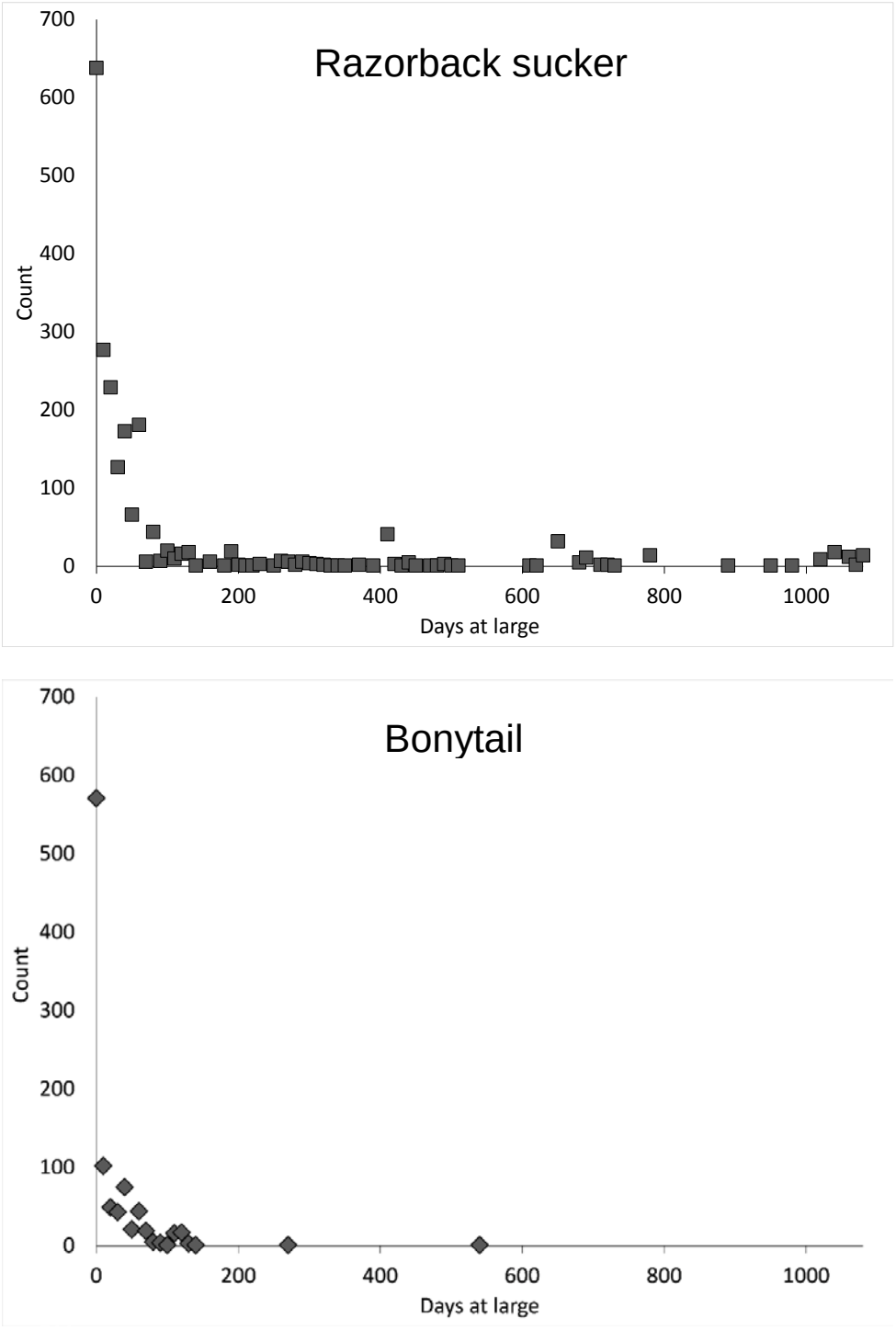

Figure 6.—The frequency of razorback suckers (top) and bonytail (bottom) contacted at a given number of days after release (DAL) via remote PIT tag sensing.

DAL was calculated as the maximum difference in the number of days between the day of release and the day of remote PIT tag sensing contact for an individual fish. Counts were then tallied within bins representing 10-day increments (0 to 9 days = 0, 10 through 19 = 10).

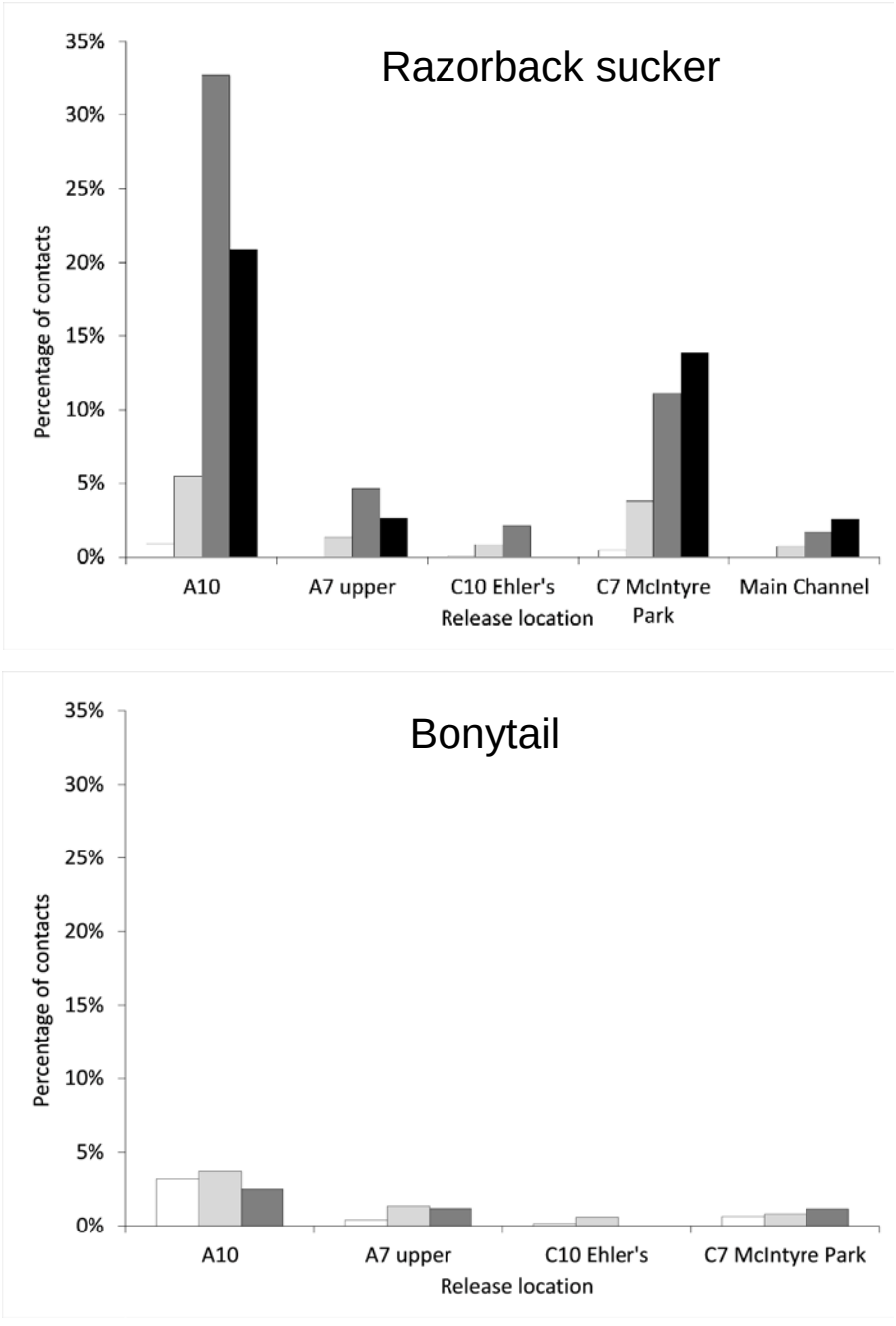

Figure 7.—Razorback suckers (top) and bonytail (bottom) contacted via remote PIT tag sensing as a percentage of total released grouped by release location and size at release (TL).
Size class 2 – 305 to 354 mm TL (white); size class 3 – 355 to 404 mm TL (light grey); size class 4 – 405 to 454 mm TL (dark grey); size class 5 – ≥ 455 mm TL (black). No fish of either species released in size class 1 (< 305 mm TL) has been contacted to date. Contact must have occurred more than 30 days after release. Releases into the A10 backwater complex (upper and lower) were combined due to ambiguous stocking records. Release groups with fewer than 30 fish were removed.

Figure 8—Razorback sucker mortality (left) and a bonytail mortality (right), both found floating deceased in A10 upper, lower Colorado River, Arizona and California.

Unless we assume all fish that enter the main channel return to a backwater to spawn, river channel contacts are needed to increase the likelihood that "apparent survival" estimates from future mark-recapture models represent survival. Post-stocking survival estimates will use the release as the "mark" and subsequent contacts as reencounters. If fishes move into the main channel and survive but are not reencountered, then they will decrease estimates of apparent survival because, in the model, they will have the same capture history as a fish that died. To date, the capture of one razorback sucker via electrofishing in the target habitat (wash fans downstream from A10 lower) is the only indication that any released fishes utilize this river channel habitat.

Deployment of remote PIT tag sensing units has been effective in contacting recently released razorback suckers within the release backwaters. However, long-term persistence of the species is still unknown. The number of contacts that met the criteria for inclusion in the population estimate was a small percentage (5% or 64 of 1,236) of the total razorback suckers contacted during SY 2018. This also was true for the estimate in SY 2017 (McCall et al. 2017). Most contacts (1,169 out of 1,234 contacted in SY 2018) were removed from the capture because they were released after the beginning of the marking period (October 1, 2016). There were 7,325 recent (after October 1, 2014) razorback sucker releases that occurred prior to the cutoff for the 2017 population estimate.

Most unique contacts that made up the mark and capture were also from one backwater complex (A10 upper and lower). The temporal and spatial limitations of the PIT scanning data in the Reach 4 continue.

Available data for bonytail were even fewer than for razorback suckers. No recaptures of bonytail were available for a population estimate. Records of individual bonytail that survived a year or more are uncommon anywhere in the Colorado River Basin (Humphrey et al. 2016; Bestgen et al. 2017), and to date, there have been too few for a population estimate. When survival has been estimated, it has been only within a few months of release and very low (Bestgen et al. 2008; Humphrey et al. 2016). The continued lack of detectable long-term persistence of either species will constrain our ability to estimate post-stocking survival using mark-recapture. The lack of detectable persistence alone indicates poor post-stocking survival for both species. However, we cannot exclude the possibility that both species disperse out of the study area. To date, there has been no evidence of permanent emigration from acoustic-tagged fishes.

Larvae collection was attempted once during the year with no success. A10 upper is the only location where spawning has been observed during this study. In early September 2017, a flash flood washed out the main spawning area within A10 upper (proximal to the road dividing A10 upper with A10 lower). The spawning area was inundated with fine alluvium and likely disrupted spawning. The area was restored and will be sampled for larvae in subsequent SYs. In addition, wash fans downstream from A10 lower and their downstream eddies will be sampled to determine successful spawning in the river channel.

The A10 backwater complex had the most contacts of fishes stocked over a year ago (see table 4) likely due to the semiclosed nature of A10 upper. It is an excellent place to gather large numbers of contacts and to look at year-to-year survival. However, when most contacts used in a mark-recapture model are from one backwater, the resultant estimates are not representative of the entire study area. Estimating survival for the entire study area will require increasing contact rates in other locations, including the main channel. Efforts to increase PIT scanning contacts outside of the A10 backwater complex will continue in SY 2019. Although no sonic-tagged fishes have been detected upstream of the I-10 bridge, there are several miles of river (and a few backwaters) between the bridge and the SUR at the Palo Verde Ecological Preserve. An additional SUR will be placed between these two sites, and PIT scanners will be deployed in the backwaters and main channel locations upstream of the I-10 bridge in SY 2019.

LITERATURE CITED

Bestgen, K.R., K.A. Zelasko, R.I. Compton, and T. Chart. 2008. Survival, condition, habitat use, and predation on stocked bonytail in the Green River, Colorado and Utah. The Southwestern Naturalist 53:488–494.

Bestgen, K.R., R.C. Schelly, R.R. Staffeldt, M.J. Breen, D.E Snyder, and M.T. Jones. 2017. First reproduction by stocked bonytail in the Upper Colorado River Basin. North American Journal of Fisheries Management 37:445–455.

Bureau of Reclamation. 2015. Native Fish Augmentation Plan, 2015–2020. Lower Colorado River Multi-Species Conservation Program, Bureau of Reclamation, Boulder City, Nevada.

Humphrey K.G., B.R. Kesner, and P.C. Marsh. 2016. Distribution and Post-Stocking Survival of Bonytail in Lake Havasu, 2015. Submitted to the Lower Colorado River Multi-Species Conservation Program, Bureau of Reclamation, Boulder City, Nevada, by Marsh & Associates, LLC, Tempe, Arizona.

Karam, A.P., B.R. Kesner, and P.C. Marsh. 2008. Acoustic telemetry to assess post-stocking dispersal and mortality of razorback sucker *Xyrauchen texanus* (Abbot). Journal of Fish Biology 73:1–9.

Martinsen, B. and T.E. Horsberg. 1995. Comparative single-dose pharmacokinetics of four quinolones, oxolinic acid, flumequine, sarafloxacin, and enrofloxacin, in Atlantic salmon (*Salmo salar*) held in seawater at 10 °C. Antimicrobial Agents and Chemotherapy. pp. 1059–1064. May 1995.

McCall, L.J., W.J. Goldsmith, B.R. Kesner, and P.C. Marsh. 2017. Population Status and Distribution of Razorback Suckers and Bonytail Downstream from Palo Verde Diversion Dam, 2017 Interim Report. Submitted to the Lower Colorado River Multi-Species Conservation Program, Bureau of Reclamation, Boulder City, Nevada, by Marsh & Associates, LLC, Tempe, Arizona, under Bureau of Reclamation Agreement No. R16PD00904.

Minckley, W.L. 1983. Status of the razorback sucker, *Xyrauchen texanus* (Abbott), in the Lower Colorado River Basin. The Southwestern Naturalist 28:165–187.

Mueller, G.M., P.C. Marsh, G. Knowles, and T. Wolters. 2000. Distribution, movements, and habitat use of razorback sucker (*Xyrauchen texanus*) in a lower Colorado River reservoir, Arizona-Nevada. Western North American Naturalists 60:180–187.

QGIS Development Team. 2017. QGIS Geographic Information System. Open Source Geospatial Foundation Project. https://qgis.org/en/site/

R Core Development Team. 2018. RStudio: Integrated development environment for R (Version 0.96.122) [computer software]. Boston, Massachusetts.

Ricker, W.E. 1975. Computation and Interpretation of Biological Statistics of Fish Populations. Bulletin of the Fisheries Research Board of Canada, No. 191. Department of the Environment Fisheries and Marine Service. 382 p.

Schooley, J.D., B.R. Kesner, J.R. Campbell, J.M. Barkstedt, and P.C. Marsh. 2008. Survival of Razorback Sucker in the Lower Colorado River, Final Report. Submitted to the Lower Colorado River Multi-Species Conservation Program, Bureau of Reclamation, Boulder City, Nevada, by Marsh & Associates, LLC, Tempe, Arizona, under Bureau of Reclamation Agreement No. 06-FC-30-0002. 86 p.

Seber, G.A.F. 1973. The Estimation of Animal Abundance and Related Parameters. Griffin, London. 506 p.

Tyers, M. 2017. Riverdist: River Network Distance Computation and Applications. R package version 0.15.0. https://CRAN.R-project.org/package=riverdist

Tyus, H.M. 1987. Distribution, reproduction, and habitat use of the razorback sucker in the Green River, Utah, 1979–1986. Transactions of the American Fisheries Society 116:111–116.