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

2019 Interim Report

April 2020

Work conducted under LCR MSCP Work Task C64

Lower Colorado River Multi-Species Conservation Program Steering Committee Members

Federal Participant Group

Bureau of Reclamation
U.S. Fish and Wildlife Service
National Park Service
Bureau of Land Management
Bureau of Indian Affairs
Western Area Power Administration

Arizona Participant Group

Arizona Department of Water Resources
Arizona Electric Power Cooperative, Inc.
Arizona Game and Fish Department
Arizona Power Authority
Central Arizona Water Conservation District
Cibola Valley Irrigation and Drainage District
City of Bullhead City
City of Lake Havasu City
City of Mesa
City of Somerton
City of Yuma
Electrical District No. 3, Pinal County, Arizona
Golden Shores Water Conservation District
Mohave County Water Authority
Mohave Valley Irrigation and Drainage District
Mohave Water Conservation District
North Gila Valley Irrigation and Drainage District
Town of Fredonia
Town of Thatcher
Town of Wickenburg
Salt River Project Agricultural Improvement and Power District
Unit "B" Irrigation and Drainage District
Wellton-Mohawk Irrigation and Drainage District
Yuma County Water Users' Association
Yuma Irrigation District
Yuma Mesa Irrigation and Drainage District

Other Interested Parties Participant Group

QuadState Local Governments Authority
Desert Wildlife Unlimited

California Participant Group

California Department of Fish and Wildlife
City of Needles
Coachella Valley Water District
Colorado River Board of California
Bard Water District
Imperial Irrigation District
Los Angeles Department of Water and Power
Palo Verde Irrigation District
San Diego County Water Authority
Southern California Edison Company
Southern California Public Power Authority
The Metropolitan Water District of Southern California

Nevada Participant Group

Colorado River Commission of Nevada
Nevada Department of Wildlife
Southern Nevada Water Authority
Colorado River Commission Power Users
Basic Water Company

Native American Participant Group

Hualapai Tribe
Colorado River Indian Tribes
Chemehuevi Indian Tribe

Conservation Participant Group

Ducks Unlimited
Lower Colorado River RC&D Area, Inc.
The Nature Conservancy

Lower Colorado River Multi-Species Conservation Program

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

2019 Interim Report

Prepared by:
Taylor F. Haas, Brian R. Kesner, and Paul C. Marsh
Marsh & Associates, LLC
5016 South Ash Avenue, Suite 108
Tempe, Arizona 85282

Lower Colorado River
Multi-Species Conservation Program
Bureau of Reclamation
Lower Colorado Basin
Boulder City, Nevada
http://www.lcrmscp.gov

April 2020

Haas T.F, B.R. Kesner, and P.C. Marsh. 2020. Population Status and Distribution of Razorback Suckers and Bonytail Downstream from Palo Verde Diversion Dam, 2019 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 contract No. R16PD00904.

ACRONYMS AND ABBREVIATIONS

Achii Hanyo	Achii Hanyo Native Fish Rearing Facility
Aggregation Site	a gravel aggregation site near the entrance to C7 McIntyre Park
C	capture
Center	Southwestern Native Aquatic Resources and Recovery Center
CI	confidence interval
cm	centimeter(s)
FDX	full duplex (passive integrated transponder tag)
HDX	half duplex (passive integrated transponder tag)
kHz	kilohertz
km	kilometer(s)
LCR MSCP	Lower Colorado River Multi-Species Conservation Program
M	mark
m	meter(s)
M&A	Marsh & Associates, LLC
mg/kg	milligram(s) per kilogram(s)
mg/L	milligram(s) per liter
mm	millimeter(s)
MS-222	tricaine methanesulfonate
PIT	passive integrated transponder
R	recapture
Reclamation	Bureau of Reclamation
SUR	submersible ultrasonic receiver
SY	study year
TL	total length
USFWS	U.S. Fish and Wildlife Service
UTM	Universal Transverse Mercator

Symbols

°C	degrees Celsius
≥	greater than or equal to
<	less than
%	percent
®	registered

CONTENTS

Tables

Figures

EXECUTIVE SUMMARY

This is the third 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 12,686 razorback suckers and 6,490 bonytail were stocked into backwaters and the main channel of the study area in La Paz County, Arizona, and Riverside County, California, from October 2018 through April 2019. An experimental release of 364 bonytail were implanted with 32-millimeter (mm), 134.2-kilohertz, half duplex passive integrated transponder (PIT) tags. All other fish released were implanted with 12-mm, 134.2-kilohertz, full duplex PIT tags.

Up to 20 portable remote PIT tag sensing units (scanners) were distributed throughout backwaters and the Colorado River main channel for 5 days during each month from October to March. During the peak razorback sucker spawning season (January – February) PIT scanners were deployed for 10 days each month. Scanning effort in the river channel was increased during the active sample period (October 1, 2018, to March 30, 2019) to identify spawning sites outside of backwater habitat and to contact individuals during spawning. Two, semipermanent scanners were placed in culverts to monitor dispersal through and out of backwater habitat. These culvert scanners ran continuously throughout the field season. Marsh & Associates, LLC (M&A) deployed PIT tag sensing units for 16,973.2 hours in the study year. M&A and the Bureau of Reclamation contacted 1,836 razorback suckers and 346 bonytail through combined efforts. There were 344 razorback suckers contacted in the study year that had been released more than a year prior to their most recent contact; 0 bonytail contacts fit this criterion. There were 337 razorback suckers and 106 bonytail contacted in the main channel during this study year. In previous years, the largest numbers of river contacts were 15 razorback suckers and 9 bonytail. The increase in river contacts is largely due to the discovery of a razorback sucker gravel aggregation site near the entrance to C7 McIntyre Park in January, where 307 razorback suckers and 3 bonytail were contacted. No bonytail contacted during the marking period (January 1 to February 28, 2018) were contacted again in the capture period (October 1 to April 30, 2018), so no population estimate was possible. The razorback sucker population estimate for 2018 was 147 (95% confidence interval 123 to 171).

Twenty subadult bonytail and 20 subadult razorback suckers were implanted with short-term (3-month) acoustic telemetry tags to examine dispersal patterns immediately following release. Ten adult razorback suckers were implanted with longer-term (36-month) tags, and 10 adult bonytail were implanted with 9-month tags to monitor long-term dispersal. This was the first year of the study in which bonytail were implanted with long-term tags. Seven of the razorback suckers implanted with long-term tags were acquired by electroshocking over the spawning site in the river.

Throughout the study year, manual tracking of acoustic tags was conducted in backwaters to supplement submersible ultrasonic receiver data used to track dispersal and to identify stationary tags. Tracking was also conducted in the main river channel January through March; three razorback suckers were contacted at the aggregation site in the river channel, and one adult was contacted downstream from all backwaters. The maximum dispersal distance of any acoustic-tagged fishes was 63.59 kilometers by a subadult razorback sucker released in November 2018. Divers recovered six acoustic tags: one 36-month tag implanted into an adult razorback sucker, three 3-month tags from subadult bonytail, and two 9-month tags from adult bonytail in the first study year.

For the first time in this study, adult razorback suckers were observed (contacted) aggregating in the mainstem Colorado River in the reach downstream from Palo Verde Diversion Dam. Population estimates for razorback suckers remain low, but continued stocking of large fish over the next few years will provide estimates of vital demographic rates. This, in turn, could be used to determine the potential for establishing a population of adult razorback suckers in the lower Colorado River.

Evidence of long-term persistence (more than 1-year post-release) of bonytail in the study area is lacking, despite contacting thousands within the first few months post-release. Bonytail tagged with large (32-mm) half duplex PIT tags had higher contact rates than those tagged with 12-mm, full duplex PIT tags during this study year (30.2 versus 11.6%, respectively), suggesting that this larger tag format may improve contact rates and increase the probability of observing long-term persistence.

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 two 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 these reaches for 45 years, with all fishes being ≥ 305 millimeters (mm) total length (TL). Beginning in 2018, an additional 4,000 bonytail per year are scheduled to be stocked to initiate a 10-year period of intense research and monitoring (Bureau of Reclamation [Reclamation] 2015). An additional 6,000 razorback suckers will be stocked for a 10-year period starting in 2019. All fishes are released with a 134.2-kilohertz (kHz) passive integrated transponder (PIT) tag.

Previous research and monitoring efforts in the study area (2006–08) estimated the annual survival of razorback suckers at less than 30%, and no estimate was available for bonytail due to low recapture rates (Schooley et al. 2008). A prominence of piscivorous fishes and birds and a high incidence of injuries from attempted avian predation were associated with low post-stocking survival for both species. Results were based on trammel net and electrofishing data, and recapture rates were low (less than 1% of total fish released) outside of release backwaters. The current research and monitoring efforts are based primarily on remote PIT tag sensing, which may provide higher contact rates while eliminating stress and mortality due to capture and 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 (FDX) 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 of the LCR MSCP 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 4/5 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 analysis to identify their potential relationship to scanning contact rates (e.g., with graphs and/or correlation analysis).

Study Area

Reach 4 of the LCR MSCP planning area extends 104 river miles downstream from Parker Dam at River Mile 192 to the southern end of the Cibola National Wildlife Refuge at River Mile 88. Reach 5 continues from here 38.8 river miles downstream to Imperial Diversion Dam at River Mile 49.2 (figure 1). The focal area of this study is from 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 Reach 4: 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 a culvert or 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 (PIT scanners), while active sampling was conducted from a boat using a directional or towable omnidirectional hydrophone. Acoustic tags were surgically implanted into 20 hatchery-reared subadult razorback suckers and bonytail, and 10 adult razorback suckers and bonytail; 3of the adult razorback suckers were from the Lake Mead Fish Hatchery, Nevada, and 7 were electrofished from a gravel aggregation site (hereon referred to as the Aggregation Site) on the Colorado River near the river access point of C7 McIntyre Park at Universal Transverse Mercator (UTM) 11 S 726450 E 3711303 N (Karam et al. 2008; Mueller et al. 2000). Telemetry and remote PIT tag sensing data were grouped by study year (SY) based on the fiscal year schedule

MSCP Reach 4/5 Lower Colorado River

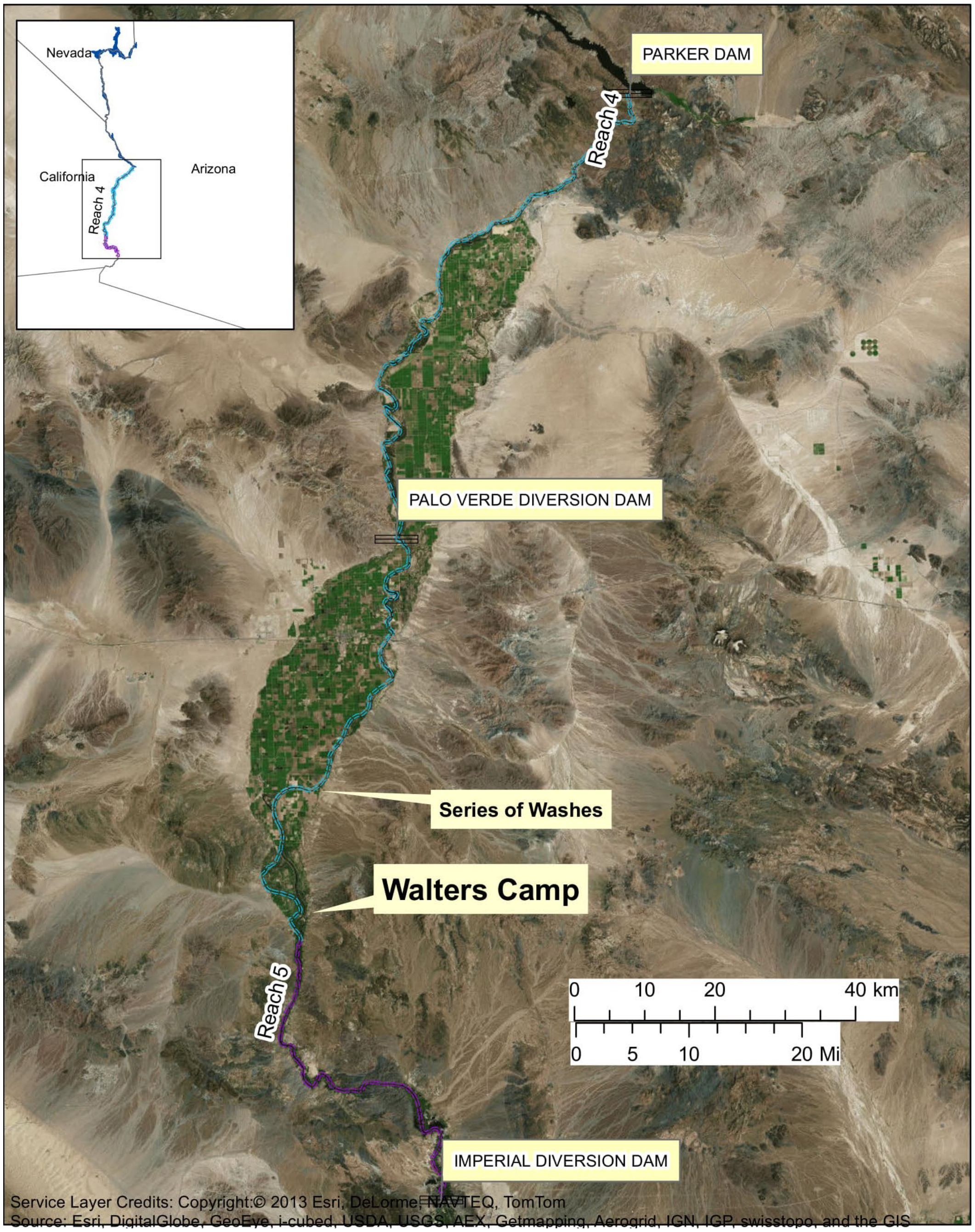


Figure 1.—LCR MSCP Reaches 4 and 5 on the lower Colorado River, Arizona and California.

Reach 4 (light blue) begins downstream from Parker Dam and continues downstream to the southern border of the Cibola National Wildlife Refuge. Reach 5 (violet) begins at the adjoining northern border of the Imperial National Wildlife Refuge and continues downstream to Imperial Diversion Dam.

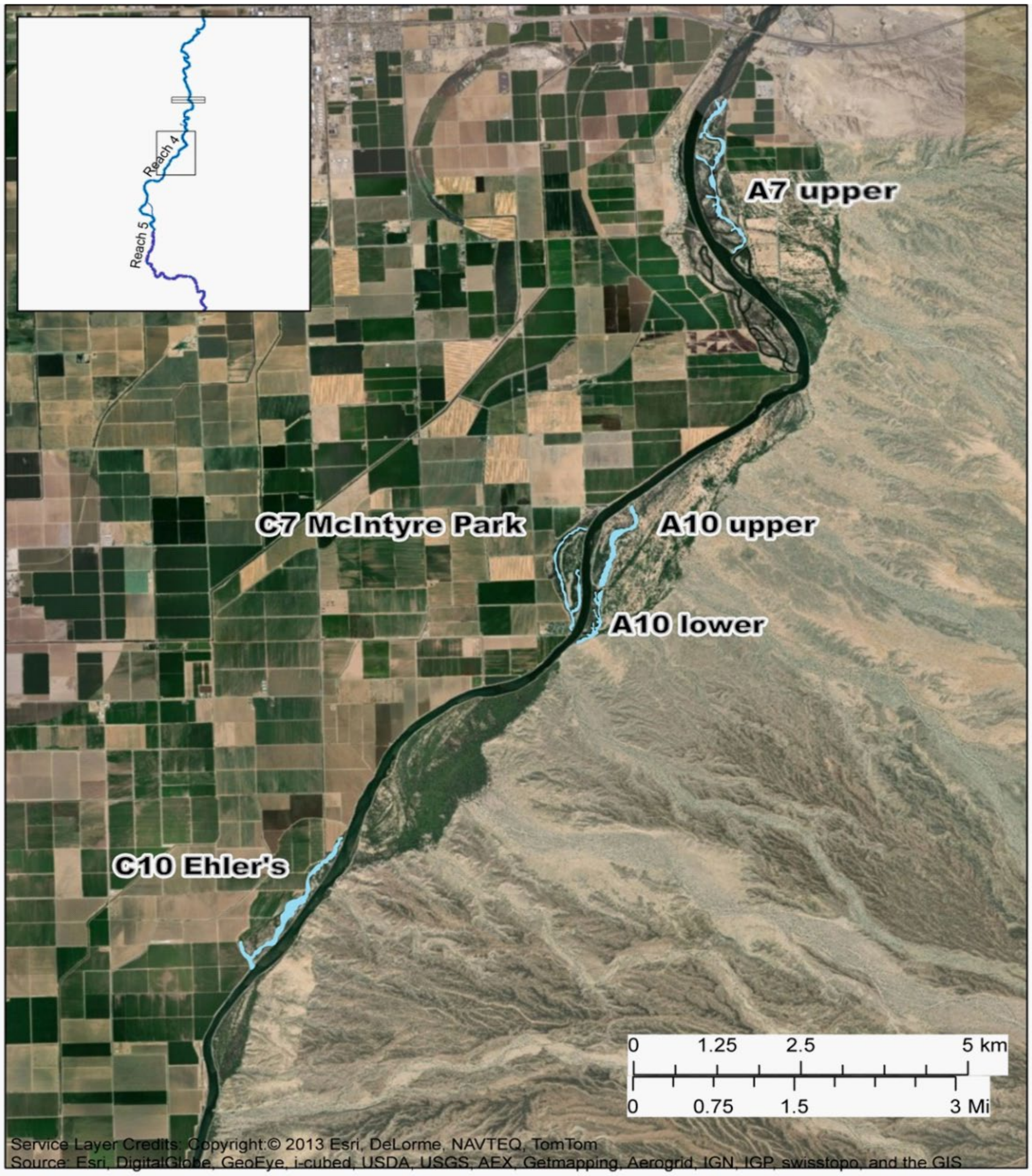


Figure 2.—Study backwaters in LCR MSCP Reach 4 on the lower Colorado River, Arizona and California.

Figure 3.—Aerial imagery of five backwaters in LCR MSCP Reach 4, lower Colorado River, Arizona and California.
These backwaters were the focal point of release and monitoring efforts during the study year.

(e.g., October 1, 2015, to September 30, 2016, is SY 2016). Unless otherwise stated, previous study year data in this report represent the entire study year, and current study year data were restricted to the active sampling period, through April 2019, to allow adequate time for data analyses.

Releases

Releases of razorback suckers and bonytail during SY 2019 were spatially and temporally distributed to accommodate an analysis of factors influencing post-stocking survival (objective 6). At least one stocking per season (autumn, winter, and spring) is planned, 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, C7 McIntyre Park, A10 upper, A10 lower, 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 SY 2017.

Telemetry

Throughout the course of SY 2019, 16 SURs were distributed throughout the study area (figure 4). Of those, 15 were still active at the end of SY 2019. 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) 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 was programmed to scan continuously with a detection range of 200 m.

At least one SUR was deployed in each major backwater (A10 upper, A10 lower, A7 upper, C7 McIntyre Park, and C10 Ehler's). C10 Ehler's and A10 upper each had two SURs due to the size and number of acoustic-tagged fishes released in them. Due to the lack of contacts from the northernmost SUR in previous years, it was translocated approximately 7 river miles south. Remaining SURs were spaced out in the river from that location downstream to Walter's Camp.

All SUR data were downloaded once every trip. In months when two trips occurred in consecutive weeks, data were downloaded once during the span of the 2 weeks. Confidence values defined by the number of detections within a timed window were

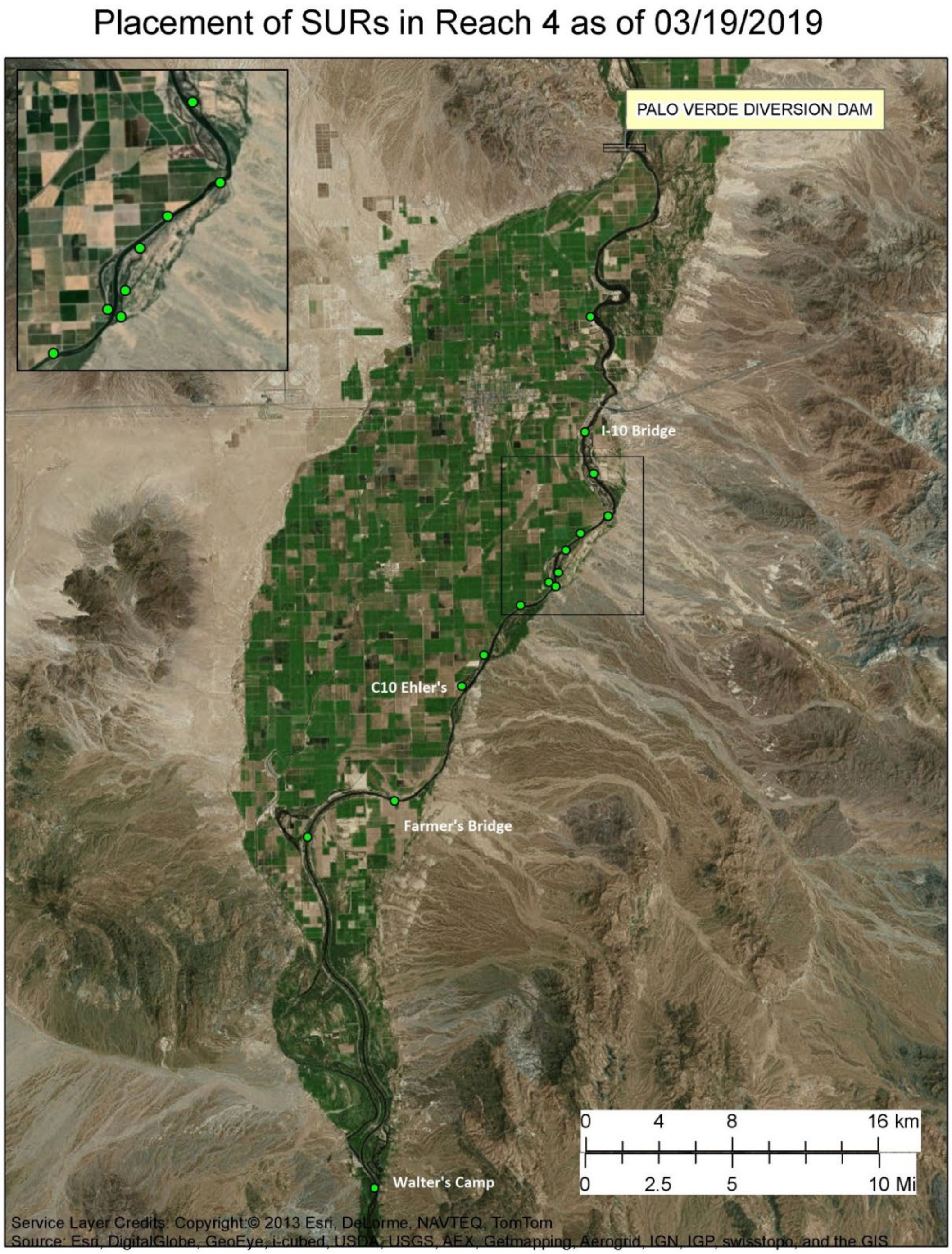


Figure 4.—Location of SURs deployed in the main channel and backwaters in Reach 4, lower Colorado River, Arizona and California.

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 the 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., Tucson, Arizona) 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 study year when time permitted, with a special focus on the spawning season. Similar to SY 2018, additional effort was made this year to manually track acoustic-tagged fishes in the main channel.

When the towable hydrophone was used, boat speed was maintained at about 10 kilometers (km) 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, and then an underwater dive receiver was used to pinpoint, within 5 meters, the location of the fish. The 5-meter estimate is based on previous tag recovery operations. When the gain on the dive receiver was set to the lowest setting, the acoustic signal from the tag was barely audible, and the recovered tags were always within 5 meters of the location where the tag was detected at this setting.

Surgery

All surgeries followed established procedures. Subadult razorback suckers and bonytail were implanted with PT-4 acoustic transmitters (Sonotronics, Inc.). This tag is small (25 x 9 mm), reliable, and has a battery life of approximately 3 months. In an effort to bolster bonytail telemetry contacts in the dataset, 10 adult bonytail were implanted with 9-month telemetry tags (IBT 96-9-I). This is an intermediate size tag (47 x 10.5 mm) and has a battery life of approximately 9 months. Adult razorback suckers captured from the river, and those from a hatchery, were implanted with CT-05-36-I acoustic transmitters. This is a larger tag (63 x 15.6 mm) and has a battery life of approximately 36 months.

Before surgery, individual fish were immersed into a dark container with approximately 16 liters of fresh water and tricaine methanesulfonate (MS-222; 125 mg L) to anesthetize them. 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 (TL in mm), weighed (nearest gram), and scanned for a 134.2-kHz PIT tag. Fishes were 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 [cm]) 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. Fishes absent of a PIT tag were implanted with a 134.2-kHz tag via the mediolateral incision. The incision was closed with two to three 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 8, 2018, 10 subadult razorback suckers were surgically implanted with model PT-4 acoustic transmitters at the A10 lower culvert (objective 4) (table 1). Fishes were released into A10 lower immediately post-surgery. The mean TL was 397 mm (347–459 mm).

Table 1.—Subadult razorback suckers released into A10 lower, lower Colorado River, Arizona, November 8, 2018

Tag ID	Frequency	Interval (milliseconds)	Code	TL (mm)	Weight (grams)	PIT tag number
100	78	1,160	4-6-6-8	406	600	3DD.003C07AB0B
102	80	1,180	5-5-6-6	459	1,009	3DD.003C07A930
104	82	1,200	5-6-8-8	431	805	3DD.003C07AAE2
108	71	910	4-4-5	357	451	3DD.003C07AB14
110	73	930	4-8-6	347	423	3DD.003C07B09F
112	75	950	6-6-7	445	823	3DD.003C07A923
114	77	970	3-3-4-7	378	460	3DD.003C07B064
116	79	990	3-3-8-4	381	547	3DD.003C07AC7E
118	81	1,010	3-4-5-6	349	336	3DD.003C07B04E
120	83	1,030	3-5-3-8	420	683	3DD.003C07AB15

December

On December 12, 2018, 10 adult bonytail were surgically implanted with model PT-4 acoustic transmitters at the A10 lower culvert (table 2). Fish were released into A10 lower immediately post-surgery. The mean TL of the bonytail was 440 mm (423–482 mm).

Table 2.—Adult bonytail released into A10 lower, lower Colorado River, Arizona, December 12, 2018

Tag ID	Frequency	Interval (milliseconds)	Code	TL (mm)	Weight (grams)	PIT tag number
101	79	1,190	5-5-5-8	423	729	3DD.003BCBF715
103	81	1,210	5-6-7-8	482	1,246	3DD.003BCBF72A
105	83	1,230	5-8-7-8	432	777	3DD.003BCBF734
107	70	900	4-4-4	445	1,030	3DD.003BCBF746
109	72	920	4-8-5	436	796	3DD.003BCBF72E
111	74	940	6-6-6	432	780	3DD.003BCBF745
113	76	960	3-3-4-6	431	840	3DD.003BCBF719
115	78	980	3-3-7-8	446	749	3DD.003BCBF740
117	80	1,000	3-4-5-5	440	833	3DD.003BCBF767
119	82	1,020	3-5-3-7	433	742	3DD.003BCBF742

January

Razorback

On January 30–31, Marsh & Associates, LLC (M&A) joined a Reclamation team to electrofish in the main channel to procure fish for tag implantation that had naturalized to the study area. Suitable habitat was targeted, and seven fish large enough for tag implantation were collected. On January 31, 2019, 10 razorback suckers were surgically implanted with CT-05-36-I acoustic transmitters at the A10 lower culvert, including the fish captured from the river (table 3, objective 3). Fish were released into A10 lower immediately post-surgery. The mean TL of these razorback suckers was 533 mm (495–635 mm).

Table 3.—Adult razorback suckers released in A10 lower, lower Colorado River, Arizona, January 31, 2019
(Fish 160–166 were captured by electrofishing in the Colorado River main channel.)

Tag ID	Frequency	Interval (milliseconds)	Code	TL (mm)	Weight (grams)	PIT tag number
160	78	1,100	3-7-7-6	510	1,552	3DD.003BEA5235
161	79	1,110	3-7-7-7	499	1,493	3DD.003BEA479A
162	80	1,120	4-4-7-5	593	2,358	3D9.1C2D6D1011
163	81	1,130	4-4-7-6	635	2,810	3D9.1C2D6BFF6D
164	82	1,140	4-5-7-8	527	1,516	3DD.003BFDB87E
165	83	1,150	4-5-8-8	526	1,566	3DD.003C0791F7
166	69	1,190	4-7-7-7	523	1,323	3DD.003C078E15
167	70	1,180	4-7-7-8	495	1,593	3D9.1C2D6BF6F5
168	71	1,210	5-5-8-6	510	1,471	3D9.1C2D6D159B
169	72	1,200	5-5-8-7	515	1,600	3D9.1C2D6C3916

Bonytail

On January 31, 2019, 10 adult bonytail were surgically implanted with an IBT-96-9-I acoustic transmitter at the A10 lower culvert (table 4). Fish were released immediately into A10 lower post-surgery. The mean TL of these bonytail was 440 mm (375–500 mm).

Table 4.—Adult bonytail released into A10 lower, lower Colorado River, Arizona, January 31, 2019

Tag ID	Frequency	Interval (milliseconds)	Code	TL (mm)	Weight (grams)	PIT tag number
200	73	990	3-3-6-8	465	980	3D9.1C2D6BBE59
201	74	1,160	4-6-5-7	375	555	3D9.1C2D6CE855
202	75	1,190	4-8-7-8	395	524	3D9.1C2D6D1D99
203	76	1,180	4-8-8-8	420	627	3D9.1C2D6D100D
204	77	1,210	5-6-6-6	460	955	3D9.1C2D6D09DC
205	78	1,200	5-6-6-7	415	760	3D9.1C2D6C3B81
206	79	1,230	5-8-6-6	425	809	3D9.1C2C852492
207	80	1,220	5-8-6-7	470	1,053	3D9.1C2D6D1519
208	81	1,250	6-8-8-8	470	1,152	3D9.1C2D6C053F
209	82	1,240	7-8-8-8	500	1,196	3D9.1C2D6C2CB5

February

On February 21, 2019, 10 subadult razorback suckers and 10 adult bonytail were surgically implanted with PT-4 acoustic transmitters at the A10 lower culvert (table 5). Fishes were released into A10 lower immediately post-surgery. The mean TL of subadult razorback suckers was 496 mm (469–526 mm), and the mean TL of bonytail was 447 (407–493 mm).

Table 5.—Subadult razorback suckers and bonytail released in A10 lower, lower Colorado River, February 21, 2019

Tag ID	Frequency	Interval (milliseconds)	Code	TL (mm)	Weight (grams)	PIT tag number
Razorback suckers						
180	83	930	5-7-6	492	1,441	3DD.003BCBF743
182	70	960	3-3-3-5	526	1,634	3DD.003BCBF75E
184	72	980	3-3-6-7	480	1,437	3DD.003BCBF735
186	74	1,000	3-4-4-4	516	1,711	3DD.003BCBF71E
188	76	1,020	3-4-7-6	469	1,395	3D9.1C2D6D131A
190	78	1,040	3-5-6-4	480	1,300	3DD.003BCBF720
192	80	1,060	3-6-3-8	500	1,360	3DD.003BCBF747
194	82	1,080	3-6-8-8	496	1,473	3DD.003BCBF777
196	69	1,130	4-4-4-6	479	1,540	3DD.003BCBF765
198	71	1,150	4-5-4-6	525	1,638	3D9.1C2D6BC713
Bonytail						
185	73	1,230	5-7-7-6	458	881	3D9.1C2D6C2E45
183	71	970	3-3-3-6	470	1,029	3DD.003BCBF727
191	79	1,050	3-5-6-5	407	591	3DD.003BCBF716
187	75	1,010	3-4-4-5	463	1,091	3DD.003BCBF75F
195	83	1,090	3-7-3-7	412	830	3DD.003BCBF73E
199	72	1,140	4-5-4-7	441	904	3DD.003BCBF739
181	69	950	5-7-7	434	917	3DD.003BCBF71C
197	70	1,120	4-4-4-7	493	1,340	3DD.003BCBF759
193	81	1,070	3-6-4-4	456	876	3DD.003BCBF755
189	77	1,030	3-4-7-7	439	794	3DD.003BCBF750

Remote PIT Tag Sensing

Twenty portable remote PIT scanners were deployed during six monthly field sampling trips between October 22, 2018, and March 22, 2019 (objectives 1 and 2). Two additional sampling trips were conducted to maximize PIT scanning contacts during peak razorback sucker spawning 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 PIT scanners throughout the sampling trips.

Similar to SY 2018, PIT scanner deployments in the main channel were increased as compared to SY 2017. Typically, between 8 and 10 units were placed in the channel compared to 3 to 5 in SY 2017 (figure 5). These deployments typically 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 has been scarce due to channelization and riprap levees on riverbanks; however, low water levels this year led to the discovery of additional areas with the potentially preferred habitat (swift riverine habitat with gravel substrate) adjacent to the channelizing riprap in several locales. Upon the discovery of these locations, these areas became the focal points of remote PIT scanners deployed in the river.

In addition to standardized PIT scanner deployments, a semipermanent custom unit was placed in each of the culverts in A10 upper (figure 6). The unit in the lower culvert was the same one placed there in SY 2018 but refurbished back into working condition after finding it inoperable on the first trip of SY 2019 (figure 6, left image). It is constructed from 1-inch flexible polyvinyl chloride, and its diameter was custom fit to the inside of the acrylonitrile butadiene styrene culvert. Three mounting holes were drilled into the culvert to secure the antenna inside the culvert with plastic hose clamps. The unit placed in the upper culvert was a 48 x 98-cm rectangle made of 1 ¼-inch schedule-80 polyvinyl chloride pipe (figure 6, right image). It was attached with brackets on each side of the circular culvert. The brackets were configured to secure the antenna in the culvert while allowing fishes to pass above or below the antenna. A 5-conductor cable connected the antennas to their respective data loggers and was passed through an additional hole drilled into the side of the culvert. The data loggers (mini-loggers) and three, 7.4-volt, 20 ampere-hour Li-Ion batteries providing power to each of the units were secured inside watertight plastic housings partially buried within 8 m of their respective culverts.

Both culvert antennas were higher inductance, lower power consumption "double-wound" antennas than those used routinely in backwaters and the river. These antennas have twice the windings of standard units, which reduces power consumption to about half, while maintaining a read range of at least 50 cm for 32-mm, half duplex (HDX) PIT tags when the tag is parallel to the field and a greater

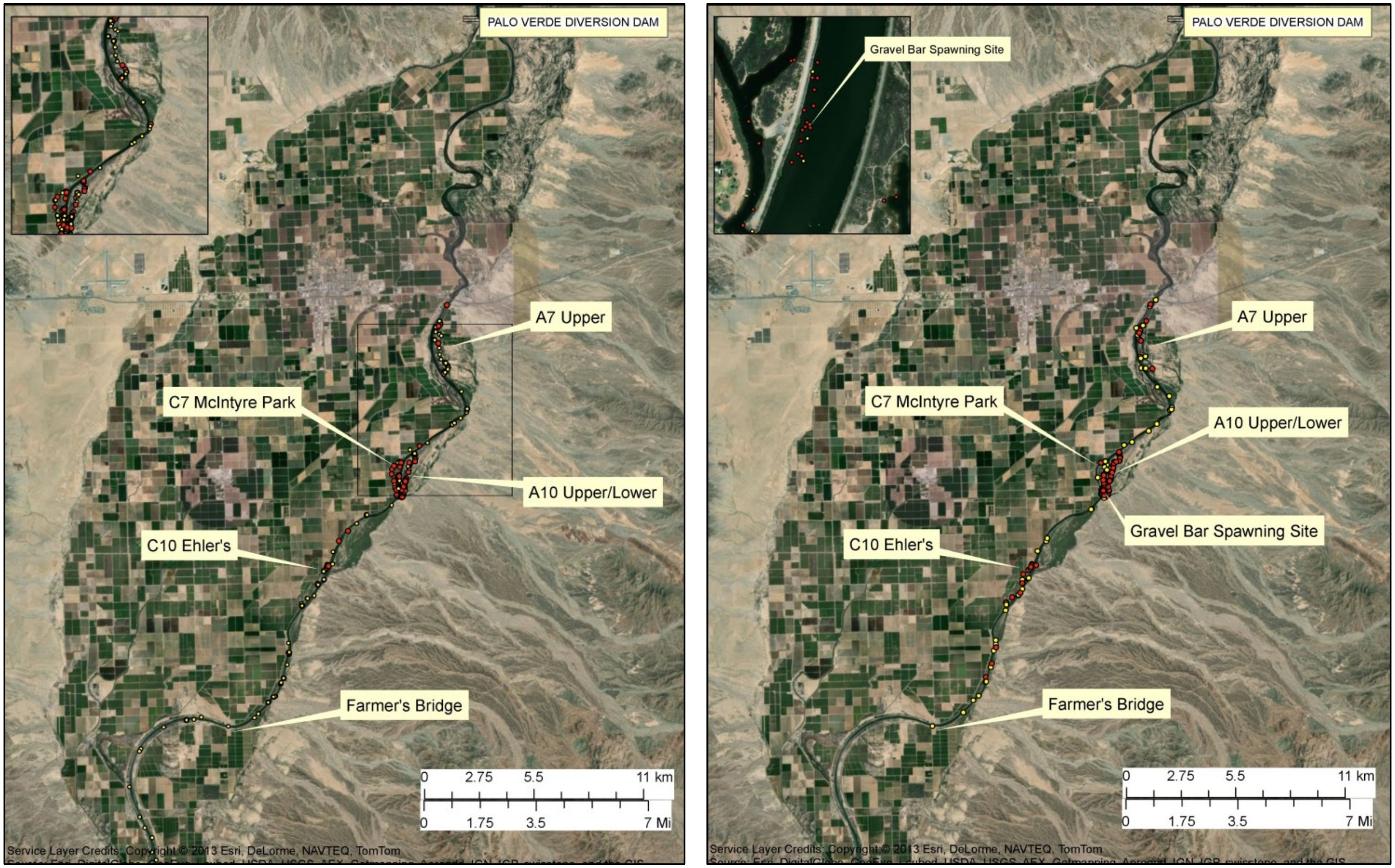


Figure 5.—Remote PIT tag sensing unit deployment locations for SY 2017 and 2018 (left) and SY 2019 (right) lower Colorado River, Arizona and California.

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.

Figure 6.—Culvert PIT scanner installation at the downstream culvert connecting A10 upper to A10 lower (left) and the upstream culvert connecting A10 upper to the mainstem Colorado River (right).

range when tag is perpendicular to the field. At the end of each sampling trip, three fully charged batteries were connected to each system, allowing for continuous operation of the antenna for approximately 15 days, with a maximum of 23.8 days.

Remote PIT Scanning Antenna Orientation Study

Due to years of low contact rates for PIT-tagged bonytail during this study, an experiment was designed to determine if contact rates could be improved by changing antenna orientation or using larger PIT tags (32-mm, 134.2-kHz HDX). Bonytail behaviorally inhabit a higher level in the water column than razorback suckers, which could reduce the contact rate of the scanning equipment when deployed flat on the substrate (Henne et al. 2007).

To test if antenna orientation would improve contact rates for bonytail, PIT scanners were placed in two orientations: bottom-flat (laying flat on the substrate), which is the standard deployment orientation for contacting razorback suckers (control orientation), and bottom-long (standing upright with the longest edge contacting the substrate), which extends the contact field higher in the water column but reduces the bottom surface area covered (experimental orientation).

On January 28, 2019, 364 bonytail implanted with 32-mm, 134.2-kHz HDX PIT tags were released in A10 upper (experimental tag). An additional 300 bonytail with standard 12-mm, 134.2-kHz FDX PIT tags were also released in this cohort to serve as the control tag group. The two culverts connecting the backwater to other bodies of water (the mainstem river at the upstream end and the lower half of the backwater at the downstream end) had PIT scanners as described above with a battery life in excess of 2 weeks. This allowed us to monitor emigration from the study area. During the 5-day sample period (January 28 to February 1), four PIT scanners were deployed throughout the study area: Two were laid flat at the bottom of the water column control orientation), and two were fitted with a buoyant float attached to the top of the antenna, causing the unit to stand upright in the water while maintaining direct contact with the substrate (experimental orientation).

Four PIT scanners were deployed at random sites daily for 4 days to test the impact of orientation on contact rates. Using ArcMap, a polygon of the study area was made that omits the area immediately adjacent to the release location. It was assumed that deployment locations immediately adjacent to the release site would have inflated contact rates for PIT scanners randomly deployed in this area regardless of orientation, making comparisons between the orientations difficult. Within the sample area polygon, a list of 30 UTM coordinates were randomly derived in QGIS (QGIS Development Team, 2017) to serve as potential deployment locations. Prior to deploying units, each unit was pseudorandomly assigned a deployment orientation. The pseudorandom function in Microsoft Excel "rand()" was used to assign the position of each unit. The lowest two pseudorandom values assigned to a unit represented bottom-long deployment, and the higher two numbers represented bottom-flat. If a deployment location was encountered during distribution of the units where the water depth was too shallow, the next location on the list was chosen.

Each deployment was retrieved as close to 23 hours as possible, and during the placement and retrieval of antennas, the units were collected and distributed in the same order throughout the week. The number of unique PIT tags associated with a bonytail release record and contacted on each study day was used to compare tag type and antenna orientation contact rates (i.e. the number of unique bonytail contacted for a given tag type), and orientation was tallied from the contacts recorded by the pair of antennas that were deployed in that orientation each study day (overnight deployment).

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); the probability of systematic bias in the estimate can be ignored if there are four or more recaptures (Ricker 1975). Data for population estimates were based on the scanning period from October 1 to April 30 of each study year, giving the fish 6 months between mark and capture periods to randomly assort.

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

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

For each mark-recapture estimate, the number of individual PIT tags contacted in a 2-month scanning period encompassing the peak of razorback suckers spawning (January 1 through the end of February) of the previous study year was the mark (*M*), the number contacted in the current study year the capture (*C*), and the number in common between both years the recaptures (*R*). Any contacts with PIT tags released after May 31 of the marking year (May 31 of the previous study year) were removed from population estimates. Contacts with the second PIT tag in double-tagged fish were assessed for inclusion, but none fit the criteria. CIs were derived from 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 51 or more recaptures (Seber 1973).

The Chapman estimate of large sample variance was used to calculate the standard error:

$$SE = \sqrt{\frac{(M+1)^2(C+1)(C-R)}{(R+2)(R+1)^2}} \quad \text{(Ricker 1975)}$$

Post-Stocking Survival and Dispersal

A combination of QGIS and R (R Core Development Team, 2018) was used to calculate dispersal between SURs. First, polyline data from the National Hydrography Dataset Plus were 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. The dispersal distance was only measured for fishes that left their release backwater.

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.

Development of a mark-recapture model to estimate post-release survival was initiated in this third year of the study (objective 6). The robust model type was assessed as an option to estimate post-stocking survival based on monthly PIT scanning data. Robust models combine closed, repeated sampling occasions during which no mortality or migration occurs (secondary sessions), with open periods between secondary sessions with mortality and temporary migration (primary sessions; Kendall et al. 1997). Routine scanning trips conducted from November through May[1] each sample year were treated as closed sampling sessions, and the time between sample years (May through October) as open periods.

The robust model assumes demographic closure during a sample year – no migration or mortality between secondary sampling occasions. Post-release apparent mortality is highest within the first 6 months after release (Karam et al. 2008; Schooley et al. 2008), so fishes released during the sample year are experiencing significant mortality between secondary occasions. In order to avoid a systematic assumption violation for the robust model, releases were coded to occur at the end of a sample season (i.e. the last secondary session prior to an open period). Development of the model is ongoing.

Temperature Logging

The primary predatory fish in the study area is the non-native flathead catfish (*Pylodictis olivaris*). Flathead catfish with a TL over 1 meter are not uncommon in the lower Colorado River and are considered the least gape-limited predator in the region (Slaughter and Jacobson 2008). Multiple studies have shown that flathead catfish disperse to a winter habitat and become immobile for the season when water temperatures reach 10 degrees Celsius (°C) (Daugherty and Sutton 2005; Vokoun and Rabeni 2005). This year, two Onset HOBO® Data Loggers were placed in the study area to record temperatures every 12 hours from October 24, 2018, to March 28, 2019. One logger was placed in A10 upper (recording near dusk and dawn at 7:40 a.m. and p.m.) and one in the mainstem of the Colorado River between A7 upper and A10 upper (recording at 1:40 a.m. and p.m.). The goal was to determine if water temperatures dropped below 10 °C at any point during the season. If temperatures were found to drop below this threshold, these data would be used to correlate future fish releases while flathead catfish were immobile in their winter habitat.

---

[1] M&A sampling trips for this contract were conducted between November and April, but a Reclamation scanning trip in May 2016 resulted in more than 100 unique PIT tag contacts. To include these contacts in the model, the sampling period was extended through May.

RESULTS

Releases

Totals of 34,446 razorback suckers and 26,743 bonytail were released into the 5 focal backwaters, as well as some river locations, between 2007 and April 9, 2019 (tables 6 and 7), based on records in the Lower Colorado River Native Fish Database. In SY 2019 (from October 1, 2018, through April 30, 2019), 12,686 razorback suckers and 7,010 bonytail were released. Fishes released across all years were reared at the Arizona Game and Fish Department Bubbling Ponds State Fish Hatchery, U.S. Fish and Wildlife Service (USFWS) Imperial Ponds Conservation Area (the Imperial ponds), USFWS Southwestern Native Aquatic Resources and Recovery Center, New Mexico (Center) (formerly named the Dexter National Fish Hatchery), Nevada Department of Wildlife Lake Mead Fish Hatchery, and the USFWS Achii Hanyo Native Fish Rearing Facility (Achii Hanyo), a satellite of Willow Beach National Fish Hatchery, Arizona. Release sizes ranged from 275 to 640 mm TL for razorback suckers and 223 to 535 mm TL for bonytail.

Remote PIT Tag Sensing

Throughout SY 2019, M&A biologists took 8 trips to the study area, each lasting 5 days and 4 nights. During these trips, 264 remote PIT tag sensing unit (scanner) deployments were made, totaling 16,973.2 hours of scan time. Of these, 176 were deployed in the 5 focal backwaters for 10,898.5 scan-hours. The remaining 88 were deployed in the main channel of the Colorado River for 6074.7 scan-hours.

Reclamation joined M&A biologists from January 29 to February 2, 2019, to maximize scanning effort during the peak razorback sucker spawning season and added 73 deployments, all of which were in the Colorado River and totaled 1,966.23 hours. Contact totals and results that follow are a combination of M&A and Reclamation PIT scanning efforts.

Totals of 1,836 razorback suckers and 346 bonytail with a release record were contacted at least once in backwaters and the main channel during scanning activities in SY 2019 (see tables 6 and 7). All bonytail contacted represented fish released in SY 2019, as were 1,492 of the razorback suckers contacted (81.3%). There were 344 razorback suckers contacted in SY 2019 that were released prior to SY 2019, 262 of which were stocked in A10 upper or A10 lower. There were four razorback suckers scanned in SY 2019 that were previously tagged at capture. Two were captured in the mainstem river near the C7 McIntyre Park backwater (see below paragraph on spawning site) in January 2019. The other two fish were captured in November 2011 and 2012 in A10 upper and A7 backwater upper, respectively.

Table 6.—Razorback sucker releases (January 2007 through April 2019) downstream from Palo Verde Diversion Dam and their subsequent remote PIT sensing contacts, lower Colorado River, Arizona and California

(TL was recorded in mm, and days at large was calculated for each PIT tag as the difference between the date of most recent remote sensing contact and the release date.)

Release date	Release location	Rearing site	Releases	Total contacts	SY 2019 Contacts	TL mean (range)	Days at large mean (range)
Before Sept. 2014			1,959	46	3	364 (300 – 624)	1,690 (314 – 4145)
11/6/2014	A10 lower	Imperial ponds	1	0	0	635 (635 – 635)	(–)
12/5/2014	A10 backwater	Imperial ponds	16	10	1	502 (275 – 585)	243 (11 – 1519)
12/5/2014	A10 backwater[1]	Imperial ponds	3	1	0	578 (520 – 615)	11 (11 – 11)
12/5/2014	A10 backwater	Imperial ponds	3	0	0	577 (560 – 610)	(–)
12/5/2014	A10 backwater	Imperial ponds	2	1	0	615 (590 – 640)	161 (161 – 161)
12/5/2014	A10 backwater	Imperial ponds	2	0	0	608 (590 – 625)	(–)
12/5/2014	A10 lower	Imperial ponds	3	1	0	590 (565 – 625)	76 (76 – 76)
12/5/2014	A10 lower	Imperial ponds	1	0	0	540 (540 – 540)	(–)
4/2/2015	A10 lower	Bubbling Ponds Fish Hatchery	1,019	188	7	344 (305 – 440)	86 (0 – 1450)
4/2/2015	A10 upper	Bubbling Ponds Fish Hatchery	778	174	59	347 (305 – 420)	836 (0 – 1450)
12/8/2015	A7 backwater upper	Achii Hanyo	1,212	31	0	336 (305 – 460)	16 (0 – 94)
12/9/2015	Oxbow Campground Recreational Area	Achii Hanyo	1,160	160	0	346 (305 – 455)	3 (0 – 76)
2/18/2016	A10 lower	Bubbling Ponds Fish Hatchery	518	12	1	338 (305 – 470)	272 (7 – 1078)
2/18/2016	Oxbow Campground Recreational Area	Bubbling Ponds Fish Hatchery	516	14	1	336 (305 – 445)	93 (5 – 1101)

Table 6.—Razorback sucker releases (January 2007 through April 2019) downstream from Palo Verde Diversion Dam and their subsequent remote PIT sensing contacts, lower Colorado River, Arizona and California

(TL was recorded in mm, and days at large was calculated for each PIT tag as the difference between the date of most recent remote sensing contact and the release date.)

Release date	Release location	Rearing site	Releases	Total contacts	SY 2019 Contacts	TL mean (range)	Days at large mean (range)
4/28/2016	A10 upper	Bubbling Ponds Fish Hatchery	1,106	22	4	351 (305 – 450)	402 (46 – 1056)
4/28/2016	Oxbow Campground Recreational Area	Bubbling Ponds Fish Hatchery	981	10	2	351 (305 – 445)	356 (47 – 1057)
10/27/2016	A10 lower	Bubbling Ponds Fish Hatchery	629	48	0	358 (305 – 440)	16 (0 – 265)
10/27/2016	A10 upper	Bubbling Ponds Fish Hatchery	628	26	1	356 (305 – 455)	131 (12 – 828)
10/27/2016	A7 backwater upper	Bubbling Ponds Fish Hatchery	630	17	0	353 (305 – 450)	20 (0 – 84)
10/27/2016	C7 backwater, McIntyre Park	Bubbling Ponds Fish Hatchery	625	45	1	359 (305 – 465)	68 (0 – 844)
10/27/2016	Ehler's backwater (C10)	Bubbling Ponds Fish Hatchery	633	63	2	360 (305 – 465)	48 (0 – 855)
11/17/2016	A10 upper	Bubbling Ponds Fish Hatchery	600	18	2	356 (305 – 465)	114 (18 – 853)
11/17/2016	A7 backwater upper	Bubbling Ponds Fish Hatchery	574	3	0	354 (305 – 485)	35 (19 – 63)
11/17/2016	C7 backwater, McIntyre Park	Bubbling Ponds Fish Hatchery	467	13	0	358 (305 – 480)	65 (18 – 446)
11/17/2016	Ehler's backwater (C10)	Bubbling Ponds Fish Hatchery	598	10	2	354 (305 – 485)	195 (18 – 829)

Table 6.—Razorback sucker releases (January 2007 through April 2019) downstream from Palo Verde Diversion Dam and their subsequent remote PIT sensing contacts, lower Colorado River, Arizona and California

(TL was recorded in mm, and days at large was calculated for each PIT tag as the difference between the date of most recent remote sensing contact and the release date.)

Release date	Release location	Rearing site	Releases	Total contacts	SY 2019 Contacts	TL mean (range)	Days at large mean (range)
12/14/2016	A10 upper	Lake Mead Fish Hatchery	10	3	2	456 (425 – 495)	565 (72 – 826)
1/25/2017	A10 lower	Lake Mead Fish Hatchery	215	0	0	447 (334 – 540)	(–)
1/25/2017	A7 backwater upper	Lake Mead Fish Hatchery	322	4	1	455 (362 – 550)	206 (21 – 760)
5/4/2017	A10 lower	Lake Mead Fish Hatchery	202	33	13	419 (320 – 539)	341 (20 – 685)
5/4/2017	C7 backwater, McIntyre Park	Lake Mead Fish Hatchery	182	39	6	418 (312 – 509)	210 (21 – 664)
5/4/2017	Mayflower at Hidden Beaches Resort	Lake Mead Fish Hatchery	200	5	2	422 (318 – 530)	356 (131 – 664)
11/16/2017	A10 upper	Bubbling Ponds Fish Hatchery	665	65	19	357 (305 – 465)	197 (0 – 491)
11/16/2017	C7 backwater, McIntyre Park	Bubbling Ponds Fish Hatchery	594	42	5	353 (305 – 455)	117 (0 – 490)
11/16/2017	Ehler's backwater (C10)	Bubbling Ponds Fish Hatchery	580	150	0	355 (305 – 455)	7 (0 – 243)
1/18/2018	A10 lower	Lake Mead Fish Hatchery	15	6	0	459 (420 – 504)	14 (0 – 43)
1/19/2018	A10 lower	Bubbling Ponds Fish Hatchery	464	277	43	411 (335 – 485)	98 (4 – 427)

Table 6.—Razorback sucker releases (January 2007 through April 2019) downstream from Palo Verde Diversion Dam and their subsequent remote PIT sensing contacts, lower Colorado River, Arizona and California

(TL was recorded in mm, and days at large was calculated for each PIT tag as the difference between the date of most recent remote sensing contact and the release date.)

Release date	Release location	Rearing site	Releases	Total contacts	SY 2019 Contacts	TL mean (range)	Days at large mean (range)
1/19/2018	A10 upper	Bubbling Ponds Fish Hatchery	459	322	79	413 (335 – 480)	139 (5 – 427)
1/19/2018	A7 backwater upper	Bubbling Ponds Fish Hatchery	461	72	25	409 (325 – 515)	170 (18 – 426)
2/7/2018	Ehler's backwater (C10)	Lake Mead Fish Hatchery	16	0	0	448 (401 – 481)	(–)
2/15/2018	A10 lower	Bubbling Ponds Fish Hatchery	506	114	14	360 (305 – 460)	58 (0 – 399)
2/15/2018	A10 upper	Bubbling Ponds Fish Hatchery	510	107	14	360 (305 – 480)	72 (5 – 400)
2/15/2018	A7 backwater upper	Bubbling Ponds Fish Hatchery	501	34	18	363 (305 – 470)	226 (6 – 399)
2/15/2018	Colorado River downstream from Ehrenberg Bridge	Bubbling Ponds Fish Hatchery	510	18	7	364 (305 – 465)	156 (4 – 397)
2/16/2018	C7 backwater, McIntyre Park	Bubbling Ponds Fish Hatchery	384	27	7	358 (305 – 460)	110 (2 – 376)
2/16/2018	Ehler's backwater (C10)	Bubbling Ponds Fish Hatchery	300	8	3	362 (305 – 470)	152 (11 – 371)
11/8/2018	A10 lower	Bubbling Ponds Fish Hatchery	393	161	161	388 (305 – 480)	86 (0 – 133)
11/8/2018	A10 upper	Bubbling Ponds Fish Hatchery	391	152	152	387 (305 – 470)	105 (0 – 134)

Table 6.—Razorback sucker releases (January 2007 through April 2019) downstream from Palo Verde Diversion Dam and their subsequent remote PIT sensing contacts, lower Colorado River, Arizona and California

(TL was recorded in mm, and days at large was calculated for each PIT tag as the difference between the date of most recent remote sensing contact and the release date.)

Release date	Release location	Rearing site	Releases	Total contacts	SY 2019 Contacts	TL mean (range)	Days at large mean (range)
11/8/2018	A7 backwater upper	Bubbling Ponds Fish Hatchery	394	64	64	389 (305 – 495)	73 (0 – 134)
11/9/2018	C7 backwater, McIntyre Park	Bubbling Ponds Fish Hatchery	394	80	80	388 (310 – 497)	89 (33 – 133)
11/9/2018	Ehler's backwater (C10)	Bubbling Ponds Fish Hatchery	371	46	46	392 (311 – 472)	103 (33 – 133)
11/29/2018	Colorado River downstream from Ehrenberg Bridge	Bubbling Ponds Fish Hatchery	599	17	17	373 (305 – 478)	62 (15 – 111)
1/17/2019	Colorado River downstream from Ehrenberg Bridge	Bubbling Ponds Fish Hatchery	312	6	6	387 (305 – 484)	50 (14 – 62)
1/31/2019	A10 lower	Bubbling Ponds Fish Hatchery	442	197	197	376 (305 – 486)	12 (0 – 50)
1/31/2019	A10 lower	Lake Mead Fish Hatchery	5	2	2	512 (495 – 530)	1 (0 – 1)
1/31/2019	A10 upper	Bubbling Ponds Fish Hatchery	440	217	217	371 (305 – 473)	15 (0 – 50)
1/31/2019	A10 upper	Lake Mead Fish Hatchery	10	10	10	505 (475 – 535)	34 (1 – 50)
1/31/2019	A7 backwater upper	Bubbling Ponds Fish Hatchery	440	51	51	376 (305 – 479)	11 (0 – 50)

Table 6.—Razorback sucker releases (January 2007 through April 2019) downstream from Palo Verde Diversion Dam and their subsequent remote PIT sensing contacts, lower Colorado River, Arizona and California

(TL was recorded in mm, and days at large was calculated for each PIT tag as the difference between the date of most recent remote sensing contact and the release date.)

Release date	Release location	Rearing site	Releases	Total contacts	SY 2019 Contacts	TL mean (range)	Days at large mean (range)
2/1/2019	C7 backwater, McIntyre Park	Bubbling Ponds Fish Hatchery	440	43	43	378 (305 – 479)	30 (17 – 49)
2/1/2019	Ehler's backwater (C10)	Bubbling Ponds Fish Hatchery	426	39	39	374 (305 – 458)	28 (17 – 49)
2/14/2019	A10 lower	Bubbling Ponds Fish Hatchery	476	84	84	359 (305 – 461)	9 (4 – 35)
2/14/2019	A7 backwater upper	Bubbling Ponds Fish Hatchery	400	9	9	360 (305 – 460)	12 (4 – 32)
2/14/2019	C7 backwater, McIntyre Park	Bubbling Ponds Fish Hatchery	404	27	27	364 (305 – 468)	12 (4 – 35)
2/14/2019	Ehler's backwater (C10)	Bubbling Ponds Fish Hatchery	404	19	19	366 (305 – 484)	11 (4 – 32)
2/21/2019	A10 lower	Lake Mead Fish Hatchery	14	6	6	490 (452 – 526)	11 (0 – 28)
2/28/2019	A10 lower	Bubbling Ponds Fish Hatchery	274	3	3	349 (305 – 427)	13 (0 – 20)
2/28/2019	A10 upper	Bubbling Ponds Fish Hatchery	550	140	140	354 (305 – 460)	2 (0 – 21)
2/28/2019	A7 backwater upper	Bubbling Ponds Fish Hatchery	299	2	2	355 (305 – 464)	0 (0 – 0)
2/28/2019	Ehrenberg Bridge boat ramp	Bubbling Ponds Fish Hatchery	550	2	2	350 (305 – 475)	18 (16 – 20)

Table 6.—Razorback sucker releases (January 2007 through April 2019) downstream from Palo Verde Diversion Dam and their subsequent remote PIT sensing contacts, lower Colorado River, Arizona and California

(TL was recorded in mm, and days at large was calculated for each PIT tag as the difference between the date of most recent remote sensing contact and the release date.)

Release date	Release location	Rearing site	Releases	Total contacts	SY 2019 Contacts	TL mean (range)	Days at large mean (range)
3/21/2019	A10 upper	Bubbling Ponds Fish Hatchery	450	52	52	354 (305 – 461)	1 (0 – 1)
3/21/2019	C7 backwater, McIntyre Park	Bubbling Ponds Fish Hatchery	475	47	47	354 (305 – 460)	0 (0 – 1)
3/21/2019	Ehler's backwater (C10)	Bubbling Ponds Fish Hatchery	480	15	15	356 (305 – 439)	1 (0 – 1)
3/21/2019	Ehrenberg Bridge boat ramp	Bubbling Ponds Fish Hatchery	476	1	1	354 (305 – 428)	1 (1 – 1)
4/4/2019	A10 lower	Bubbling Ponds Fish Hatchery	489	0	0	359 (305 – 475)	(–)
4/4/2019	A7 backwater upper	Bubbling Ponds Fish Hatchery	564	0	0	361 (305 – 454)	(–)
4/4/2019	C7 backwater, McIntyre Park	Bubbling Ponds Fish Hatchery	398	0	0	354 (305 – 456)	(–)
4/4/2019	Ehler's backwater (C10)	Bubbling Ponds Fish Hatchery	394	0	0	358 (305 – 475)	(–)
4/5/2019	A10 upper	Bubbling Ponds Fish Hatchery	249	0	0	358 (305 – 457)	(–)
4/5/2019	Ehrenberg Bridge boat ramp	Bubbling Ponds Fish Hatchery	283	0	0	356 (305 – 462)	(–)
		Totals	**34,446**	**3,731**	**1,836**		

[1] Release record did not specify the upper or lower half of the A10 backwater.

Table 7.—Bonytail releases (January 2007 through April 2019) downstream from Palo Verde Diversion Dam and their subsequent remote PIT sensing contacts, lower Colorado River, Arizona and California
(TL was recorded in mm, and days at large was calculated for each PIT tag as the difference between the date of most recent remote sensing contact and the release date.)

Release date	Release location	Rearing site	Releases	Contacts	SY 2019 contacts	Total length mean (range)	Days at large mean (range)
Before Sept. 2014			150	0	0	320 (275 – 405)	0 (–)
12/10/2014	A10 lower	Center	1,996	113	0	346 (305 – 425)	30 (6 – 278)
9/23/2015	A10 backwater[1]	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 backwater upper	Center	600	13	0	326 (240 – 401)	25 (12 – 149)
10/26/2016	C7 backwater, 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 backwater upper	Center	456	0	0	324 (305 – 397)	0 (–)
11/16/2016	C7 backwater, McIntyre Park	Center	700	3	0	326 (305 – 387)	21 (19 – 23)
11/16/2016	Ehler's backwater (C10)	Center	700	1	0	326 (305 – 535)	20 (20 – 20)
12/14/2016	A10 upper	Lake Mead Fish Hatchery	14	0	0	415 (405 – 428)	0 (–)
1/25/2017	A10 lower	Lake Mead Fish Hatchery	5	0	0	402 (385 – 416)	0 (–)
1/25/2017	A7 backwater upper	Lake Mead Fish Hatchery	15	0	0	401 (366 – 435)	0 (–)
3/20/2017	C7 backwater, McIntyre Park	Lake Mead Fish Hatchery	1,445	206	0	349 (305 – 444)	3 (0 – 91)
4/25/2017	A7 backwater upper	Center	750	1	0	312 (305 – 431)	31 (31 – 31)
10/11/2017	A10 upper	Center	404	27	0	339 (305 – 419)	80 (34 – 130)

Table 7.—Bonytail releases (January 2007 through April 2019) downstream from Palo Verde Diversion Dam and their subsequent remote PIT sensing contacts, lower Colorado River, Arizona and California
(TL was recorded in mm, and days at large was calculated for each PIT tag as the difference between the date of most recent remote sensing contact and the release date.)

Release date	Release location	Rearing site	Releases	Contacts	SY 2019 contacts	Total length mean (range)	Days at large mean (range)
10/11/2017	A7 backwater upper	Center	500	17	0	336 (305 – 461)	47 (35 – 123)
10/11/2017	C7 backwater, McIntyre Park	Center	500	24	0	333 (305 – 439)	75 (34 – 124)
11/16/2017	C7, upper culvert	Lake Mead Fish Hatchery	15	0	0	447 (412 – 476)	0 (–)
12/5/2017	A10 lower	Center	600	48	0	343 (305 – 456)	67 (42 – 82)
12/5/2017	A10 upper	Center	600	85	0	343 (305 – 436)	35 (8 – 69)
12/5/2017	A7 backwater upper	Center	600	6	0	344 (305 – 447)	45 (6 – 168)
12/5/2017	Ehler's backwater (C10)	Achii Hanyo	413	10	0	332 (305 – 440)	20 (6 – 52)
1/24/2018	A10 upper	Lake Mead Fish Hatchery	400	134	0	362 (305 – 466)	2 (0 – 19)
1/24/2018	C7 backwater, McIntyre Park	Lake Mead Fish Hatchery	300	78	0	361 (305 – 473)	4 (0 – 34)
1/24/2018	Ehler's backwater (C10)	Lake Mead Fish Hatchery	300	27	0	360 (305 – 458)	4 (1 – 36)
2/7/2018	A10 lower	Lake Mead Fish Hatchery	500	77	0	379 (305 – 475)	6 (0 – 104)
2/7/2018	A7 backwater upper	Lake Mead Fish Hatchery	500	3	0	376 (305 – 510)	26 (12 – 43)
2/7/2018	Ehler's backwater (C10)	Lake Mead Fish Hatchery	350	1	0	359 (305 – 465)	23 (23 – 23)
4/4/2018	A10 upper	Lake Mead Fish Hatchery	390	11	0	355 (305 – 455)	56 (48 – 128)

Table 7.—Bonytail releases (January 2007 through April 2019) downstream from Palo Verde Diversion Dam and their subsequent remote PIT sensing contacts, lower Colorado River, Arizona and California
(TL was recorded in mm, and days at large was calculated for each PIT tag as the difference between the date of most recent remote sensing contact and the release date.)

Release date	Release location	Rearing site	Releases	Contacts	SY 2019 contacts	Total length mean (range)	Days at large mean (range)
4/4/2018	C7 backwater, McIntyre Park	Lake Mead Fish Hatchery	407	3	0	363 (305 – 480)	49 (48 – 50)
5/3/2018	A7 backwater upper	Lake Mead Fish Hatchery	1,258	69	0	362 (305 – 480)	41 (19 – 127)
11/19/2018	A10 lower	Center	520	4	4	320 (305 – 396)	73 (22 – 123)
11/19/2018	A10 upper	Center	542	1	1	323 (305 – 395)	23 (23 – 23)
11/19/2018	A7 backwater upper	Center	519	1	1	322 (305 – 396)	26 (26 – 26)
12/6/2018	C7 backwater, McIntyre Park	Achii Hanyo	430	2	2	348 (305 – 451)	8 (7 – 8)
12/6/2018	Ehler's backwater (C10)	Achii Hanyo	436	1	1	338 (305 – 426)	43 (43 – 43)
12/12/2018	A7 backwater lower	Lake Mead Fish Hatchery	17	1	1	416 (358 – 482)	49 (49 – 49)
1/28/2019	A10 upper	Lake Mead Fish Hatchery	664	316	316	362 (318 – 448)	5 (0 – 31)
1/31/2019	A10 lower	Lake Mead Fish Hatchery	14	8	8	425 (375 – 500)	3 (0 – 20)
1/31/2019	A10 upper	Lake Mead Fish Hatchery	2	2	2	343 (315 – 370)	0 (0 – 0)
2/21/2019	A10 lower	Lake Mead Fish Hatchery	15	7	7	439 (384 – 493)	2 (0 – 7)
3/20/2019	A7 backwater upper	Center	668	2	2	331 (305 – 430)	2 (1 – 2)
3/20/2019	Ehrenberg Bridge boat ramp	Center	601	1	1	316 (305 – 435)	2 (2 – 2)

Table 7.—Bonytail releases (January 2007 through April 2019) downstream from Palo Verde Diversion Dam and their subsequent remote PIT sensing contacts, lower Colorado River, Arizona and California
(TL was recorded in mm, and days at large was calculated for each PIT tag as the difference between the date of most recent remote sensing contact and the release date.)

Release date	Release location	Rearing site	Releases	Contacts	SY 2019 contacts	Total length mean (range)	Days at large mean (range)
3/25/2019	C7 backwater, McIntyre Park	Lake Mead Fish Hatchery	400	0	0	344 (305 – 410)	0 (–)
3/25/2019	Ehler's backwater (C10)	Lake Mead Fish Hatchery	400	0	0	337 (305 – 410)	0 (–)
3/25/2019	Ehrenberg Bridge boat ramp	Lake Mead Fish Hatchery	400	0	0	324 (305 – 410)	0 (–)
3/27/2019	A10 lower	Lake Mead Fish Hatchery	400	0	0	337 (305 – 440)	0 (–)
3/27/2019	A10 upper	Lake Mead Fish Hatchery	400	0	0	320 (305 – 420)	0 (–)
3/27/2019	A7 backwater upper	Lake Mead Fish Hatchery	400	0	0	340 (305 – 422)	0 (–)
4/8/2019	Ehrenberg Bridge boat ramp	Lake Mead Fish Hatchery	179	0	0	333 (305 – 427)	0 (–)
4/9/2019	Imperial National Wildlife Refuge, main channel	Lake Mead Fish Hatchery	3	0	0	348 (315 – 385)	0 (–)
		Totals	**26,743**	**1,404**	**346**		

[1] Release record did not specify the upper or lower half of the A10 backwater.

River Aggregation Site

A native fish Aggregation Site and potential spawning site (figure 7) was identified during SY 2019; a gravel bar in the mainstem Colorado River near the entrance to C7 McIntyre Park along the California shoreline. A total of 443 unique PIT tags with records in the Lower Colorado River Native Fish Database were contacted in the mainstem during SY 2019, and 310 (69.9%) of those were contacted at the Aggregation Site (table 8). The 310 fish consisted of 307 razorback suckers and 3 bonytail. All three bonytail were released in FY 2019, with one each released at A10 upper, A10 lower, and the Ehrenberg Bridge boat ramp.

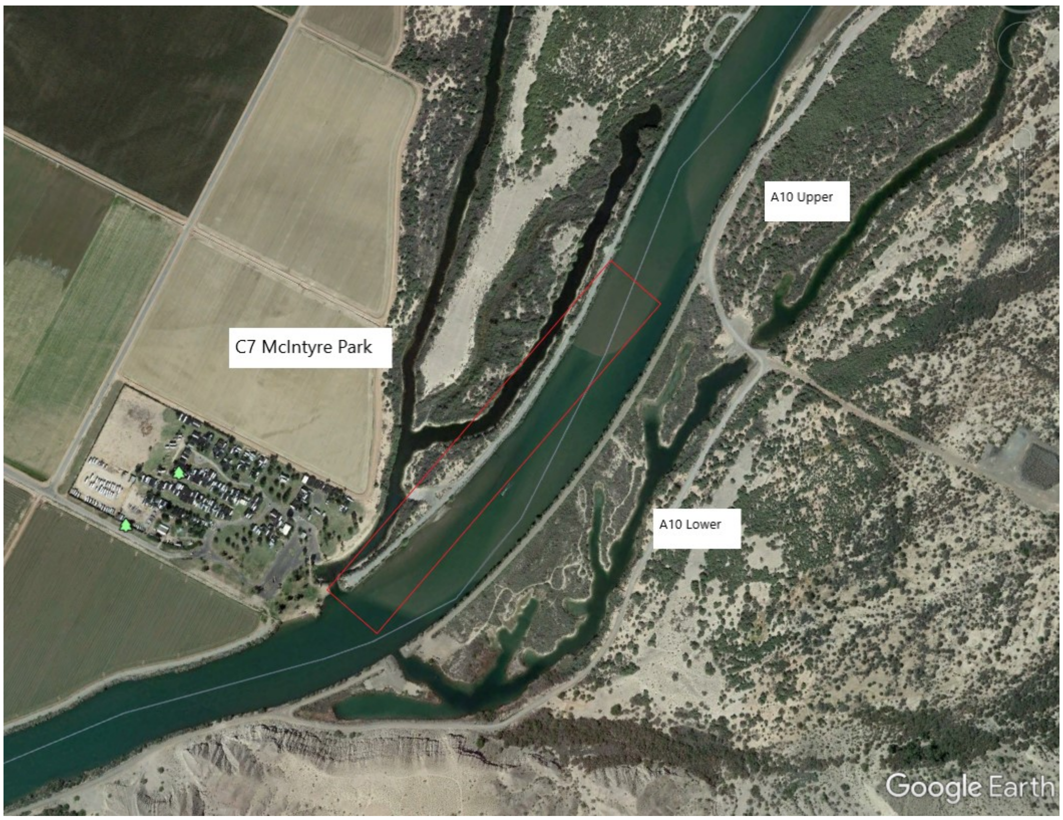


Figure 7.—Satellite imagery of an Aggregation Site on a gravel bar within the study area.

The river section in the red box indicates the gravel bar where 310 fish were contacted in SY 2019.

Table 8.—Remote PIT scanning data from the Aggregation Site near C7 McIntyre Park

Release location	Number of fishes contacted	Mean days at large	Number of fishes > 1 year days at large
A10 lower	98	276.1	45 (45.9%)
C7 McIntyre Park	65	130.6	9 (13.8%)
A7 backwater upper	62	278.8	38 (61.2%)
A10 upper	54	455.3	31 (57.4%)
Colorado River downstream from Ehrenberg Bridge	14	200.9	6 (42.8%)
C10 Ehler's	9	345	2 (22.2%)
Ehrenberg Bridge boat ramp	3	7.3	0 (0.0%)
Mayflower at Hidden Beaches Resort	2	646.5	2 (100.0%)
Oxbow Campground Recreational Area	2	1,052.5	2 (100.0%)
A10 backwater (No record of upper or lower)	1	1,519	1 (100.0%)
Totals	**310**		**136**

The majority of razorback suckers contacted on the Aggregation Site, 216 of 310 (69.7%), were released in the most proximate backwaters (C7 McIntyre Park, A10 lower, and A10 upper). Two razorback suckers contacted at the Aggregation Site were captured via electroshocking at the same location on January 30, 2019. A greater percentage of razorback suckers contacted on the Aggregation Site were released in a previous study year, 148 of 305 (48.5%, excluding the 2 fish tagged at capture), compared to the percentage for total contacts in SY 2019 (344 of 1,836, 18.7%). Out of the 148 contacted on the Aggregation Site and released in a previous study year, 103 (69.6%) were not contacted at any other location in SY 2019.

Remote PIT Scanning Antenna Orientation Study

During the course of the 4-day scanning period, randomly deployed PIT scanners (figure 8) collectively scanned for an average of 1382.5 minutes (23.03 hours) per deployment and for a total of 19,356 minutes. A total of 110 of 364 (30.2%) bonytail with 32-mm ,HDX PIT tags (experimental tag) were contacted as compared to 35 out of 300 (11.6%) bonytail with 12-mm, 134.2-kHz FDX tags (control tag).

Figure 8.—Satellite imagery of remote sensing deployments used to test antenna orientation in SY 2019.

Numbers denote the number of unique PIT tags contacted. White boxes indicate "bottom-flat" orientation; all other numbers represent "bottom-long" orientation.

The same proportion of fishes scanned by antennas laying bottom-flat (control orientation) versus bottom-long (experimental orientation) was reflected by the experimental and control tag types. In the experimental tag group, bottom-flat (control orientation) PIT scanners accounted for 66.4% (85/128) of total contacts.

In the control tag group, 65% of total contacts were recorded by PIT scanners laying bottom-flat (control orientation). These similar proportions in the total contacts were reflected in the daily totals (figure 9). However, on the fourth day of the study, the number of bonytail contacted laying bottom-long (experimental orientation) was higher for both the experimental and control tag groups.

Population Estimates

No bonytail contacted in SY 2019 were released prior to SY 2019 (October 1, 2018), so no population estimate was possible. The razorback sucker population estimate for SY 2018 was 147 (95% CI 123 to 171), with 81 encountered in SY 2018 (marking period January through February 2018), 112 encountered in SY 2019 (capture period October 2018 through May 2019), and 62 encountered in both periods (recaptures). For comparison, the estimated population of razorback suckers in A10 (upper and lower) for SY 2018 was 97 (95% CI 84 to 111), with 68, 78, and 55 for marks, captures, and recaptures, respectively.

Post-Stocking Survival and Dispersal

Dispersal distances were calculated for acoustic-tagged fishes contacted outside their release backwater (tables 9, 10, and 11). Of 60 fish that were tagged this year, 30 were contacted outside their release backwater, 25 were not contacted outside of their backwater, and 4 fish were never contacted (A10 lower and A10 upper are considered a singular complex here). Of the 30 fishes contacted outside their release backwater, 8 were adult razorback suckers, 12 were subadult razorback suckers, 5 were adult bonytail with 9-month tags, and 5 were subadult bonytail with short-term tags.

This was the first year of the study in which all surgeries took place at the same location (A10 lower culvert). An elevated rate of dispersal was observed this year, with 52% of implanted fishes leaving their release backwater, which was up from 40% in SY 2018. Results were mixed for the 31 fishes that dispersed from their release location. The largest proportion of fishes (50%, 15 of 30) dispersed only a short distance across the main river channel between A10 lower and C7 McIntyre Park. A total of 46% (14 of 30) dispersed downstream; two of which were contacted by the furthest downstream SUR in the study area, south of Walter's Camp. Three

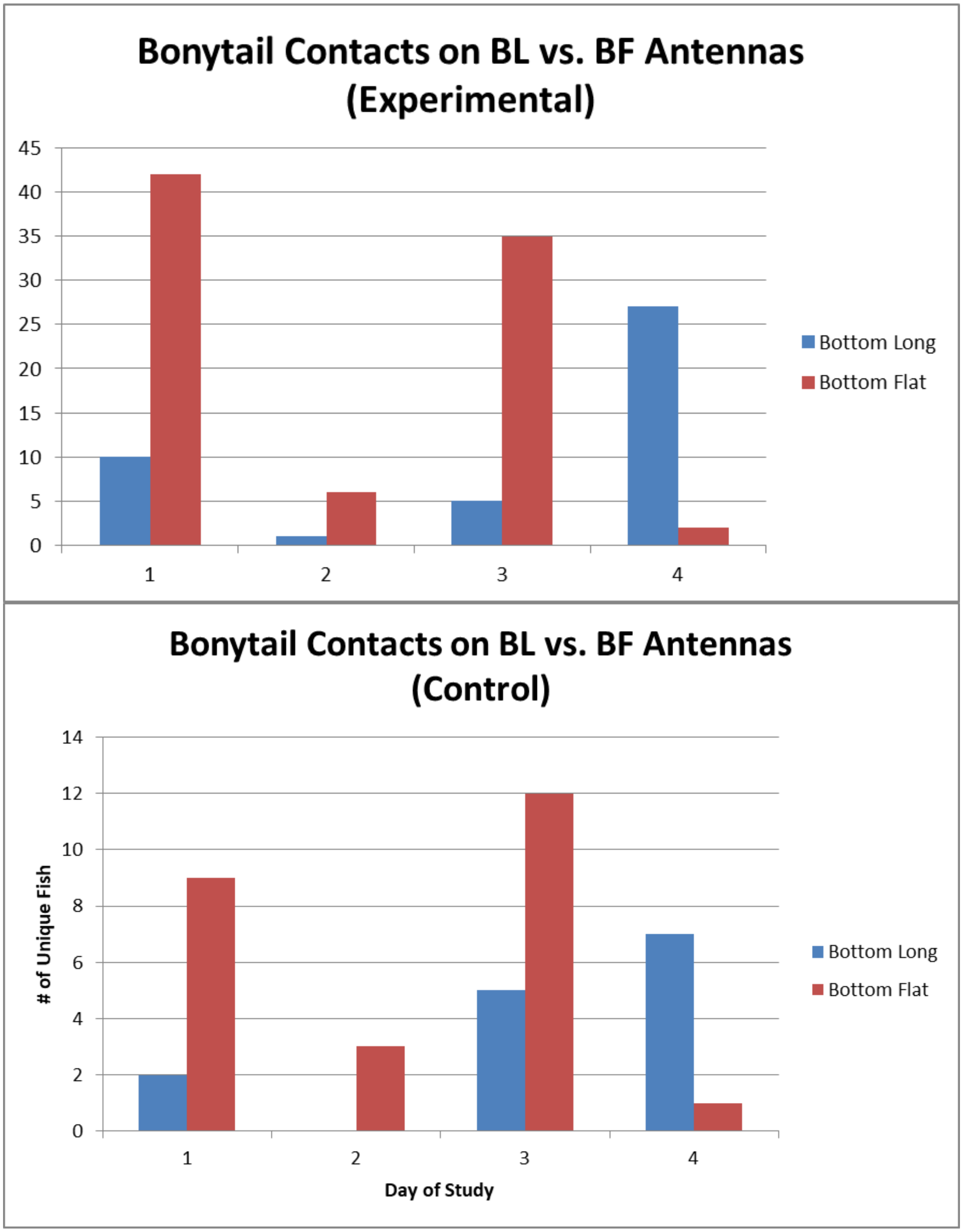


Figure 9.—Unique PIT tags, 32-mm HDX (experimental; top) and 12-mm FDX (control; bottom) contacted by remote sensing antennas during an orientation experiment in A10 upper.
BL denotes bottom-long orientation; BF denotes bottom-flat orientation.

Table 9.—Dispersal statistics for acoustic-tagged razorback suckers released in SY 2019, lower Colorado River, Arizona and California
(Days at large was calculated by the difference in days from the day of last contact and the day of release. Tags 160–69 are adult fishes; all other tags are subadults.)

Tag ID	Dispersal distance (km)	Days at large	Displacement/day (km)
100	41.46	119	0.34
104	63.59	51	1.24
114	1.33	5	0.26
116	2.98	91	0.03
118	45.37	396	0.11
120	7.41	129	0.05
160	1.33	48	0.02
161	4.83	41	0.11
163	18.19	12	1.51
164	8.86	46	0.19
165	20.66	43	0.48
167	9.024	26	0.34
168	2.98	5	0.59
169	2.98	8	0.37
182	20.27	4	5.06
184	2.98	4	0.74
186	21.74	26	0.83
188	21.48	26	0.82
192	2.98	3	0.99
194	5.96	12	0.4

Table 10.—Dispersal statistics for acoustic-tagged bonytail released in SY 2019, lower Colorado River, Arizona and California
(Days at large was calculated by the difference in days from the day of last contact and the day of release. Tags 200–209 are adult fishes; all other tags are subadults.)

Tag ID	Dispersal distance (km)	Days at large	Displacement/day (km)
103	5.30	5	1.06
117	8.86	40	0.22
183	3.33	3	1.11
187	5.30	2	2.65
199	2.98	9	0.33
200	6.63	22	0.30
201	5.30	4	1.32
205	8.86	7	1.26
207	7.61	7	1.08
209	5.30	25	0.21

Table 11.—Dispersal statistics for acoustic-tagged adult razorback suckers released prior to SY 2019, lower Colorado River, Arizona and California
(Data are for fishes contacted outside of their release backwater after 3/21/2018 (last field day of SY 2018). Tag ID 146 is from SY 2017.)

Tag ID	Dispersal distance (km)	Location of last contact	Date of last contact
146	1.06	A10 lower	3/21/2019
Y2_10	1.06	A10 lower backwater	5/12/2018
Y2_148	94.44	Hart Mine Bridge	4/4/2018
Y2_152	7.91	A7 upper	4/27/2018
Y2_154	52.07	Farmer's Bridge	11/27/2018
Y2_155	45.73	Farmer's Bridge	5/31/2018
Y2_40	18.38	A7 upper	5/8/2018

of these 14 fishes initially dispersed upstream but returned downstream later in the study year. Only one fish (3%) dispersed from its release backwater and had a last recorded contact at a SUR upstream of its release area.

In previous study years, no contacts were recorded on the northernmost SUR located riverside at the Palo Verde Ecological Preserve, California. This SUR was translocated approximately 7 river miles downstream during SY 2019 in an attempt to better determine the northern extent of dispersed fishes. No contacts were recorded on this SUR during the study year, and the furthest upstream fish was contacted at a SUR in the river adjacent to A7 upper.

Several fishes from previous study years were contacted in SY 2019. Two adult razorback suckers from SY 2017 (20%) were contacted since the end of SY 2018. One was last contacted on May 8, 2018. The other fish was continuously contacted until October 13, 2018, near C7 McIntyre Park, where it was contacted in the river channel south of the backwater. The fish has not been contacted by SUR since, but it was contacted by manual tracking in the A10 lower backwater on March 20 and March 21, 2019.

Five adult razorback suckers released with acoustic telemetry tags in SY 2018 were contacted in SY 2019 (50%). The latest contact from this group of fish was fish Y2_154 at Farmer's Bridge on November 27, 2018.

The greatest calculated dispersal distance for a fish released in this study year was 63.6 km by a subadult razorback sucker released in November 2018. This fish dispersed from the A10 lower backwater, traveled upstream as far as C5 Goose Flats, and then downstream as far as Walter's Camp. The last contact was December 29, 2018. The SUR at Walter's Camp is the southernmost SUR currently deployed, and this fish may have dispersed from the study area. The cumulative dispersal average for all fishes released this year was 12.2 km; with 7.9, 19.79, and 6.28 km being the average calculated dispersal distances for adult razorback suckers, adult bonytail, and subadult razorback suckers, respectively.

The greatest calculated dispersal distance for an adult razorback sucker (Tag ID 165) was 20.66 km (see table 9). This fish was released on January 31, 2019, into the A10 lower backwater. It was recorded on SURs in A10 lower up to February 7, 2019, after which it traveled upstream to a SUR adjacent to the A7 upper backwater, where it was contacted on February 7, 2019. It then traveled down to C7 McIntyre Park, where it was last contacted on March 15, 2019. The greatest dispersal by a bonytail was 8.86 km by two individuals (tag IDs 117 and 205; see table 10). Tag ID 117 was released on December 12, 2018, was contacted in A10 lower repeatedly until January 6, 2019, and then was contacted in C10 Ehler's repeatedly from January 7, 2019, until its last contact on January 21, 2019. Tag ID 205 was released on January 31, 2019, was contacted in A10 lower until February 5, 2019, was contacted in the river channel below C7 McIntyre Park on February 6, 2019, and then in C10 Ehler's, where its last contact was recorded on February 7, 2019.

Manual tracking effort resulted in four fish contacted in the main channel during SY 2019, all were adult razorback suckers. Three of the four contacts were at the gravel spawning bar in the river channel outside of C7 McIntyre Park. The fourth river contact was a fish tagged after being caught via electrofishing. This fish was contacted near the series of washes downstream from all backwaters in the study area.

On March 21, 2019, a diver recovered six acoustic tags from the study area. Five tags were from bonytail implanted this study year: three 3-month PT-04 tags and two 9-month IBT-96-9-I tags. Additionally, one CT-05-36-I tag from SY 2017 implanted in a razorback sucker was recovered. No identifiable fish remains were observed near the tags at the time of recovery.

Estimates of post-stocking survival based on mark-recapture analysis were not assessed this year. Prior to the current study year, PIT scanning contacts that met the criteria for use in a mark-recapture model (contacted in a study year after study year of release) outside the A10 backwater complex were low (figure 10). This reduces the likelihood that estimates would be representative of the population in the reach. In addition, parameterizations of the robust model that allowed released data to be incorporated as a "first capture" failed to result in logical estimates. Mark-recapture model assessment is ongoing.

Avian Predation Observations

Throughout the SY 2019 field season, multiple species of predatory birds were seen within the study area. Bald eagle (*Haliaeetus leucocephalus*) presence was observed in the study area for the first time in the study. As in previous years, multiple fishes throughout the year were observed floating dead in backwaters with wounds consistent with bird strikes and attacks (figure 11). One osprey (*Pandion haliaetus*) was observed flying with a fish that appeared to be a bonytail clutched in its talons (figure 12). The number of double-crested cormorant (*Phalacrocorax auritus*) observed also remains high (figure 13), as was the case in SY 2017 and SY 2018. Great blue herons (*Ardea herodias*) were also observed in the area.

Multiple cormorant roosting aggregations were observed throughout the study area, notably at locations directly above the main channel of the Colorado River, such as power lines and the gas pipeline immediately south of the I-10 bridge (figure 13). A tag was contacted directly below the gas pipeline on February 27, 2019, which came from a bonytail stocked on January 28, 2019, in the A10 upper backwater.

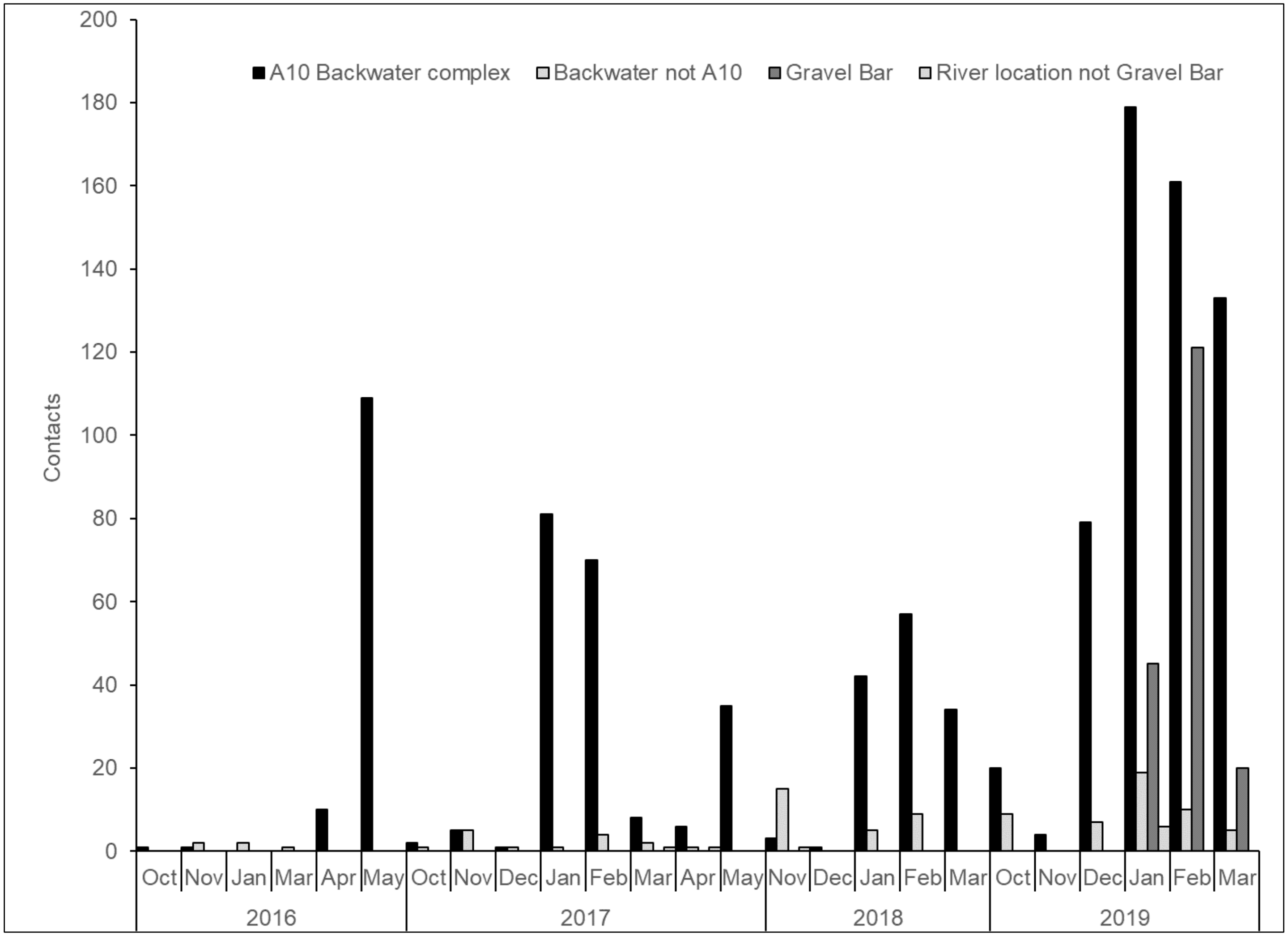


Figure 10.—Remote PIT scanning contacts of razorback suckers downstream from Palo Verde Diversion Dam for use in mark-recapture models.

Contacts (y-axis) represent the number of individual razorback suckers contacted within a month regardless of location.

Figure 11.—Razorback sucker mortality (left) and a bonytail mortality (right), both found floating deceased in the A10 upper backwater, lower Colorado River, Arizona.

Figure 12.—An osprey near the C10 Ehler's backwater flies with a fish that appears to be a bonytail in its talons.
This picture was taken 5 days after a stocking event.

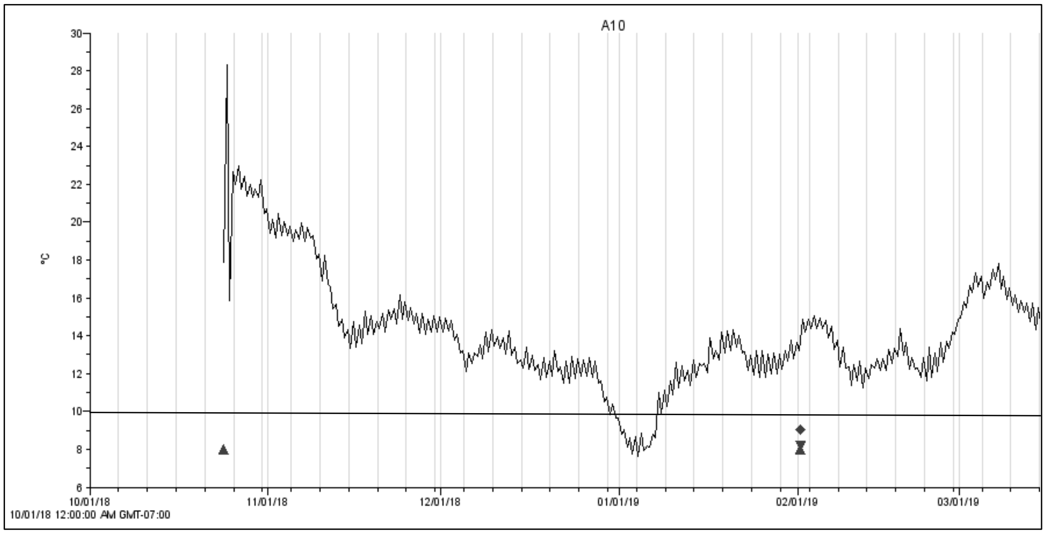
Figure 13.—A roosting site of double-crested cormorants located on a natural gas pipeline spanning the Colorado River immediately south of the I-10 bridge.

Temperature Observations

Onset HOBO® Data Loggers placed in the A10 upper backwater and the Colorado River recorded temperatures every 12 hours (figure 14). The water temperature was below 10 °C for less than 5% of the 150-day field season: 10 days in the A10 upper backwater (December 30, 2018 – January 8, 2019) and 4 days in the Colorado River (January 2–5, 2019).

DISCUSSION

This is the first year razorback suckers have been observed aggregating in the mainstem river downstream from Palo Verde Diversion Dam. Prior to SY 2019, razorback suckers were observed aggregating within backwaters (this study; Schooley et al. 2008), or a few individuals were captured at wash fans downstream from A10 lower (Schooley et al. 2008). The newly identified Aggregation Site is proximal to two release backwaters (A10 lower and C7 McIntyre Park). The razorback suckers contacted at the Aggregation Site were, on average, older than razorback suckers contacted elsewhere, and most of the adult razorback suckers (released in a previous study year) contacted on the Aggregation Site were not contacted elsewhere during the study year (103 of 148). The group of razorback suckers contacted at the Aggregation Site appear to represent a different group of fish than those contacted in



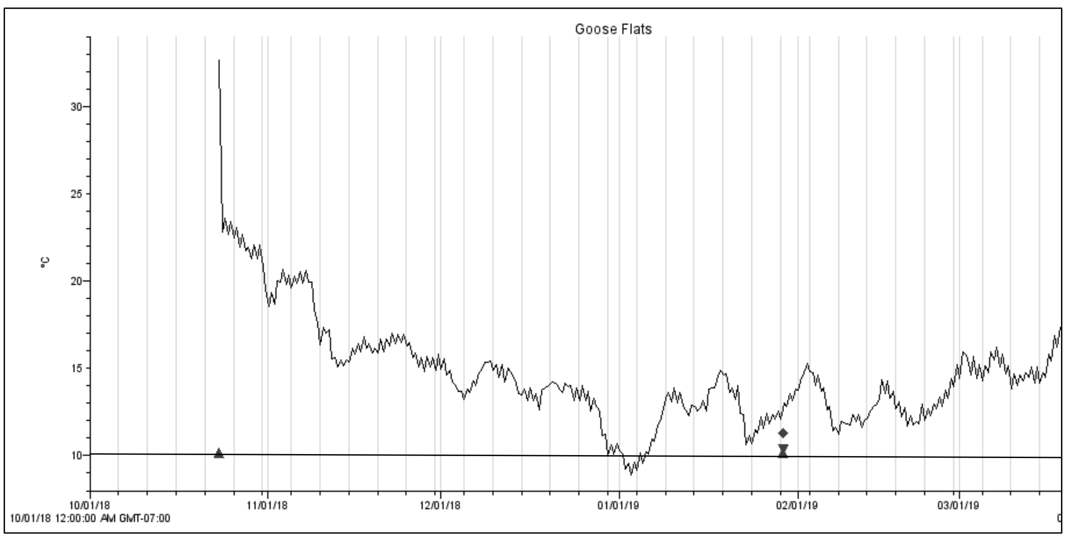


Figure 14.—Line graph charting temperature data (every 12 hours) throughout the field season in the A10 upper backwater (top figure) and Colorado River (bottom figure).
The line is at 10 °C – the temperature at which flathead catfish become immobile.

the release backwaters based on age structure and lack of contacts elsewhere in the study area during this study year. The area will be a focus of PIT scanning in SY 2020 while additional aggregation sites within the mainstem are identified.

Although contacts outside of the A10 complex (A10 upper and A10 lower) were dramatically increased in SY 2019, one year of representative contacts cannot be used to estimate "apparent survival." Additional years of data are required, and initial estimates for razorback suckers will be provided in the SY 2020 annual report if contacts outside of the A10 complex remain high.

Telemetry of adult razorback suckers thus far has resulted in few additional insights into spawning behavior. Of the 10 adult razorback suckers tagged in SY 2017, it is likely that only 1 of them remained alive at the end of SY 2019. Determining mortality of the 10 adult razorback suckers tagged in SY 2018 is more difficult. Two were last contacted downstream in the main channel by SURs at Hart Mine Bridge and Farmer's Bridge. Two additional SURs further downstream did not record either fish or any other adult razorback suckers. It is unlikely the other eight razorback suckers dispersed past four SURs downstream without being detected. The largest distance of dispersal for a SY 2018 fish was 188.9 km, Tag ID 148 (Haas et al. 2018), since its last contact in SY 2018. Active tracking downstream from the main study area during peak spawning (January and February) may be used to locate the few potentially surviving acoustic-tagged adult razorback suckers.

Deployment of PIT scanners has been effective in contacting recently released bonytail within the release backwaters; however, long-term persistence of the species is still unknown. No recaptures of bonytail were available for a population estimate. Records of individual bonytail that survived a year or more continue to be uncommon anywhere in the Colorado River Basin (Bestgen et al. 2017; Humphrey et al. 2016), and to date, there have been too few for a population estimate. The continued lack of detectable long-term persistence of bonytail will constrain our ability to estimate post-stocking survival using mark-recapture. The increased detectability of bonytail stocked with 32-mm HDX tags may be a useful tool to elucidate post-stocking fate of this elusive species.

The impact of PIT scanner orientation on bonytail PIT tag contact rates was unclear. Overall contacts were higher with the control orientation (bottom-flat), but the experimental orientation (bottom-long) recorded five times more contacts than the control orientation on the last day of the 4-day experiment, possibly indicating a temporal shift in detectability between the two orientations. Bonytail may be more bottom oriented immediately after release, moving up in the water column once they become acclimated. The potential for different antenna orientations to improve contact rates with bonytail should be investigated further over a longer time scale post-release.

The A10 complex continues to provide the bulk of remote sensing data; however, in February 2019, contact with razorback suckers within the mainstem river nearly matched those from the A10 complex. Estimating survival for the entire study area will require continued high contact rates in other locations, including the main channel. Efforts to increase PIT scanning contacts outside of the A10 complex will continue in SY 2020. The focus of SUR deployments in SY 2020 will be the area immediately downstream from the new Aggregation Site to track movement of telemetered fish in and out of this area, and active tracking downstream from the main study area may be used during the peak spawning period to locate missing adult razorback suckers and potentially additional aggregation sites.

LITERATURE CITED

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.

Daugherty, D.J. and T.M. Sutton. 2005. Seasonal movement patterns, habitat use, and home range of flathead catfish in the lower St. Joseph River, Michigan. North American Journal of Fisheries Management, 25:256–269.

Haas T.F, A.A Burgad, B.R. Kesner, and P.C. Marsh. 2018. Population Status and Distribution of Razorback Sucker and Bonytail Downstream from Palo Verde Diversion Dam, 2018. Interim report submitted to the Lower Colorado River Multi-Species Conservation Program, Bureau of Reclamation, Boulder City, Nevada, by Marsh & Associates, Tempe, Arizona, under contract No. R16PD00904.

Henne J.P., M.M. Romero, and G.J. Carmichael. 2007. Polyculture of endangered bonytails and razorback suckers in recirculated water, North American Journal of Aquaculture 69(4):388–394, DOI: 10.1577/A06-041.1

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 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*. Journal of Fish Biology 73:1–9.

Kendall, W.L., J.D. Nichols, and J.E. Hines. 1997. Estimating temporary emigration using capture-recapture data with Pollock's robust design. Ecology 78:563–578.

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.

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. http://qgis.osgeo.org

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 Bureau of Reclamation, Boulder City, Nevada, by . Arizona State University, Tempe, Arizona. under 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.

Slaughter IV, J.E. and B. Jacobson. 2008. Gape: body size relationship of flathead catfish. North American Journal of Fisheries Management 28:198–202.

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.

Vokoun, J.C and C.F. Rabeni. 2005. Variation in an annual movement cycle of flathead catfish within and between two Missouri watersheds, North American Journal of Fisheries Management 25:563–572.