Minute 323

Colorado River Limitrophe and Delta

Environmental Flows Monitoring

Interim Report for 2018

February 2022

Authority

This report and study were carried out by the United States and Mexico in accordance with Section VIII, "Environment" under Minute 323 to the 1944 Water Treaty of the International Boundary and Water Commission, United States and Mexico entitled "Extension of Cooperative Measures and Adoption of a Binational Water Scarcity Contingency Plan in the Colorado River Basin" dated September 21, 2017. This interim report was prepared as a step in furtherance of Minute 323, Section VIII, C.5 and includes information on the environmental benefits achieved through the delivery of water for environmental purposes.

Participating Agencies

International Boundary and Water Commission
United States and Mexico

For the United States:
National Audubon Society
Sonoran Institute
The Colorado River Basin States
The Nature Conservancy
University of Arizona
U.S. Department of the Interior, Bureau of Reclamation
U.S. Geological Survey

For Mexico:
El Colegio de la Frontera Norte
Comisión Nacional de Áreas Naturales Protegidas (CONANP)
Comisión Nacional del Agua (CONAGUA)
Pronatura Noroeste
Restauremos el Colorado
Universidad Autónoma de Baja California

Acknowledgements

This report was compiled and edited for the Environmental Work Group of the International Boundary and Water Commission by Dr. Karl Flessa (University of Arizona), Dr. Eloise Kendy (The Nature Conservancy), and Dr. Martha Gomez-Sapiens (University of Arizona) on behalf of all the people and organizations engaged in monitoring in the Colorado River Delta under Minute 323.

These efforts represent a collaboration among many entities who directly and indirectly participated in all phases of this study, promoting a binational partnership among federal agencies, universities, and non-governmental organizations.

Cover photo credit: Karl Flessa, University of Arizona. Chaussé restoration site, May 2018

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Section 1: Introduction and Executive Summary

Introduction

Minute 323, "Extension of Cooperative Measures and Adoption of a Binational Water Scarcity Contingency Plan in the Colorado River Basin", was signed by the two Sections of the International Boundary and Water Commission (IBWC) on September 21, 2017. A component of Minute 323 is Section VIII, Environment which notes "…the continued interest of both governments in cooperating with regards to the riparian and estuarine ecology of the Colorado Limitrophe and Delta as expressed in Minute 306, 'Conceptual Framework for United States-Mexico Studies for Future Recommendations concerning the Riparian and Estuarine Ecology of the Limitrophe Section of the Colorado River and its Associated Delta' dated December 12, 2000, and in Minute 319. They referred to the results achieved in the Minute 319 pilot program for water for the environment, including enhancing the ecosystem's vegetation and wildlife, generating social and recreational benefits, improving conditions in the estuary, and recharging the aquifer. They also reflected on how to maintain the benefits of the pilot program while continuing joint cooperative efforts to provide water for the environment." [p. 15-16]

The "Minute 319 Colorado River Limitrophe and Delta Environmental Flows Monitoring Final Report" dated November 28, 2018, documents the environmental benefits realized under Minute 319. The report is available at https://www.ibwc.gov/Files/Minute_319_Monitoring_Report_112818_FINAL.pdf.

Under Minute 323, Section VIII, C. 5, the Binational Environmental Work Group "… reports every two years on progress in the Water Delivery and Restoration Plan program, to include environmental benefits achieved…". This interim report is the first of such reports on environmental benefits realized in 2018.

Ecological and hydrologic monitoring under the auspices of Minute 323 was conducted from January 1, 2018 to December 31, 2018. Monitoring activities were conducted in the Limitrophe and Delta (Fig. 1-1) by binational teams (Table 1-2).

Table 1-1. Members of the binational Minute 323 Environmental Work Group (2018)

Co-Chairs
Gabriela Caloca, Pronatura Noroeste
Jennifer Pitt, National Audubon Society

Members
Alejandro Aguilar, Comisión Nacional del Agua
Homey Bon, Comisión Nacional del Agua
Robert Cardenas, International Boundary and Water Commission, U.S. Section
Yamilett Carrillo, Restauremos el Colorado
Alfredo de la Cerda, International Boundary and Water Commission, Mexican Section
Peter Culp, Culp & Kelly Blueshift LLP
Carlos de la Parra, Colegio de la Frontera Norte
Christopher Dodge, U.S. Department of the Interior, Bureau of Reclamation
Antonio Espinosa, Comisión Nacional del Agua
Karl Flessa, University of Arizona
Albert Flores, International Boundary and Water Commission, U.S. Section
Daniel Galindo, International Boundary and Water Commission, Mexican Section
Liliana García, Secretaría de Medio Ambiente y Recursos Naturales
Matthew Grabau, U.S. Fish and Wildlife Service
Angel Guillen, Secretaría de Desarrolla Agropecuario
Jessica Gwinn, U.S. Fish and Wildlife Service
Amy Haas, Upper Colorado River Commission
Humberto Hernández, Organismo Operador Municipal de Agua Potable, Alcantarillado y Saneamiento
Vineetha Kartha, Arizona Department of Water Resources
Eloise Kendy, The Nature Conservancy
James Leenhouts, U.S. Geological Survey
Nathan Lenon, U.S. Department of the Interior, Bureau of Reclamation
Angel López, Secretaría de Desarrollo Agropecuario
Francisco López, Comisión Nacional del Agua
Anna Morales, International Boundary and Water Commission, U.S. Section
Antonia Navarro, Organismo Operador Municipal de Agua Potable, Alcantarillado y Saneamiento
Jessica Neuwerth, Colorado River Board of California
Sara Price, Colorado River Commission of Nevada
Jorge Ramírez Hernández, Universidad Autónoma de Baja California
Adriana Rodríguez, Comisión Nacional del Agua
Martin Sau, Comisión Nacional de Áreas Naturales Protegidas
Seth Shanahan, Southern Nevada Water Authority
Eduardo Soto, Comisión Nacional de Áreas Naturales Protegidas
Mike Vargas, Pronatura Noroeste
Meena Westford, The Metropolitan Water District of Southern California
Amy Witherall, U.S. Department of the Interior, Bureau of Reclamation
Francisco Zamora, Sonoran Institute

Figure 1-1. Colorado River Limitrophe (Reaches 1 and 2) and Delta reaches and locations mentioned in this report.

Executive summary

Environmental flows totaling 11.9 Mm^3 (million cubic meters) (9,647 af (acre-feet)) were delivered to the Miguel Alemán, Chausse, and Laguna Grande restoration areas and to the Ayala Drain during 2018. Environmental flows delivered by month in each restoration site are reported in the Hydrology Section below. Delivery data in this report are from Restauremos el Colorado.

Methods

Methods used in monitoring for hydrology, vegetation, remote sensing, avian populations and the upper estuary are described in each section and/or in the Monitoring Programmatic Framework.

Geography of the study area

The area that was monitored consists of the Colorado River channel and its floodplain extending from Morelos Dam approximately 160 river km (≈100 river miles) to the Upper Gulf of California. The 680-km^2 (260-mi^2 or 166,000-acre) study area is defined by levees and highways that confine the channel. Detailed maps of the Colorado River Delta's riparian corridor are shown in Figures 1-2 to 1-6. The maps show the locations of discharge measuring stations (DMS), restoration areas and other places referred to in this report. Hydrologic Monitoring Network (surface water discharge stations, staff gauges, and piezometers) are shown in Appendix A. Appendix B describes Vegetation Monitoring, including Bird monitoring sites in Table B-1. Control Sites are listed and described in Appendix C and Indicator Bird Species are listed in Appendix D.

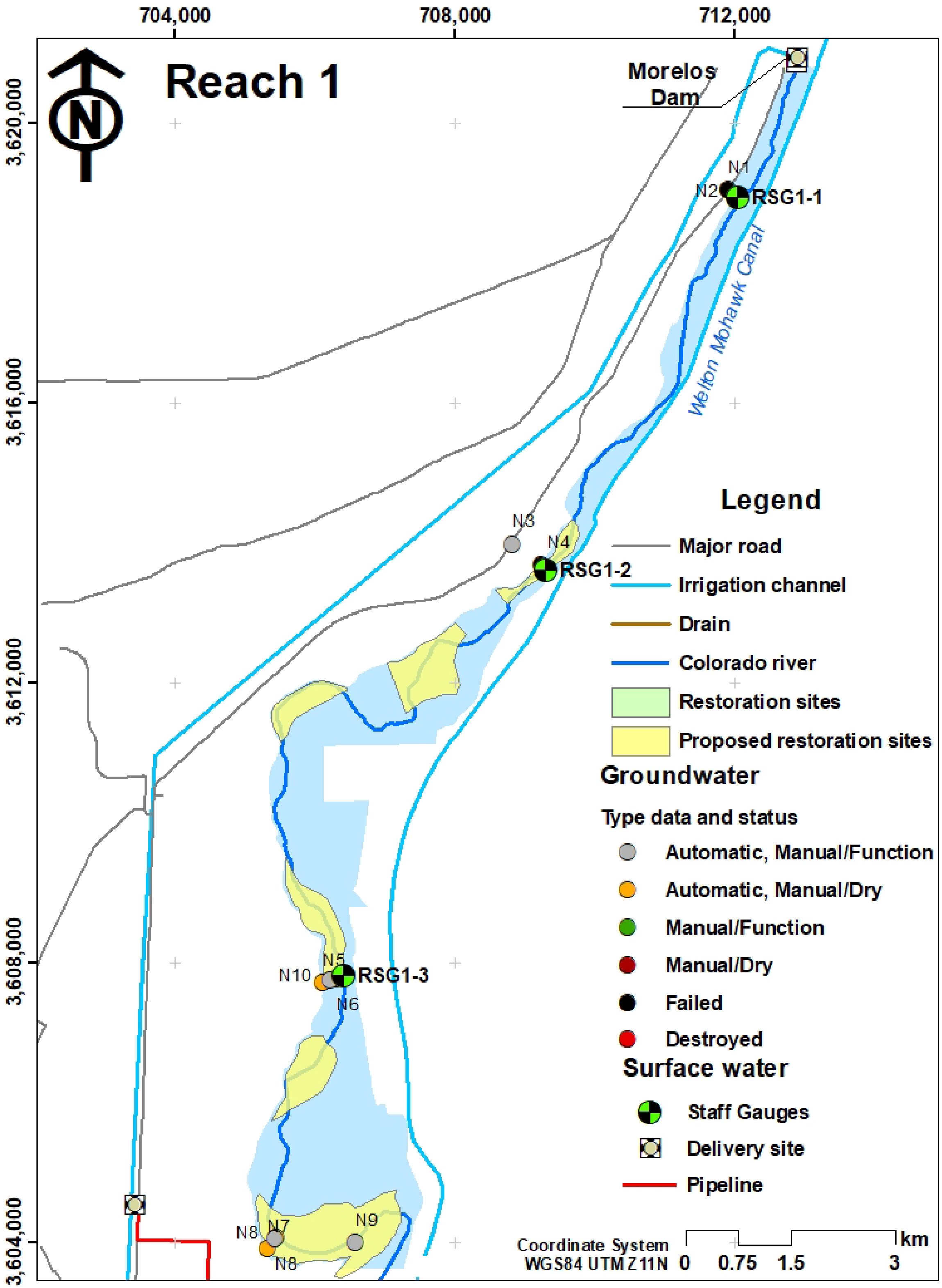

Figure 1-2. Study area., Reach 1.

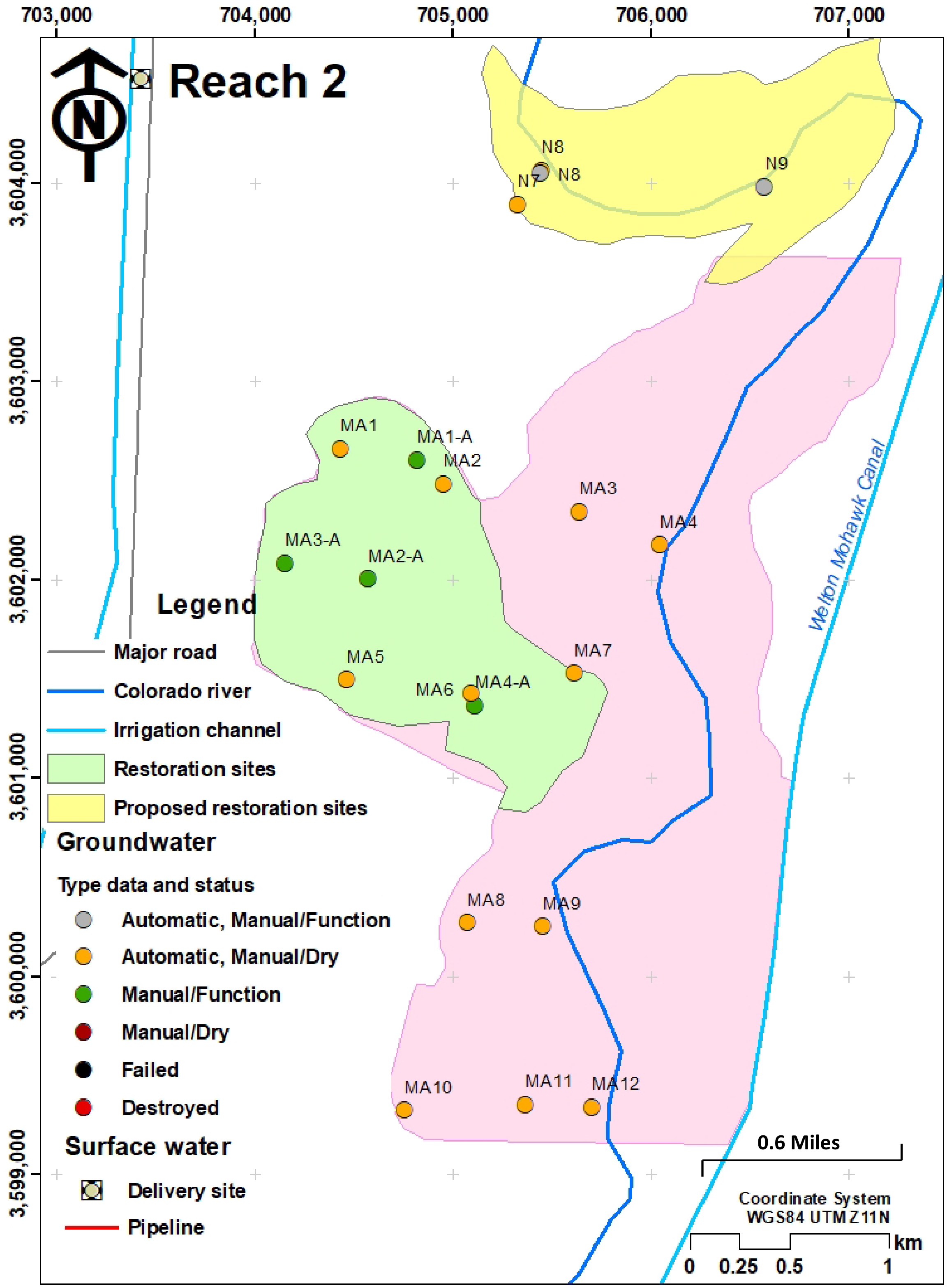

Figure 1-3. Study area, Reach 2.

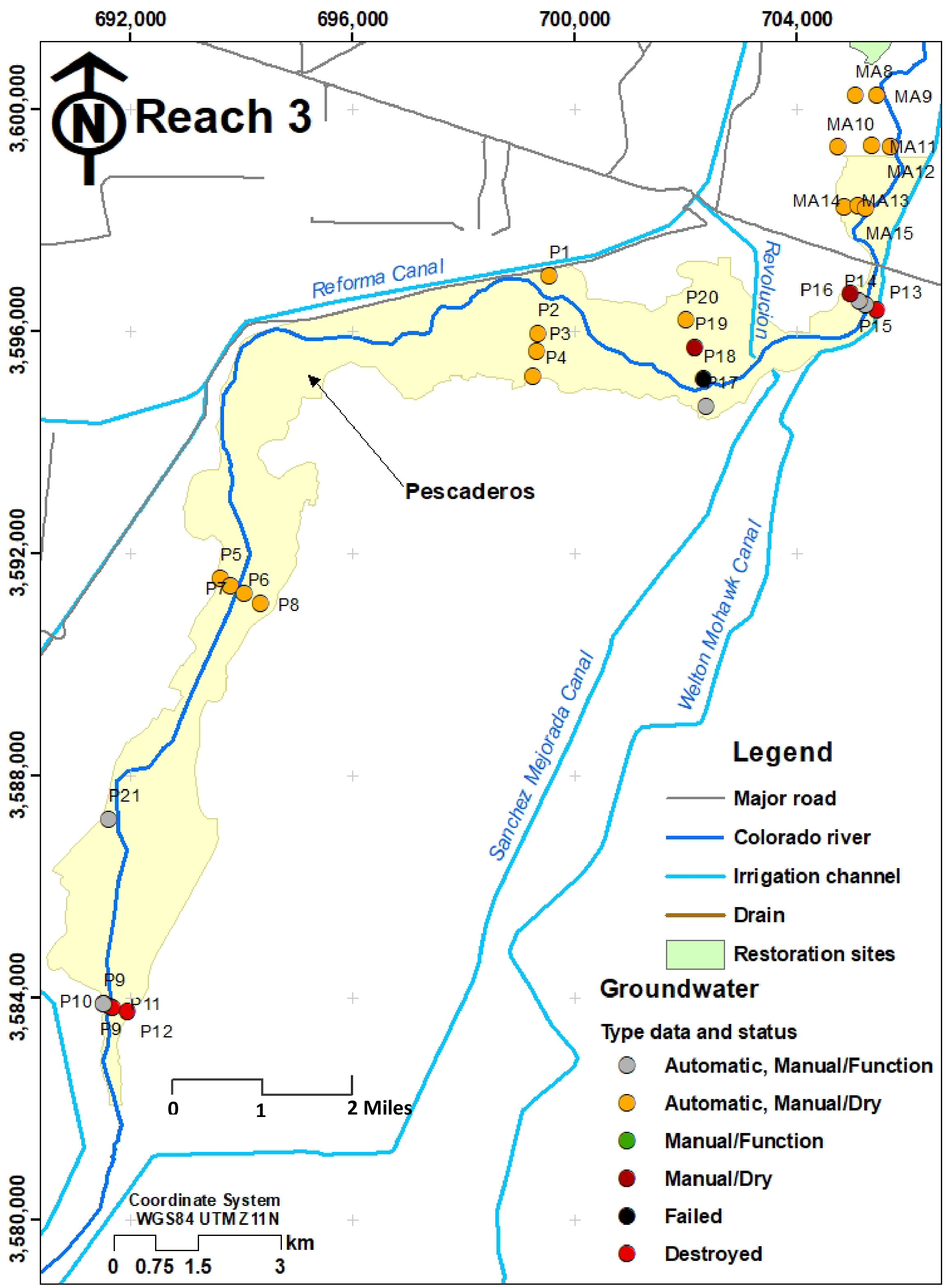

Figure 1-4. Study area, Reach 3.

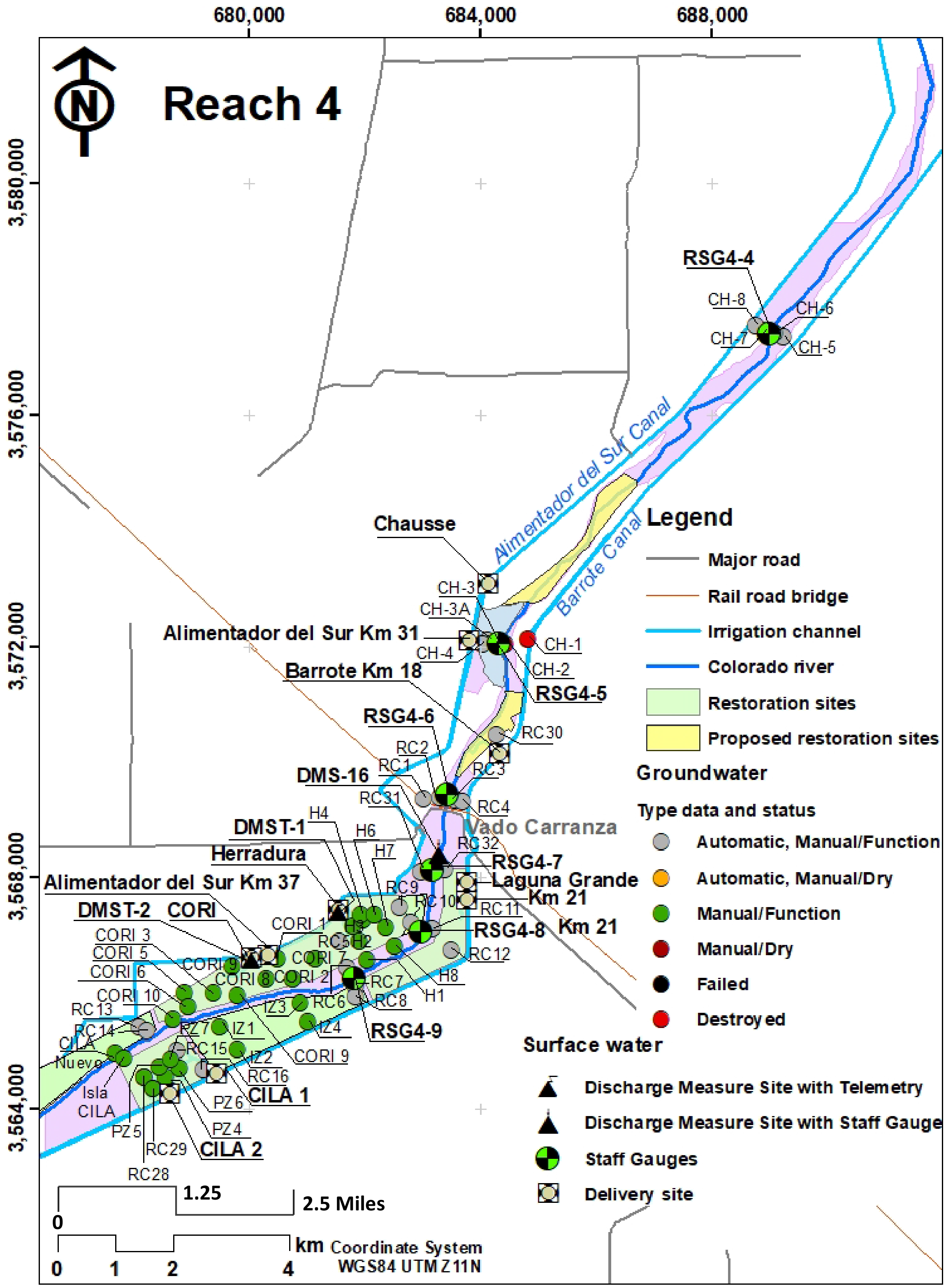

Figure 1-5. Study area, Reach 4.

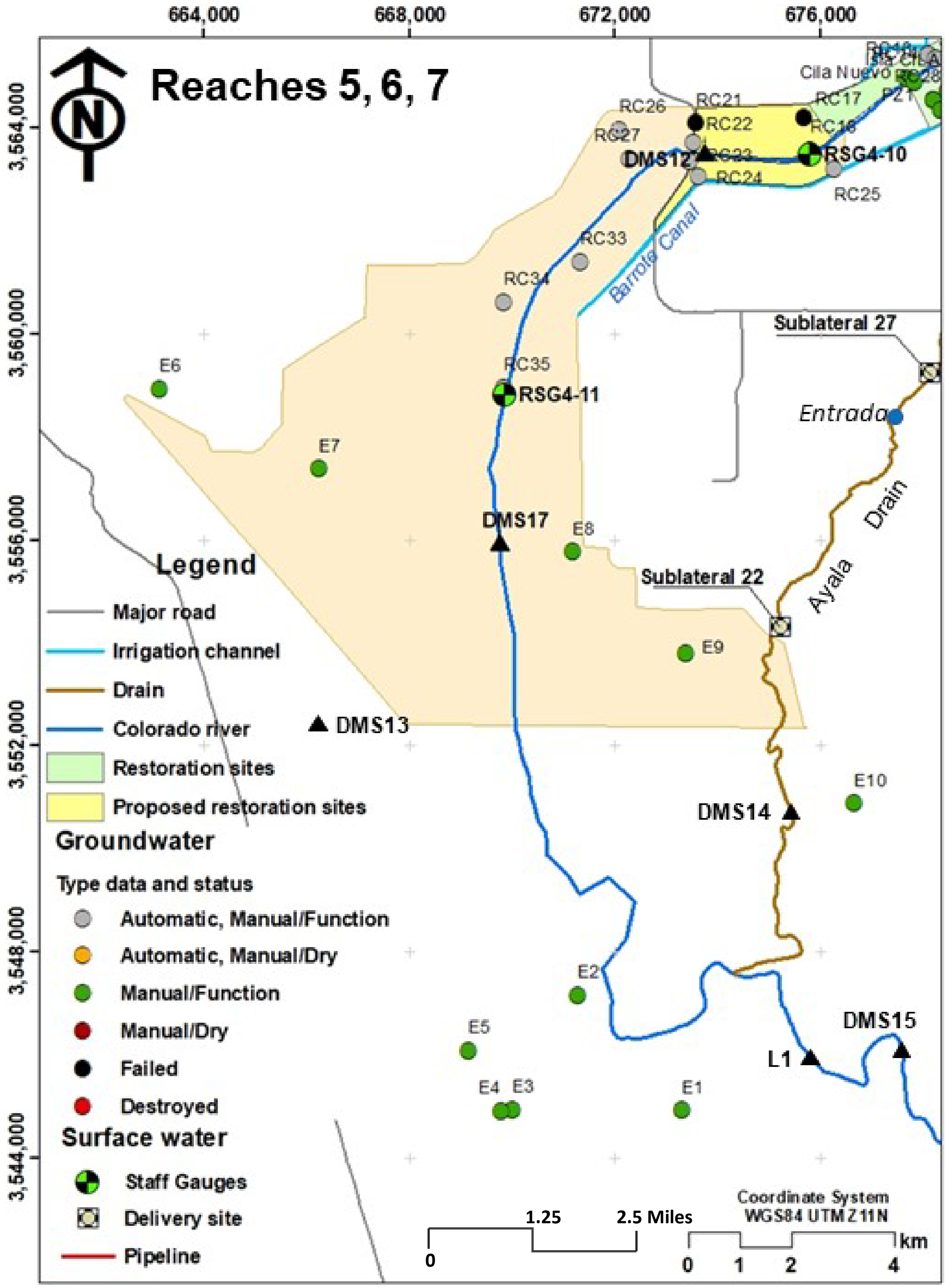

Figure 1-6. Study area, Reaches 5,6 and 7.

Summary of observations and analyses made through December 31, 2018

Detailed presentation and discussion of these results with supporting data are in the subsequent sections and Appendices of this report.

1. Ninety-eight percent of the water volume requested in 2018 (12.1 Mm^3; 9,808 af) by the Environmental Work Group was delivered. Twenty-six percent of the annual water delivery occurred in December, approximately ten times the amount requested. Vegetation is dormant in December. Water delivered after the growing season may have some benefits, such as flushing of salts and groundwater recharge, although these benefits have not been documented.
2. New monitoring equipment installed at Herradura in 2018 improved the accuracy of water delivery measurement and revealed that previously reported deliveries may have been overestimated.
3. Groundwater levels continued to decline beneath the lower part of Reach 1, Reach 2 and Reach 3.
4. Groundwater in Reach 4 responded to environmental water deliveries and irrigation return flows, and generally maintained historic levels.
5. A sustained flow release to Ayala Drain in June to December 2018, after it was dredged in January, showed that water delivered to Ayala Drain can flow unimpeded into the Colorado mainstem, and from there to the estuary, without significant seepage loss.
6. Areas under active restoration more than two years old totaled 198 ha (489 ac) in 2018.
7. Restoration sites in the riparian corridor have more native species and greater vegetation volume than control sites.
8. There was no significant difference in Cottonwood-Willow cover from 2017 to 2018.
9. Vegetation volume decreased at the CILA site from 2017 to 2018, probably because the site did not receive water as scheduled. Vegetation volume increased at the Miguel Alemán site and was unchanged at the Herradura site.
10. Monitoring of pre-existing vegetation and bird composition and diversity should be conducted prior to the development of any new restoration sites.
11. Greenness and evapotranspiration decreased in the riparian corridor of the delta from 2000 to 2013. The Minute 319 Pulse Flow of 2014 produced a 17% increase in NDVI (“greenness”) throughout the riparian corridor in the subsequent growing season of 2014. By 2018, NDVI values had decreased to pre-pulse (2013) values in all reaches.
12. NDVI values continue to be highest in Reaches 1, 4 and 5, where the water table is shallow.
13. Bird diversity and abundance of indicator species are 20% and 74% higher, respectively, in the restoration sites than in unrestored control sites.
14. Abundance of indicator riparian bird species has been declining since 2015, including a 15.6% decline at the restoration sites from 2017 to 2018. (“Indicator species” are 9 resident species and 6 breeding visitors, which were selected for their association with the quality of the riparian habitat.)
15. Populations of priority marsh bird species (Least Bittern and Yuma Ridgway’s Rails) have increased exponentially in the last 10 years in Hardy River bird monitoring sites.
16. The size of breeding colonies of seven water bird species in the Upper Estuary and Hardy River has increased since 2014.

17. Although the June-December flow delivery to Ayala Drain reached the upper estuary, it did not measurably change water levels, salinity, or biota in the estuary. The flow was requested at 0.5 m^3/sec (18 cfs) over 55 days in June and July, but instead was delivered over 183 days at 0.19 m^3/sec (6.7 cfs) during June, July, August, October, and December.
18. Salinity in the upper estuary varied seasonally, from a low of 3 ppt in the irrigation season to a high of 134 ppt at the most seaward station in the late summer.
19. Crustacean arthropods, including post-larvae of shrimp, were the most common organisms found in the upper estuary. Freshwater, brackish and marine fish were also found in the area.

Section 2: Hydrology

Eloise Kendy
The Nature Conservancy
Helena, Montana

Key observations[1]

- Ninety-eight percent of the water volume requested in 2018 (12.1 Mm^3; 9,808 af) by the Environmental Work Group was delivered. Twenty-six percent of the annual water delivery occurred in December, approximately ten times the amount requested. Vegetation is dormant in December. Water delivered after the growing season may have some benefits, such as flushing of salts and groundwater recharge, although these benefits have not been documented.
- New monitoring equipment installed at the Herradura restoration site in 2018 improved the accuracy of water delivery measurement and revealed that previously reported deliveries may have been overestimated.
- Groundwater levels continued to decline beneath the lower part of Reach 1, Reach 2, and Reach 3.
- Groundwater in Reach 4 responded to environmental water deliveries and irrigation return flows, and generally maintained historic levels.
- A sustained flow release to Ayala Drain in June 2018, after it was dredged in January, showed that water delivered to Ayala Drain can flow unimpeded into the Colorado mainstem, and from there to the estuary, without significant seepage loss. 2,179,352 m^3 (1,767 af) was delivered over 183 days instead of the requested amount of 2,400,000 m^3 (1,9456 af) over 55 days. Section 7 shows that this flow had no detectable effects on water levels, salinity or biota.

Hydrologic Monitoring Network

The Minute 323 on-the-ground hydrologic monitoring network consists of 56 piezometers for measuring groundwater levels, 11 staff gauges for measuring surface-water levels, 11 discharge measurement stations, and 14 water delivery sites. Restauremos el Colorado owns and monitors additional hydrologic monitoring sites, the results from which were not provided for this report.

Appendix A inventories the metadata and maps the location of each Minute 323 hydrologic monitoring site, plus 38 additional piezometers that were installed under Minute 319 but have since been destroyed or gone dry and 15 additional discharge stations that were discontinued after the 2014 pulse flow. See also Figures 1-2 through 1-6.

New monitoring equipment installed in 2018

In 2018, several new hydrologic monitoring instruments were installed along the riparian corridor, as recommended by binational science team hydrologists during an April 24, 2018, workshop and subsequent

[1] Comprehensive biannual reporting of hydrologic monitoring requires scientific evaluation of trends in groundwater levels and flows and documentation of the flow paths and final uses of environmental water delivered to the riparian zone and estuary of the Delta. Limited project funding availability resulted in the evaluations and technical report writing not being fully conducted in 2018 by the Universidad Autónoma de Baja California (UABC) hydrologists.

written communications. These include two water-delivery discharge stations with telemetry equipment, three in-channel discharge stations, 11 staff gauges, and 11 piezometers, as described below. All are mapped and inventoried in Appendix A.

The two new water-delivery discharge stations were installed at Herradura (DMST-1) and Cori (DMST-2) and consist of Parshall flumes fitted with telemetry equipment to enable remote monitoring of deliveries from Canal Alimentador del Sur via email or text. The remote monitoring capability addresses communication issues between water managers and restoration teams by alerting hydrologists immediately when water deliveries begin and enabling them to monitor changes in flow rates. Additional calibration is needed to verify the stage-discharge relationships and extend them to higher flows because in some cases measured flows exceeded automatically recorded flows.

Three new discharge measurement stations (DMS-12, DMS-16, and DMS-17) were established in 2018 to monitor in-channel flows at Vado Carranza (DMS-12), immediately upstream from Laguna Grande (DMS-16), and in the pilot channel between R5 and R7 (DMS-17).

Eleven new river staff gages (RSG 1-11) were installed in 2018 along groundwater transects. By measuring surface-water levels relative to groundwater levels, the staff gages enable gaining and losing river reaches to be identified.

Eleven new piezometers were installed in 2018 to meet specific monitoring objectives:

<u>Reach 1</u>

- N10 is located near a control site, near the transition from a wet to dry river channel, and serves dual purposes of understanding groundwater dynamics in the control site and monitoring groundwater depth in an area of hydrologic and ecological transition.
- N8 (new) is located in the planned Janitzio restoration area (see Figure 1-1) and replaces the previous N8, which went dry in 2016.
- N9 is also located in Janitzio, downstream from N8 and across the river channel following a perpendicular transect with a U.S. Bureau of Reclamation piezometer in the opposite river bank. Together, data from these piezometers provide the depth and relative horizontal direction of groundwater flow needed to optimize water deliveries to Janitzio.

<u>Reach 3</u>

- P9 (new) and P21 are located in an area of declining groundwater levels and inform predictions of future groundwater levels in downstream restoration sites. P9 (new) replaces the previous P9, which went dry in 2016.

<u>Reach 4</u>

- RC30 is located downstream from Chaussé to document hydrologic responses to in-channel flow releases from Chaussé. Some of the water that is released recharges the aquifer and some flows downstream in the river channel.
- RC31 and RC32 are located near San Felipito, a potential future restoration area. Groundwater depths measured in these piezometers inform the restoration design, including vegetation types and their water delivery needs.

Reach 5

- C33, RC34, and RC35 are located on both sides of the river to test the hypothesis that shallow groundwater levels explain high bird abundance and diversity in this area and to inform future restoration efforts.

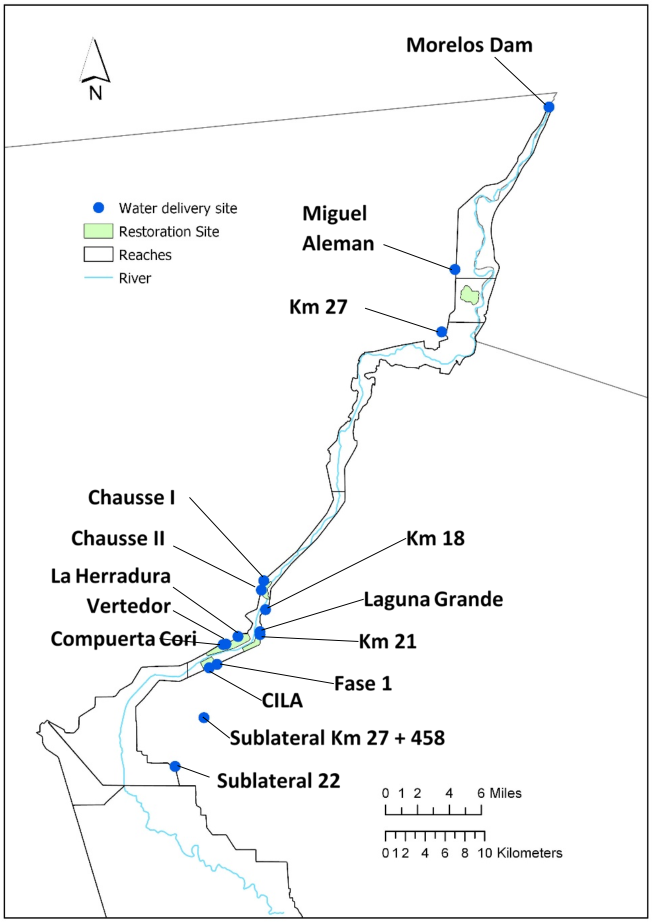

Figure 2-1. Locations of water delivery sites.

Environmental Water Deliveries

Environmental water can be delivered to restoration areas and to the river channel from fourteen delivery points (Figure 2-1). Of the 12,096,864 m^3 (9,807 af) of water requested in 2018 by the Environmental Work Group, 11,851,949 m^3 (9,607 af), or 98% of the requested amount, was delivered.

However, delivery dates differ from the requested dates. During the growing season, deliveries to Miguel Alemán and Chaussé (Figure 2-2, upper left and top right) were not significantly less than the requested volume, while all other sites received significantly less water than requested. To fulfill the annual request, a large volume was delivered to each of five downstream sites in December. Consequently, 25.6% (3,035,059 m^3; 2,461 af) of the annual water delivery occurred in December, in contrast to the 3.4% (408,800 m^3; 331 af) that was requested.

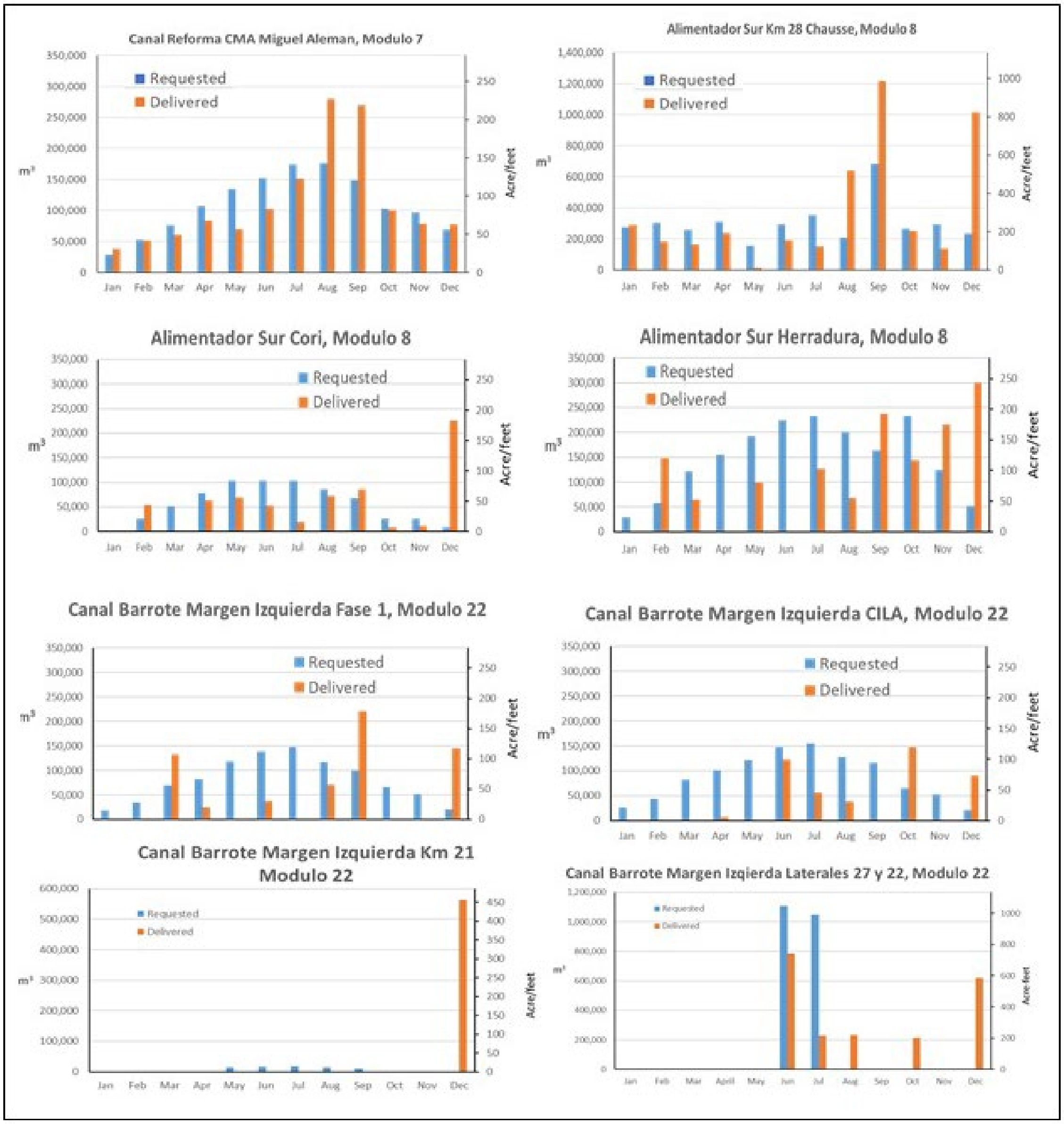

Figure 2-2. Environmental water requests and deliveries, 2018. Data from Restauremos el Colorado. Vertical scales vary by site.

Water deliveries typically are measured once daily, with the assumption that the flow rate remains constant until it is next measured. To test this assumption, hourly flow measurements were compared to daily flow measurements at Herradura, where a new recorder was installed in August 2018. The data indicate that flow rates often decreased after the daily measurements were taken (Figure 2-3). As a result, monthly water delivery volumes based on daily flow measurements exceeded the reported volumes based on hourly measurements (Figure 2-3). When flow rates decrease over the course of a day, hourly measurements yield more accurate water delivery volumes than do once-daily morning measurements.

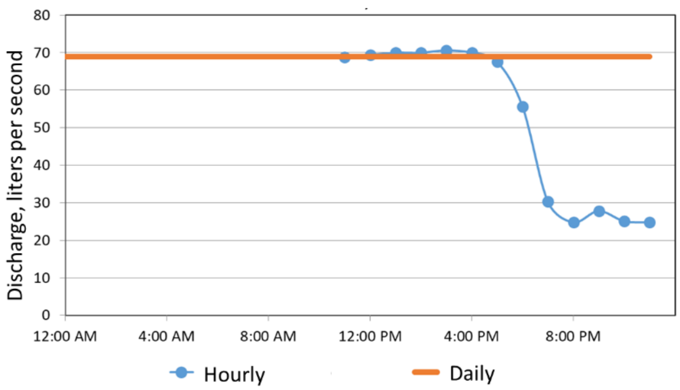

Figure 2-3. Comparison between water delivery rates based on hourly versus daily flow measurements at Herradura, November 26, 2018.

Surface-Water Flows

Surface water discharge was measured at Discharge Monitoring Stations (DMS) 12, 16, and 17 in the riparian corridor and DMS 13, 14, and 15 and FDA and L1 in the upper estuary. These sites are inventoried and mapped in Appendix A.

Groundwater Levels and Flows

Groundwater levels measured in 56 piezometers along the riparian corridor in 2018 are recorded as depths below the land surface and as elevations above mean sea level.

Manual measurements were reviewed for consistency with past and nearby measurements and continuous data were corrected as needed for barometric pressure changes, transducer drift, and suspension system slippage. This is the first year for formal QA/QC review of hydrologic data collected by other hydrologists. In 2018 hydrologists adopted consistent checks on their measurements, both in the field and in the office.

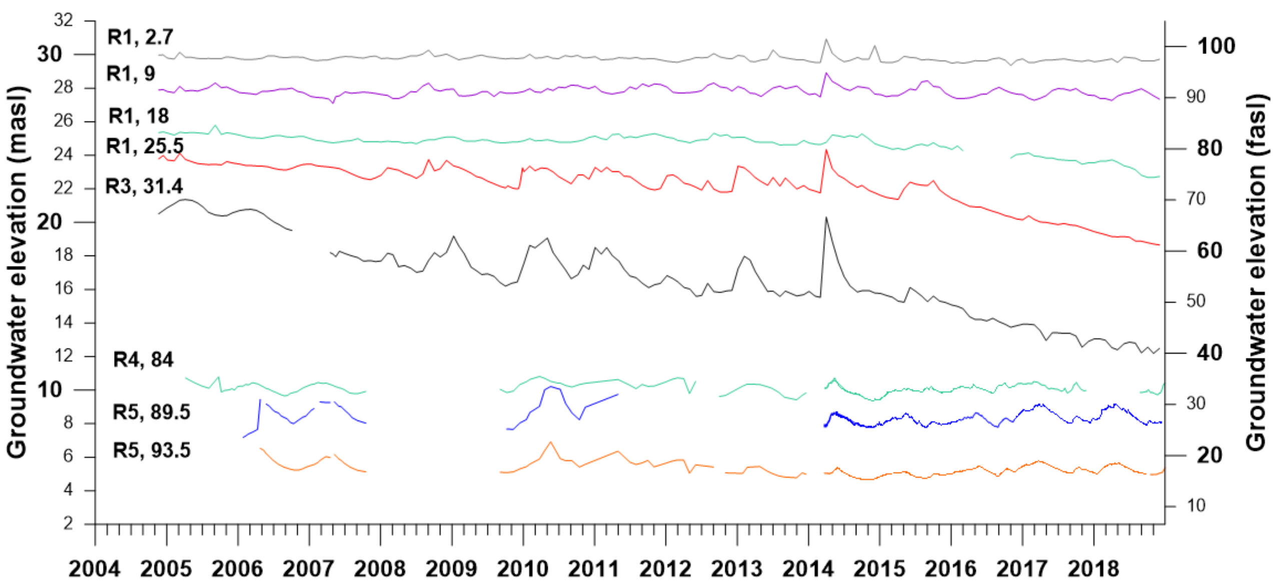

Figure 2-4. Long-term groundwater hydrographs, indicating the reach number (R) and river kilometer (downstream distance from Morelos Dam) of the piezometer for which each hydrograph was recorded. Units: masl = meters above sea level; fasl = feet above sea level. Graph courtesy E. Rodríguez-Burgueño, UABC.

Figure 2-4 depicts temporal trends in groundwater levels across the project area.

Groundwater levels beneath Reach 4 responded to environmental water deliveries. For example, Figure 2-5 shows the groundwater response to periodic inundation of the meander at the Chaussé restoration site. Generally, Chaussé restoration managers request water deliveries when the groundwater depth drops to about 3.2 meters.

In the Laguna Grande restoration complex, groundwater levels typically rose during the irrigation season in response to irrigation return flows, declined after irrigation ended, and rose again in response to fall and winter environmental water deliveries, as shown in Figure 2-6. The groundwater response to the December water deliveries was most pronounced in piezometers located close to delivery points and the river channel. The maximum observed water-level rise at Laguna Grande in December was 1.3 meters in RC7.

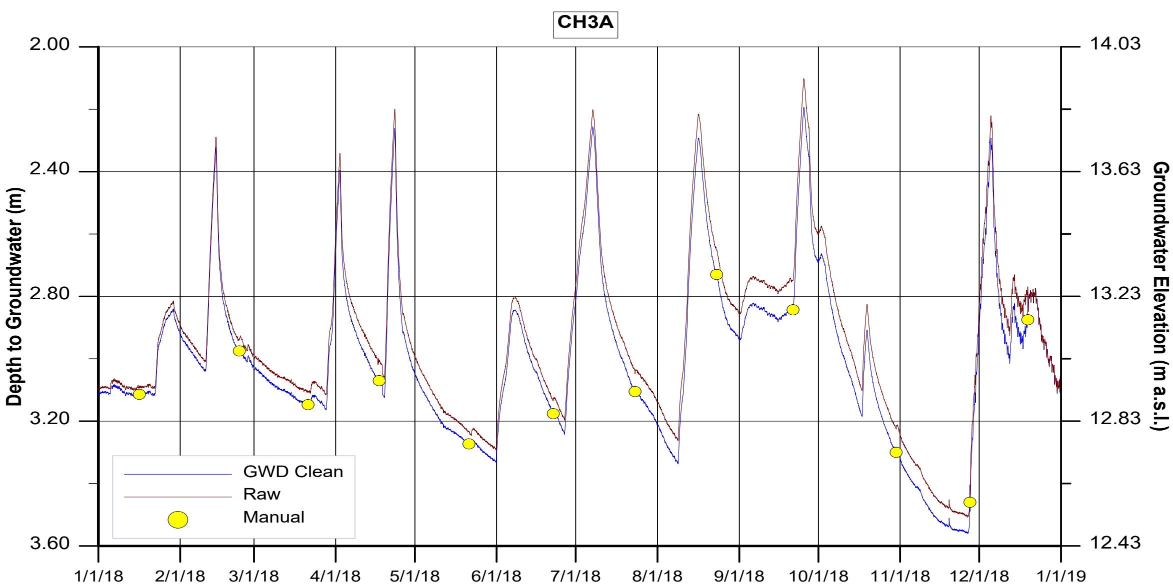

Figure 2-5. Depth to groundwater in piezometer CH3A (Chaussé). Manual=Manual measurement, Raw=Continuous registered data from the pressure transducer, GWD Clean= Continuous data corrected. From UABC and ETS 2019.

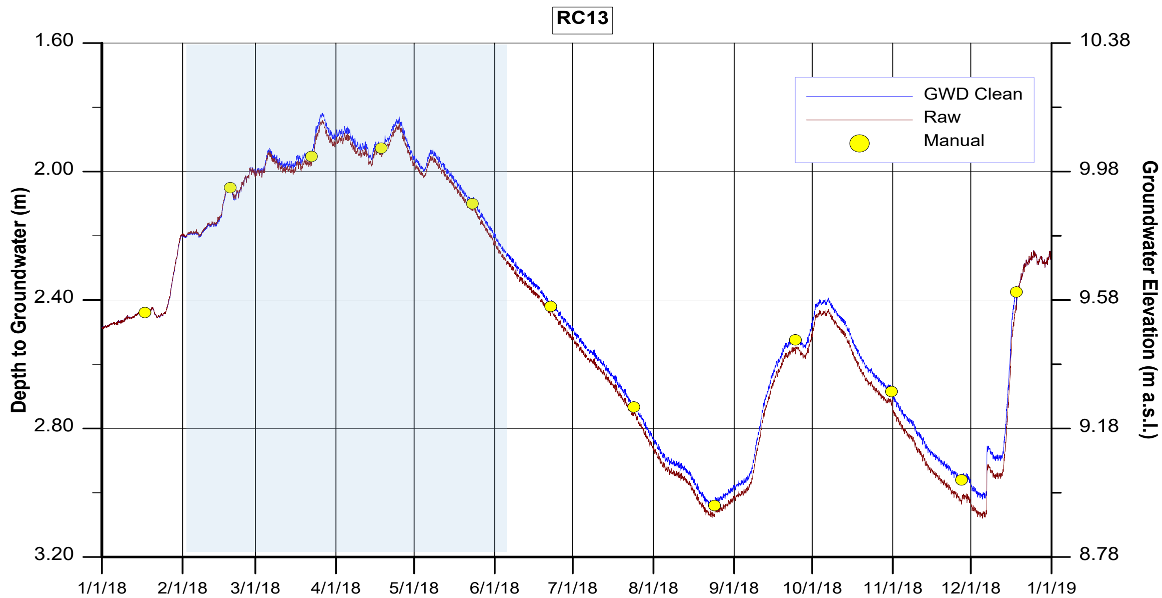

Figure 2-6. Depth to groundwater in piezometer RC13 (Laguna Grande). Manual=Manual measurement, Raw=Continuous registered data from the pressure transducer, GWD Clean= Continuous data corrected. Blue shaded area indicates irrigation season.

Groundwater levels in Herradura restoration site (Figure 2-7) rose in response to water deliveries (Figure 2-2) in February, March, May, July, September, and December. However, the August, October, and November deliveries had little effect on groundwater. This response pattern is consistent with the water delivery volumes that were calculated from hourly flow measurements (Figure 2-3).

Figure 2-7. Groundwater levels in piezometers at Herradura, 2018. Masl = meters above sea level. Piezometer locations are shown in Appendix A.

Ayala Drain Pilot Test

In January 2018, Sonoran Institute dredged the lowermost 1.8 km (1.1 mi) of Ayala Drain to improve its connection with the Colorado River below its confluence with the Hardy River. During the following summer, environmental water was delivered to Ayala Drain to test the effectiveness of the dredging and to measure the ability of Ayala Drain to convey water to the upper estuary.

The test successfully demonstrated that water delivered to Ayala Drain can flow unimpeded down the drain and into the Colorado mainstem, and from there to the estuary without significant seepage loss. Moreover, simultaneous discharge measurements at multiple sites along the flow path on July 5, 2018, revealed an input drain (entrada) that contributed additional water to Ayala Drain (Appendix A, map of reaches 4, 5,6). During the simultaneous measurements, agricultural drainage (0.041 m^3/s; 1.5 ft^3/s), the environmental water delivery (0.19 m^3/s; 6.5 ft^3/s), and the input drain (0.21 m^3/s; 7.5 ft^3/s) contributed 0.44 m^3/s (15 ft^3/s) of inflow to the Colorado mainstem.

There were no detectable impacts of the Ayala Drain pilot test on estuarine water levels, salinity and biota. For more details on the Ayala Drain pilot test, see Section 7 – Upper Estuary.

References cited

Flessa, K., Kendy, E., Rodríguez Burgueño, J. E., & Schlatter, K., eds. 2018. Minute 319 Colorado River Limitrophe and Delta Environmental Flows Monitoring Report: International Boundary and Water Commission, United States and Mexico, 89 p.

Section 3: Vegetation Monitoring

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Patrick B. Shafroth[4], Eduardo Gonzalez[5]

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[4] U.S. Geological Survey, Fort Collins, Colorado, U.S.A.

[5] Colorado State University, Fort Collins, Colorado U.S.A.

Key observations

- Areas under active restoration for more than two years totaled 198 ha (489 ac) in 2018.
- Monitoring of pre-existing vegetation and bird composition and diversity should be conducted prior to the development of any new restoration sites.
- Restoration sites in the riparian corridor have more native species and greater vegetation volume than unrestored control sites. There was no significant difference in cottonwood-willow cover from 2017 to 2018.
- Vegetation volume decreased in the CILA site from 2017 to 2018; vegetation volume in other Laguna Grande sites was unchanged. Vegetation volume increased at the Miguel Alemán site and was unchanged at the Herradura site.

Introduction

Sonoran Institute, Pronatura Noroeste, and University of Arizona conducted vegetation monitoring in riparian restoration sites and control sites along the Colorado River corridor in Mexico during the fall (end of the growing season) of 2018. The overall goal of the vegetation monitoring program was to quantify impacts of restoration actions on the extent, composition, and structure of riparian habitat and to relate habitat characteristics to bird abundance and diversity. Specific monitoring objectives were to measure the vegetation vertical structure, density, and cover by species in active riparian restoration sites that had been planted prior to 2017 (> 2 years of growth) in Laguna Grande (CILA, Herradura, and Cori sites) and Miguel Alemán (Fig. 3-1) and to compare vegetation metrics in the restoration sites to the control sites to assess impacts of restoration. The Chaussé restoration site is scheduled for initial monitoring in 2021.

This report summarizes 2018 results from the restoration and control sites and compares restoration site results between 2017 and 2018.

Study Area

Restoration sites

All active restoration sites (meaning non-"passive" restoration sites, or sites with varying levels of activities described below) were subject to the following restoration activities prior to 2017: removal of undesirable vegetation (primarily salt cedar (*Tamarix* spp.) and arrowweed (*Pluchea sericea*)), land grading and contouring, planting of native vegetation, and irrigation. Table 3-1 describes restoration site characteristics.

Miguel Alemán

The Miguel Alemán restoration site is located in Reach 2 in the Limitrophe zone (Fig. 3-1) and is 200 ha (494 acres) in area. Water for the site is delivered from Canal Reforma, under water rights that are within Irrigation Module 7 (local irrigation management sector). Cottonwood-willow (CW) habitat is irrigated by flooding, while mesquite bosque and upland habitats are irrigated with drip and sprinkler systems.

Laguna Grande

The Laguna Grande Restoration Area (Laguna Grande) is located in the central Delta region (Fig. 3-1) and extends from the railroad bridge (locally known as San Felipito) to about six river miles downstream. Laguna Grande consists of three separate land concessions (Mexican federal land designated for restoration)—CILA (115 ha/285 acres), Laguna Cori (318 ha/785 acres, which includes the Herradura and the Cori sites), and Laguna Larga (140 ha/345 acres) (Fig. 3-2).

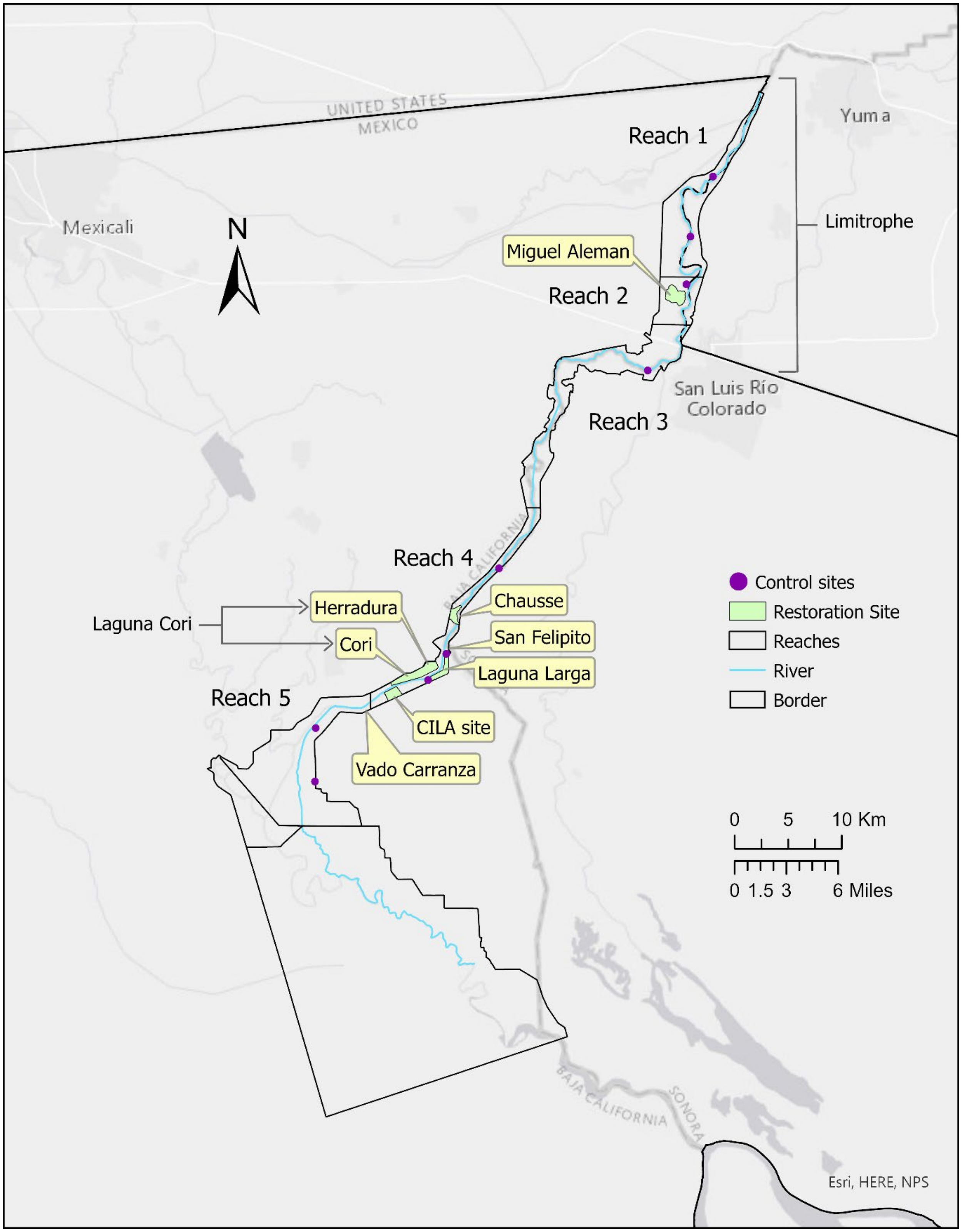

Figure 3-1. Restoration sites and control sites along the Colorado River riparian corridor in Mexico.

CILA site

The majority of revegetation work at the CILA site was carried out between 2013 and 2016. Most planted vegetation at the CILA site is irrigated by flooding, with smaller areas of drip and no irrigation (planted directly into groundwater).

Herradura

A large area of Herradura overlies groundwater at a depth of <2m. Herradura was planted in 2015-2017, with areas of flood irrigation, flows to the meander channels and laguna, and a small area of drip.

Cori

The Cori site is irrigated primarily by flooding with a small area of drip (see Appendix B, Figure B-1).

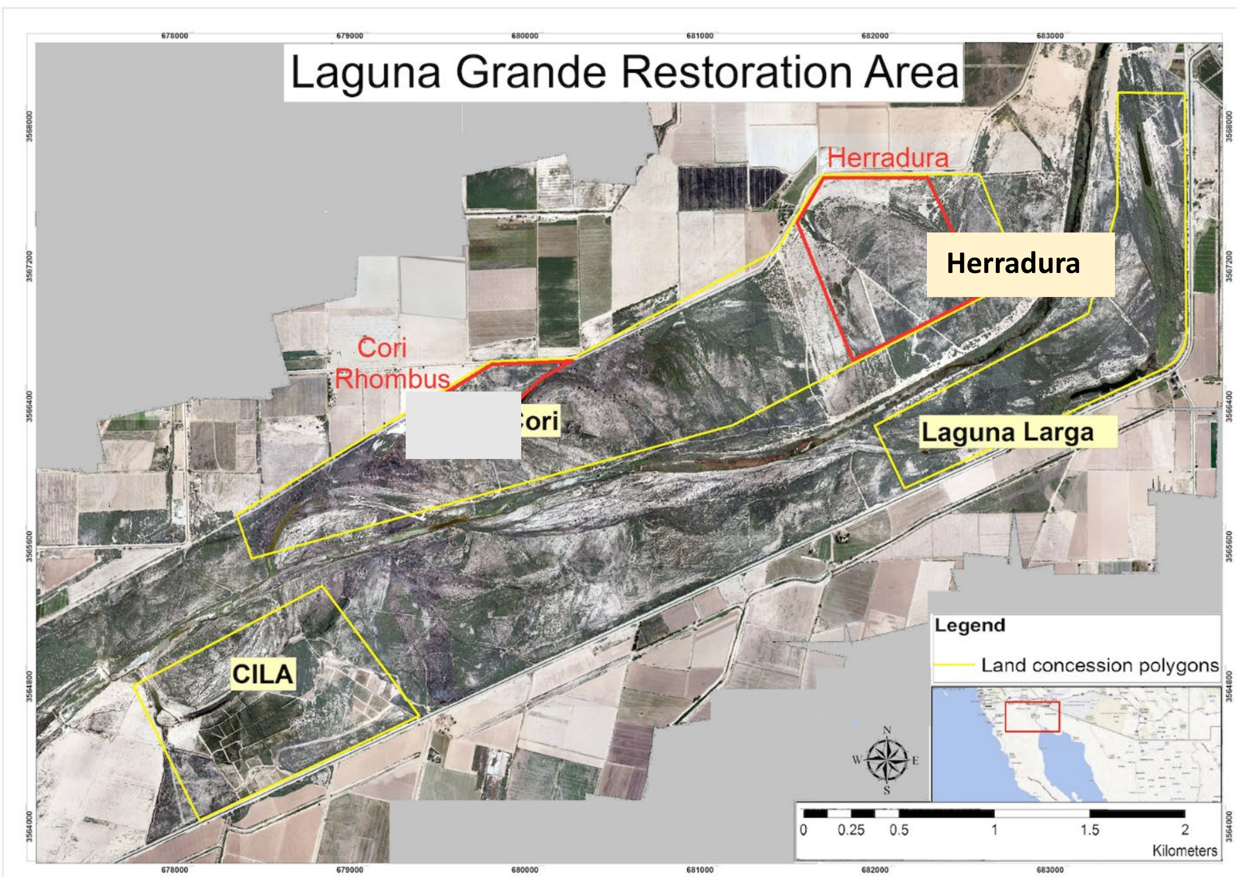

Figure 3-2. Map of the Laguna Grande restoration area and the three restoration sites discussed here: Cori, Herradura and CILA.

Table 3-1. Characteristics of restoration sites. Habitat type: Cottonwood-willow = *Populus fremontii* and *Salix gooddingii*); mesquite bosque = *Prosopis glandulosa* and *P. pubescens*; upland habitat is dominated by mesquite (*P. glandulosa*) and palo verde species (*Parkinsonia* spp). Area: Ha = hectares, Ac = acres. Initial monitoring of Chaussé site is scheduled for 2021.

Restoration Site	Year restoration began	Areas of restored habitat (>2 years old)												Average depth to groundwater
		Open Water		Marsh		Cotton-wood-willow		Mesquite bosque		Upland		Total area planted		
		Ha	Ac	Ha	Ac	Ha	Ac	Ha	Ac	Ha	Ac	Ha	Ac	m
Miguel Alemán	2014	0	0	0	0	14	35	24	59	22	54	**60**	**148**	11-15
CILA	2010	1.5	3.7	1.5	3.7	70	173	13	32	0	0	**86**	**213**	0-4
Herradura	2015	1	2.5	1	2.5	27	67	6	15	0	0	**35**	**86**	0-4
Cori	2016	0	0	0	0	1	2.5	16	40	0	0	**17**	**42**	2-5
Total		**2.5**	**6.2**	**2.5**	**6.2**	**112**	**277**	**59**	**146**	**22**	**54**	**198**	**489**	

Control sites

Control sites were established along Reaches 1-5 to allow for quantitative comparisons of riparian vegetation conditions between sites where restoration actions were and were not implemented. All but two control sites are located in existing bird point count areas (for information on bird point count areas, see Section 7) so that vegetation data can be related to bird abundance and diversity metrics. Although pre-restoration surveys were not conducted in the restoration sites, on-site observations, satellite imagery, and groundwater data suggest similar geomorphic, hydrologic, and vegetation conditions between control sites and restoration sites prior to the initiation of restoration activities (see Appendix C).

The two control sites in Reach 1 are dominated by saltcedar and arrowweed with less than 10% CW tree cover. Reach 2 has one control site, which is located upstream of Miguel Alemán and is dominated by saltcedar and arrowweed-saltbus cover. Reach 3 has one control site, which is dominated by saltcedar. Reach 4 has three control sites, one of which is located upstream of Chausse with saltcedar, arrowweed, and non-native emergent vegetation (*Phragmites australis*); the other Reach 4 control sites are located upstream and downstream of the Laguna Larga land concession and are dominated by saltcedar and arrowweed with scattered mesquite trees. Reach 5 has two control sites, which are located downstream of Vado Carranza and are dominated by saltcedar and arrowweed cover but have more bare ground than in the Reach 4 control sites with similar vegetation.

Methods

Three 5x15-m vegetation monitoring plots were randomly established in each bird point count area in both restoration and control sites. As restoration sites expand, additional bird count areas with vegetation monitoring plots will be added to the existing network. In 2017 there were 8 bird point count areas (24 vegetation plots) in Miguel Alemán; 19 bird count areas (57 plots) in CILA; and 5 bird count areas (15 plots) in Herradura. In 2018 there were 19 bird count areas (57 plots) in Miguel Alemán; 17 bird count areas in CILA (51 plots); 7 bird count areas in Herradura (19 plots: plot #1 in bird point 5 and plot #2 in bird point 8 were removed); 5 bird count areas in Cori (14 plots: plot #3 in bird point 2 was removed); and 7 existing bird count areas (21 plots) and 2 new sites outside of bird count areas (6 plots) in the control sites (see Appendix B and C).

Restoration is primarily focused on riparian woody plant species that are either removed (arrowweed (*Pluchea sericea*) and saltcedar (*Tamarix* spp.)) or actively restored (baccharis (*Baccharis salicina, B. salicifolia*), cottonwood (*Populus fremontii*), Gooding's willow (*Salix gooddingii*), coyote willow (*Salix exigua*), honey mesquite (*Prosopis glandulosa*), and screwbean mesquite (*Prosopis pubescens*)).

In each plot, surveys estimated the foliar (leaf) cover of trees and shrubs by species, for all shrubs, for all trees, and in total (combined trees and shrubs). Maximum cover was 100% for categories of separate species, all shrubs, all trees, and combined trees and shrubs. For the categories of cottonwood-willow, mesquite, and native shrubs reported here, individual species foliar cover estimations were added to obtain combined species covers; this process sums areas of overlapping species cover (double counts overlapping areas). Surveys also recorded target restoration tree and shrub species density, mesquite canopy height, and total vegetation volume (TVV, calculated as hits to pole).

Plot data quantifying vertical structure, density, and cover by species were averaged by bird point count area (i.e., 3 plots averaged) and then by restoration site or reach in the case of control sites. In the case of Miguel Alemán, surveys stratified the site into cottonwood and mesquite habitat (referred to henceforth as Miguel Alemán CW and Miguel Alemán mesquite habitat) due to the distinct geographic separation of the two habitat types; this separation was unique to Miguel Alemán. One-way ANOVA and Tukey multiple comparisons of means were used to test for differences between restoration sites. Paired *t*-test and Wilcoxon signed-rank test were used to determine differences between 2017 and 2018 CW cover and TVV. Statistical tests were conducted on Excel and R Studio v. 1.0.143 (2016).

Results and Discussion

Foliar Cover of Trees and Shrubs

The average foliar cover of trees and shrubs at restoration sites (53%) was greater than that of control sites (27%). Miguel Alemán CW (Reach 2), Herradura, and CILA (Reach 4) sites had 50% and 170% percent more woody species cover than the Reach 2 and Reach 4 control sites, respectively (Fig. 3-3). The Reach 3 control site had the lowest percent woody species cover (10%).

The Miguel Alemán mesquite habitat area had significantly lower woody species cover than the other restoration sites ($p<0.05$).

Although Cori and Reach 4 control sites had similar percent cover of woody species, the two have different species compositions; Cori is a mesquite-dominated site with grass and other herbaceous species, while Reach 4 control sites are dominated by saltcedar and arrowweed. Cori site plantings were only two years old at the time of survey; mesquites grow much more slowly than cottonwood, willow, and baccharis, which dominate Herradura (about the same age as Cori) and CILA (older than Cori) sites. This may explain why Cori had less foliar cover than the other Reach 4 restoration sites.

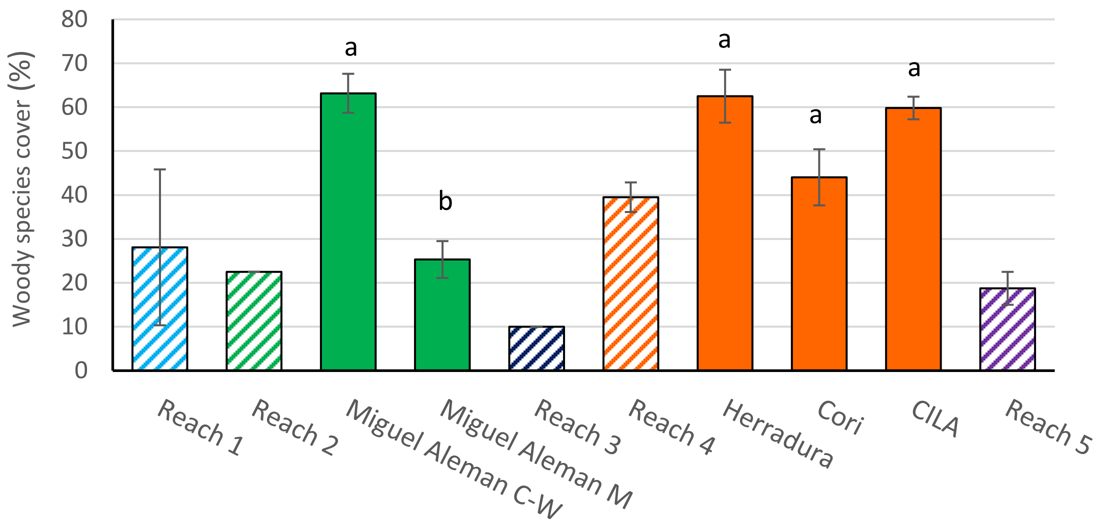

Figure 3-3. Mean foliar cover of woody species in restoration sites (solid color), and control sites (diagonal hatch pattern). Bars represent standard error of the mean. Restoration sites and control sites that share the same color are grouped by reach. Lowercase letters indicate homogeneous groups after Tukey test, significant difference ($p<0.05$).

The average native shrub cover at restoration sites (19%) was more than double that of control sites (8%). Native shrub species cover was highest at CILA site (30%) (Fig. 4), where there is abundant *Baccharis salicina* and arrowweed (Fig. 3-8). Native shrub cover was similar in Cori and Herradura (Fig. 3-4), although Cori was dominated largely by *Baccharis salicifolia* while Herradura native shrubs include coyote willow, arrowweed, and *Baccharis salicina* (Fig. 3-8). Native shrub species cover in Miguel Alemán was significantly lower than in other restoration sites ($p<0.05$) and was similar to control sites in Reaches 1, 2, 3 and 5.

The average CW cover at restoration sites was 23%, while there was no presence of CW cover in the control sites. The mean cover of CW was significantly lower ($p<0.05$) at Miguel Alemán mesquite and Cori sites (<5% cover) than at Miguel Alemán CW, CILA, and Herradura sites (26-37% cover) (Fig. 3-5). The Miguel Alemán mesquite area is dominated by mesquite and upland habitat types, with only 23% of the restored area being CW habitat. Similarly, 94% of habitat in Cori is mesquite. In CILA, although the majority of the area was planted with cottonwood and willow, over time, mesquite, baccharis, and arrowweed have naturally established in some areas. Additionally, water deliveries to the CILA site were much reduced in 2018, and cottonwood and willow leaves had yellowed and/or fallen off at the time of surveying probably due to the lack of water. There was no CW cover in control sites in any reaches, suggesting that active restoration is successful at establishing and maintaining target species cover.

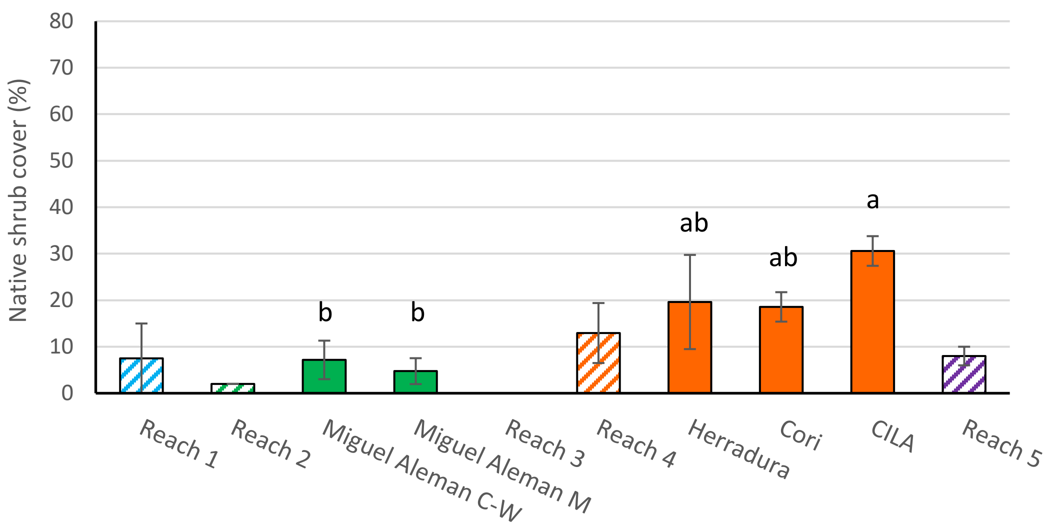

Figure 3- 4. Mean foliar cover of native shrubs (*Atriplex* spp*.*, *Baccharis* spp*.*, *Pluchea sericea, Salix exigua*) in restoration sites (solid color) and control sites (diagonal hatch pattern). Note that native shrub cover is the sum of individual species' cover, which double counts areas where native shrub species overlap. Bars represent standard error of the mean. Restoration sites and control sites that share the same color are grouped by reach. Lowercase letters indicate homogeneous groups after Tukey test, significant difference ($p<0.05$).

In all restoration sites, cottonwood cover exceeded willow cover, but only significantly so in the CILA site ($p<0.001$) (Fig. 3-5). There is more willow cover at the Herradura than in CILA site due to the shallow groundwater conditions (willows prefer shallower groundwater conditions than cottonwood) that allowed for dense planting of willow species at Herradura. At this site there is more area of mesic riparian vegetation (in which Goodding's and coyote willow species are dominant) that was planted and seeded than at other sites.

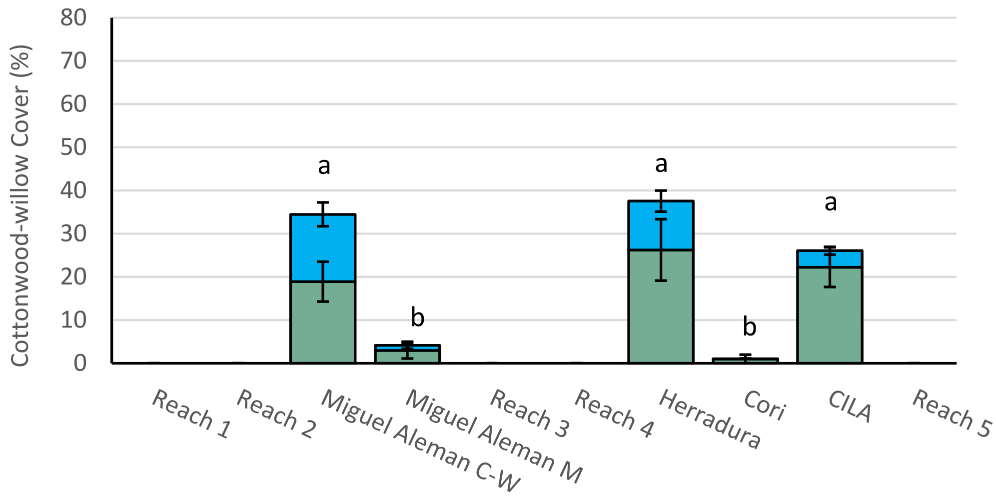

Figure 3-5. Cottonwood (green) and Goodding's willow (blue) foliar cover in restoration sites. Note that cottonwood-willow cover is the sum of individual species' cover, which double counts areas where cottonwood and willow species overlap. Bars represent standard error of the mean. Lowercase letters indicate homogeneous groups (for combined cottonwood willow) after Tukey test, significant difference ($p<0.05$).

Saltcedar was present in all restoration and control sites but was less dense in restoration sites (6%) than control sites (18%), with the largest percent cover in Reach 4 control sites (Fig. 6). In Cori and CILA, saltcedar mean cover was 12% and 14%, respectively. Herradura and Miguel Alemán had the lowest mean foliar cover of saltcedar (< 1%), which was significantly different than foliar cover of saltcedar at the Cori and CILA sites ($p<0.05$). The differences in saltcedar cover among restoration sites are likely related to 1) depth to groundwater (saltcedar can naturally establish where the water table is relatively deep); 2) irrigation method at the restoration sites (flood irrigation tends to promote saltcedar establishment in a larger area due to expanse of wetted soils); and 3) frequency and timing of last saltcedar weeding. Compared to their respective control sites (Herradura, Cori, and CILA to Reach 4; Miguel Alemán to Reach 2), restoration sites had lower foliar cover of saltcedar, which suggests that active restoration efforts have been effective at reducing and maintaining low levels of this non-native species.

In the Reach 1-3 control sites, saltcedar cover ranged from 13 to 18%. Of all control and restoration sites, saltcedar cover was highest (>25%) in Reach 4 control sites. This was also observed during Minute 319 transect monitoring (Shafroth et al. 2017) and is likely due to the shallow groundwater conditions throughout much of the Reach. Reach 1, which has shallow groundwater conditions that are favorable for saltcedar establishment, had less saltcedar cover than Reach 2 and was similar to Reach 3, which is drier than Reach 1. In Reach 1, native shrubs outcompete saltcedar. In addition, recent fires and groundwater table declines have further reduced saltcedar cover in Reach 1.

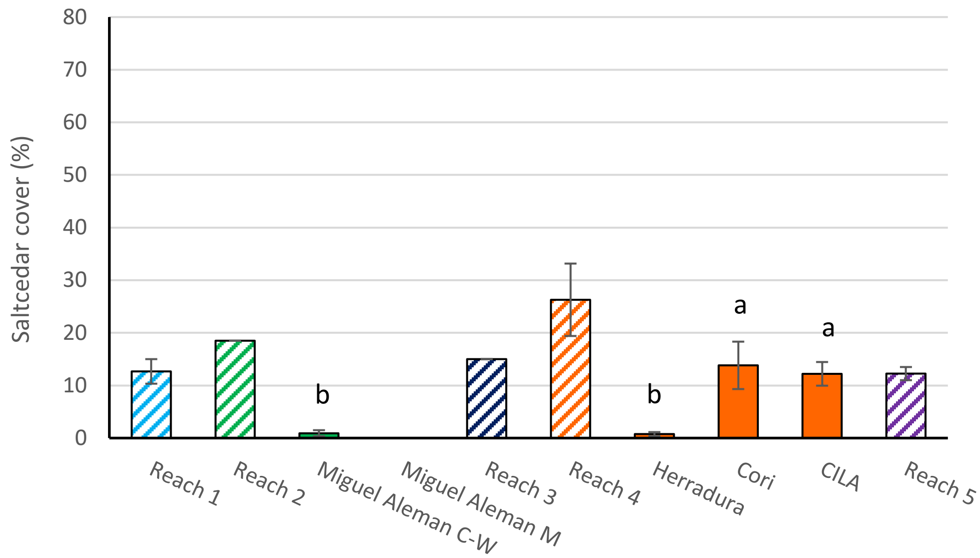

Figure 3-6. Mean foliar cover of saltcedar in restoration sites (solid color) and control sites (diagonal hatch pattern). Bars represent standard error of the mean. Restoration sites and control sites that share the same color are grouped by reach. Lowercase letters indicate homogeneous groups after Tukey test, significant difference ($p<0.05$).

In the restoration sites, average foliar cover of honey and screwbean mesquite was 13%, while there was no mesquite cover present in control sites. Within restoration sites, CILA had the lowest mesquite cover, which was significantly different ($p<0.01$) than the highest at Miguel Alemán (Fig. 3-7). The variability between restoration sites is primarily due to the habitat types planted and naturally established at each restoration site, which depend on groundwater levels (Table1) and soil types. We expect mesquite cover to increase significantly in the Cori, Miguel Alemán mesquite, and Herradura sites over time as the mesquite canopy fills out; areas of mesquite in these sites were planted in the past 2-3 years so the trees are still quite young and as noted previously, they do not grow as quickly as cottonwood and willow. Although mesquite species were not present in the control site plots, scattered individuals were observed outside the plots within the bird monitoring areas (100 m (328.1 ft) radius).

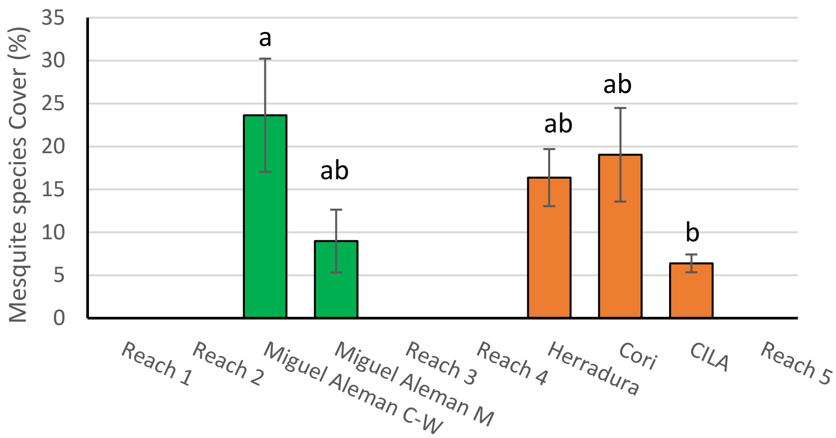

Figure 3-7. Mean foliar cover of mesquite (both screwbean and honey mesquite) in restoration sites and control sites. Note that mesquite cover is the sum of individual species' cover, which double counts areas where honey and screwbean mesquite species overlap. Bars represent standard error of the mean. Different letters indicate a significant difference ($p<0.05$).

Density of target restoration species

Restoration sites had an average of 0.2 individuals of target restoration species per m^2 (859/acre; 2,123/ha), while control sites had no target restoration species present. The restoration sites have variable densities of target native woody species: the most abundant species in the CILA site are cottonwood and *Baccharis salicina* (0.11 individuals/m^2); in Cori, *Baccharis salicifolia* (0.14 individuals/m^2) was the most abundant; the Herradura is highly diverse, with 0.07-0.09 individuals/m^2 of cottonwood, coyote willow, Goodding´s willow, and screwbean mesquite; in Miguel Alemán CW the most abundant species are cottonwood, Goodding's willow, and honey mesquite with about 0.04-0.05 individuals/m^2; and in the Miguel Alemán mesquite area, honey mesquite (0.03 individuals/m^2) and cottonwood (0.01 individuals/m^2) are most abundant (Fig. 3-8). Screwbean mesquite is not planted in Reach 4 restoration sites; it establishes naturally and in high abundances given adequate soil moisture conditions. Combined mean density of native species was lowest at the Miguel Alemán site and highest in Herradura, likely because the water table is deepest at Miguel Alemán and shallowest at Herradura.

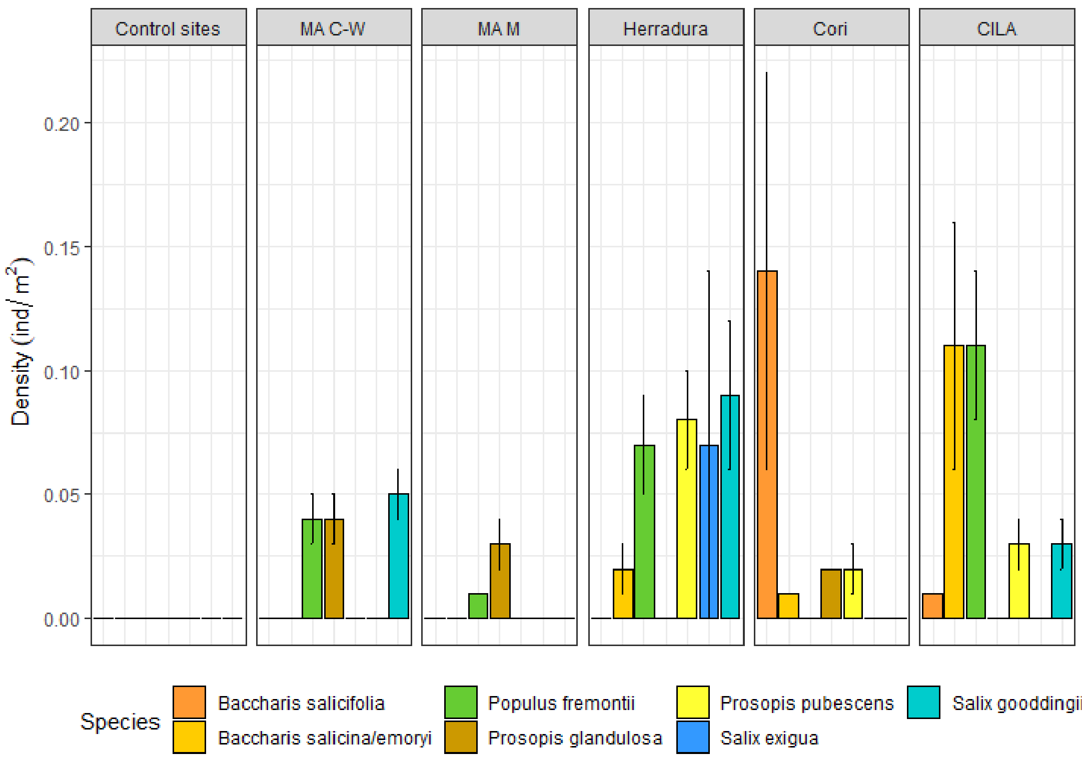

Figure 3-8. Density of native woody species in restoration sites and control sites. Bars represent standard error of the mean.

Canopy Height of Mesquite

The average height of honey mesquite and screwbean mesquite in restoration sites ranged from 1 to 4 m (3.3 ft to 13.1 ft). Four meters (13.1 ft) is two meters (6.6. ft) less than what is considered to be their maximum height (Felger 2000) (Fig. 3-9). The oldest individuals (likely 5-6 years old in restored areas) of screwbean mesquite in CILA had a mean height of 3.5 m (11.5 ft), while screwbean mesquite trees at Miguel Alemán (just over 2 years of age) had a mean height of 4.5 m (14.5 ft) and 2.4 m (7.9 ft) in Miguel Aleman C-W and Miguel Alemán M, respectively.

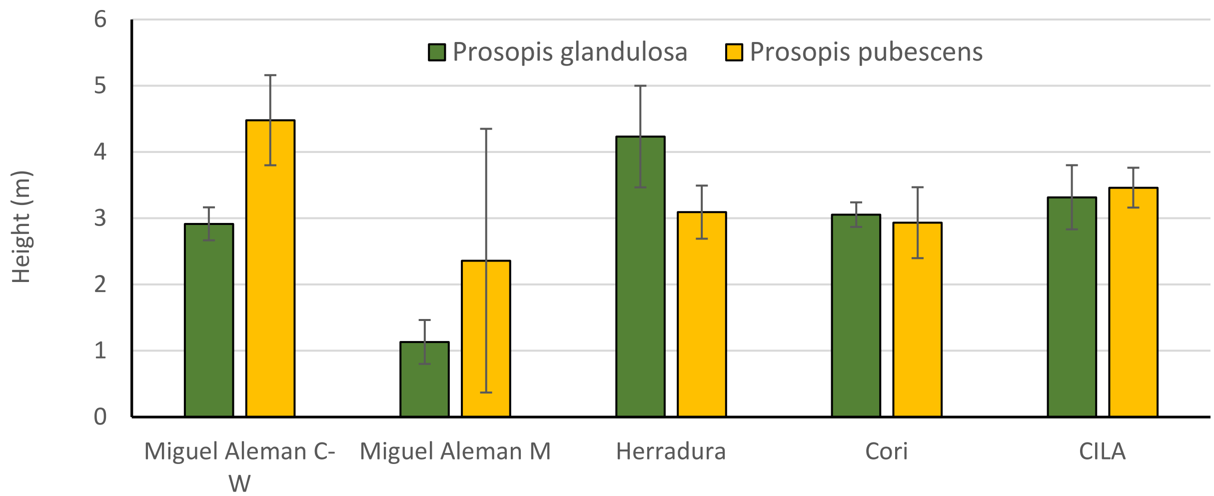

Figure 3-9. Mean height of *Prosopsis glandulosa* (honey) and *Prosopsis pubescens* (screwbean) mesquite trees species, with bars representing standard error of the mean.

Total vegetation volume

The average total vegetation volume (TVV) at the restoration sites (0.8 m^3/m^2), was 300% greater than at control sites (0.2 m^3/m^2). Among restoration sites, Miguel Alemán CW had significantly higher TVV than other restoration sites ($p<0.001$). The average TVV of mesquite at Miguel Alemán was significantly lower ($p<0.05$) in comparison to all the other restoration sites (Fig. 10). Average TVV was higher at Cori than at CILA and Herradura sites, but not significantly so. While Cori has little cottonwood-willow cover and abundance, it has a diverse understory of herbaceous species (Appendix B), which likely contributes to its high TVV. Of the restoration sites dominated by CW, the CILA site had the lowest average TVV. This could be because:

1) There could be underestimation of the vegetation volume of the top canopy layer at the CILA site as hits to pole for canopy heights above 5 m cannot be directly counted. Much of CILA's top canopy is above 5 m – it is the oldest restoration site TVV values may not provide an accurate measure of its structure above 5 m; and/or

2) In mature stands with 5-6 years of growth, as in the CILA site, total vegetation volume may become reduced because the top canopy layer shades out and reduces understory diversity.

Average TVV was generally lower in control sites (0.1-0.3 m^3/m^2) than in restoration sites (Fig. 10), which may be due to differences in vegetation vertical structure (i.e., sites with diverse vertical structure will tend to have higher TVV than sites with less vertical complexity). Most of the control sites are dominated by stands of saltcedar or saltcedar-arrowweed mix, which typically have lower vegetation structural diversity. In addition to the lack of cottonwood and willow species in control sites, there were also impacts from recent and old fires, groundwater declines in Reach 1, as well as some vegetation removal for agriculture in Reach 1, 4, and 5 control sites. These factors also contributed to the differences in structure between restored and control sites (more bare ground in control sites).

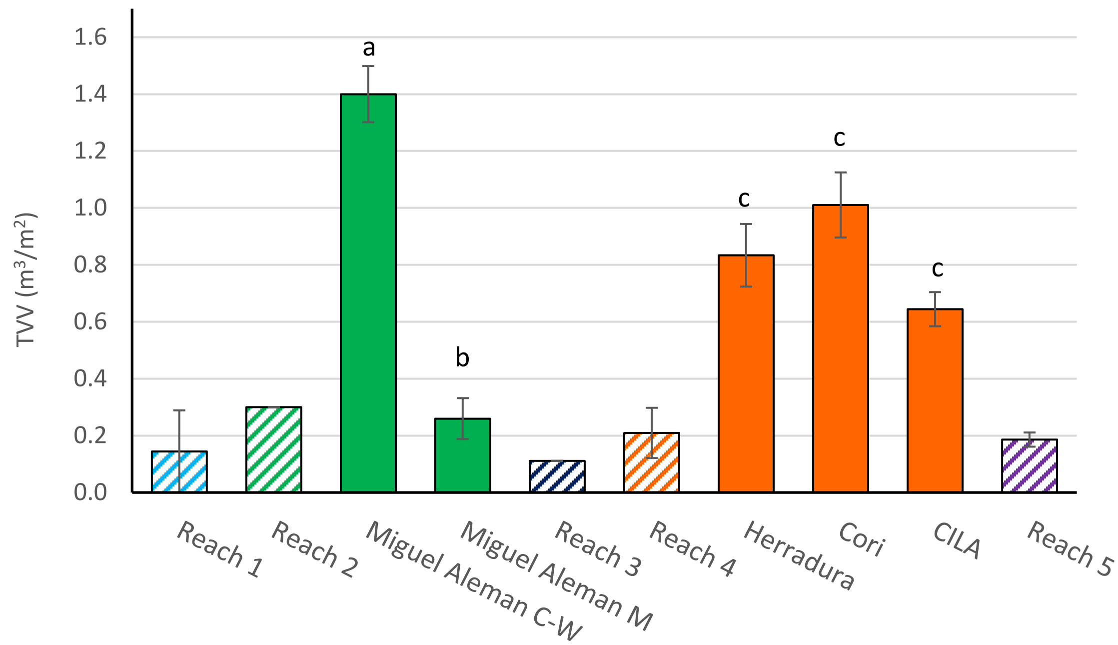

Figure 3-10. Average total vegetation volume (m^3/m^2) of all live vegetation in restoration sites (solid color) and control sites (diagonal hatch). Bars represent standard error of the mean. Restoration sites and control sites that share the same color are grouped by reach.

Vegetation change from 2017 to 2018

The foliar cover of cottonwood-willow and total vegetation volume were compared between 2017 and 2018 in CILA, Herradura, and Miguel Alemán (Cori was only added in 2018 surveys) sites. Note that in the Herradura and Miguel Alemán sites, some additional vegetation plots were added in 2018; these plots were not used in the comparison between years. For that reason, values presented below for 2018 are different for the Herradura and Miguel Alemán sites than those previously presented (Flessa et al 2018).

<u>Cottonwood-willow foliar cover</u>

The average foliar cover of CW in the restoration sites did not significantly change from 2017 to 2018 (Table 3-2).

Table 3-2. Comparison of average cottonwood-willow foliar cover (%) (with standard error in parentheses) at restoration sites between 2017 and 2018. N = number of bird point count areas.

	CILA site	Herradura	Miguel Alemán
2017	27.6 (4.08)	36.0 (10.52)	36.4 (4.12)
2018	26.1 (4.91)	36.0 (9.55)	35.6 (6.69)
Wilcoxon signed rank test	*p*-value =0.4683	*p*-value =0.8339	*p*-value =0.8335
Paired-t test	*p*-value = 0.6741	*p*-value = 0.5	*p*-value = 0.8095
N	18	7	8

Total vegetation volume

From 2017 to 2018, average Total Vegetation Volume (TVV) significantly decreased by 21% at the CILA site ($p<0.01$), significantly increased by 32% in Miguel Alemán ($p<0.01$) and did not significantly change at the Herradura site (Table 3-3). TVV decreases could be explained by: (i) reduced water availability at several of the sites (a lack of 2018 water deliveries in the CILA restoration site), (ii) shading by overstory species, and/or (iii) underestimation of TVV of the top canopy layer, as noted previously.

Table 3-3. Mean TVV (m^3/m^2) (standard error in parentheses) comparison between 2017 and 2018 at CILA, Herradura and Miguel Alemán sites.

	CILA site	Herradura	Miguel Aleman
2017	0.81 (0.07)	0.76 (0.20)	1.07 (0.11)
2018	0.64 (0.06)	0.81 (0.15)	1.41 (0.11)
Wilcoxon signed rank test	*p*-value =0.0040	*p*-value =0.8125	*p*-value =0.0156
Paired-t test	*p*-value = 0.0056	*p*-value = 0.3639	*p*-value = 0.0050
N	18	7	8

Conclusions

Restoration sites have significantly higher average foliar cover, greater densities, and greater total vegetation volume of native species than control sites, indicating that restoration actions have successfully increased the extent and distribution of desirable native riparian plants as well as reduced the extent and distribution of undesirable and nonnative species. But some restoration sites have more native habitat establishment than others.

These observations suggest that restoration site vegetation composition, density, and structure are functions of groundwater conditions, restoration design, and irrigation type within sites. For instance, restored native shrubs thrive in Reach 4 restoration sites, where the groundwater is shallow. Overall, the Herradura site with the greatest abundance of target native species, has the greatest area of shallow groundwater. These hypotheses can be tested by analyzing relationships between environmental and vegetation variables.

Current protocols that estimate vegetation vertical structure may underestimate canopy layer structure at heights greater than five meters. In older sites that lack open areas, the tree canopy may prevent the establishment of understory species. Additionally, a lack of surface water irrigation likely decreased structural diversity, as understory herbaceous species typically require frequent surface water flooding because they rely less on groundwater. All of these factors could explain the TVV differences observed in comparisons between 2017 and 2018 for Miguel Alemán, the CILA site, and Herradura.

Next steps for monitoring include: 1) analyzing relationships between environmental, bird, and vegetation metrics; and 2) ongoing evaluation of the use of drones to assess vegetation metrics, including aerial vegetation cover, canopy height, and Normalized Difference Vegetation Index (NDVI), which could improve cost and time efficiency of monitoring.

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Section 4: Influence of surface- and ground-water hydrology on riparian tree growth and mortality in the Limitrophe segment of the Colorado River: A progress report

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Key observation

- Branch sections and cores of cottonwood and willow trees were collected from two sites in the Limitrophe. Tree-ring analyses may reveal the relationships among tree growth, streamflow and groundwater.

Background and Introduction

Ecological drought [1]can contribute to the decline of cottonwood-dominated riparian forests across western North America. Low water availability is the most commonly reported cause of stress, die back and mortality in riparian forests dominated by cottonwood (*Populus*) and willow (*Salix*). In arid to semi-arid regions, riparian species in these genera are typically dependent on supplemental moisture, beyond that provided by precipitation alone. Most often, this moisture supplement is provided by streamflow and/or shallow alluvial groundwater. Declines in streamflow and groundwater elevations have been shown to decrease water availability for riparian cottonwoods and lead to physiological stress (Tyree et al. 1994; Rood et al. 2003), reduced growth (Scott et al. 1999), crown die back (Scott et al. 1999; Rood et al. 2000), and mortality (Rood and Mahoney 1990; Rood et al. 1995; Shafroth et al. 2000). Low water availability can be the result of low natural streamflow due to weather or climatic factors, water management operations, or other factors.

One of the objectives of restoration efforts in the Limitrophe and delta is to create and enhance additional habitat to support wildlife species diversity and promote additional recreational and economic opportunities for local communities in the Delta region consistent with the targets outlined in Minute 323. Achieving this objective not only requires planting trees in new restoration sites, but also ensuring the long-term survival and growth of trees regardless of whether they were established naturally or artificially. Several high flow releases to the Colorado River delta between 1983 and the early 2000's resulted in natural regeneration of cottonwood and willow trees (Zamora-Arroyo et al. 2001; Nagler et al. 2005). Some of these trees persist in the upper Limitrophe (within the first 20 km downstream of Morelos Dam; Figure 4-1) and in parts of the Laguna Grande area (See Section 3). Recent field observations indicate that many of the trees in the Limitrophe are stressed or have died.

The objectives of this ongoing study are to clarify the extent, causes and consequences of the recent tree dieback and mortality in the Limitrophe. The progress to date described here consists of a description of study site locations and field methods. Future results may contribute to efforts to develop management strategies for successful restoration, may be combined with similar data from other sites in western North

[1] an episodic deficit in water availability that drives ecosystems beyond thresholds of vulnerability, impacts ecosystem services, and triggers feedbacks in natural and/or human systems (Crausbay, et al. 2017).

America to better understand the impacts of reduced water availability on cottonwood survival across the region, and/or may be used to design ecological flows for maintaining these critical riparian forests.

Methods

This study began in 2018 as an effort to understand relationships among surface water releases from Morelos Dam into the Colorado River, groundwater levels in wells and piezometers, and the growth and mortality of Fremont cottonwood (*Populus fremontii*) and Goodding's willow (*Salix gooddingii*) trees at two sites in the Limitrophe.

Tree sampling: In October 2018, cores or, in the case of dead trees, complete stem cross sections were collected from 10-15 trees at each of two sites in the Limitrophe, approximately 8 and 17km (5 and 11 mi) downstream of Morelos Dam, respectively (Figure 4-1). For each living tree the proportion of the maximum tree crown volume (i.e., vigor) containing leaves at the time of sampling was estimated visually. Core samples for interpretation were prepared by mounting them on blocks of wood. The cores and stem cross-sections were sanded with progressively finer sandpaper from 100 to 600 grit to clarify annual ring boundaries. Measuring, interpreting, and cross-dating the annual growth rings on these samples is currently in progress and is following standard methods (Phipps 1985).

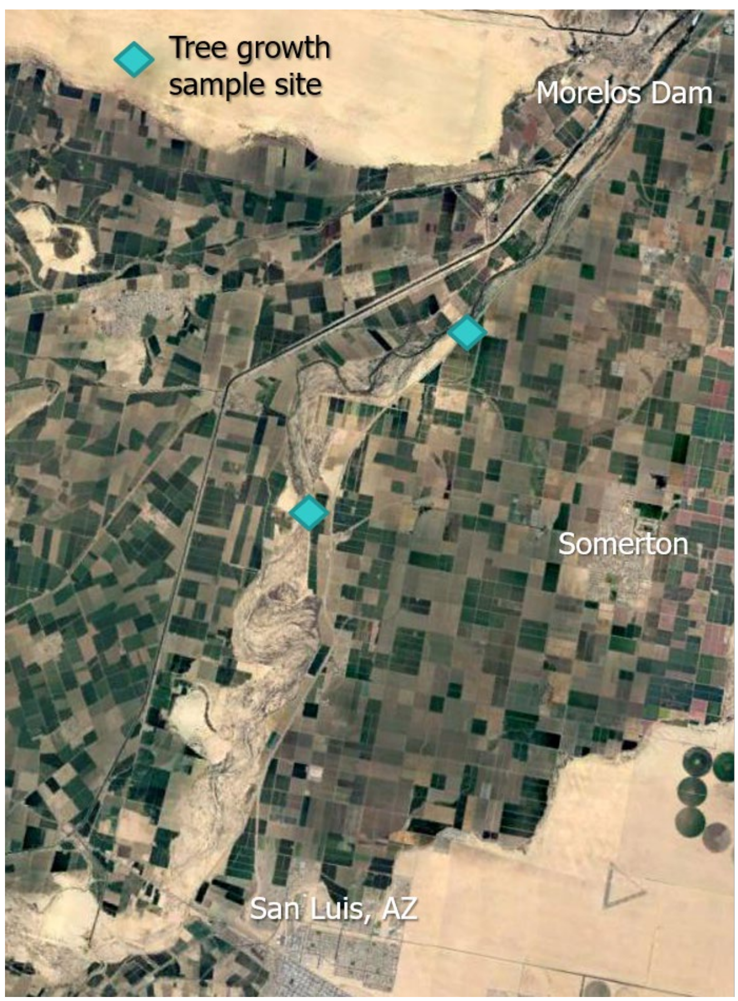

Figure 4-1. Location of tree samples in the Limitrophe.

Hydrologic data: The Limitrophe sites were selected, in part, because of their proximity to groundwater wells or piezometers. In addition, there are some records of surface water releases into the Colorado River channel from Morelos Dam and at flow measurement stations downstream. Available surface and groundwater data from these sources are being compiled and will be used as independent variables in analyses relating tree growth and mortality to hydrologic variables (Reily and Johnson, 1982; Scott et al. 1999).

No results or conclusions have been reached at this time. This is a work in progress.

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Section 5: Remote sensing of vegetation in the riparian corridor of the Colorado River Delta: 2013-2018

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Key observations

- Greenness and evapotranspiration decreased in the riparian corridor of the delta from 2000 to 2013, a period of time in which little surface water reached the riparian zone.

- The Minute 319 Pulse Flow of 2014 produced a 17% increase in NDVI ("greenness") throughout the riparian corridor in the subsequent growing season of 2014.

- At the reach scale, by 2018, NDVI values had decreased to pre-pulse (2013) values.

- NDVI values continue to be highest in Reaches 1, 4 and 5, where the water table is shallow.

Introduction

This remote sensing section is based on Nagler et al. (in preparation for the journal Hydrological Processes) and is a summary of the USGS preliminary findings to date.

This report documents the changes in green foliage density (greenness) as measured by satellite vegetation index (VI) data and corresponding evapotranspiration (ET) in the riparian corridor of the Colorado River delta associated with the Minutes 319 and 323 environmental water deliveries using time-series data from 2013 through 2018. The report focuses on what happened only within the riparian corridor's seven reaches since the 2014 flows, and despite being a continuation of measuring greenness and ET after the 2017 end of Minute 319, this study continued the tracking of these two variables, greenness and ET, in these original riparian corridor focal areas. Two spatial scales are used here: (1) Landsat satellite imagery at 30 m pixels and (2) the EOS-1 satellite sensor the Moderate Resolution Imaging Spectrometer (MODIS) with a resolution of 250 m pixels. The focal period includes 2013 (pre-pulse flow) and the years 2014-2018, with a focus on imagery collected from the Summer growing seasons 2014 through 2018 (one-year, pre-pulse and several post-pulse years, respectively).

This report re-creates the 2013-2017 Landsat-based results from Jarchow et al. (2017a, b) by using the same region of interest (ROI). The report now provides revised and re-created results using all new imagery acquisition and processing techniques, as well as extraction code, created by the Vegetation Index and Phenology (VIP) Lab of the Biosystems Engineering Department of the University of Arizona (UofA). In 2018, methods employed by the VIP lab (and not ArcGIS) were used. ArcGIS was only used in the newly processed data to display the final difference maps. The entire spatial tile data from NASA was downloaded and processed at the VIP Lab using satellite imagery at two resolutions: 250 m MODIS and 30 m Landsat using three sensors, Landsat 5, Landsat 7 ETM+ and Landsat 8 Operational Land Imager (OLI), with added scenes for each year based on new clear atmosphere requirements. The VIP lab clipped the river boundary and seven riparian reaches from the previously existing ROI used in Jarchow et al. (2017 a, b) for the analyses done under Minute 319. The NASA image datasets for this riparian corridor ROI in seven reaches were re-processed to produce additional vegetation index (VI) information for years 2013 to 2018 for this report. At the same time, the report acquired and processed imagery from 2000-2018 (data outside the scope of this report and data not shown here). The additional VIs (NDVI, scaled NDVI, EVI, EVI2) were analyzed so that new assessments of greenness and ET could be produced from the imagery datasets following methods in Nagler et al. (2013). These VI choices were based on previous performance comparisons between biophysical ground-based data and radiometric satellite-based data collected from this riparian ecosystem (Nagler et al., 2001) as well as performance related to ET estimation (Nagler et al., 2005a, b) and current advancements in VIs such as EVI2.

Background and methods

The lack of significant surface flow from 2000 to 2013 was accompanied by a marked decrease in ET during that time period. During the Spring of 2014 (March 23 to May 18), approximately 130 million cubic meters (105.4 kaf) of water was released from Morelos Dam to the lower Colorado River in the U.S. to Mexico, along seven reaches, allowing water to reach the Gulf of California (Figure 5-1). Compared to 2013, the Minute 319 Pulse Flow in the Spring of 2014 produced a 17% increase in NDVI ("greenness") which extended throughout the riparian corridor (Jarchow et al., 2017a, b). Only Landsat 8 OLI imagery (30 m or 98 ft) resolution, 16-day return time was used for this analysis of the 2013-2017 trends (Jarchow et al., 2017a). Landsat NDVI was averaged across the growing season (May-Oct.) using approximately five scenes per year from 2013-2018 for each river reach and all reaches combined as well as for the active restoration plots. Significant greening was observed across reaches within the riparian zone, as well as in the non-inundated outer parts of the riparian floodplain. This was due to the surface flow from the pulse flow in 2014 in addition to the short-term rise in the water table, which allowed groundwater to support existing vegetation. From 2015-2017, Jarchow et al. (2017a) reported that this greening steadily declined, eventually falling below pre-pulse levels.

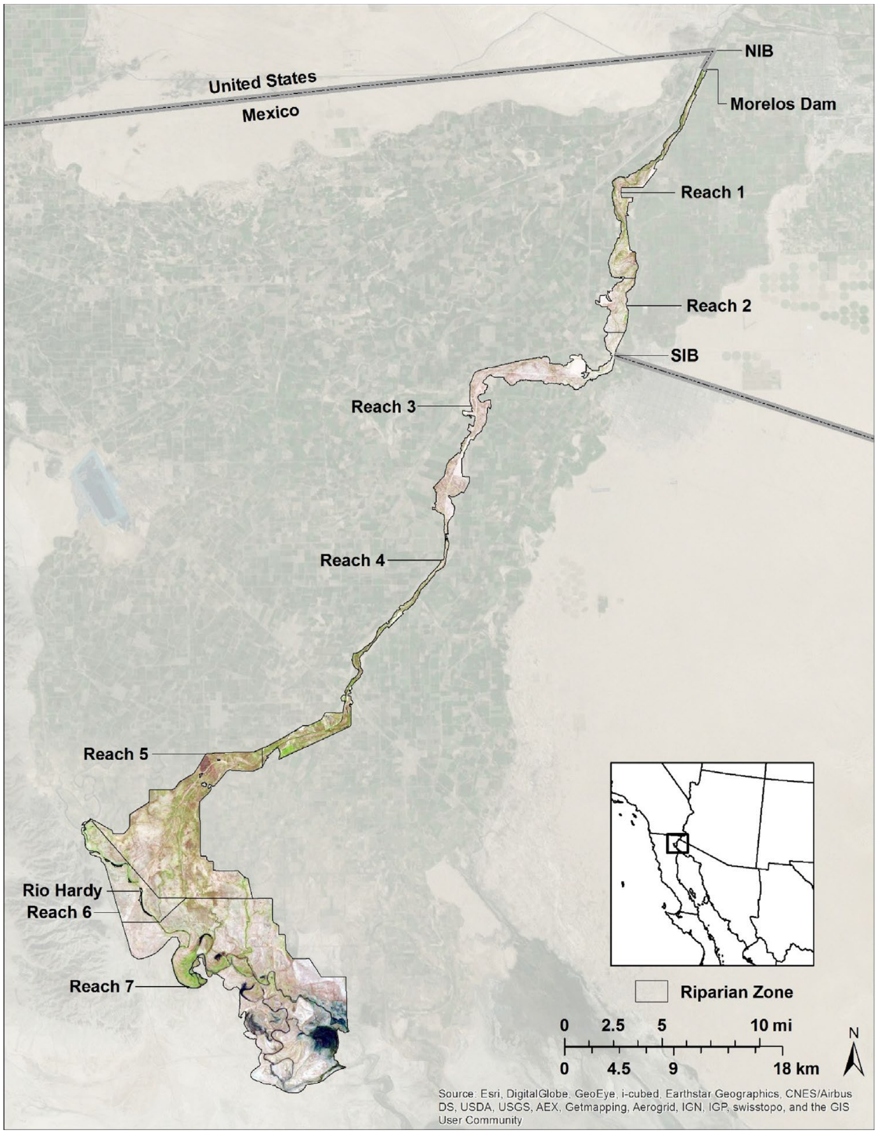

Figure 5-1. The Colorado River delta riparian corridor with seven reaches along the 132 km long river used for Minute 319 science and monitoring activities, from Jarchow et al., (2017a).

Two empirically calibrated algorithms for estimating evapotranspiration (ET)

The first algorithm for predicting ET is based on Landsat images following the Groeneveld et al. (2007) method and was used in Jarchow et al. (2017a, b):

$$\text{ET (Landsat): } NDVI_{scaled} \text{ (this is NDVI*)} \times ET_o \quad [1]$$

where ETo = potential ET from weather stations, such as in Yuma, AZ for this study.

The analysis here reproduced the entire ET time-series using Landsat imagery at 30 m resolution by substituting Landsat NDVI* into the Nagler et al. (2013) ET equation [2] which originally used MODIS EVI, as follows:

$$\text{ET (MODIS)} = ETo \times 1.65(1\text{-}e^{-2.25EVI}) - 0.169 \quad [2]$$

NDVI and ET Response to Minute 319 Environmental Flows

NASA Landsat 30 m resolution data provided landcover change information for the vegetation in the riparian corridor. Figure 5-2 shows Landsat scaled NDVI results, adjusted for each image between bare soil and fully-saturated vegetation across the growing season (May to October) for each reach and the entire riparian corridor for years 2013 through 2018. Error bars show standard error of the means (SE) for the number of scenes (ca. n=5) used for the growing season, annually. After 2018, data was created to update Fig. 5-2 through 2019, following the same methods in Jarchow et al. (2017a), but also using years dating back to 2000, with new acquisition and processing methods applied (data not shown for this time period, unpublished). Additional imagery data from the NASA-sponsored VIP Lab is depicted in Table 1.

Table 5-1. Satellite imagery was acquired and processed to study the effects of the 2014 Pulse Flow. The number of images analyzed for years prior to the pulse and following the pulse flow using Landsat Thematic Mapper 5 (TM5) for years 2011 and prior, Landsat 7, Enhanced Thematic Mapper (ETM+) for years 2011-2013, and Landsat 8 OLI from years 2013-2018.

Landsat (30 m) Data Availability

←-------L5 TM – L7 ETM+ -L8 OLI ---→

No Obs	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
1	13	15	2	5	8	10	13	16	19	5	24	11	6	8	3	6	9	11	30
2	29	31	18	21	24	26	29	32	35	21	40	27	22	24	19	22	41	27	46
3	45	63	50	37	40	42	45	48	67	37	56	43	38	40	35	38	73	43	62
4	61	79	130	53	56	58	61	4	83	53	72	59	54	56	51	86	89	59	110
5	93	95	146	85	72	74	93	80	99	69	88	75	70	72	67	102	105	75	126
6	109	111	162	101	88	90	109	96	115	85	104	91	86	88	131	118	121	91	142
7	125	127	178	117	104	106	125	112	131	101	120	107	102	104	147	134	137	123	158
8	141	143	194	133	120	122	141	128	147	11	136	123	118	112	163	150	153	139	174
9	157	159	210	149	136	138	157	144	163	133	152	139	134	144	179	166	169	155	206
10	173	175	226	165	152	154	173	160	179	149	168	155	150	176	211	182	185	171	238
11	189	191	242	181	168	170	189	176	195	165	184	171	166	208	227	198	201	203	254
12	205	207	258	197	184	186	205	192	211	181	200	187	182	224	243	214	217	219	270
13	221	223	274	213	200	202	221	208	227	197	216	203	198	240	259	230	233	235	286
14	237	239	290	229	216	218	237	224	243	213	232	219	214	256	275	246	249	267	302
15	253	255	306	245	232	234	253	240	259	229	248	235	230	272	291	262	297	283	318
16	269	271	322	261	248	250	269	256	275	245	264	251	246	288	307	278	313	299	334
17	285	287	338	277	264	266	285	272	291	261	280	267	262	304	323	310	329	315	350
18	301	303	354	293	280	282	301		307	277	296	283	278	320	339	326	345	331	
19	333	319		309	296	298	317		323	293	312	299	294	352	355	342	361	347	
20	349	335		325	312	314	333		339	309	328	315	310			358		363	
21	365			341	328	330	349		355	325	344	323	326						
22				357	344		365			341	360	339	342						
23					360							355	358						

Jarchow et al. (2017a, b) showed that the Minute 319 pulse had an impact on vegetation growth primarily in the first year after the 2014 pulse flow. Following the 2014 pulse flow, NDVI was higher in 2014 than in 2013 for all reaches. The overall NDVI increase from 2013 to 2014 was 17% ($P < 0.001$). The most intense greening in 2014 took place in the zone of inundation by the pulse flow and increases in NDVI also occurred outside the zone of inundation, indicating that the pulse flow likely enhanced groundwater conditions in those areas as well. Jarchow et al. (2017a, b) found that NDVI was greatest in Reaches 1, 4 and 5, where shallow groundwater and surface water supports vegetation. Reaches 2 and 3 are within the “dry reach” where the water table is deep and vegetation is sparse. Reach 6 is dominated by the Río Hardy drainage and was largely unaffected by the pulse flow and subsequent base flows. Reach 7, where groundwater is shallow, includes the upper estuary and received surface water from the pulse flow in 2014 and flows from the Río Hardy. The overall peak NDVI values occurred in Reach 4 in 2015, perhaps reflecting the effects of planting and vegetation growth in the Laguna Grande restoration site.

Jarchow et al. (2017a) also reported that from 2016-2017, NDVI decreased steadily for Reaches 1, 4, 5 and the sum outcome of these regions, falling below 2013 levels. The rapid decrease in NDVI values in Reach 1 in the year 2016, and the drop in Reach 2 in 2017 may be a consequence of the expanding cone of depression lowering the water table in this region (Kennedy et al., 2016; Nelson et al., 2017). By 2017, NDVI values in Reaches 2 and 3 (the dry reaches), Reach 6 (Río Hardy) and Reach 7 (the upper estuary) fell to values similar to or slightly lower than those observed in 2013. The area of the Miguel Alemán site is small compared to the area of the entire reach, making its influence on the reach-level NDVI small. From 2017-2018, NDVI decreased for all reaches, falling below 2013 levels. There was an exception for Reach 7, which was higher in 2018 than in 2017, but still below 2013 levels.

Reach 4 continued to have the highest greenness as measured by NDVI. Reach 4 includes the Laguna Grande and Chausse restoration sites. This higher greenness is likely a result of the planting and growth of vegetation in the restoration sites in Reach 4, and due to the high groundwater table through the reach.

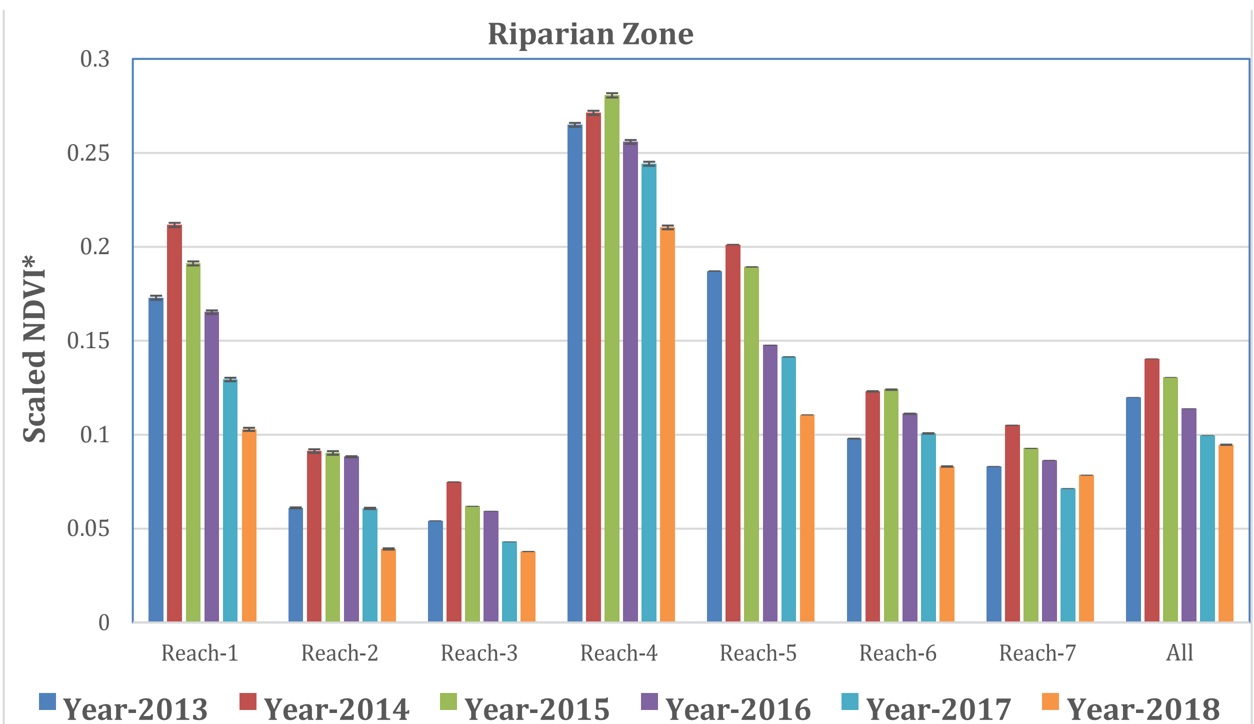

Figure 5-2. Scaled NDVI from Landsat 8 OLI data (30 m) for years 2013-2018 for the riparian zone, by river reach (Nagler et al., 2018b). Landsat scenes were acquired for each of the five periods during the summer growing season from May through October, annually. Error bars show Standard Errors (SE). Data for 2013-2017 in Jarchow et al. (2017a).

After NDVI* from Landsat 8 OLI was produced, several other VIs were calculated, including NDVI, EVI and EVI2 for use in estimating ET. Figure 5-3 shows ET which was calculated from Eq. [2] using Landsat-based VI in place of MODIS EVI for all seven reaches and the total area from 2003 to 2018. No data were available for 2012.

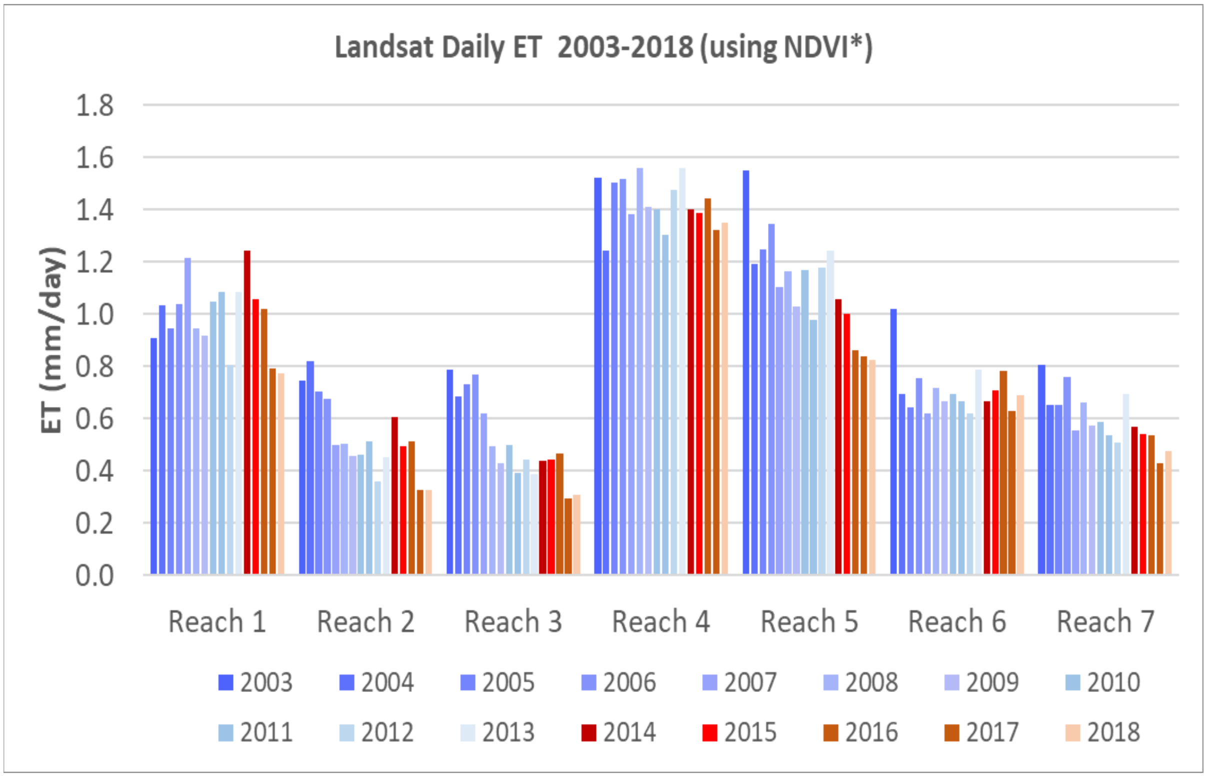

Figure 5-3. Average growing season ET for years 2003-2018 as calculated from Eq. [2] which uses NDVI* from Landsat (30 m). The years 2003-2012 are ET derived from Landsat 5 and are shown in shades of blue. The 2013-2018 years use the Landsat 8 OLI satellite and are shown in shades of red for years 2013-2018 and show an over-estimate in ET because the VI amplitude has not yet been adjusted in this preliminary data.

Observations from Landsat

The Minute 319 Pulse Flow produced a 17% increase in NDVI ("greenness") throughout the riparian corridor in 2014, when compared to 2013. Increases in NDVI in 2014 occurred in the zone inundated by the pulse flow as well as in the non-inundated outer parts of the riparian floodplain, where groundwater supported existing vegetation. From 2015-2017, this greening-up steadily declined, eventually falling to or below 2013 (pre-pulse) levels. We acquired Landsat data for 2018 and processed NDVI following methods in Jarchow et al. (2017a). The declining trend continued for all reaches of the Colorado River Delta in 2018.

The pulse flow and subsequent base flows did not—at the scale of reaches, and at 30-m satellite image resolution—produce effects on vegetation greenness in the riparian zone that persisted through the end of the 2018 growing season. Increases in greenness within restoration sites supplied with base flows are not sufficient to maintain the high average, reach-level, NDVI values observed in the growing season after the 2014 pulse flow. The restoration sites may be too small to have a strong effect on reach-level averages.

The two following maps show annual changes in vegetation greenness within the zone of inundation only. The first change map (Figure 5-4) shows changes from 2013 (pre-pulse) to 2014 (the summer after the pulse flow). There was extensive green-up in all areas, except for a portion in the lower part of Reach 4 where extensive land-clearing took place prior to the pulse flow. Much of the land cleared was not inundated during the pulse flow. A greener color indicates that NDVI was higher in 2014 than in 2013. Figure 5-5 shows the change from 2017 to 2018.

Note that the overall trend was a decrease in greenness, but the area corresponding to the inundation zone in Reach 7 shows a slight increase in greenness.

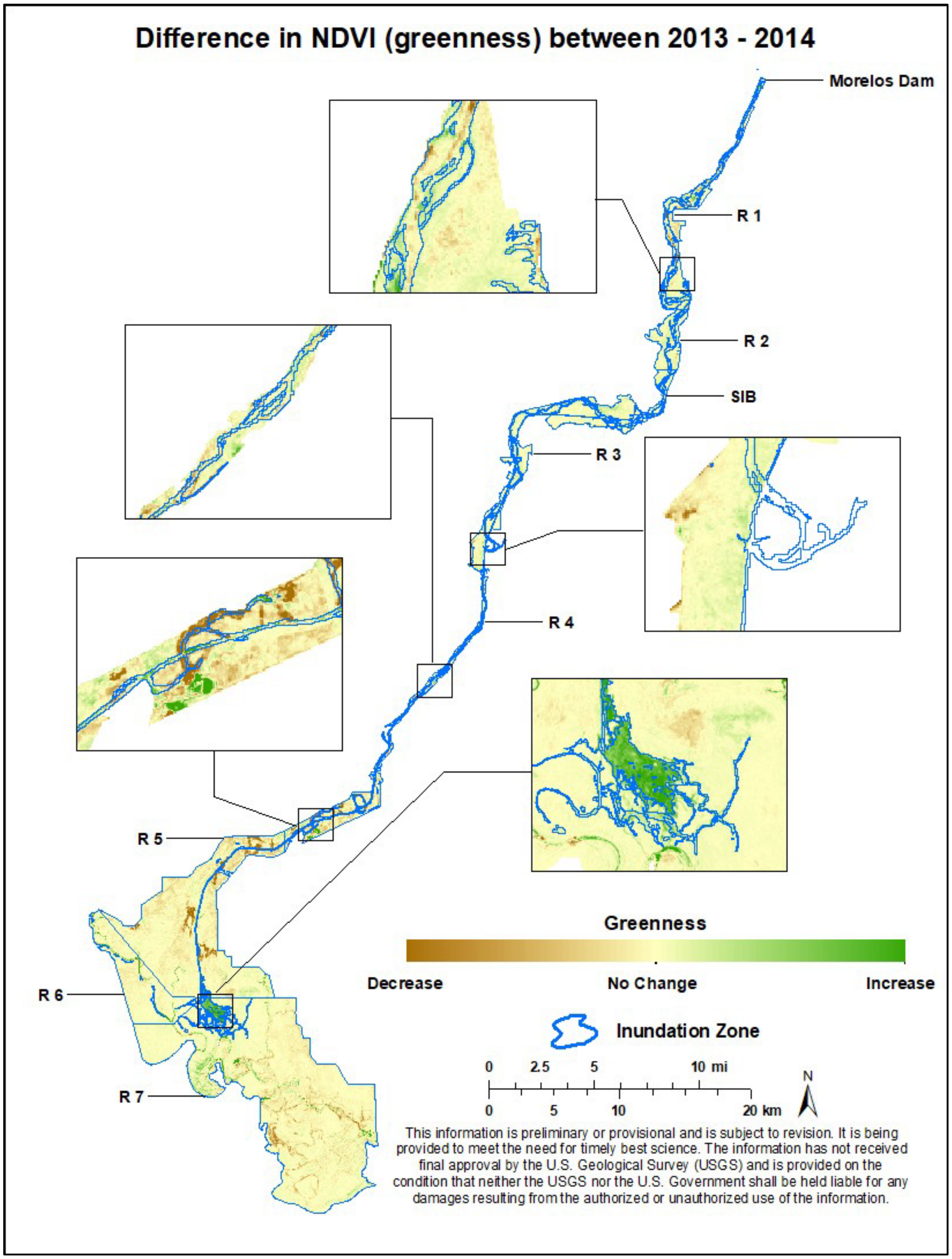

Figure 5-4. Areas within the riparian corridor during the 2014 pulse flow and differences in NDVI between 2013 (pre-pulse) and 2014 (post-pulse), with highlighted ROIs of the riparian corridor. A greener color indicates that NDVI was higher in 2014 than in 2013.

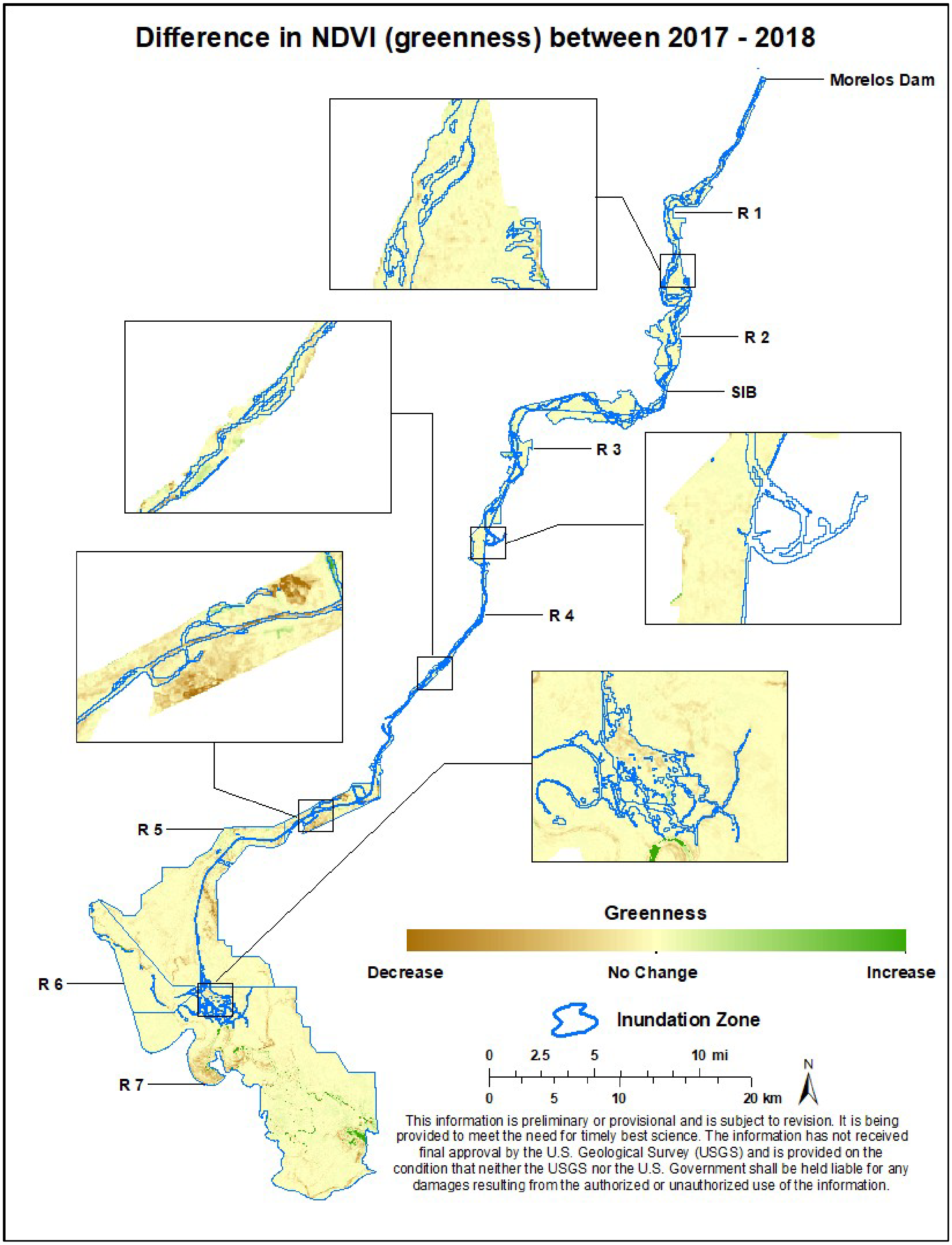

Figure 5-5. Areas in the riparian corridor during the 2014 pulse flow and differences in NDVI between 2017 and 2018.

Observation from MODIS (250 m spatial resolution)

The MODIS imagery provides Enhanced Vegetation Index (EVI) values which represent plant greenness similar to NDVI. MODIS data is averaged over a 16-day period and was calculated for each reach in the Colorado River delta's riparian corridor for years 2000 to 2018, but for this report, we focus on the years 2013 (pre-pulse) and 2014-2018 (post-pulse). Figure 5-6 shows MODIS EVI time-series data across 18 years by reach depicted in colors, and the overall average area depicted in black. This data is preliminary and is subject to revision.

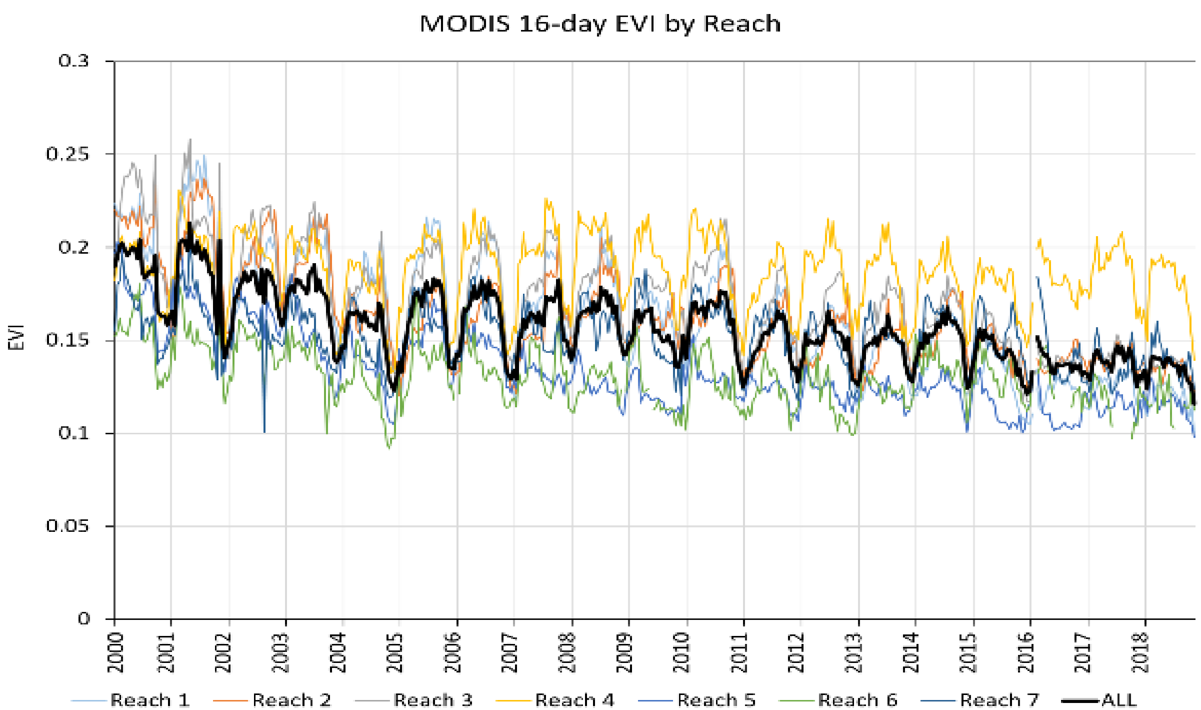

Figure 5-6. Preliminary findings from MODIS (250 m spatial resolution) Enhanced Vegetation Index (EVI) values averaged for every 16 days by reach and for all of the Colorado River delta's riparian corridor for years 2000 to 2018.

Summary

The Minute 319 pulse flow had a positive, but short-lived, impact on vegetation growth in the riparian corridor of the delta. At the reach-scale, greenness, as estimated by NDVI, continued to decline after 2014 in all river reaches, with 2018 values reporting below those measured in 2013 (pre-pulse). Greenness was highest in those reaches (1, 4 and 5) with a shallow water table.

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Section 6: Response of birds to Minute 323 environmental flows to the riparian zone of the Colorado River Delta

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Key observations

- Bird diversity and abundance of indicator species are 20% and 74% higher, respectively, at the restoration sites than in unrestored control sites.
- Abundance of indicator riparian bird species has been declining since 2015, including a 15.6% decline at the restoration sites from 2017 to 2018.
- Populations of priority marsh bird species (Least Bittern and Yuma Ridgway's Rails) have increased exponentially in the last 10 years in Hardy River sites.
- The size of breeding colonies of seven water bird species in the Upper Estuary and Hardy River has increased since 2014.

Introduction

Pronatura Noroeste has been monitoring bird populations in the floodplain of the Colorado River delta since 2002 to assess the changes in abundance, diversity and composition of the avian community in relation to habitat and hydrological changes (Hinojosa-Huerta et al., 2008, 2013). The same monitoring design continued during the period of Minute 319 (2012-2017), to assess the response of birds to the flow releases and the restoration efforts in the area. As part of Minute 323 binational science and monitoring efforts, bird monitoring activities continued through 2018, with updates on the protocols based on lessons learned and with an emphasis on optimizing data collection and analysis. This report concentrates on the changes in bird diversity and abundance of indicator species along the different reaches of the floodplain and at the restoration sites during the previous five years, as well as on changes in water bird populations along the Hardy River and Upper Estuary. The purpose of the report is to inform the restoration and flow delivery practices that are being implemented in the area.

Methods

The study area is located within the floodplain of the Colorado River in Baja California and Sonora, Mexico, from Morelos Dam downstream to the confluence with the Hardy River and into the Upper Estuary. The floodplain traverses the Mexicali Valley as the river flows toward the Gulf of California and is confined by flood control levees on both banks. This study area includes the main stem of the Colorado, secondary streams, backwater lagoons, the dry sections of the floodplain, the Hardy River, and the Upper Estuary, covering 68,000 ha (168,031 acres) and extending for 160 river kilometers (100 river miles).

The monitoring protocols include: 1) standardized variable distance point counts for all species along the floodplain and restoration sites of the Colorado River (Reaches 1 to 5), 2) standardized marsh bird surveys along the wet portions of the Colorado (Reaches 1 and 4) and Hardy rivers (Reaches 6 and 7), and 3) census of the water bird colonies in the Hardy River and Upper Estuary (Reaches 6 and 7).

Standardized Point Counts

Pronatura Noroeste monitored birds at 371 points (circular 100 m (328 ft)-radius plots) in the Colorado River and Rio Hardy floodplains and the Upper estuary following a variable distance point count methodology (Ralph et al. 1995) three times during the breeding season (May, June and July). Transects were run by teams of two persons, starting at sunrise and continuing until no later than 4 hours after sunrise. At each point the team counted all birds heard or seen within a 5-minute period, recording the species, the distance from the observer to the bird and the time at which it was detected. Surveys were started in 2002 at 128 of these points (grouped in 16 transects), all located downstream from the Southerly International Boundary. These transects were randomly selected, at least 2 km (1.24 mi) apart, along the 146 km (91 mi) of levees within the study area. Each transect is composed of 8 points, 200 m (656 ft) apart, and extends for 1.6 km (1 mi) from the levee toward the main channel of the river. In 2014 four transects (32 points) were added along the Limitrophe section on the Mexican side. Since 2013, survey points have been added at the restoration sites, as these continue to expand. In 2018, Pronatura Noroeste surveyed 56 points in 4 restoration sites (Miguel Alemán in Reach 2, and Cori, Herradura and CILA in Reach 4; Table 6-1).

During 2017 and 2018, surveys concentrated on evaluating the responses at the restoration sites in contrast with the rest of the floodplain and conducted three visits during the breeding season to increase the statistical power to detect differences on bird abundance and diversity (Hinojosa-Huerta and Hernández-Morlán 2016). The average number of individuals and species per point at each reach or restoration site was used to perform the analyses. Surveys excluded all fly-over detections (birds flying over the site but not using the habitat directly). Analyses used the average abundance for 15 indicator species, which were selected for their association with the quality of the riparian habitat (see Appendix D). For the diversity analysis, Hill's N_2 index was used considering all species, as this index is less sensitive to rare occurrences than other diversity metrics, allowing for a more cohesive comparison across sites and years (Magurran 2004).

Standardized Marsh Bird Surveys

Surveys followed the procedures established by the Standardized North American Marsh Birds Monitoring Protocols (Conway, 2002), which have been used since 2003 (Hinojosa-Huerta et al. 2008b, 2013b), targeting California Black Rails, Soras, Virginia Rails, Least Bitterns, Yuma Ridgway's Rails and American Bitterns. The protocol consists of call-response surveys in variable-distance point counts located 200 m (656 ft) apart, in which pre-recorded vocalizations are broadcasted to elicit the response of the targeted marsh birds. Survey points were located along the main channel of the Colorado (101 points in Reach 1 and 102 points in Reach 4), the Hardy River (160 points in Reach 6) and the Upper Estuary (8 points in Reach 7).

At each survey point, the surveyors recorded the number of individuals detected (heard or seen) of each target species during a 5-min passive period prior to broadcasting the recorded calls, and during a 6 min period in which pre-recorded vocalizations of Black Rail, Sora, Virginia Rail, Least Bittern, Ridgway Rail and

American Bittern were played, in that order. The sequence includes 30 sec (seconds) playback and 30 sec of silence for each species. Surveys started at sunrise and continued until no later than 1030 h. We visited each survey point twice during the breeding season (March-May).

Census of Water Bird Colonies

Pronatura Noroeste conducted full counts of water birds nesting in colonies in the lower Hardy River and Upper Estuary, which included a scoping visit during spring to locate all potential colonies in an area of approximately 12,500 hectares (38,888 acres) between “El Riñón” in the lower Hardy, downstream into the Upper Estuary and Laguna del Indio. Target species include Great Egret, Great Blue Heron, Snowy Egret and Black-crowned Night-Heron from the Ardeidae family and Double-crested Cormorant from the Phalacrocoracidae family, as well as any other potential breeding species from these families.

Once the colonies were located, they were visited three times during the breeding season (May to June) to count the total number of adults and the total number of active nests present. The number of eggs and juveniles was recorded when possible, but the protocol is not designed to estimate productivity or breeding success. Surveys also documented the habitat characteristics of the site (vegetation cover, plant species and water depth) as well as the preferred nesting substrate of the species.

Results

Floodplain of the Colorado River

During the breeding season of 2018, the bird diversity was 20% higher ($p = 0.051$) and the abundance of the 15 indicator species was 74% higher ($p < 0.001$) at the restoration sites (Miguel Alemán, CILA, Cori and Herradura) than in the rest of the floodplain (Reach 1 to Reach 5; Figure 6-1). Both the highest diversity ($N_2 = 7.19$) and the highest abundance of indicator species (6.42 birds per point) were observed at the Cori site. The lowest diversity ($N_2 = 2.53$) and abundance (0.92 birds per point) were observed in the unrestored transects across Reach 2 (Figures 6-2 and 6-3).

Table 6-1. Survey points and avian parameters at the restoration sites during 2017 and 2018. Cori was not monitored in 2017. Hill's N_2 diversity following Magurran (2004); Abundance is number of individuals per site; richness is average number of species per site.

Site	Points	N2 Diversity	Abundance of Priority Species	Number of Priority Species	Average Richness	Total Species
	2017					
Miguel Alemán	8	4.94	3.63	10	8.88	48
CILA site	19	6.62	6.42	12	8.53	66
Herradura	4	8.41	5	9	10.58	42
Cori						
Reach 1	16	5.25	3.04	12	11.28	77
Reach 2	16	4.41	1.75	7	7.29	36
Reach 3	48	3.79	1.79	10	6.43	64
Reach 4	40	5.99	3.7	12	11.38	96
Reach 5	40	5.63	3.78	14	6.88	85
	2018					
Miguel Alemán	17	4.38	2.82	12	9.76	41
CILA site	19	6.34	5.32	15	14.26	62
Herradura	11	6.65	5.30	10	11.73	40
Cori	6	7.19	6.56	12	15.17	40
Reach 1	16	4.56	2.65	11	10.63	55
Reach 2	16	2.53	0.92	7	4.42	30
Reach 3	48	3.97	1.64	12	7.05	61
Reach 4	40	6.71	3.55	13	13.65	83
Reach 5	40	6.25	3.54	14	11.06	67

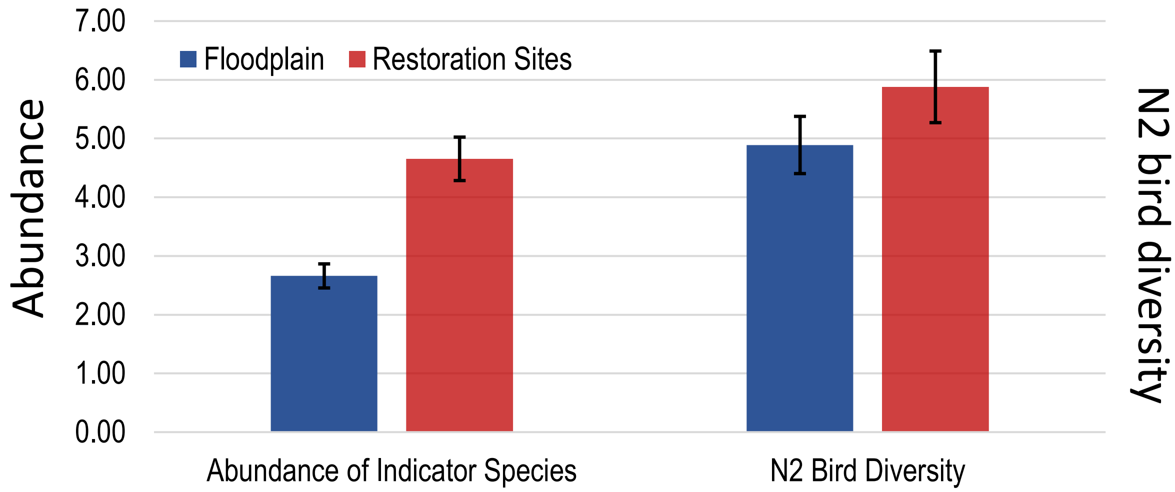

Figure 6-1. Abundance of indicator species (birds per point) and bird diversity (N_2 per point) at the restoration sites and along unrestored floodplain transects during the breeding season of 2017.

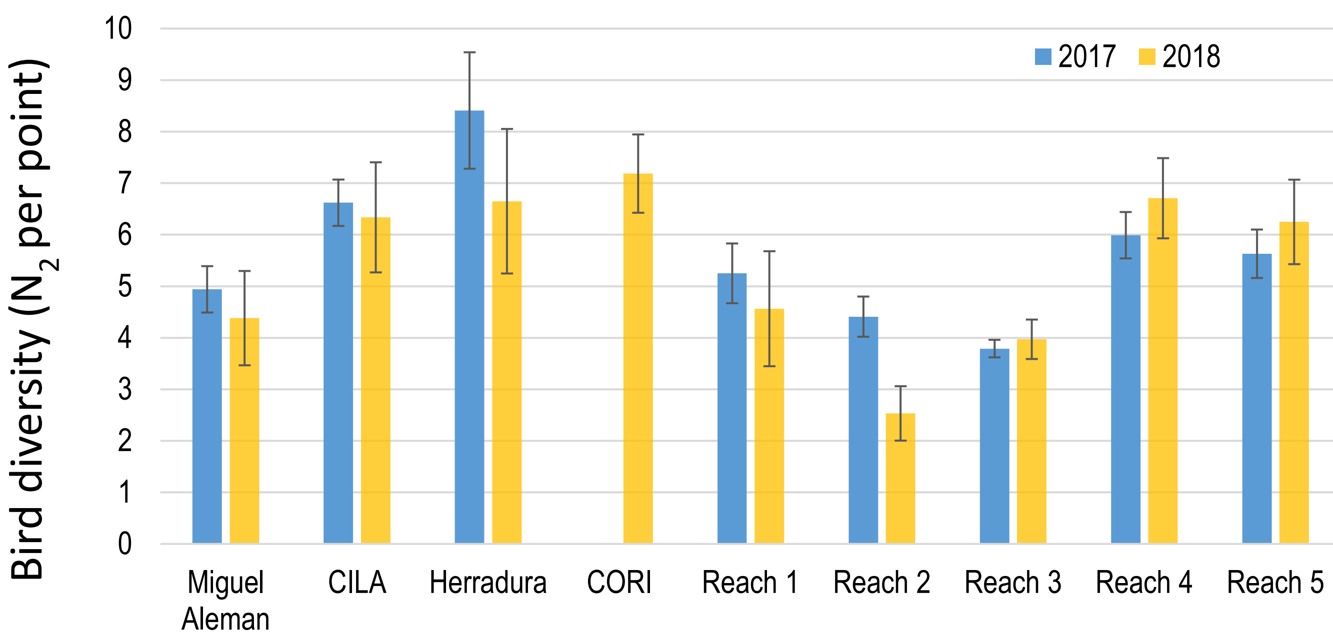

Figure 6-2. Bird diversity (N_2 per point) at the restoration sites and at unrestored floodplain transects across Reaches 1-5 during the breeding seasons of 2017 and 2018. Diversity was not measured at Cori in 2017. CILA refers to CILA restoration site.

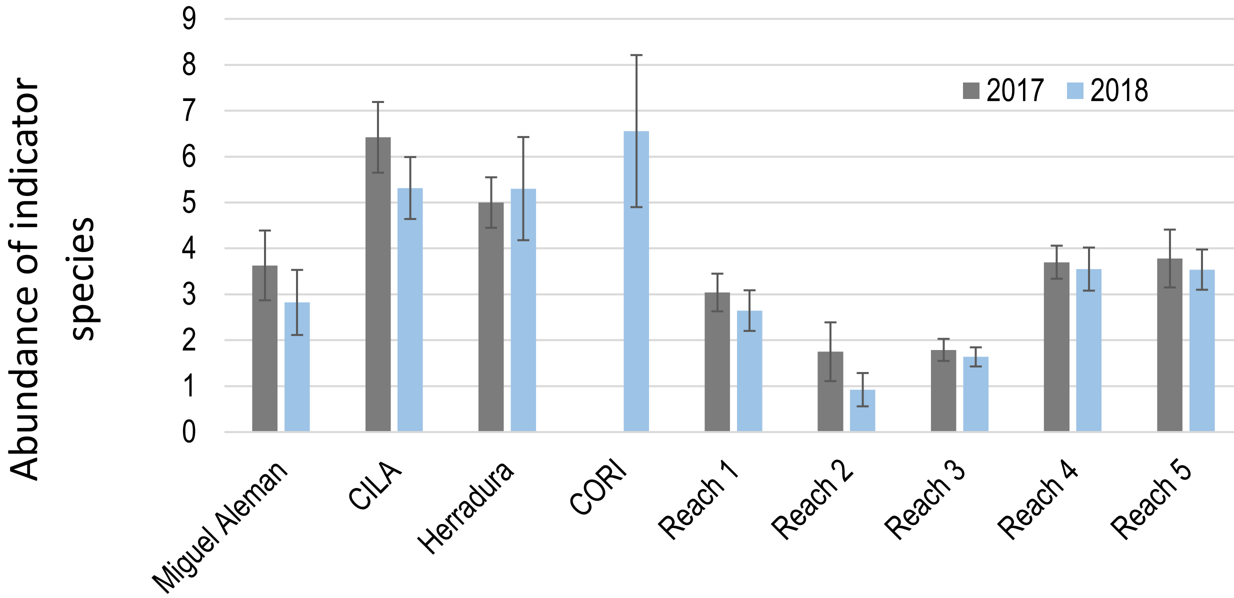

Figure 6-3. Abundance of indicator species (birds per point) at individual restoration sites and at unrestored floodplain transects across Reaches 1-5 during the breeding seasons of 2017 and 2018. Abundance was not measured at CORI in 2017. CILA refers to CILA restoration site.

Between 2013 and 2018, the diversity of birds has been increasing in the restoration sites (49% in this period overall) and throughout the floodplain (36%), although there was a slight decrease (8% at the restoration sites and 3% throughout the floodplain) between 2017 and 2018 (Figure 6-4). This decrease in diversity during 2018 occurred at all restoration sites and in Reaches 1 and 2, while it increased in Reaches 3, 4 and 5 (Figure 6-5). In general, bird diversity has an upward trend in the region, with fluctuations among years, except in Reach 5, where it has been increasing consistently (Figure 6-5).

On the other hand, the combined abundance of the 15 indicator species at the floodplain increased 32% in 2015 compared to 2013 and 2014, but then decreased again to similar levels during 2016 and 2017, and further declined in 2018 (Figure 6-6). The decline in indicator species has been consistent in Reaches 1 and 2 since 2013, while in Reaches 3, 4 and 5, the abundance increased in 2015, but has been declining since then (Figure 6-6). At the restoration sites, the abundance of indicator species increased consistently between 2013 and 2017 (60% increase over the 4 years) but had a 15.6% decrease during 2018 (Figure 6-6), particularly at the CILA site (Figure 6-7), where both foliar cover of cottonwood-willow and total vegetation volume also decreased, likely due to water delivery interruptions.

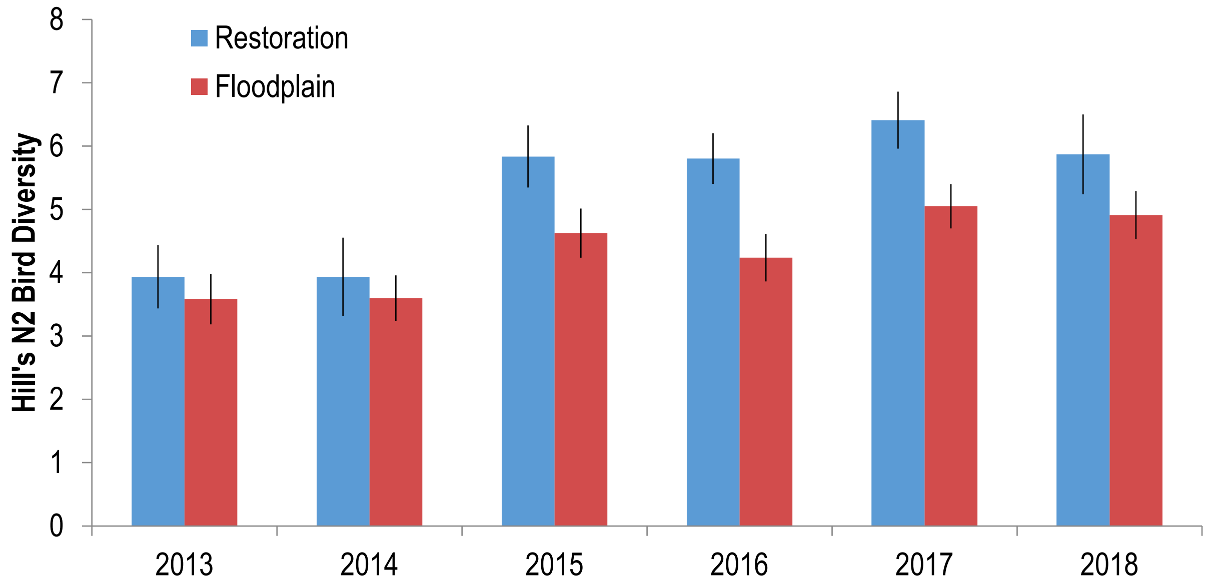

Figure 6-4. Bird diversity (N_2 per point) at the restored areas compared to unrestored floodplain transects across Reaches 1-5 from 2013 to 2018.

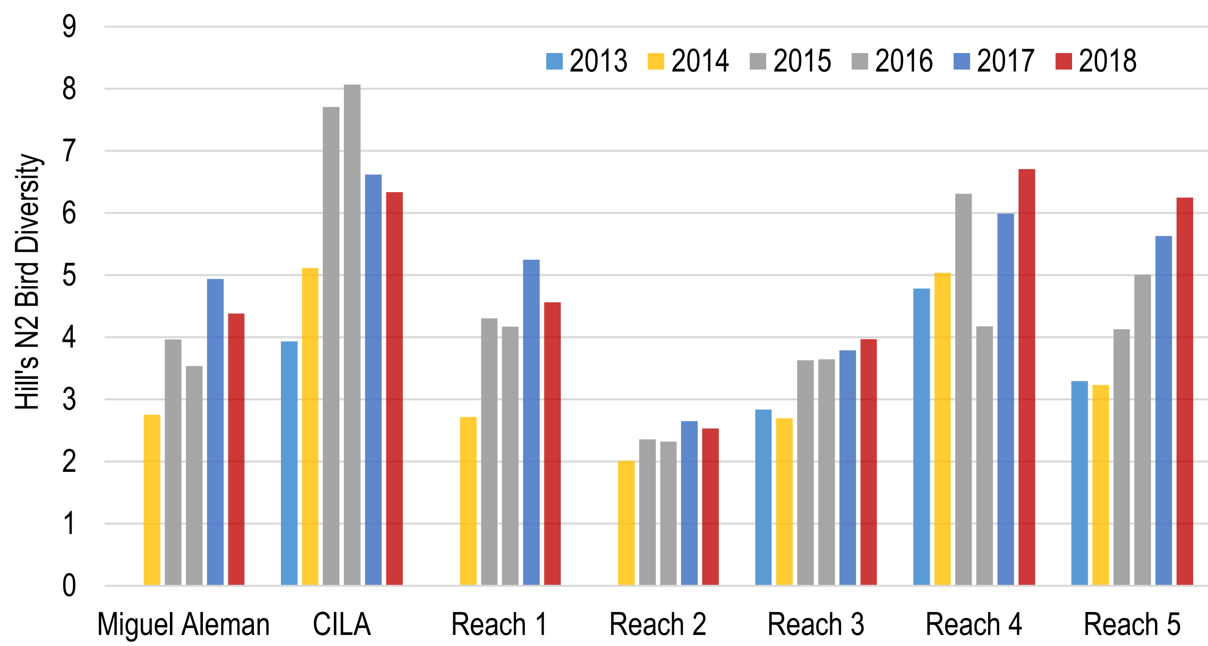

Figure 6-5. Bird diversity (N_2 per point) at individual restoration sites and unrestored floodplain transects across Reaches 1-5 from 2013 to 2018. CILA refers to restoration site.

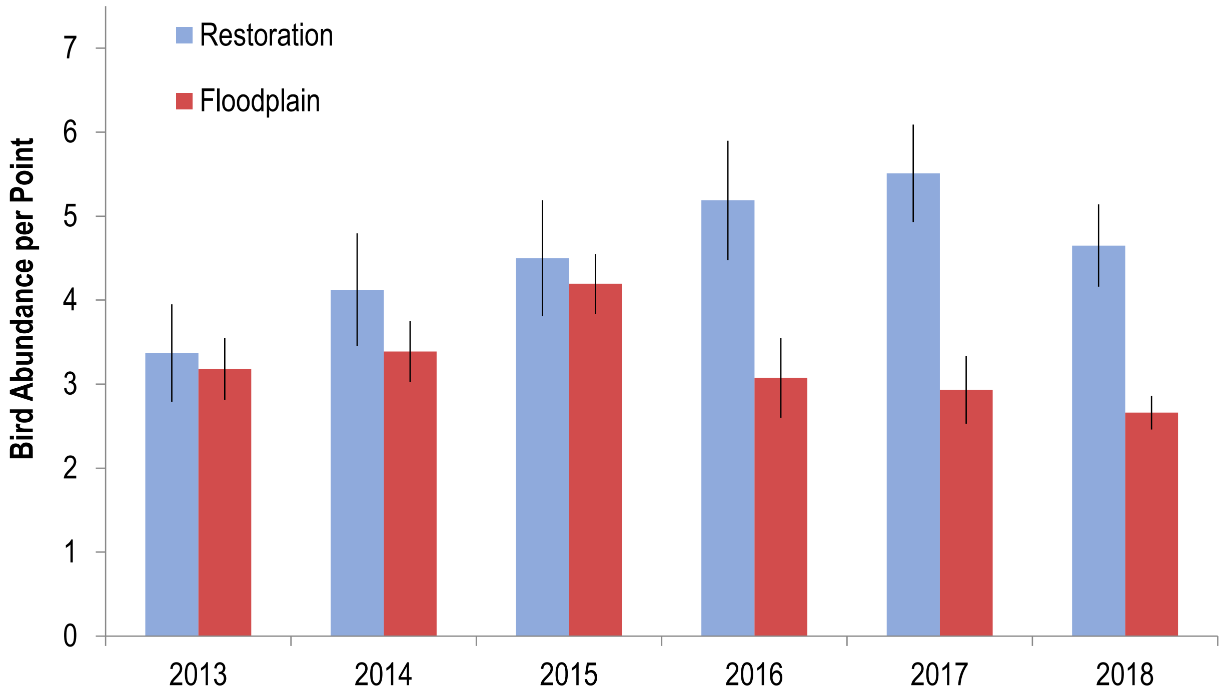

Figure 6-6. Abundance of indicator species (number of birds per point) at the restored areas and at unrestored floodplain transects across Reaches 1-5 from 2013 to 2018.

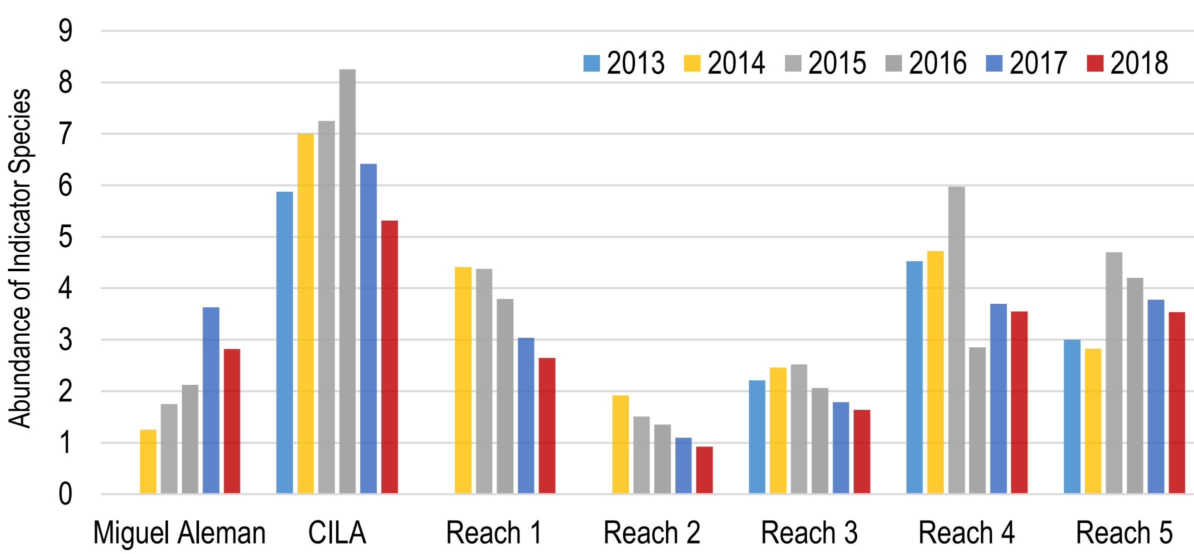

Figure 6-7. Abundance of indicator species (birds per point) at the restoration sites and at unrestored floodplain transects across Reaches 1-5 from 2013 to 2018. CILA refers to CILA restoration site.

The difference in abundance of indicator species between the restoration sites and the unrestored floodplain transects has been growing, from 6% in 2013, up to 74% ($p < 0.001$) in 2018, in part due to increases of abundance at the restoration sites and decreases in the rest of the floodplain. The decrease in abundance and diversity in 2018 at the restoration sites could be partially explained by the addition of survey points at new (younger) restored sections that are also dominated by upland and/or mesquite habitat types, which might require more time to mature, in contrast with riparian habitats.

Marsh Birds

Before 2009, marsh birds were scarce outside the Cienega de Santa Clara and El Doctor (Hinojosa-Huerta et al. 2001, 2008b). Since 2003, the numbers of Yuma Ridgway's Rails and Least Bitterns started to increase slowly along the Hardy River, initially apparently in response to local restoration projects that increased water levels in the area of "El Riñón" (El Tapón project, Hinojosa-Huerta et al. 2005). The numbers then increased exponentially for both species after 2009 (Figure 6-8), likely due to a combination of flow increases in the Hardy coming from Las Arenitas and the subsidence caused by the April 4, 2010 earthquake (Nelson et al. 2013). The detections of Yuma Ridgway's Rails increased from 8 detections in 1999 to 347 detections in 2018 (average increase of 25% yearly during 20 years, exponential trend $r^2 = 0.84$, $y = 3.15e^{0.2x}$, $p < 0.001$), while Least Bitterns changed from 18 detections in 2003 to 259 detections in 2018 (average increase of 22% yearly during 15 years, exponential trend $r^2 = 0.88$, $y = 7.53e^{0.2x}$, $p < 0.001$).

Detections of Virginia Rails have also increased in the Hardy River, but in lower numbers and with larger fluctuations between years. The species was first detected in the area in 2005 (4 detections), had a maximum number of 54 detections in 2013, and had 24 detections in 2018 (Table 2). Black Rails have not been detected in the Hardy, while Soras and American Bitterns have only been detected as migrant birds.

Along Reach 4 on the Colorado River, the detections of marsh birds have fluctuated over the last 10 years. Least Bittern has been the most common species, with minimum counts of 10 individuals in 2009 and maximum counts of 111 in 2017, with 31 detections in 2018 (Table 2). Yuma Ridgway's Rails have been consistent in the area, but with few records: a maximum of 25 in 2011 and a minimum of 2 in 2018 (Table 2). In the Limitrophe section (Reach 1), marsh birds are scarce, with only two records of Yuma Ridgway's Rails in the last 5 years, a maximum count of 16 Least Bitterns, and no species detected during 2018.

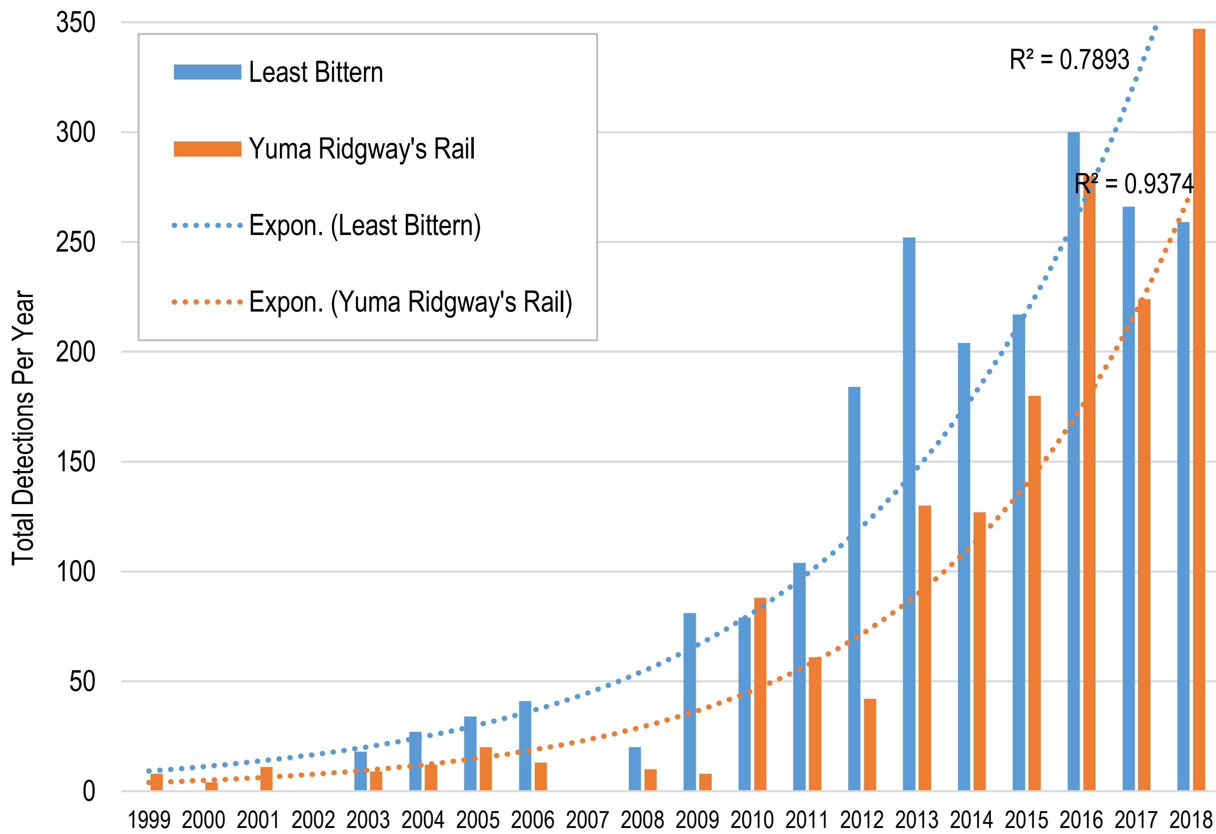

Figure 6-8. Detections and estimated trend curves of Least Bitterns and Yuma Ridgway's Rails at the Hardy River from 1999 to 2018. Surveys were not conducted during 2002 and 2007. "Expon" refers to exponential fit of trend of abundance through time.

Table 6-2. Detections of Least Bitterns (LEBI), Yuma Ridgway's Rails (RIRA), and Virginia Rails (VIRA) at the Hardy River, Reach 1 and Reach 4 of the Colorado River, from 2003 to 2018. Cells in gray indicate that no surveys were performed in that particular year and area.

	Hardy River			Reach 4			Reach 1		
Year	**LEBI**	**RIRA**	**VIRA**	**LEBI**	**RIRA**	**VIRA**	**LEBI**	**RIRA**	**VIRA**
2003	18	9	0						
2004	27	12	0						
2005	34	20	4						
2006	41	13	0						
2007									
2008	20	10	4						
2009	81	8	1	10	3	0			
2010	79	88	3	26	2	33			
2011	104	61	1	39	25	0			
2012	184	42	5	102	11	1			
2013	252	130	54	96	22	26	0	0	0
2014	204	127	17	98	5	9	12	1	0
2015	217	180	9	83	22	13	2	0	0
2016	300	280	23	71	13	3	2	0	0
2017	266	224	15	111	18	0	16	1	0
2018	259	347	24	31	2	3	0	0	0

Water Bird Colonies

No breeding colonies of water birds were reported for the lower Hardy River or Upper Estuary before 2012, when breeding records were concentrated at Montague Island and Cerro Prieto (Mellink et al. 2000, 2002, Hinojosa-Huerta et al. 2007, Mellink and Hinojosa, 2018). Since 2012, initial breeding attempts by colonial water birds were observed in the Upper Estuary region, both near the levee (Laguna del Indio area) and in the estuarine restoration lagoons in the lower Hardy (Mellink and Hinojosa, 2018).

In 2014 Pronatura Noroeste conducted the first census of breeding water birds in the area, with a total of 186 adults and 52 active nests from 5 species (Great Egret, Great Blue Heron, Black-crowned Night-Heron, Snowy Egret and Double-crested Cormorant, Table 3). In 2017, the numbers increased to 568 adults and 174 active nests, and in 2018 we counted 961 adults and 517 active nests, with two additional species: Tricolored Heron, which is a federally protected species in Mexico (Special Protection), and the Neotropic Cormorant. The Neotropic Cormorant was first detected in the Colorado River delta / Upper Gulf region in 2013 (Gerardo Marrón, eBird), and has now expanded its breeding range into this area, from previous known breeding locations in coastal Southern Sonora and south-central Arizona (Telfair II and Morrison, 2005). Other semi-colonial or non-colonial water birds confirmed breeding in the area included Least Tern, Snowy Plover, Killdeer, Black-necked Stilt, American Avocet and Green Heron.

The recent occupation and expansion of the breeding water bird colonies in the lower Hardy and Upper Estuary appear related to the expansion of wetland habitat caused by the subsidence after the 2010 earthquake and the consequent increase of tidal influence in the area. The nesting water birds might have benefited also from the channel restoration and connectivity efforts in the estuary and the increase in flows in the Hardy River coming from Las Arenitas since 2009.

Table 6-3. Numbers of adults and nests counted at the water bird breeding colonies in the Hardy River and Upper Estuary during 2014, 2017 and 2018.

	2014		**2017**		**2018**	
Species	**Adults**	**Nests**	**Adults**	**Nests**	**Adults**	**Nests**
Great Egret	8	3	112	63	82	72
Great Blue Heron	47	21	26	7	109	84
Black-crowned Night-Heron	36	12	16	5	85	19
Snowy Egret	21	9	198	78	234	111
Double-crested Cormorant	51	7	216	21	203	22
Tricolored Heron	0	0	0	0	12	6
Neotropic Cormorant	0	0	0	0	236	3
Total	**186**	**52**	**568**	**174**	**961**	**217**

Conclusions

Diversity and abundance of indicator riparian bird species are 20% and 74% higher, respectively, at the restoration sites than along unrestored floodplain transects. Throughout the region, bird diversity has been increasing since 2013, with the highest rates occurring in Reaches 4 and 5. On the other hand, the abundance of indicator species has been declining since 2015, including a 15.6% decline at the restoration sites in 2018.

In the Hardy River and the Upper Estuary, the populations of priority marsh bird species (Least Bittern and Yuma Ridgway's Rails) have increased exponentially in the last 10 years, as has the size of breeding colonies of seven water bird species. These responses appear to be related to seismic subsidence, increase of flows, and the restoration of hydrological connectivity.

The interpretation of results is complex at the restoration sites, because every year survey points are added within recently restored areas with younger vegetation. The patterns are also complex because of the combination of habitat types at each site (aquatic, riparian, mesquite and upland). The bird data need to be explored considering the age of vegetation and the percent cover of habitat type at each survey point, as well as other variables, such as vegetation volume and irrigation practices. At the level of river reach, bird patterns should be explored in relation to habitat variables, as well as fluctuations of groundwater levels and surface flows. In addition to the hydrological and habitat relationships, future bird analyses will include the evaluation of population trends of individual species and changes in the community assemblage, both at the Colorado River floodplain and the Hardy River. Future work will also explore data on the avian productivity and survivorship collected at restored and unrestored sites.

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Section 7: Upper Estuary

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Key Observations

- Fresh water flows to the estuary are primarily from the Hardy River (73%) and also from the Ayala Drain (27%).
- A sustained flow release to Ayala Drain in June to December 2018, after it was dredged in January, showed that water delivered to Ayala Drain can flow unimpeded into the Colorado mainstem, and from there to the Upper Estuary, without significant seepage loss.
- Although the 2.2 Mm^3 (1,767 acre-ft) flow delivery to Ayala Drain reached the Upper Estuary, it did not measurably change water levels, salinity, or biota.
- Salinity in the Upper Estuary varied seasonally, from a low of 3 ppt in the irrigation season to a high of 134 ppt at the most seaward station in the late summer.
- Crustacean arthropods, including post-larvae of shrimp, were the most common organisms found. Freshwater, brackish and marine fish were also found in the area.

Introduction

The Upper Estuary (Reach 7) receives fresh water from the Colorado River, the Ayala Drain (agricultural drain), the Hardy River (treated effluent and irrigation return flows), and other agricultural drains, and receives sea water from the Sea of Cortez. Restoration for the Upper Estuary aims to increase freshwater flows to the site and increase tidal exchange with the Sea of Cortez by improving the physical connection between the river channel and the tidal channels. These restoration efforts intend to improve and create habitats for fish, invertebrates and shorebirds.

A tidal sandbar has long obstructed interchange between freshwater and seawater in the Upper Estuary (Nelson et al. 2013). In 2012, sediment was manually excavated to form a pilot channel through the sandbar barrier in order to increase freshwater flow and tidal exchange. In September-November 2016, the pilot channel was extended 11.1 km (6.8 mi), first by manual digging, and then with an amphibious excavator dredge (purple line, Figure 7-1).

The Ayala Drain conveys irrigation return flow and some municipal wastewater toward the Upper Estuary, but needed maintenance to restore its carrying capacity. In December 2017 to January 2018, 1.8 km (1.1 mi) of the Ayala Drain track (green line in Figure 7-1) was dredged to improve flow to the Upper Estuary.

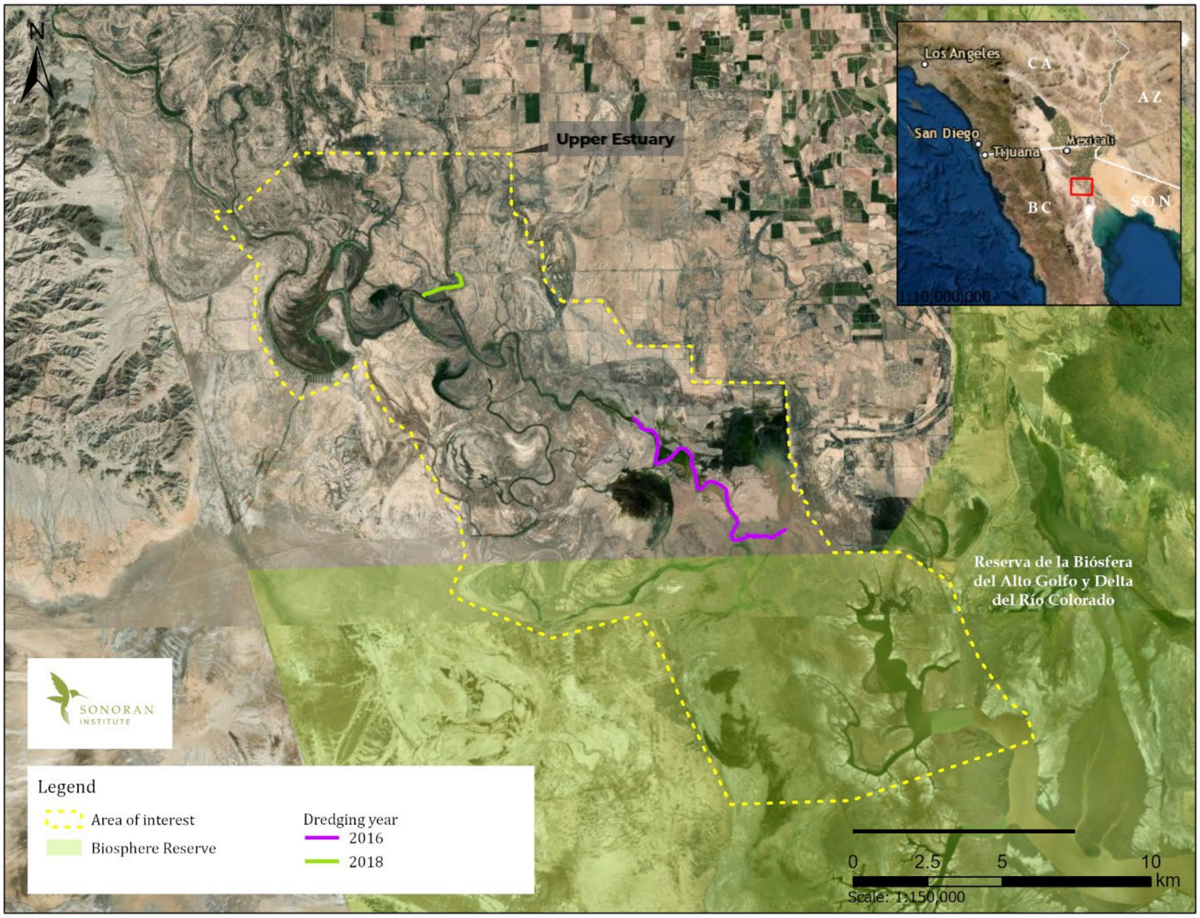


Figure 7-1. Locations completed, for sediment removal along the river and tidal channel of the Upper Estuary. Horizontal bar above km scale = 5 miles.

To assess how the dredging affected connectivity between Ayala Drain and the upper estuary, 2.4 Mm^3 (1,934 acre-feet) of temporary and permanent water rights were allocated to the Ayala Drain for an environmental flow in 2018. The water was scheduled to be delivered at 500 l/s (17.7 cfs) for 55 days, beginning on June 5, 2018. However, the irrigation module did not deliver water as scheduled; instead, water was delivered intermittently with fluctuations in discharge, including periods exceeding one month without any water deliveries. (See Figure 2-2, lower right panel, in Hydrology section.) The actual environmental flow to Ayala Drain began on June 4, 2018 and ended on January 4, 2019. The total volume discharged was 2,179,352 m^3 (1,767 af) of which 2,011,980 m^3 (1,631 af) (92.3%) was delivered by the sub-lateral gate km 27+ 458 and 167,372 m^3 (136 af) (7.7%) by the 22 km + 160 gate (Figure 7-2).

To document and understand the impacts of dredging and related estuarine restoration strategies, the Upper Estuary monitoring program measures surface water flows, levels, and quality; groundwater levels; saltgrass extent; and fish and zooplankton abundance.

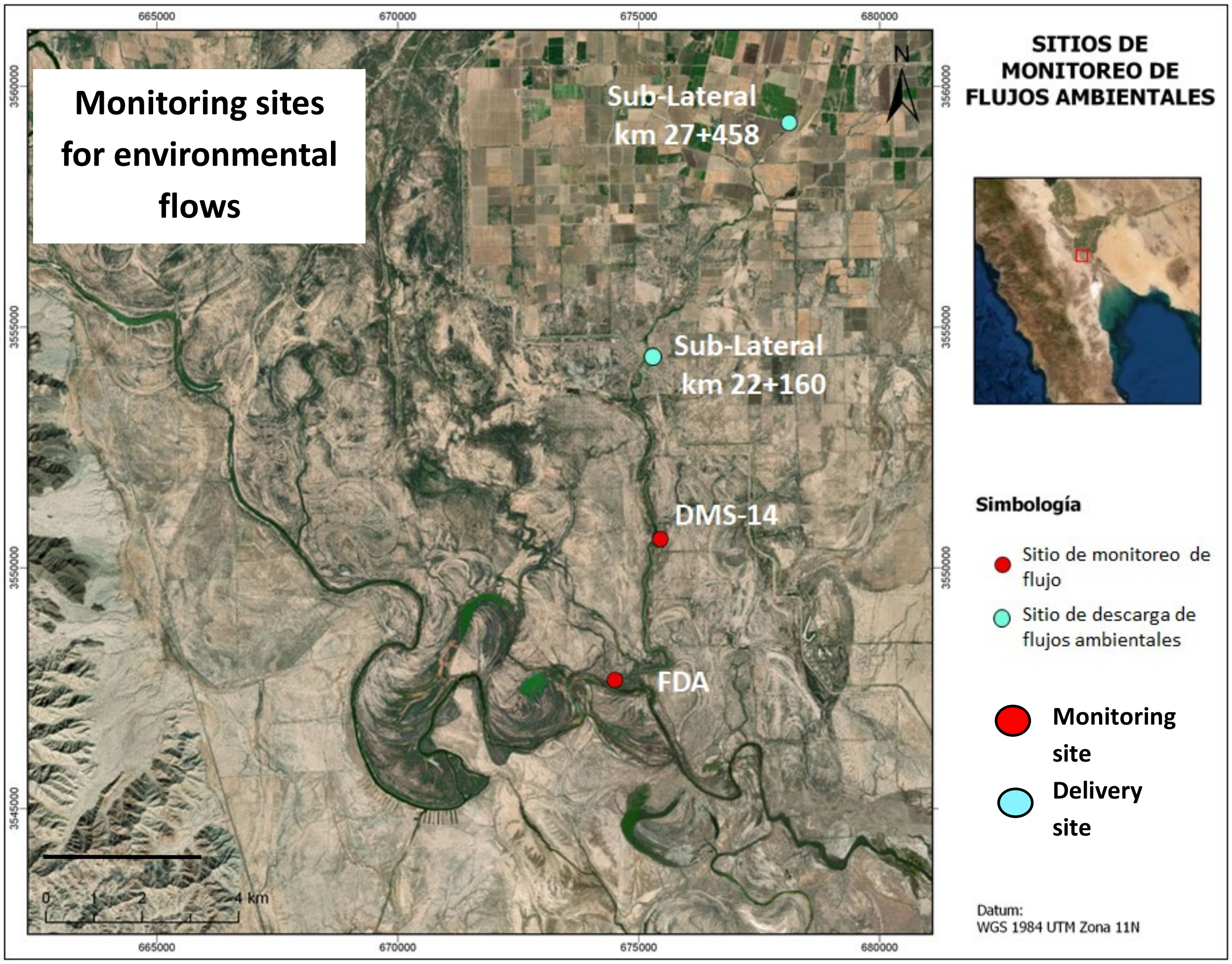


Figure 7-2. Location of 2018 water delivery and hydrologic monitoring sites along Ayala Drain. Horizontal bar above km scale = 2 miles

Hydrology

Surface water flows

Figure 7-2 shows the locations of water delivery and monitoring sites along Ayala Drain in greater detail. Monthly flow measurements were made with a portable FlowTracker at six sites located in the lowermost part of Reach 7 (Figure 7-2) from October 2014 to December 2018. An additional 182 flow measurements (136 in the discharge gates and 46 in the Ayala drain channel (DMS-14 and Fin Dren Ayala (FDA)) and 46 salinity measurements were made during the Ayala Drain environmental flow.

Figure 7-3 shows the locations of hydrologic monitoring sites in the Upper Estuary area.

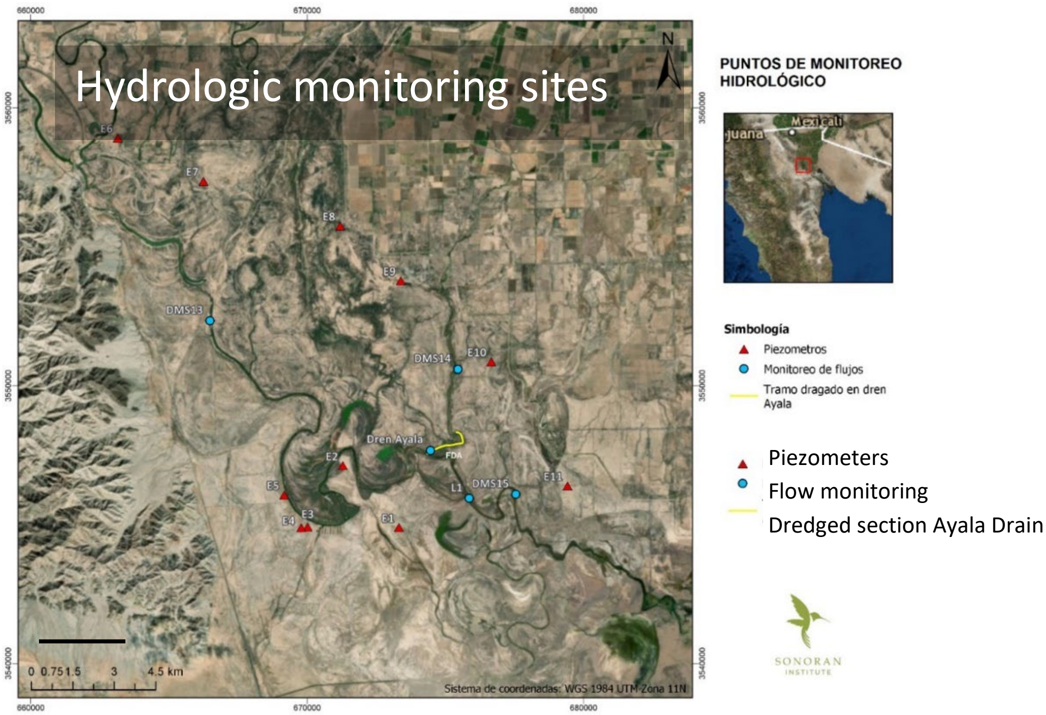


Figure 7-3. Locations of 2018 hydrologic monitoring sites. The yellow line indicates the dredged portion of the Ayala Drain. Horizontal bar above km scale = 2 miles.

Streamflow into the Upper Estuary increases in winter and spring, when irrigation return flows discharge into the Hardy River, Colorado River and Ayala Drain, and decreases during summer and autumn (Figure 7-4). The highest flows were recorded in January and February 2016, reaching a maximum of 1.6 m^3/s (56.5 cfs) at DMS-13, and minima occurred periodically at all sites during each summer with some almost undetectable flows (less than 0.03 m^3/s (0.1 cfs)).

The main sources of freshwater flows to the estuary are the Hardy River (DMS-13), with measured flows averaging 0.581 m^3/s (20.5 cfs) and the Ayala Drain (DMS-14), with measured flows averaging 0.198 m^3/s (7.0 cfs) in 2018. Both flows join downstream before site L1 (0.421m^3/s (14.9 cfs)) and DMS-15 (0.457m^3/s (16.3 cfs)).

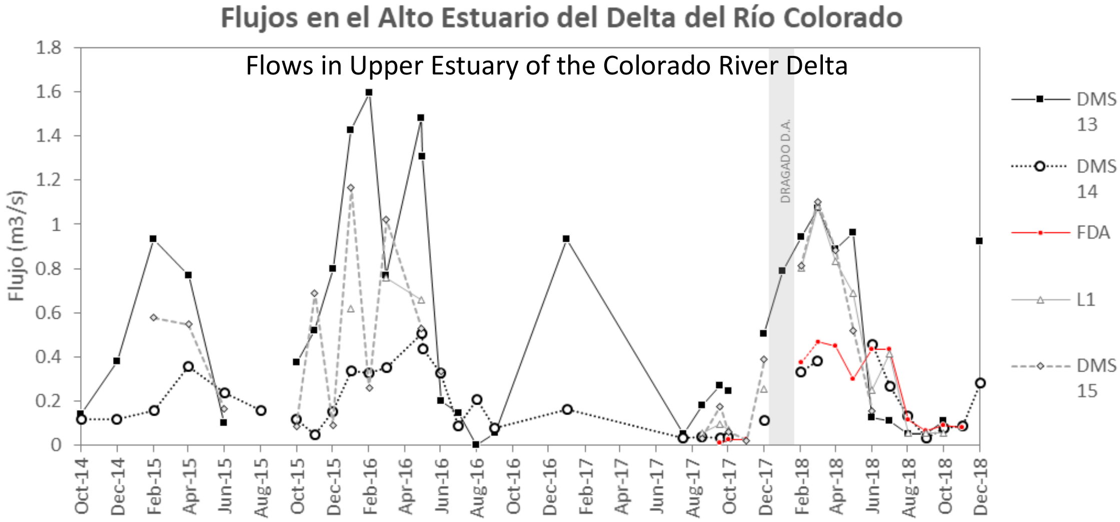


Figure 7-4. Flow hydrograph of monitoring sites. The gray bar indicates the period during which the Ayala Drain was dredged.

Simultaneous flow measurements during the 2018 Ayala Drain environmental flow indicate unimpeded flow through the dredged Ayala drain (see Hydrology, Section 2).

To further evaluate the effects of dredging, average monthly discharges were compared between DMS-14 and FDA for February to December 2018. Average monthly inflow at the FDA site (0.255 m^3/s (9.0 cfs) exceeded outflow at DMS-14 (0.220 m^3/s (7.8 cfs)), meaning all incoming water arrived, in addition to a surplus (0.025 m^3/s (0.9 cfs)), possibly from groundwater discharge. In contrast, pre-dredging measurements (October 2017) showed less outflow (0.021 m^3/s (0.7 cfs) than inflow (0.039 m^3/s (1.4 cfs)) suggesting poor connectivity for that period. Note, however, that the pre-dredging values are near the limits of detection.

Groundwater levels

Groundwater monitoring consisted of the monthly measurement of water table (WT) elevations in 11 piezometers (Figure 7-3). The measurements were made with an electric contact flexometer that measures the depth from a point on the ground surface to the top of the WT. The measuring points were surveyed in order to report water levels in meters above sea level (masl). Figure 7-5 shows water levels measured from July 2017 to December 2018. Some data are missing due to difficulties in accessing the monitoring sites.

The WT (Figure 7-5) seasonally rose beginning in winter (January), reaching maximum values in spring (May). In summer, the levels decreased and then generally stabilized during autumn. As with surface water flows, the groundwater levels suggest a relationship with agricultural irrigation because excess irrigation water infiltrates and recharges the aquifer.

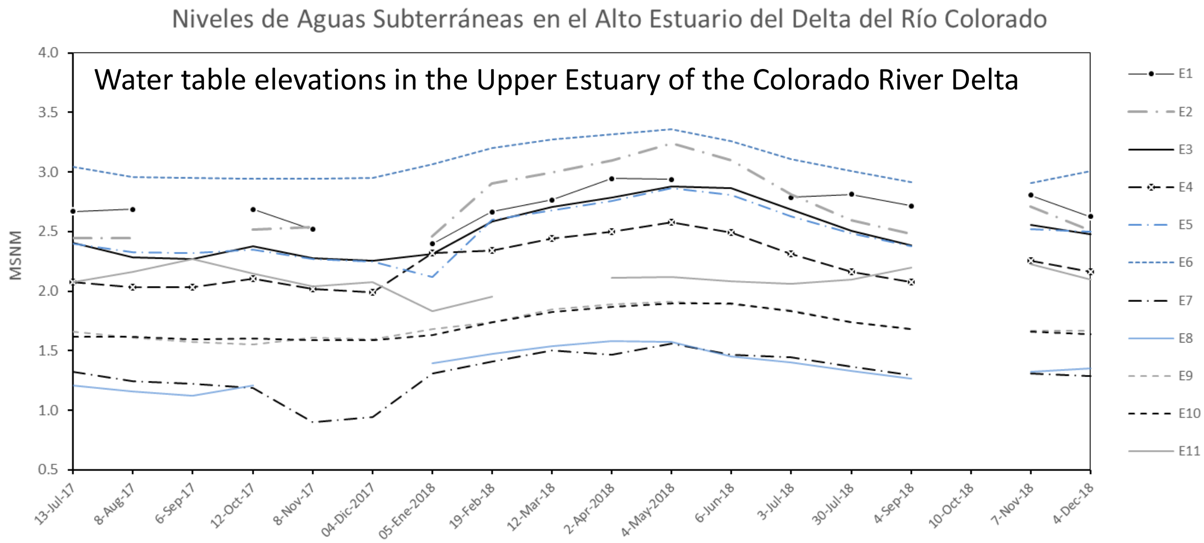


Figure 7-5. Variation of groundwater levels taken from point measurements

The averages of the point measurements varied from 0.9 to 3.36 masl (2.9 to 11.0 feet above sea level) (Table 7-1). The highest levels were recorded in the E6 piezometer located in the north, which is topographically higher than the others. In contrast, the lowest levels were recorded in E7 and E8, (Figure 7- 2). WT gradients indicate that in the northwest zone, groundwater flows in a west to east direction and that aquifer recharge occurs in the margins of the Cucapa mountain range and surrounding agricultural areas. In piezometers E1, E2, E3, E4 and E5, located near the area known as the kidney, the river's water recharges into the aquifer, as can be seen in the differences in WT between E3 and E4, which indicate that the flow direction is east to west. Piezometers E9 and E10 have similar behavior and levels, therefore it is not possible to infer a preferential flow direction. The E11 piezometer shows a behavior unlike the rest of the piezometers, possibly related to flow from another source or the influence of saltwater intrusion.

Table 7-1. Average water table elevations measured in each piezometer (unit: masl).

Piezometer	Average	Max	Min	SD
E1	2.72	2.95	2.40	0.142
E2	2.72	3.24	2.44	0.269
E3	2.51	2.88	2.25	0.207
E4	2.23	2.58	1.99	0.186
E5	2.49	2.86	2.12	0.206
E6	3.07	3.36	2.91	0.148
E7	1.31	1.56	0.90	0.173
E8	1.36	1.58	1.12	0.142
E9	1.72	1.91	1.55	0.115
E10	1.71	1.90	1.59	0.111
E11	2.10	2.27	1.83	0.102

To supplement groundwater monitoring activities, level-loggers were installed in 10 piezometers in January and February 2018. These loggers recorded water levels at 60-minute intervals based on the pressure differential (total pressure - atmospheric pressure). The E4 piezometer was not included in the sensor installation because of its proximity to E3. The sensor in E1 had data download problems and was re-installed in December (Figure 7-6).

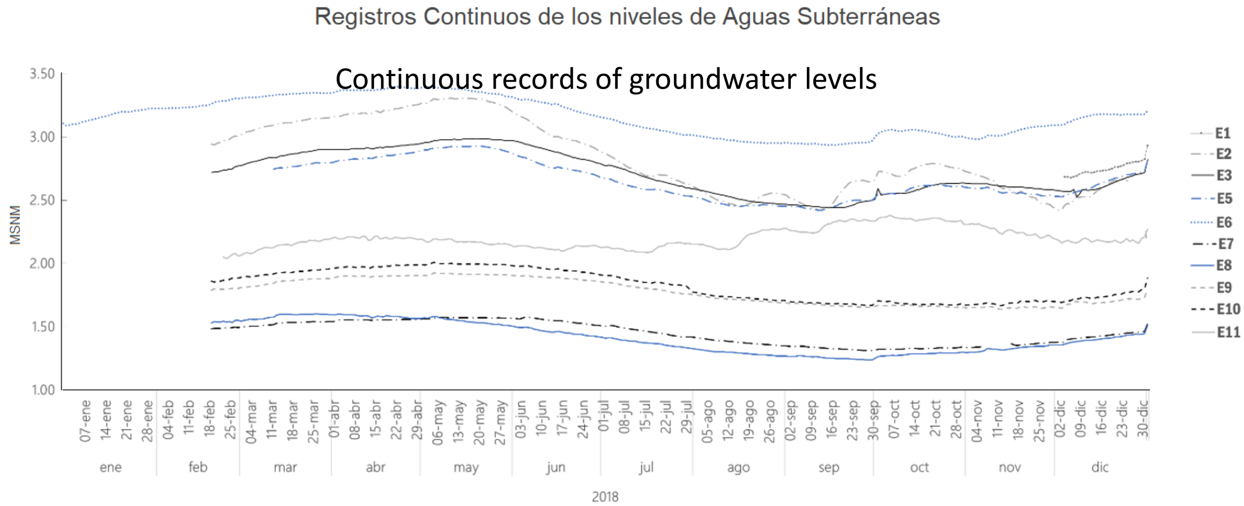


Figure 7-6. Daily average of groundwater levels obtained from level loggers.

Note the increase in levels during the first weeks of October (associated with the influence of precipitation events) and the behavior of the E11 piezometer whose level increases in summer. Similarities in behavior and elevation of the WT were identified in piezometers E3 and E5, E7 and E8, E9 and E10.

We did not detect any changes in groundwater levels resulting from the 2018 environmental flow delivery to Ayala Drain.

Surface Water Depth and Quality

The depth and quality (temperature, dissolved oxygen and salinity) of surface water are continuously monitored at 30-minute intervals using YSI multi-parameter sensors at five monitoring points in the Hardy River, Colorado River, and the Upper Estuary (RHUP7, RHUP4, RHDO6, RHDO8, E3) (Figure 7-7). The probe in RHUP7 stopped working in mid-January 2018, so no level or quality results are available for this point.

Of the water quality parameters, salinity is the most important indicator of the functionality of the estuary habitat because it indicates the degree of mixing of fresh water with salt water and is therefore an indicator of the connectivity between the river and the sea. In addition, the range and level of water salinity affect aquatic species and their diversity, food, reproduction and survival.

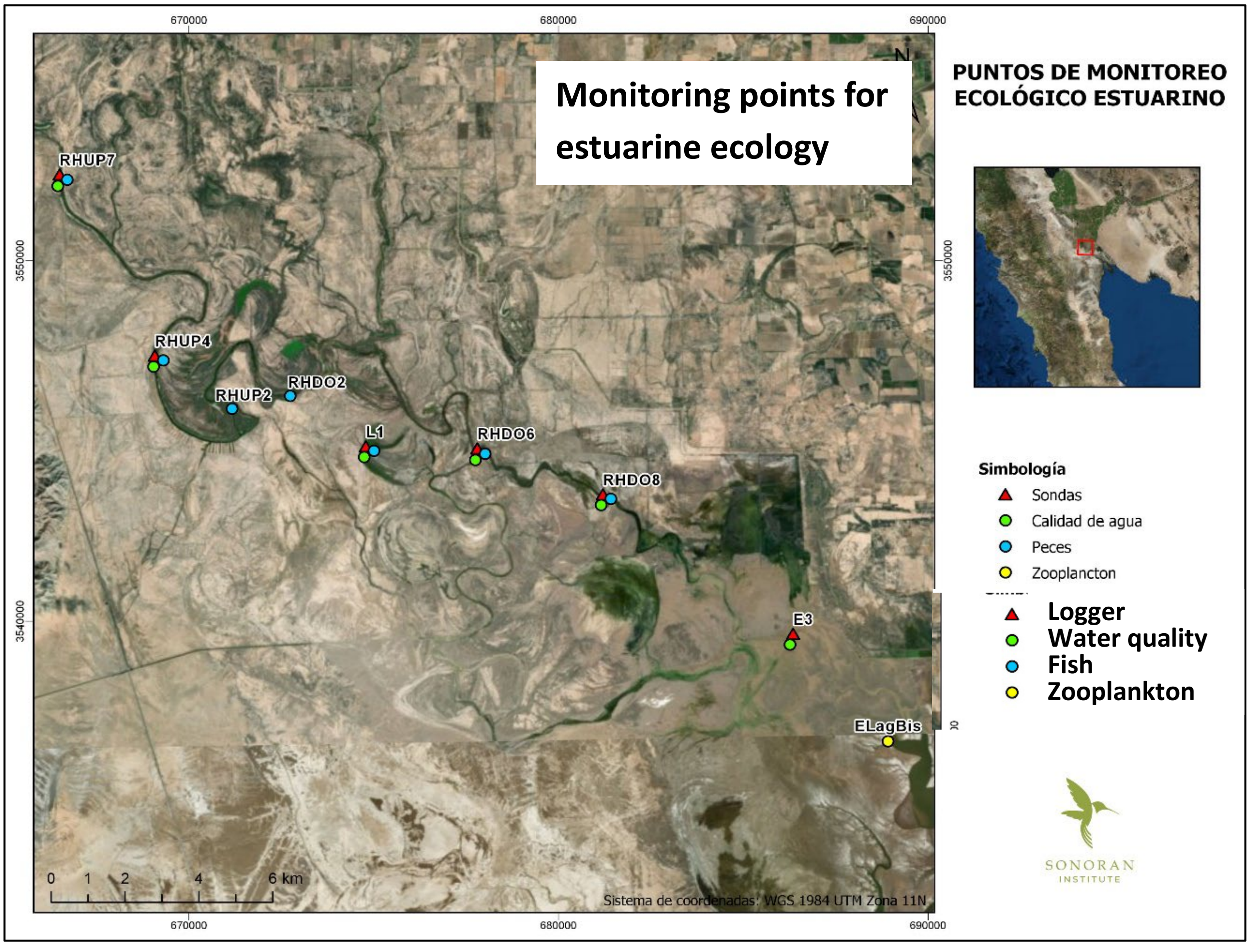


Figure 7-7. Map of the monitoring points for water quality, fish, and zooplankton along the Hardy River and Upper Estuary. Horizontal bar above km scale = 2 miles.

Salinity and water depth

The annual average salinity increased at all monitoring points from 2017 to 2018 (there was insufficient data from RHUP7 in 2018) (Table 7-2; Figure 7-8)). This pattern was contrary to expectations after the dredging in 2016, which resulted in a decrease in salinity at almost all points in 2017. However, annual averages may mask significant seasonal variation

At point E3, which is located at the end of the recently dredged Ayala Drain, salinity was higher in the first six months of 2018 than in 2017, indicating a lack of fresh water in the area and limited connectivity between the river and the sea. Also, salinity from June to August was much higher in 2018 than in 2015-2017; see Figure 7-9. This dramatic increase could have resulted from problems with the probe, so the equipment was removed at the end of the summer of 2018. This station was eliminated because of problems with access. The increase in salinity in the Upper Estuary in 2018 may be due to presence of dredging materials in the canal, less fresh water in the Hardy River or problems with the probes. The probes had been operated on the sites for several years and are being replaced.

On the other hand, the depth of surface water at point E3 demonstrates better entry and exit of the tides after 2016 dredging, with higher peaks and lower lows in 2017 and 2018. Similarly, water depth at site RHDO8 shows more evidence of tidal influence in 2018 than in 2017. See Figures 7-10 and 7-11.

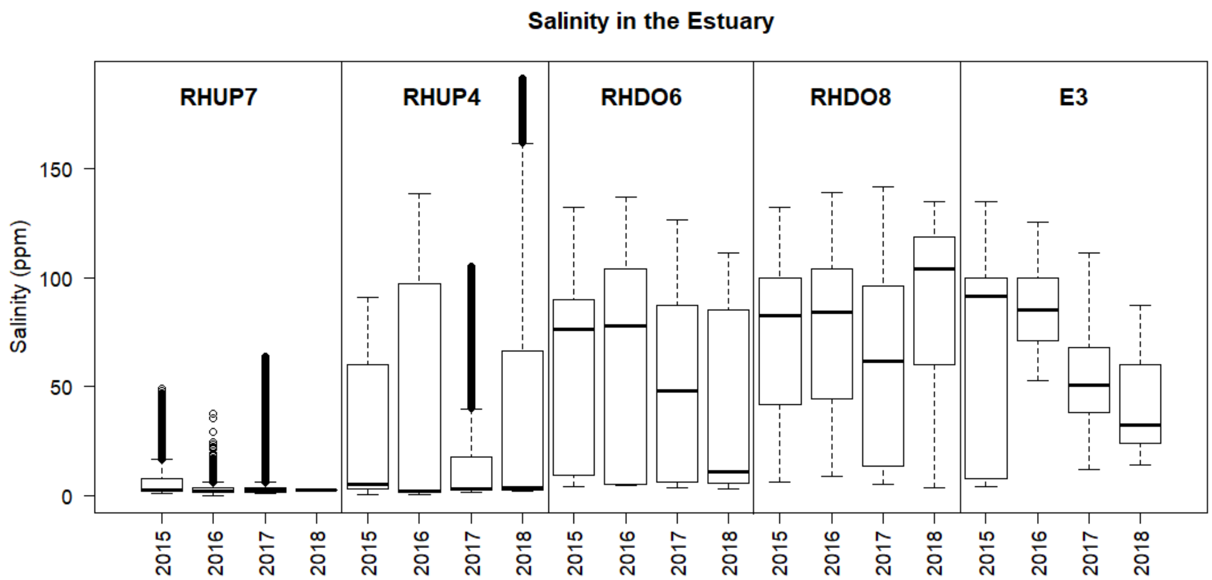


Figure 7-8. Salinity variation in the estuary sites.

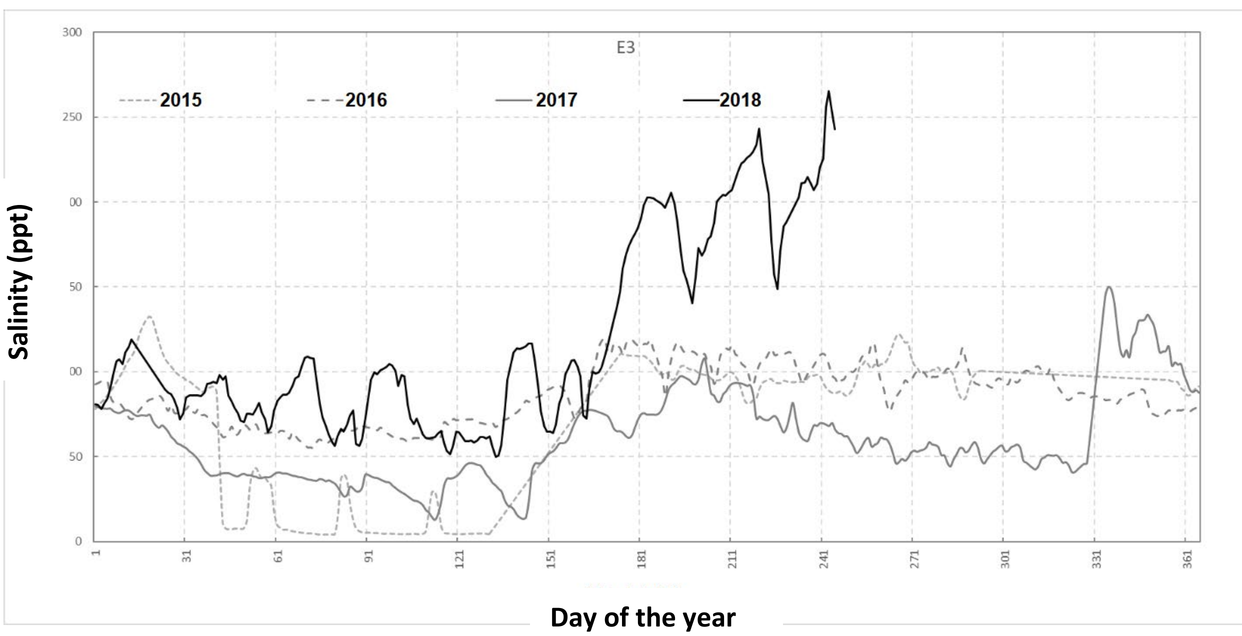


Figure 7-9. Salinity records at site E3 in 2015-2018.

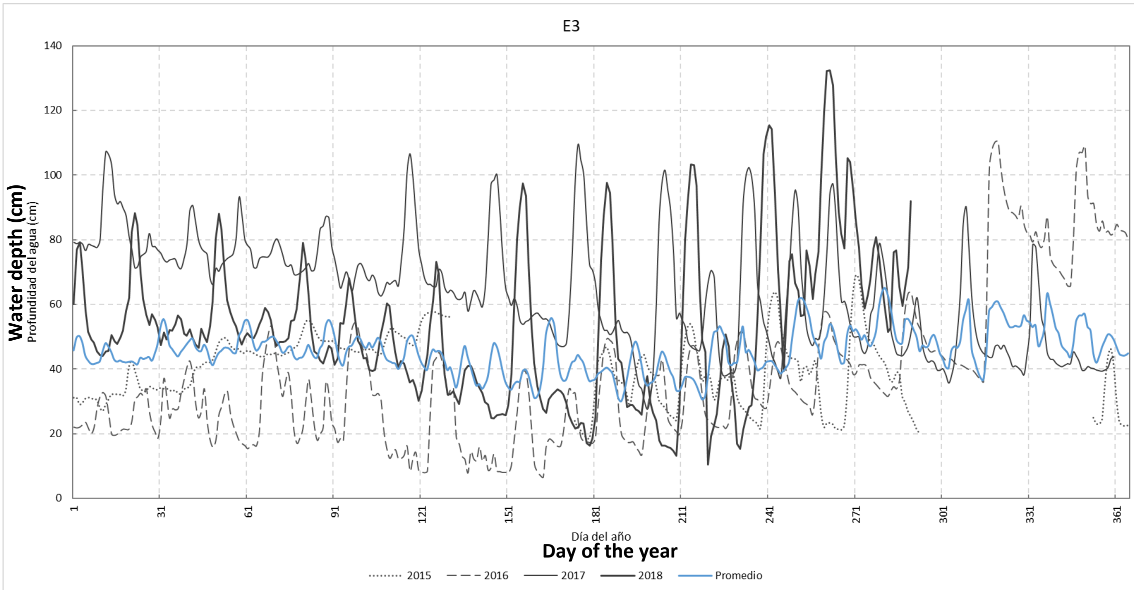


Figure 7-10. Water depth at site E3. The blue line represents the average.

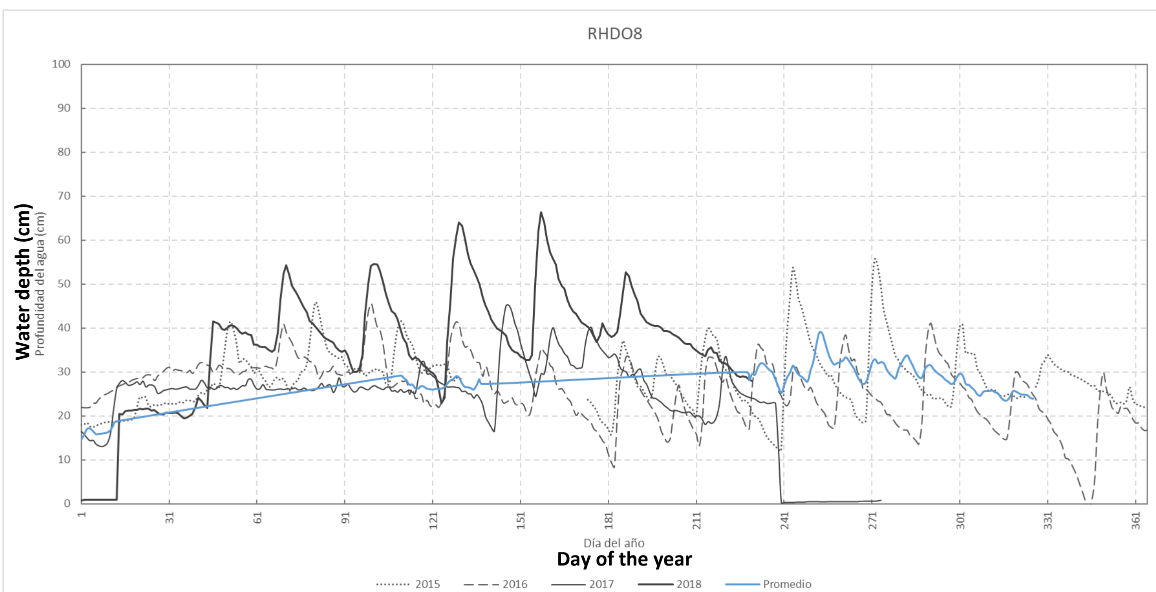


Figure 7-11. Water depth at the RHDO8 site. The blue line represents the average. Sensor malfunction on Day 240 of 2018; sensor now removed.

Salinity in the Ayala Drain

Environmental flows directly affected water quality in the Ayala Drain. Ayala Drain salinity values remained between 2.2 and 5.0 ppt during periods of the environmental flows. In the dry periods (September and November), without environmental flows, salinity values reached 100 ppt.

Biology

Zooplankton

Samples were collected using a cone-shaped zooplankton trawler net with 350-micron mesh size. The trawls were conducted monthly during the new moon – when the tidal range is high and the moon is dark. The trawls lasted 5 minutes at 1-hour intervals and were performed twice daily, during the daytime and during the nighttime. One to four samples were collected during each incoming tide (high tide) from August 4, 2016 to June 13, 2018. Table 7-2 lists the zooplankton collected.

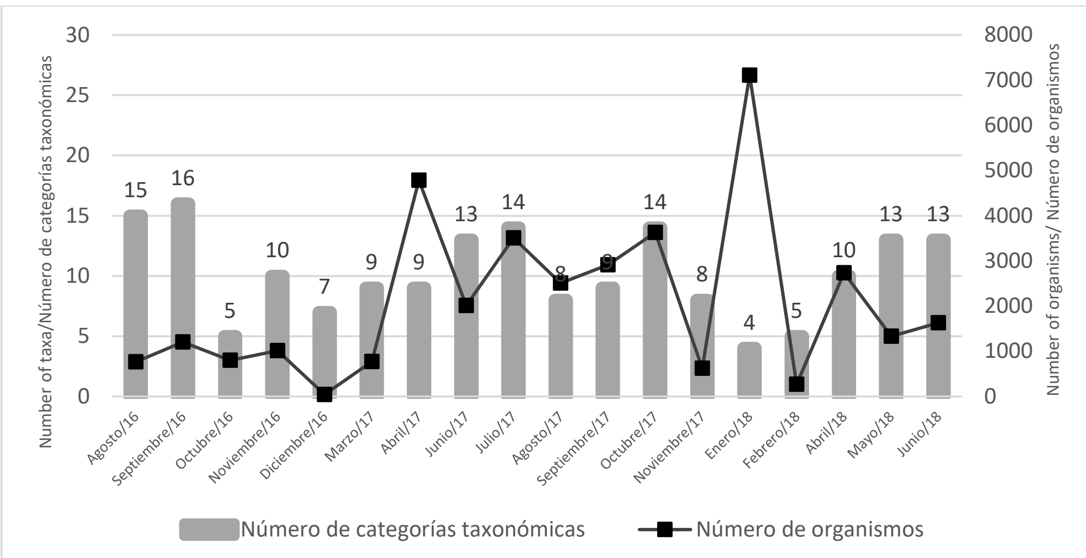
The E Laguna Bis (ELagBis) site was abandoned in June 2018 because illegal fishing activities took place nearby when water was in the channel. Field teams are instructed to avoid contact with groups conducting illegal activities.

Table 7-2. Zooplankton collected at E Laguna Bis (ELagBis) site.

Scientific name	Common name (English)	Common name (Spanish)	Code (Fig 7-13)
fish eggs	fish eggs	huevos de peces	fish.eggs
fish larvae	fish larvae	larvas de peces	fish.larv
Litopenaeus stylirostris post-larvae	blue shrimp postlarvae	poslarva de camarón azul	Lito.stly.PL
Litopenaeus stylirostris juveniles	blue shrimp juveniles	juveniles de camarón azul	Lito.stly.JU
Farfantepenaeus californiensis post-larvae	brown shrimp post-larvae	poslarva de camarón café	farf.cali.PL
crab zoea	crab larvae	zoea de cangrejos	crab.ZOEA
crab growth stage	crab growth stage	megalopa de cangrejos	crab.MEGA
non-portunid Crab juveniles	non-portunid crab juveniles	juveniles de cangrejos no portunideaos	crab.JUVE
portunid crab juveniles	portunid crab juveniles	juveniles de cangrejos portunideos (jaibas)	crab.port.JU
calanoid copepods	calanoid copepods	copépodos calanoideos	cope.cala
cyclopod copepods	cyclopod copepods	copépodos ciclopoideos	cope.cycl
harpactipoid copepods	harpactipoid copepods	copépodos harpacticoideos	cope.harp
amphipods	amphipods	anfípodos	amphipo
isopods	isopods	isópodos	isopods
mysids	mysids	mísidos	mysids
Artemia	brine shrimp	artemias	artemia

insect larvae	insect larvae	larvas de insectos	inse.LARV
insects	insects	insectos	insects
gastropods	snails	gastrópodos	gastropo
ctenophores	comb jellies	ctenóforos	ctenopho
chaetognaths	arrow worms	quetognatos	chaetogn

Figure 7-12 shows the abundance and taxonomic diversity in 66 samples of zooplankton collected at the ELagBis site (see Figure 7-7) in the intertidal zone.



Number of taxa Number of organisms

Figure 7-12. Number of taxonomic categories and organisms collected at site E Laguna Bis (ElagBis) during the sampling period.

The number of organisms found ranged from 500 to 1400 per fraction, of which 19 taxonomic categories, corresponding to five phyla, were identified (Figure 7-12). Arthropods were the dominant phylum (Arthropoda: Crustacea and Insecta). Other phyla included Ctenophora, Mollusca, Chaetognatha and Chordata. Calanoid and cyclopoid copepods were the most abundant arthropods. Penaeid shrimp post-larvae occurred almost exclusively in summer, exceeding 20% of the total abundances on some of 2016 samplings, but less than 15% of the total in the summer of 2017. Other abundant organisms were the zoea larvae and megalopas of brachyuran crabs. The presence of fish larvae was observed in almost all the samples, although in low abundance. The greatest number of individuals was observed in the months of spring and summer. In June 2017, numerous dipteran insect larvae were noted, possibly of the genus *Ephydra* (a genus capable of withstanding high salinity) (Figure 7-13).

Of typical brackish water organisms, branchiopods (*Artemia*) were observed; they were present in samples from October 31 and November 1 in 2016. Mysids, shrimp-like crustaceans that were previously scarce (except for a peak of abundance in June 2017) were identified in spring 2018 and, to a lesser extent, in September 2016.

Copepods -- mostly cyclopoids -- were the most frequently observed organism; they were dominant in the months of January and February. Calanoids copepods made up the majority of the organisms counted for all samples (Figure 7-13). From an ecological point of view, copepods are the main food of numerous species of fish, and are often vectors within the life cycle of some parasites. Therefore, understanding the composition and diversity of this group will provide information on their role in the estuary's health.

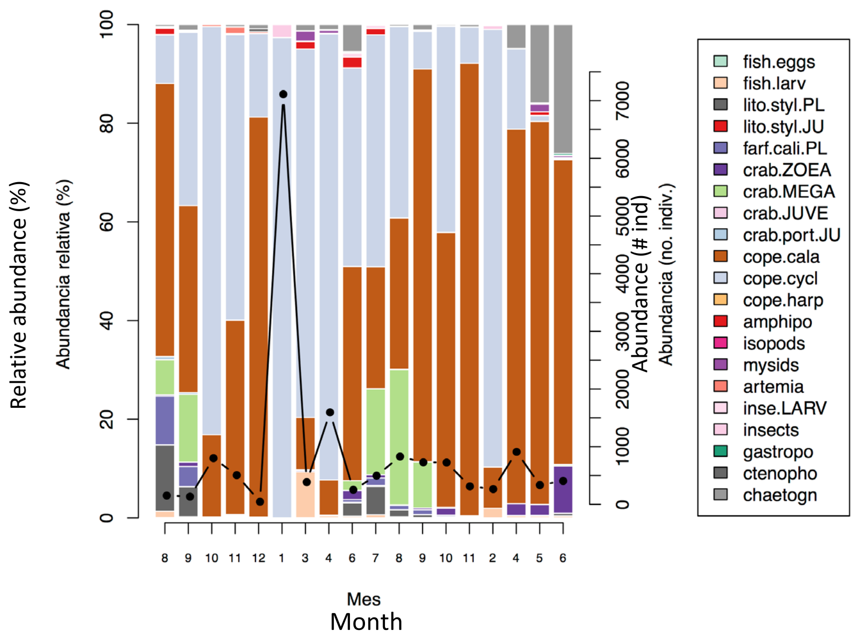


Figure 7-13. Monthly variation of the relative abundance of zooplankton groups, and of the total abundance of organisms per m^3. Sampling was not done in all months because of safety and difficulties with access to site.

Shrimp postlarvae were observed in 56 of the 66 samples analyzed. No postlarvae were captured between December and April (Figure 7-14). The abundance of postlarvae was higher than that reported by Galindo-Bect et al. (2007), considering both brown shrimp and blue shrimp together. The data show that high densities of shrimp postlarvae can be expected between June and September, regardless of the salinity differences observed between years. For example, the largest abundances of postlarvae were recorded between July and August 2017, in the middle of a summer with salinity values significantly lower than those of 2016.

The postlarvae of both shrimp species have a strong seasonal pattern with a maximum abundance in mid-summer. Although there was no clear relationship between abundance and salinity, these marine postlarvae clearly tolerate high salinity (Figure 7-14).

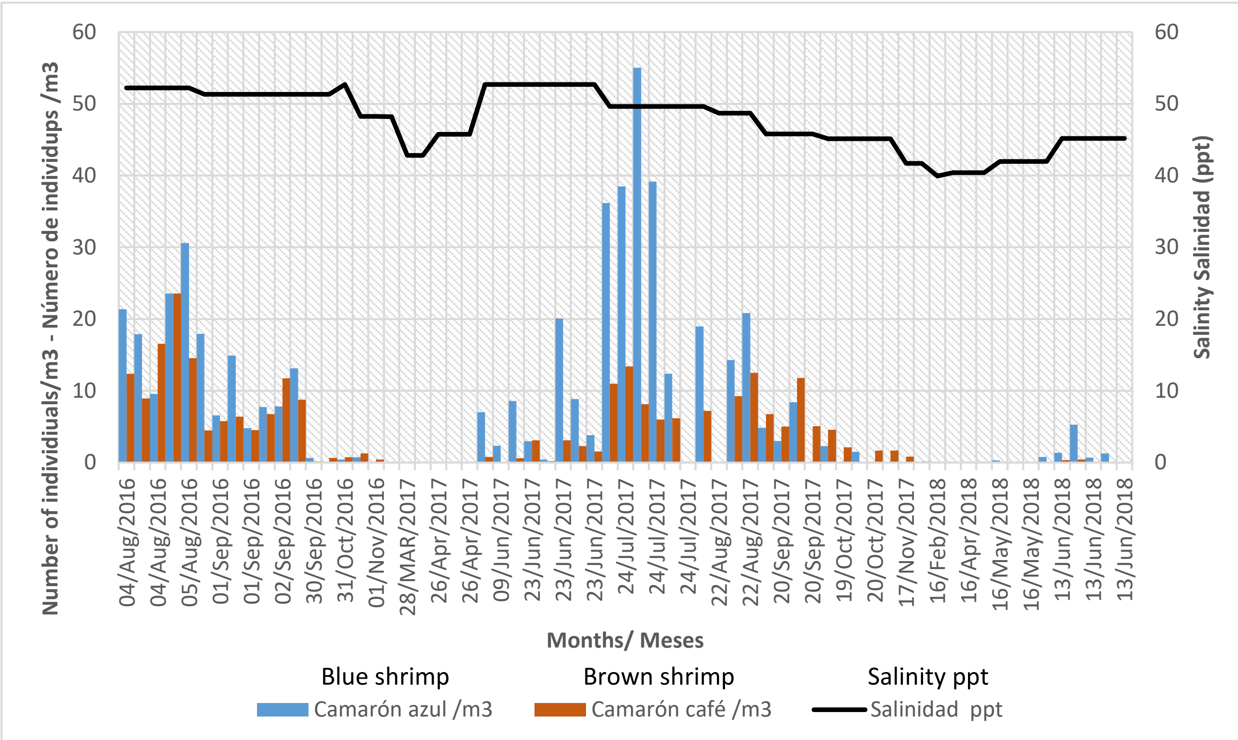


Figure 7-14. Monthly variation of post-larvae abundance of the two shrimp species. Site abandoned after June 2018 because of safety and difficulties with access.

Fish

Fish monitoring was conducted at seven points: one in the Hardy River and six in the Colorado River and its estuarine portion (Figure 7-7). Two fishing nets were placed at each point: a 63-mm (2.5-in) experimental net and an 89-mm (3.5-in) net for medium and large fish. In addition, a minnow trap was used for small fish. The monitoring was conducted every three months during 2018 in spring, summer, autumn and winter. The monitoring data from previous years (2014 to 2017) are shown here for comparison.

For the entire period (2014-2018), 925 individual fish from seven orders, 10 families and 15 species were collected and released (Table 7-3). The most abundant species was the machete (*Elops affinis*), followed by the flathead grey mullet (*Mugil cephalus*). Both species are marine, but their juveniles may enter the estuary area to feed. Other species with more than 40 captured specimens were the common carp (*Cyprinus carpio*), Mozambique tilapia (*Oreochromis mossambicus*) and the American gizzard shad (*Dorosoma cepedianum*). These three species occur in brackish and freshwater habitats, and are introduced into the Colorado River. The delta mudsucker (*Gillichthys detrusus*), an endemic species restricted to the estuarine zone, was also recorded.

A slight increase in the numbers of two freshwater species (common carp – from nine in 2014 to 29 in 2018 and the American gizzard shad – from zero in 2014 to 28 in 2018) and a decrease in the presence of marine species (machete and grey mullet) from 2014 to 2018 may be the result of a change from more saline conditions to more brackish conditions in 2015 and 2017.

Table 7-3. Abundance of fish by species and per year, in the seven monitoring points of the Hardy and Colorado Rivers and the Upper Estuary.

Order	Family	Species	2014	2015	2016	2017	2018	Total
Clupeiformes	Clupeidae	*Dorosoma cepedianum*	0	0	0	4	38	42
		Dorosoma petenense	0	1	0	0	0	1
Cypriniformes	Cyprinidae	*Carassius auratus*	0	0	0	2	0	2
		Cyprinus carpio	9	1	12	5	29	56
Cyprinodonti-formes	Poeciliidae	*Gambusia affinis*	0	0	0	0	1	1
		Poecilia latipinna	0	0	10	0	0	10
Elopiformes	Elopidae	*Elops affinis*	65	243	57	42	55	462
Gonorynchiformes	Chanidae	*Chanos chanos*	1	0	0	0	0	1
Mugiliformes	Mugilidae	*Mugil cephalus*	32	27	127	36	32	254
Perciformes	Centrarchidae	*Micropterus salmoides*	0	16	0	3	16	35
		Pomoxis annularis	0	0	0	1	0	1
	Cichlidae	*Coptodon zillii*	0	0	0	2	0	2
		Oreochromis mossambicus	3	21	0	3	17	44
	Eleotridae	*Dormitator latifrons*	0	1	0	0	0	1
	Gobiidae	*Gillichthys detrusus*	0	0	0	0	13	13
Total			**110**	**310**	**206**	**98**	**201**	**925**

Biological changes could not be unambiguously attributed to the environmental flows.

Salt grass

Saltgrass (*Distichlis spp.*) is an important genus of salt-tolerant grass in Pacific coast intertidal wetlands (Zedler, 2005) and is a target species for restoration efforts there. *Distichlis palmeri* in the upper Gulf of California provides habitat for intertidal invertebrates and juvenile fish. Detritus from its decomposing leaves and roots is an important link in estuarine food webs.

During the February and October 2018, drone overflights were conducted in an area of 111 hectares (274 acres) to document the extent and seasonal occurrence of salt grass. The drone traveled a length of 16.8 km (10.4 mi) for 25 minutes. The flight plan was designed through the dronedeploy web application. Overflight altitude was 150 m (492 ft), with a 75% frontal overlap and a 70% horizontal overlap, which generated a total of 237 photographs. An orthomosaic was created using the photographs on ESRI's drone2map software. (Figure 7-15).

The area occupied by the salt grass was estimated through a digitization process applied to the orthomosaic to delineate each of the 283 patches (elements) of salt grass that were selected on the first monitoring flight in August 2017.

The area of salt grass decreased by 0.11 ha (0.27 acres) from October 2017 to February 2018, perhaps reflecting a seasonal pattern of herbaceous expansion and contraction. By October 2018, there was an increase of 3.25 ha (8 acres) of coverage since February 2018 and an increase of 3.14 ha (7.8 acres) since October 2017 (Table 7-4). The increase in the area of salt grass may reflect changes in estuary conditions due to restoration actions or natural variation.

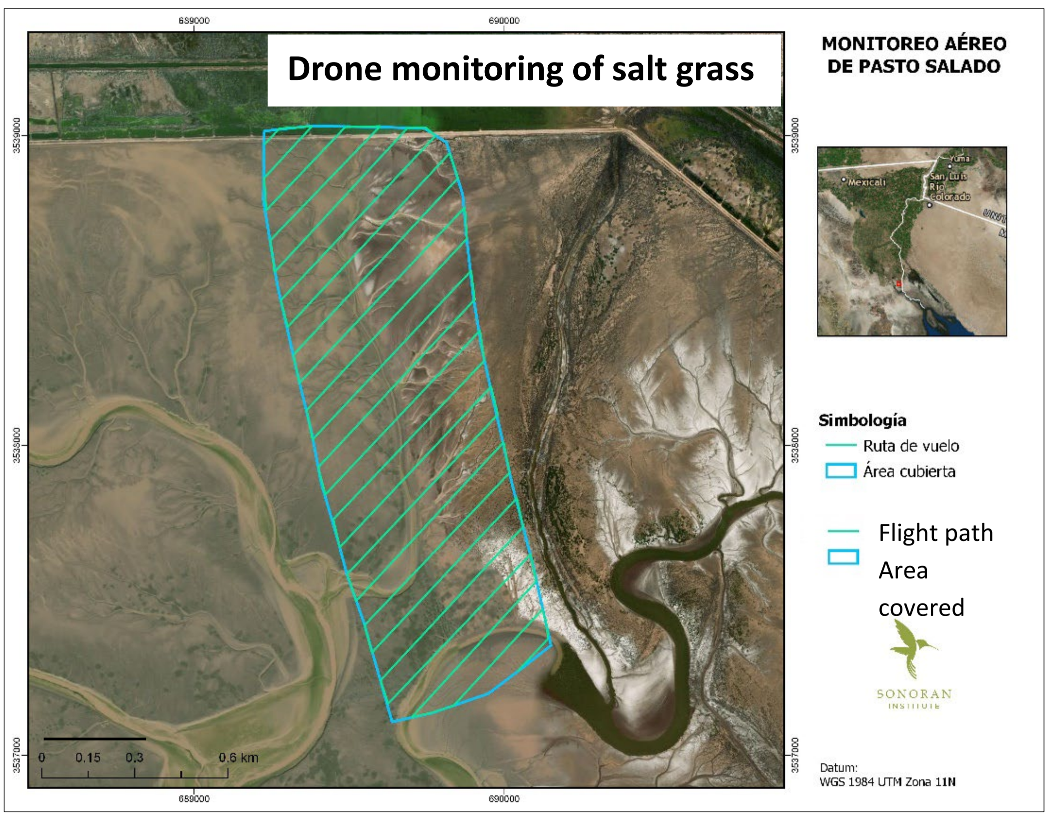


Figure 7-15. Location of the salt grass monitoring area, flight plan and drone flight route. Horizontal line above km scale = 0.2 miles

Table 7-4. Salt grass extent by season in the monitoring area.

Season	Area (hectares)	Increase (%)	
		From the previous season	Cumulative
Summer 2017 (August)	5.12	0 (initial survey)	0 (initial survey)
Fall 2017 (October)	5.99	16	1
Spring 2018 (February)	5.88	-2	14
Fall 2018 (October)	9.13	55	78

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Section 8: General Conclusions and Recommendations

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General conclusions

In 2018, the first year of Minute 323, approximately 12 million m^3 (9,700 af) of water was delivered for environmental purposes. While generally sufficient to sustain restored riparian habitat, some water deliveries did not conform to the requested amounts and schedules. Groundwater levels continue to decline in Reaches 1-3. Starting in Reach 4, and continuing downstream, irrigation return flows and environmental water deliveries maintained a shallow water table.

Restoration sites have a significantly higher average foliar cover, densities, and total vegetation volume of native species than control sites, indicating that restoration actions through 2018 have successfully increased the extent and distribution of desirable native riparian plants as well as reduced the extent and distribution of undesirable and nonnative species.

At the reach scale, vegetation greenness continued to decline to 2013 (pre-pulse flow) levels.

Bird diversity and abundance of indicator species are significantly higher at the restoration sites than in unrestored control sites. However, the abundance of indicator riparian bird species has been declining since 2015, including a significant decline at the restoration sites from 2017 to 2018.

In the Upper Estuary, the areal extent of saltgrass increased, while other metrics were largely unchanged. Increased connectivity and delivery of environmental water through the Ayala Drain had no measurable effect on the Upper Estuary's salinity, water level or biological characteristics.

Recommendations

1. <u>Timely notification of water delivery to restoration sites</u>. Readily deployable technology exists to convey real-time hourly flow data to responsible parties via cell phone. This capacity was tested successfully in 2018. Restoration depends on the delivery of water to sites at the right times and in the right amounts.

2. <u>Integrating water management across sites</u> can achieve multiple social and ecological outcomes. Monitoring surface water flow and groundwater levels between restoration sites will complement onsite measurements and remotely sensed evapotranspiration. Together, these data can explain the fate and environmental effects of water after it leaves a restoration site.

3. <u>Annual Adaptive Management Workshops</u> can support continual learning and improvement by reviewing scientific findings and restoration outcomes by involving restoration teams, the Binational Science Team, and the Environmental Work Group. The workshop can serve to update monitoring and reporting protocols based on experience and technological improvements.

4. Annual review of monitoring priorities and budgets. The Binational Science Team and the Environmental Work Group can ensure that funds are allocated to the highest priorities via coordinated reviews of all funded activities and budgets.

5. Monitoring of the social and recreational benefits of the water for the environment could facilitate community support for restoration activities.

6. Development of a binational monitoring database can both archive monitoring data and enable interdisciplinary, integrative analyses and systematic improvement in both restoration and monitoring practices.

7. A standard format for monitoring reports can result in an efficient system for reporting and presenting monitoring results.

Appendix A. Hydrology Monitoring Network

Surface-water discharge monitoring stations

Organization responsible for monitoring is listed in “owner” column. DMS-13, DMS-14, and DMS-15 were measured by the Universidad Autónoma de Baja California (UABC) during the 2014 pulse flow; Sonoran Institute (SI) assumed responsibility in October 2014.

Site	Location	Owner	Period of Record	
			Start Date	End Date
NIB	Northern International Boundary at Morelos Dam	CILA	4/23/2014	active
DMS-0	Below Morelos Dam, R1	USGS	3/27/2014	4/23/2014
DMS-1	Below Morelos Dam, R1	USGS	3/24/2014	3/27/2014
DMS-2	5.5 km downstream Morelos Dam, R1	USGS	3/24/2014	4/23/2014
DMS-3	26.5 km downstream Morelos Dam, R2	USGS	3/24/2014	3/27/2014
DMS-3A	27 km downstream Morelos Dam, R2	USGS	3/29/2014	4/23/2014
DMS-4	SIB, 33.5 km downstream Morelos Dam, R3	IBWC	3/26/2014	4/21/2014
DMS-5	Km 27 Spillway, R3	UABC	4/13/2014	5/2/2014
IFON	37 km downstream Morelos Dam, R3	UABC	3/29/2014	4/7/2014
MS-6	46.5 km downstream Morelos Dam, R3	UABC	3/29/2014	5/3/2014
DMS-7	61 km downstream Morelos Dam, R3	UABC	4/3/2014	5/3/2014
MS-8	68 km downstream Morelos Dam, R4	UABC	3/23/2014	5/7/2014
DMS-9	Km 18 Spillway, R4	UABC	5/5/2014	5/20/2014
DMS-10	79 km downstream Morelos Dam, R4	UABC	3/23/2014	5/20/2014
DMS-11	86.7 km downstream Morelos Dam, R4	UABC	3/23/2014	5/25/2014
DMS-12	91.6 km downstream Morelos Dam, R5	UABC	4/9/2014	5/25/2014
DMS-12 new	Vado Carranza	UABC	2018	active
DMS-13	Hardy River Campo Muñoz, R6	UABC	3/24/2014	active
DMS-14	Ayala Drain, R7	UABC	3/24/2014	active
DMS-15	121.6 km downstream Morelos Dam, R7	UABC	3/24/2014	active
DMS-16	Immediately above Laguna Grande	UABC	2018	active
DMS-17	Pilot channel between R5 and R7	UABC	2018	active
DMST-1	La Herradura water delivery point, R4	SI	2018	active
DMST-2	CORI water delivery point, R4	SI	2018	active
FDA	Ayala Drain, R7	SI	9/26/2017	active
L1	R7	SI	1/26/2017	active

Staff gauges installed in 2018

Site name	Coordinates UTM Zone 11 WGS84		
	X (m)	Y (m)	Z (m.a.s.l)
RGS1-1	712,067	3,618,952	28.283
RGS1-2	709,310	3,613,621	27.317
RGS1-3	706,419	3,607,820	25.289
RGS4-4	689,022	3,577,411	11.727
RGS4-5	684,333	3,572,057	11.321
RGS4-6	683,458	3,569,444	10.652
RGS4-7	683,190	3,568,150	10.674
RGS4-8	682,981	3,567,080	10.374
RGS4-9	681,831	3,566,265	9.814
RGS4-10	675,805	3,563,487	9.045
RGS4-11	669,869	3,558,823	6.530

Piezometer construction data

Notes:

- Type of data collected: c = continuous water level, d = discrete water level.
- Status: d = dry, x = destroyed, f = functioning.
- Owner: CONAGUA = Comisión Nacional del Agua, UABC = Universidad Autónoma de Baja California, PN = Pronatura Noroeste
- MP Elev = measuring point elevation; m a.s.l = meters above sea level; m b.l.s = meters below land surface.

Site name	Coordinates UTM Zone 11 WGS84		Type of Data Collected	Status	MP Elev (m a.s.l) NAVD88	Total Depth (m b.l.s)	Screen Depth (m b.l.s)	Owner
	X	Y						
N1	711,916.57	3,619,048.46	c, d	f	37.03	8.21	7-8.2	CONAGUA
N2	712,019.67	3,618,978.44	c, d	f	35.57	6.75	5.7-6.7	CONAGUA
N3	708,826.44	3,613,971.88	c, d	f	34.90	unknown	>100	UABC
N4	709,244.46	3,613,684.78	c, d	f	31.66	4.27	4.27-3.27	CONAGUA
N5	706,119.20	3,607,700.45	c, d	d	28.64	5.86	5.86-4.86	CONAGUA
N6	706,315.05	3,607,762.51	c, d	d	28.57	2.83	SEDIMENTED	UABC
N7	705,333.72	3,603,893.10	c, d	d	26.77	8.15	8.1-7.1	UABC
N8	705,451.49	3,604,064.36	c, d	d	27.32	8.63	8.63-7.63	UABC
N8 new	705,444.34	3,604,048.66	d	f	27.40	20.41	18.9	UABC
N9	706,579.23	3,603,982.76	d	f	27.96	20.93	19.4	UABC
N10	706,217.45	3,607,741.73	d	f	30.15	19.04	17.6	UABC
MA1-A	704,825.57	3,602,602.79	d	f	25.67	18.91	18.91-17.91	PN
MA2-A	704,575.67	3,602,002.18	d	f	27.987	20.93	20.93-19.93	PN
MA3-A	704,153.55	3,602,083.36	d	f	25.686	21.82	21.82-20.82	PN
MA4-A	705,115.23	3,601,363.11	d	f	27.399	20.615	20.61-19.61	PN
MA1	704,435.12	3,602,659.63	c, d	d	25.16	9.29	9.29-8.29	UABC-PN
MA2	704,957.63	3,602,481.52	c, d	d	22.83	4.51	SEDIMENTED	UABC-PN

MA3	705,644.50	3,602,341.68	c, d	d	26.98	8.11	SEDIMENTED	CONAGUA
MA4	706,047.70	3,602,172.90	c, d	d	23.13	2.32	2.32-1.32	UABC-PN
MA5	704,469.09	3,601,494.32	c, d	d	26.73	9.61	9.61-8.61	UABC-PN
MA6	705,093.87	3,601,423.91	c, d	d	26.14	7.70	7.7-6.7	UABC-PN
MA7	705,619.57	3,601,524.82	c, d	d	27.22	8.81	8.8-7.8	UABC
MA8	705,074.99	3,600,266.92	c, d	d	26.23	8.89	8.8-7.8	UABC
MA9	705,456.30	3,600,249.25	c, d	d	25.96	8.48	8.4-7.4	UABC
MA10	704,756.38	3,599,321.82	c, d	d	25.44	12.19	12.19-11.19	CONAGUA
MA11	705,368.73	3,599,350.23	c, d	d	25.90	10.53	10.53-9.53	UABC
MA12	705,706.58	3,599,335.20	c, d	d	25.44	10.79	10.79-9.79	UABC
MA13	704,873.47	3,598,252.61	c, d	d	25.15	10.52	10.52-9.52	UABC
MA14	705,100.68	3,598,266.69	c, d	d	25.33	11.37	11.37-10.37	UABC
MA15	705,243.66	3,598,225.14	c, d	d	24.99	11.04	11-10'	CONAGUA
P1	699,537.00	3,597,004.95	c, d	d	22.02	12.75	12-11'	CONAGUA
P2	699,350.55	3,595,972.39	c, d	d	22.55	13.67	13.6-12.6	UABC
P3	699,319.37	3,595,638.77	c, d	d	23.32	13.78	13.7-12.7	UABC
P4	699,257.88	3,595,200.98	c, d	d	22.70	12.41	12.4-11.4	UABC
P5	693,616.99	3,591,553.95	c, d	d	20.56	9.33	9.3-8.3	CONAGUA
P6	693,809.99	3,591,423.01	c, d	d	21.02	8.70	8.7-7.7	UABC
P7	694,054.97	3,591,288.98	c, d	d	20.32	12.10	12.1-11.1	UABC
P8	694,350.98	3,591,089.95	c, d	d	19.65	10.44	10.4-9.4	UABC
P9	691,519.99	3,583,881.97	c, d	d	17.52	8.47	8.4-7.4	CONAGUA
P9 new	691,520.99	3,583,884.13	d	f	17.37	18.56	17.1	UABC
P10	691,628.04	3,583,838.00	c, d	x	15.47	7.07	7.07-6.07	UABC
P11	691,683.00	3,583,808.98	c, d	x	17.56	9.45	9.45-8.45	UABC
P12	691,954.97	3,583,742.96	c, d	x	16.20	7.44	7.4-6.4	UABC
P13	705,461.33	3,596,385.65	c, d	x	28.52	18.28	18.2-17.2	CONAGUA
P14	705,244.14	3,596,478.12	c, d	f	24.77	15.99	15.9-14.9	UABC
P15	705,124.88	3,596,559.24	c, d	f	25.07	17.06	17.06-16.06	UABC
P16	704,973.24	3,596,675.51	d	d	25.32	16.12	16.12-15.12	UABC
P17	702,370.24	3,594,659.43	c, d	f	24.15	15.94	15.9-14.9	CONAGUA
P18	702,318.12	3,595,136.73	c, d	f	24.07	15.27	15.2-14.2	UABC
P19	702,165.98	3,595,718.95	d	d	25.63	13.85	13.8-12.8	UABC
P20	702,005.86	3,596,199.75	c, d	d	24.64	12.13	12.1-11.1	UABC
P21	691,613.65	358,205.03	d	f	18.99	20.88	19.4	UABC
CH-1	684,838.96	3,572,126.01	c, d	x	18.11	7.68	7.6-6.6	CONAGUA
CH-2	684,449.23	3,572,028.11	c, d	x	16.82	8.14	8.1-7.1	UABC
CH-3	684,277.25	3,572,082.35	c, d	f	15.43	5.00	SEDIMENTED	UABC
CH-3a	684,146.28	3,572,093.46	c, d	f	16.03	7.30	7.3-6.3	UABC
CH-4	684,057.38	3,572,046.63	c, d	f	15.27	6.90	6.9-5.9	UABC
CH-5	689,263.88	3,577,344.91	c, d	f	16.71	6.97	6.9-5.9	CONAGUA
CH-6	689,109.10	3,577,408.80	c, d	f	14.69	7.40	7.4-6.4	UABC
CH-7	688,926.41	3,577,446.64	c, d	x	19.48	10.10	10.1-9.1	UABC

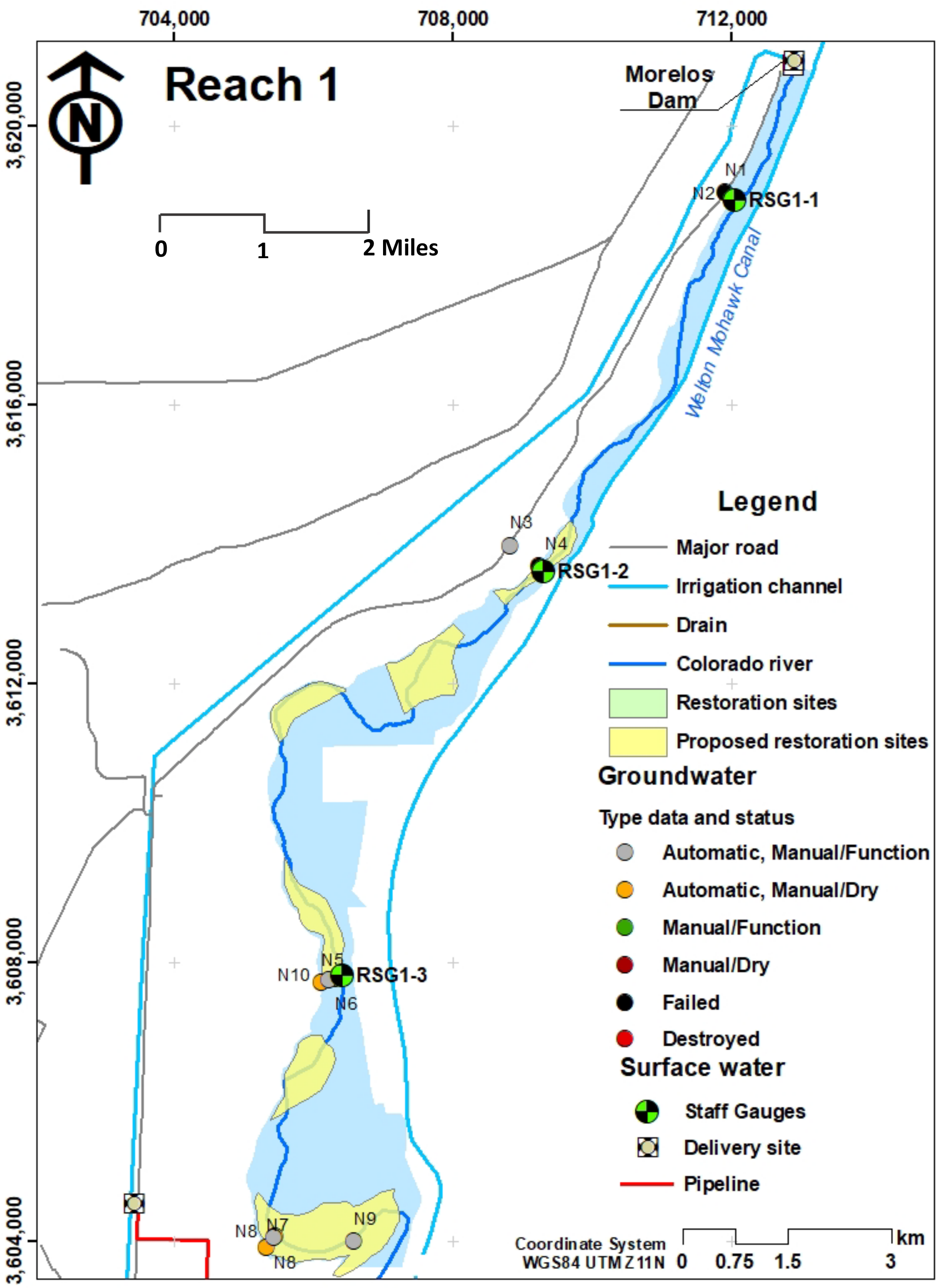
CH-8	688,776.12	3,577,552.61	c, d	f	19.42	8.79	8.7-7.7	CONAGUA
RC1	683,035.64	3,569,351.85	c, d	f	15.48	8.28	8.2-7.2	UABC
RC2	683,310.17	3,569,377.08	c, d	f	15.40	5.96	5.9-4.9	CONAGUA
RC3	683,579.99	3,569,341.01	c, d	f	16.01	6.33	6.3-5.3	UABC
RC4	683,700.22	3,569,314.61	c, d	f	15.08	4.37	4.3-3.3	UABC
RC5	681,578.11	3,566,897.76	c, d	f	13.85	7.49	7.4-6.4	UABC
RC6	681,714.15	3,566,445.20	c, d	f	13.93	5.39	5.3-4.3	CONAGUA
RC7	681,866.71	3,566,127.13	c, d	f	12.38	2.92	SEDIMENTED	UABC
RC8	681,864.87	3,565,940.37	c, d	f	13.90	5.36	5.3-4.3	UABC
RC9	682,625.86	3,567,489.88	c, d	f	14.44	4.20	4.2-3.2	CONAGUA
RC10	682,817.58	3,567,235.41	c, d	f	13.80	5.02	5.02-4.02	UABC
RC11	683,183.89	3,567,117.63	c, d	f	14.66	6.01	6.01-5.01	UABC
RC12	683,506.00	3,566,750.34	c, d	f	14.89	5.81	5.8-4.8	UABC
RC13	678,111.16	3,565,428.64	c, d	f	11.98	5.38	5.3-4.3	UABC
RC14	678,244.31	3,565,351.75	c, d	f	12.33	6.04	6.04-5.04	CONAGUA
RC15	678,768.33	3,565,005.57	c, d	f	12.46	7.28	7.2-6.2	UABC
RC16	679,223.81	3,564,687.09	c, d	f	12.23	7.32	7.3-6.3	CONAGUA
RC17	675,678.30	3,564,205.24	c, d	f	11.79	5.90	5.9-4.9	CONAGUA
RC18	675,820.58	3,563,564.94	c, d	f	11.70	9.49	9.4-8.4	UABC
RC21	673,577.32	3,564,097.58	c, d	f	11.20	4.97	4.9-3.9	CONAGUA
RC22	673,540.33	3,563,720.93	c, d	f	11.46	5.15	5.1-4.1	UABC
RC23	673,457.02	3,563,355.51	c, d	f	10.88	6.13	6.1-5.1	UABC
RC24	673,629.83	3,563,050.44	c, d	f	11.22	6.92	6.9-5.9	CONAGUA
RC25	676,262.74	3,563,197.91	c, d	f	10.85	4.44	4.4-3.4	UABC
RC26	672,087.70	3,563,968.70	c, d	f	11.03	9.74	9.7-8.7	UABC
RC27	672,300.50	3,563,396.19	c, d	f	10.93	6.83	6.8-5.8	CONAGUA
RC28	678,201.55	3,564,551.17	c, d	f	12.05	4.65	4.6-3.6	UABC
RC29	678,358.40	3,564,350.21	c, d	f	12.69	6.91	6.9-5.9	UABC
RC30	684,287.51	3,570,468.91	d	f	13.47	12.20	10.7	UABC
RC31	683,000.27	3,568,093.00	d	f	15.83	12.65	11.2	UABC
RC32	683,404.99	3,568,139.82	d	f	12.23	8.63	7.1	UABC
RC33	671,344.20	3,561,397.46	d	f	10.18	12.48	11	UABC
RC34	669,846.75	3,560,624.69	d	f	9.96	12.65	11.2	UABC
RC35	669,848.37	3,558,948.23	d	f	10.00	12.69	11.2	UABC
H1	682,064.01	3,566,572.67	d	f	12.97	2.22	0.55 - 2.13	SI
H2	681,934.20	3,566,914.90	d	f	13.06	2.23	0.61 - 2.22	SI
H3	681,814.19	3,567,175.58	d	f	12.28	2.38	0.74 - 2.37	SI
H4	681,979.35	3,567,269.02	d	f	12.73	2.52	0.85 - 2.40	SI
H5	681,945.22	3,567,367.39	d	f	12.76	5.48	1.50 - 2.73	SI
H6	682,189.85	3,567,351.10	d	f	12.97	5.33	3.02 - 3.61	SI
H7	682,375.13	3,567,136.43	d	f	12.79	3.65	2.04 - 2.91	SI
H8	682,528.89	3,566,813.32	d	f	14.11	4.72	1.95 - 2.93	SI
CORI 1	680,500.71	3,566,605.13	d	f	12.35	3.57	1.54 -2.93	SI

CORI 2	680,766.86	3,566,242.09	d	f	13.64	5.36	3.26 - 4.30	SI
CORI 3	679,731.82	3,566,479.19	d	f	13.25	6.4	2.50 - 3.78	SI
CORI 4	679,818.04	3,565,973.39	d	f	13.25	6.49	2.65 - 3.89	SI
CORI 5	678,907.79	3,566,018.63	d	f	13.01	6.82	2.29 - 3.58	SI
CORI 6	678,962.84	3,565,764.46	d	f	12.45	5.14	1.84 - 3.17	SI
CORI 7	681,154.20	3,566,600.76	d	f	12.66	6.05	2.16 - 3.32	SI
CORI 8	680,306.98	3,566,248.26	d	f	12.47	5.09	1.98 - 2.93	SI
CORI 9	679,392.39	3,566,010.64	d	f	12.80	4.74	2.35 - 3.39	SI
CORI 10	678,705.29	3,565,560.87	d	f	12.71	5.09	2.32 - 3.41	SI
CILA Nuevo	677,701.60	3,564,964.48	d	f	12.41	6.85	2.01 - 3.81	SI
Isla CILA	677,849.25	3,564,875.42	d	f	11.34	4.51	1.01 - 2.6	SI
PZ1	678,202.38	3,564,549.99	d	f	12.02	4.62	1.51 - 3.40	SI
PZ2	678,358.48	3,564,350.19	d	f	12.72	6.36	2.35 -4.22	SI
PZ3	678,673.86	3,564,305.14	d	f	12.95	5.3	2.00 - 4.15	SI
PZ4	678,563.91	3,564,561.98	d	f	12.34	5.05	1.58 - 3.46	SI
PZ5	678,473.17	3,564,725.86	d	f	12.22	5.73	1.25 - 3.55	SI
PZ6	678,802.99	3,564,697.00	d	f	12.56	5.02	1.98 - 3.57	SI
PZ7	678,660.03	3,564,865.48	d	f	11.96	5.91	1.32 - 4.06	SI
IZ1	679,511.33	3,565,435.45	d	f	12.42	4.17	2.36 - 3.25	SI
IZ2	679,811.21	3,565,025.09	d	f	13.35	6.6	3.42 - 4.48	SI
IZ3	680,910.74	3,565,828.97	d	f	13.18	5.41	2.90 - 4.61	SI
IZ4	681,028.51	3,565,511.26	d	f	13.91	5.82	3.87 - 4.82	SI
E1	673,317.79	3,544,913.32	d	f	4.99	6.68	1.80 - 2.58	SI
E2	671,289.42	3,547,143.99	d	f	5.54	6.21	2.04 -2.99	SI
E3	670,015.63	3,544,927.13	d	f	5.12	3.03	2.12 - 3.51	SI
E4	669,785.33	3,544,906.07	d	f	5.30	4.78	3.3-4.8	SI
E5	669,169.53	3,546,078.97	d	f	5.34	6.65	2.22 - 3.20	SI
E6	663,148.65	3,558,934.25	c, d	f	6.39	6.19	4.7-6.2	SI
E7	666,249.02	3,557,375.98	c, d	f	5.34	7.12	5.6-7.1	SI
E8	671,194.01	3,555,766.54	d	f	6.30	6.35	4.88 - 5.18	SI
E9	673,384.86	3,553,795.34	d	f	5.70	5.94	3.88 - 4.15	SI
E10	676,662.00	3,550,877.00	d	f	4.12	4.61	2.22 - 2.98	SI
E11	679,417.00	3,546,407.00	d	f	3.75	4.99	1.48 - 1.97	SI

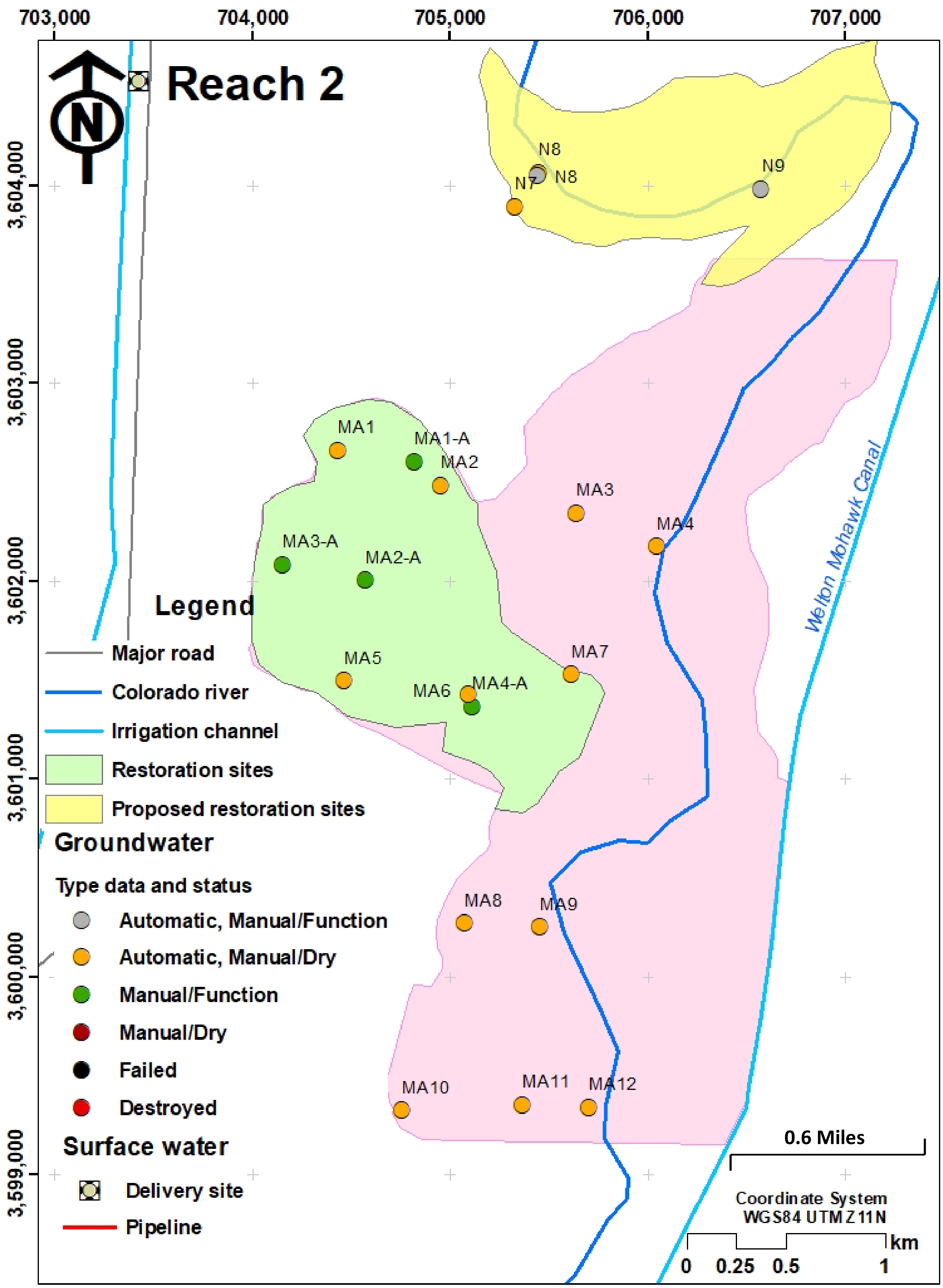
Maps

The following maps depict the status of hydrologic monitoring network components and the types of measurements made during 2018. Source: UABC and Enviro Terra Soluciones SC (2019). Sites monitored by Restauremos el Colorado are not shown.

Reach 1



Reach 2



Reach 2
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3,599,000
N8
N8
N7
N9
MA1
MA1-A
MA2
MA3
MA4
MA3-A
MA2-A
MA5
MA6
MA4-A
MA7
MA8
MA9
MA10
MA11
MA12
Wellton Mohawk Canal
Legend
Major road
Colorado river
Irrigation channel
Restoration sites
Proposed restoration sites
Groundwater
Type data and status
Automatic, Manual/Function
Automatic, Manual/Dry
Manual/Function
Manual/Dry
Failed
Destroyed
Surface water
Delivery site
Pipeline
0.6 Miles
Coordinate System
WGS84 UTM Z11N
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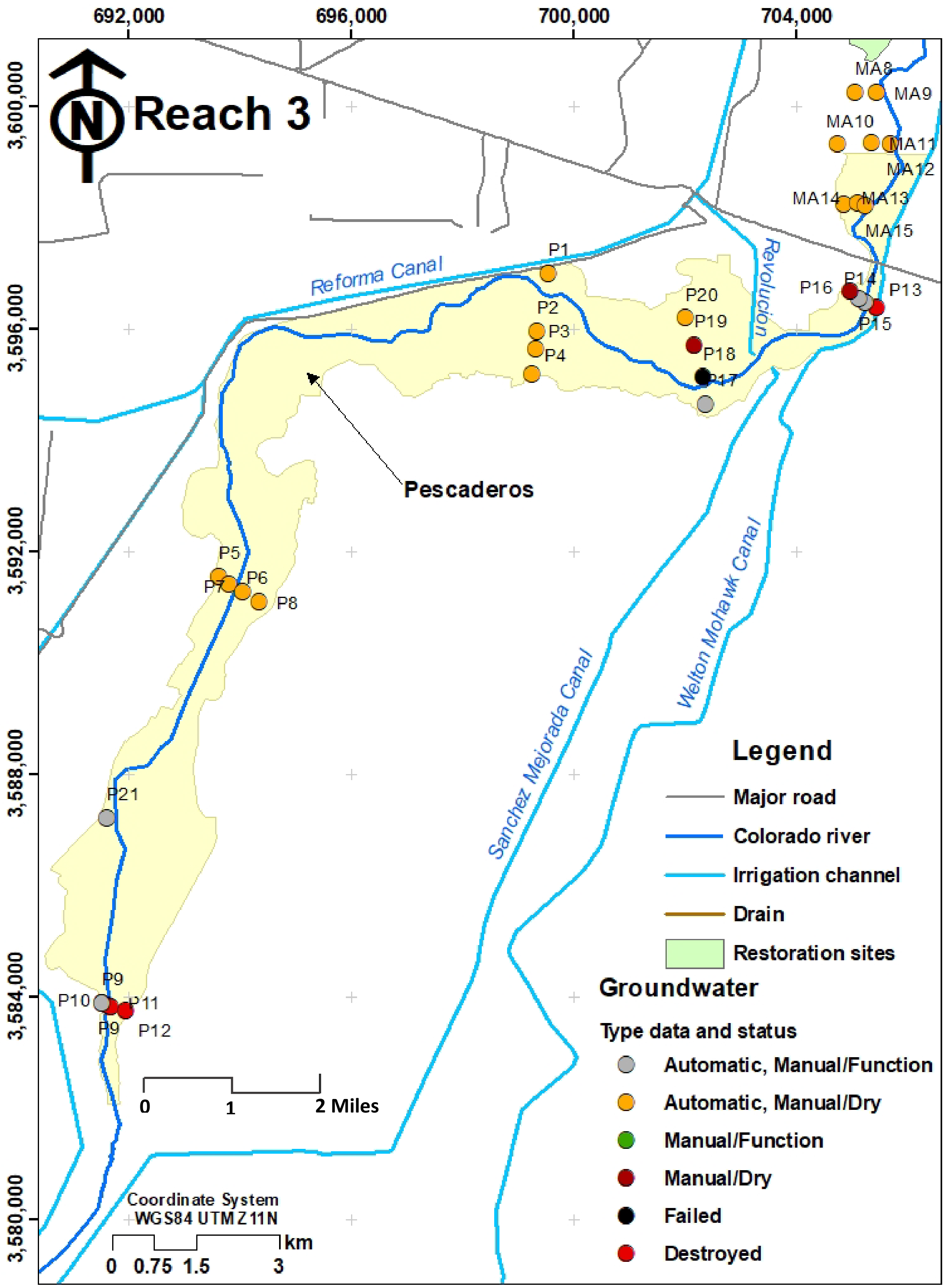
0.25
0.5
1
km

Reach 3



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704,000
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3,584,000
3,580,000
N
Reach 3
Reforma Canal
Revolucion
Pescaderos
Sanchez Mejorada Canal
Welton Mohawk Canal
MA8
MA9
MA10
MA11
MA12
MA13
MA14
MA15
P1
P2
P3
P4
P5
P6
P7
P8
P9
P10
P11
P12
P13
P14
P15
P16
P17
P18
P19
P20
P21
Legend
Major road
Colorado river
Irrigation channel
Drain
Restoration sites
Groundwater
Type data and status
Automatic, Manual/Function
Automatic, Manual/Dry
Manual/Function
Manual/Dry
Failed
Destroyed
0 1 2 Miles
Coordinate System
WGS84 UTM Z11N
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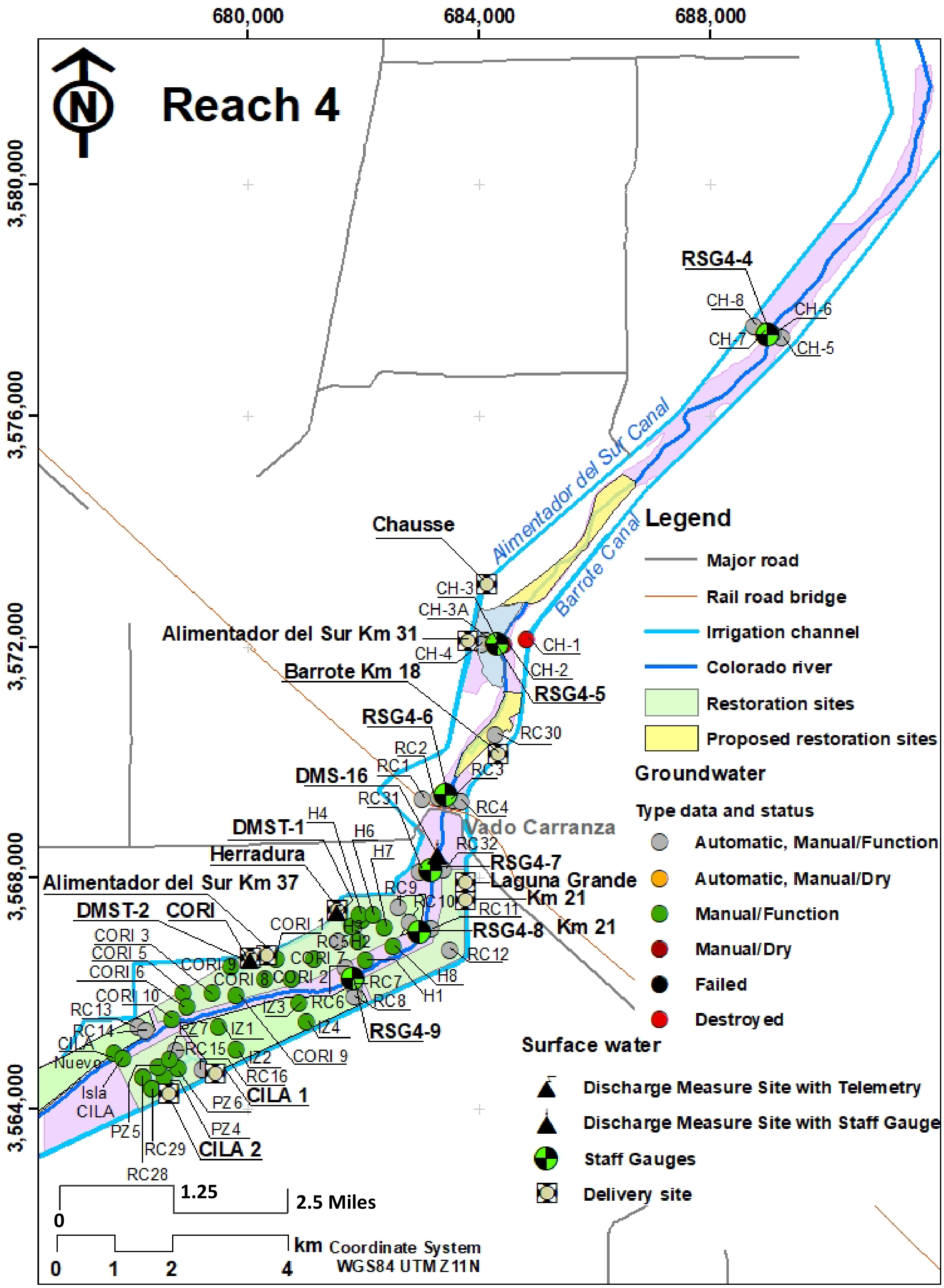
Reach 4


Reach 4
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3,564,000
Alimentador del Sur Canal
Barrote Canal
RSG4-4
CH-8
CH-6
CH-7
CH-5
Chausse
CH-3
CH-3A
Alimentador del Sur Km 31
CH-4
CH-1
CH-2
Barrote Km 18
RSG4-5
RSG4-6
RC30
RC2
RC1
RC3
DMS-16
RC31
RC4
H4
DMST-1
H6
Vado Carranza
Herradura
H7
RC32
RSG4-7
Laguna Grande
Alimentador del Sur Km 37
RC9
RC10
Km 21
RC11
Km 21
DMST-2
CORI
CORI 1
RC5
H3
H2
RSG4-8
CORI 3
CORI 5
CORI 9
CORI 7
RC12
CORI 6
CORI 8
CORI 2
RC7
H8
CORI 10
IZ3
RC6
RC8
H1
RC13
PZ7
IZ1
IZ4
RSG4-9
RC14
CILA Nuevo
RC15
IZ2
CORI 9
RC16
CILA 1
Isla CILA
PZ6
PZ5
PZ4
RC29
CILA 2
RC28
Legend
Major road
Rail road bridge
Irrigation channel
Colorado river
Restoration sites
Proposed restoration sites
Groundwater
Type data and status
Automatic, Manual/Function
Automatic, Manual/Dry
Manual/Function
Manual/Dry
Failed
Destroyed
Surface water
Discharge Measure Site with Telemetry
Discharge Measure Site with Staff Gauge
Staff Gauges
Delivery site
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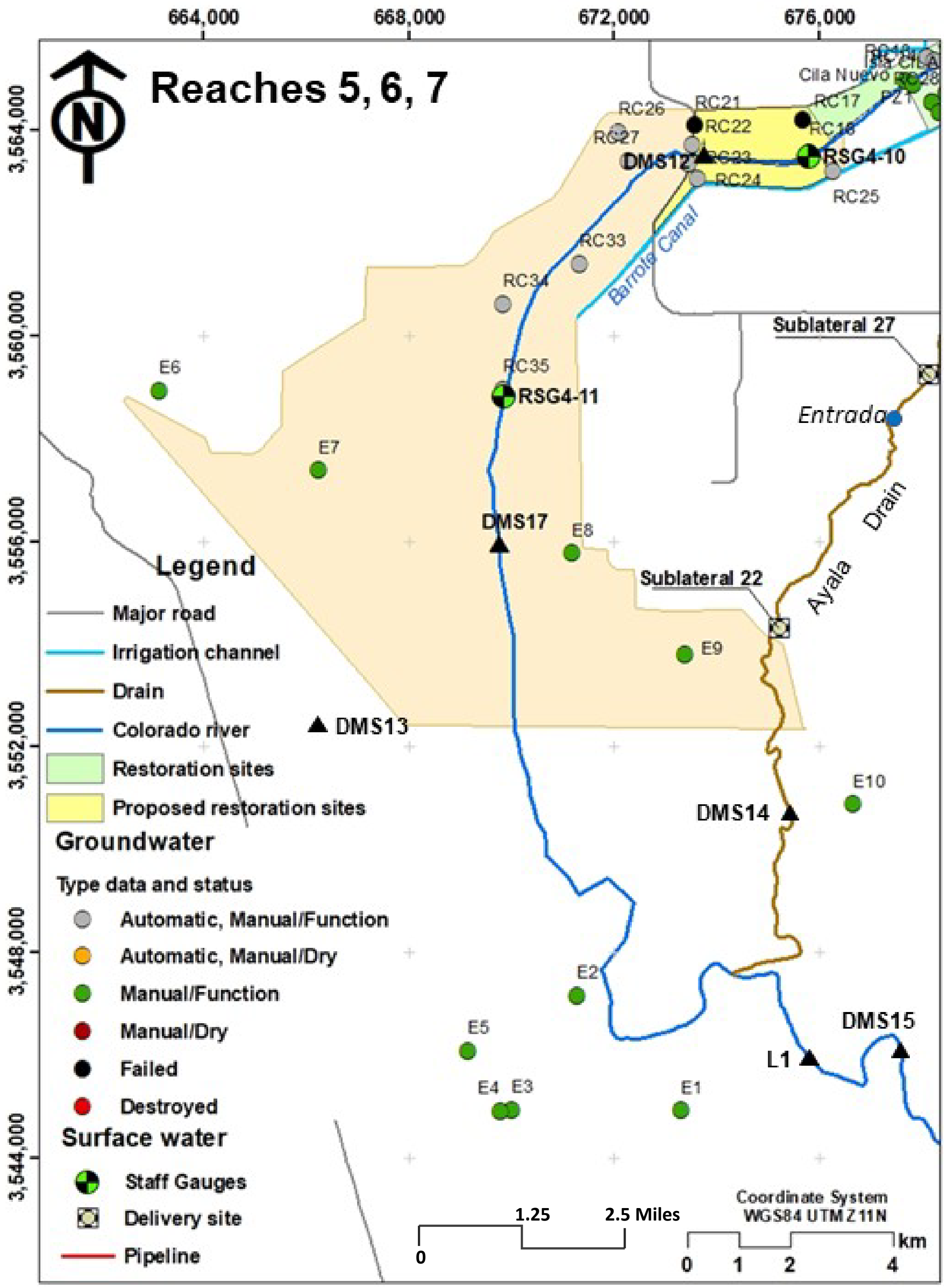
1.25
2.5 Miles
0
1
2
4
km
Coordinate System
WGS84 UTM Z11N

Reaches 5, 6, and 7



Appendix B. Vegetation Monitoring

Site Maps

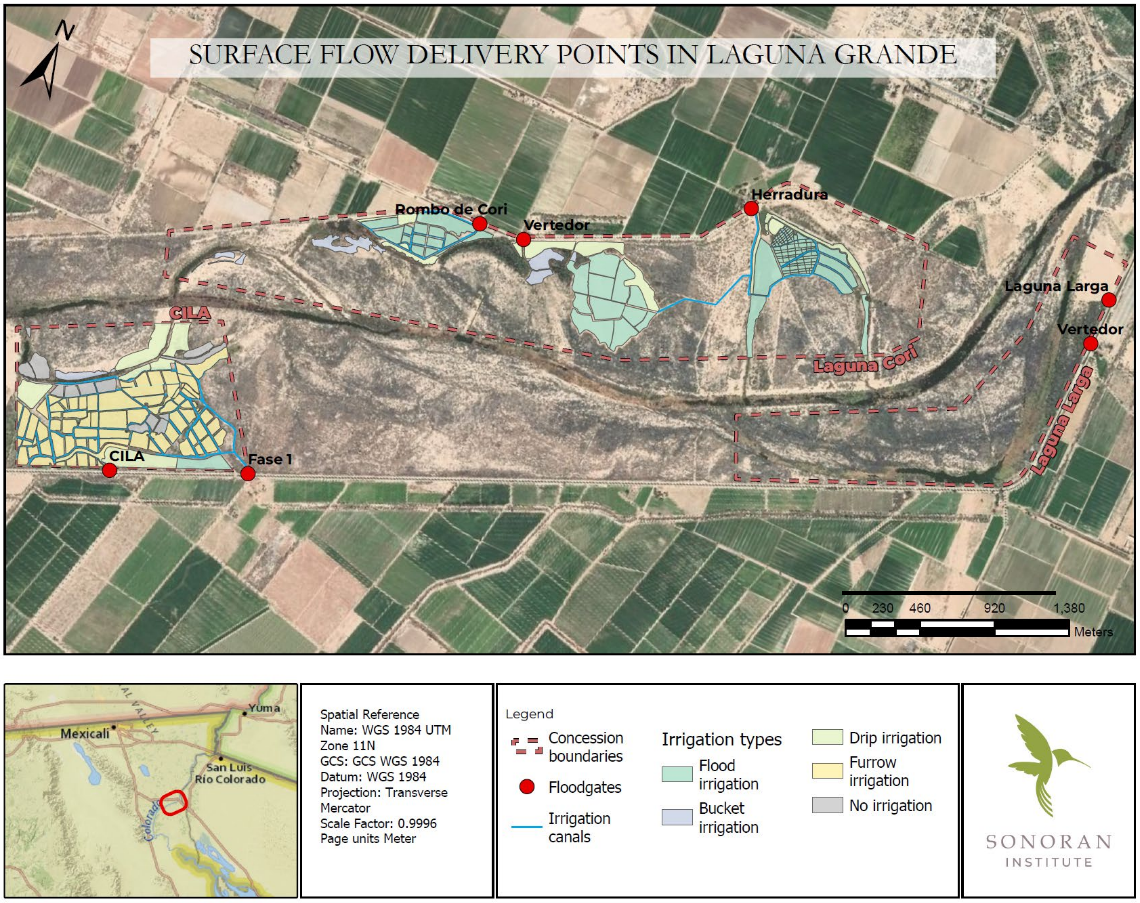


Figure B-1. Laguna Grande water delivery points and irrigation types in restored areas. Solid line above metric scale = 4,000 ft.

Figure B-2. The Miguel Aleman restoration site with 2018 bird and vegetation monitoring points. Bar above metric scale approx. 1000 ft.

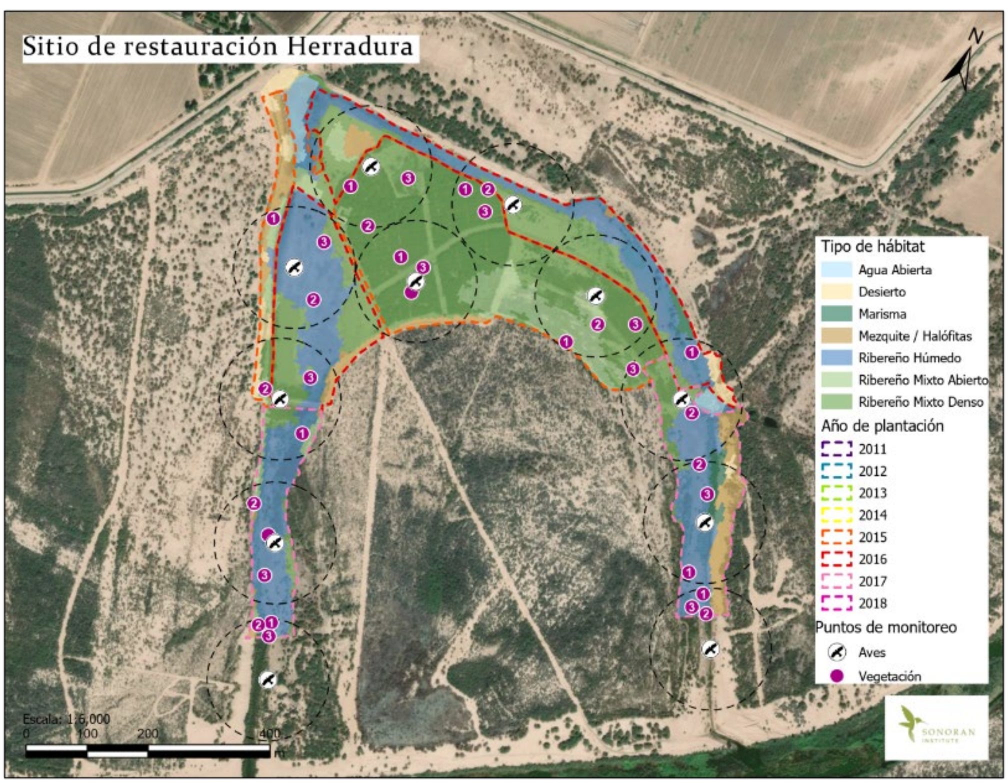


Figure B-3. The Herradura restoration site with habitat types, year planted, and 2018 bird and vegetation monitoring points.

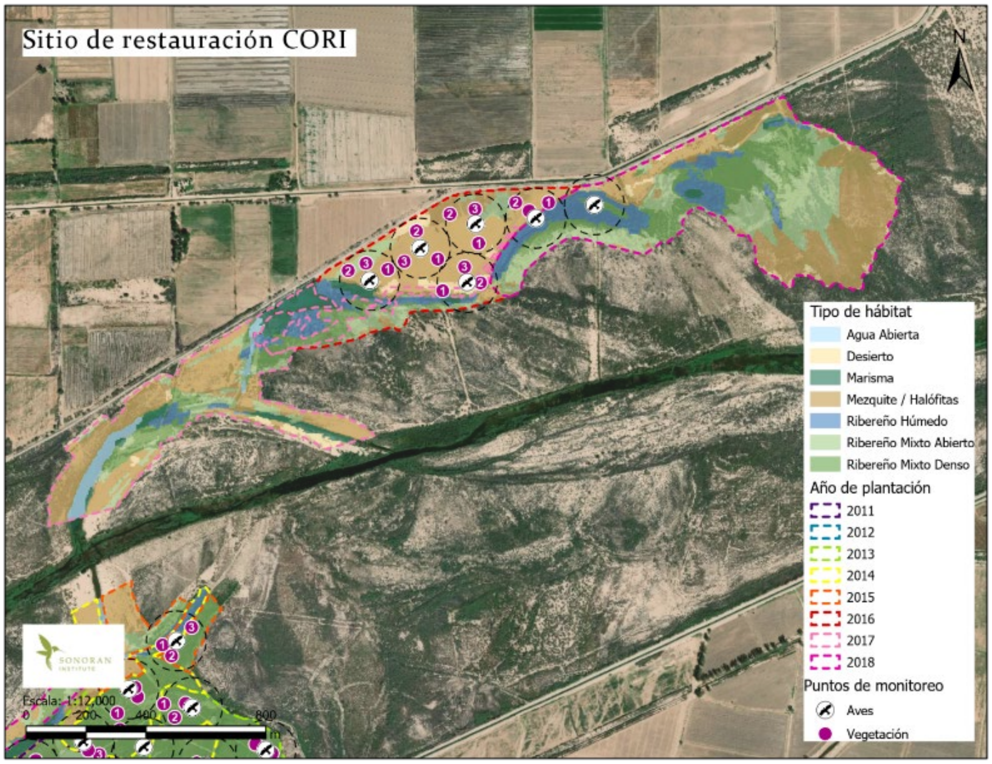


Figure B-4. The Cori restoration site with habitat types, year planted, and 2018 bird and vegetation monitoring points.

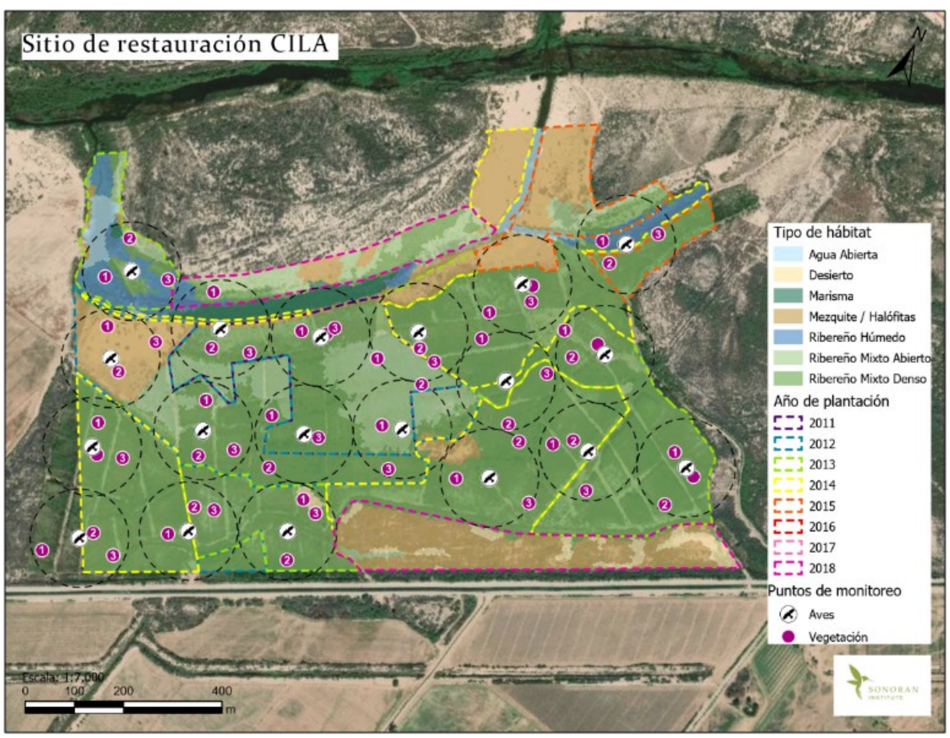


Figure B-5. CILA restoration site with habitat types, year planted, and 2018 bird and vegetation monitoring points.

Table B-1. Vegetation Plots and Bird Point Count Stations (coordinates in UTM, WGS84).

Site	Bird point	Veg Point	X	Y
Miguel Alemán	1	1	704416	3602695
Miguel Alemán	1	2	704477	3602722
Miguel Alemán	1	3	704468	3602787
Miguel Alemán	2	4	704706	3602785
Miguel Alemán	2	5	704625	3602813
Miguel Alemán	2	6	704539	3602727
Miguel Alemán	3	7	704825	3602656
Miguel Alemán	3	8	704798	3602677
Miguel Alemán	3	9	704683	3602692
Miguel Alemán	4	10	704857	3602492
Miguel Alemán	4	11	704828	3602581
Miguel Alemán	4	12	704865	3602590
Miguel Alemán	5	13	704885	3602309
Miguel Alemán	5	14	704926	3602371
Miguel Alemán	5	15	704736	3602365
Miguel Alemán	6	16	704931	3602161
Miguel Alemán	6	17	704890	3602243
Miguel Alemán	6	18	704901	3602140
Miguel Alemán	7	19	705025	3602101
Miguel Alemán	7	20	704981	3601929
Miguel Alemán	7	21	704947	3601988
Miguel Alemán	8	22	705123	3601966
Miguel Alemán	8	23	705022	3601870
Miguel Alemán	8	24	705031	3601929
Miguel Alemán	9	25	704427	3602617
Miguel Alemán	9	26	704349	3602462
Miguel Alemán	9	27	704289.9	3602657
Miguel Alemán	10	28	704494.9	3602733

Miguel Alemán	10	29	704455.9	3602806
Miguel Alemán	10	30	704515.9	3602784
Miguel Alemán	11	31	704267.9	3602548
Miguel Alemán	11	32	704241	3602259
Miguel Alemán	11	33	704250	3602211
Miguel Alemán	12	34	704429	3602399
Miguel Alemán	12	35	704475	3602277
Miguel Alemán	12	36	704427	3602242
Miguel Alemán	13	37	704578	3602443
Miguel Alemán	13	38	704687	3602389
Miguel Alemán	13	39	704695	3602308
Miguel Alemán	14	40	704242	3602185
Miguel Alemán	14	41	704197	3602129
Miguel Alemán	14	42	704284	3602102
Miguel Alemán	15	43	704264	3601970
Miguel Alemán	15	44	704162	3601893
Miguel Alemán	15	45	704271	3601878
Miguel Alemán	16	46	704204	3601833
Miguel Alemán	16	47	704284	3601787
Miguel Alemán	16	48	704228	3601735
Miguel Alemán	17	49	705192	3601802
Miguel Alemán	17	50	705260	3601769
Miguel Alemán	17	51	705255	3601729
CILA	A00_11	A00_11_1	678039	3564061
CILA	A00_11	A00_11_2	678119	3564136
CILA	A00_11	A00_11_3	678175	3564110
CILA	A00_12	A00_12_1	678259	3564196
CILA	A00_12	A00_12_2	678285	3564269
CILA	A00_12	A00_12_3	678324	3564279
CILA	A00_13	A00_13_1	678480	3564374

CILA	A00_13	A00_13_2	678501	3564248
CILA	A00_13	A00_13_3	678515	3564359
CILA	A00_14	A00_14_1	678746	3564541
CILA	A00_14	A00_14_2	678831	3564661
CILA	A00_14	A00_14_3	678901	3564556
CILA	A00_15	A00_15_1	677972	3564530
CILA	A00_15	A00_15_2	678031	3564455
CILA	A00_15	A00_15_3	678075	3564542
CILA	A00_16	A00_16_1	678217	3564476
CILA	A00_16	A00_16_2	678250	3564367
CILA	A00_16	A00_16_3	678311	3564407
CILA	A00_17	A00_17_1	678351	3564503
CILA	A00_17	A00_17_2	678390	3564404
CILA	A00_17	A00_17_3	678457	3564502
CILA	A00_18	A00_18_1	678564	3564577
CILA	A00_18	A00_18_2	678603	3564686
CILA	A00_18	A00_18_3	678613	3564501
CILA	A00_19	A00_19_1	678676	3564821
CILA	A00_19	A00_19_2	678798	3564685
CILA	A00_19	A00_19_3	678826	3564811
CILA	A00_20	A00_20_1	678896	3564686
CILA	A00_20	A00_20_2	678932	3564709
CILA	A00_20	A00_20_3	678997	3564627
CILA	A00_21	A00_21_1	677927	3564620
CILA	A00_21	A00_21_2	677940	3564712
CILA	A00_21	A00_21_3	678045	3564667
CILA	A00_22	A00_22_1	678140	3564682
CILA	A00_22	A00_22_2	678184	3564578
CILA	A00_22	A00_22_3	678258	3564601
CILA	A00_23	A00_23_1	678336	3564684

CILA	A00_23	A00_23_2	678385	3564700
CILA	A00_23	A00_23_3	678395	3564718
CILA	A00_24	A00_24_1	678499	3564697
CILA	A00_24	A00_24_2	678570	3564751
CILA	A00_24	A00_24_3	678608	3564739
CILA	A00_25	A00_25_1	678668	3564876
CILA	A00_25	A00_25_2	678726	3564961
CILA	A00_25	A00_25_3	678736	3564931
CILA	A00_26	A00_26_1	678823	3564906
CILA	A00_26	A00_26_2	678859	3564863
CILA	A00_26	A00_26_3	678896	3564908
CILA	A00_27	A00_27_1	679129	3564773
CILA	A00_27	A00_27_2	679154	3564668
CILA	A00_27	A00_27_3	679184	3564743
CILA	A00_28	A00_28_1	678036	3564344
CILA	A00_28	A00_28_2	678061	3564284
CILA	A00_28	A00_28_3	678111	3564299
CILA	A00_29	A00_29_1	678818	3565103
CILA	A00_29	A00_29_2	678850	3565067
CILA	A00_29	A00_29_3	678915	3565162
Herradura	D01_0	D01_0_1	681733	3567365
Herradura	D01_0	D01_0_2	681786	3567318
Herradura	D01_0	D01_0_3	681783	3567306
Herradura	D01_1	D01_1_1	681849	3567287
Herradura	D01_1	D01_1_2	681896	3567249
Herradura	D01_1	D01_1_3	681896	3567293
Herradura	D01_2	D01_2_1	681949	3567406
Herradura	D01_2	D01_2_2	681906	3567439
Herradura	D01_2	D01_2_3	681941	3567453
Herradura	D01_3	D01_3_1	682252	3567352

Herradura	D01_3	D01_3_2	682196	3567326
Herradura	D01_3	D01_3_3	682160	3567279
Herradura	D01_4	D01_4_1	682279	3567283
Herradura	D01_4	D01_4_2	682348	3567341
Herradura	D01_4	D01_4_3	681640	3567265
Herradura	D01_5	D01_5_2	681754	3567171
Herradura	D01_5	D01_5_3	681731	3567264
Herradura	D01_8	D01_8_1	681743	3567005
Herradura	D01_8	D01_8_3	681803	3567052
Cori	D02_1	D02_01_01	705175	3601924
Cori	D02_1	D02_01_02	679438	3566353
Cori	D02_1	D02_01_03	679497	3566377
Cori	D02_2	D02_02_01	679738	3566393
Cori	D02_2	D02_02_02	679666	3566484
Cori	D02_2	D02_02_03	679625	3566384
Cori	D02_3	D02_03_01	679777	3566329
Cori	D02_3	D02_03_03	679836	3566361
Cori	D02_4	D02_04_01	679858	3566432
Cori	D02_4	D02_04_02	679777.1	3566543
Cori	D02_4	D02_04_03	679863	3566568
Cori	D02_5	D02_05_01	680085	3566586
Cori	D02_5	D02_05_02	679984	3566586
Cori	D02_5	D02_05_03	680058	3566563
Reach1	R1-1	R1_1_1	709305	3613483
Reach1	R1-1	R1_1_2	709164	3613351
Reach1	R1-1	R1_1_3	709491	3613604
Reach1	R1-2	R1_2_1	706373.4	3607487
Reach1	R1-2	R1_2_4	706344	3607439
Reach1	R1-2	R1_2_5	706244	3607395
Reach2	R2-3	R2_3_1	705947.5	3602884

Reach2	R2-3	R2_3_2	705947.9	3602999
Reach2	R2-3	R2_3_3	705877.3	3602965
Reach3	R3-4	R3_4_1	702332.7	3594944
Reach3	R3-4	R3_4_2	702347.7	3594988
Reach3	R3-4	R3_4_3	702382.7	3594844
Reach4	R4-5	R4_5_1	688496.3	3576404
Reach4	R4-5	R4_5_2	688430	3576473
Reach4	R4-5	R4_5_3	688441.8	3576340
Reach4	R4-6	R4_6_1	6834769	3568396
Reach4	R4-6	R4_6_2	683536	3568462
Reach4	R4-6	R4_6_3	683514	3568454
Reach4	R4-7	R4_7_1	681831.3	3566068
Reach4	R4-7	R4_7_2	681833	3565967
Reach4	R4-7	R4_7_4	681875.3	3566067
Reach5	R5-8	R5_8_1	671421.6	3561541
Reach5	R5-8	R5_8_2	671327.3	3561550
Reach5	R5-8	R5_8_3	671297	3561455
Reach5	R5-9	R5_9_1	671302.5	3556476
Reach5	R5-9	R5_9_3	671208.3	3556473
Reach5	R5-9	R5_9_4	671212.9	3556531

Figure B-6. Photos from 2018 of the Herradura site showing the diversity of vegetation composition and habitat types (cottonwood-willow, coyote willow, mesquite, native shrubs, herbaceous species).

Figure B-7. (Top) Cori restoration site in February 2018 (top), and March 2019 (bottom). Note herbaceous ground cover (top) and evident growth of mesquite trees from 2018 to 2019.

Figure B-8. CILA restoration site photos in 2018. Note dense cottonwood-willow forest and tall canopy (trees greater than 11-12 m tall).

Fire Detection in 2018

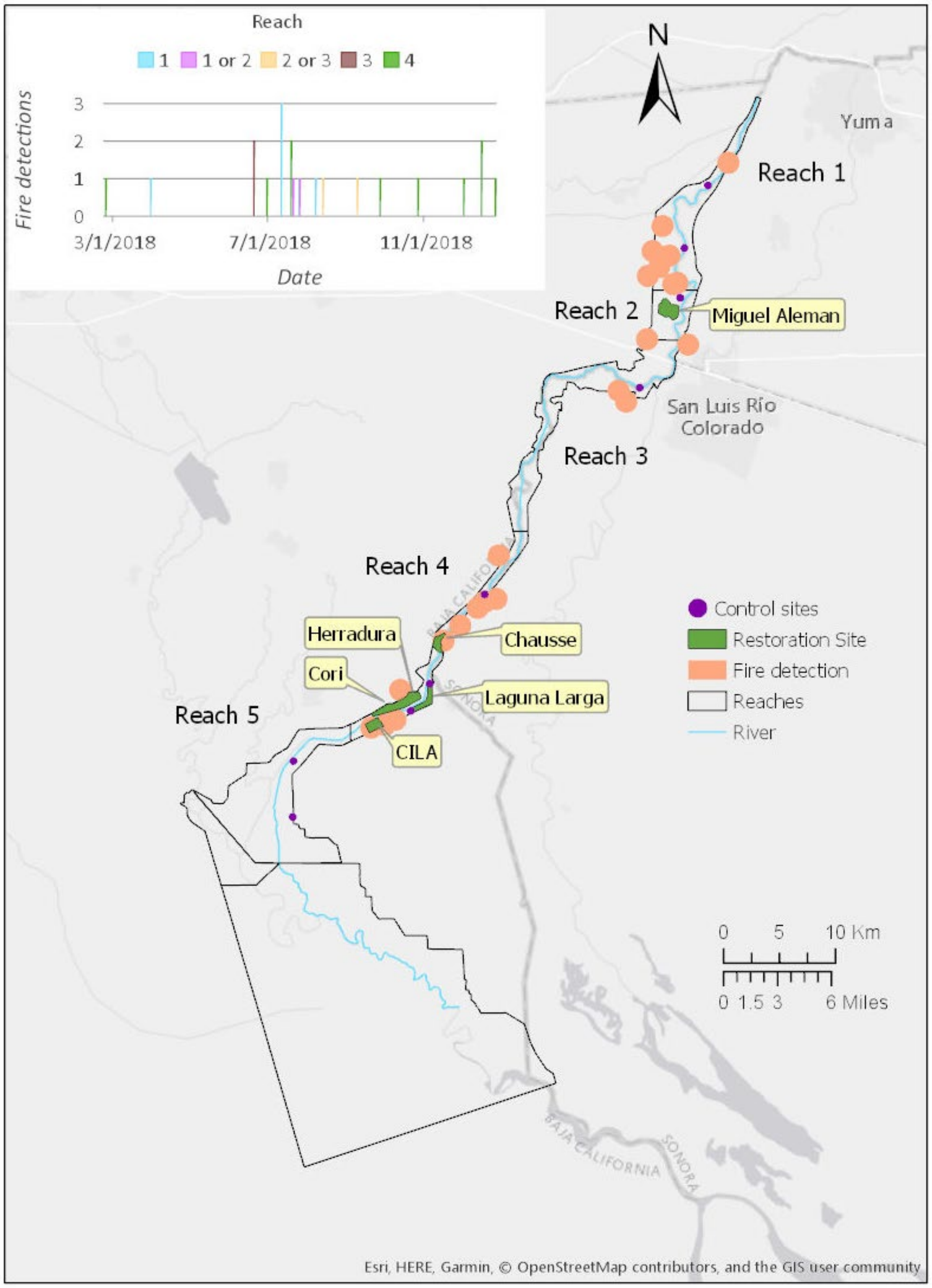


Figure B-9. MODIS fire active detections during 2018, 50 km south of the U.S-Mexico border (Reaches 1-4) and within the riparian corridor Reaches' boundary + 1 km buffer zone to account for the fire detection pixel size. These fire detection data are collected for the USDA Forest Service MODIS Active Fire Mapping Program (https://fsapps.nwcg.gov/afm) and provide a synoptic view of active fires over 2018. The data are collected at a spatial resolution of 1 kilometer and therefore are only intended for geographic display and analysis at the national and regional levels. In the upper Reach 1, a fire was detected April 2018. For the lower portion of Reach 1, all fires occurred in July 2018.

Appendix C. Control Sites

Selection. Control sites document conditions in non-restored areas using the same vegetation monitoring protocols and metrics that are implemented in the restoration sites. This allows us to compare the response in composition, vegetation cover, and vertical structure. In addition, seven of the nine control sites are located at bird monitoring stations, which allows us to associate the vegetation response in control sites to the bird indicators.

We used five criteria to select the control sites (Fig. C-cc1): 1) outside of current restoration sites; 2) proximity to current (Miguel Alemán, Chausse, Laguna Grande) or future restoration sites; 3) within bird monitoring stations if possible; 4) proximity to piezometers; and 5) representative vegetation and topographic characteristics as what is found in restoration site.

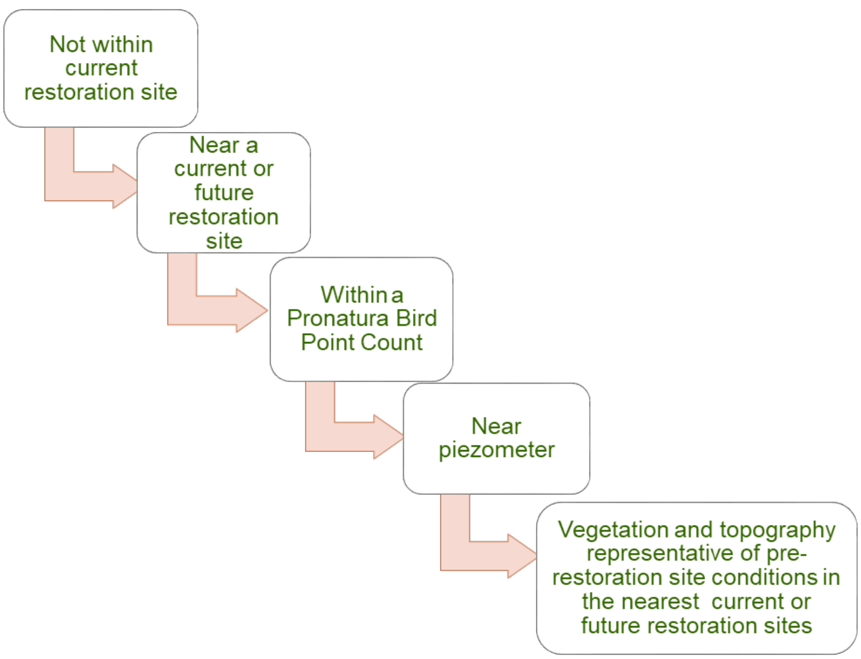


Figure C-1. Decision path to select control sites using five criteria.

The specific criteria included areas with the following landscape attributes:

- Minimum distance of 500 m from active restoration sites. This is based on bird territory size during the reproductive season.
- Within 200 m diameter bird survey points excluding farm fields.

- Within a distance of 250 m active piezometers and future piezometer locations.
- Similar topography and vegetation in current and future restoration sites at the scale of the bird transect (composed of 8 bird point counts, with a distance of 200 m between points).

After several iterations of potential control sites, we selected 9 sites, 2 in Reach 1, 1 in Reach 2, 1 in Reach 3, 3 in Reach 4 and 2 in Reach 5 (Fig. C-2). Some sites do not meet all of the criteria, since it was impossible in all cases to find bird point counts close to piezometers and outside of restoration of future restoration sites. Attributes of the sites are showed in Table 1 and represented in Fig. C-3.

Selection of vegetation plot location in control sites

We randomly placed five plots (Table C-1) within the bird monitoring station area (3.14 ha) using a random points function and selecting a minimum allowed distance of 30 m. The coordinates represent the plot center. Out of the five points generated, we selected the first three points for each control site following ascendant numerical order. The additional two points are provided for cases where a point needed to be replaced due to its location in the main river channel, within farmland, or in disturbed areas such as roads (according to the Pre-pulse vegetation classification map (Milliken, 2016)).

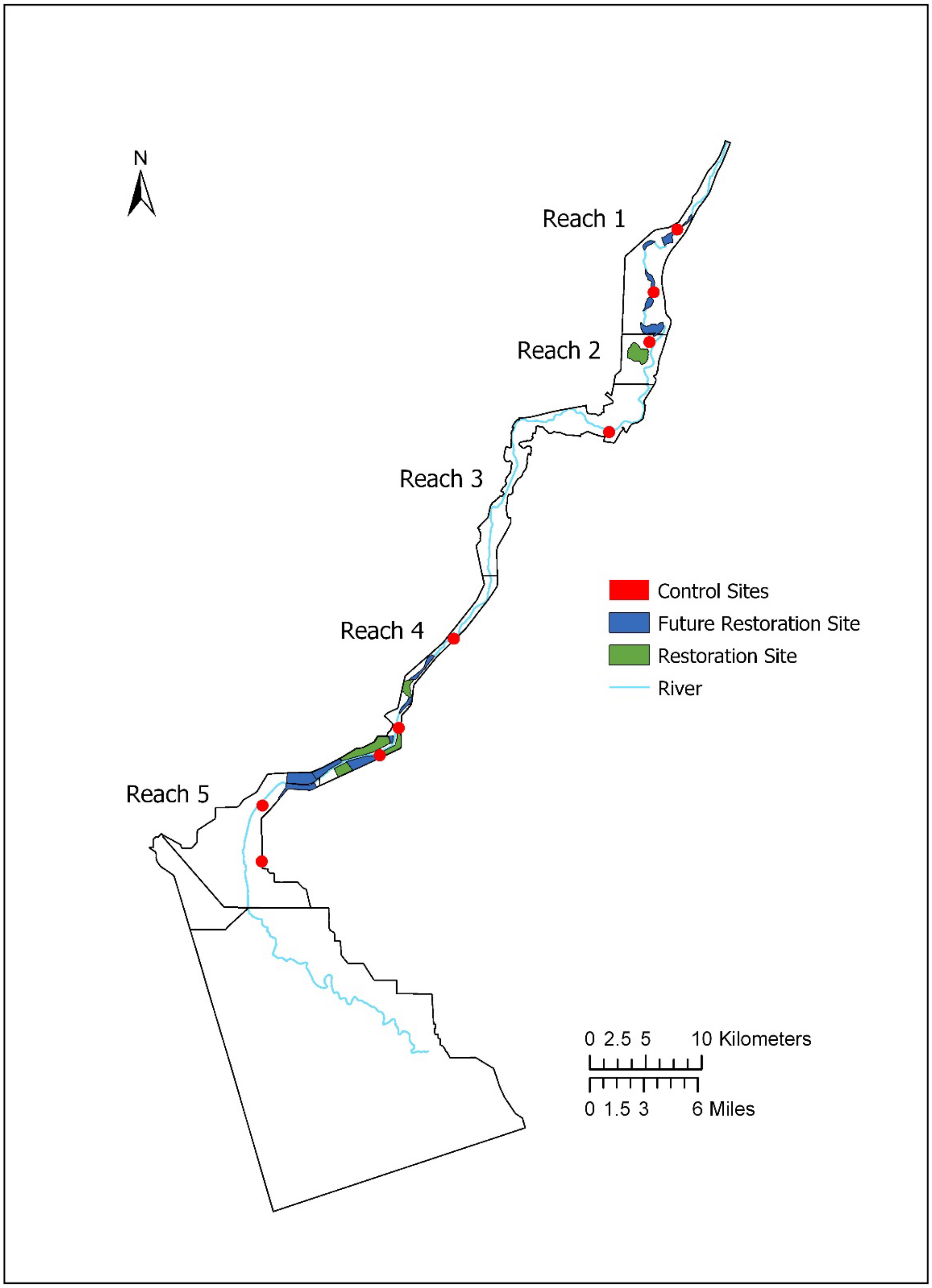


Figure C-2. Location of Control Sites in the riparian corridor reaches.

Table C-1. Selected control sites and their attributes.

Reach	Site	Distance to Restoration Site (RS), Future RS*	Within Bird Point Count	Within 250 m Piezometer radius
1	1	200 m *	Yes	No, 1 km
1	2	250 m *	Yes	No, 350 m
2	3	500 m	No	No, 1.1 km
3	4	6.6 km from Miguel Aleman, 4.0 km from * San Luis Bridge	Yes	Yes
4	5	2.3 km*	Yes	No, 1.1 km
4	6	280 m *	Yes	No, 342 m
4	7	Within *	Yes	Yes
5	8	1.7 km *	No	Yes
5	9	5.7 km	Yes	No, 770 m

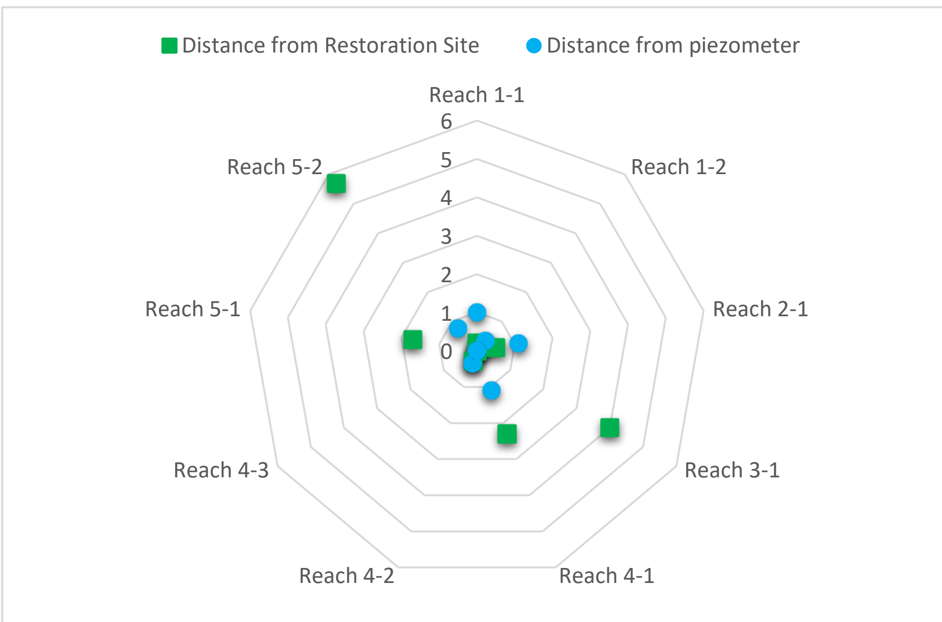


Figure C-3. Distance (km) from control sites to restoration sites in green squares and to piezometers in blue dots.

Figure C-4. *Top*: Control site 1 in Reach 1 showing burned vegetation after a fire that took place in early 2018 (image from March 2019). *Bottom:* Control site 9 in Reach 5 showing burned vegetation (image from November 2018).

Appendix D. Indicator Bird Species

List of 15 indicator species associated with riparian health in the Colorado River, used to compare avian response at restoration sites and the floodplain of the river.

Common Name	Scientific Name	Seasonal Status
Abert's Towhee	*Pipilo aberti*	Resident
Ash-throated Flycatcher	*Myiarchus cinerascens*	Breeding Visitor
Blue Grosbeak	*Passerina caerulea*	Breeding Visitor
Black Phoebe	*Sayornis nigricans*	Resident
Black-tailed Gnatcatcher	*Polioptila melanura*	Resident
Cactus Wren	*Campylorhynchus brunneicapillus*	Resident
Crissal Thrasher	*Toxostoma crissale*	Resident
Gila Woodpecker	*Melanerpes uropygialis*	Resident
Hooded Oriole	*Icterus cucullatus*	Breeding Visitor
Ladder-backed Woodpecker	*Dryobates scalaris*	Resident
Song Sparrow	*Melospiza melodia*	Resident
Vermillion Flycatcher	*Pyrocephalus rubinus*	Breeding Visitor
Verdin	*Auriparus flaviceps*	Resident
Western Kingbird	*Tyrannus verticalis*	Breeding Visitor
Yellow-breasted Chat	*Icteria virens*	Breeding Visitor