Monitoring Program for the Ciénega de Santa Clara

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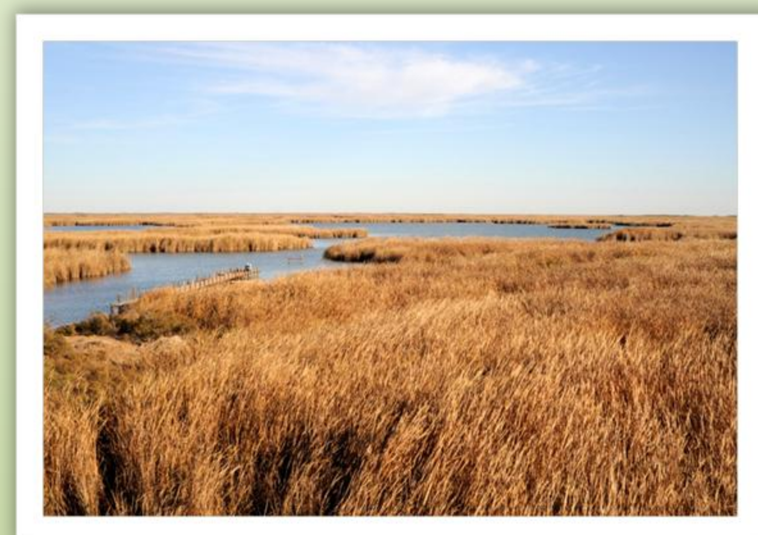

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Monitoring Program for the Ciénega de Santa Clara

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Table of Contents

Table of Acronyms and Abbreviations

AAS	Atomic Absorption Spectroscopy
AchE	Acetilcholinesterase Enzyme
ADV	Acoustic Doppler Velocimeter
AIC	Akaike's Information Criterion
AOI	Area of Interest
AZMET	Arizona Meteorological Network
BHC	Benzene hexachloride
BIA	Bureau of Indian Affairs
BOR	Bureau of Reclamation
C	Celsius
CART	Classification and Regression Tree
CAP	Central Arizona Project
CACWD	Central Arizona Water Conservation District
CCC	Criterion Continuous Concentration
C.I.	Confidence Interval
CIAD	Centro de Investigación en Alimentación y Desarrollo
CILA	Comisión Internacional de Límites y Aguas
CONANP	Consejo Nacional de Áreas Naturales Protegidas
CONAGUA	Comisión Nacional del Agua
CMC	Criterion Maximum Concentration
DF	Drainage Fraction
DDT	Dichlorodiphenyltrichloroethane
DDE	Dichlorodiphenyldichloroethylene
DN	Digital Number
DO	Dissolved Oxygen
dw	Dry Weight
EC	Electrical Conductivity
E. coli	Escherichia coli
EPA	Environmental Protection Agency
ERDAS	Earth Resource Data Analysis System
ET	Evapotranspiration
ETo	Potential evaporation
Eveg	Emergent Vegetation
EVI	Enhanced Vegetation Index
Ewater	Evaporation from open water areas

F	Fahrenheit
FTU	Formazin Turbidity Unit
GIS	Geographic Information System
GOF	Goodness of Fit
GPS	Global Positioning System
Ha	Hectare
IBWC	International Boundary and Water Commission
IDW	Inverse Distance Weighted
LAI	Leaf Area Index
LCR MSCP	Lower Colorado River Multi-Species Conservation Program
MODE	Main Outlet Drain Extension
MODIS	Moderate Resolution Imaging Spectrometer
MWD	Metropolitan Water District of Southern California
NDVI	Normalized Difference Vegetation Index
NE-SW	Northeast Southwest
NGO	Non-governmental Organization
NIB	Northern International Border
NIR	Near-Infrared
NIWQP	National Irrigation Water Quality Program
NOM	Norma Official Mexicana
NOAA	National Oceanic and Atmospheric Administration
NRC-CNRC	National Resource Council Canada
ORNL	Oak Ridge National Laboratory
ORP	Oxidation Reduction Potential
PCB	Polychlorinated biphenyl
PC	Principal Components
pH	Potential Hydrogen
QB	QuickBird
QC/QA	Quality Control/Quality Assurance
SAVI	Soil Adjusted Vegetation index
SI	Sonoran Institute
SIB	Southerly International Boundary
SNWA	Southern Nevada Water Authority
SW-NE	Southwest - Northeast
TDE	Tetrachlorodiphenylethane
TDS	Total Dissolved Solids
Tmean	Mean monthly temperature
TSS	Total Suspended Solids
UA	University of Arizona

UABC	Universidad Autónoma de Baja California
US FDA	United States Food and Drug Administration
USFWS	United States Fish and Wildlife Service
USGS	Unites States Geological Survey
UTM	Universal Transverse Mercator (coordinate system)
UV	Ultra Violet
VI	Vegetation Index
WUA	Water Users Association
WUE	Water Use Efficiency
WMIDD	Wellton-Mohawk Irrigation and Drainage District
WV2	World View 2
WW	Wet Weight
YDP	Yuma Desalting Plant

Executive Summary

The Ciénega de Santa Clara (the Ciénega) is the largest wetland on the Mexican portion of the Colorado River Delta.   The origins of the Ciénega date back to 1977 with the beginning of the disposal of brackish groundwater from the Wellton-Mohawk Irrigation and Drainage District in Arizona into the region now known as the Ciénega de Santa Clara. The Ciénega lies within the Reserva de la Biosfera del Alto Golfo de California y Delta del Río Colorado (Upper Gulf of California and Colorado River Delta Biosphere Reserve), a protected area managed by Mexico's Comisión Nacional de Áreas Naturales Protegidas (National Commission on Protected Natural Areas). The Ciénega provides habitat for over 260 species of birds, including marsh birds, shorebirds, waterfowl, and migratory birds, as well as for dozens of fish species. Two listed species (threatened or endangered; both in the U.S and Mexico) inhabit the Ciénega: the Yuma Clapper Rail and the Desert Pupfish.

A pilot run of the Yuma Desalting Plant (YDP) from May 3, 2010 to March 26, 2011 used some of the water that normally flows to the Ciénega and added saline effluent to the canal that supplies water to the Ciénega. A binational program was established to monitor environmental conditions in a ~6,000 hectare area characterized by emergent vegetation and associated open-water areas in the vicinity of, and south of, the termini of the Bypass and Santa Clara-Riito Drains. Monitoring began in December 2009 and extended to June 2011 – from approximately three months before until three months after the 33% capacity (pilot) operation of the Yuma Desalting Plant (YDP). Data from smaller-scale monitoring efforts that began in August 2006 were also utilized in this study.

Other events during the 2009-2011 monitoring period included dredging of the Santa Clara-Riito Drain, the nearby magnitude 7.2 El Mayor-Cucapa earthquake of April 4, 2010, the delivery of approximately 30,000 acre-feet (37 million cubic meters) of "arranged" water to the Ciénega de Santa Clara, and the late-March 2011 fire that burned approximately 80% of the Ciénega's vegetation.

High-resolution GPS technology was employed to map the topography, bathymetry and water levels within the Ciénega de Santa Clara. A weather station was also installed that recorded temperature, humidity, precipitation, wind speed, wind direction and solar radiation during the monitoring period.   Water loss through evapotranspiration was estimated using both ground-based and satellite-based methods.

Monitoring included measurement of water quality (total dissolved solids [TDS], temperature, pH, dissolved oxygen, and suspended solids), with values recorded monthly at two inflow sites and at 19 sites within the wetland. Data-loggers took readings of temperature and electrical

conductivity (a proxy for TDS) at six sites every two hours. Trace metals (selenium, mercury, arsenic, lead, cadmium, copper) and organic compounds (pesticides) in water, sediment and tissue of largemouth bass were examined in February 2010 and February 2011. Nutrient and coliform concentrations in water were examined at approximately bimonthly intervals beginning in December 2009 and ending in April 2011. The distribution and photosynthetic vigor of marsh vegetation was examined using satellite imagery and repeat oblique aerial photography from a small plane. The population sizes, trends and distribution of six species of resident marsh birds were estimated, including the endangered Yuma Clapper Rail, through standardized call-response surveys in variable distance point counts during the breeding season.

The Ciénega de Santa Clara is a shallow (generally less than 1 meter deep) NNW-SSE trending, asymmetric basin bounded sharply to the ENE by desert vegetation and to the WSW by a gentle slope toward bare mudflats occasionally inundated by oceanic tides. The northern end is defined by the terminus of the Bypass Drain that brings agricultural wastewater from the U.S. and the Santa Clara-Riito Drain that delivers agricultural wastewater from farms in the San Luis Valley of Mexico. The vegetated portion of the Ciénega de Santa Clara drains to the south into a shallow, un-vegetated basin subject to periodic evaporation and tidal exchange. The bathymetry in the Ciénega is irregular, consisting of several small basins bounded by thick stands of emergent vegetation.

Most of the Ciénega de Santa Clara's water is delivered by the Bypass Drain, less than 10% arrives from the Santa Clara-Riito Drain, and precipitation is negligible. TDS of water entering from the Bypass Drain (commonly ranging from 2400 mg/l to 3700 mg/l) is generally lower than TDS of water entering from the Santa Clara-Riito Drain (commonly ranging from 3100 mg/l to 4800 mg/l). Water loss occurs principally through direct evaporation and through transpiration by plants during their growing season. It was estimated that the residence time of water in the Ciénega is approximately 70 days. Approximately half of the water entering the Ciénega de Santa Clara annually leaves via evapotranspiration; the other half drains into the lower basin to the south. Drainage to the south occurs mostly during the winter months when plants are not active. This winter flushing stabilizes the TDS of the Ciénega's water.

Total Dissolved Solids varied at several sites during the monitoring period. The most common pattern was increases in the spring and summer of 2010. Spring and summer increases of these magnitudes and duration were not observed at the same sites in spring and summer periods dating back to summer 2006. This pattern occurred at both interior and marginal sites. The increases were roughly coincident with the operation of the YDP at times when little or no arranged water was delivered to the Bypass Drain. TDS values returned to their baseline range of variability after the summer of 2010.

Some sites showed elevated (>chronic; U.S. National Oceanographic and Atmospheric Administration standards) selenium values in both February 2010 and February 2011. Mercury concentrations were below the U.S. National Irrigation Water Quality (NIWQP) toxicity threshold values in sediment and fish tissue in both February 2010 and 2011, but all ten sediment values were above NIWQP toxicity thresholds established for habitats of a different clapper rail subspecies in San Francisco Bay. Arsenic concentrations in water were not above the NIWQP toxicity threshold in any sites in 2010 but were above them in five of ten sites in 2011. Arsenic in sediment was below the NIWQP toxicity threshold in all ten sites in February 2010 but exceeded the threshold in two out of ten sites in 2011.

Concentrations of selenium, mercury and arsenic in largemouth bass tissue were under the U.S. (FDA) and Mexican toxicity thresholds. Lead, cadmium and copper were under detection limits in water, sediment and largemouth bass tissue at all sites in both February 2010 and February 2011. The pesticides most frequently detected in water were pp-DDT, endosulfan sulphate, heptachlor and the BHC´s and in sediment they were trans-chlordane, heptachlor epoxide, pp-DDT, endosulfan sulphate, pp-TDE, and BHC alpha. The organophosphate pesticides, pyrethroid pesticides and PCBs were under detection limits in samples of water, sediment and fish. No organochlorine compounds were detected in edible tissue of largemouth bass, although they were detected in other species at low concentrations in 2010. *E. coli* concentrations higher than the limits set by the U.S. EPA water quality standards for recreational use were detected in Bypass Drain water at one sampling (see Chapter III, Figure 3-24 for specific EPA standards). Nutrient (N, P) concentrations decreased inside the Ciénega and the water was generally clear.

The Ciénega's vegetation is dominated by cattail (*Typha domingensis*) with some stands of common reed (*Phragmites australis*) and bulrush (*Scirpus americanus*). Satellite imagery and repeat oblique aerial photography showed strong seasonal changes in photosynthetic activity, specifically a temporary reduction in photosynthetic activity in the northwest margin following a temporary decrease in water level in this area during the summer of 2010, and a strong rebound in photosynthetic activity following an extensive fire in late March 2011. The vegetated "footprint" of the Ciénega did not change substantially during the monitoring period and the vegetation recovered quickly from short-term disturbances such as changes in water level and fire.

Changes in marsh bird populations during the monitoring period were within the normal range of variability observed since surveys began in 1999, with 631 total detections of Yuma Clapper Rails during 2011, and a population estimate of 8,642 individuals (95% C.I. 7,714- 9,686) for the same year. Marsh bird populations are not evenly distributed within the Ciénega, indicating variation in habitat preferences among species. Yuma Clapper Rails show changes in their distribution within the Ciénega since the surveys started, and in 2011, these rails had the highest number of detections per point since the marsh bird surveys began in 1999.

The short-term changes associated with the pilot operation of the YDP accompanied by the ~30,000 af of arranged water did not cause significant changes to the features of the Ciénega de Santa Clara monitored during the period of this study. The Ciénega de Santa Clara appears to be an ecosystem that is resilient in the face of short-term disturbances and minor changes in water quality and quantity, minor changes in drainage resulting from earthquakes, and fire.

Chapter I: Introduction

A. Background

The Ciénega de Santa Clara is the largest wetland in the Colorado River Delta region of Baja California and Sonora Mexico. It was created in 1977 by the completion of the Bypass Drain and the discharge of brackish drainage water from the Wellton-Mohawk Irrigation and Drainage District (WMIDD) in the lower Gila River valley, AZ into a wetland area, the Santa Clara Slough, in Sonora, Mexico. The construction of the Bypass Drain and the discharge of the brackish drainage water were authorized by Minute 242 of the 1944 treaty between the U.S. and Mexico, "Utilization of Waters of the Colorado and Tijuana Rivers and of the Rio Grande." Minute 242, signed in 1972, among other items, authorized the construction of the Bypass Drain from the United States and Mexico and permits the discharge of all or a portion of the Wellton-Mohawk drainage waters, the volumes of brine from such desalting operations in the United States as are carried out to implement the Minute (http://www.usbr.gov/lc/region/pao/pdfiles/min242.pdf).

The signing of Minute 242, along with the passage of the Colorado River Basin Salinity Control Act, Public Law 93-320, which directed the Secretary of the Interior to proceed with a program to enhance and protect the quality of water available in the Colorado River for use in the United States and Republic of Mexico, prompted the construction of the Yuma Desalting Plant. Construction began in 1975 and the plant was completed in 1992. As noted by the U.S. Bureau of Reclamation, the operators of the plant, (see http://www.usbr.gov/lc/yuma/facilities/ydp/yao_ydp_history.html):

"The purpose of the Yuma Desalting Plant is to save water for beneficial use while desalting sufficient drainage returns from the Wellton-Mohawk Irrigation and Drainage District in Arizona, in order to maintain salinity levels at Morelos Dam as specified by the Minute." [Minute 242]

Since completion of the YDP in 1992, it has operated for three intervals: an initial start-up period at one-third capacity from July 31, 1992 through January 15, 1993; a demonstration run at 10% capacity from March 1 to May 31, 2007 (http://www.usbr.gov/lc/yuma/facilities/ydp/YDPdemrun07.pdf), and a pilot run at one-third capacity from May 3, 2010 until March 26, 2011.

Since June 23, 1977, water has been pumped from drainage wells in the WMIDD and sent to the Ciénega de Santa Clara via the Wellton-Mohawk Canal, the Main Outlet Drain Extension (MODE) canal and the Bypass Drain. Surface runoff water from the San Luis valley in the Colorado River agricultural district in Mexico also drains into the Ciénega via the Santa Clara-Riito drain. The Ciénega de Santa Clara has expanded from several hundred hectares in 1977 to nearly 6,000 hectares of vegetated area today. Reviews of the development and character of the Ciénega de Santa Clara, are provided by Glenn et al., (1992, 1995, 1996); Burnett et al., (1993) and Zengel et al., (1995). A timeline of significant events in the recent history of the Ciénega de Santa Clara are provided in Appendix I of this report.

The history of water discharge from the United States to Mexico at the Southerly International Boundary (SIB), which are assumed to represent discharge to the Ciénega de Santa Clara via the Bypass Drain, are shown in Figure 1-1. Deliveries since 2000 are shown (daily resolution) in Figure 1-2.

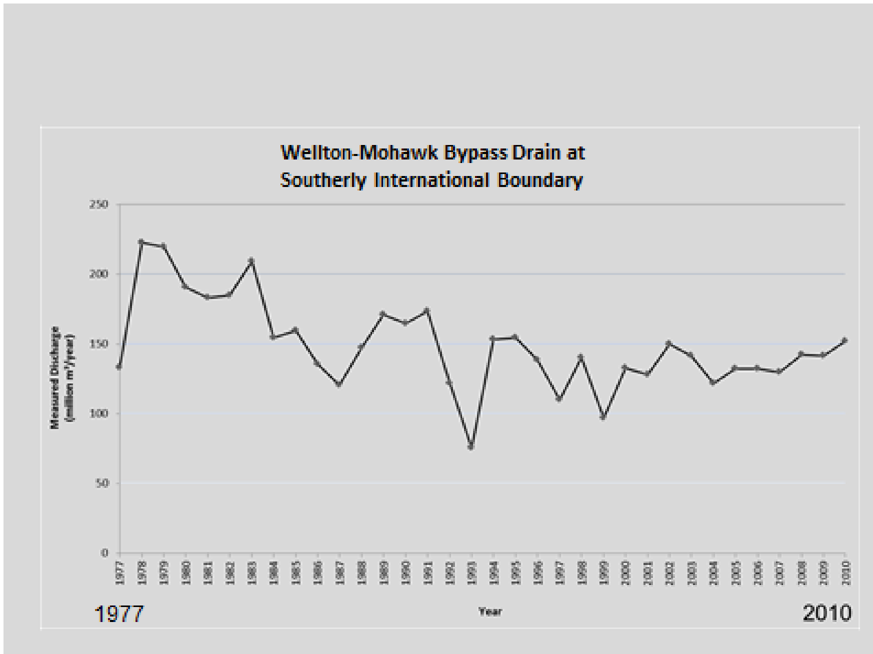


Figure 1-1. Annual water deliveries since 1977 to the Bypass Drain at the Southerly International Boundary. Source: IBWC. http://www.ibwc.gov/wad/DDQWMSIB.HTM

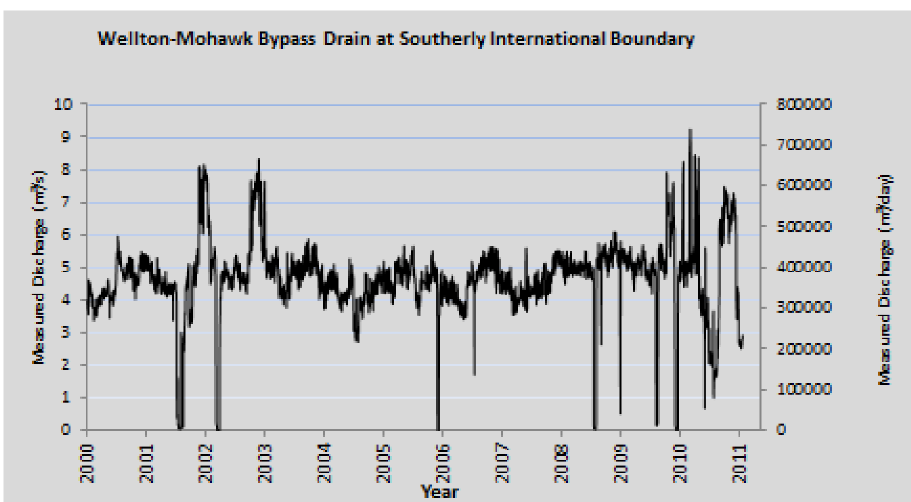


Figure 1-2. Daily water deliveries since 2000 to the Bypass Drain at the Southerly International Boundary. Source: IBWC http://www.ibwc.gov/wad/DDQWMSIB.HTM
Mexico, in 1993 in recognition of the value of the Ciénega de Santa Clara, included the wetland within the borders of the Upper Gulf of California and Colorado River Delta Biosphere Reserve. Appendix II shows the limits of the entire Biosphere Reserve. The northern part of the Ciénega de Santa Clara lies with a zone - commonly called the "buffer zone"- that permits the sustainable use of natural resources, while the southern portion lies with the "Zona Núcleo" or core region of the Biosphere Reserve.

Management and conservation within the Upper Gulf of California and Colorado River Delta Biosphere Reserve is outlined by the 2007 management plan (CONANP, 2007; http://www.conanp.gob.mx/que_hacemos/pdf/programas_manejo/Final_AltoGolfo.pdf). According to this plan, activities in the buffer zone of the "Ciénega de Santa Clara Norte" are limited to activities such as fishing, tourism and ecotourism (CONANP, 2007, p. 150). In the core zone, conservation of marine species, migratory birds and ecological processes are the highest priority. Research, monitoring, control of introduced species, ecotourism, restoration, and environmental education are allowed in the core zone (CONANP, 2007, p. 133). See Figure 1-3 below for CONANP's map of this region.

In 1997, the wetlands of the Colorado Delta, including the Ciénega de Santa Clara, were added to the List of Wetlands of International Importance under the Ramsar Convention (http://www.ramsar.org/cda/ramsar/display/main/main.jsp?zn=ramsar&cp=1-36-55_4000_0__). In 2005, the Ciénega de Santa Clara was identified as a "conservation priority" area by Zamora-Arroyo et al. (2005).

In general, the wetland habitat consists of approximately 6,000 hectares of dense marsh vegetation, mainly cattails (*Typha domingensis*) and more than 10,000 hectares of open water habitat. However, there are observed seasonal and annual variations in the size of vegetated and open water areas as a result of changing farming operations in the United States and Mexico, MODE and Bypass Drain maintenance, YDP operations, earthquake, fire, and other events. Open water habitat ranges from slightly brackish near the mouth of the MODE and within the vegetated zone to hypersaline south of the vegetated zone. The ecological value of the Ciénega de Santa Clara has been recognized in many studies (Hinojosa-Huerta et al. 2004a; Zamora-Arroyo et al, 2005). The Ciénega is situated along the Pacific Flyway and is critical habitat for migratory birds, including ducks and geese, and for resident marsh birds, including the largest population of the Yuma Clapper Rail, listed as endangered in the U.S. and threatened in Mexico (US: (http://ecos.fws.gov/speciesProfile/profile/speciesProfile.action?spcode=B00P; Mexico: http://dof.gob.mx/nota_detalle.php?codigo=5173091&fecha=30/12/2010) (Hinojosa-Huerta, et al., 2004). The Desert Pupfish, listed as endangered in the U.S. and Mexico (US: http://ecos.fws.gov/speciesProfile/profile/speciesProfile.action?spcode=E044; Mexico: http://dof.gob.mx/nota_detalle.php?codigo=5173091&fecha=30/12/2010) also inhabits the Ciénega (Varela-Romero et al. 2002).

The Ciénega de Santa Clara is an important resource for the economy of three local communities, or ejidos (Carrillo-Guerrero, 2005). Residents use the resources (fish, building materials) and have established ecotourism cooperatives based on the biological richness of the marsh.

Since 2000, drought and development in the Colorado River Basin prompted concerns over possible water shortages, leading to consideration of the operation of the Yuma Desalting Plant as a means to conserve Colorado River water supplies. By 2007, these concerns prompted the USBR to conduct a 90 day test of the YDP, operating at 10% of capacity, to demonstrate the ability of the plant to operate in its present configuration.

After reviewing the results of the demonstration run and in light of continued drought in the Colorado River basin, in 2009, CAP, MWD, and SWNA requested the USBR to conduct a pilot run of the YDP to determine the "real world" operating costs to operate the plant to conserve Colorado River water. The three agencies signed a funding and operating agreement with USBR to conduct pilot run of the YDP with the goal of operating the plant at 1/3rd capacity for 1 year. As a measure of binational cooperation, in 2010, representatives of the U.S. and Mexico signed Minute 316 to the 1944 treaty. This Minute, and the "Joint report of the Principal Engineers Concerning U.S.-Mexico Joint Cooperative Actions related to the Yuma Desalting Plant (YDP) pilot run and the Santa Clara Wetland" that is part of the Minute noted:

- "the intention of the U.S. Bureau of Reclamation to operate the YDP for 365 days within an 18 month period beginning in May 2010;
- The commitment of $250,000 by the non-federal parties (MWD, SNWA and CAWCD) toward a comprehensive binational monitoring program of the Santa Clara Wetland;
- The intention of the U.S., Mexico and Non-Governmental Organizations to each arrange for 10,000 acre-feet (12.3 mcm) of water delivered to the Bypass Drain." (http://www.ibwc.gov/Files/Minutes/Minute_316_w_JR.pdf)

In preparation for the 2010-2011 pilot run of the YDP, a binational group of scientists from universities, agencies and non-governmental organizations issued, in January 2009, the *Binational Comprehensive Monitoring Program for the Ciénega the Santa Clara* (Peters et al., 2009). This report provided essential guidance for the design and implementation of the monitoring program reported on here. Peters et al. (2009) recommended twelve components: water inflows, water levels, bathymetry/topography, water quality, species of interest, vegetation, macroinvertebrates, economic impact, soils and sediments, local weather: micrometeorology and plankton. The monitoring effort and study, as described in this report, implemented seven of the twelve elements: water inflows, water levels, bathymetry/topography, water quality, species of interest, vegetation and local weather (micrometeorology).

This report documents the results of the binational monitoring program cited in Minute 316. The monitoring program was facilitated by the activities of IBWC and CILA, was funded by the three non-federal partners (MWD, SNWA and CAWCD). Elements of the monitoring program also received financial support from Mexico's Comisión Nacional de Áreas Naturales Protegidas (CONANP) and Instituto Nacional de Ecología (INE).

B. Project Scope

1. Management

This monitoring project was a collaborative effort among the University of Arizona, the Sonoran Institute (Tucson, AZ), Pronatura Noroeste (San Luis, R.C., Sonora), the Universidad Autónoma de Baja California (UABC, Mexicali, Baja California campus), and Centro de Investigación en Alimentación y Desarrollo (CIAD, Guaymas, Sonora). Project management and budget administration was based at the University of Arizona and funded largely through a contract with Central Arizona Water Conservation District, Metropolitan Water District of Southern California (MWD) and Southern Nevada Water Authority (SNWA), with additional funding from Mexico's Comisión Nacional de Áreas Naturales Protegidas (CONANP) and the Instituto Nacional Ecología (INE). The Sonoran Institute's field crews and project activities were closely coordinated with the Upper Gulf of California and Colorado River Delta Biosphere Reserve of the Mexican Commission for Natural Protected Areas (CONANP).

2. Spatial Coverage and Usage of Terms

In this report, we use the term "Ciénega de Santa Clara" to refer to the wetland characterized by vegetation that emerges above the surface of the water ("emergent vegetation") – and associated open-water areas - in the vicinity of, and south of, the termini of the Bypass and Santa Clara-Riito Drains.

The scope of the monitoring program does not include any attempt to describe or establish the boundaries or extent of the Ciénega de Santa Clara. A formal description or definition is beyond the scope of this effort and is hampered not only by the seasonal and other fluctuations in the geographic extent of the emergent vegetation and associated open-water areas, but also by the formal and informal application of the term "Cienega de Santa Clara". The use of the term has included areas adjacent to or near to the area monitored in this report.

Consider, for example, the official map of the Biosphere Reserve Appendix II), a portion of which is enlarged below in Figure 1-3.

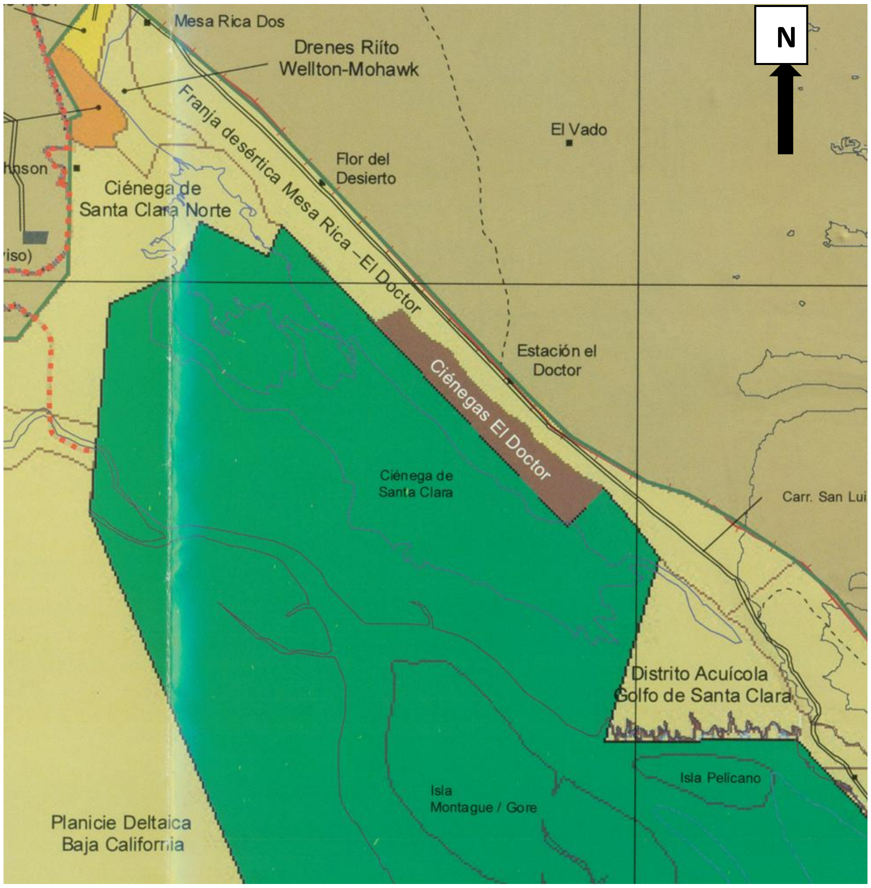


Figure 1-3. Portion of official map of Biosphere Reserve showing the location of the Ciénega de Santa Clara (For full map see Appendix II). Green areas represent part of the core zone of the Biosphere Reserve, pale yellow indicates the Reserve's buffer zone, bright yellow (upper left) indicates a zone for the sustainable use of ecosystems, orange indicates an area set aside for traditional uses, and the brown area, "Ciénegas El Doctor" is a zone set aside for restoration. See text for discussion.

The area that is the focus of the monitoring program lies partly within the portion of the map labeled "Ciénega de Santa Clara Norte," a management area of approximately 9,986 hectares (CONANP, 2007, p. 160), and partly within the core zone (dark green) of the Biosphere Reserve within the landscape feature "Ciénega de Santa Clara" to the southeast of the area labeled "Ciénega de Santa Clara Norte".

As could be suggested by this map, the Ciénega de Santa Clara is sometimes taken to mean both the vegetated area to the northwest and the largely unvegetated area to the southeast. The largely unvegetated area to the southeast is sometimes referred to as the "southern basin", "Ciénega de Santa Clara mudflats" or the "Santa Clara Slough". While this area is hydrologically and ecologically connected to the vegetated area to the north, it was not monitored in this study. Mexico's Comisión Nacional del Agua (CONAGUA) is currently conducting an inventory of its wetlands and the Ciénega de Santa Clara is one of the first wetlands that will receive official definition of its extent.

Note that Figure 1-3 shows an area labeled "Ciénegas El Doctor". This region is characterized by ground-water springs, salt-tolerant vegetation, mudflats and salt flats. There appears to be little, if any hydrologic connection between this area and the "Ciénega de Santa Clara" as used in this report.

The term "Santa Clara Slough" is also commonly used in the older (pre-1977) literature and maps to refer to a narrow, linear, northwest – southeast trending, zone of southeast flowing streams, freshwater springs, wetlands and tidal channels that terminate at the head of the Gulf of California, northwest of the settlement of El Golfo de Santa Clara. For example, Sykes (1937, Plate I) indicates this area from northwest to southeast, as "Riito Salado – Estero Santa Clara (Santa Clara Slough)". This appears to be the area identified as the "Santa Clara Slough" in the 1972 Minute 242 and 2000 Minute 306 to the 1944 Treaty.

Glenn et al., 1992 first used the term "Ciénega de Santa Clara" in the scientific literature. Their map, reproduced below (Figure 1-4) includes the unvegetated part within the "Ciénega de Santa Clara". Their text refers to both an "upper marsh" and a "lower marsh", with the upper part characterized by stands of *Typha*, or cattail, and with the lower marsh "devoid of vascular plants" (p. 822), meaning that only algae are present in the "lower marsh". Their map does not show the boundary between the upper and lower marshes.

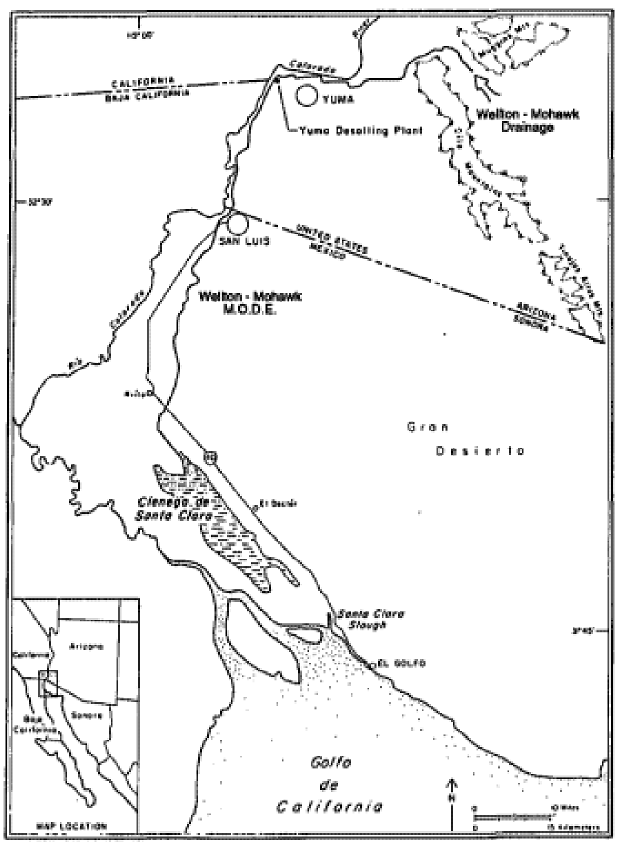


Figure 1-4. First map in the scientific literature that uses the place name "Ciénega de Santa Clara". (Glenn et al., 1992)

In 2010, Minute 316 of the treaty refers to the "Santa Clara Wetland". The text of the Minute does not indicate if "Wetland" refers only to the vegetated area or to both the vegetated area and the unvegetated area to the southeast.

The legal definition of "wetland" or "humedales" in Mexico does not provide any guidance in this regard:

"Las zonas de transición entre los sistemas acuáticos y terrestres que constituyen áreas de inundación temporal o permanente, sujetas o no a la influencia de mareas, como pantanos, ciénagas y marismas, cuyos límites los constituyen el tipo de vegetación hidrófila de presencia permanente o estacional; las áreas en donde el suelo es predominantemente hídrico; y las áreas lacustres o de suelos permanentemente húmedos por la descarga natural de acuíferos;" (Comisión Nacional del Agua, 2004)

In English: Transition zones between aquatic and terrestrial systems, which encompass areas under temporary or permanent flooding, and that can be subject to tidal influence, such as bogs, cienegas, and marshes and whose boundaries are defined by:

1) Hydrophytic vegetation (seasonal or permanent presence)
2) Predominantly hydric soils
3) Lacustrine areas or permanent wet soils due to the natural discharge of aquifers.

This review illustrates the range of terms that have been applied to the wetlands in and in the immediate vicinity of this report's study area. **When we use the term "Ciénega de Santa Clara" or "Ciénega", for short, we refer here to the wetland characterized by vegetation that emerges above the surface of the water ("emergent vegetation") – and associated open-water areas - in the vicinity of, and south of, the termini of the Bypass and Santa Clara-Riito Drains.** Our monitoring program did not include the area to the south that lacks emergent vegetation. The boundaries of our maps and images are not intended to define the boundaries, nor do we make any claim that the term "Ciénega de Santa Clara" should, or should not, also refer to the unvegetated zone to the southeast.

C. Monitoring elements

This project focused on monitoring some of the parameters that are sensitive to changes in the volume and quality of water flows to the Ciénega de Santa Clara. The project was designed to monitor these parameters at least three months before, during, and three months after the pilot operation of the Yuma Desalting Plant (YDP). We also make reference to previously published articles in the published literature and in Masters Theses where relevant to our understanding of the key environmental parameters.

The particular objectives of the monitoring program were linked to the estimated 12-month trial run of the Yuma Desalting Plant, which started on May 3, 2010 and ended on March 26, 2011. The specific objectives were:

1. Capture conditions of key parameters in the Ciénega de Santa Clara before the pilot operation of the YDP;

2. Document any temporal and spatial trends of these key parameters over a 12 month period;

3. Determine the relationships among these trends and their mechanisms and potential causes, and;

4. Provide timely information about the conditions of the Ciénega to the environmental group of the Colorado River Joint Cooperative Process (CRJCP), representatives of the funding partners and other stakeholders before and during the pilot run of the YDP.

We were able to expand the spatial coverage of previous monitoring efforts, both in terms of spatial distribution of sampling sites for water quality and level as well as the type of parameters to be measured. We initially planned to use the 23 sites shown in Figure 1-5. Table 1-1 shows the name, coordinates, and the type of equipment and parameters measured at each sampling site.

We were only able to establish 21 sites that were visited monthly during this effort. Two sites, 14 and 15 were inaccessible except for a few months during this project. Sites, 5, 6, and 21 became inaccessible after the Mexicali earthquake on April 4, 2010 and a few instruments were damaged by a fire after the conclusion of the pilot run.

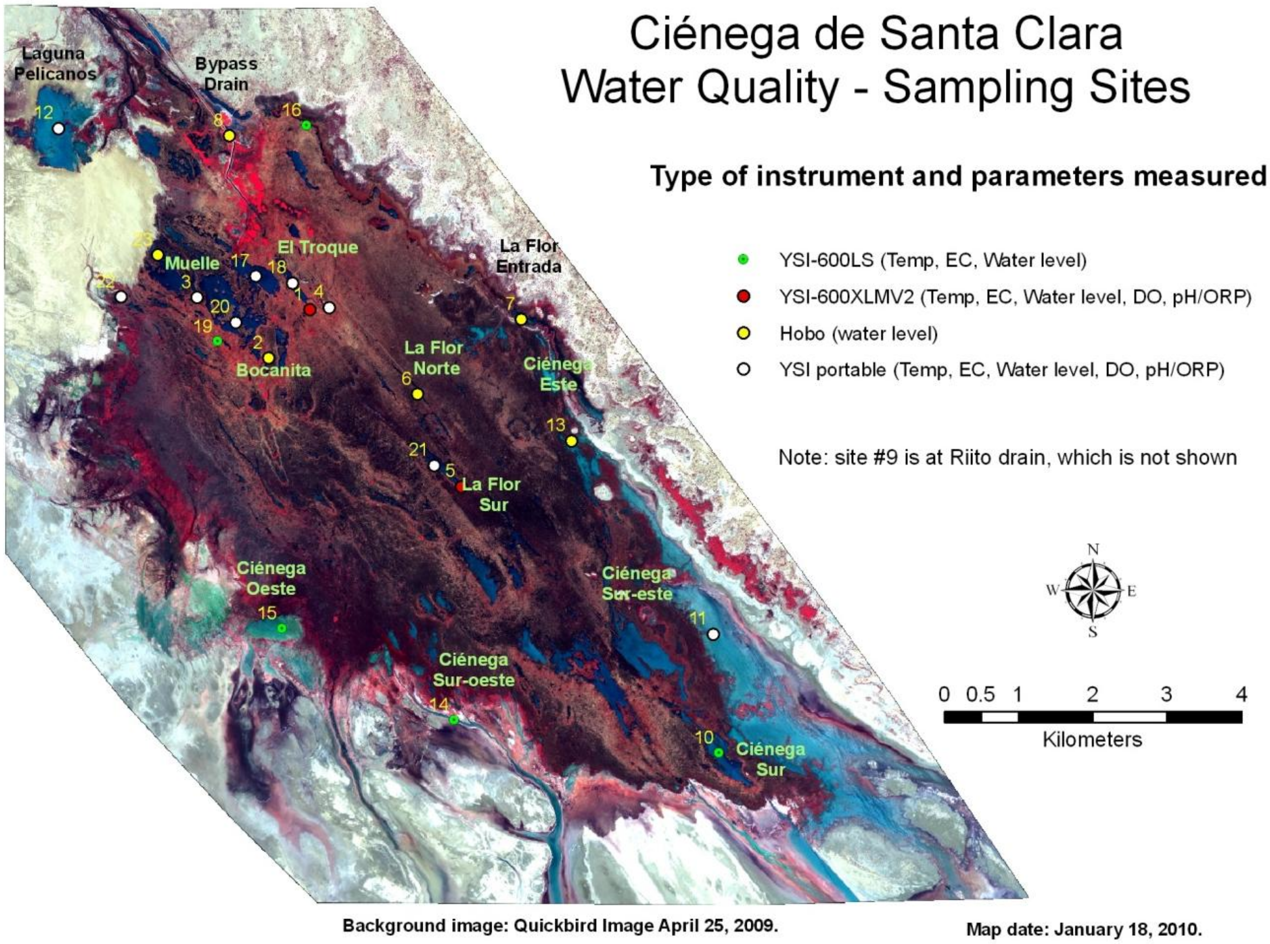


Figure 1-5. Location of sampling sites and installed water quality sensors. (Temp.=temperature, EC=electrical conductivity, DO=dissolved oxygen, ORP=oxidation reduction potential). Red color indicates vegetation.

Access by foot or small boat to most sites in the Ciénega is difficult. There are no roads or trails along the Ciénega's muddy southwestern margin and few launching sites for boats along the southeastern border. Within the Ciénega, not all open water areas are connected and dense stands of cattail prevent access by boat or on foot. As a result, most of our sample sites for water quality are concentrated in the north and along the Ciénega's eastern margin.

However, in addition to the sites shown in Figure 1-5 and listed in Table 1-1, we also mapped and monitored the Ciénega by using satellite imagery and remotely-sensed data derived from satellites, periodic overflights from small planes We used transects on foot and from small boats to survey bathymetry, and transects to survey populations of resident birds. The exact nature and location of each of these specific monitoring efforts is discussed in the relevant sections of this report.

Sampling Site #	Sampling Reference Name	X-coordinate	Y-coordinate	Type of Equipment Installed
1	El Troque Sur	699,513	3,546,232	YSI XLM and water gauge
2	Entrada Bocanita	698,963	3,545,581	HOBO, water gauge
3	Mojonera No.2	698,003	3,546,390	Water gauge
4	El Letrero	699,778	3,546,256	Water gauge
5	La Flor Laguna sur	701,557	3,543,826	YSI XLM, water gauge
6	La Flor laguna norte	700,994	3,545,106	Nothing
7	La Flor Entrada	702,167	3,546,142	HOBO, water gauge
8	Bypass Drain	698,314	3,548,739	HOBO, water gauge
9	Dren Riito	693,550	3,553,864	YSI 600LS, water gauge
10	Ciénega Sur	705,027	3,540,265	YSI 600LS, water gauge
11	Punta Sureste	704,945	3,541,861	Water gauge
12	Laguna Pelicano	696,138	3,548,674	Water gauge
13	Ciénega Este	703,036	3,544,467	HOBO, water gauge
14	Ciénega Sur-oeste	701,454	3,540,705	YSI 600LS, water gauge - pending
15	Ciénega Oeste	699,138	3,541,936	YSI 600LS, water gauge - pending
16	Ciénega Nor-este	699,578	3,548,800	YSI 600LS, water gauge
17	Laguna Grande	698,786	3,546,685	Nothing
18	El Troque Centro	699,283	3,546,585	Nothing
19	Ciénega Nor-oeste	698,281	3,545,806	YSI 600LS, water gauge
20	Cerca de Boya 5	698,528	3,546,060	Nothing
21	Entre dos	701,074	3,544,344	Water gauge
22	Torre Observacion	696,974	3,546,409	HOBO, water gauge
23	Muelle	697,467	3,546,972	Nothing

Table 1-1. Name and location of sampling sites and equipment installed in the Ciénega de Santa Clara. Coordinates refer to WGS-1984 UTM Zone 11N.

The results of the monitoring program are presented in the following chapters:

Chapter II. Hydrology: water inflows, water levels, bathymetry / topography

Chapter III. Water Quality: physicochemical parameters, nutrients, pesticides, heavy metals and coliforms

Chapter IV. Vegetation

Chapter V. Oblique Aerial Photography

Chapter VI. Marshbirds

Chapter VII. Summary of results

Chapter VIII. References

D. Monitoring vs. Experiments

Finally, we note that we report here the results of a monitoring program, not a carefully controlled experiment. Variability is a common characteristic of nature. We could not, for example, hold temperature and evapotranspiration constant throughout the year and vary only water quality. As discussed below, some of the arranged water was delivered prior to the YDP pilot run, some during and some after. An ideal experiment might have coordinated the delivery of the arranged water with the operation of the YDP. This was not possible. Nor could we prevent perturbations such as earthquakes and fires. Both of these occurred during the monitoring period. In addition, it is conceivable that some effects of the earthquake, fire, arranged water and the YDP pilot run might not be expressed for several years.

Because of our monitoring efforts prior to the YDP pilot run, we were able to estimate the range of variability in some environmental parameters during this time. It is against that “background” variability that we sought to detect any changes in the monitored parameters during the period of the program. This natural and human-caused variation makes it difficult to evaluate the Ciénega de Santa Clara’s environmental condition “before”, “during” and “after” the pilot run of the YDP. And on a more technical level, the statistical distribution of some of the environmental parameters may not lend themselves to conventional tests for significant differences.

These typical problems with “natural experiments” notwithstanding, the results of this monitoring program provide enormous insight into the range of natural variability in water flow, level and quality, in the distribution and productivity of vegetation, and in the populations of resident birds. We can now better evaluate the effects of variability induced by changes in water quality and flow, and by major perturbations like earthquakes and fire. The monitoring program has allowed us to estimate the degree of resilience of this ecosystem in the face of short term environmental variation. The results of this monitoring program are likely to be valuable in evaluating and defining the environmental values of the the Ciénega de Santa Clara

Chapter II: Hydrology

A. Water Inflows

Water sources to the Ciénega include brackish groundwater from the U.S. Wellton-Mohawk Irrigation and Drainage District (WMIDD) delivered through the Main Outlet Drain Extension (MODE) to the Bypass Drain in Mexico and agricultural return water from Mexico's San Luis valley through the Santa Clara-Riito Drain (Figure 2-1). The International Boundary and Water Commission (IBWC/CILA) measures daily flows to the Ciénega in the U.S. at a point along the Bypass Drain near the Southerly International Boundary (SIB) that is about 32 miles (51 kilometers [km]) from the Ciénega. Mexico's National Water Commission (CONAGUA) measures flows from the Santa Clara Drain where the drain crosses the San Luis-El Golfo highway, about 6.5 miles (10.5 km) from the Ciénega (Figure 2-2). Downstream from this point of measurement, the Riito Drain meets the Santa Clara Drain (Figure 2-3), but this contribution is not measured by CONAGUA.

In addition to using these existing data, we measured water flows at the point of discharge to the Ciénega by carrying out manual flow measurements at two locations: the Santa Clara-Riito Drain and at the Bypass Drain.

1. Measuring locations

Manual discharge measurements with the Flow Tracker occurred from January 8, 2010 to July 12, 2011. One measurement was taken at each location every two weeks. The measurement at the Bypass Drain is located on the upstream side of the access bridge (Figure 2-2), which is about 0.3 miles (0.5 km) from the end of the lined section of the drain, and 0.5 miles (0.8 km) from the discharge point into the Ciénega. At the beginning of the project, water in the Santa Clara Drain was stagnant due to the accumulation of sediments, with indications from CONAGUA that water was backing up. This prevented reliable measurements at the Santa Clara Drain. Therefore, we decided to measure flows at the Riito Drain. Flows at Riito Drain were also very small, and the only point where there was a high probability of taking a reliable measurement was at a culvert located where the drain intersects with the road to the Ejido Luis Encinas Johnson. We measured at this location from January 2010 to February 2011. After CONAGUA performed maintenance work on the Santa Clara and Riito Drains in winter 2010, the measuring location was changed in March 2011 to a point at which the two sources could be captured and remain the same for the remaining of the monitoring program (Figure 2-3).

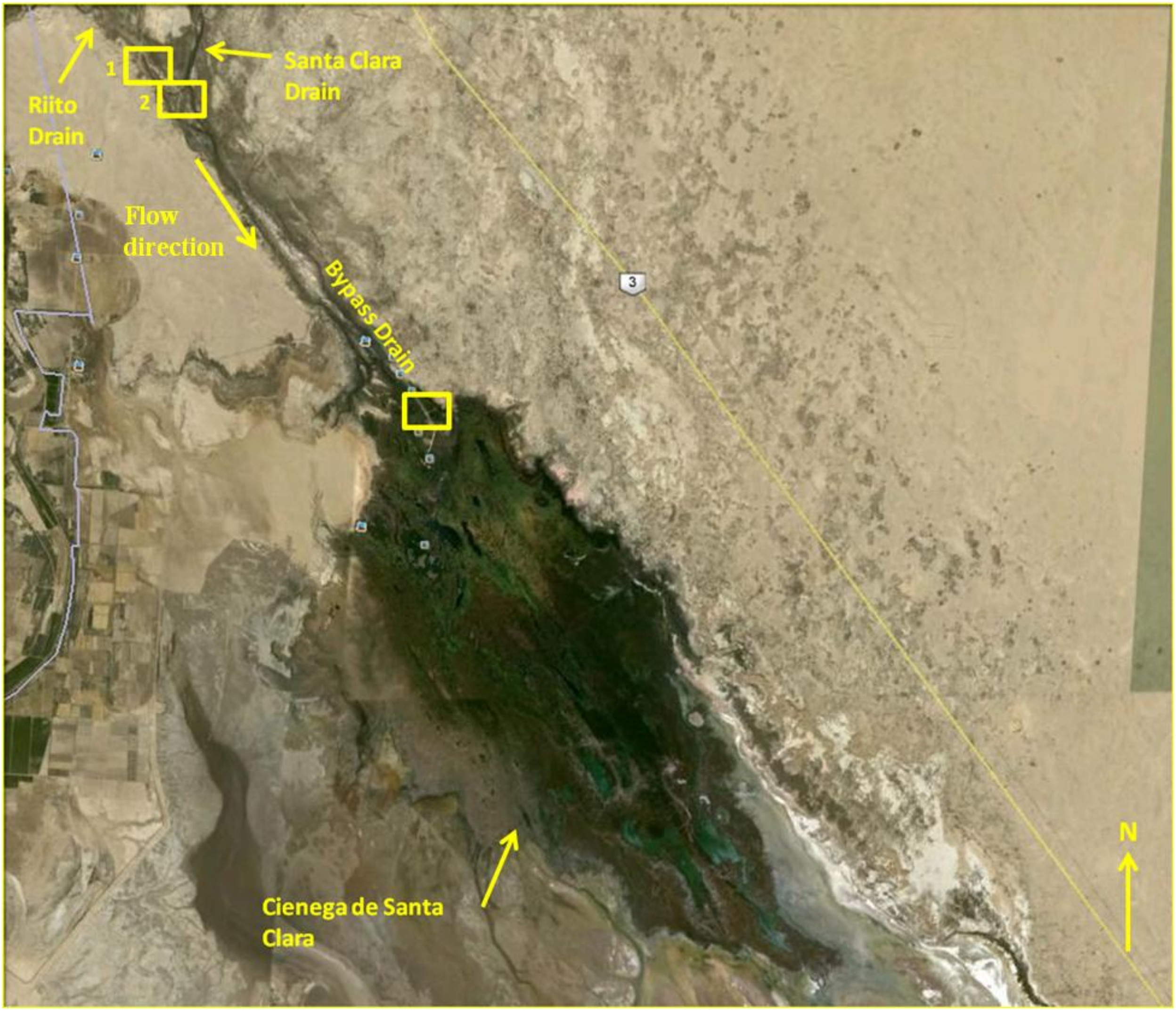


Figure 2-1. Overview of the Ciénega de Santa Clara and surrounding area showing location of flow discharge monitoring points along the Bypass and Santa Clara-Riito drains.

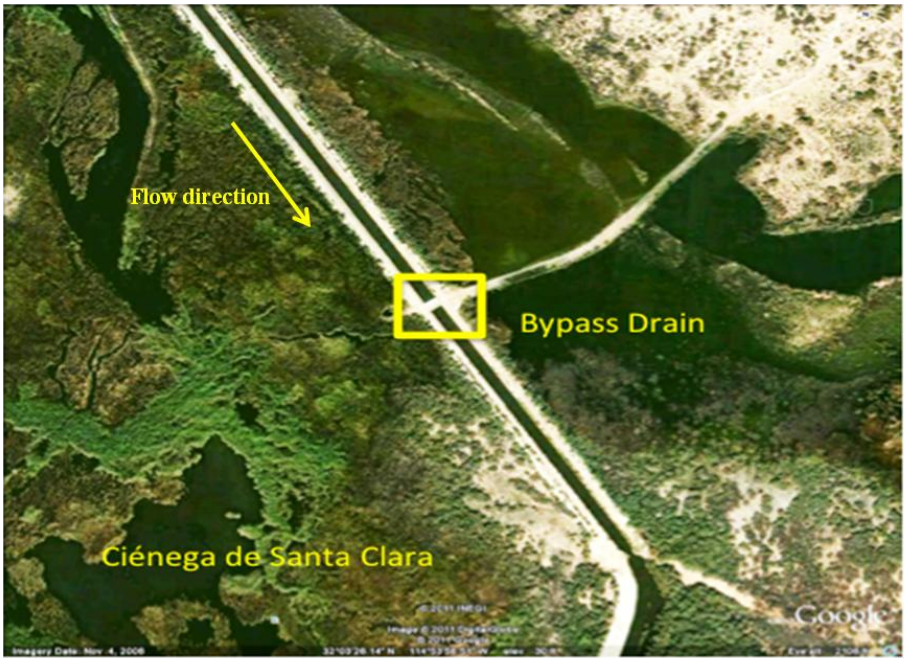


Figure 2-2. Discharge measuring point at the Bypass drain.

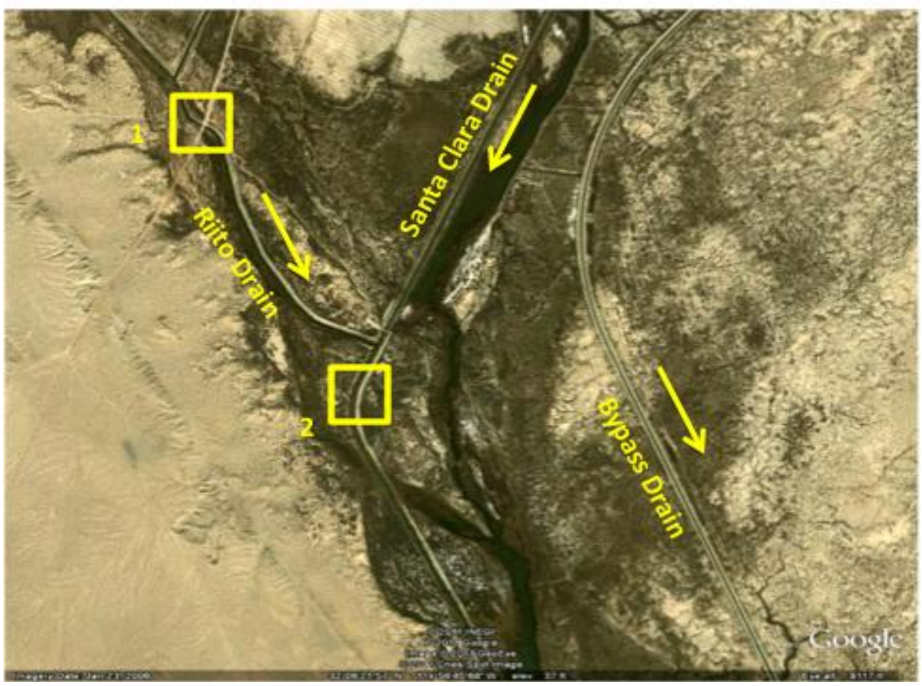


Figure 2-3. Flow discharge measuring points at the Santa Clara-Riito Drain. Yellow arrows show flow direction. We measured at Site 1 from January 2010 to February 2011. After CONAGUA performed maintenance work on the Santa Clara and Riito Drains in winter 2010 to remove sediment buildup, the measuring location was changed in March 2011 to a point at which the two sources could be captured (Site 2) and remained the same for the remaining of the monitoring program.

In both flow-measuring locations we installed a water gauge and a pressure-based water level logger. The logger at Riito is a YSI 600 LS logger (see description below) and the logger at the Bypass Drain is a HOBO. The loggers measure water levels every hour, while the stream gauge is used to manually measure water level every time a flow measurement is taken with the Flow Tracker. The water gauge reading allows us to verify the actual elevation measured by the loggers.

a) Measuring protocols

To measure water flows into the Ciénega we acquired a FlowTracker Handheld ADV (Acoustic Doppler Velocimeter) made by SonTek/YSI Inc (Figure 2-3, upper left). This discharge measurement device is of the highest quality in the market, with a velocity range of +- 0.001 meters per second (m/s) to 4.0 m/s (+- 0.003 to 13 feet per second [ft/s]) and a velocity accuracy of +- 1% of measured velocity, +- 0.25 centimeters per second (cm/s). It has been tested by the USGS under different conditions and was found to perform well in many stream environments (USGS, 2004). The FlowTracker Handheld ADV is a single-point Doppler current meter designed for field velocity measurements. It uses the proven Doppler technology of the SonTek/YSI Acoustic Doppler Velocimeter (ADV), the leading high-resolution velocity sensor (SonTek/YSI Inc, 2007).

Figure 2-4. Flow discharge measurements in Bypass Drain using FlowTracker. Upper left box shows the FlowTracker controller.

To perform these measurements we followed the guidelines for use of Flow Trackers in making discharge measurements specified by the USGS (2004). Dr. Jorge Ramirez of the Autonomous

University of Baja California (UABC) supervised data collection and was responsible for data analysis. We took flow measurements every two weeks from January 2010 through July 2011 (Figure 2-4). Teams from Sonoran Institute and the UABC alternated every two weeks to measure flows.

b) Inflow Results

To characterize flows in the Bypass Drain during the pilot operation of the YDP, it is helpful to first look at the flow patterns in the Bypass Drain for the last ten years (2000-2010), and use this as a reference (Figure 2-5). Flow data from the United States Bureau of Reclamation (BOR) shows that annual average flow at the Bypass Drain for this period is 4.29 cubic meters per second (m^3/s) (151.5 cubic feet per second [CFS]). During this period flows were higher in the months of October and November (late fall-early winter) and lowest in the summer months (July-August) (see Figure 2-5). Figure 2-5 shows average monthly flow values and their variability for this period. During the year of the pilot operation of the YDP (2010), flows showed the same general pattern as the previous ten years, with higher flows in winter and lowest in summer. However, there are significantly higher flows in March and April than in the previous decade. Also, the variability among months in 2010 is larger than the previous ten years, with year 2010 having the lowest monthly average flow in August with 1.78 m^3/s (compared to 3.56 m^3/s for the 10-year average) and the highest flow in October with 6.36 m^3/s (compared to 5.17 m^3/s in November) (Figure 2-6). Figure 2-6 also shows average monthly discharge at the Bypass Drain for the data available for 2011.

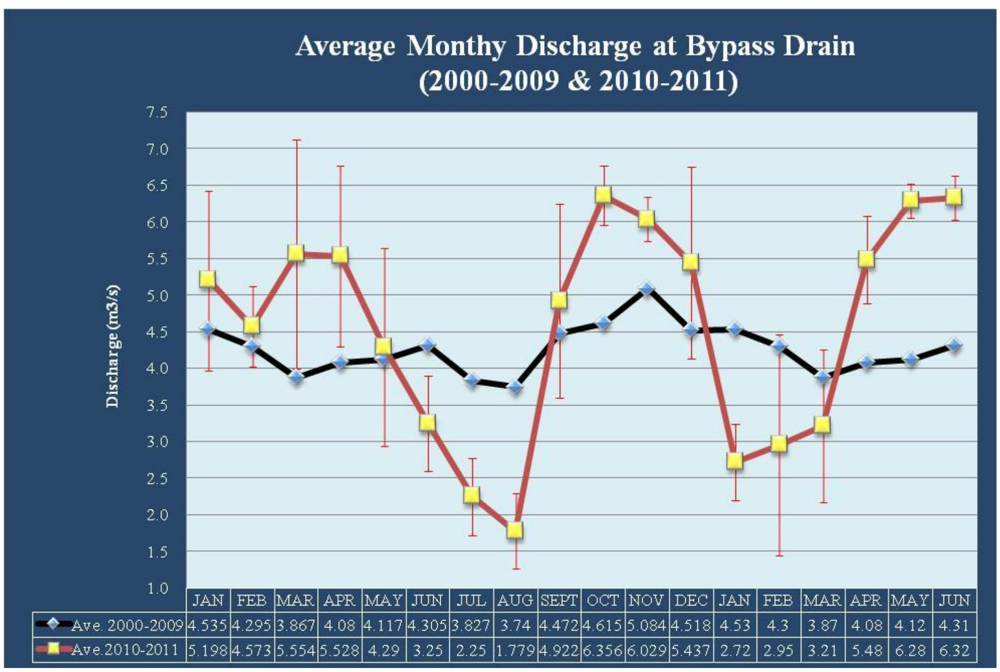
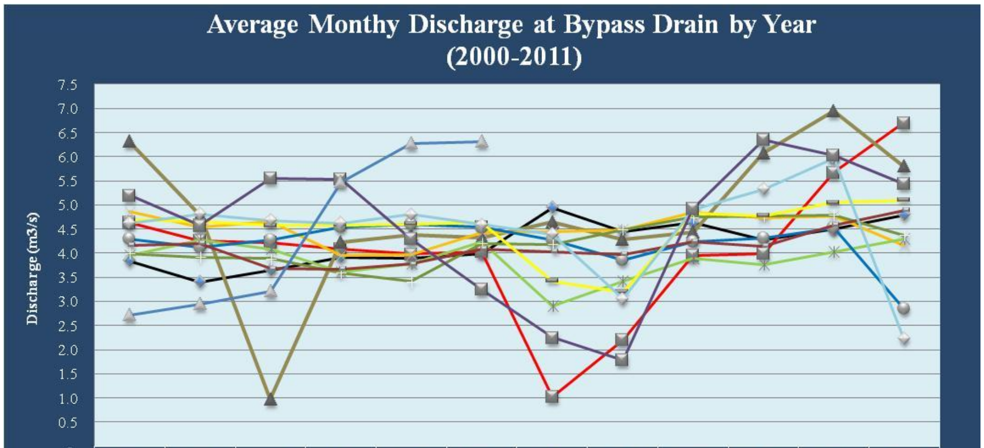


Figure 2-5. Average monthly flows at Bypass Drain for the 2000-2009 period and for 2010-2011. Data is from U.S. BOR. Data for 2010-2011 represents the monthly average for each month calculated from daily measurements. Error bars represent a 95% confidence level of flows in that month.



	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
2000	3.84	3.40	3.64	3.91	3.89	3.99	4.94	4.45	4.63	4.27	4.50	4.79
2001	4.64	4.25	4.23	4.08	3.98	4.03	1.02	2.20	3.96	3.99	5.68	6.70
2002	6.31	4.77	0.97	4.23	4.37	4.32	4.65	4.28	4.44	6.07	6.95	5.79
2003	4.86	4.55	4.65	3.96	3.97	4.43	4.45	4.49	4.85	4.73	4.78	4.16
2004	3.95	4.28	4.09	3.62	3.78	4.24	2.91	3.42	3.90	3.76	4.02	4.29
2005	4.29	4.12	4.28	4.55	4.60	4.53	4.28	3.86	4.24	4.31	4.53	2.86
2006	4.00	3.91	3.89	3.60	3.41	4.20	4.18	4.49	4.74	4.77	4.79	4.38
2007	4.16	4.20	3.68	3.66	3.77	4.09	4.03	3.97	4.24	4.15	4.58	4.89
2008	4.69	4.65	4.57	4.58	4.60	4.63	3.42	3.19	4.82	4.78	5.05	5.09
2009	4.62	4.81	4.68	4.62	4.80	4.59	4.39	3.05	4.90	5.33	5.97	2.22
2010	5.20	4.57	5.55	5.53	4.29	3.25	2.25	1.78	4.92	6.36	6.03	5.44
2011	2.72	2.95	3.21	5.48	6.28	6.32						

Figure 2-6. Average monthly discharge at Bypass Drain shown by year (2000-2011). Data available through June 2011.

In this project we measured flows at the Bypass Drain beginning in January 2010 and through July 2011. Figure 2-7 and Table 2-1 show these results along with the flow measurements taken by the BOR at SIB for the Bypass Drain. Results show that manual measurements at the Bypass Drain at the measuring point near the Ciénega follow the same pattern as the flows measured by BOR at SIB. We attribute differences to difficulties in taking these measurements because of the presence of sediments in the drain as well as the depth of the water column. This could have introduced some minor errors into the parameters measured in the field.

Flow measurements near the Ciénega also show that there are no significant water losses or gains in the 35 miles (56.3 km) that the water travels from the measuring point at SIB to the end of the Bypass Drain. For practical purposes, we believe that values measured by the BOR at SIB provide reliable data on flows for the Bypass Drain near the discharge point. On the other hand, our manual measurements of flows for the Santa Clara-Riito Drain are the only ones available, and therefore provide valuable information. We present detailed information for all discharge measurements made in Appendix III.

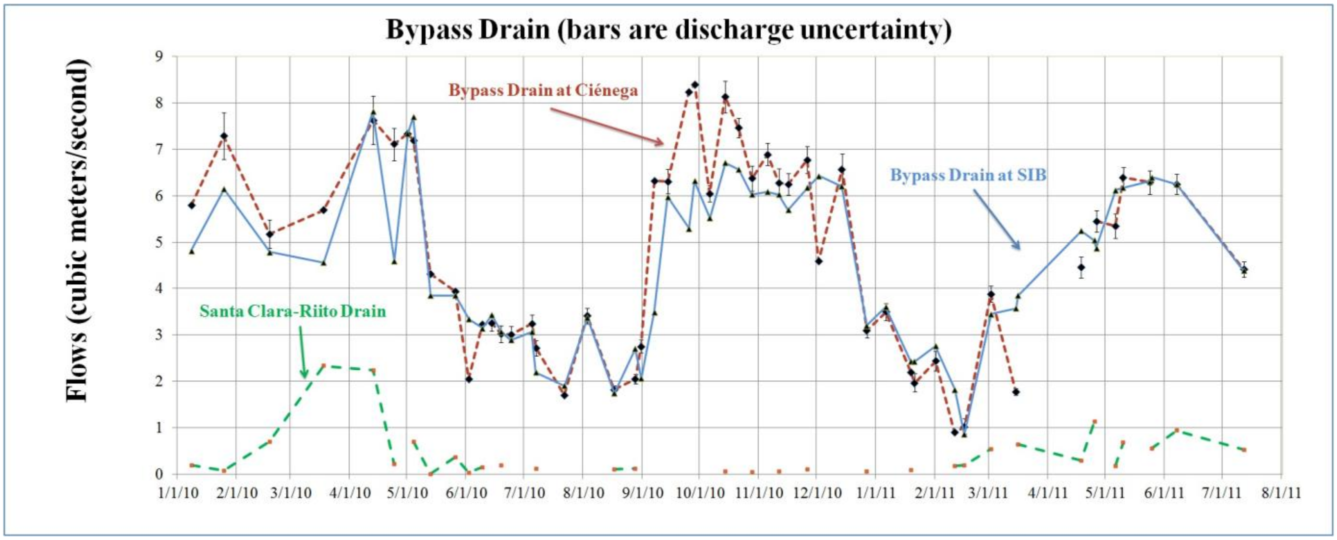


Figure 2-7. Average monthly discharge at Bypass Drain at Ciénega, Santa Clara-Riito Drain, and Bypass drain at SIB (January 2010 - July 2011)

All manual measurements were processed on the Sontek FlowTracker Software to obtain the total discharge. Uncertainty of each discharge estimate included in the Sontek FlowTracker report sheet according to the ISO Uncertainty Calculation method (ISO-748) was included in the discharge at Bypass Drain graph (Sontek, 2009).

The ISO uncertainty calculation is based on a working version of ISO Standard 748. While it is normally not appropriate to use a working version, an exception was made since the working version provides a more thorough calculation than the released ISO standard (1997).

Equation 1 below shows the ISO method to calculate uncertainty applied to a FlowTracker discharge measurement, while Table 2-2 shows number of verticals versus uncertainty.

Date	Bypass Drain at Ciénega (m^3/s)	Bypass Drain at SIB (m^3/s)	Santa Clara-Riito Drain (m^3/s)	Bypass Drain at Ciénega (cfs)	Bypass Drain at SIB (cfs)	Santa Clara-Riito Drain (cfs)
1/8/2010	5.80	4.81	0.18	204.80	170.00	6.50
1/25/2010	7.29	6.15	0.08	257.35	217.00	2.75
2/18/2010	5.18	4.79	0.69	182.75	169.00	24.54
3/18/2010	5.69	4.56	2.33	200.92	161.00	82.36
4/13/2010	7.63	7.82	2.24	269.36	276.00	79.08
4/24/2010	7.11	4.59	0.21	251.19	162.00	7.47
5/1/2010	7.34	7.33	FBDL	259.14	259.00	FBDL
5/4/2010	7.20	7.70	0.70	254.24	272.00	24.81
5/13/2010	4.32	3.85	0.00	152.54	136.00	0.04
5/26/2010	3.94	3.85	0.36	139.27	136.00	12.62
6/2/2010	2.05	3.34	0.03	72.36	118.00	0.97
6/9/2010	3.22	3.14	0.15	113.65	111.00	5.23
6/14/2010	3.26	3.43	FBDL	115.02	121.00	FBDL
6/19/2010	3.02	3.06	0.18	106.57	108.00	6.36
6/24/2010	3.01	2.89	FBDL	106.37	102.00	FBDL
7/5/2010	3.24	3.06	ND	114.35	108.00	ND
7/7/2010	2.71	2.19	0.11	95.76	77.30	3.94
7/22/2010	1.70	1.90	FBDL	59.92	67.10	FBDL
8/3/2010	3.41	3.37	FBDL	120.53	119.00	FBDL
8/17/2010	1.81	1.74	0.10	63.99	61.40	3.59
8/28/2010	2.05	2.70	0.12	72.39	95.30	4.27
8/31/2010	2.75	2.06	ND	97.19	72.70	ND
9/7/2010	6.32	3.48	ND	223.16	123.00	ND
9/14/2010	6.31	5.98	ND	222.87	211.00	ND
9/25/2010	8.24	5.30	ND	290.96	187.00	ND
9/28/2010	8.40	6.32	ND	296.61	223.00	ND
10/6/2010	6.05	5.52	ND	213.47	195.00	ND
10/14/2010	8.14	6.71	0.06	287.43	237.00	1.98
10/21/2010	7.46	6.57	ND	263.53	232.00	ND
10/28/2010	6.37	6.03	0.04	225.01	213.00	1.44
11/5/2010	6.89	6.09	ND	243.39	215.00	ND
11/11/2010	6.28	6.03	0.06	221.59	213.00	2.10
11/16/2010	6.25	5.69	ND	220.72	201.00	ND
11/26/2010	6.77	6.17	0.10	239.23	218.00	3.47
12/2/2010	4.59	6.43	ND	161.98	226.98	ND
12/14/2010	6.58	6.20	ND	232.19	218.98	ND
12/27/2010	3.10	3.20	0.06	109.30	112.99	2.07
1/6/2011	3.50	3.60	ND	123.44	127.12	ND
1/19/2011	2.19	2.43	0.09	77.46	85.81	3.18
1/21/2011	1.97	2.42	ND	69.40	85.45	ND
2/1/2011	2.43	2.76	ND	85.97	97.46	ND
2/11/2011	0.89	1.82	0.18	31.54	64.27	6.29
2/16/2011	1.02	0.85	0.18	36.06	30.01	6.53
3/2/2011	3.88	3.45	0.53	137.15	121.82	18.83
3/15/2011	1.77	3.57	ND	62.56	126.06	ND
3/16/2011	ND	3.85	0.64	ND	135.95	22.62
4/18/2011	4.46	5.24	0.29	157.32	185.03	10.27
4/25/2011	ND	5.04	1.14	ND	177.97	40.22
4/26/2011	5.45	4.87	ND	192.60	171.96	ND
5/6/2011	5.34	6.12	0.18	188.66	216.10	6.27
5/10/2011	6.39	6.17	0.68	225.81	217.87	24.13
5/24/2011	6.29	6.31	ND	222.04	222.81	ND
5/25/2011	ND	6.40	0.56	ND	225.99	19.68
6/7/2011	6.25	6.25	0.94	220.77	220.69	33.04
7/12/2011	4.41	4.39	0.52	155.72	155.01	18.51

Table 2-1. Water flows discharged into the Ciénega by source. Flows for Santa Clara-Riito Drain between January 2010 and February 2011 represent only flows at Riito drain. After this date flows captured both Santa Clara and Riito drains. ND (no data collected); FBDL (flow below detection level or no flow). Note: Data for Bypass Drain at SIB is from BOR. Data for Bypass Drain at Ciénega and for Santa Clara-Riito Drain were measured manually with the Flow Tracker.

$$u_Q{}^2 = u_m{}^2 + u_s{}^2 + \frac{\sum_{i=1}^{m}(b_i\, d_i v_i\,(u_{bi}{}^2 + u_{di}{}^2 + u_{pi}{}^2 + (\frac{u_{ci}{}^2 + u_{ei}{}^2}{n_i})))}{\sum_{i=1}^{m}(b_i\; d_i\, v_i)^2} \qquad (1)$$

Where:

= relative (percentage) uncertainty in discharge calculation
= relative uncertainty due to the number of verticals (stations); Table 2-2.
= relative uncertainty due to calibration errors in measurements of width, depth and velocity. This is assumed to be the accuracy of the FlowTracker calibration (1%).
= number of verticals across the width of the stream
= width at vertical i
= depth at vertical i
= mean velocity at vertical i
= relative uncertainty in the width measurement at vertical i. From the ISO standard, this is assumed to be 0.5%.
= relative uncertainty in the depth measurement at vertical i. From the ISO standard, this is assumed to be 0.5% for depth > 0.30 m (1 ft), and 1.5% for depth < 0.30 m (1 ft).
= relative uncertainty due to limited number of velocity measurements at vertical i; Table 2.
= relative uncertainty in velocity measurements at vertical i, with contributions from instrument uncertainty ( ) and real fluctuations in the river ( ). The combination of these two terms is directly measured by the FlowTracker as the standard error of velocity (V_{i_err}), and is calculated as ($u_{ci} + u_{ei} = V_{i\_err} / V_i$).
= number of velocity measurements at vertical i.

Number of Verticals	Uncertainity %
5	7.5
10	4.5
15	3

Table 2-2. - Number of Verticals Uncertainty % ( )

Sauer and Meyer (1992) provide the same data as Equation 2 below to calculate this uncertainty for any number of verticals. In this equation, $\boldsymbol{u_m}$ is given in percent and $\boldsymbol{m}$ is the number of verticals. This is the equation used by the FlowTracker when calculating the ISO uncertainty estimate.

Eq. 2

This estimate is based on a statistical analysis of many streams. It does not take into account the data available for an individual stream that could strongly influence the overall uncertainty. Table 2-3 shows measurement methods against uncertainty.

Measurement Method	Uncertainty ( ) %
1 point (0.6 * depth)	7.5
2 points (0.2 and 0.8 * depth)	3.5
5 points (near surface, near bottom, and 0.2 / 0.6 / 0.8 * depth)	2.5
Velocity distribution method (multiple points with the change between points not exceed 20% of the higher value)	0.5

Table 2-3. - Measurement Method vs. Uncertainty

FlowTracker calculations have simplified Table 2-3 above to estimate the uncertainty based only on the number of measurements in the vertical as shown in Table 2-4 below.

Number of Measurements	Uncertainty (upi) %
1	7.5
2	3.5
3	3
4	2.7
5 or more	2.5

Table 2-4. - Number of Measurements vs. Uncertainty

c) Conditions during the YDP pilot operation

The pilot operation of the YDP started on May 3, 2010 and concluded on March 26, 2011. Our flow measurements as well as those by BOR show that before the beginning of the pilot operation, the Ciénega received up to 1.5 m^3/s (52.5 cfs) more water on average than the equivalent for October through April in the previous decade. If we look at the arranged water deliveries to the Ciénega (Figure 2-8), these high flows correspond to the contribution from BOR, which was delivered during those months (October to March). With the start of the YDP, flows decreased significantly in the months of May through August to 2 m^3/s (70 cfs) less than the average for those months during the previous decade. During these months only 1,267 acre-feet (af) (1.6 million cubic meters [mcm]) of the arranged water was delivered to the Ciénega. However, beginning in October 2010, the Ciénega received higher volumes than average and these remained high until mid-December; these higher volumes again correspond to the deliveries of arranged water. Flows declined again from mid-December to mid-March, during which time only about 1,526 af of arranged water was delivered to the Ciénega. By mid-March, near the end of the pilot operation of the YDP, flows in the Bypass Drain began to increase, and reached 6.0 m^3/s (210 cfs) by June, once again above average for those months. This increase coincides with the 13,648 af (16.8 mcm) of arranged water that was delivered during April through July. (See Tables 2-5 and 2-6 for volumes of arranged water by source).

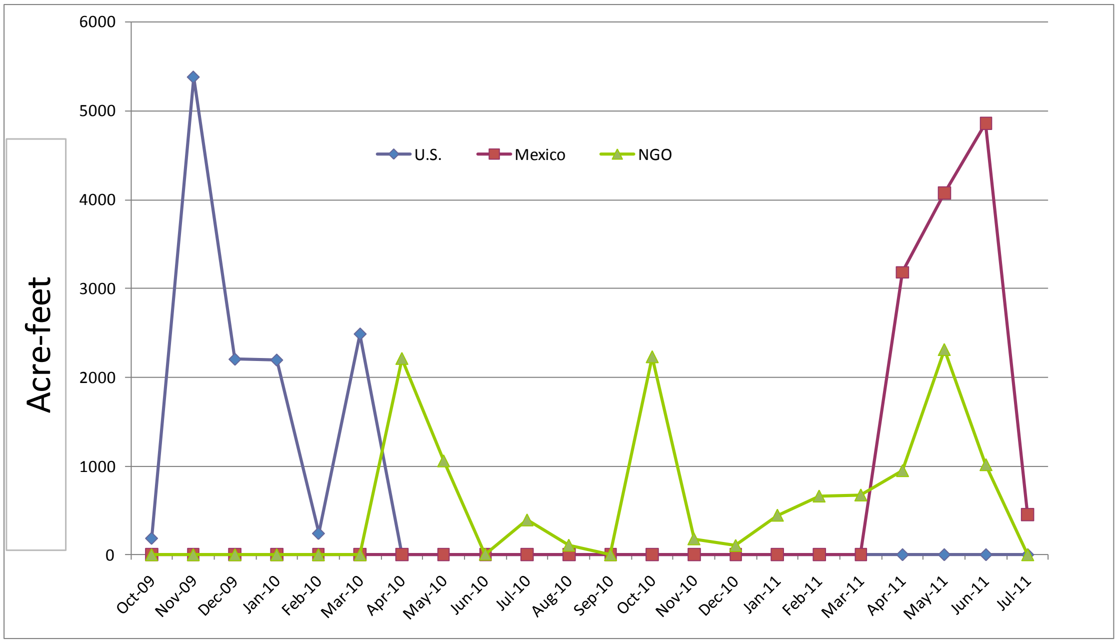


Figure 2-8. Volume in acre-feet of arranged water to the Ciénega by source. Data is from CILA.

Month/year	USA* (acre-feet)	MEXICO (acre-feet)	NGO** (acre-feet)	USA* (1000 m^3)	MEXICO (1000 m^3)	NGO** (1000 m^3)
Oct-09	149	0	0	184	0	0
Nov-09	4,363	0	0	5,382	0	0
Dec-09	1,785	0	0	2,202	0	0
Jan-10	1,778	0	0	2,193	0	0
Feb-10	194	0	0	239	0	0
Mar-10	2,016	0	0	2,487	0	0
Apr-10	0	0	1,792	0	0	2,210
May-10	0	0	857	0	0	1,057
Jun-10	0	0	5	0	0	6
Jul-10	0	0	318	0	0	392
Aug-10	0	0	87	0	0	107
Sep-10	0	0	0	0	0	0
Oct-10	0	0	1,807	0	0	2,229
Nov-10	0	0	145	0	0	179
Dec-10	0	0	84	0	0	104
Jan-11	0	0	361	0	0	445
Feb-11	0	0	536	0	0	661
Mar-11	0	0	546	0	0	673
Apr-11	0	2,580	768	0	3,182	947
May-11	0	3,304	1,873	0	4,075	2,310
Jun-11	0	3,939	822	0	4,859	1,014
Jul-11	0	368	0	0	454	0
Total by source	10,285	10,191	10,001	12,687	12,570	12,334

* Accounting of flows began in October 2009, after the approval of the IBWC/CILA Principal Engineer's report signed in July 2009. Water deliveries ended in July 5, 2011.
** Contributions include those from Santa Clara Drain.

Table 2-5. Volumes of arranged water by source—USA, Mexico, and Non-governmental Organizations (NGO). Data is from CILA.

	Deliveries through Bypass Drain				Deliveries through Santa Clara Drain	
	USA*		MEXICO		MEXICO **	
Month/Year	(Acre-feet)	(1000 m^3)	(Acre-feet)	(1000 m^3)	(Acre-feet)	(1000 m^3)
Oct-09	149	184	0	0	0	0
Nov-09	4,363	5,382	0	0	0	0
Dec-09	1,785	2,202	0	0	0	0
Jan-10	1,778	2,193	0	0	0	0
Feb-10	194	239	0	0	0	0
Mar-10	2,016	2,487	0	0	0	0
Apr-10	0	0	1,792	2,210	0	0
May-10	0	0	857	1,057	0	0
Jun-10	0	0	5	6	0	0
Jul-10	0	0	318	392	0	0
Aug-10	0	0	87	107	0	0
Sep-10	0	0	0	0	0	0
Oct-10	0	0	1,807	2,229	0	0
Nov-10	0	0	145	179	0	0
Dec-10	0	0	0	0	84	104
Jan-11	0	0	0	0	361	445
Feb-11	0	0	127	157	409	504
Mar-11	0	0	0	0	546	673
Apr-11	0	0	2,580	3,182	768	947
May-11	0	0	4,323	5,332	854	1,053
Jun-11	0	0	4,170	5,144	591	729
Jul-11	0	0	368	454	0	0
Total by source	10,285	12,686	16,579	20,450	3,612	4,455
Total all sources	**30,476**	**Acre-feet**				
Total all sources	**37,591**	**1,000 Cubic meters**				

* Accounting of flows began in October 2009, after the approval of the IBWC/CILA Principal Engineer's report signed in July 2009. Water deliveries ended in July 5, 2011.
** Contributions from Santa Clara drain.

Table 2-6. Volumes of arranged water by source and delivery point.. Data from CILA.

B. Topography and Bathymetry

This project implemented the first topographic and bathymetric survey of the Ciénega. The principal areas of interest for the surveys were the marsh and open lagoon areas as well as the transition areas inside and outside the existing or known highest shoreline (watermark) surrounding the Ciénega. The goal of the topographic survey was to document those areas near the wetland edge that could be inundated or exposed by small changes in water flows (water volume) into the Ciénega (Figure 2-9). The dense stands of cattail made access very difficult and presented a major challenge to the bathymetric survey. Therefore, this initial survey was designed to capture the elevation of the bottom of all major open water areas and reference them to mean sea level.

The University of Arizona (UA) partnered with the Autonomous University of Baja California (UABC) and the Sonoran Institute (SI) to survey the Ciénega, with the UABC leading its implementation. The UABC used GR-3 Topcon differential Global Positioning System (GPS) equipment to implement the surveys. This equipment is a high precision differential GPS that provides a precision of 10 mm+1 parts per meter in horizontal and 15 mm+1 ppm in vertical position (www.topconpositioning.com/products/gps/receivers/gr-3). On land, we implemented the survey by placing the GPS receiver antenna on an all-terrain vehicle or a four-wheel drive pick-up truck as well as by walking when these vehicles were unable to access some areas. Inside the Ciénega, we used an airboat provided by the IBWC Mexican Section.

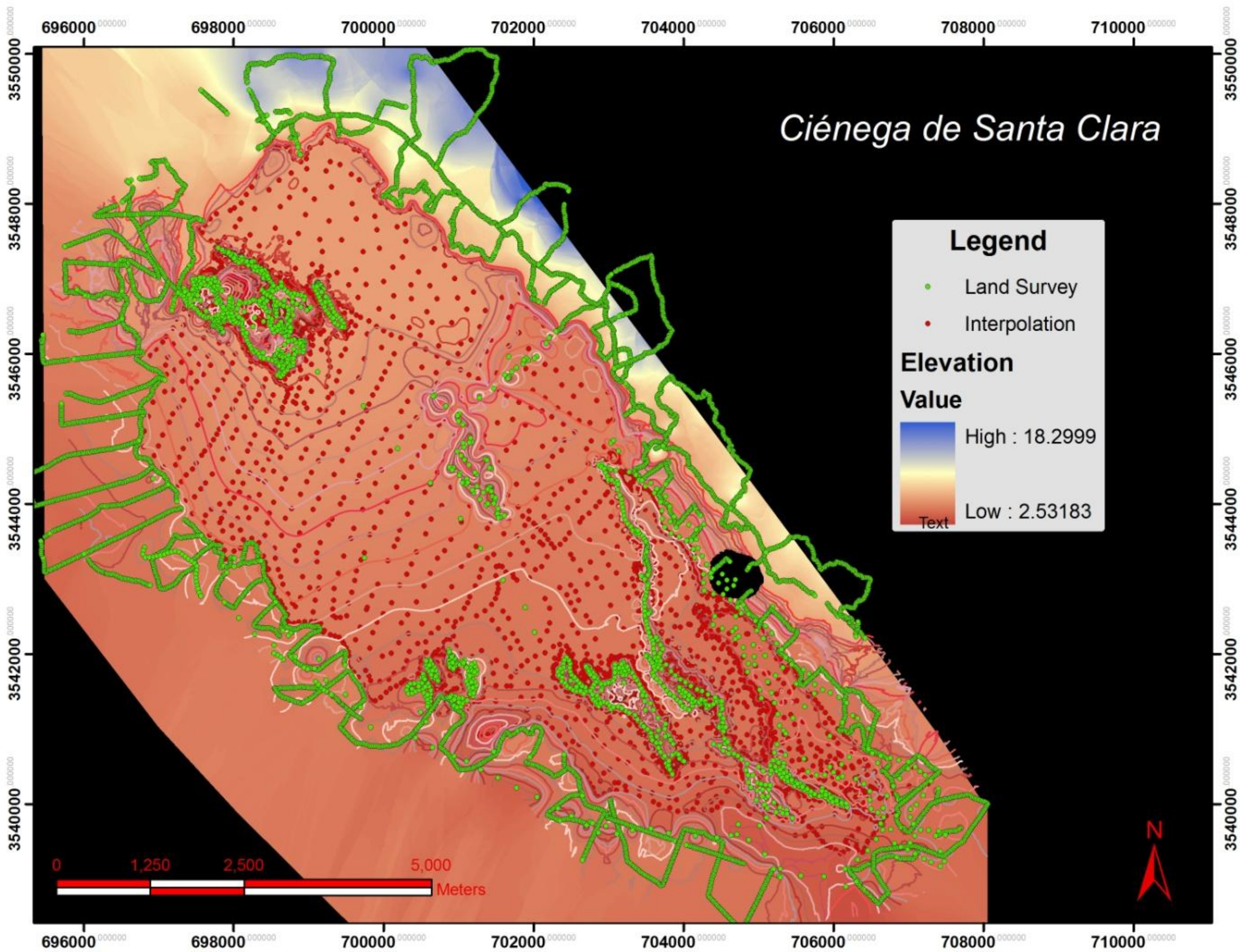


Figure 2-9. Map of bathymetry monitoring points and interpolated points in the Ciénega de Santa Clara. Elevation units are meters above mean sea level.

a) Results

Five benchmarks were placed around the perimeter of the Ciénega in order to establish fixed reference points. A GPS antenna was secured to the benchmarks and placed at less than 5 kilometers from the farthest point of the ROVER antenna. This was in order to reduce error and maintain radio communication between the two antennas. The locations of the benchmark stations are shown in Figure 2-10 and their coordinates are shown in Table 2-7.

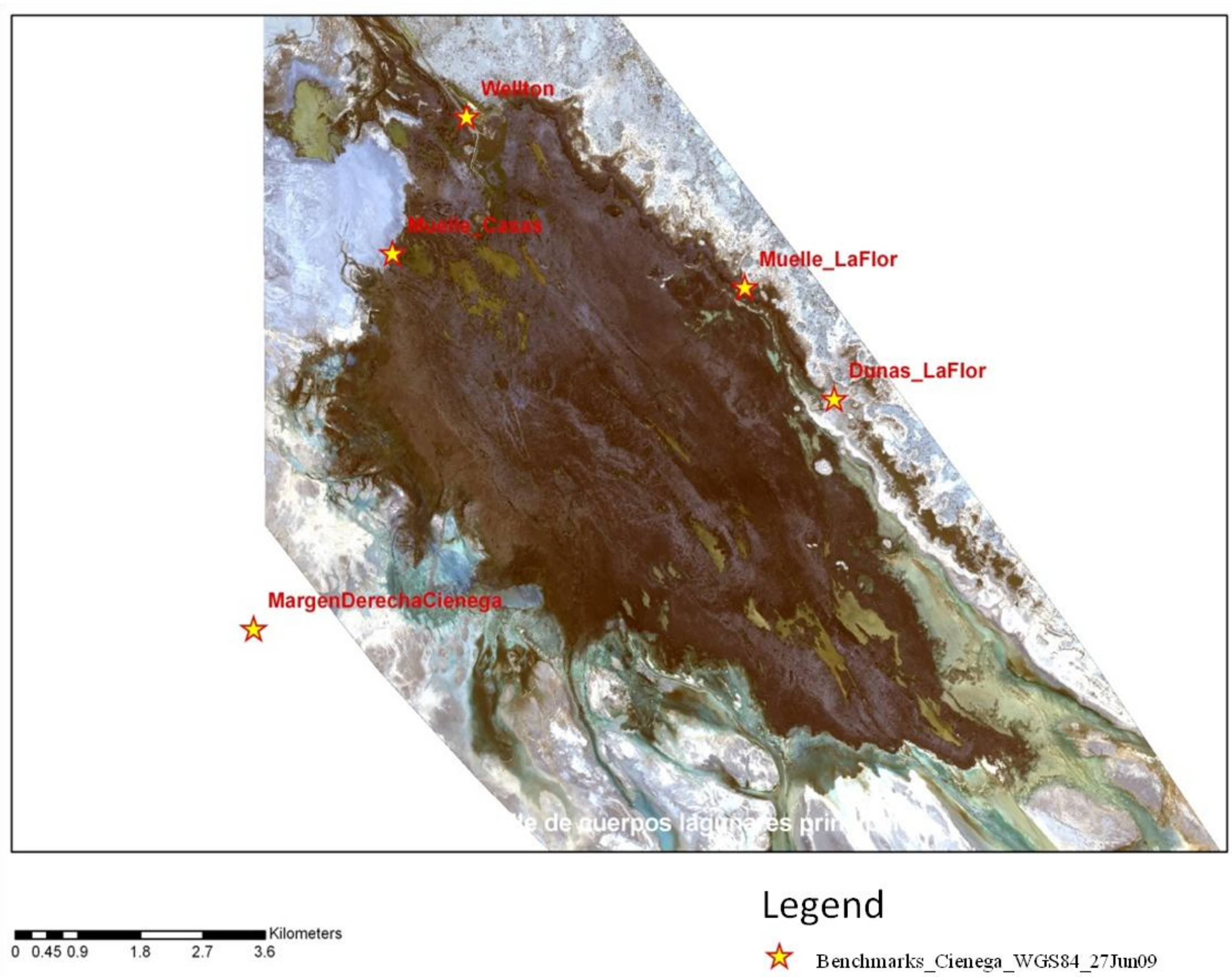


Figure 2-10. Location of the benchmarks along the perimeter of the Ciénega. Benchmarks were placed in order to reduce the distance between GPS antennas and to maintain radio communication without interference. Datum WGS84, 11N zone. Units in meters. Image from June 27, 2009.

No	x	y	h (m)	Descripción
1	703625.951	3544743.961	9.212	Dunas_LaFlor
2	702335.693	3546324.337	5.241	Muelle_LaFlor
3	698330.345	3548737.356	7.309	Wellton
4	697259.952	3546803.844	5.925	Muelle_Casas
5	695257.139	3541492.496	3.704	MargenDerechaCienega

Table 2-7. Coordinates for the benchmarks in Universal Transverse Mercator (UTM Zone 11) and Datum WGS84 and height of the water above sea level, measured in meters (m).

During the topographic and bathymetry surveys, a GPS base station was installed at one of the benchmarks sites, and we used the mobile GPS unit to obtain the elevation of points throughout the Ciénega, with an emphasis on the accessible lagoons in the Ciénega. At the water quality sampling sites, water elevation was taken both from the bottom and the surface of the lagoons in order to determine the depth of the water. Figure 2-11 shows the points taken in the lagoons located in the northwest of the Ciénega near the dock. Points were taken around the lagoons in order to precisely establish their perimeters. They were also used to evaluate the standing water surface area inside the Ciénega in the evaporation calculations.

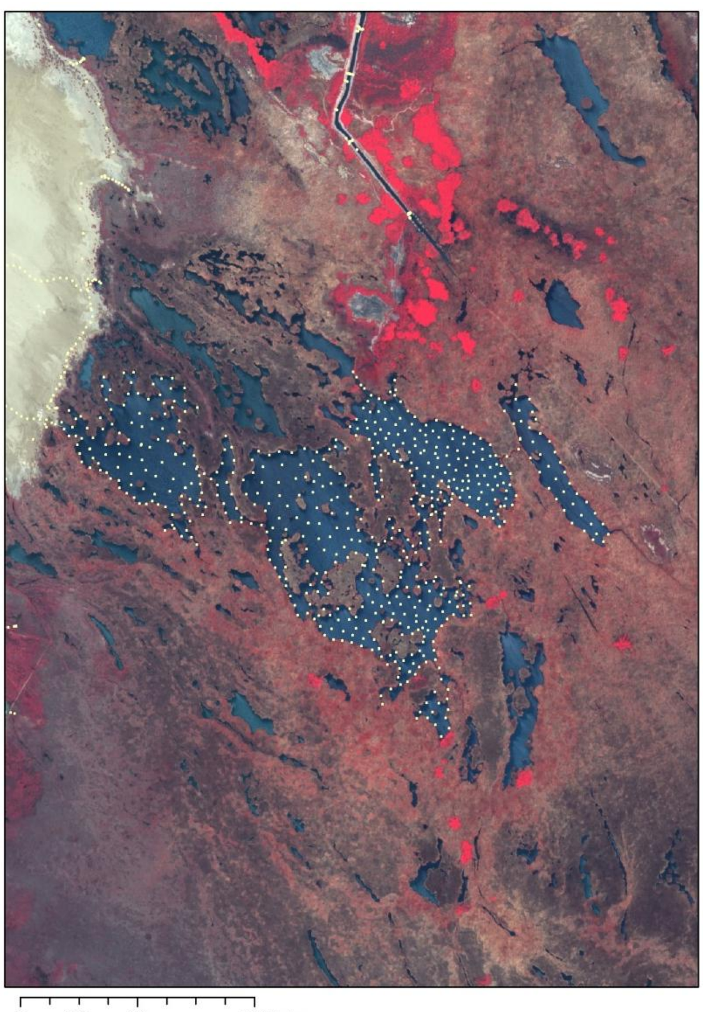


Figure 2-11. Location of topography and bathymetry survey points in the lagoons near the dock in the northwest part of the Ciénega. Image from April 25, 2009.

At the sites that were inaccessible by water, we used an airboat to access the lagoons through the dense vegetation. In this way the geometry and depth of many lagoons mainly located in the south and southeast of the Ciénega were obtained. Unfortunately, it was not possible to access all of the lagoons since at times extremely thick vegetation prevented the airboat from passing. Points were taken along the perimeter of the lagoons while a few points were located in the center.

In order to represent the topography of the Ciénega area--including the vegetation zones that were inaccessible--interpolated data were obtained under the following criteria: a) vegetation zones were interpolated assuming they were 0.15 m above the water level of the nearest lagoon, and b) water levels in the farthest lagoons identified in the images were linearly interpolated between the nearest measured lagoons. Figure 2-12 shows the bathymetry of the Ciénega and the topography of the land area surrounding it.

It is important to notice that areas lacking topographic information appear as smooth continuous areas. The smooth contours are artifacts of the contouring program and lack of data. Areas with abundant data reveal the many irregularities in bathymetry. Therefore, for the purposes of analyzing bathymetry in areas with abundant data, four profiles of the Ciénega were created in areas with abundant data, three of which are oriented southwest (SW)-northeast (NE). Profiles 1 and 2 are located in the northern portion of the Ciénega. Profile number 1 is shown in Figure 2-13. It shows that the eastern edge of the Ciénega is blocked by a topographic barrier more than 3 meters high, which prevents the expansion of the wetland along this edge. This high slope of the bottom extends for less than one kilometer from the eastern edge of the profile up to an elevation of dry land of nearly 8 meters above sea level.

In the first portion of the profile the elevation remains around 5 meters above sea level. However, elevation drops to less than 4 meters in the larger lagoons. Along the western edge of these lagoons another barrier reaches almost 5 meters and prevents the lagoons from emptying to the west. After this barrier a gentle slope to the west continues to the edge of the profile where it reaches an elevation of 3.85 meters.

Profile No. 2 shows very similar pattern to that shown in Profile No. 1. The high elevation to the east is the limit of the wetland area along this edge (Figure 2-14). Lagoons occur in the central part of the profile and are located at the same elevation as those in Profile No. 1. To the west, the elevation deceases reaching 3.78 meters on the west edge of the profile. This profile does not show the barrier that divides the lagoons from the drop in topography seen in Profile No. 1.

Profile No. 3 is in the south-central part of the wetland and has the same SW-NE orientation as the previous profiles. This profile also shows rapid increase in elevation in the east that limits the wetland zone from the rest of the sandy mesa with elevations greater than 5 meters at the far eastern edge of the profile. This profile shows that the bottom of the central lagoons are slightly above 3 meters deep and are separated by zones of vegetation with elevations greater than 4 meters above mean sea level (Figure 2-15). Elevation decreases toward the SW, where a sand barrier is present that is typically dry and fluctuates in elevation from greater than 4 meters to as low as 3.3 meters. The most important characteristic of this last profile is that it shows that the elevation of the south-central lagoons is less than the elevation of the lagoons in the northern portion of the Ciénega. This gradient allows water to pass between lagoons as it drains to the south.

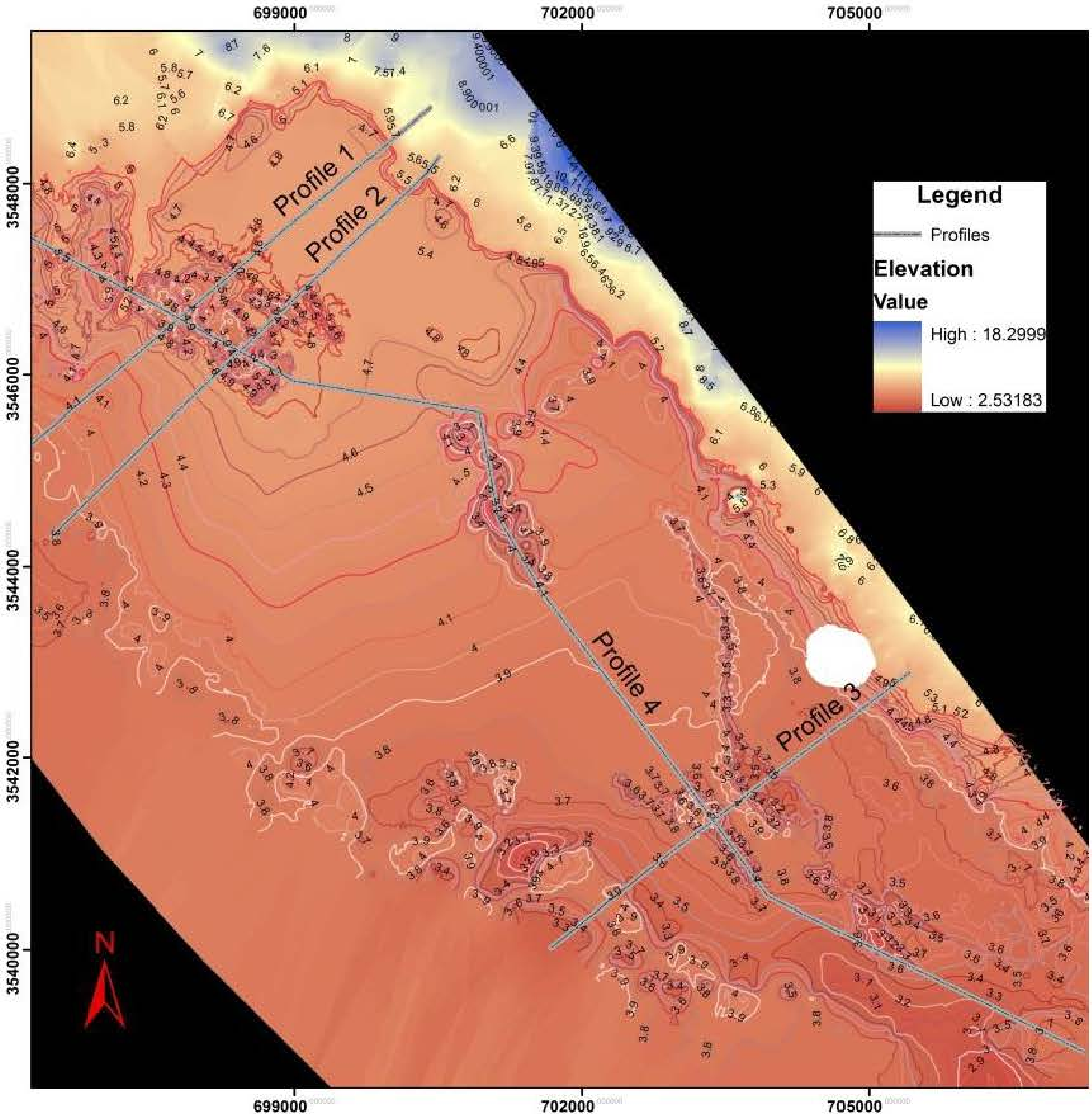


Figure 2-12. Topographic and bathymetric rendering of elevation of the Ciénega bottom obtained during the period of study. The contours are in meters above sea level and are at intervals of 0.10 meters. The gray lines show the location of the profiles. Extensive smooth areas are artifacts of limited data and interpolation algorithm.

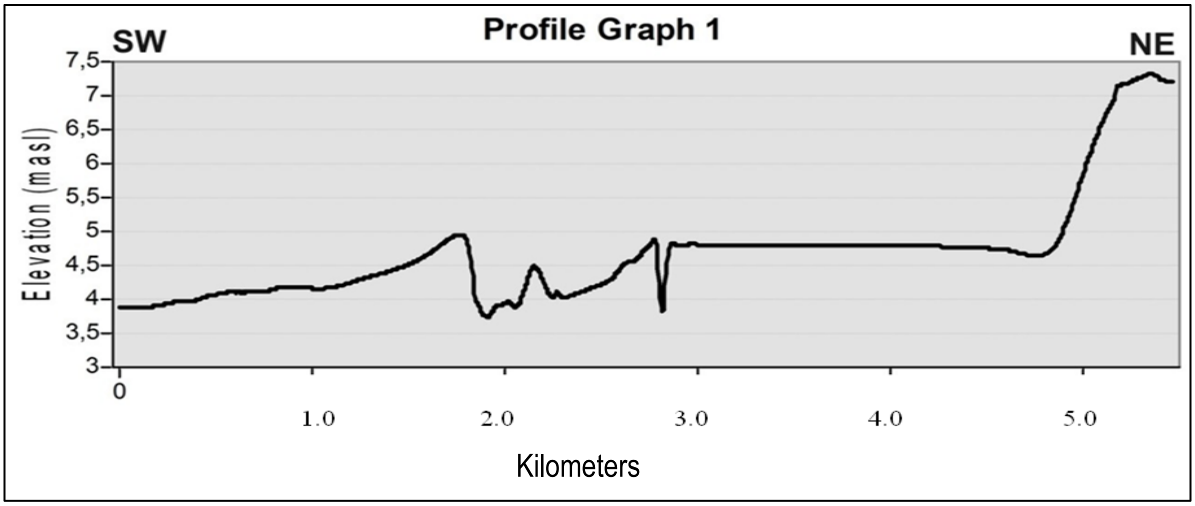


Figure 2-13. Profile No. 1 is oriented SW-NE and located in the northern part of the wetland. The left-hand portion of the profile corresponds with the SW and the right-hand portion with the NE. See Figure 2-9 for its location within the wetland.

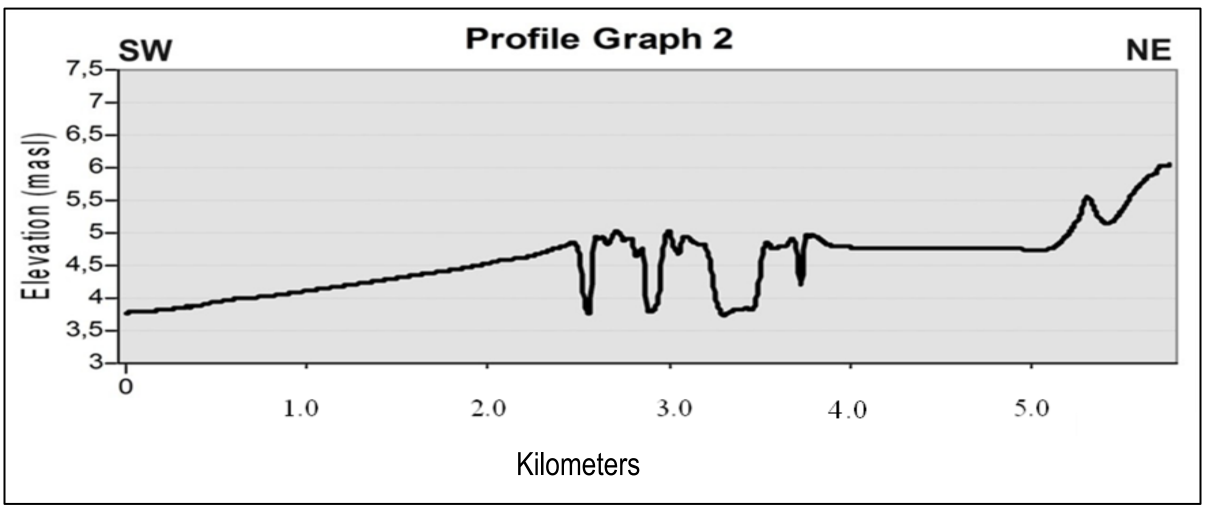


Figure 2-14. Profile no. 2 is oriented SW-NE and located in the northern portion of the wetland. The left-hand portion of the profile corresponds to the NE and the right-hand portion to the SW. See Figure 2-9 for its location within the wetland.

Profile No. 4 is oriented northwest (NW)-southeast (SE) along the axis of the Ciénega (Figure 2-16). It shows how the bottom elevation of the different lagoons drops toward the SE, where the water drains at the south end of the Ciénega. The first lagoons located from kilometers 0+500 have a bottom depth of approximately 4.0 m and drain to the lagoons located farther south.

The central lagoons in profile 4 between kilometers 5+000 and 7+000 are the deepest with an elevation of almost 2 meters above mean sea level (masl) but have a maximum depth of 4 m. The lagoons located at the south end from kilometers 9+600 to 14+200 have elevations between 3 and 3.4 masl; however, the margins of the lagoons drop progressively in elevation to a depth of 3.8 m. This gradual decrease in elevation of the lagoon edges suggests that the Ciénega fills from NW to SE directly when water breaches the height of the basin divides. The Ciénega fills indirectly or within the vegetative base of the borders by filtration or infiltration and discharges at the southeastern edge. A well-formed drainage canal in the southeast empties Ciénega water into the lower, unvegetated basin.

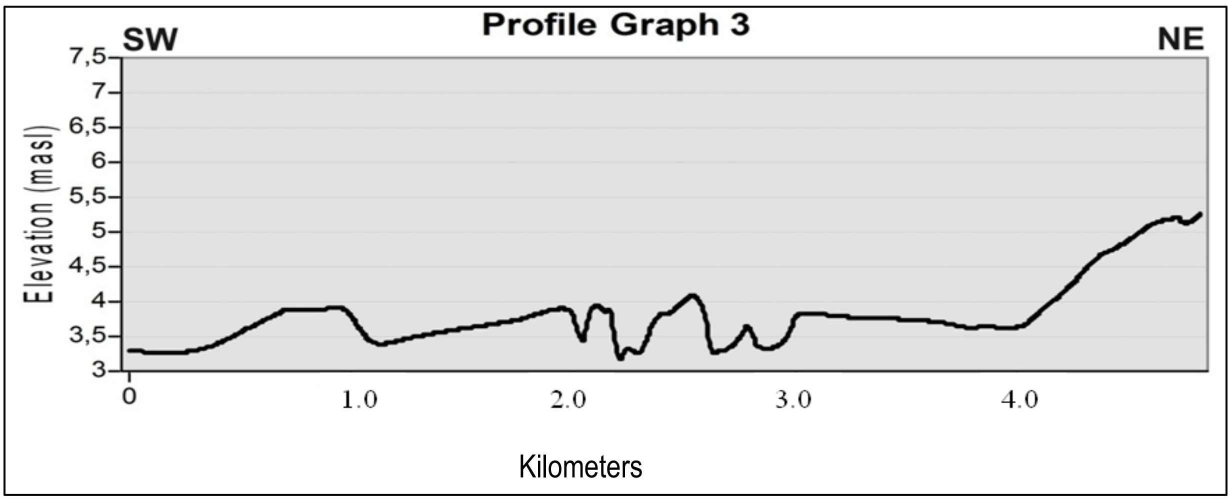


Figure 2-15. Profile No. 3 is oriented SW-NE and located in the south-central portion of the wetland. The left-hand portion of the profile corresponds to the SW and the right-hand portion to the NE. See Figure 2-9 for its location within the wetland.

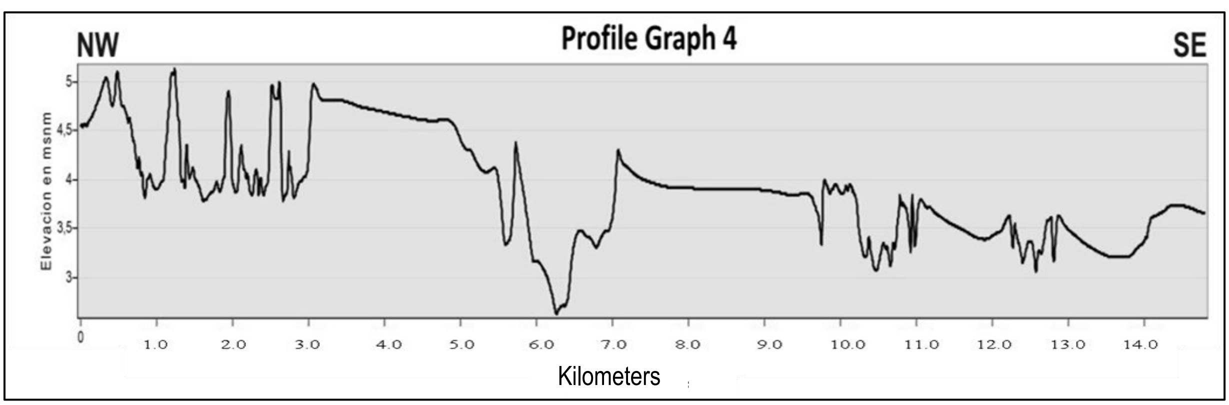


Figure 2-16. Profile 4 is oriented longitudinally to the wetland and in NW-SE direction crossing the most extended lagoons. See Figure 2-9 for its location within the wetland.

These topographic and bathymetric measurements indicate that the Ciénega de Santa Clara consists of many small basins, defined by bottom topography and stands of vegetation. Overall, the Ciénega is an asymmetric basin with its steep margin to the northeast and sloping gently to the SW. Under normal inflow conditions, water flows from the NW to the SE along the sloping axis of the basin. When water levels are high, the Ciénega may expand its wet area to the southwest. High tides and the saline water from the sea may also define the southwestern margin of the Ciénega de Santa Clara.

The bathymetric data provides key information to better understand possible effects of changes in water levels in the Ciénega. Figure 2-17 shows the difference in surface water elevation from the time of maximum flow (October 2010) to the time of the minimum flow (February 2011) in the Bypass Drain during the operation of the YDP. A positive difference indicates a higher water level while a negative difference indicates a lower water level. Note that the high flows in the Bypass Drain did not produce a comparably high difference in the level of the water in the northeast portion of the Ciénega (Ciénega Noreste). This is likely because the Ciénega Noreste is larger in volume than the Bypass Drain and that water can easily drain into lower sub-basins. The decrease in water level at Torre de Observación suggests that this sub-basin is not well connected to the rest of the Ciénega and that evaporation or evapotranspiration can drive its water levels down. The increase at Ciénega Sur indicates that high inflows result in drainage of the Ciénega to the south.

The site located at the farthest southeastern part of the Ciénega, which showed a variation of 0.15m, suffered a sharp decrease in water level due to the lack of water entering the Ciénega during the period of low-flow (winter 2011); however, it showed good recovery during the period of elevated flows (October 2010). This could indicate the sensitivity of this edge of the Ciénega to variations in flow during a long period of time (greater than one month) and to the area where decreases in flows result in a greater decrease in water level.

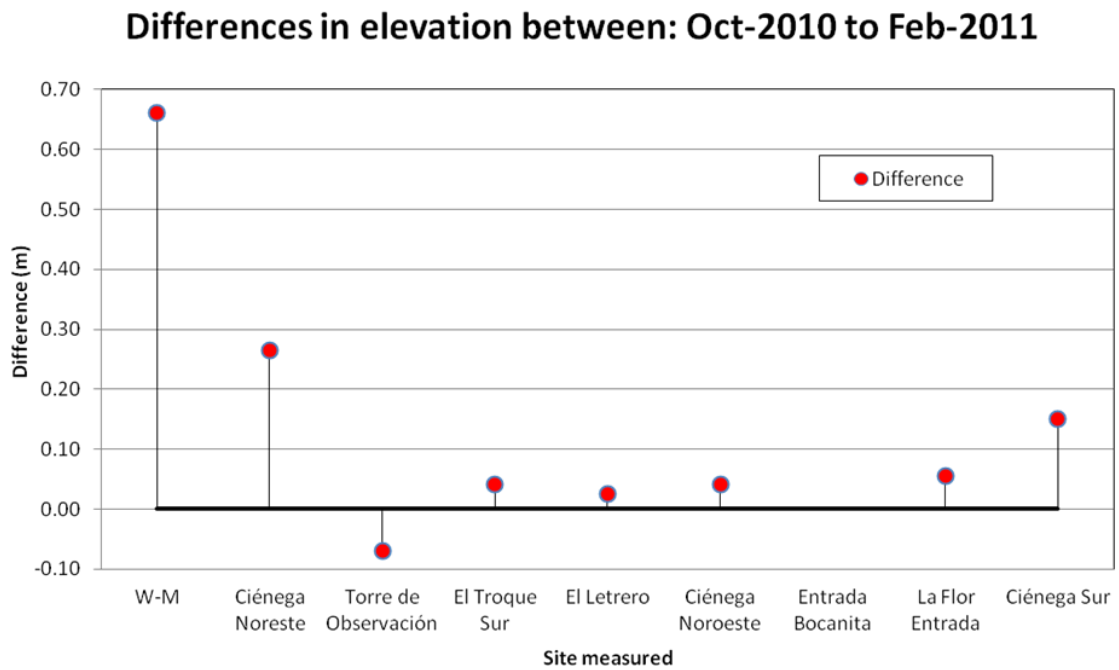


Figure 2-17. Differences in surface water elevation between the winter records from February 16, 2011 and fall records from October 21, 2010. See Figure 2-25 for location of sites. Sites are arranged from the northwest (Bypass Drain) to the southeast (Ciénega Sur).

C. Water levels and depth in the Ciénega

We used two methods to determine water levels inside the Ciénega. One is through manual reading of water level at stream gauges, and one uses pressure-based water level loggers. The main objective of installing water gauges was to have an instantaneous water elevation measurement to be used as a reference level when setting up and downloading data from the pressure-based water loggers.

We installed water gauges at 20 of the 23 samplings sites to manually record water elevation in the Ciénega. We selected the same sampling sites described above in order to have an adequate spatial coverage of the Ciénega. These water gauges have a special porcelain enamel finish to ensure easy reading and resist rust or discoloration. They are graduated in metric units, which made it easier to read by field technicians.

The water gauges are located at the following sampling sites: 1, 2, 3, 4, 5, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 19, 20, 22 and 23 (Figures 1-1 and 2-18 and Table 1-1). We did not install water gauges at sites 6, 18, and 21. In addition, there are three water gauges that were installed previously at the buoys location in the open lagoon areas of the northern portion of the Ciénega. This makes a total of 23 water gauges that were installed in this monitoring effort. Not all gauges were installed at the same time. Twelve were installed by February 2010 and thus have a longer period of data collection. Other gauges were installed later, and by the end of the monitoring effort in July 2011, seventeen gauges were regularly monitored at sampling sites; the other three sampling sites were only sporadically monitored due to limited access to sites 10, 14, and 15.

Each water gauge was leveled to mean sea level. This allowed us to reference water levels through the Ciénega to the same reference system and compare water levels among sites. In addition to the water level, we also measured water depth. Some events prohibited us from accessing some of the water gauges. For example, the El Mayor-Cucupah earthquake in April 2010 caused changes in access channels in the Ciénega and site 5 became inaccessible. The locations of sites 14 and 15 often made them inaccessible, and although we attempted to reach these sites, we could only access them a few months during the monitoring period.

Figure 2-18. An example of a WaterMark® water gauge at site 7.

a) Pressure-based water level loggers

Figure 2-19. YSI 600 LS

The monitoring design for analyses of water level also consists of 11 sites in which we installed pressure-based loggers. Two types of loggers are being used, six are YSI loggers (Figure 2-19) and five are HOBO loggers. The YSI loggers include six 600 LS and two 600 XLM, both of which used a vented level system to measure water level; that is, they account for barometric pressure.

On the other hand, the HOBO loggers measure water level with a non-vented system and temperature within a range of 0-9 m, with a resolution of ±0.0021 m and accuracy of ±0.005 m. The non-vented system requires the removal of the atmospheric pressure variations registered in other HOBO loggers located on the air. We used the HOBO loggers because they are not as expensive as the YSI and can be used in sampling sites that are more susceptible to vandalism. Fortunately, we only lost one HOBO logger, installed at the Bypass Drain, to vandalism. All loggers measured water level every hour, and data was downloaded every month. Figure 2-20 below shows an example of a site with a YSI sensor. The sensor is installed inside a 4 inch PVC pipe that is attached to a frame. The YSI sensors have a vented system that requires a cable from the sensor to be outside the PVC to measure and account for barometric pressure. Each PVC pipe has a plug with a lock to prevent vandalism.

Figure 2-20. YSI logger installed at site 19.

The protocol to download data from sensors consists of first taking a measurement of water level using the water gauge and then to use the portable multi-parameter YSI sonde to measure temperature, conductivity, dissolved oxygen, and pH/ oxygen reduction potential (ORP). This allows us to compare these measurements with those measured by the logger and identify any potential concerns. Next, data is transferred into the hand-held display unit, after which the logger is set up for the next monitoring cycle.

b) Water Depth

i. Water depth in the Ciénega

We used the results from all water level loggers and information about the elevation of the bottom at each site to estimate water depth with reference to mean sea level. Figure 2-21 shows a graph with a time series of water depth for sites 1, 2, 4, 5, 7, 13, 16, 19 and 22 beginning in January 2010 and continuing through June 2011. The graph shows the events that happened during the monitoring period: the El Mayor-Cocopah earthquake, the run of the YDP, and the fire in March 2011. We interpret the high-frequency variation in the measurements after the March 2011 fire to heat damage to the data-loggers.

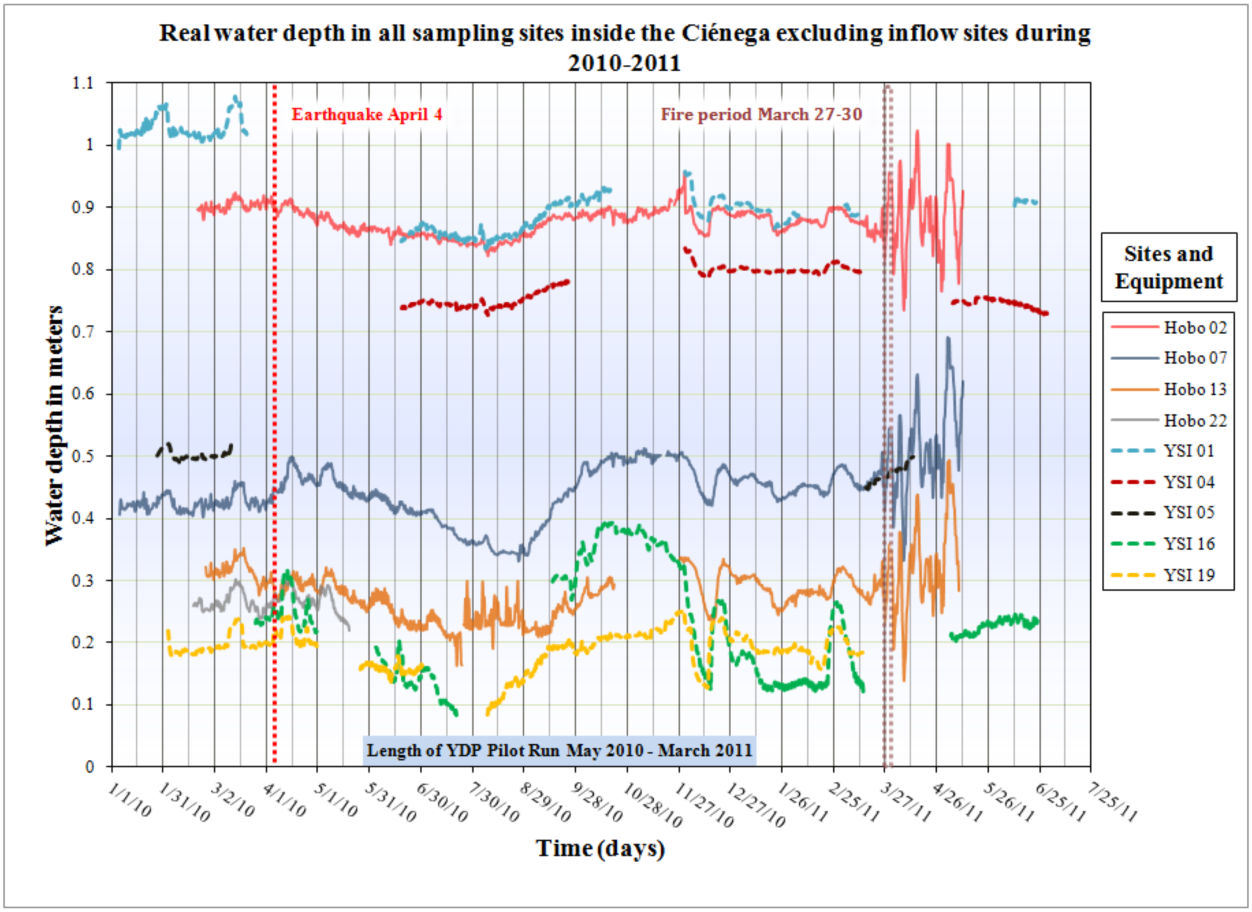


Figure 2-21. Water depth (in meters) at sampling sites in the Ciénega excluding inflow sites.

The figure shows two interesting results. First, water depth at each site varied throughout the monitoring period, with all sites showing a similar pattern – a decrease in water depth in May through August of 2010, increase in September through November of 2010, and another decrease in December 2010 to February 2011 of less magnitude than the previous one. This pattern follows the same pattern of inflows described above. That is, water depth changes in the Ciénega when the volume of water flowing into the Ciénega changes. The variation is, however, not the same for all sites. Sites along the edges of the Ciénega, such as sites 7 and 16, show the highest variation with 0.20-0.25 meters, while sites in the central lagoons show variation that is less than 0.15 meters.

The second significant finding is, as expected, that water depth is not the same at all sites. It varies from shallow sites with about 20-30 centimeters (cm) of water column at sites 16 and 19 to 1 meter at site 1. Site 1 is in the area of open lagoons, while site 16 is at the edge of the Ciénega.

ii. Water elevation above mean sea level

Results of water elevation (with respect to mean sea level) show some unexpected results (Figure 2-22), but are confirmed by the bathymetric data described above. Water elevation differs in different regions of the Ciénega. The elevation of the water at the Bypass Drain and Santa Clara-Riito Drain is the highest, at more than 7 meters above mean sea level. Sites along the eastern edge of the Ciénega, sites 7 and 13, show the lowest water level (less than 4.5 meters), while sites 1, 2, 4, 5, 16, 19 and 22 all show higher water elevation at approximately 5 meters above sea level. Although small, there exist variations among those sites (see Figure 2-22). This is an indication that there are several sub-basins in the Ciénega and not just one basin.

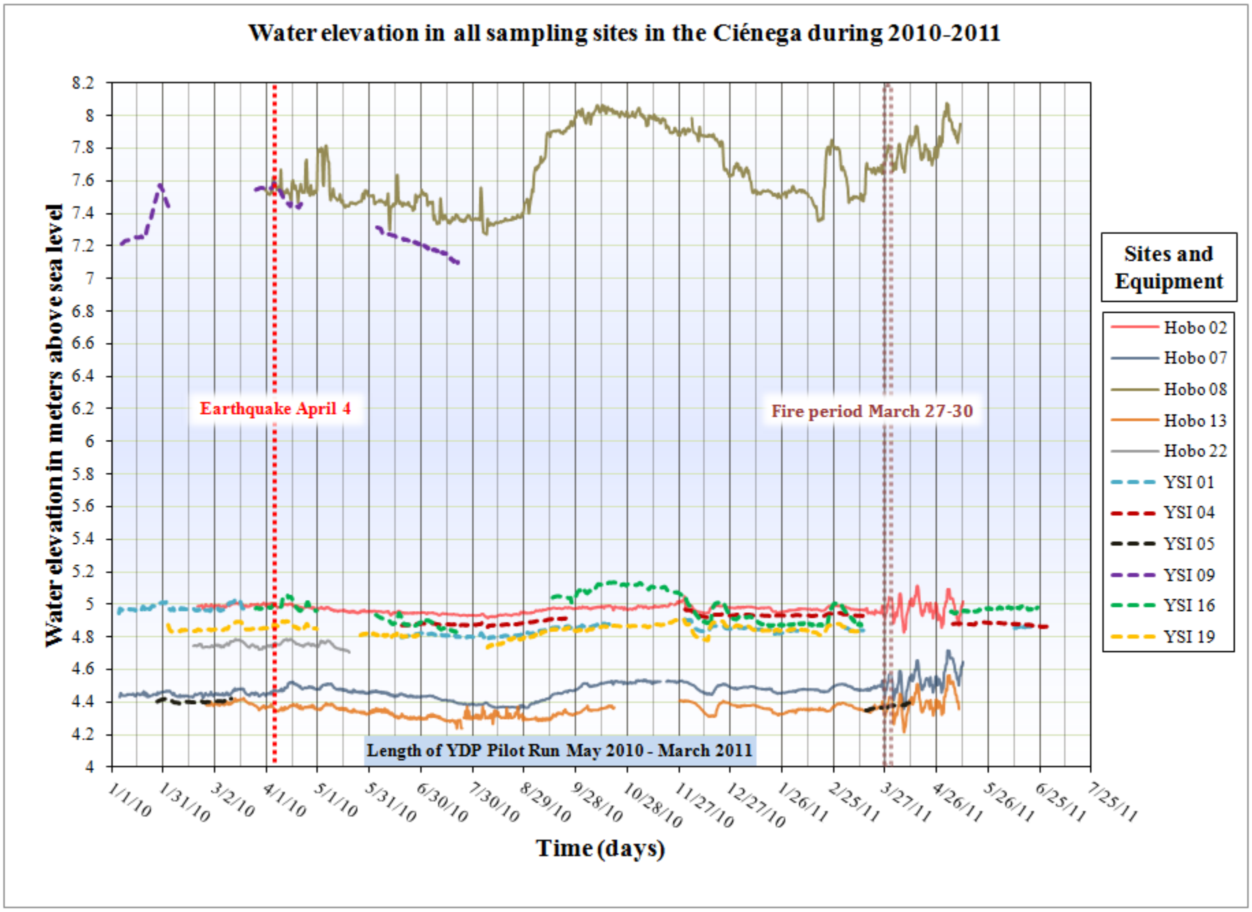


Figure 2-22. Water elevation in all sampling sites from 2010-2011, including inflow sites

An examination of the water levels without considering the two inflow sites makes it easier to see the variations of water elevation within and among sites inside the Ciénega throughout the monitoring period (Figure 2-23).

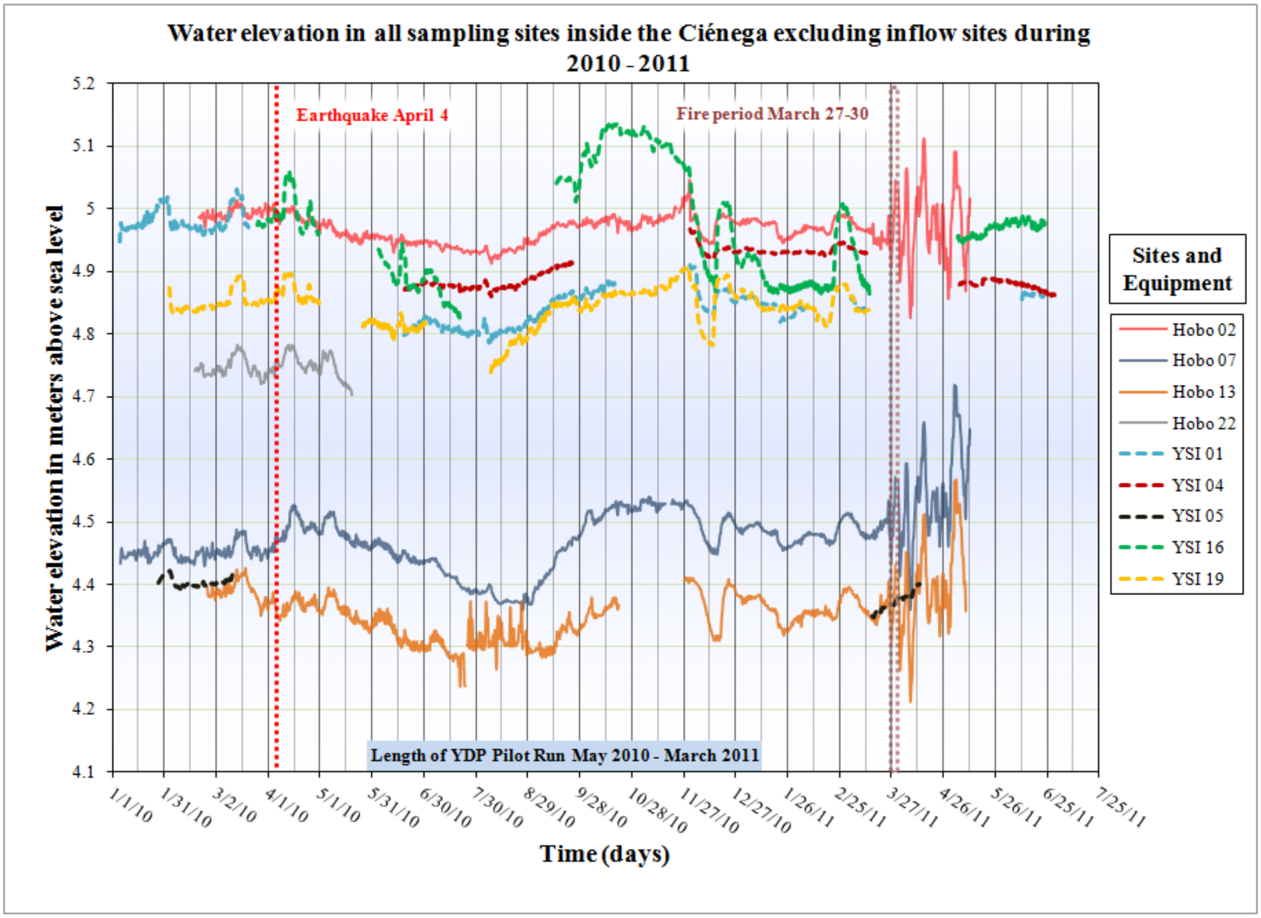


Figure 2-23. Water elevation in all sampling sites from 2010-2011, excluding inflow sites.

Figures 2-24 and 2-25 show another way to look at the water elevation results. We selected the months of October 2010 and February 2011 because there is water elevation data for most sampling sites.

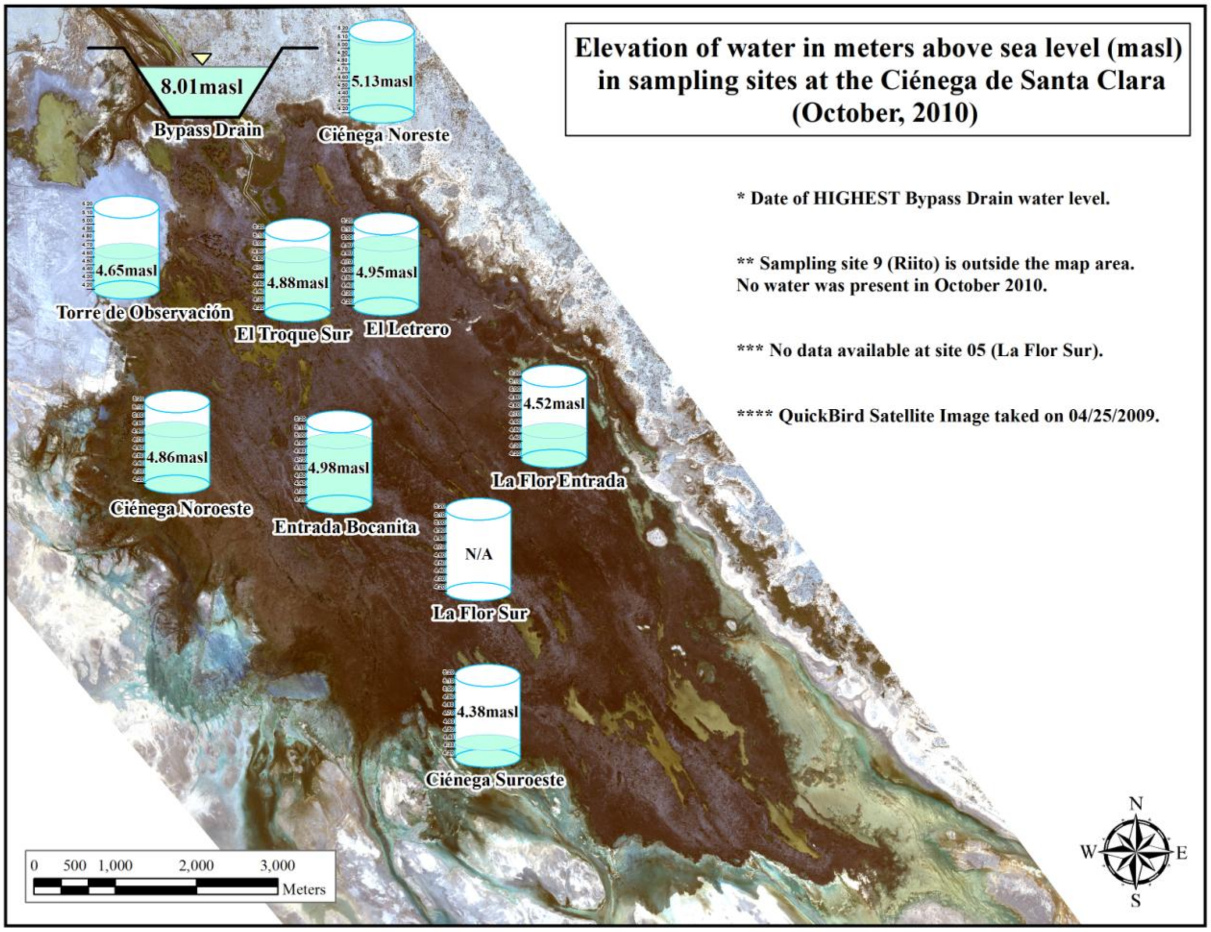


Figure 2-24. Elevation of surface water at distinct measuring points for October 2010 during which time the highest water level was recorded in the Bypass Drain.

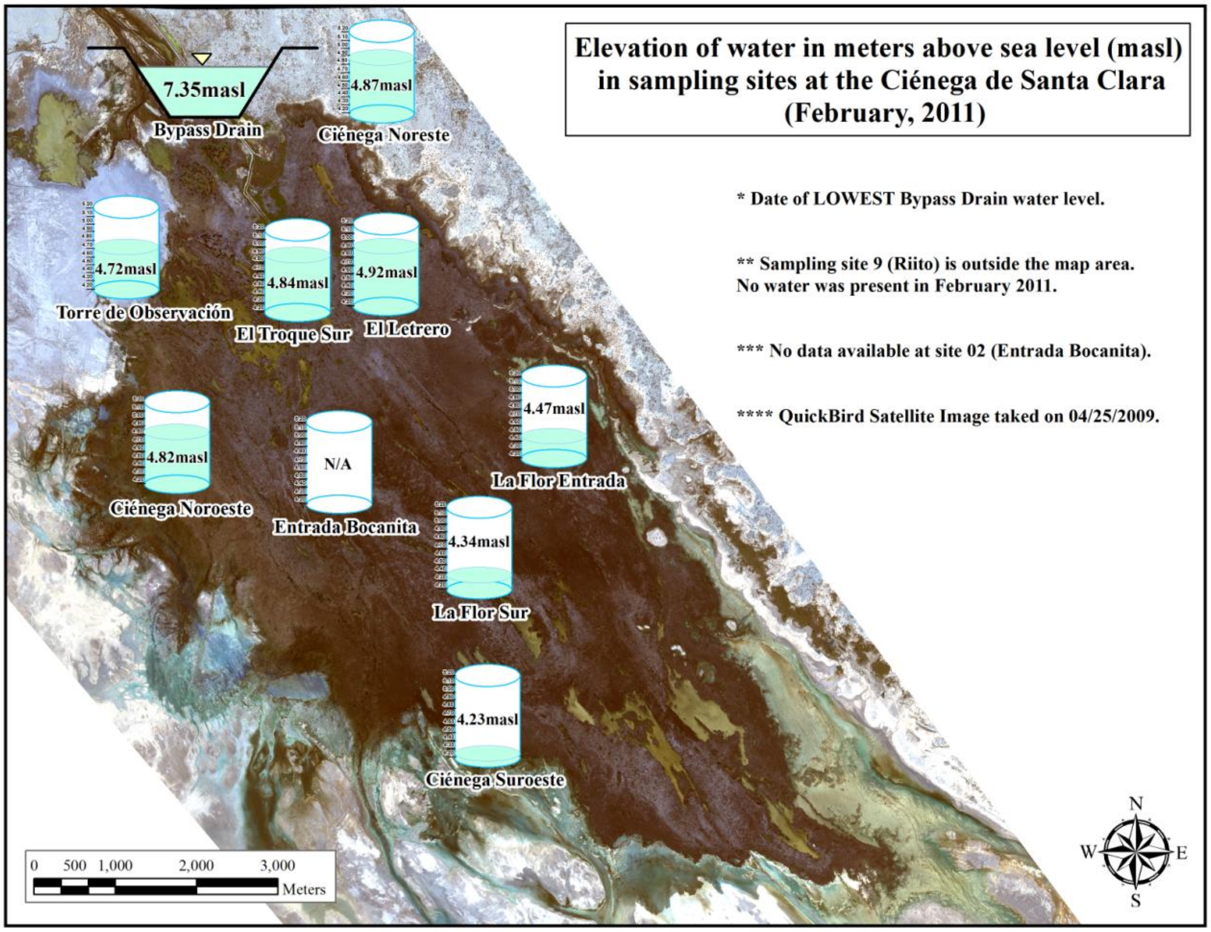


Figure 2-25. Elevation of surface water at distinct measuring points for February 2011, during which time the lowest level of water was recorded in the Bypass Drain.

D. Weather Data

The main objective for the installation of a weather station in the Ciénega was to record principal meteorological variables *in situ* to support the estimation of potential evaporation and evapotranspiration, which are key factors in understanding the hydrology of the Ciénega. For example, this data will help estimate the volume of water that enters the Ciénega through precipitation and the volume that leaves through direct evaporation and transpiration.

We installed a Vantage Pro2 Plus weather station made by Davis Instruments and containing Ultraviolet (UV) and Solar Radiation Sensors. We selected a small island between sampling sites 1 and 4 to install the weather station. Figure 2-26 shows the weather station and its location within the Ciénega de Santa Clara. This island provided a dry location inside the Ciénega that was near the open water lagoons for easy access, but also hidden from visitors to the Ciénega to prevent vandalism.

The station registered data almost continuously from March 5, 2010 to March 25, 2011. The station stopped registering data due to the fire in the Ciénega on March 26, 2011. The fire burned the sensors and destroyed the data logger. The data recovered during the March 2010 – March 2011 period were recorded every 30 minutes. The variables measured were: precipitation; temperature; atmospheric pressure; solar radiation; ultraviolet rays; velocity and direction of the wind and relative humidity. It calculates the daily maximum and minimum temperatures, solar energy, high solar radiation, UV index, UV12, High-UV, and heat index. These data are given in Appendix IV.

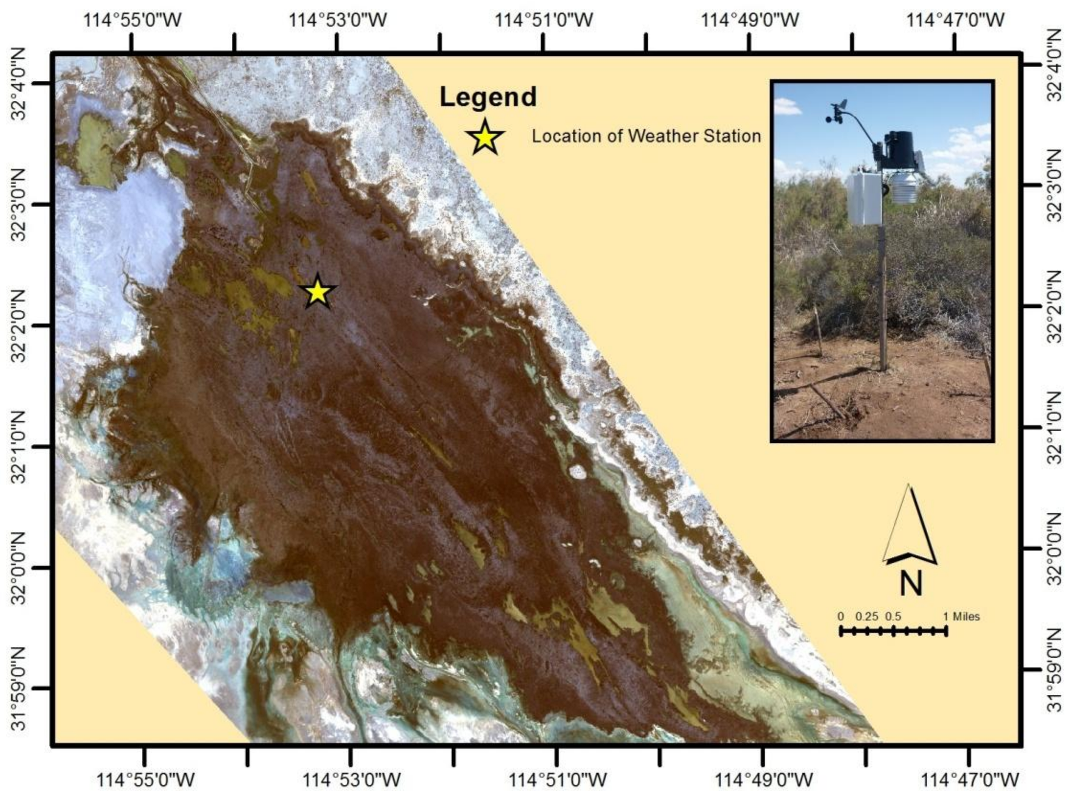


Figure 2-26. Location of the Weather station in the Ciénega de Santa Clara. Image is from April 25, 2009.

1. Precipitation

The total precipitation registered during the operation of the weather station was 19.45 millimeters (mm) concentrated in 4 main events (see Figure 2-27): one in August with a total precipitation of 3.55mm; the second in October with precipitation of 7.61mm; the third event was in December with a total precipitation of 3.26mm distributed over a number of days and related to the winter rains and the presence of a cold front; finally, the last event was in February with 3.53mm from another winter rain. Precipitation constituted a very small source of the water for the Ciénega during the monitoring period.

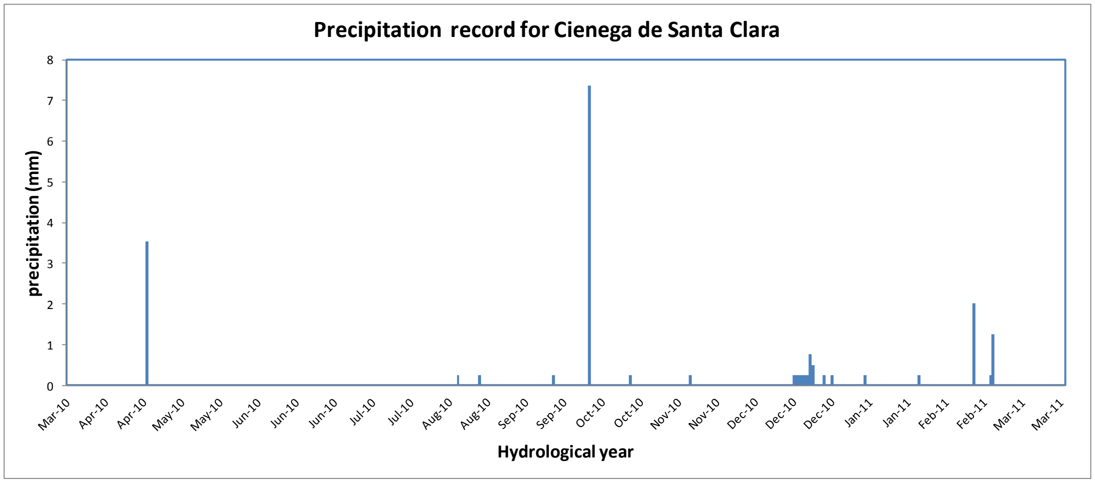


Figure 2-27. Precipitation in mm at the Ciénega de Santa Clara between March 2010 and March 2011.

2. Temperature

Figure 2-28 shows maximum, minimum, and monthly average air temperatures recorded by the weather station. The figure clearly shows the temperature increase during the summer months. The maximum monthly average temperature reached 30.7 degrees Celsius (C) in the month of August while the maximum daily temperature reached 44.8 degrees C on July 1, 2010. The minimum average temperature reached 11.6 degrees C in January and February. The temperature dropped below 0 degrees C during November, January and February, and reached its lowest point of -4.9 degrees C on February 3, 2011.

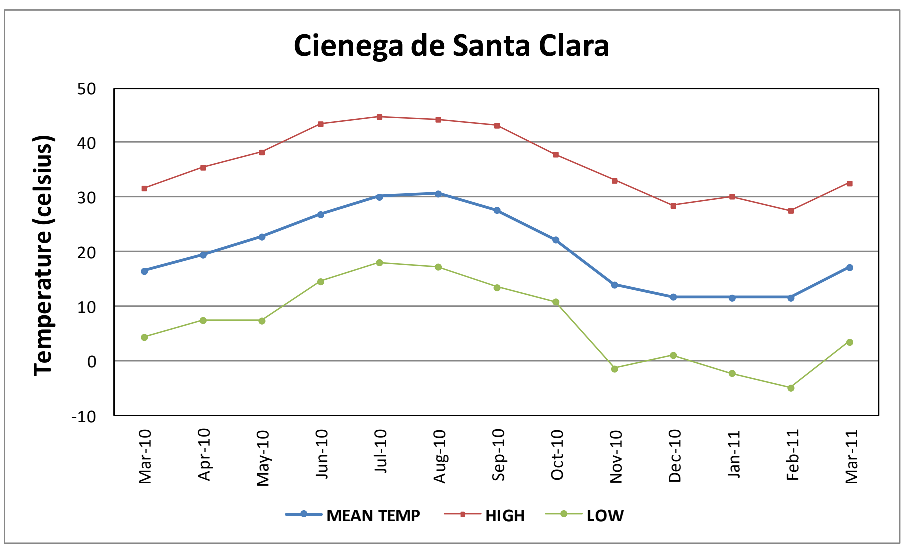


Figure 2-28. Maximum, minimum, and monthly average air temperatures recorded by the weather station in the Ciénega de Santa Clara.

3. Wind Velocity and Direction

Average registered monthly wind velocity is shown in Figure 2-29. The maximum average velocity reached 4.9 m/s for the month of June. The months with the smallest average wind velocity were August, September, and October with values of 1.1 m/s, 0.7 m/s, and 0.74 m/s, respectively. The maximum wind velocity of 41.8 m/s was registered on May 23, 2010. The daily recorded values are in Appendix IV.

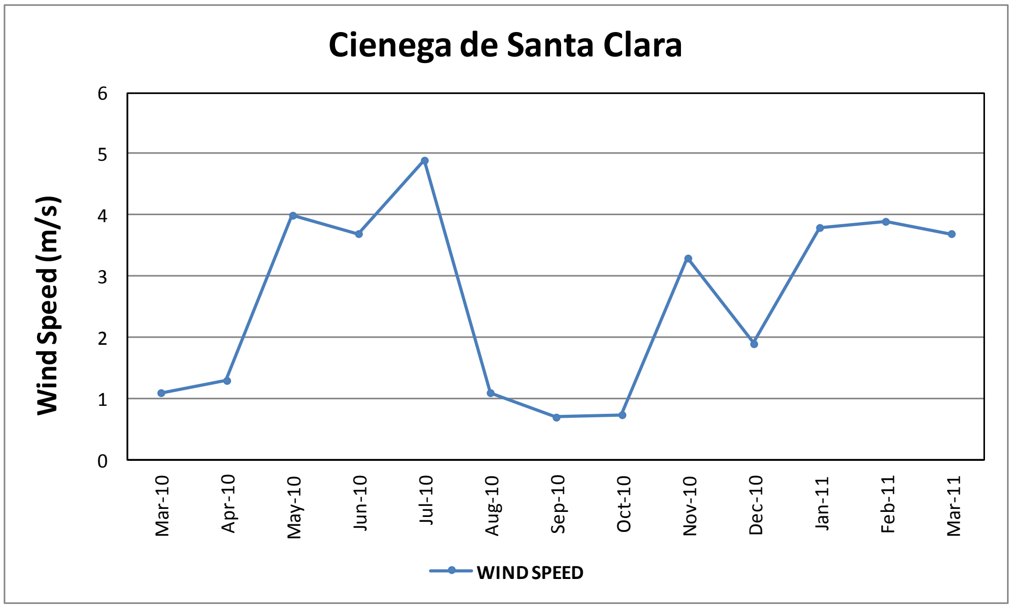


Figure 2-29. Average registered monthly wind velocity in the Ciénega de Santa Clara.

The predominant average monthly wind direction is shown in Table 2-8 and in Figure 2-30. The predominant wind directions were from the SE and NW. The predominant wind direction during spring and summer was from the SE, which corresponds to the winds coming up from the Gulf of California that generally bring high temperatures and humidity. The end of summer brought in winds from the NW, often accompanied by cold fronts and lower temperatures - typical for the fall and winter seasons. The rose diagram below shows that more than 46% of the dominant winds came from the NW, 39% from the SE, and 15% from the SSE.

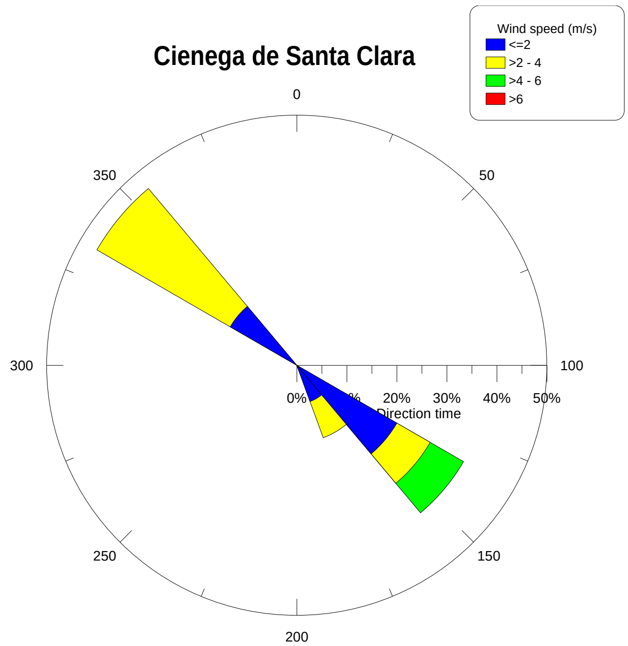


Figure 2-30. Predominant average monthly wind direction in the Ciénega de Santa Clara.

	Temperature (Celsius)			Rain (mm)	Wind (m/s)		
Month	Mean	High	Low		Speed	High	Dominant Dir
Mar-10	16.5	31.7	4.4	5.1	1.1	11.6	NW
Apr-10	19.5	35.5	7.5	10.7	1.3	11.6	SSE
May-10	22.8	38.3	7.4	0	4	41.8	SSE
Jun-10	26.9	43.5	14.6	0	3.7	33.8	SE
Jul-10	30.1	44.8	18.1	1	4.9	32.2	SE
Aug-10	30.7	44.3	17.3	0.8	1.1	10.7	SE
Sep-10	27.7	43.2	13.5	0.3	0.7	11.2	SE
Oct-10	22.3	37.9	10.9	17	0.74	10.3	SE
Nov-10	14.0	33.1	-1.4	1	3.3	33.8	NW
Dec-10	11.8	28.5	1.1	0	1.9	24.1	NW
Jan-11	11.6	30.2	-2.2	0.5	3.8	35.4	NW
Feb-11	11.6	27.6	-4.9	6.4	3.9	40.2	NW
Mar-11	17.2	32.6	3.5	0	3.7	38.6	NW

Table 2-8. Monthly averages of principal weather variables from the weather station located in the Ciénega de Santa Clara.

E. Evaporation and Water budget

Two different methods were used to estimate the water budget of the Ciénega: 1) using data from the weather station to estimate potential evapotranspiration and 2) using spatial analysis of vegetation to estimate evapotranspiration.

a) Water Budget based on weather data

Using spatial analysis, direct evaporation was estimated for open bodies of water following the Penman-Monteith formula (methodology from Custodio and Llamas 1983). The size and location of the open bodies of water were estimated by drawing polygons with the help of the program ArcGIS (version 10) from the image QuickBird from the 25th of April, 2009. The resulting number for evaporation obtained was 1.687m/year, considering the year to be from March 2010 to March 2011. Assuming a surface area of open bodies of water of 2,350 hectares (ha), it is estimated that the direct evaporation is 398 million cubic meters (mcm)/year (32,252 af/year). Figure 2-31 shows the values for the estimated evaporation with a trend line that was adjusted to generate the data from the periods that were not recorded by the weather station.

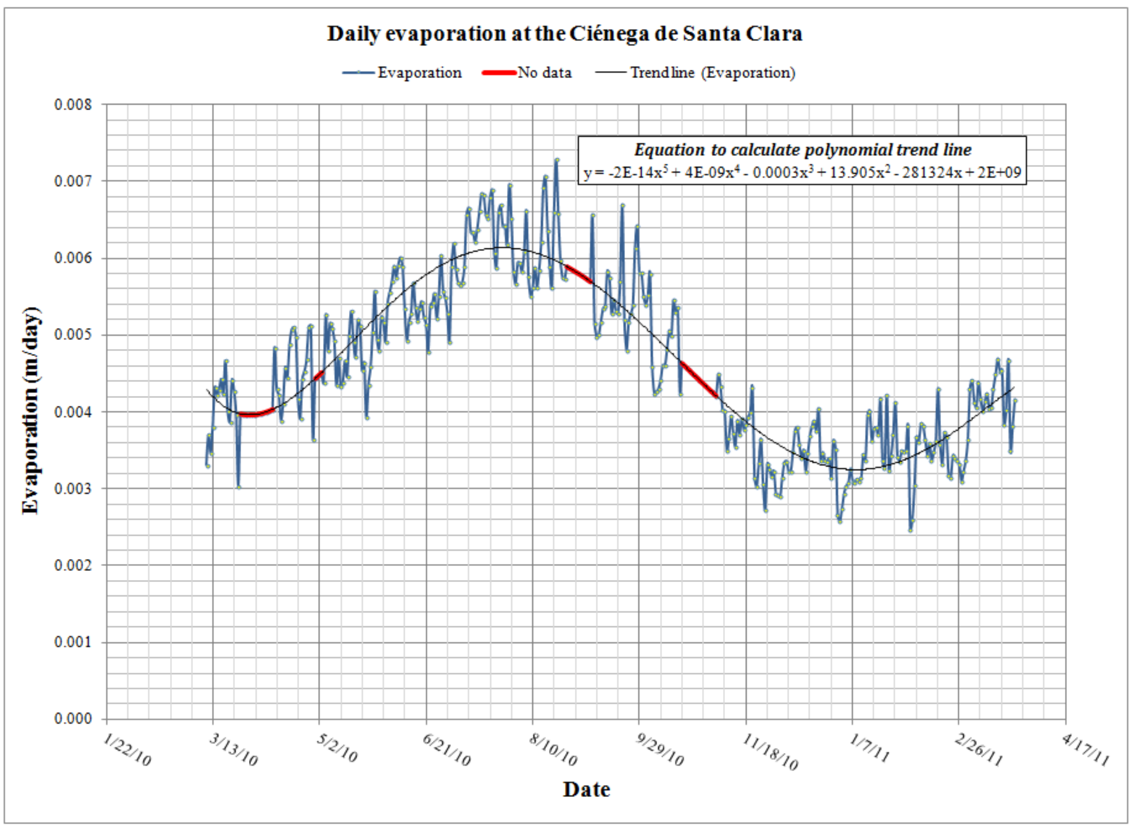


Figure 2-31 Daily estimated evaporation for the Ciénega de Santa Clara between March 2010 and March 2011. Red lines show the estimated values for the periods of missing information.

The estimated potential transpiration (from plants) from the data obtained from the weather station, also based on the Penman-Monteith formula (following Allen et al., 2005), was 1.517m/year. This method is considered the standard reference for the American Society of Civil Engineers. For purposes of this estimation, however, we used the weather station within the Ciénega. Considering a surface area covered in cattail of 4,405 hectares (no distinction in other types of vegetation is made), and with an albedo of 0.05 (equivalent to that of alfalfa because no other specific value for the albedo of cattail was found), the total potential transpiration during one year and across the whole monitored surface is 668 mcm/year (54,132 af/year) (Figure 2-32).

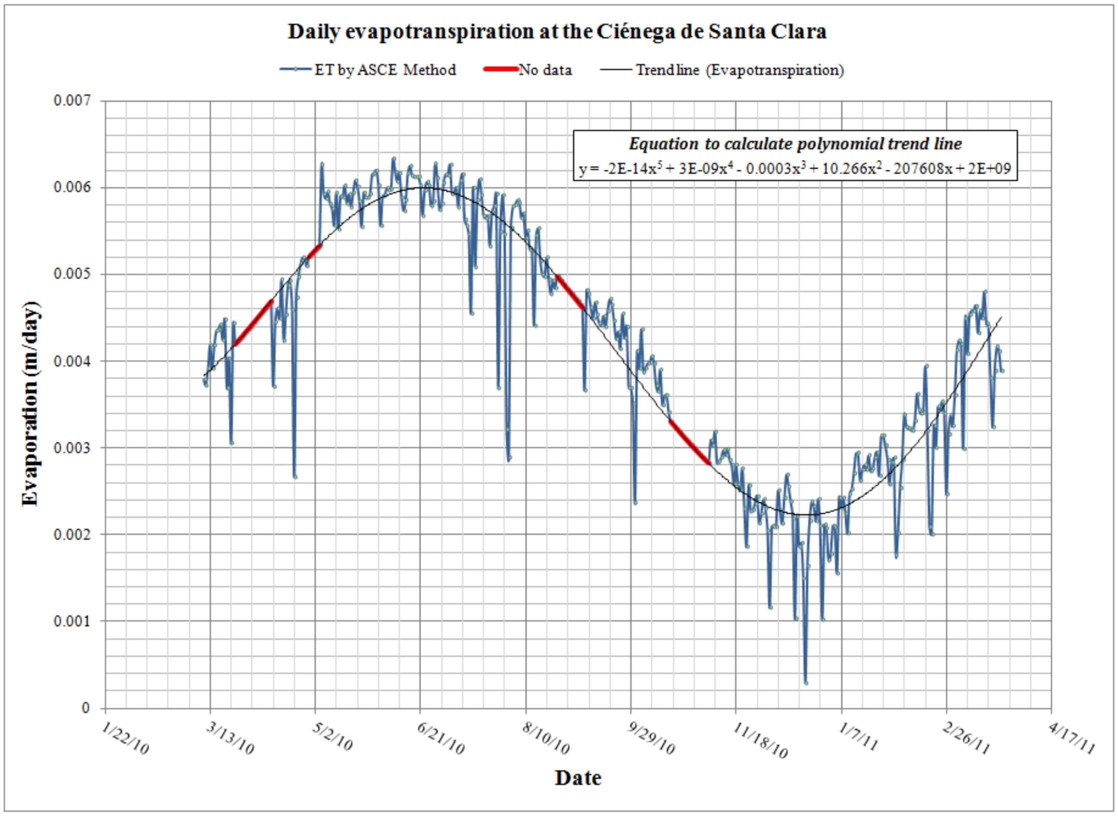


Figure 2-32. Daily evapotranspiration at the Ciénega de Santa Clara from March 2010 to March 2011. Values in red were interpolated for periods when weather information was not recorded.

These estimates of evaporation and transpiration total 106 mcm/year (86,000 af/year). Assuming that approximately 110,000 acre-feet of water is delivered to the Ciénega each year, this estimate suggests that 78% is lost due to direct evaporation or by transpiration by plants, and that the remainder, approximately 22%, drains to the southern basin.

b) Water Budget based on Vegetation Analysis

In this section we report on vegetation density and evapotranspiration in the Ciénega de Santa Clara using Enhanced Vegetation Index (EVI) values from Moderate Resolution Imaging Spectroradiometer (MODIS) Sensors on the Terra Satellite. Estimates of foliage density and evapotranspiration (ET) are needed for monitoring vegetation dynamics in the Ciénega.

The Moderate Resolution Imaging Spectrometer (MODIS) sensors on the Terra satellite provide near-daily coverage of the earth with 250 m spatial resolution. Images with 250 m resolution in the Red and near infrared NIR bands and 500 m in the Blue band are georectified and radiometrically and atmospherically corrected before being released to end users as vegetation index (VI) and other products (Huete et al., 2002). MODIS products are valuable in phenological and change-detection studies, which require stable vegetation index values over time (Glenn et al., 2010). We used methods developed in other studies (Nagler et al., 2005a,b, 2009) and described briefly here.

The MODIS EVI product was used to measure foliage density and ET in the Ciénega at 16-day intervals from 2000 to 2011. We used the free images over this 12 year period to estimate seasonal and year-to-year variability in vegetation density and evapotranspiration. Peak foliage density in summer varied from year to year, and was especially high in 2006 and 2011 following spring fires that burned accumulated thatch and returned nutrients to the water. In most years peak summer ET values were about half of potential ET (ETo) determined from weather data, but in 2006 and 2011 they were equal to ETo. EVI and ET values were lower in 2010 during the pilot run of the Yuma Desalting Plant than in 2009, but values for both years were within the normal range of values for previous years. Comparison of MODIS ET predictions with mass balance predictions based on inflow volumes and Ciénega salinities produced mean values of 4.15 mm per day (mm/day) and 3.49 mm/day, respectively. Both types of estimates have sources of error and uncertainty, but agree within 20% of each other.

i. Methods

MODIS and other satellite imagery. The EVI is similar to the more familiar Normalized Difference Vegetation Index (NDVI) in combining Red and NIR bands in a ratio that captures the distinct spectral signature of green vegetation, and allows the landscape to be divided into water, soil and vegetation components. EVI also uses the Blue band on MODIS and is less sensitive to soil effects than NDVI, and saturates at higher levels of leaf area index (LAI) than NDVI (Huete et al., 2002). EVI is calculated as:

$$EVI = G(NIR - Red)/(NIR + C_1 \times Red + C_2 \times Blue + L) \qquad (1)$$

where C_1 and C_2 are coefficients designed to correct for aerosol resistance, which uses the blue band to correct for aerosol influences in the red band. The coefficients, C_1 and C_2, are set at -6 and 7.5, respectively, G is a gain factor (set at 2.5), and L for this model is a canopy background adjustment (set to 1.0). Like NDVI, green vegetation has high EVI values (up to 0.85), while bare soil or dormant vegetation has slightly positive values (about 0.10) and water generally has negative values (-0.35 to 0.0). EVI data were obtained from the Oak Ridge National Laboratory Distributed Active Archive Center (DAAC) site (ORNL DAAC, 2009). The MOD13Q1 products was used, which is a 16-day composite of 3-5 high quality images (as close to cloud-free as possible) collected during each measurement period.

In estimating foliage density and ET via EVI, it was important to avoid pixels that included open water areas, because the negative values for water can artificially lower estimates of vegetation density and ET. Two methods were compared for obtaining spatially-distributed EVI data over the Ciénega. In the first, Geotiff images of the Ciénega and surrounding areas were overlain with an ERDAS Area of Interest (AOI) shape file which encompassed most of the vegetated area in the Ciénega, but excluded the main open water areas. These were identified on high-resolution QuickBird images and excluded in preparing the AOI file for MODIS images. In the second method, individual pixels from 20 sites distributed throughout the Ciénega (Figure 2-33) were obtained using the Oak Ridge National Laboratory MODIS subset tool. This tool displays the footprint of a selected pixel on a high-resolution QuickBird image. The Ciénega was divided into 4 quadrants of approximately equal area and 5 pixels were randomly selected in each quadrant. If a selected pixel contained water on inspection of the QuickBird image, a new pixel was selected.

Determining vegetation cover and open water areas. An AOI file was created that encompassed the vegetated footprint of the Ciénega (Figure 2-28) based on an August 2009 QuickBird Image. The AOI file encompassed 5635 ha and was used for analysis of all images. EVI values were converted to scaled values (EVI*) between bare soil and full vegetation cover by the formula:

$$EVI^* = 1 - (EVImax - EVI)/(EVImax - EVImin) \qquad (2)$$

where EVImax and EVImin were set at 0.542 and 0.091, respectively, based on a large data base of wetland and riparian values from a previous study (Nagler et al., 2005a,b). The advantage of this transformation is that it allows regressions of ET versus EVI* to pass through the origin, where at 0 ET (bare dry soil) EVI* = 0. Open water areas within the Ciénega were estimated on seven QuickBird and WorldView 2 images acquired from September 2008 to July 2010. Open water areas were fairly stable, with a mean value of 738 ha (Std. Error = 82 ha), representing 13.1% of the surface area.

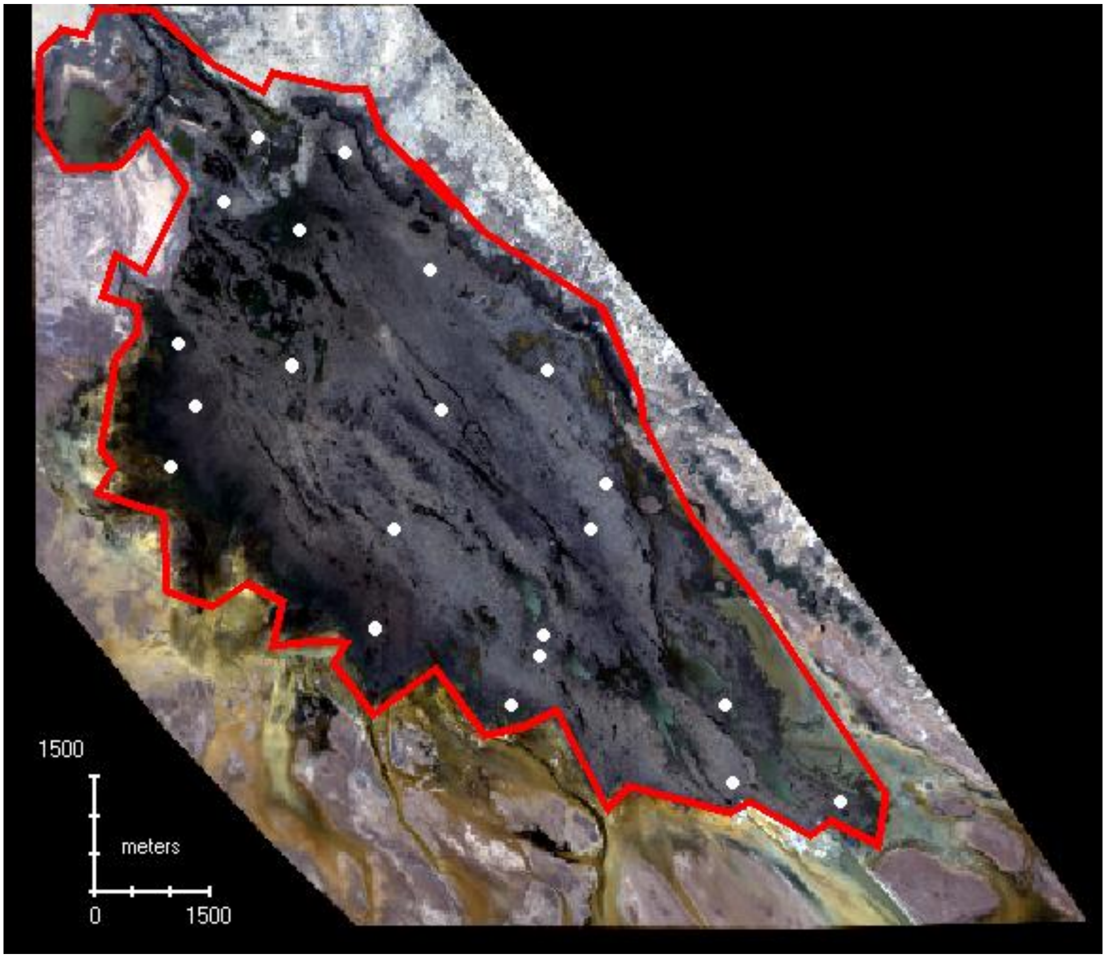


Figure 2-33. Footprint of the Ciénega de Santa Clara and locations from which MODIS EVI data were acquired. Image from April 25, 2009.

Procedure for calculating ET. ET in this wetland is a combination of transpiration by emergent vegetation (Eveg) and evaporation from open water areas (Ewater). The two parameters were estimated separately and added together to estimate total ET. Both estimates depended on an estimate of potential evapotranspiration (ET_o) as determined from meteorological data. We used the Blaney-Criddle formula for ETo, which requires mean monthly temperature (Tmean). Because we did not have local data we used hours of potential sunlight based on latitude (obtained from a table) (Brouwer and Heibloem, 1986):

$$ETo = p(0.46Tmean+8) \quad (3)$$

Ewater was calculated by multiplying monthly values of ETo by the open water area in the Ciénega, assumed to be constant at 738 ha for these analyses. Evegetation was calculated by an algorithm relating EVI to ETo, developed for crop and riparian vegetation on the Lower Colorado River (Nagler et al., 2009):

$$Eveg = 1.22(EVI*veg)ETo \quad (4)$$

Equation (2) was developed by regressing ET measured on the ground for alfalfa and riparian plants on the Lower Colorado River with EVI* and meteorological data obtained from AZMET stations. It has an error or uncertainty of about 20%, within the range of error of the ground methods used to measure ET (Glenn et al., 2010). The equation is similar to the simple equation developed by Groeneveld et al. (2007) for riparian and desert phreatophytes in the western US, in which ET is scaled between 0 (bare soil) and 1 (a fully transpiring crop such as alfalfa, with Eveg assumed to be equal to ETo). The factor 1.22 in Equation (4) was derived from the regression line of best fit between EVI* and measured ET in the study of Nagler et al. (2009). The validity of using vegetation indices for estimating ET, and underlying assumptions and sources of error inherent in the methods, are discussed in Glenn et al. (2010). Tmean data was obtained from the Yuma Valley AZMET station for the period 2000 – 2011 (AZMET, 2011).

Other data sources. Salinity data was collected from nine stations in 2009 and from 23 stations in 2010 by the Ciénega Monitoring Team. Monthly inflow salinity was from Station 8 and monthly mean salinity was the average of all reporting stations. Inflow data was from the IBWC gage station at the Southerly International Boundary, covering 2009 and through September 2010.

ii. Results and Discussion

Comparison of methods for determining spatially distributed EVI values. The AOI and pixel-sampling methods were highly correlated ($r^2 = 0.98$) (Figure 2-34), but the AOI method produced EVI values 7.5% lower than the pixel-sampling method. Because the AOI method was unable to exclude all pixels containing mixtures of open water and vegetation, we chose to use the pixel-sampling method to represent foliage density and ET in the vegetated fraction of the Ciénega.

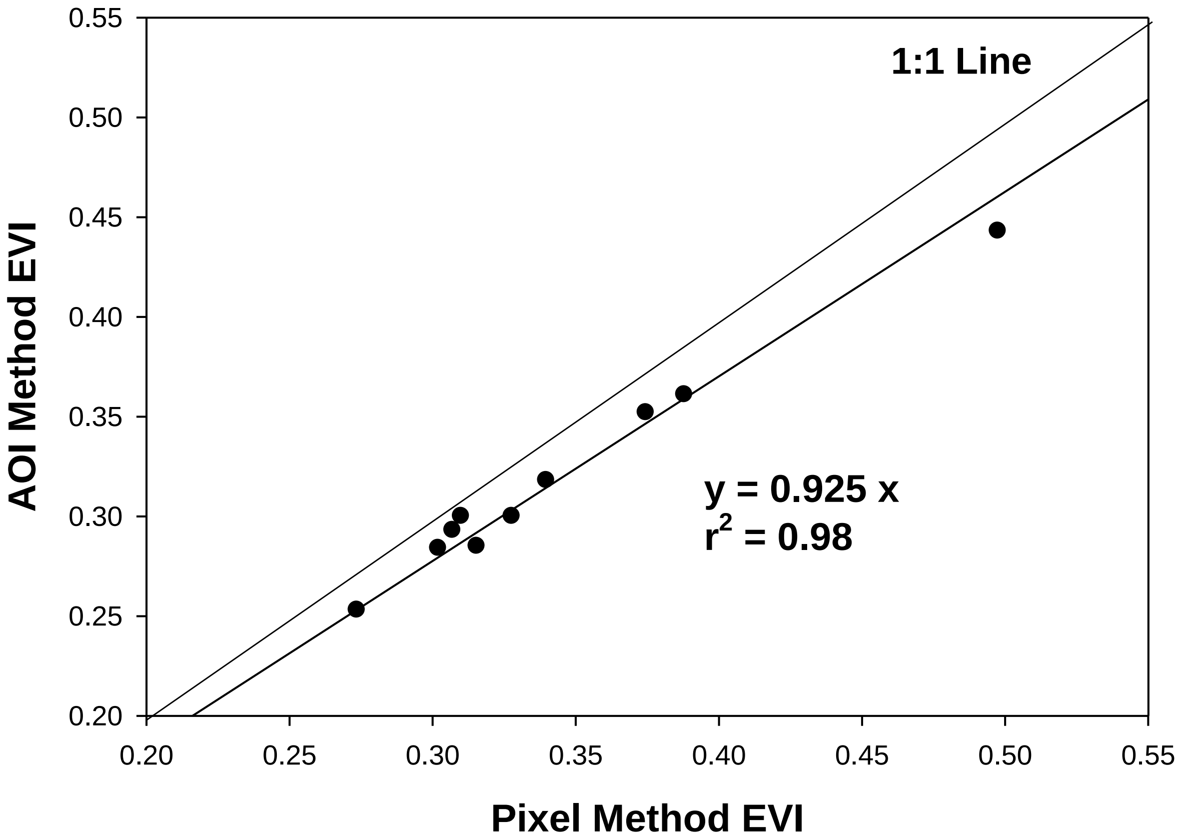


Figure 2-34. Comparison of two methods to determine mean MODIS EVI over the vegetated portion of the Ciénega. The Area of Interest (AOI) method used a shape file that included vegetation but excluded major open water areas; the pixel method sampled 20 individual pixels in which standing water was not present based on inspection of high-resolution QuickBird imagery.

Foliage density in the Ciénega. EVI trends from 2000 to 2011 are in Figure 2-35A, showing the expected annual trend of lowest EVI in winter and highest in summer EVI. The lowest EVI value was 0.123 following a fire in March, 2010 that burned most vegetation; winter/spring values were higher in other years. *Phragmites australis*, which covers about 400 ha, is green all year, whereas *Typha domingensis*, the dominant emergent species, is dormant November to April, and is not fully green until late May. Hence, some green vegetation is normally present all year.

Peak summer EVI varied by as much as 50% from year to year (Figure 2-35A). Values were markedly higher in 2006 and 2011 than in other years, following major fires in spring that burned over the entire Ciénega. These fires removed thatch and returned nutrients to the water and sediments, producing a substantial boost in foliage density the following summer.

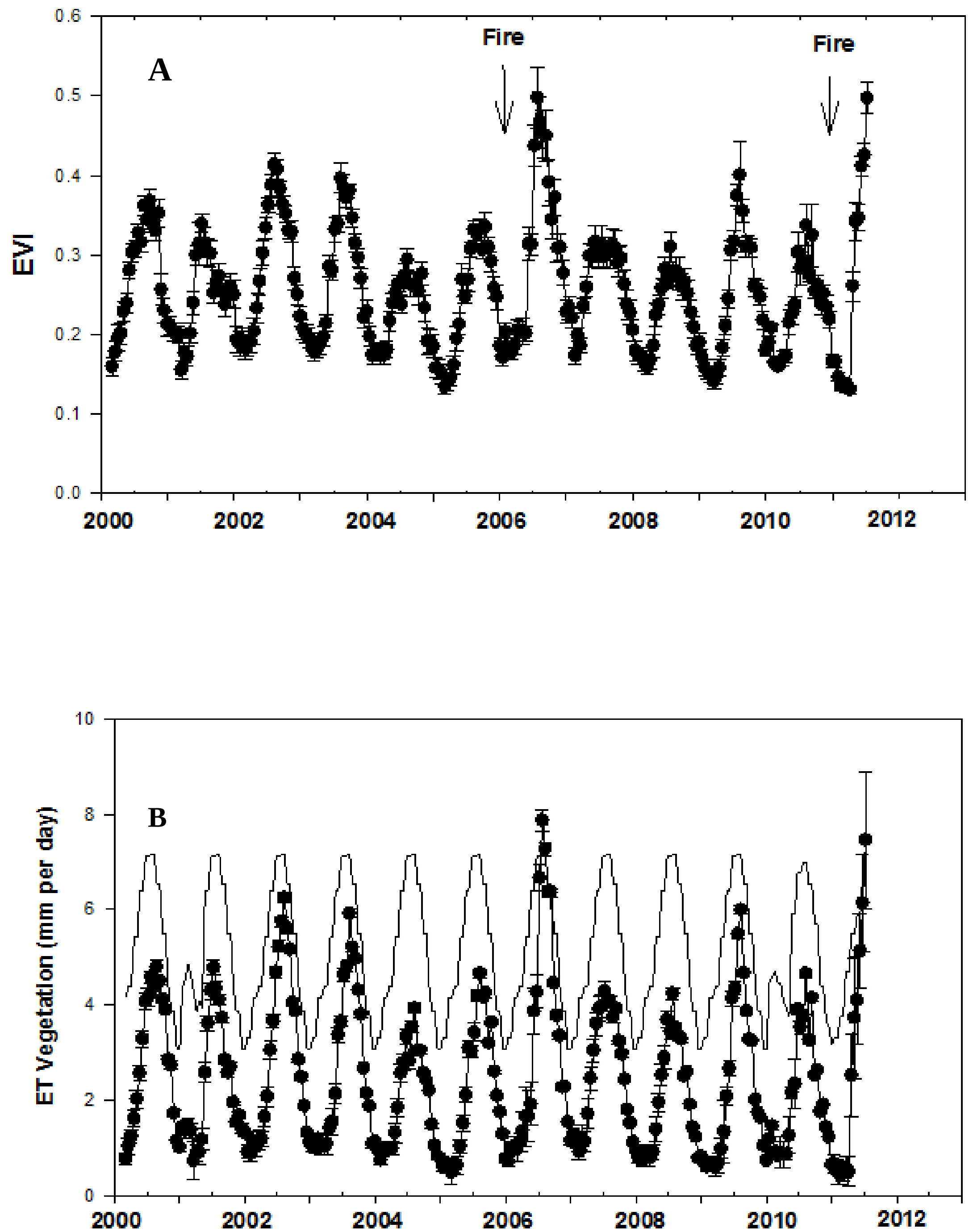


Figure 2-35. (A) MODIS EVI values and (B) ET values in the Ciénega de Santa Clara, 2000-2011. Arrows show when major fires occurred. Solid line without symbols in B shows potential ET.

ET in the Cienega. ET in the vegetated part of the Cienega is in Figure 2-35B. Following fires in 2006 and 2010, peak Eveg values were equal to ET_o. However, in other years peak rates were about half of ET_o, due to the accumulation of thatch in the *Typha* stands. *Typha* grows by initiating new shoots from underground rhizomes each spring, but the senescent shoots from the previous year remain in the canopy until removed by decay or fire, and their presence reduces the light interception by new green shoots. Eveg and Ewater from 2009-2011 are shown separately by month in Figure 2-36; Eveg dominated ET, accounting for 77 % of ET over all months and 83% of ET in June - August. Over all years, total annual ET was 1027 mm per year (yr^{-1}) (SE = 112), equal to 55% of ET_o (1879 mm yr-1). Since the ET estimates are based on vegetation index values, the relative magnitude of ET in the Ciénega is shown in the classified QuickBird NDVI images in the section on vegetation dynamics.

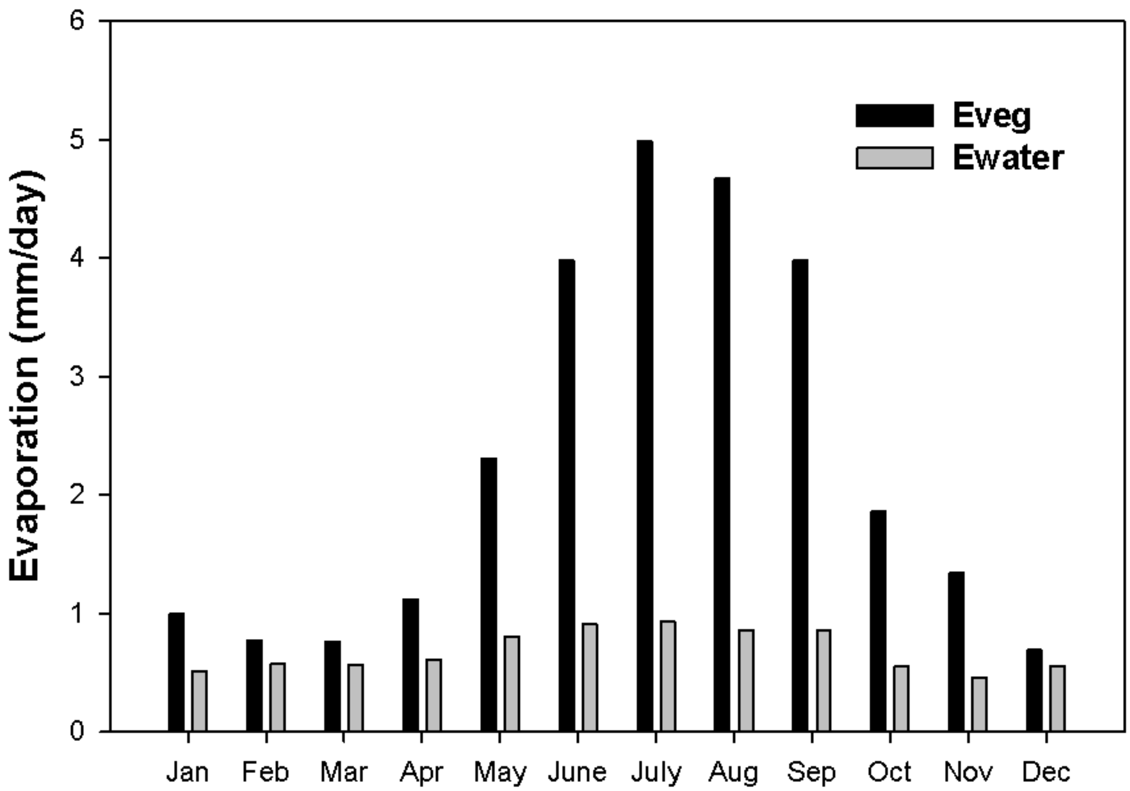
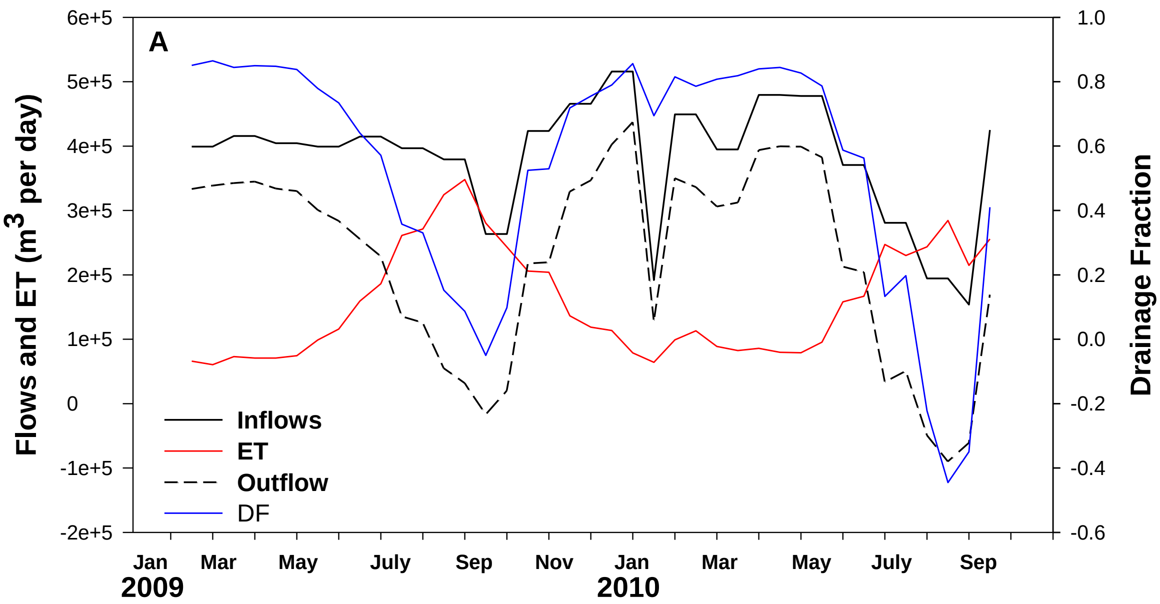


Figure 2-36. Evaporation estimated from vegetation by transpiration (Eveg) and by open-water evaporation (Ewater) in the Ciénega de Santa Clara, 2009-2011.

Monthly inflow volumes and salinities and projections of outflow from MODIS ET data.

Figure 2-37A shows inflow data for 2009-2010, as well as ET and outflows estimated from MODIS data, and the drainage fraction (DF). DF is the inflow volume divided by the outflow volume, calculated by subtracting ET from inflows (Bypass water, Riito drain water, and rainfall). It is a measure of how much water passes through the system without supporting vegetation. It is high in winter and goes to near zero in the summer. Inflows tended to be variable on a monthly basis, with brief dips in September 2009 and January 2010, and a more prolonged dip in May to August 2010, during flow reductions during the operation of the Yuma Desalting Plant test run, followed by recovery in September 2010.



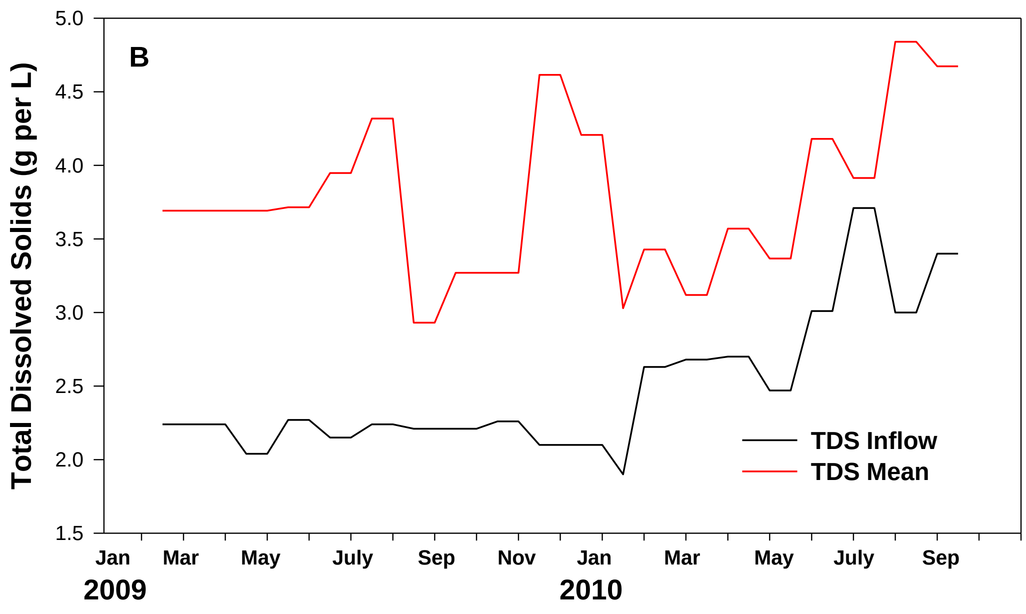


Figure 2-37. (A) Measured inflows, and calculated ET, outflows and drainage fraction (DF) in the Ciénega de Santa Clara, 2009-2010. (B) Measured inflow salinities and mean salinity of the Ciénega estimated from recording stations.

ET peaked in September 2009, but the summer peak in 2010 was truncated. Calculated outflows were highest in winter in both 2009 and 2010. Outflows were near zero during September 2009, due to high ET rates. The calculated values became negative in August 2010, as ET exceeded inflows, presumably leading to a decrease in the volume of water in the Ciénega. DF was greater than 0.8 during both winters, indicating that most of the inflow water in winter exited the Ciénega without supporting ET, since *Typha* was dormant and surface evaporation was low. DF went to zero during summer 2009, and was calculated as being negative in summer 2010 during flow reductions.

Inflow salinities and measured mean salinities are shown in Figure 2-37B. Inflow salinity averaged 2.494 grams per liter ($L^{-1)}$ TDS in 2009 and 2010, ranging from 2.0 to a high of 3.6 in July, 2010. Mean salinity in the Ciénega was 3.845 g L^{-1}. Mean salinity tended to be variable from month to month in 2009, perhaps due to the limited number of recording stations (nine), but it closely tracked inflow salinities in 2010, with 21 stations in operation. Both inflow and mean salinities trended upward in summer 2010 during the test run of the Yuma Desalting Plant.

Comparison of MODIS ET estimates to a mass balance estimate.

This method has been used in various riparian and agricultural evapotranspiration studies (Nagler et al., 2005a,b, 2009). Assuming precipitation is negligible and no change in storage in the surface water or groundwater takes place, ET in the Ciénega should be equal to:

$$\text{ET} = \text{Inflow Volume} - \text{Outflow Volume} \qquad (5)$$

Outflows are not measured in the Ciénega as there is not a single exit point for water. However, salts are assumed to be conserved in the water body and outflow during ET as water evaporates into the atmosphere. Therefore, the volume of outflows should be proportional to the increase in salinity in the outflow:

$$\text{Outflow Volume} = \text{Inflow Volume} - (\text{Outflow Salinity}/\text{Inflow Salinity})\text{Inflow Volume} \qquad (6)$$

(e.g., Ayars and Westcott, 1985). Outflow salinity is not measured due to lack of a single exit point, but Inflow Salinity is measured, and Mean Salinity in the Ciénega can be estimated from the spatially distributed salinity measurements throughout the water body. Mean Salinity is related to Inflow and Outflow Salinity by:

$$\text{Mean Salinity} = (\text{Inflow Salinity} + \text{Outflow Salinity})/2 \qquad (7)$$

Then:

$$\text{Outflow Salinity} = 2\ \text{Mean Salinity} - \text{Inflow Salinity} \qquad (8)$$

and ET can be calculated by Equations (6) and (8) using inflow volume and salinity and mean salinity data.

Equation (6) cannot accurately model ET over short time steps, because the large volume of water in the Cienega relative to inflows modulates changes in salinity over short time periods. However, over longer time periods, the increase in mean salinity above inflow salinity should reflect the amount of water lost to ET. Based on an assumed volume of 2820 mcm (i.e., 5635 ha with an average depth of 0.5 m) and a mean inflow of 38.5 mcm d^{-1}, the turnover time for water in the Cienega is 73 days. From January, 2009 to September, 2010, water should have exchanged about nine times.

Over that period, Equation 6 predicts that ET in the Cienega was 196,420 $m^3 d^{-1}$ (3.49 mm $m^{-2} d^{-1}$) , or 71.6 mcm/yr; 58,123 af/yr) compared to an estimate of 169,327 $m^3 d^{-1}$ (3.00 mm $m^{-2} d^{-1}$) (61.8 mcm/yr; 50,105 af/yr) by the MODIS method, which is 14% lower. The Equation 6 approach estimates water loss from evaporation and transpiration at 53%; the MODIS method estimates water loss from evaporation and transpiration at 46%. The rest of the water flows into the lower basin.

Sources of possible error or uncertainty in the MODIS ET estimate are: the ET algorithm; the estimates of vegetated and open water areas in the Cienega; the representativeness of the sampled pixels to the whole Cienega; and the estimate of ET_o from Yuma temperature data. The main sources of uncertainty in the mass balance estimate are: how closely the point estimates of salinity predict the true mean salinity; lack of actual outflow data; and possible changes in the volume of the Cienega over time. The 14% difference between estimates is well within the range of similar comparisons between remotely sensed ET estimates and ground measurements over a wide range of biome types and measurement methods (Glenn et al., 2010).

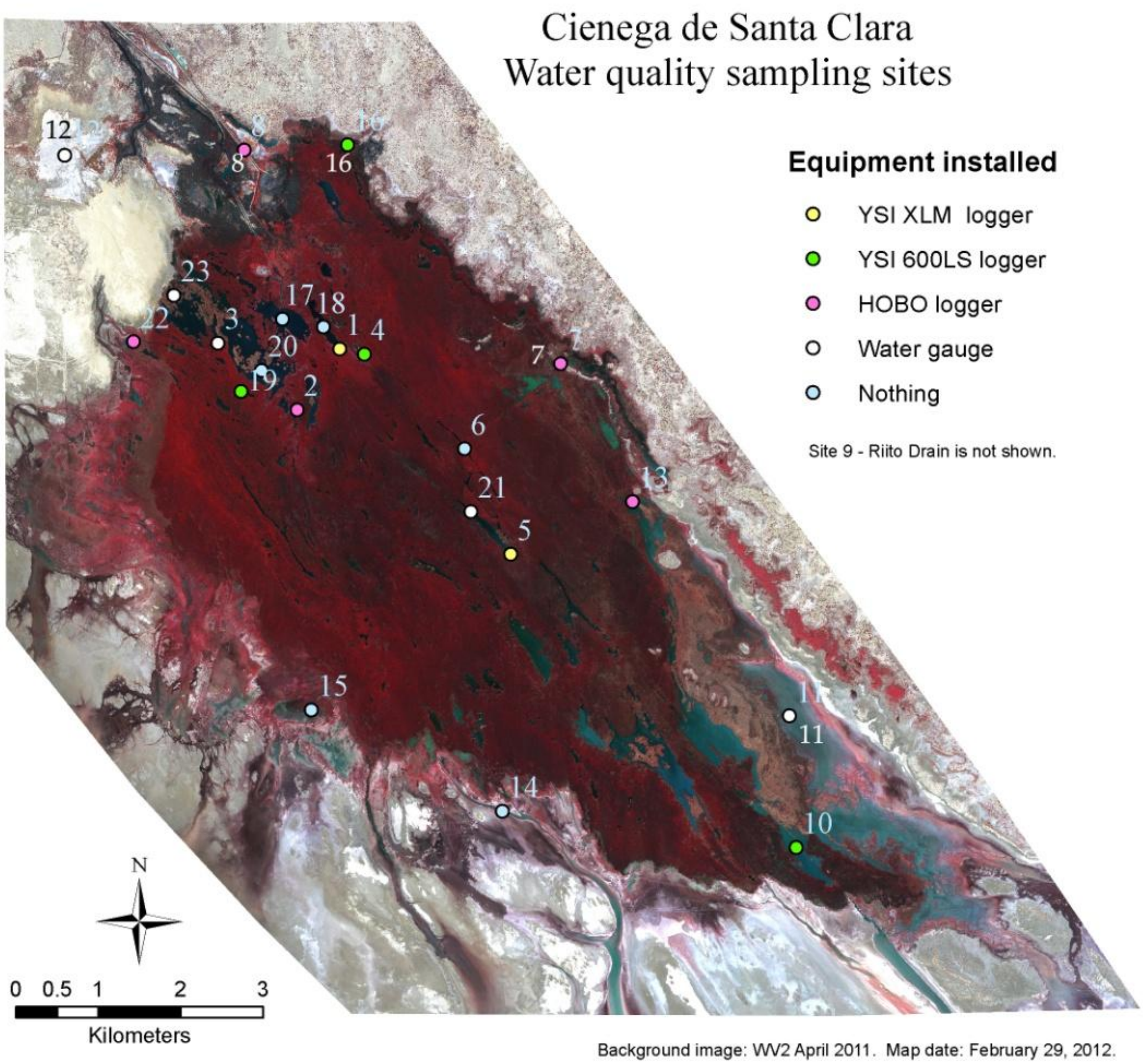
F. Summary

Topographic and bathymetric measurements indicate that the Ciénega de Santa Clara consists of many small basins, defined by bottom topography and stands of vegetation. The Ciénega is an asymmetric basin with its steep margin to the northeast and sloping gently to the SW. Under normal inflow conditions, water flows from the NW to the SE along the sloping axis of the basin. When water levels are high, the Ciénega may expand its wet area to the southwest. High tides and the saline water from the sea may also define the southwestern margin of the Ciénega de Santa Clara.

Three different estimates of evapotranspiration suggest that 50,105 af (62 mcm), 58,123 af (72 mcm), or 86,000 af (106 mcm) are lost to evapotranspiration each year, which represent approximately 46%, 53%, or 78% of the water inflow to the Ciénega (considering an average annual flow of 110,000 af [136 mcm]). The data indicate that from 22% to 54% of the incoming water exits the Ciénega onto the adjacent mudflats and especially into the tidal basin at the southern end of the Ciénega. Much of this discharge occurs in winter when *Typha* plants are dormant and ET is low. This wintertime drainage prevents the buildup of salts in the Ciénega by flushing the more saline water into the basin to the south.

Chapter III: Water Quality

Water quality monitoring consisted of both spot measurements as well as daily measurements. Spot measurements were taken at 21 sampling sites using portable YSI equipment and by taking water samples. Daily measurements were taken at 6 sampling sites using YSI data loggers. See Figure 3-1 for site locations and Table 3-1 for a list of equipment installed at each site.



All YSI loggers measure temperature, electrical conductivity, and water elevation.
In addition, the YSI XLM loggers measure pH and dissolved oxygen.
HOBO loggers measure water elevation. All parameters are measurd with a portable YSI at all sites.

Figure. 3-1. Location of sampling sites and installed water quality and water level sensors. UTM-1984 UTM Zone 11N.

A. Measurement methods

Sites were chosen based on accessibility by boat and foot. This resulted in more sites in the north and along the eastern margin of the Ciénega. We used a multi-parameter YSI 6600V2 sonde to make spot measurements of temperature, specific conductance (conductivity corrected to 25° C), dissolved oxygen, and pH/ORP (Table 3-1). The following graphs show results from the spot measurements since 2006 for some of the sites and key parameters. (Also see Appendix VII).

For Total Dissolved Solids (TDS) we report values calculated in the lab from the analysis of water samples. TDS is calculated in the lab by using a well-mixed water sample, which is filtered through a standard glass fiber filter, and the filtrate is evaporated to dryness in a weighed dish and dried to constant weight at 180°C. The increase in dish weight represents the TDS.

TDS obtained by laboratory determination was then compared with EC measurements in the field, and a linear regression model was constructed with field EC vs. lab TDS. Using the regression formula, a value of calculated TDS was obtained for each EC of the data set. A standard deviation (std dev) was also obtained; therefore, all values have a ± std dev of the mean calculated TDS. For 2006-2009, a factor of 0.635 was obtained with laboratory readings from 2008 and 2009. And for 2010 we used a different mean factor each month, since laboratory results were available monthly. Appendix VIII is an Excel file with data for these parameters from November 2009 through June 2011.

Sampling Site #	Sampling Reference Name	X-coordinate	Y-coordinate	Type of Equipment Installed
1	El Troque Sur	699477	3546320	YSI XLM logger, water gauge
2	Entrada Bocanita	698963	3545581	HOBO logger*, water gauge
3	Mojonera No.2	698003	3546390	Water gauge
4	El Letrero	699778	3546256	YSI LS logger, water gauge
5	La Flor Laguna sur	701557	3543826	YSI XLM logger**, water gauge
6	La Flor laguna norte	700994	3545106	Nothing
7	La Flor Entrada	702167	3546142	HOBO logger, water gauge
8	Bypass Drain	698314	3548739	HOBO logger
9	Dren Riito	693550	3553864	YSI 600LS logger***, water gauge
10	Ciénega Sur	705027	3540265	YSI logger
11	Punta Sureste	704945	3541861	Water gauge
12	Laguna Pelicano	696138	3548674	Water gauge
13	Ciénega Este	703036	3544467	HOBO logger, water gauge
14	Ciénega Sur-oeste	701454	3540705	Nothing
15	Ciénega Oeste	699138	3541936	Nothing
16	Ciénega Nor-este	699578	3548800	YSI 600LS logger, water gauge
17	Laguna Grande	698786	3546685	Nothing
18	El Troque Centro	699283	3546585	Nothing
19	Ciénega Nor-oeste	698281	3545806	YSI 600LS logger****, water gauge
20	Cerca de Boya 5	698528	3546060	Nothing
21	Entre dos	701074	3544344	Water gauge
22	Torre Observacion	696974	3546409	HOBO logger*****, water gauge
23	Muelle	697467	3546972	Water gauge

Table 3-1. Name and original location of sampling sites and equipment installed in the Ciénega de Santa Clara. UTM 11S WGS84
*Equipment damaged
**Site made inaccessible by April 2010 earthquake; equipment removed and replaced, but then damaged by March 2011 fire.
***Removed July 2010 for dredging of Riito Drain
****Equipment damaged by fire March 2011
*****Equipment removed

B. Conditions during the monitoring period

To compare conditions in the Ciénega over the entire monitoring period we grouped sampling sites into those measuring the water quality at the inflows, at sites within the open water and dense cattail areas—which we refer to as sites inside the Ciénega—and those along the edges of the Ciénega, which tend to be shallower.

C. Monitoring parameters

1. Total dissolved solids

We recorded variation in TDS during the monitoring period because this water quality parameter affects plant growth. TDS is highly correlated with salinity. High TDS retards growth in cattail, *Typha domingensis*—the dominant vegetation of the Ciénega de Santa Clara. Glenn et al., (1995) showed that cattail growth in the Ciénega de Santa Clara was reduced to half its maximum value when salinity reached 3.5 parts per thousand (ppt) (TDS = 3,700 parts per million [ppm]) and growth ceased above 6.0 ppt (TDS = 6,900 ppm). These numbers were corroborated by Baeza (2011) through field and greenhouse experiments which showed *T. domingensis* growth reduced by half at 3ppt and a salinity tolerance threshold of 6ppt. A previous study (Beare and Zedler, 1987) showed decreased growth in *T. domingensis* at 5‰ salinity (5ppt) and a pronounced decrease in growth at 10‰ salinity (10 ppt). The variance in the Beare and Zedler (1987) study from Glenn et al., (1995) and Baeza (2011) is most likely due to different research methods and length of study, as Baeza (2011) points out.

The following graphs show TDS for these areas (Figures 3-2 through 3-6). Note that, with the exception of one data point in April 2011 (Figure 3-2), TDS values were always higher in the Santa Clara-Riito Drain than in the Bypass Drain. However, these higher values have little effect on TDS values within the Ciénega because flows from the Santa Clara-Riito Drain are a small fraction of the flows from the Bypass Drain (see Chapter II, Hydrology).

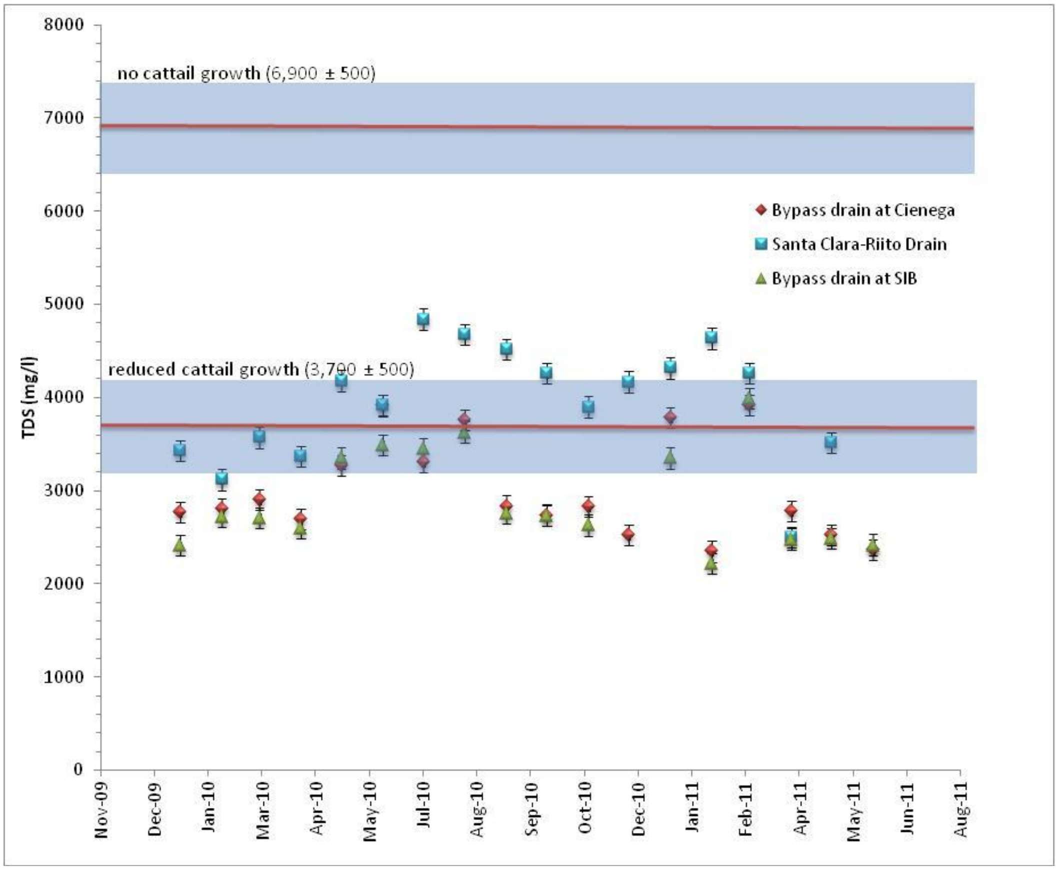


Figure 3-2. Calculated TDS (milligrams per liter [mg/l]) at the Bypass Drain measured by us at the Ciénega (in red); measured at the Southerly International Border (in green) by the U.S. Bureau of Reclamation and at the Santa Clara-Riito Drain – measured by us (in blue) through March 2011. Cattail growth thresholds (red line) and 95% error bars (blue zone) according to Glenn et al., 1995. Salinity of 3.2 ppt corresponds to a TDS of 3,700 ppm, and salinity of 6 ppt corresponds to a TDS of 6,900 ppm.

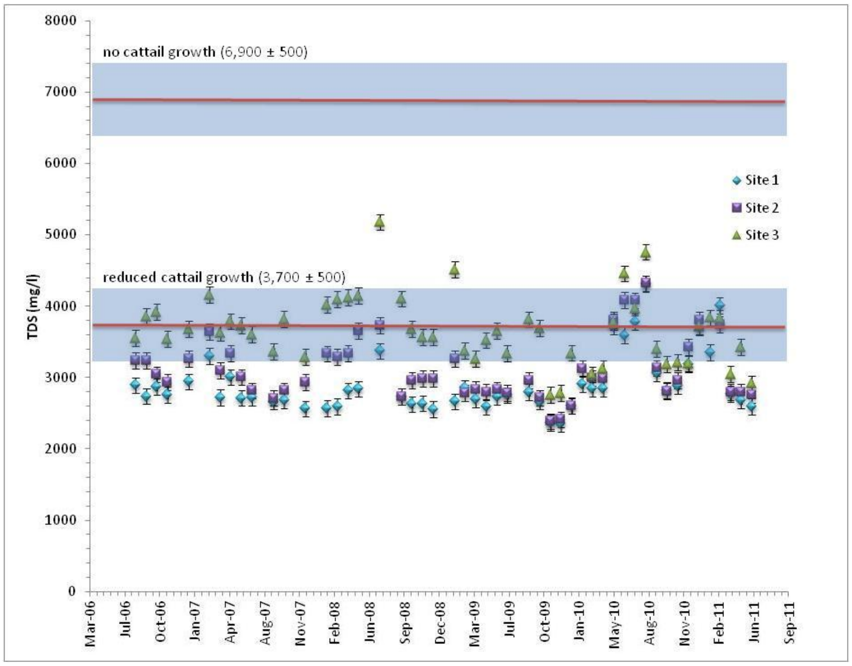


Figure. 3-3. Mean calculated TDS (mg/l) inside the Ciénega (sites 1,2,3). Cattail growth thresholds and 95% confidence limits according to Glenn et al., 1995. Salinity of 3.2 ppt corresponds to a TDS of 3,700 ppm, and salinity of 6 ppt corresponds to a TDS of 6,900 ppm.

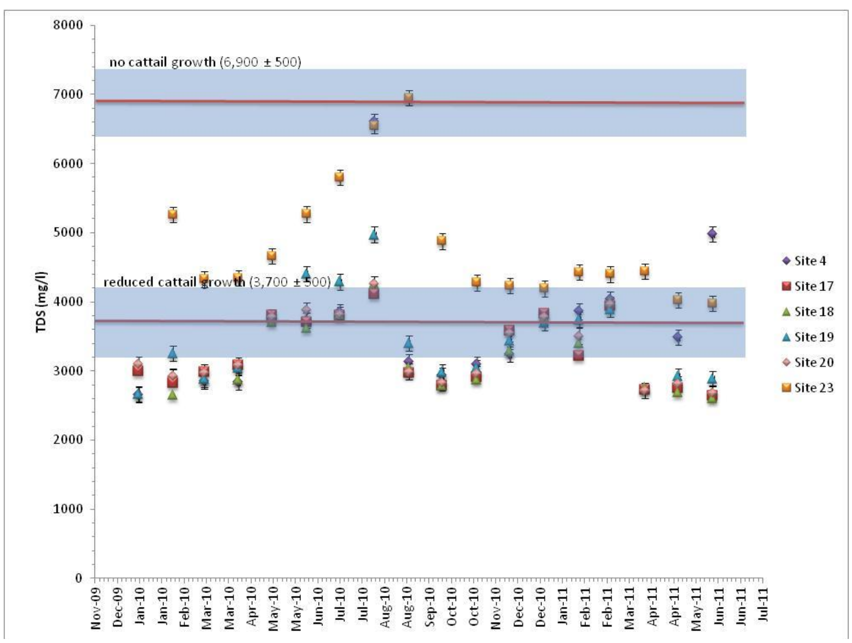


Figure 3-4. Mean calculated TDS (mg/l) inside the Ciénega at monitoring sites established in December 2009 (sites 4, 17, 18, 19, 20, and 23). Cattail growth thresholds and 95% confidence limits according to Glenn et al., 1995. Salinity of 3.2 ppt corresponds to a TDS of 3,700 ppm, and salinity of 6 ppt corresponds to a TDS of 6,900 ppm.

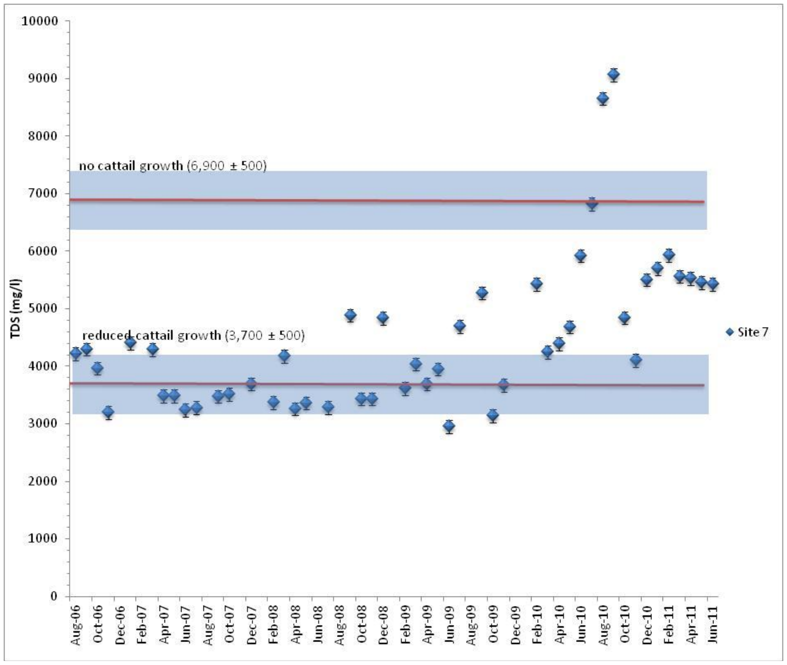


Figure 3-5. Mean calculated TDS (mg/l) at the edge site of the Ciénega (site 7). Site 7 has the longest time series. Note the adjustment in the scale to show range of values. Cattail growth thresholds according to Glenn et al., 1995.

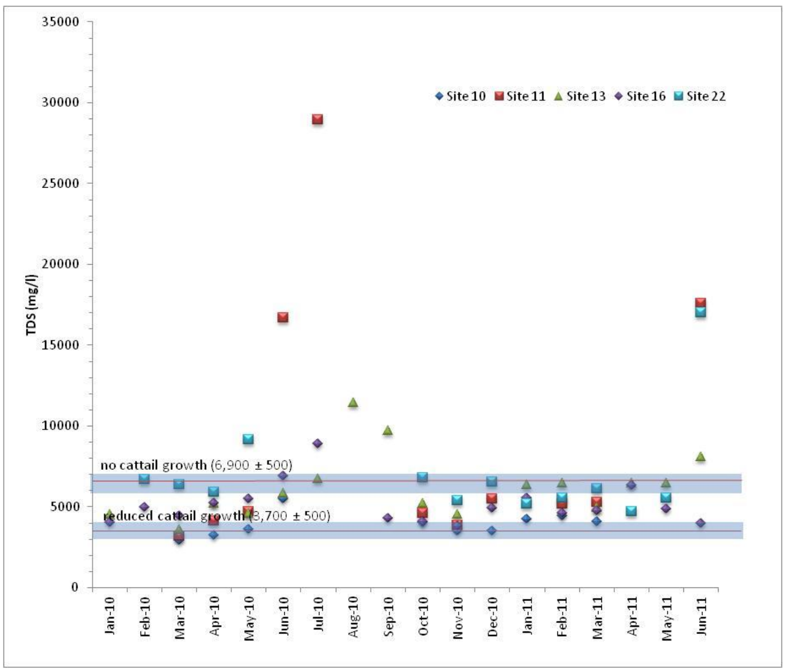


Figure 3-6 Mean calculated TDS (mg/l) at the edge sites of the Ciénega at new monitoring sites (sites 10, 11, 13, 16, 22). Site 11 was 17,000 ppm in June 2010 and 30,000 ppm in July 2010. Site 11 was also high in June 2011 – as was site 22. Note the adjustment in the scale to show range of values. Sites without values in summer 2010 were dry and no TDS measurement could be made. Cattail growth thresholds according to Glenn et al., 1995.

a) TDS estimated by electrical conductivity loggers

Loggers that recorded Electrical Conductivity and Temperature were installed at sites 1, 4, 9, 10, 16 and 19. Loggers from sites 1, 4 and 19 were in the vegetated portion of the Ciénega, and loggers 10 and 16 were at the edge (Fig 3-1). Also, there was a logger at the terminus of Santa Clara-Riito Drain (site 9), which only functioned for a few months because it was removed after CONAGUA began dredging operation along the drain. EC was converted to TDS and these values were compared to the monthly laboratory determined TDS values (Figs 3-7 through 3-12).

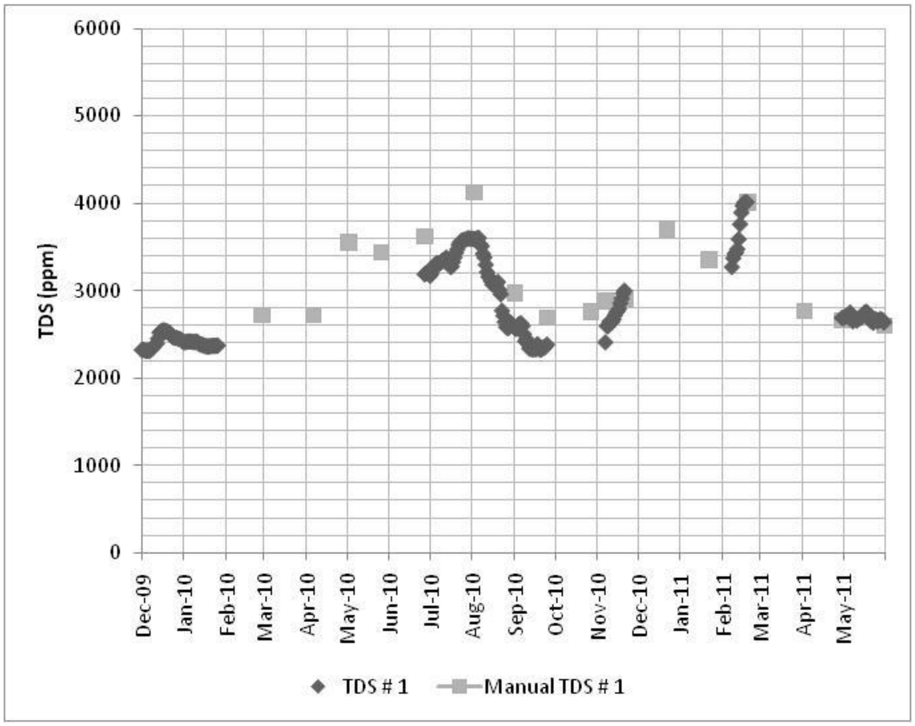


Figure 3-7. Daily TDS average calculated using YSI data loggers (dark diamonds) and monthly TDS from spot manual measurements (gray squares) for Site 1. (All values are calculated TDS adjusted with laboratory calculated TDS).

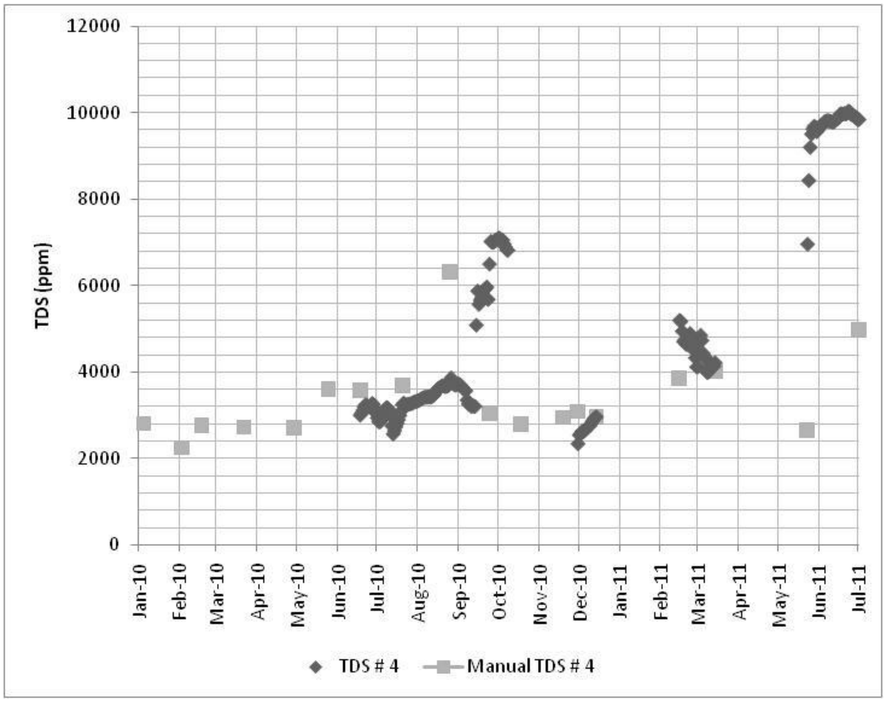


Figure 3-8. Daily TDS average calculated using YSI data loggers (dark diamonds) and monthly TDS from spot manual measurements (gray squares) for Site 4. (All values are calculated TDS adjusted with laboratory calculated TDS).

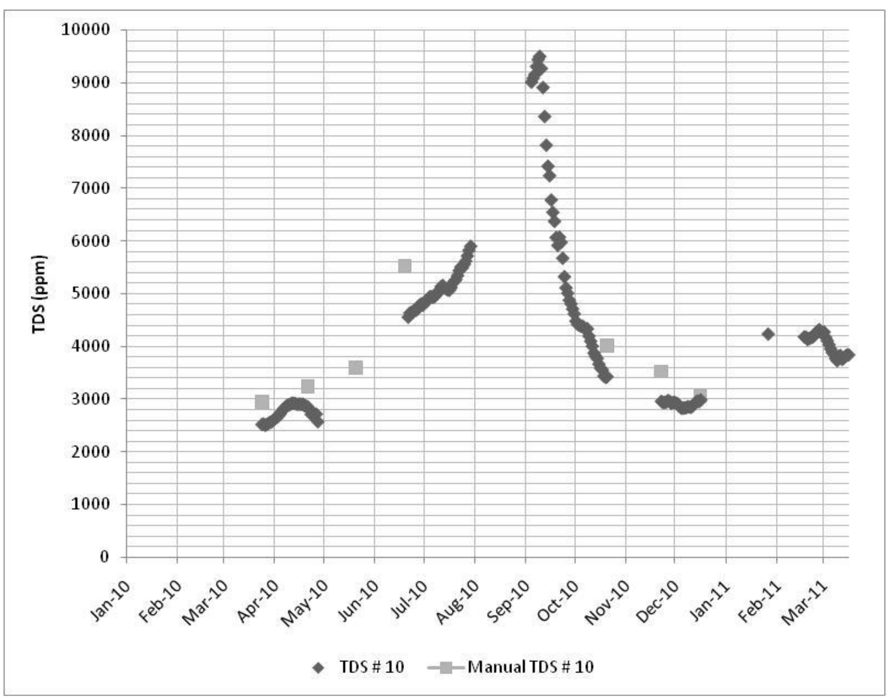


Figure 3-9. Daily TDS average calculated using YSI data loggers (dark diamonds) and monthly TDS from spot manual measurements (gray squares) for Site 10. (All values are calculated TDS adjusted with laboratory calculated TDS).

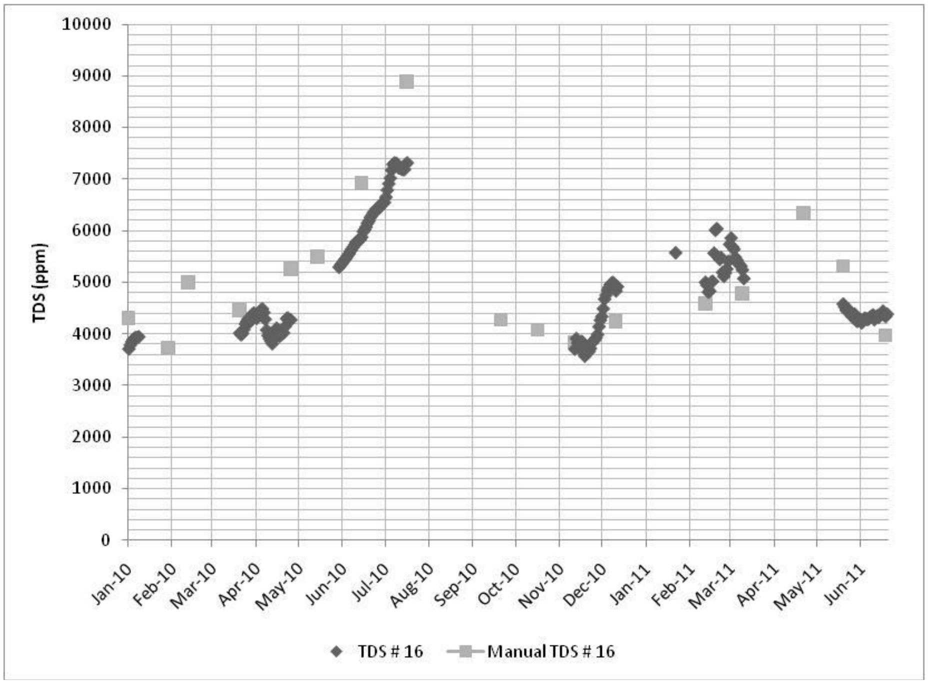


Figure 3-10. Daily TDS average calculated using YSI data loggers (dark diamonds) and monthly TDS from spot manual measurements (gray squares) for Site 16. (All values are calculated TDS adjusted with laboratory calculated TDS).

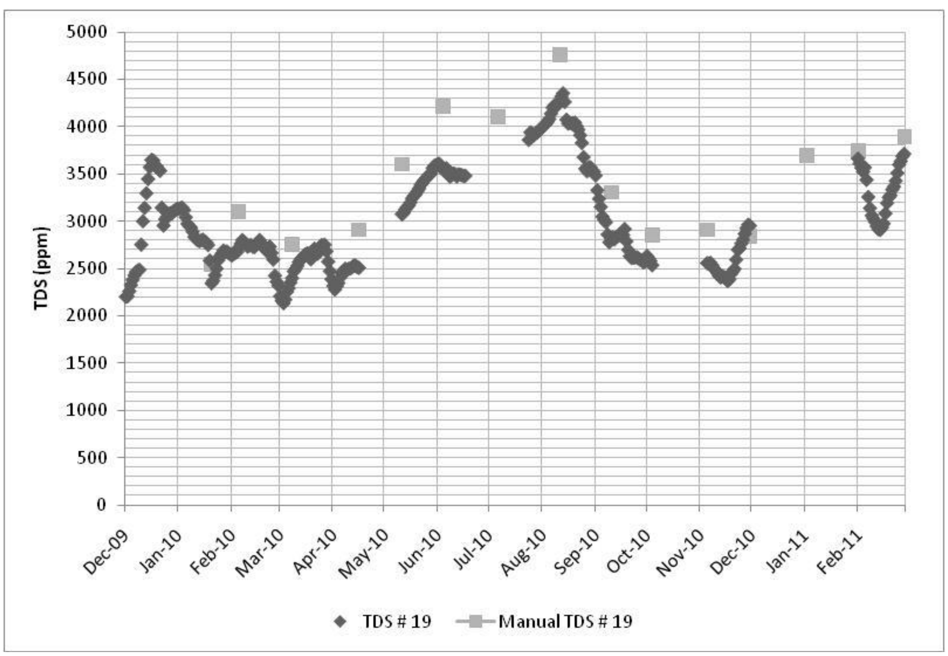


Figure 3-11. Daily TDS average calculated using YSI data loggers (dark diamonds) and monthly TDS from spot manual measurements (gray squares) for Site 19. (All values are calculated TDS adjusted with laboratory calculated TDS).

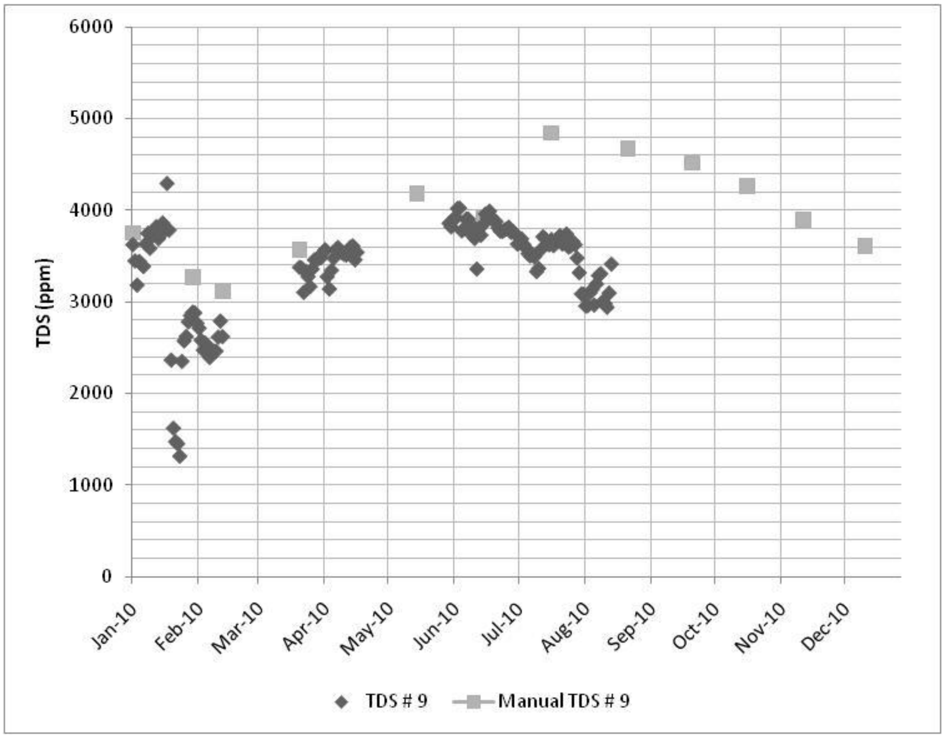


Figure 3-12. Daily TDS average calculated using YSI data loggers (dark diamonds) and monthly TDS from spot manual measurements (gray squares) for Site 9. (All values are calculated TDS adjusted with laboratory calculated TDS).

TDS values varied at several sites during the monitoring period. The most common pattern was an increase in the spring and summer of 2010. Spring and summer increases of these magnitudes were not observed at the same sites in spring and summer periods dating back to summer 2006. This pattern occurred at both interior and edge sites. The increases were roughly coincident with the operation of the YDP at times when little or no arranged water was delivered to the Bypass Drain.

Tables 3-2a and 3-2b (a continuation of 3-2a) show concentrations of TDS measured in laboratory from Dec 2009 to May 2011. Laboratory results adjusted well to field measurements (R^2 = 0.90) and data was used to obtain a calculated TDS.

Site	Dec-09	Jan-10	Feb-10	Mar-10	Apr-10	May-10	Jun-10	Jul-10	Aug-10
Bypass Drain	2545	2934	2888	2976	2702	3270	3928	3349	3834
Santa Clara-Riito Drain	2833	2848	3088	3420	3302	3368	3368	3578	4254
1	2340	2434	2974	2908	2874	3734	3528	3928	4390
2	2433	2632	3155	3004	2932	3790	3272	3952	4392
3	2790	4297	3744	3018	3152	3710	4376	3934	4784
4	2428	2438	2924	2892	2798	3762	3992	3964	4474
5	NA	NA	2814.5	2670	NA	NA	NA	NA	NA
6	2415	NA	2788	2894	2968	NA	NA	NA	NA
7	NA	NA	5327.5	3944	4352	4386	5762	7048	9022
10	NA	NA	NA	3012	3226	3478	6014	NA	NA
11	NA	NA	3530	3182	4212	4568	NA	34034	NA
12	NA	NA	NA	4782	5172	5608	8214	17246	NA
13	NA	4636	4086	3580	5006	4335	5816	6936	12106
14	NA	NA	NA	NA	NA	NA	NA	NA	NA
15	NA	NA	NA	NA	NA	NA	NA	NA	NA
16	NA	3842	4672	4154	4852	5024	NA	7980	NA
17	NA	2560	3020	2972	2972	3813	NA	3814	4176
18	NA	2424	2960	2900	2898	3724	3526	3850	4276
19	NA	2736	3066	2892	3058	3761	4450	4242	5182
20	NA	2666		2940	3028	3772	3806	3820	4260
21	NA	NA	2838	2682	NA	NA	NA	NA	NA
22	NA	5664	6963	6602	5974	9573	NA	NA	NA
23	NA	NA	4690	4324	4340	4516	5192	5856	6588

Table 3-2a. Total Dissolved Solids (TDS) mg/l measured in laboratory
NA = not analyzed due to inaccessibility to the site (i.e. earthquake blocked several passages)

Site	Oct-10	Nov-10	Dec-10	Jan-11	Feb-11	Mar-11	Apr-11	May-11
Bypass drain	2736	2830	2600	3856	2324	3964	2826	2640
Santa Clara-Riito Drain	4060	3782	4140	4222	4378	4058	2403	3630
1	2860	2924	3196	3730	3404	4034	2804	2732
2	2844	2964	3390	3770	NA	NA	2758	2908
3	3222	3220	3248	3676	3868	3700	3040	3060
4	2892	2962	3234	3742	3658	4002	NA	2740
5	NA	NA	NA	NA	4020	3796	3234	2888
6	NA	NA	NA	NA	3522	4016	3076	2820
7	4428	4126	5292	5306	5532	5120	5700	5674
10	4134	3674	2810	4316	4612	4006	NA	NA
11	4728	4051	3825	5848	5451	5254	NA	6444
12	NA	NA	NA	NA	NA	NA	NA	NA
13	5280	4666	NA	6040	6273	4822	6606	6146
14	8162	5352	NA	NA	8344	NA	NA	NA
15	6116	4394	NA	NA	5405	NA	NA	NA
16	3444	3586	4440	4614	3802	4102	6052	4334
17	2798	3966	3444	3838	3196	3918	2476	2736
18	2836	2930	3280	3738	3354	4030	2828	2674
19	3002	3090	3504	3788	3772	3870	NA	2944
20	2830	3000	3494	3812	3278	3946	2736	2796
21	NA	NA	NA	NA	4028	3904	3226	2836
22	5852	5566	6960	5124	5652	5674	4854	6620
23	4944	4348	4318	4123	4498	4267	4262	3962

Table 3-2b. (Continuation of 3-2a). Total Dissolved Solids (TDS) mg/l measured in laboratory. NA = not analyzed due to inaccessibility to the site (i.e. earthquake blocked several passages)

2. Water temperature, pH, dissolved oxygen

Water temperature from all stations and from Aug 2006 to June 2011 varied between 5.8 and 36.4 °C with an average of 20.6 °C and a standard deviation of 6.4 °C. Higher water temperatures were detected in the summer months (June to September) and the lower temperatures in the winter (December to February). (See figure 3-1 for the map of sampling site locations). This pattern was also observed during the YDP trial period (Figures 3-13 and 3-14).

pH varied little (standard deviation 0.36). Values ranged between 6.63 and 9.63 with an average 8.04 (Figure 3-15) from August 2010 to June 2011, and during the YDP trial period, pH varied from 6.6 to 9.6 with an average of 7.9 and standard deviation of 0.34.

Oxygen concentration varied from 0.17 to 23.48 mg/l with a standard deviation of 3.8 mg/l. Although oxygen measurements were not made at the same time every survey, there seems to be a pattern with high oxygen levels in the winter and lower levels during the summer (Figure 3-16). While there is no general trend of increasing oxygen, the concentrations of dissolved oxygen in water are dependent on temperature and atmospheric pressure as well. The equilibrium (100% saturation) concentration of dissolved oxygen in water increases as water temperature decreases and as atmospheric pressure increases (Anning, 2003). Using dissolved oxygen and temperature data (2006-2011) we can see that 63% of the oxygen concentration variations were due to temperature variations: lower temperatures presented higher oxygen levels and higher temperatures presented lower oxygen levels (Figure 3-17). This pattern was also observed during the YDP trial in 2010. Lower oxygen in the summer months could be related to vegetation decay and/or higher oxygen demand from the aquatic organisms.

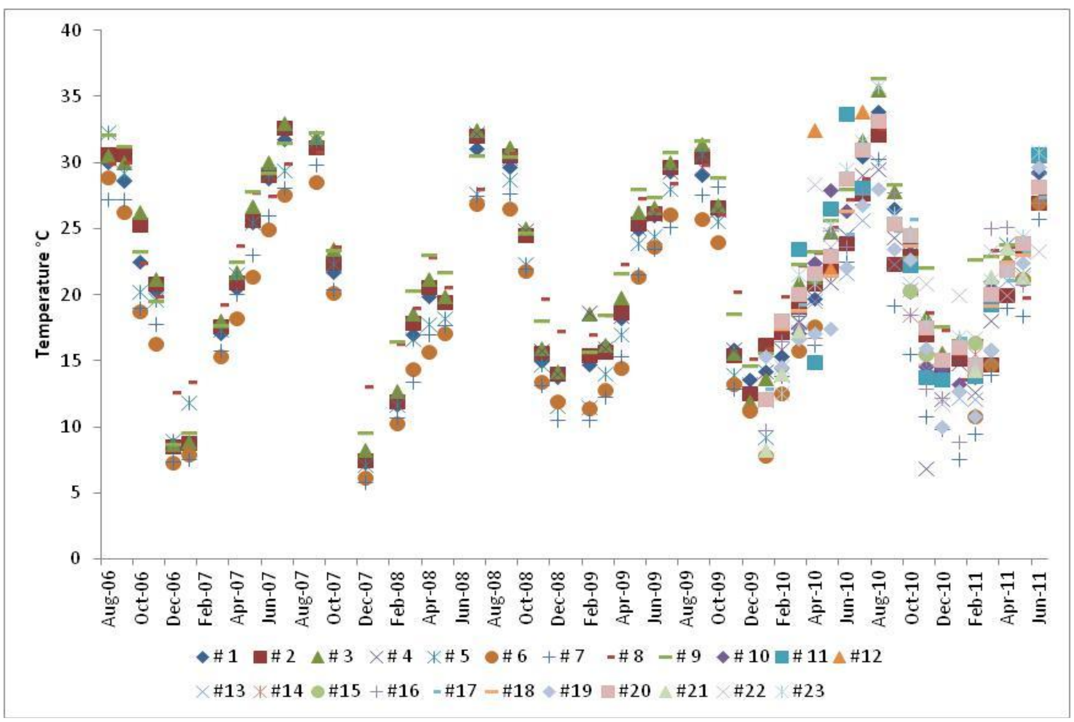


Figure. 3-13. Temperature variations at all sites from Aug 2006 to June 2011.

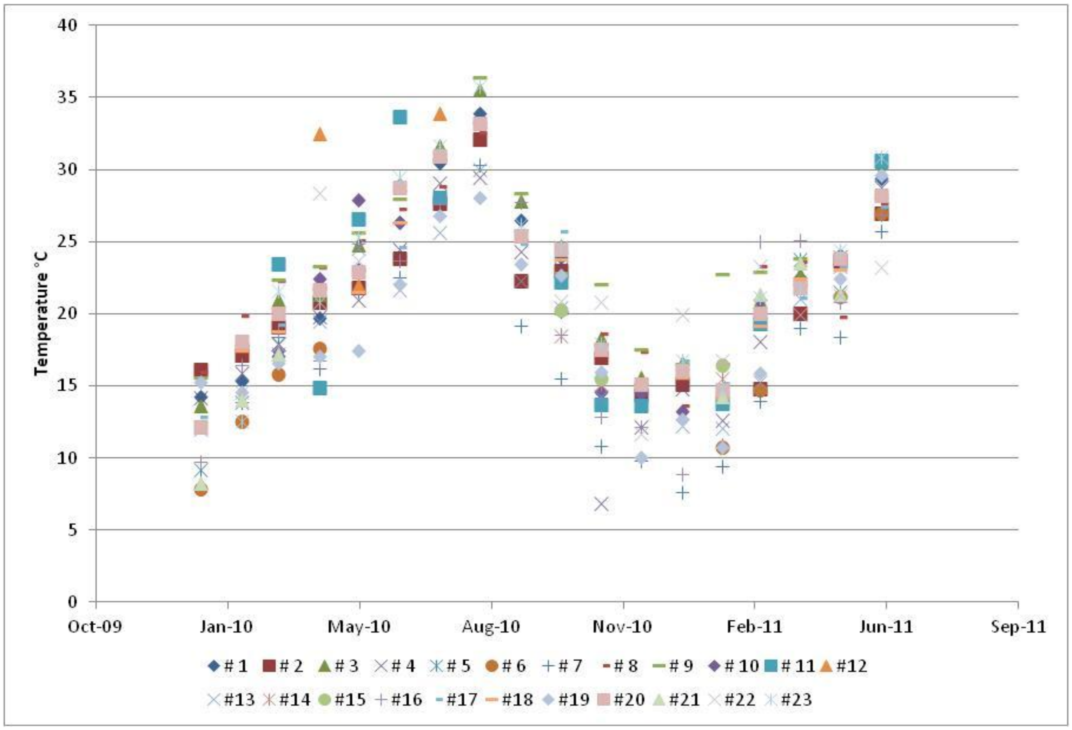


Figure. 3-14. Temperature variations from January 2010 to June 2011.

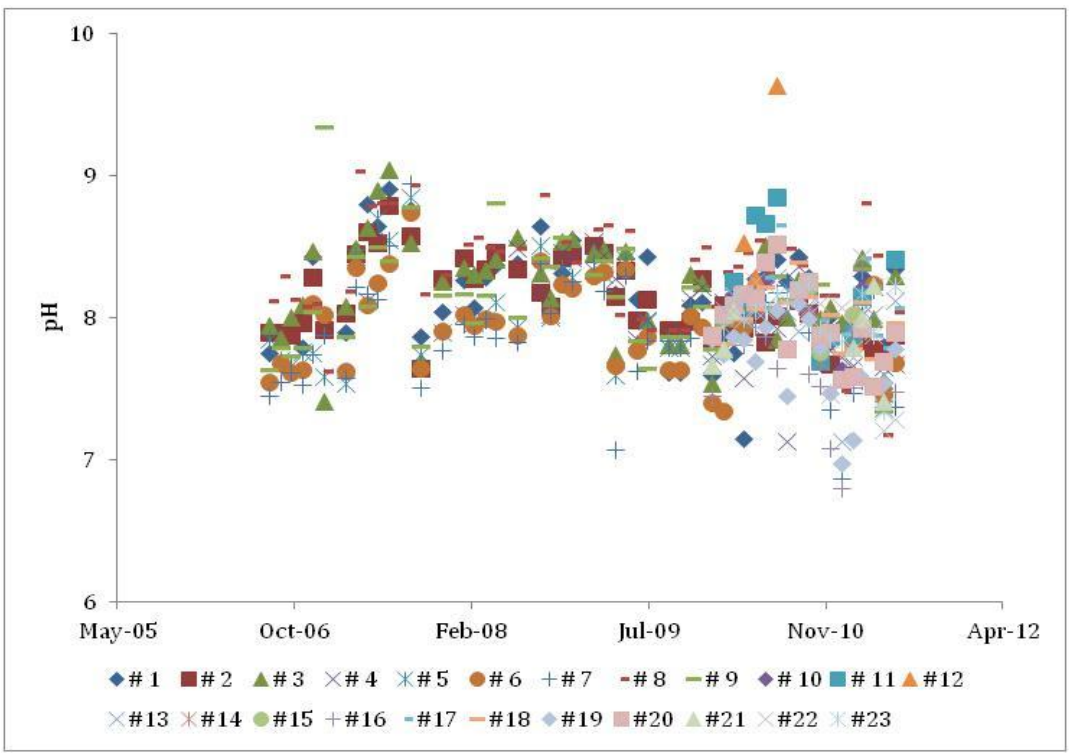


Figure 3-15. pH variations from August 2006 to June 2011 at all sites.

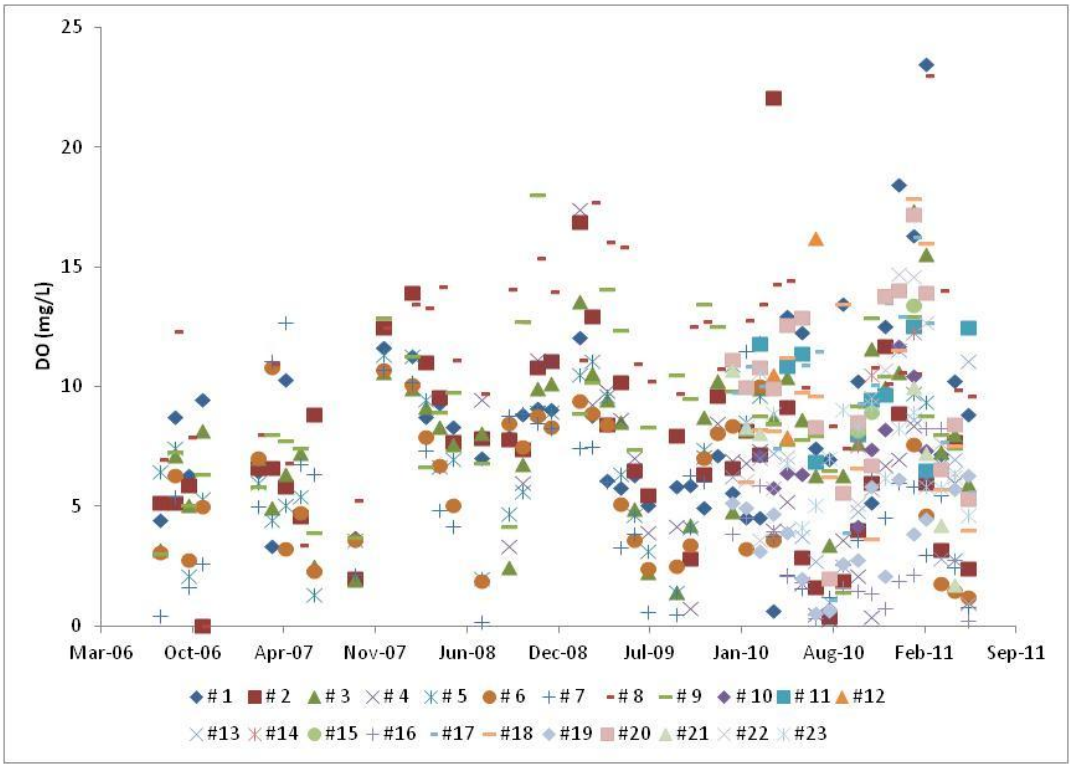


Figure 3-16. Dissolved oxygen (DO) (mg/l) variations from Aug 2006 to June 2011.

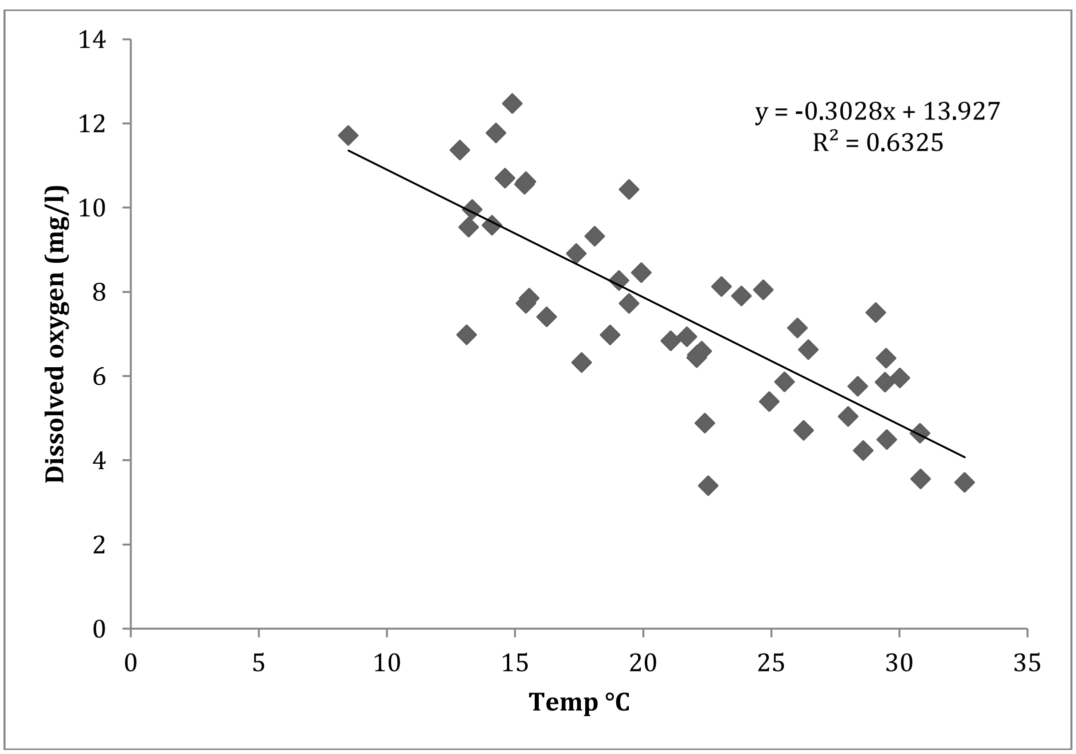


Fig 3-17. Linear regression between temperature and Dissolved oxygen (2006-2011 data from all sites). (Anning, D.W. 2003).

3. Contaminants

Long term monitoring of pollutants in the Ciénega de Santa Clara is necessary because it is a semi-closed basin that receives agricultural return water from the U.S. and México. Additionally, from May 2010 to March 2011 the YDP operated at 33% capacity and brine from the plant was placed into the Bypass Drain. In February 2010 (prior to the operation of the plant) and again in February 2011 (during the operation of the plant) we surveyed for metals and pesticides in samples of water, sediment and fish from different stations inside the Ciénega and from the two inflows. Because monitoring of water samples does not provide information on the possible bioaccumulation of contaminants in the food web, we sampled sediment and fish tissue as well.

Fish (largemouth bass, *Micropterus salmoides*) were collected at the northern sites in both February 2010 and February 2011 (sites 1, 2, 3, 4, 17, 18, 20).

On February 15, 2010 we collected water and sediment samples from sites 1, 5, 6, 12, 13, 16, 21 and 23 in addition to the Santa Clara-Riito and Bypass Drains (sites 9 and 8 respectively). Site 1 is at the end of the Bypass Drain inside the wetland, sites 5, 6 and 21 are in the center section of the wetland, site 12 is located in a newly formed lagoon on the north, sites 13 and 16 are on the eastern side of the Ciénega and site 23 is near the ecotourism center in the north (Figure 3-1).

On February 15 2011, some of these sites were inaccessible due to the earthquake; therefore, it was not possible to sample the same points as the previous year. The sites we visited in 2011 were: 1, 2, 10, 13, 14, 15, 16, 23 and the two inflows (Figure 3-1 and Table 3-1). Common sites were 1, 13, 16, 23 and the two inflows. Site 2 was in the central lagoons, site 10 was the southernmost lagoon and sites 14 and 15 were on the western edge of the Ciénega.

a) Metals

The analysis of metals was performed using Atomic Absorption Spectroscopy (AA). Mercury was analyzed with a Perkin-Elmer 1100-B AA coupled with hydride generator model MHS-20 and the method used was Environmental Protection Agency (EPA)-7471 (1986). Arsenic was analyzed with the same AA coupled with graphite furnace and the method used was EPA-7060A (1994). Lead (Pb), cadmium (Cd), and copper (Cu) were measured also with the Perkin-Elmer 1100-B AA coupled with flame using EPA methods 7420, 7130 and 220 respectively (See Appendix IX). Selenium was analyzed with a Varian SpectrAA-240-FS coupled with a hydride generation system model VGA-77 and the method used was EPA-7742. Quality Control/Quality Assurance (QC/QA) results for metals are presented in Table 3-3.

(1) Monitoring methods

Water samples were extracted using a Microwave digestion-extraction system ($Mars_X$ CEM Corp.) where 50 ml of sample, 20 ml of pesticide grade dichloromethane and an internal standard were extracted at 115°C for 20 min, the extract was purified with florisil, dried and exchanged to hexane during concentration to a volume of 1 ml prior analysis (U.S. EPA Method 608). Sediment samples were homogenized at the laboratory, dried at 40°C for 48 hours and ground using a porcelain mortar and pestle. Dried sediment (2g), 20 ml of hexane:acetone (1:1) and internal standard was extracted in the Microwave digestion and extraction system following the same program as water samples, sediment extracts were purified with copper sheets and then purified with florisil, extracts were dried and exchanged to ethylic ether: hexane at 6%, 15% and 50% to a volume of 1 ml, then dried again and exchanged to isooctane to a volume of 1 ml prior analysis (PAM method 302, U.S. EPA methods 8081, 3620c, 8082). 1 g of fresh fish tissue is extracted in the Microwave system with 20 ml of dichloromethane:petroleum ether (1:1) and internal standard following the same program as water and sediment. Extracts are dried and exchanged to hexane to a 1 ml volume, then are purified with florisil, extracts were dried and exchanged to ethylic ether: hexane at 6%, 15% and 50% to a volume of 1 ml, then dried again and exchanged to isooctane to a volume of 1 ml prior analysis (U.S. EPA methods 3546, 3620c, 8081a). For quality control purposes, each extraction batch (14 vessels) had a duplicate, a fortified sample, an analytical blank, a glassware blank and the addition of 10 ul of 5 ppm decachlorobiphenil (pesticide surrogate) as internal standard to each sample vessel.

Analysis of extracts in 2010 was made in CIAD Culiacan at the certified pesticide laboratory. Samples were analyzed using gas chromatography (GC) with electron capture detector (ECD) and electrolytic conductivity detector ELCD to detect and quantify chlorinated compounds and to detect organophosphate pesticides. Samples were analyzed using GC with flame photometric detector (FPD) and thermionic selective detector (TSD). Analyses in 2011 were made at CIAD Hermosillo at the certified laboratory of toxic residues. Samples were analyzed using GC with ECD for chlorinated compounds and for organophosphate pesticides they were analyzed with nitrogen-phosphorus detector (NPD).

Researchers from the three laboratories involved in the pesticide analysis of the Cienega project (Guaymas, Culiacan and Hermosillo) two years ago formed a Pesticide Research Network (REDIP, Red de Investigación de Plaguicidas) coordinated by Dr. Jaqueline Garcia, which has undertaken inter-laboratory exercises and training courses to obtain comparable results between the three laboratories.

Table 3-3 below shows Quality Control/Quality Assurance results of metal analysis.

Metal/Matrix	Detection limit (µg/l)	% Recovery*	% Relative difference
Selenium			
Water	1		10.0
Sediment	1	191	3.9
Fish	1	104	2.7
Mercury			
Water	1		13.2
Sediment	1	82	19.1
fish	1	79	7.5
Arsenic			
water	20		18.9
Sediment	20	126	5.2
fish	20	161	15.7
Lead	500	73	<DL**
Cadmium	500	120	<DL
Copper	500	133	<DL

Table 3-3. Quality Control/Quality Assurance results of metal analysis (µg/l=micrograms per liter).
*For sediment we used PACS-2 (Marine sediment reference materials for trace metals and other constituents) and for fish we used DORM-2 (Dogfish muscle certified reference material for trace metals) and DOLT-4 (Dogfish liver certified reference material for trace metals). All are certified reference material from the National Research Council Canada (NRC-CNRC)
** <DL = under detection limit

i. Selenium (Se)

- Se in water (total recoverable selenium)

Selenium commonly occurs as a mixture of several chemical species in natural waters, although two inorganic chemical species, selenite and selenate, are usually the predominant form. Normal background concentrations of selenium in uncontaminated freshwater range from 0.25 to 0.4 µg/l (parts per billion [ppb]) (NIWQP, 1998a). An important factor confounding interpretation of field data for waterborne selenium is the differential partitioning of selenium mass loads between the water column and other compartments of the aquatic ecosystem. Partitioning ratios can be strongly influenced by the overall biotic productivity of a water body. In highly productive waters, less dissolved selenium is left in the water column even though food-chain exposure of fish and wildlife may be substantial. Therefore low waterborne selenium can indicate either low mass loading (low risk) or high biotic uptake (high risk). This interpretative problem can be partially ameliorated by measuring total recoverable selenium (unfiltered samples) rather than dissolved selenium (filtered samples). Total recoverable selenium includes suspended detrital particulate matter, a function of biotic uptake, and thus more accurately reflects the total mass load of selenium fluxing through a water column (NIWQP, 1998a). Therefore, in the present study we collected total recoverable selenium.

The U.S. EPA has promulgated aquatic life criteria for selenium (U.S. EPA, 2009) based on field data from Belews Lake in North Carolina. The Criterion Continuous Concentration (CCC) was set at 5 µg/l, which was the concentration of selenium in a portion of the lake where no chronic effects were observed. The Criterion Maximum Concentration (CMC) was calculated by adding the toxicities of each selenium species resulting in a range between 13 and 186 µg/l. The CCC is an estimate of the highest concentration of a material in surface water to which an aquatic community can be exposed indefinitely without resulting in an unacceptable effect. The CMC is an estimate of the highest concentration of a material in fresh surface water to which an aquatic community can be exposed briefly without resulting in an unacceptable effect (U.S. EPA, 2009). These guidelines are under revision and could change in the future.

In February 2010, prior to the operation of the YDP and during arranged water deliveries, Bypass Drain water concentrations exceeded the chronic limit guideline. Inside the wetland, concentrations at the central sites and the north lagoon exceeded the acute limit guideline for protection of aquatic life (Table 3-4). In February 2011, during the operation of the YDP with no arranged water, concentrations of selenium decreased at the Bypass Drain to half the values of 2010, and concentrations inside the Ciénega were also lower than the previous year. None of the values was above the acute guideline level in 2011 (Table 3-5).

Distribution of total selenium in the Ciénega was consistent in the two sampling periods: lower concentrations were found on the eastern edge of the Ciénega (sites 10 and 13) and higher on the central and northern lagoons.

As mentioned previously, on February 15, 2010 we collected water and sediment samples from sites 1, 5, 6, 12, 13, 16, 21 and 23 in addition to the Riito-Santa Clara and Bypass Drains (sites 9 and 8 respectively). On February 15 2011, some of these sites were inaccessible due to the earthquake; therefore, it was not possible to sample the same points as the previous year. The sites we visited in 2011 were: 1, 2, 10, 13, 14, 15, 16, 23 and the two inflows (Figure 3-1 and Table 3-1). Common sites between the two years were 1, 13, 16, 23 and the two inflows.

Guideline/site	Se in Water (μg/l)	
SQuiRT[1]	Chronic	Acute
	5.0	13-186
1	7.31	
5	**13.86**	
6	**20.18**	
12	**13.86**	
13	0.33	
16	0.33	
21	0.54	
23	0.95	
Bypass Drain	10.71	
Santa Clara-Riito Drain	7.56	

Table 3-4. Concentrations of selenium (Se) in water in the Ciénega de Santa Clara in 2010. Bold numbers indicate acute concentrations in fresh water.
[1]Buchman, M.F. 2008. NOAA Screening Quick Reference Tables (SQuiRT), NOAA OR&R Report 08-1, Seattle WA, Office of Response and Restoration Division, National Oceanic and Atmospheric Administration, 34 pages.

Guideline/site	Se in Water (μg/l)	
SQuiRT[1]	Chronic	Acute
	5.0	13-186
1	7.09	
2	8.44	
10	1.33	
13	1.20	
14	6.89	
15	5.73	
16	5.83	
23	10.59	
Bypass Drain	5.36	
Santa Clara-Riito Drain	1.00	

Table 3-5. Concentrations of selenium in water in the Ciénega de Santa Clara in 2011.
[1]Buchman, M.F. 2008. NOAA Screening Quick Reference Tables, NOAA OR&R Report 08-1, Seattle WA, Office of Response and Restoration Division, National Oceanic and Atmospheric Administration, 34 pages.

- Se in bottom sediment (top 3 cm)

Currently there is little empirical basis for assessing fish and wildlife risk as a function of sediment concentrations of selenium. One comparison showed poor correlation between selenium concentrations in sediments and benthic invertebrates (NIWQP, 1998a). As a general rule, anytime the maximum selenium concentration in sediments exceeds 5 milligrams per kilogram (mg/kg), further investigation is strongly warranted (NIWQP, 1998a).

Our results show concentrations ranging from 1.3 to 3.0 mg/kg in both years (Tables 3-6 and 3-7); none of the samples were above the 5 mg/kg limit. Concentrations in bottom sediments were lower in 2011 than in 2010 at the Bypass Drain and at all sites inside the wetland. Higher concentrations seem to occur in the central lagoons especially in the 2010 sampling.

Guideline/Site	**Se in Sediment (mg/kg)**
NIWQP[1]	5
1	1.57
5	3.01
6	1.09
12	2.24
13	2.26
16	1.46
21	1.86
23	1.64
Bypass Drain	2.32
Santa Clara-Riito Drain	2.18

Table 3-6. Concentrations of selenium in bottom sediment from the Ciénega de Santa Clara in 2010.

[1]National Irrigation Water Quality Program. 1998a. Guidelines for interpretation of the biological effects of selected constituents in biota, water and sediment. Selenium. Information Report No. 3. BOR, USFWS, USGS, BIA. 47 pp.

Guideline/Site	**Se in Sediment (mg/kg)**
NIWQP[1]	5
1	1.77
2	1.71
10	1.43
13	1.39
14	1.37
15	1.78
16	1.66
23	1.53
Bypass Drain	1.80
Santa Clara-Riito Drain	1.64

Table 3-7. Concentrations of selenium in bottom sediment from the Ciénega de Santa Clara in 2011.
[1]National Irrigation Water Quality Program. 1998. Guidelines for interpretation of the biological effects of selected constituents in biota, water and sediment. Selenium. Information Report No. 3. BOR, USFWS, USGS, BIA. 47 pp.

- Se in fish muscle

National and global monitoring programs have revealed that most species of fish average less than 4 mg/kg Se on a whole-body basis. Fish sampled at two confirmed Se-normal lakes, have concentrations lower than 2 mg/kg. Background concentrations of selenium in skeletal muscle, gonads and eggs also tend to average 2-4 mg/kg or less (NIWQP, 1998). We measured selenium in skeletal muscle of largemouth bass (*Micropterus salmoides*) from the Ciénega de Santa Clara collected in the northern lagoons. We selected this species because there is a subsistence and recreational fishery targeted to this species. Concentration of selenium in fish varied from 0.8 to 1.5 mg/kg; none of the samples exceeded the 4 mg/kg guideline (Table 3-8, Figure 3-18). Similar to our water and sediment analyses, concentrations in fish tissue in 2011 were lower than in 2010 (t-test *p-value* = 0.001) (Table 3-8, Figure 3-18). A negative relationship was found between total length (and weight) and Se concentration. 40% of Se variability was explained by the size and weight of the organisms: larger (and heavier) organisms have lower selenium in muscle than younger individuals (Figure 3-19).

Collection Date	**Total Length (cm)**	**Weight (g)**	**Se (mg/kg)**
NIWQP[1]			2-4
feb-10	38	1000	1.19
feb-10	36	466	1.41
feb-10	42	1000	1.24
feb-10	31	448	1.28
feb-10	32	526	1.49
feb-10	32	476	1.32
feb-10	31	522	1.54
jun-10	51	1.9	0.84
jun-10	41	1.153	1.36
jun-10	18	0.076	0.97
jun-10	47	1.628	0.83
jun-10	45	1.327	0.82
oct-10	36	0.74	1.33
oct-10	30	0.33	1.41
oct-10	42	1.069	0.96
oct-10	47	1.783	0.82
oct-10	49	2.15	1.19
feb-11	36	0.715	1.11
feb-11	37	0.653	1.16
feb-11	34	0.545	1.13
feb-11	30	0.398	1.01
feb-11	32	0.548	1.07
feb-11	43	1.39	1.10

Table 3-8. Concentration of selenium in largemouth bass from the Ciénega de Santa Clara in 2010 and 2011(g=grams).
[1]National Irrigation Water Quality Program. 1998a. Guidelines for interpretation of the biological effects of selected constituents in biota, water and sediment. Selenium. Information Report No. 3. BOR, USFWS, USGS, BIA. 47 pp.

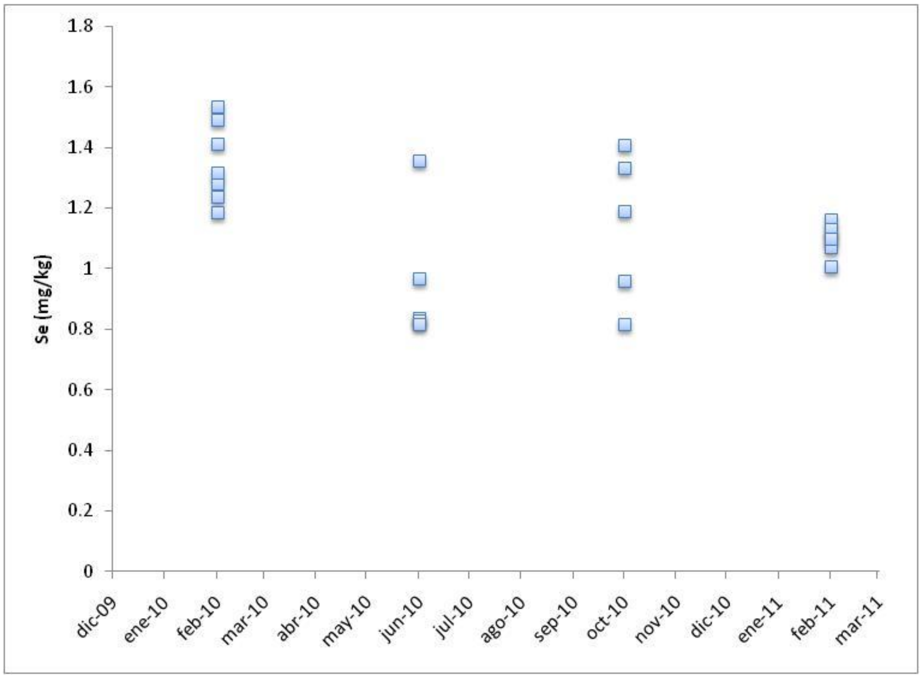


Figure. 3-18. Concentration of Se in largemouth bass (mg/kg) from the Ciénega de Santa Clara.

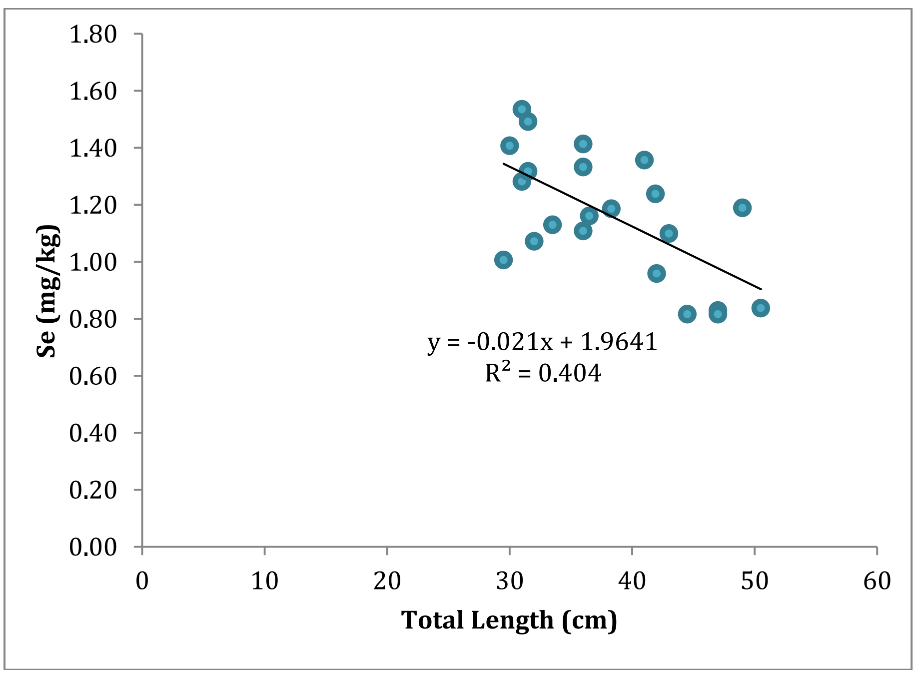


Figure 3-19. Linear regression between total length of largemouth bass and selenium concentration (mg/kg).

ii. Mercury (Hg)

- Hg in water

In other locations, background concentrations in freshwater are generally in the range of 0.00001-0.00005 µg/l, however concentrations greater than background are routinely found in continental rainwater (NIWQP, 1998b). Water concentrations are typically used to assess mercury hazards to fish and aquatic life; total mercury concentrations in water of 100-2000 µg/l are fatal to sensitive aquatic species, and concentrations between 30 and 100 µg/l cause significant sub-lethal effects in fish (NIWQP, 1998b).

Concentration of mercury (Hg) in water from the Ciénega de Santa Clara varied from 0.25 to 7.73 µg/l, which is higher than background levels but lower than the recommended guideline for protection of fish health (Tables 3-9 and 3-10). Distribution of Hg in the Ciénega in 2010 was lower on the eastern edges and higher in the center and northern lagoons, and in 2011 this distribution showed higher concentrations in the edges and center and lower at the north.

Guideline/Site	**Hg in Water (µg/l)**
NIWQP[1]	**Toxicity Threshold**
	>30
1	3.08
5	3.92
6	< DL
12	6.68
13	2.85
16	7.73
21	5.38
23	1.43
Bypass Drain	5.62
Santa Clara-Riito Drain	2.83

Table 3-9. Concentrations of mercury in the Ciénega de Santa Clara in 2010.
[1]National Irrigation Water Quality Program. 1998b. Guidelines for interpretation of the biological effects of selected constituents in biota, water and sediment. Mercury. Information Report No. 3. BOR, USFWS, USGS, BIA. 24pp.

Guideline/Site	**Hg in Water (µg/l)**
SQuiRT[1]	**Toxicity Threshold**
	>30
1	7.00
2	2.88
10	1.77
13	5.11
14	2.88
15	5.44
16	2.66
23	1.44
Bypass Drain	3.44
Santa Clara-Riito Drain	5.88

Table 3-10. Concentrations of mercury in the Ciénega de Santa Clara in 2011.
[1]National Irrigation Water Quality Program. 1998b. Guidelines for interpretation of the biological effects of selected constituents in biota, water and sediment. Mercury. Information Report No. 3. BOR, USFWS, USGS, BIA. 24pp.

- Hg in bottom sediment

Sediment can be both a sink for mercury and a source of it, with changing physical and biological conditions. High natural concentrations are sometimes observed in geothermal areas like Yellowstone National Park where concentrations are as high as 500 mg/kg. Sediment is definitely a source of methyl-mercury to biota and the water column. Even relatively low concentrations may result in bioaccumulation. A toxicity threshold of 0.2 mg/kg total mercury in sediment has been proposed to protect the California Clapper Rail (*Rallus longirostris obsoletus*), a benthic forager in San Francisco Bay (NIWQP, 1998b).

Concentrations of mercury in bottom sediment from the Ciénega de Santa Clara varied from < DL up to 1.46 mg/kg (Tables 3-11 and 3-12). Concentrations of Hg in bottom sediment of the Bypass Drain were higher in 2011 compared to 2010. Hg in bottom sediment in the Ciénega de Santa Clara was higher at the entrance and northern lagoons in 2010 and in 2011 at the entrance and south edges. Because concentrations in sediment in 2011 exceeded the threshold limit where possible effects on California clapper rails may occur, a continuous monitoring of this element is needed in order to detect possible trends and effects on the biota, especially the Yuma Clapper Rail.

Guideline/Site	Hg in Sediment (mg/kg dry wt.)
NIWQP[1]	0.2
1	< DL
5	< DL
6	< DL
12	< DL
13	< DL
16	0.35
21	< DL
23	0.47
Bypass Drain	0.43
Santa Clara-Riito Drain	< DL

Table 3-11. Concentrations of Hg (mg/kg) dry weight in bottom sediment from the Ciénega de Santa Clara in 2010.
[1]National Irrigation Water Quality Program. 1998b. Guidelines for interpretation of the biological effects of selected constituents in biota, water and sediment. Mercury. Information Report No. 3. BOR, USFWS, USGS, BIA. 24 pp.

Guideline/Site	Hg in Sediment (mg/kg dry wt.)
NIWQP[1]	0.2
1	**0.98**
5	**0.36**
6	**1.06**
12	**0.79**
13	**1.04**
16	**0.79**
21	**1.10**
23	**0.85**
Bypass Drain	**1.46**
Santa Clara-Riito Drain	**0.87**

Table 3-12. Concentrations of Hg (mg/kg) dry weight in bottom sediment from the Ciénega de Santa Clara in 2011.
[1]National Irrigation Water Quality Program. 1998b. Guidelines for interpretation of the biological effects of selected constituents in biota, water and sediment. Mercury Information Report No. 3. BOR, USFWS, USGS, BIA. 24 pp.

- Hg in fish

The US Food and Drug Administration (FDA) action level for methyl mercury in the United States is 1 mg/kg wet weight in edible portion of fish. Action levels represent limits at or above which FDA will take legal action to remove products from the market (FDA, 2000). In Mexico, the official regulation NOM-027-SSA1-1993, specifies a maximum concentration of 1 mg/kg of total mercury and 0.5 mg/kg of methyl mercury in edible fish tissue. In the Ciénega de Santa Clara, concentrations varied from < DL up to 0.42 mg/kg wet weight (ww) in muscle tissue; none of the samples exceeded the regulatory limits. Lower concentrations in muscle were detected in fish collected in 2011 compared to the previous year (t-test *p-value* = 0.0057). (Table 3-13).

Collection Date	Total Length (cm)	Weight (g)	Hg (mg/kg ww)
FDA[1] and NOM-027[2]			1
feb-10	38	1000	0.09
feb-10	36	466	0.11
feb-10	42	1000	0.02
feb-10	31	448	0.09
feb-10	32	526	0.13
feb-10	32	476	0.14
feb-10	31	522	0.05
jun-10	51	1900	0.38
jun-10	41	1153	0.24
jun-10	18	76	0.40
jun-10	47	1628	0.42
jun-10	45	1327	0.32
oct-10	36	740	0.19
oct-10	30	330	0.17
oct-10	42	1069	0.38
oct-10	47	1783	0.40
oct-10	49	2150	0.33
feb-11	36	715	< DL
feb-11	37	653	< DL
feb-11	34	545	< DL
feb-11	30	398	0.06
feb-11	32	548	< DL
feb-11	43	1390	< DL

Table 3-13. Concentration of Mercury in largemouth bass from the Ciénega de Santa Clara in 2010 and 2011.

[1]Appendix 5-FDA and EPA Safety levels in regulations and guidance 3rd edition. June 2001. Fish and fisheries products hazards and controls guidance.

[2]NOM-027-SSA1-1993. Bienes y servicios. Productos de la pesca. Pescados frescos-refrigerados y congelados. Especificaciones sanitarias.

Mercury correlated positively with length and weight of largemouth bass (linear regression R^2 = 0.48), larger and heavier fish had more Hg in their tissues than younger individuals (Figure 3-20). This is a common trend observed in predatory fish (Andersen et al., 1997; García-Hernández et al., 2007).

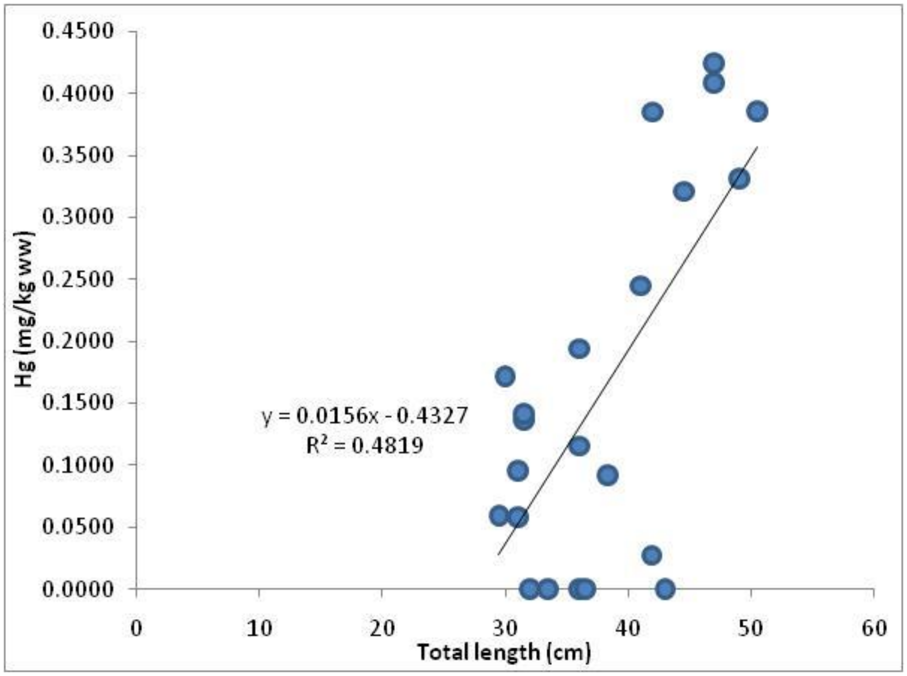


Figure. 3-20. Total length (cm) and Hg concentrations (mg/kg wet weight) in largemouth bass from the Ciénega de Santa Clara in four surveys (2010-2011).

iii. Arsenic (As)

- Arsenic in water samples

Arsenic is not normally considered an essential element to most species, and it has been shown to be both teratogenic and carcinogenic in many mammal species. However beneficial effects have been reported in some organisms (NIWQP, 1998c). In general, inorganic forms of arsenic are more toxic than organic compounds, and arsenite (the reduced form of arsenic) is more toxic than arsenate (the oxidized form of arsenic). In aerobic aquatic environments the natural conversion of arsenite to arsenate somewhat reduces the overall hazard of this element (NIWQP, 1998). In the Mexicali Valley arsenic was used as pesticide before the DDT era, and concentrations up to 30 ppm in sediment have been detected in sediment and soils from the region (Deasslé et al, 2008).

Concentrations of As in water in the Ciénega varied from 28 to 435 µg/l (Tables 3-14 and 3-15). However, the highest concentrations in 2010 and 2011 were found at the edges of the Ciénega at sites 10,12,13,14,15 and 16 where more evaporation occurs and concentrations increase. Concentrations at the Bypass Drain were higher in 2011 than in 2010.

Site/Guideline	**As (µg/l)**
NIWQP[1]	**Toxicity Threshold**
	190
1	105.56
5	74.07
6	97.78
12	160.00
13	68.89
16	93.33
21	60.00
23	28.89
Bypass Drain	94.44
Santa Clara-Riito Drain	77.78

Table 3-14. Concentrations of As (µg/l) in water from the Ciénega de Santa Clara in February 2010.
[1]National Irrigation Water Quality Program. 1998c. Guidelines for interpretation of the biological effects of selected constituents in biota, water and sediment. Arsenic Information Report No. 3. BOR, USFWS, USGS, BIA. 17 pp.

Site/Guideline	**As (µg/l)**
NIWQP[1]	**Toxicity Threshold**
	190
1	140.00
2	125.78
10	**213.44**
13	**435.00**
14	**306.67**
15	188.22
16	**238.67**
23	**198.11**
Bypass Drain	126.78
Santa Clara-Riito Drain	171.78

Table 3-15. Concentrations of As (µg/l) in water from the Ciénega de Santa Clara in February 2011.
[1]National Irrigation Water Quality Program. 1998c. Guidelines for interpretation of the biological effects of selected constituents in biota, water and sediment. Arsenic Information Report No. 3. BOR, USFWS, USGS, BIA. 17 pp.

- Arsenic in sediment

Arsenic concentrations of 8.2 mg/kg dry weight or less do not usually produce adverse biological effects, but concentrations of 70 mg/kg or higher usually do, according to studies made for estuarine and marine sediments (NIWQP, 1998c). Concentrations of arsenic in the Ciénega de Santa Clara varied from 21.5 to 90.17 mg/kg dry weight, concentrations above 70 mg/kg were found at sites 14 and 15 which are on the west edges of the Ciénega. Concentrations of arsenic in sediments from the Bypass Drain in 2011 were higher than those recorded in 2010. (Tables 3-16 and 3-17).

Site/Guideline	**As (mg/kg dw)**
NIWQP[1]	**Toxicity Threshold**
	70
1	32.04
5	33.34
6	37.40
12	23.10
13	50.56
16	53.00
21	29.93
23	22.99
Bypass Drain	24.07
Santa Clara-Riito Drain	27.29

Table 3-16. Concentrations of As in sediment (mg/kg dry weight [dw]) in the Ciénega de Santa Clara in February 2010.

[1]National Irrigation Water Quality Program. 1998c. Guidelines for interpretation of the biological effects of selected constituents in biota, water and sediment. Arsenic. Information Report No. 3. BOR, USFWS, USGS, BIA. 17 pp.

Site/Guideline	**As (mg/kg dw)**
NIWQP[1]	**Toxicity Threshold**
	70
1	39.73
2	42.44
10	49.06
13	62.36
14	**87.03**
15	**90.17**
16	29.34
23	37.08
Bypass Drain	44.00
Santa Clara-Riito Drain	21.50

Table 3-17. Concentrations of As in sediment (mg/kg dw) in the Ciénega de Santa Clara in February 2011.
[1]National Irrigation Water Quality Program. 1998c. Guidelines for interpretation of the biological effects of selected constituents in biota, water and sediment. Arsenic. Information Report No. 3. BOR, USFWS, USGS, BIA. 17 pp.

- Arsenic in fish tissue

In the aquatic environment, adverse effects of arsenic have been reported at a wide range of concentrations in water, sediment, and diets. In fish the toxicity threshold is 12 mg/kg dry weight (dw) in tissue (NIWQP, 1998).

Concentrations in largemouth bass from the Ciénega de Santa Clara range from < DL to 6.2 mg/kg dry weight (Table 3-18). None of these values were above the toxicity threshold for fish, or above the FDA safety level for fish consumption. There was no apparent relationship with total length or weight. Because high concentrations of As were found at the edges of the Ciénega (sites 10, 14 and 15) it will be advisable to sample fish from these lagoons and test them for arsenic, because water and sediment are above the toxicity threshold for organisms.

Collection Date	**Total Length (cm)**	**Weight (g)**	**As (mg/kg dw)**
FDA[1]			86
NIWQP[2]			12
feb-10	38	1000	< DL
feb-10	36	466	< DL
feb-10	42	1000	< DL
feb-10	31	448	< DL
feb-10	32	526	< DL
feb-10	32	476	< DL
feb-10	31	522	< DL
feb-11	36	715	1.42
feb-11	37	653	< DL
feb-11	34	545	0.38
feb-11	30	398	6.26
feb-11	32	548	2.14
feb-11	43	1390	< DL

Table 3-18. Concentrations of As in fish (mg/kg dry weight) from the Ciénega de Santa Clara in 2010 and 2011.
[1]Appendix 5-FDA and EPA Safety levels in regulations and guidance 3rd edition. June 2001. Fish and fisheries products hazards and controls guidance.
[2]National Irrigation Water Quality Program. 1998c. Guidelines for interpretation of the biological effects of selected constituents in biota, water and sediment. Arsenic Information Report No. 3. BOR, USFWS, USGS, BIA. 17 pp.

iv. Lead, Cadmium and Copper

The toxicity threshold for Cu in fish tissue is 13 mg/kg, for Cd 50 mg/kg and for lead 20 mg/kg (NIWQP, 1998; Eisler, 1971; USDHHS, 2007). Action levels for human consumption are: Cd 4 mg/kg and Pb 1.7 mg/kg (FDA, 2000). All of these limits are above our detection limit (0.5 mg/kg). None of the samples (water, sediment or fish) exceeded this detection limit for any of the three metals (See Appendix X).

b) Organic compounds

Collection of water, sediment and fish samples was made in February 2010 and again in February 2011. Locations of sampling sites were the same as metals (Figure 3-1 and Table 3-1). Analysis of pesticides was performed at two certified laboratories at CIAD. All QA/QC procedures were followed and observed.

Although concentrations were orders of magnitude lower than the FDA action level (Table 3-19), detectable concentrations of organochlorine pesticides were observed in water and sediment in both 2010 and 2011 (See Appendix X). Some of these organochlorine pesticides were also detected in fish. Largemouth bass seem to accumulate lower concentrations than other species like mullet and carp, therefore we recommend sampling those species instead of largemouth bass for monitoring of pesticides in the Ciénega.

The pesticides more frequently detected in water were pp-DDT, endosulfan sulphate, heptachlor and the BHC´s. In sediment the pesticides most frequently detected were thrans-chlordane, heptachlor epoxide, pp-DDT, endosulfan sulpahate, pp-TDE, and BHC alpha (Figure 3-21). The organophosphate pesticides, pyrethroid pesticides and PCBs were under detection limits in samples of water, sediment and fish.

Note that despite the ban on the use of DDT and its relatively short persistence in that form (half-life is approximately 4-30 years), DDT was found in water at all sites sampled (including the Bypass Drain) in 2011. The DDT detected likely comes from residues in soil blown into the Bypass Drain.

Substance	FDA Action level (ppm) Edible Portion of Fish (FDA, 2000)
Aldrin and Dieldrin	0.3
Chlordane	0.3
DDT, DDE, TDE	5.0
Heptachlor and Heptachlor epoxide	0.3
Mirex	0.1

Table 3-19. Food and Drug Administration (FDA) Action level of organic substances detected in edible portion of fish (ppm).

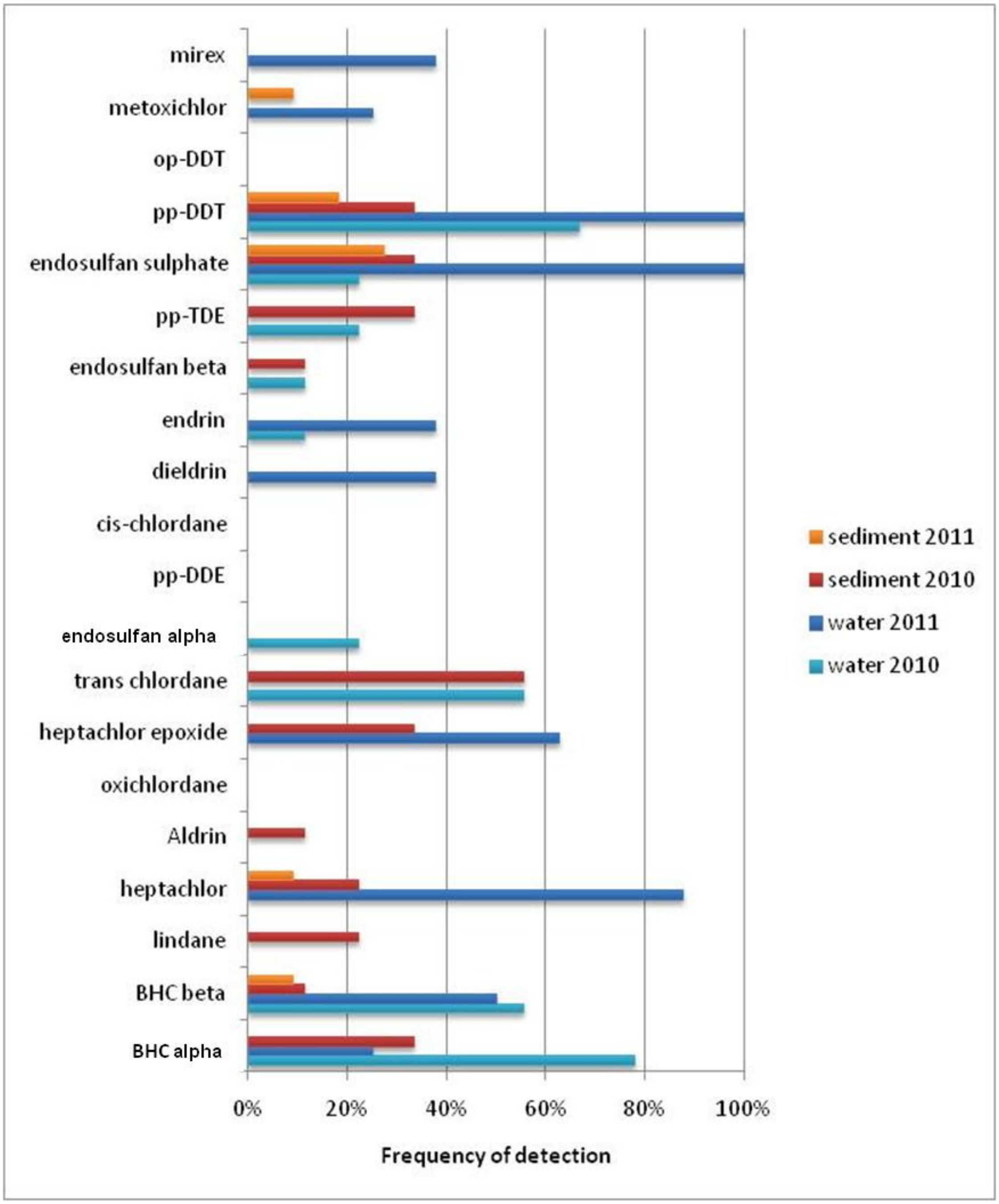


Figure 3-21. Frequency of organochlorine pesticide detection in samples of water and sediment from 2010 and 2011.

Below are three tables which provide references for organochlorine pesticides in water (Table 3-21), in sediment (Table 3-22), and concentrations of pp-DDT in water in 2010 and 2011 (Table 3-23).

Pesticide	**Acute effect[1] (µg/ml)**	**Chronic effect[1] (µg/ml)**
a-BHC	0.039	0.0022
b-BHC	0.039	0.0022
Heptachlor	0.00026	0.0000019
Aldrin	0.0015	0.000017
Heptacl epox	0.00026	0.0000019
Chlordane	0.0012	0.0000025
Endosulfan i,ii,a,b	0.00011	0.000028
ppDDE	1.05	0.105
Dieldrín	0.00024	0.000056
Endrín	0.00086	0.000036
Endosulfan sulf		0.00222
ppDDT	0.00055	0.0000005

Table 3-21. Reference table for organochlorine pesticides in water.
[1]M. F. Buchman, *NOAA Screening Quick Reference Tables*, Office of Response and Restoration Division, National Oceanic and Atmospheric Administration, Seattle, WA, 2008: Primary entry is the US Ambient Water Quality Criteria, followed by the lowest tier II SAVs or available standards or guidelines. Lowest observable effect levels (LOELs) previously published by EPA are also included since these essentially were the basis for many state standards.

Pesticide	**Probable Effect Level (PEL) (µg/g)[1]**
Heptacl epox	0.00274
ppDDE	0.00675
Endrín	0.0624
ppDDT	0.00477

Table 3-22. Reference table for organochlorine pesticides in sediment.
[1]M. F. Buchman, *NOAA Screening Quick Reference Tables*, Office of Response and Restoration Division, National Oceanic and Atmospheric Administration, Seattle, WA, 2008: MacDonald et al 2000 Arch ET&C 39(1):20-24. And Canadian Sediment Quality guidelines for the protection of aquatic life, summary tables update 2002.

Site	2010	2011
1	0.00013	0.00544
2	NS	0.00016
5	< DL	NS
6	0.00037	NS
10	NS	0.00292
12	< DL	NS
13	0.00008	NS
14	NS	0.00097
16	< DL	0.01103
23	0.00026	0.00398
Bypass	0.00006	0.00127
Riito	0.0001	0.00195

Table 3-23. Concentrations of pp-DDT in water in 2010 and 2011
NS= no sample

In 2010 concentrations of pp-DDTdid not exceed the ambient water quality criteria for acute effect in organisms, but in 2011, 6 out of 7 samples exceeded this guideline, with the highest concentration found in site 16 (northeast).

D. Evaluation of fish health

Organic and inorganic contaminants can have an effect of fish health, even if concentrations of toxicants are under thresholds or international standards. For this project we selected Largemouth bass (*Micropterus salmoides*) for health effect studies because it is a common and abundant fish in the Ciénega, it has a commercial importance (sport and subsistence fishery) and is a carnivorous fish that could be subject to higher levels of contaminants due to bioaccumulation.

A total of 97 fish were collected in three surveys in the Ciénega de Santa Clara (June 2010, September 2010 and December 2010). Weight varied from 0.07 kg to 2.56 kg, with a mean of 0.90 kg ± 0.60 kg (Figure 3-22) and total length varied from 18 to 56 cm with a mean of 37 cm ± 8 cm. This is a slow-growing species: they need more than 3 years to reach the preferential catch size of 38 cm (which was our average length). At this size the organisms have sexually matured and spawned more than once (Huskey and Turigan, 2001).

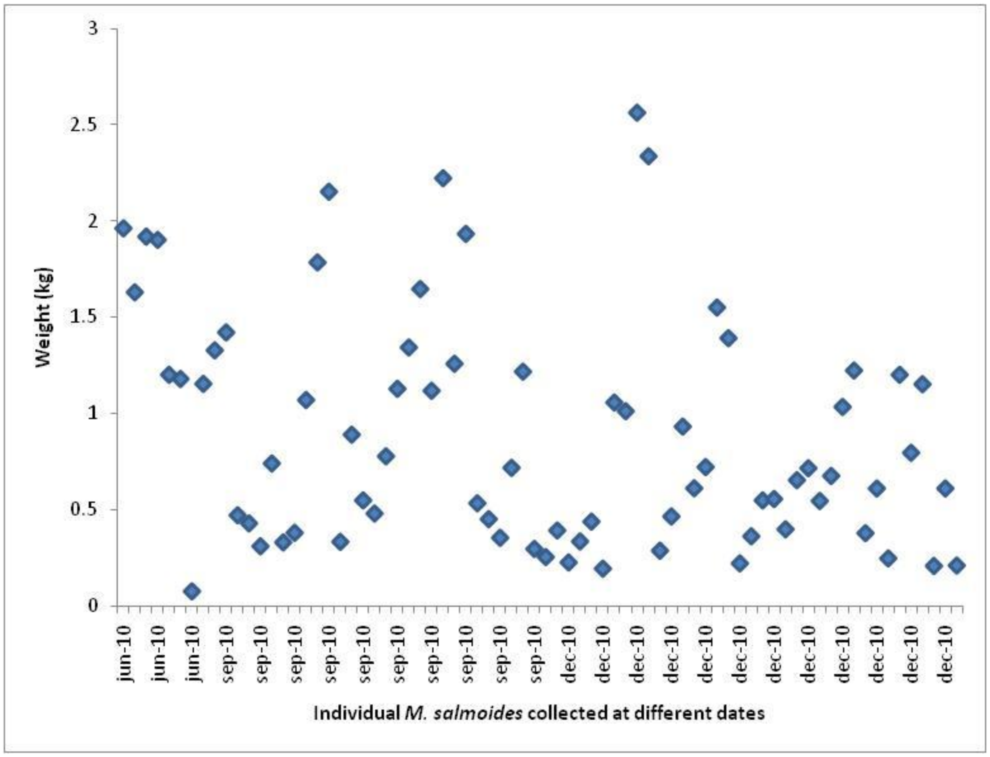


Figure 3-22. Total weight of fish collected in the Ciénega de Santa Clara in June, September and December 2010

The condition factor - the relationship between total weight and liver weight, is a simple indicator of fish health (Slooff, et al. 1983). The liver is the organ that detoxifies the organism; therefore livers with larger mass relative to total weight indicate a greater rate of detoxification due to external conditions such as presence of pollutants in water or food. Fish growth should be isometric, all organs and structures should present a direct relationship with size and/or weight. In the Ciénega de Santa Clara, total length had a linear relation with liver weight ($R^2 = 0.73$) with the equation for Liver Weight = -0.183 + 9(fish total weight) (Figure 3-23).

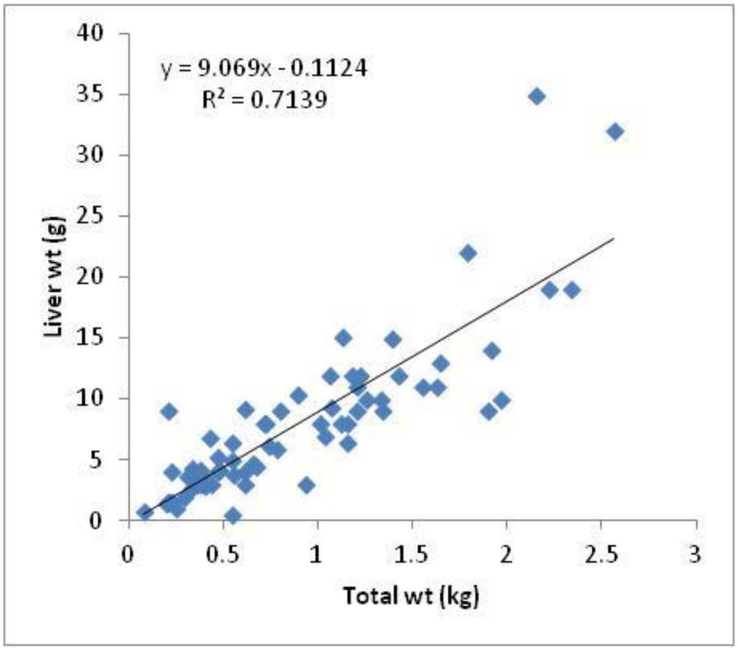


Figure 3-23. Liver weight (g) vs. total weight (kg) in largemouth bass (*M. salmoides)* from the Ciénega de Santa Clara.

The acetilcholinesterase (AChE) enzyme is responsible for the correct transmission of nervous impulse in living organisms. When there is an inhibition of this enzyme, the organisms become paralyzed or, if the effect is high enough, organisms could die. Organophosphate pesticides and mercury are neurotoxins, and in the case of pesticides they were designed to interrupt the nervous system of insects, therefore, they are highly toxic although their persistence in the environment is very low (days to weeks). Because very low concentrations of pesticides could affect the organisms, we analyzed the AChE activity in brain tissue of largemouth bass (*M. salmoides).*

Total Activity of the AChE in 23 individuals of *M. salmoides* brain varied from 3.6 to 232.3 micro mols per minute per milligram (µmol min^{-1} $mg^{-1)}$ of total protein, with a mean of 64.4 ± 57 µmol min^{-1} mg^{-1} of total protein. Higher activities were detected in smaller (probably younger) individuals, because they have a more active metabolism (Philips et al., 2002) than large (older) fish (Figure 3-24).

No inhibition of the AChE enzyme was detected in brain tissue for *M. salmoides* in any of the three surveys (June, October and December 2010). This indicates that there were no health effects of pesticides or mercury in the fish sampled.

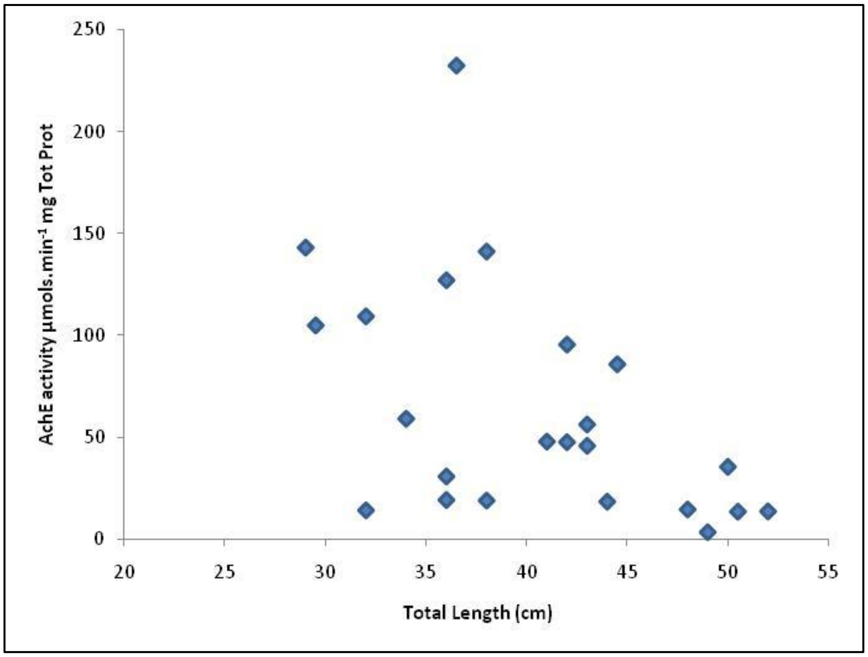


Figure. 3-24. AChE activity (µmol min^{-1} mg of total protein) vs. total length in largemouth bass (*M. salmoides*) from the Ciénega de Santa Clara collected in June, October and December 2010.

E. Nutrients and other parameters

Table 3-24 below lists Mexican and U.S. water quality standards for protection of human health and wetlands. These standards were used for the Ciénega de Santa Clara monitoring program.

Microbiological loads to the Ciénega de Santa Clara are rare. However, in December 2009 we detected a discharge at the Bypass Drain (site 8) of 14,000 MPN/100 ml of *E. coli*, (Table 3-25) which was higher than the limit set for recreational use (Table 3-24). In February 2010, this number decreased to 68 MPN/100 ml at the Bypass Drain, but at site 1, it was still high (2,000 MPN/100 ml). In April, concentrations were lower at all sites. Concentrations higher than the standards were not detected afterwards. It may be necessary to continue monitoring this parameter on a long term basis. Table 3-26 shows the total coliforms (MPN/100 ml) detected in the Ciénega between 2010 and 2011, while Table 3-27 shows the number of fecal coliforms (MPN/100 ml) detected in the Ciénega de Santa Clara in 2010 and 2011.

Parameter	Limit	Reference
Fecal coliforms (MPN/ml)	2000	NOM-001-ECOL-1996. Norma Oficial Mexicana que establece los límites máximos permisibles de contaminantes en las descargas residuales
E. coli (MPN/100 ml)	126	US EPA.2004. Water Quality Standards for Coastal and Great Lakes Recreation Waters; Final Rules, Part II. Environmental Protection Agency. 67218 Federal Register/vol. 69, No. 220/Rules and Regulations
Organic nitrogen (mg/l)	5	US EPA. 2000. Arizona water quality standards, In: Water quality standards. 40 CFR Ch. I (7-1-00 Edition).
Ammonia (mg/l)	1	US EPA. 1985. Ambient water quality criteria for Ammonia. EPA 440/5-85-001. 228 pp
Nitrates (mg/l)	7	US EPA. 2000. Arizona water quality standards, In: Water quality standards. 40 CFR Ch. I (7-1-00 Edition).
Total-Nitrogen (mg/l)	25	NOM-001-ECOL-1996. Norma Oficial Mexicana que establece los límites máximos permisibles de contaminantes en las descargas residuales
Total-Phosphorous (mg/l)	0.1	US EPA. 2000. Arizona water quality standards, In: Water quality standards. 40 CFR Ch. I (7-1-00 Edition).
Total –Phosphorous (mg/l)	10	NOM-001-ECOL-1996. Norma Oficial Mexicana que establece los límites máximos permisibles de contaminantes en las descargas residuales
Sedimentable Solids (Sólidos Sedimentables), ml/l	2	NOM-001-ECOL-1996. Norma Oficial Mexicana que establece los límites máximos permisibles de contaminantes en las descargas residuales
Total suspended solids (TSS), mg/l	60	NOM-001-ECOL-1996. Norma Oficial Mexicana que establece los límites máximos permisibles de contaminantes en las descargas residuales

Table 3-24. Mexican and U.S. water quality standards for protection of human health and wetlands.

Site	Dec-09	Feb-10	Apr-10	Jul-10	Oct-10	Jan-11	Apr-11
Limit*	126	126	126	126	126	126	126
Bypass Drain	**14,136**	68	12	60	37	25	37
Riito-Sta Clara Drain	78	21	14	9	22	13	31
1	121	**2,489**	38	33	48	26	24
5	NA	23	NA	NA	NA	NA	50
6	48	54	78	NA	NA	NA	65
9	78	21	14	9	22	13	31
12	NA	NA	0.1	13	NA	NA	NA
13	NA	24	5	49	25	7	19
16	NA	17	24	126	43	9	65
23	NA	37	59	9	19	6	12

Table 3-25. *Escherichia coli* concentrations MPN/100 ml in the Ciénega de Santa Clara. Bold numbers indicate findings above the parameter limits listed in Figure 3-19.
NA = not analyzed due to inaccessibility of the site (i.e. earthquake blocked several passages)
* USEPA.2004. Water Quality Standards for Coastal and Great Lakes Recreation Waters; Final Rules, Part II. Environmental Protection Agency. 67218 Federal Register/vol. 69, No. 220/Rules and Regulations

Site	Feb-10	Apr-11
Bypass Drain	120	23
Santa Clara-Riito Drain	11	23
1	2,400	< 3
5	11	NA
6	11	43
13	7	23
16	NA	43
21	4	7.3
23	15	9.1

Table 3-26. Total coliforms MPN/100 ml in the Ciénega de Santa Clara in 2010 and 2011
There are no legal limits for total coliforms because they include coliforms from sources other than humans, such as wildlife.
NA = not analyzed due to inaccessibility of the site (i.e. earthquake blocked several passages)

Site	Feb-10	Apr-11
Limit*	2000	2000
Bypass Drain	23	23
Santa Clara-Riito Drain	< 3	4
1	240	< 3
5	4	NA
6	4	23
13	7	23
16	NA	23
23	15	9.1

Table 3-27. Fecal coliforms MPN/100 ml in the Ciénega de Santa Clara in 2010 and 2011
NA = not analyzed due to inaccessibility of the site (i.e. earthquake blocked several passages)
*NOM-001-ECOL-1996. Norma Oficial Mexicana que establece los límites máximos permisibles de contaminantes en las descargas residuales

Nutrient concentrations in the Ciénega were monitored as organic nitrogen (Kjeldahl nitrogen), N-nitrites (NO_2-N), N-nitrates (NO_3-N), ammonia and total phosphorous (total-P) (Tables 3-28, 3-29, 3-30).

Organic nitrogen concentrations ranged from < 0.10 to 0.78 mg/l; all concentrations were under the 5 mg/l standard (Table 3-28, Table 3-29). Concentrations were higher at the Bypass Drain. Inside the wetland, concentrations decreased to less than detection limits (< 0.1 mg/l).

Site	Dec-09	Feb-10	Apr-10	Jul-10	Oct-10	Jan-11	Apr-11
Bypass Drain	0.75	< 0.1	0.7	0.24	0.89	< 0.1	0.84
Santa Clara-Riito Drain	0.08	< 0.1	0.05	< 0.1	< 0.1	< 0.1	NA
1	0.08	1.4	0.32	0.65	0.24	0.6	0.67
5	NA	0.4	NA	NA	NA	NA	0.78
6	0.33	0.5	0.6	NA	NA	NA	0.22
12	NA	NA	< 0.1	< 0.1	NA	NA	NA
13	NA	< 0.1	0.8	< 0.1	< 0.1	< 0.1	0.22
16	NA	< 0.1	0.05	0.12	< 0.1	< 0.1	0.22
21	NA	0.4	NA	NA	NA	NA	0.34
23	NA	< 0.1	0.1	< 0.1	< 0.1	0.7	NA

Table 3-28. Concentrations of organic nitrogen (Kjeldahl) in the Ciénega de Santa Clara (mg/l).
NA = not analyzed due to inaccessibility of the site (i.e. earthquake blocked several passages)

Nitrates (N-NH_4) were measured in December 2009, February 2010, March 2010, April 2010 and May 2010 (Table 3-24). Nitrites (N-NH_3) were measured at the same locations and dates as organic nitrogen, and all concentrations were under detection limits (< 1 mg/l), including ammonia (< 1mg/l). Concentrations increased in March and April at the inflows and inside the lagoons, probably due to the input of fertilizers during the growing season of crops in the region, and then decreased in May 2010. It is important to monitor nitrates in the wetland in order to identify the potential for eutrophication.

Site	Dec-09	Feb-10	Mar-10	Apr-10	May-10
Bypass Drain	5.53	7.27	**17.27**	**18.64**	2.73
Santa Clara-Riito Drain	4.81	6.14	**18.64**	**20.00**	2.27
1	4.6	< 1.0	**10.91**	**12.273**	3.41
2	4.12	NA	NA	NA	2.95
3	2.88	NA	NA	NA	2.27
4	4.17	NA	NA	NA	3.18
5	NA	4.55	**14.09**	NA	2.27
6	3.79	5.23	**25.91**	**12.50**	2.05
12	NA	NA	NA	**27.27**	1.36
13	NA	NA	**16.82**	**8.64**	2.05
16	NA	3.18	**20.91**	**17.27**	3.64
21	NA	4.32	**9.32**	NA	NA
23	NA	< 1.0	**10**	**19.55**	NA

Table 3-29. Concentrations of N-Nitrates (mg/l) in the Ciénega de Santa Clara (mg/l). Bold numbers indicate findings which were above the parameter limits listed in Figure 3-19.
NA = not analyzed due to inaccessibility of the site (i.e. earthquake blocked several passages)

Total phosphorous (total-P) was higher than the detection limit (1 mg/l) in December 2009 and in April 2010. The rest of the months were under the detection limit (< 1 mg/l) (Table 3-30). The Mexican standard for discharges into wetlands is 10 mg/l, which was met at the inflows; however a more specific regulation (US EPA. 2000. Water quality standards. 40 CFR Ch. I (7-1-00 Edition)) for streams in Arizona recommends concentrations lower than 0.1 mg/l, which was exceeded at the Bypass Drain on December 2009, April 2010 and May 2010. Inside the lagoons, concentrations decreased considerably, probably due to the uptake of nutrients by the emergent vegetation. We also recommend monitoring of total-P because it is a nutrient that could cause eutrophication.

Site	Dec-09	Feb-10	Apr-10	May-10	Jul-10	Aug-10	Apr-11
Bypass Drain	1.3	<1	1.4	0.25	<1	<1	<1.0
Santa Clara-Riito Drain	1.0	<1	<1	0.07	<1	<1	<1.0
1	1.0	<1	<1	0.07	<1	<1	<1.0
2	<1	NA	NA	0.05	NA	NA	NA
3	1.2	NA	NA	0.02	NA	NA	NA
4	1.1	NA	NA	0.04	NA	NA	NA
5	NA	<1	NA	0.01	NA	NA	<1.0
6	1.1	<1	<1	0.10	NA	NA	<1.0
12	NA	NA	<1	<0.01	<1	NA	NA
13	NA	<1	<1	0.03	<1	<1	<1.0
16	NA	<1	1.2	0.06	<1	<1	<1.0
17	NA	NA	NA	0.1	NA	NA	NA
18	NA	NA	NA	0.19	NA	NA	NA
19	NA	NA	NA	0.14	NA	NA	NA
20	NA	NA	NA	<0.01	NA	NA	NA
21	NA	<1	NA	NA	NA	NA	<1.0
22	NA	NA	NA	NA	NA	NA	NA
23	NA	<1	1.2	NA	<1	<1	<1.0

Table 3-30. Concentrations of Total-P (mg/l) in the Ciénega de Santa Clara (mg/l)
NA = not analyzed due to inaccessibility to the site (i.e. earthquake blocked several passages)

1. Turbidity

Turbidity was measured in three ways: sedimentable solids; total suspended solids (TSS); and "turbidity" in the technical sense of the extent of light penetration. All three measures of turbidty were used because all these measures are used in Mexico.

a) Sedimentable Solids

Sedimentable solids present in a water sample indicate the quantity of solids that can be settled from a specified sample volume in a determined time, and is a measure of the amount of solids that can be eliminated by primary treatment in a sewage treatment plant (method used predominantly in Mexico). Sedimentable solids were detected in water samples from the Bypass Drain in December 2009, February and March 2010, then again in December 2010, April 2011 and May 2011 (Table 3-31); none of the values exceeded the 2 ml/l recommended by the Mexican standard. Higher values were detected at site 19, which is inside the vegetation and probably had debris from the site due to collection, but otherwise the Ciénega has clear water at all points, in part due to the low solids inflow but also because the high density of vegetation traps most of the solids.

Site	Dec-09	Feb-10	Mar-10	Apr-10	May-10	Jun-10	Jul-10	Aug-10	Oct-10	Nov-10	Dec-10	Jan-11	Feb-11	Mar-11	Apr-11	May-11
By	0.5	0.4	0.4	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.2	<0.1	<0.1	<0.1	0.2	0.1
Rii	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
1	<0.1	1.1	<0.1	0.8	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	NA	NA	<0.1	<0.1
3	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
4	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	1.5	<0.1	NA	<0.1
5	NA	<0.1	<0.1	NA	<0.1	NA	NA	NA	NA	NA	NA	NA	<0.1	<0.1	0.3	0.5
6	0.2	<0.1	<0.1	<0.1	<0.1	NA	NA	NA	NA	NA	NA	NA	<0.1	<0.1	<0.1	<0.1
7	NA	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
8	0.5	0.4	0.4	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.2	<0.1	<0.1	<0.1	0.2	0.1
9	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
10	NA	NA	<0.1	1	<0.1	<0.1	NA	NA	<0.1	<0.1	0.4	0.4	<0.1	<0.1	NA	NA
11	NA	<0.1	<0.1	<0.1	<0.1	NA	<0.1	NA	<0.1	<0.1	<0.1	<0.1	0.2	0.4	NA	<0.1
12	NA	NA	<0.1	1	<0.1	<0.1	<0.1	NA	NA	NA	NA	NA	NA	NA	NA	NA
13	NA	<0.1	0.2	<0.1	<0.1	<0.1	1	0.5	<0.1	<0.1	NA	<0.1	<0.1	<0.1	<0.1	<0.1
14	NA	NA	NA	NA	<0.1	NA	NA	NA	<0.1	<0.1	NA	NA	<0.1	NA	NA	NA
15	NA	NA	NA	NA	<0.1	NA	NA	NA	<0.1	<0.1	NA	NA	<0.1	NA	NA	NA
16	NA	<0.1	<0.1	<0.1	<0.1	NA	**5**	NA	<0.1	<0.1	<0.1	<0.1	<0.1	**4**	0.8	0.3
17	NA	<0.1	<0.1	<0.1	<0.1	NA	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
18	NA	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
19	NA	1.3	<0.1	<0.1	0.8	0.7	0.6	<0.1	**8**	**2**	<0.1	<0.1	**7.5**	0.3	NA	0.7
20	NA	NA	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	**2.9**	<0.1	<0.1	<0.1	<0.1	<0.1
21	NA	<0.1	<0.1	NA	NA	NA	NA	NA	NA	NA	NA	NA	<0.1	<0.1	<0.1	<0.1
22	NA	<0.1	0.2	<0.1	0.2	NA	NA	NA	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
23	NA	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.2	<0.1	<0.1	<0.1

Table 3-31. Concentration of sedimentable solids in water samples (ml/l) (By=Bypass Drain, Rii= Riito Drain). Bold numbers indicate findings which were higher than the parameter limits listed in Figure 3-19.
NA = not analyzed due to inaccessibility to the site (i.e. earthquake blocked several passages)

b) Total Suspended Solids (TSS)

Total Suspended Solids (TSS) are all the solids that remain in a glass fiber filter, including salts and particulate matter. High concentrations of TSS can lower water quality by absorbing light. Water then become warmer and lessens the ability of the water to hold the oxygen necessary for aquatic life, photosynthesis decreases and less oxygen is produced. The combination of warmer water, less light and less oxygen makes it impossible for some forms of life to exist (Clescerl L. et al. 2006). Water with a TSS concentration less than 20 mg/l is considered clear, water with

TSS between 40 and 80 mg/l tends to appear cloudy, while concentrations more than 150 mg/l usually makes water appear dirty (Clescerl L. et al. 2006).

TSS at the Ciénega was generally low. TSS at the Bypass Drain decreased from April 2010 to March 2011. Concentrations of TSS decreased considerably from the Bypass Drain to all monitoring stations inside the Ciénega (Table 3-32).

Site	Jan -10	Feb -10	Mar -10	Apr -10	May -10	Jun -10	Jul -10	Aug -10	Oct -10	Nov -10	Dec -10	Jan -11	Feb -11	Mar -11	Apr -11	May -11
Bypass Drain	27	58	67	16	14	19	13	3	37	10	38	7	13	17	79	87
Santa Clara-Riito Drain	4	12	4	9	6	14	8	4	9	6	8	11	23	29	25	4
1	38	41	6	40	13	16	16	9	14	3	7	11	8	22	10	8
2	11	7	12	11	14	11	11	15	27	3	10	8	NA	NA	15	9
3	16.5	4	8	13	13	5	7	4	3	7	3	9	19	26	10	4
4	7	3	6	4	4	5	7	5	5	4	3	4	72	9	NA	9
5	NA	15.5	11	NA	NA	NA	NA	NA	NA	NA	NA	NA	18	17	76	97
6	NA	10	5	4	NA	NA	NA	NA	NA	NA	NA	NA	7	10	5	4
7	NA	2	18	17	3	4	8	4	2	2	6	5	11	9	5	5
10	NA	NA	58	77	47	86	NA	NA	84	130	184	166	109	68	NA	NA
11	NA	7	6	18	69		46	NA	11	33	59	33	111	105	NA	61
12	NA	NA	97	64	51	28	8	NA	NA	NA	NA	NA	NA	NA	NA	NA
13	6	4	88	6	60	30	73	183	17	10	NA	6	56	64	8	22
14	NA	NA	NA	NA	NA	NA	NA	NA	9	2	NA	NA	61	NA	NA	NA
15	NA	NA	NA	NA	NA	NA	NA	NA	18	12	NA	NA	36	NA	NA	NA
16	3	9	2	12	5	NA	36	NA	3	3	3	8	6	361	45	12
17	6	4	5	32	11	NA	16	7	10	8	6	9	10	21	7	8
18	6	4	5	11	3	11	13	5	3	3	9	10	8	9	4	2
19	12	26	2	6	21	33	14	3	151	32	55	4	92	26	NA	15
20	8	NA	9	26	16	12	12	1	8	6	10	10	8	19	12	14
21	NA	38.5	19	NA	NA	NA	NA	NA	NA	NA	NA	NA	23	23	35	3
22	27	31	38	13	118	NA	NA	NA	1	2	11	17	4	42	7	33
23	NA	11	4	6	4	5	5	1	2	10	3	9	48	2	3	5

Table 3-32. Total Suspended Solids (TSS) (mg/l) in water samples from the Ciénega de Santa Clara.

c) "Turbidity"

Turbidity is also a measurement of water quality. Material suspended in water decreases the passage of light through the water. Suspended materials include soil particles, algae, plankton, microbes, and other substances. These particles are typically in the size range of 0.004 mm to 1 mm. Turbidity at the Bypass Drain was different with respect to Total Suspended Solids. There was no significant decrease during the YDP pilot operation. Also there were two peaks in December 2009 and on May 2010 (Figure 3-25), and inside the wetland variation was lower although a peak was detected in May 2010 (Figure 3-26). Total Suspended Solids (TSS) was also monitored in the Ciénega (Figures 3-27 and 3-28).

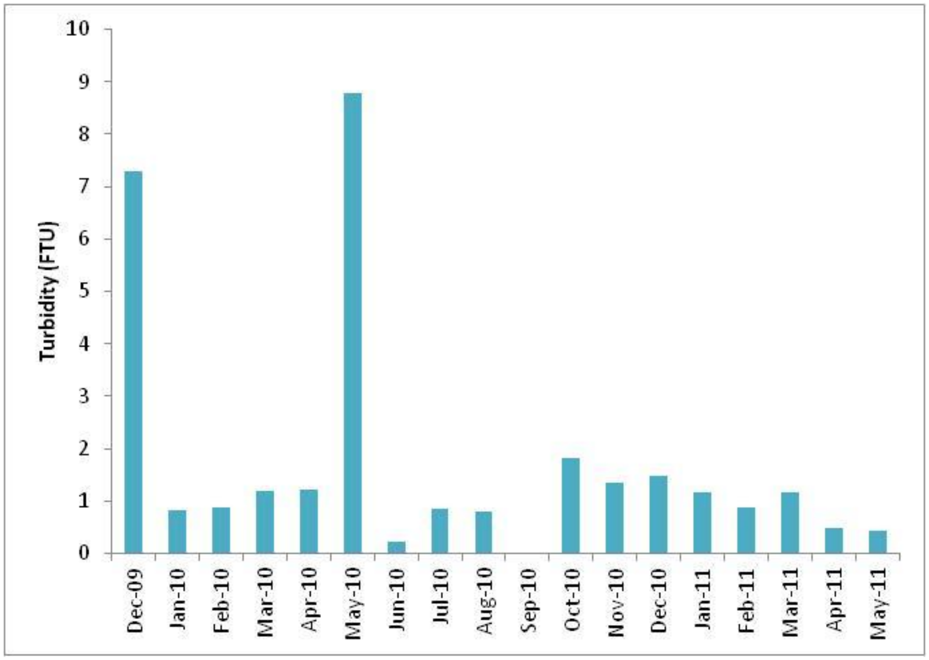


Figure 3-25. Formazin Turbidity Unit (FTU) at the Bypass Drain during the monitoring period

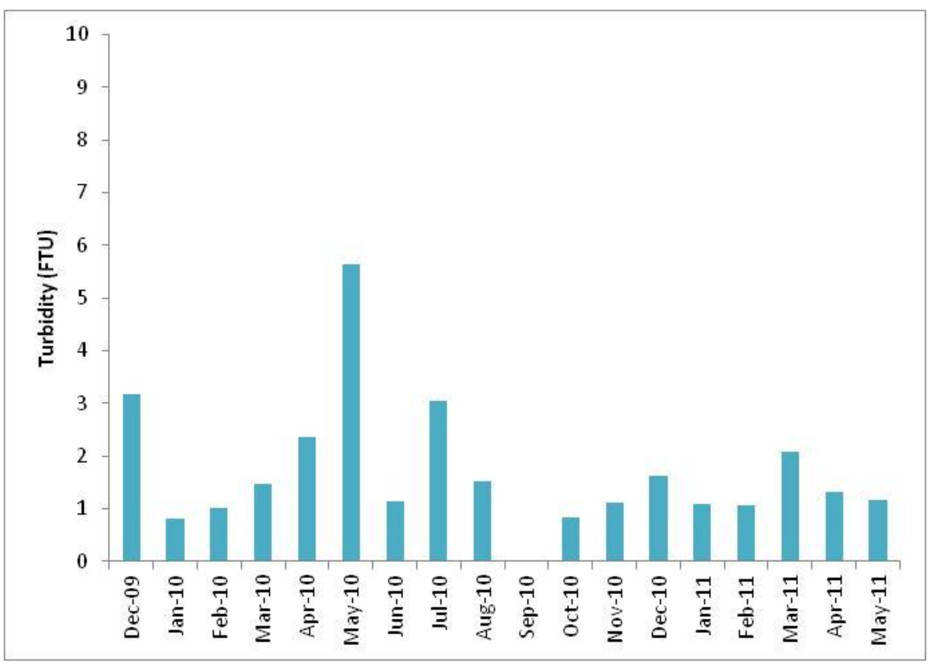


Figure 3-26. Turbidity (FTU) inside the vegetated portion of the Ciénega de Santa Clara

Site	Dec -09	Jan -10	Feb -10	Mar -10	Apr -10	Jun -10	Jul -10	Aug -10	Oct -10	Nov -10	Dec -10	Jan -11	Feb -11	Mar -11	Apr -11	May -11
Bypass Drain	7.3	0.8	0.9	1.2	1.2	0.2	0.8	0.8	1.8	1.3	1.5	1.2	0.9	1.2	0.5	0.4
Santa Clara-Riito Drain	4.0	1.1	1.1	0.8	2.3	0.6	1.4	1.9	1.3	1.4	1.9	1.8	1.7	1.9	0.7	1.2
1	1.4	0.5	1.0	1.2	2.6	2.4	5.7	2.3	1.4	1.3	2.4	1.3	0.8	2.1	1.0	1.3
2	3.5	1.2	1.1	3.4	2.9	2.4	2.9	2.3	0.9	1.4	2.2	1.4	NA	NA	1.4	1.6
3	4.2	1.8	1.5	2.6	3.5	0.9	2.0	1.0	0.9	1.4	1.3	1.3	1.4	2.8	2.2	1.5
4	3.6	0.6	0.7	0.7	2.0	0.7	2.6	2.8	1.1	0.8	1.3	0.6	0.8	1.8		0.9
5	NA	NA	6.1	1.1	NA	NA	NA	NA	NA	NA	NA	NA	3.3	4.6	1.3	1.2
6	5.3	NA	5.5	0.7	1.0	NA	NA	NA	NA	NA	NA	NA	0.8	1.5	2.1	0.7
7	NA	NA	2.3	2.0	4.4	0.4	3.3	2.0	1.1	0.6	1.3	1.5	2.0	1.5	1.0	0.7
10	NA	NA	NA	4.2	20.3	0.6	NA	NA	1.3	7.5	3.2	6.5	8.9	5.2	NA	NA
11	NA	NA	3.1	1.4	5.5	NA	14	NA	0.8	2.8	2.6	7.6	5.0	24.4	NA	2.7
12	NA	NA	NA	9.6	26.4	2.5	4.8	NA	NA	NA	NA	NA	NA	NA	NA	NA
13	NA	1.8	0.9	11.2	2.8	1.2	13	1.7	1.3	0.9	NA	2.1	4.6	4.8	1.3	2.6
14	NA	NA	NA	NA	NA	NA	NA	NA	1.1	0.5	NA	NA	1.4	NA	NA	NA
15	NA	NA	NA	NA	NA	NA	NA	NA	1.3	1.1	NA	NA	1.8	NA	NA	NA
16	NA	0.9	1.2	1.1	1.9	NA	69	NA	1.1	0.7	1.2	2.4	1.0	1.4	0.7	0.9
17	NA	0.8	0.8	1.5	4.3	NA	3.7	1.4	1.0	1.5	2.1	1.5	1.6	1.6	0.6	0.7
18	NA	0.9	1.0	0.6	0.8	0.5	4.7	1.3	0.7	0.8	2.0	1.1	1.2	2.1	0.9	0.9
19	NA	0.9	0.8	0.5	1.9	0.7	0.8	0.3	0.4	0.7	0.4	0.6	0.6	1.5	NA	0.8
20	NA	0.6	NA	1.3	3.0	0.4	2.7	0.7	0.7	1.3	1.9	1.4	1.6	2.3	1.2	1.2
21	NA	NA	15.7	0.1	NA	NA	NA	NA	NA	NA	NA	NA	3.1	5.9	0.8	0.5
22	NA	1.8	2.4	3.3	5.2	NA	NA	NA	0.4	0.9	2.0	1.3	0.6	2.8	0.9	0.7
23	NA	NA	1.2	0.4	1.5	0.9	1.2	0.7	0.6	0.9	0.8	0.7	0.3	0.5	1.0	0.9

Table 3-33. Turbidity (FTU) at the Ciénega de Santa Clara.

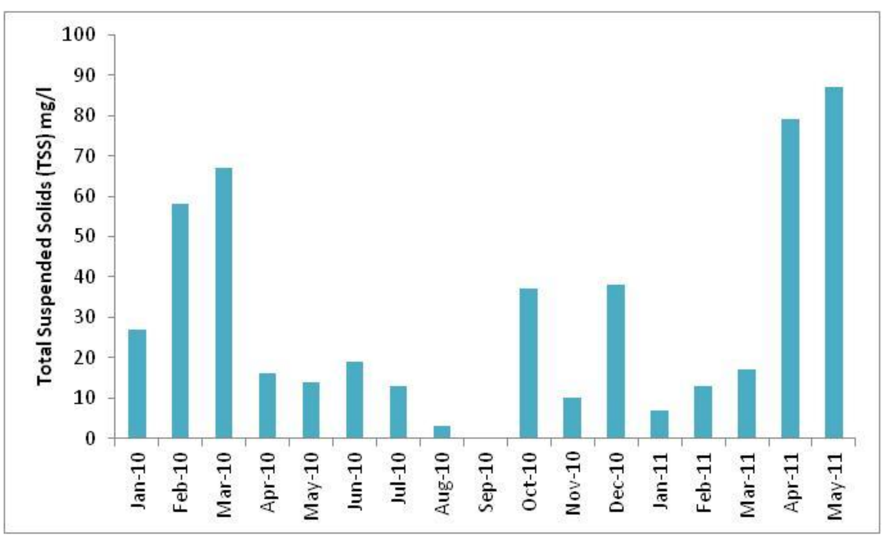


Fig. 3-27. TSS (mg/l) at the Bypass Drain during the monitoring period.

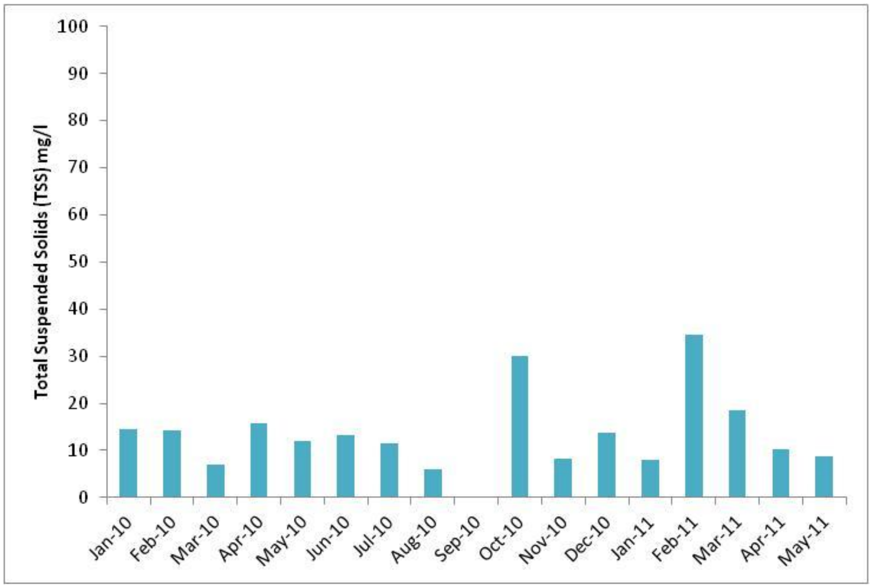


Figure 3-28. TSS (mg/l) in the vegetated portion of the Ciénega.

Other parameters such as sulphates, total chlorine, calcium and hardness were also monitored. No clear change in the concentrations of these parameters was observed at the Bypass Drain or inside the wetland during the period of the YDP operation (Tables 3-34 through 3-37).

Site	Feb-10	Apr-10	Jul-10	Oct-10	Jan-11	Apr-11
Bypass Drain	930	840	1190	970	1380	970
Santa Clara-Riito Drain	890	730	930	980	1020	770
1	1050	960	1460	930	1340	890
5	880	NA	NA	NA	NA	940
6	950	850	NA	NA	NA	990
12	NA	1300	3920	NA	NA	NA
13	1020	1030	1830	1530	1380	1630
16	870	810	850	1060	740	1060
21	960	NA	NA	NA	NA	1000
23	1250	1120	1770	1370	1280	1170

Table 3-34. Concentration of sulphate (mg/l) in water at the Ciénega de Santa Clara.

Site	Feb-10	Apr-10	Jul-10	Oct-10	Jan-11	Apr-11
Bypass Drain	0.6	< 0.1	1.1	0.2	0.77	0.2
Santa Clara-Riito Drain	0.5	< 0.1	< 0.1	< 0.1	0.19	< 0.1
1	< 0.1	< 0.1	0.54	< 0.1	< 0.1	0.14
5	< 0.1	NA	NA	NA	NA	< 0.1
6	< 0.1	< 0.1	NA	NA	NA	0.14
12	NA	< 0.1	< 0.1	NA	NA	NA
13	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
16	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
21	< 0.1	NA	NA	NA	NA	< 0.1
23	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1

Table 3-35. Concentration of Total Chlorine (mg/l) in water at the Ciénega de Santa Clara.

Site	Feb-10	Apr-10	Jul-10	Oct-10	Jan-11	Apr-11
Bypass Drain	162.7	142	170	169	219	312
Santa Clara-Riito Drain	178.6	190	170	190	177	142
1	162.7	149	174	165	202	154
5	162.7	NA	NA	NA	NA	170
6	166.7	138	NA	NA	NA	158
8	162.7	142	170	169	219	312
9	178.6	190	170	190	177	142
12	NA	190	413	NA	NA	NA
13	182.5	198	259	244	206	231
16	186.5	182	239	194	168	202
21	166.7	NA	NA	NA	NA	166
23	186.5	170	198	219	202	178

Table 3-36. Concentration of calcium (mg/l) in water at the Ciénega de Santa Clara.

Site	Feb-10	Apr-10	Jul-10	Oct-10	Jan-11	Apr-11
Bypass Drain	770	697	788	704	977	687
Santa Clara-Riito Drain	780	828	717	798	746	556
1	770	707	838	714	924	677
5	790	NA	NA	NA	NA	758
6	780	737	NA	NA	NA	737
12	NA	990	2424	NA	NA	NA
13	928	990	1414	1134	1050	1233
16	810	789	939	198	588	848
21	790	NA	NA	NA	NA	758
22	NA	NA	NA	NA	NA	NA
23	1008	889	1111	1050	882	899

Table 3-37. Hardness (mg/l) of water at the Ciénega de Santa Clara.

F. Summary

TDS values varied at several sites during the monitoring period. TDS was generally higher in the Santa Clara-Riito drain than in the Bypass Drain. Within the Ciénega, the most common pattern was an increase in the spring and summer of 2010. Spring and summer increases of these magnitudes were not observed at the same sites in spring and summer periods dating back to summer 2006. This pattern occurred both at interior and edge sites. The increases were roughly coincident with the operation of the YDP at times when little or no arranged water was delivered to the Bypass Drain.

Water temperatures increased during summer and dissolved oxygen deceased. pH did not vary with seasons.

Selenium values in water at some localities exceeded chronic (6 localities out of 10) or acute (3 out of 10) thresholds in February 2010. Selenium values in water at seven localities (out of 10) exceeded the chronic threshold but none exceeded the acute threshold in February 2011. Selenium concentrations in edible tissue of largemouth bass were all below the 4 mg/kg toxicity threshold.

Mercury concentrations in water were all below the toxicity threshold in 2010 and 2011. Mercury concentrations in sediment exceeded the recommended threshold for protection of California Clapper Rails (there is no threshold established for the Yuma Clapper Rail, a closely related subspecies) in 3 out of 10 sites in 2011 and in all ten sites in 2011. Mercury concentrations in largemouth bass tissue were below the 1 mg/kg international standard for fish consumption.

Arsenic concentrations in water did not exceed the toxicity threshold at any of the ten sites in February 2010 but exceeded them at five of the ten sites in February 2011. Arsenic in sediment was below the toxicity threshold at all ten sites in February 2010 but exceeded them at two out of ten sites in 2011. Concentrations in largemouth bass tissue were under the toxicity threshold.

Lead, cadmium and copper were under detection limits in water, sediment and largemouth bass tissue at all sites in both February 2010 and February 2011.

The pesticides most frequently detected in water were pp-DDT, endosulfan sulphate, heptachlor and the BHC´s and in sediment they were thrans-chlordane, heptachlor epoxide, pp-DDT, endosulfan sulpahate, pp-TDE, and BHC alpha. The organophosphate pesticides, pyrethroid pesticides and PCBs were under detection limits in samples of water, sediment and fish. No organochlorine compounds were detected in edible tissue of largemouth bass, although they were detected in other species at low concentrations in 2010.

No inhibition of the AChE enzyme was detected in brain tissue for largemouth bass (*M. salmoides*) in any of the three surveys (June, October and December 2010). This indicates that there were no health effects of pesticides or mercury on the fish sampled.

In December 2009 *E. coli* was detected in concentrations higher than the U.S. EPA standard for recreational use. No other peak was detected afterwards.

Nutrient concentrations were higher at the Bypass Drain and decreased considerably inside the wetland. No changes were detected during the YDP trial operation.

Water inside the Ciénega is considered clear (< 20 mg/kg of Total Suspended Solids - TSS) although inflow concentrations of TSS are considered cloudy. TSS decreased considerably during the YDP trial operation at the Bypass Drain.

Sulphates, total chlorine, calcium and hardness did not show a change during the operation of the YDP at the Bypass Drain or inside the wetland.

Chapter IV: Vegetation

Vegetated and open water areas are the most important functional components of marsh wetlands. The coverage and distribution of these areas are sensitive to inflow volumes as well as water quality parameters such as salinity. Vegetation and open water serve as habitat for biological resources and plants are key indicators of wetland water quality. Changes in the extent and structure (patchiness) of vegetated and open water areas affect the distribution and abundance of wildlife species. For these reasons it is very important to properly monitor these features in the Ciénega de Santa Clara.

The main objective for this project was to develop a land cover map for each season (four maps) during the pilot run of the YDP. A second objective was to find the most efficient, objective, and repeatable methodology of producing an accurate land cover map of the Ciénega de Santa Clara area, for landscape monitoring purposes. To accomplish these objectives we used remote sensing and field survey techniques.

A. Types of Satellite Images

We acquired two types of satellite images. We first acquired the QuickBird image, which was the one with the best spatial resolution available at the beginning of the project. This image has a panchromatic band with a resolution of 0.60 meters and a 4-band multispectral with a resolution of 2.4 meters. In early 2010 the WorldView2 (WV2) image became available, with a panchromatic band of 0.5 meters and a 8-band multispectral image with 2.0 meters resolution. We decided to acquire the WV2 image to see if the improved spatial and spectral resolution would be better for our purposes. Table 4-1 shows the satellite images used in this analysis. A total of nine images were available for this study. Four images, those prior to the operation of the YDP pilot run, were available through the Research Coordination Network-Colorado River Delta of the University of Arizona, and five new images were acquired for this study. It was important to have images collected prior to May 2010 (the beginning of the YDP pilot run) to be able to compare seasonal patterns not only between seasons during the pilot run operation, but also between years, when the YDP was not in operation.

Type of Image	Collection date
Quick Bird	8 September 2008
Quick Bird	12 February 2009
Quick Bird	25 April 2009
Quick Bird	19 August 2009
Quick Bird	16 January 2010
World View 2	7 April 2010
World View 2	July 2010
World View 2	April 2011
Quick Bird	7 October 2011

Table 4-1. Satellite images available for this study

B. Land Cover Classification Techniques

We used two different classification techniques to develop the land cover maps for the Ciénega. One research team developed land cover maps using a non-supervised classification technique. Independently, a second research team used a supervised classification technique for developing these maps. Both research teams are from the University of Arizona; the Department of Soil, Water and Environmental Science developed the unsupervised classification, and the Arizona Remote Sensing Center developed the supervised classification. The overall results from each classification technique are similar as they both indicate that the vegetated area of the Ciénega changes as it responds to hydrological and weather changes, as well as other events, such as fire. Overall, both classification techniques show that the vegetated portion of the Ciénega before and after the operation of YDP remained stable, but the intensity of greenness of vegetation showed changes. These changes in the intensity of the greenness of vegetation are also evident in images taken in 2008 and 2009, prior to the operation of the YDP. Overall, results indicate that the Ciénega is a resilient ecosystem to short-term changes in the hydrological conditions. The next sections of this report present the details of these results for each classification technique.

1. Unsupervised Classification

High-resolution QuickBird and WorldView-2 images were analyzed to detect seasonal and longer-term changes in the vegetation of Ciénega de Santa Clara. We analyzed winter, spring and summer images for 2008-2011. Red and near-infrared (NIR) bands were converted to Normalized Difference Vegetation Index (NDVI) values and an unsupervised classification program was used to separate values into ranges representing water, bare soil or dormant cattail (*Typha domingensis*) and four vegetation classes corresponding to different foliage densities. Foliage densities ranged from low to highest, depending on NDVI values.

Interpretation of the classified images showed that the overall vegetated footprint of the Ciénega de Santa Clara was stable over the study period, but that changes in vegetation density occurred. In September 2008, the western arm of the Ciénega had low vegetation density. That portion re-greened in the summers of 2009 and 2010, following dredging work by Mexico's National Water Commission (CONAGUA). Winter and spring images for 2009 and 2010 showed areas of dormant *Typha domengensis*, the dominant vegetation, and patches of common reed *Phragmites australis*, made evident because common reed is green all year in the Ciénega. The July 2010 image showed a marked reduction in the highest-density vegetation class relative to previous summer images. The decrease in NDVI during this time period was within the normal range of year to year variability in vegetation density in this wetland. A fire burned most of the dry *Typha* in March 2011, but regrowth was vigorous, as seen in April and October 2011 images.

a) Rationale

We developed a classification protocol that can be used for measuring seasonal and longer-term vegetation changes in the Ciénega de Santa Clara. This protocol was designed to detect any changes in surface vegetated area, amount of bare soil, water, and vegetation intensity. The protocol is semi-quantitative in nature, and can be combined with other remote sensing and ground-based observations to accurately quantify changes.

Preliminary analyses showed that 4 bands on QuickBird images and WorldView2 (Blue, Green, Red, NIR) can be used in a number of combinations in unsupervised or supervised classification programs to depict the major land cover types in the Ciénega de Santa Clara: wet soil, dry soil, water, and different intensities of vegetation on any image. However, the classes on one image cannot necessarily be transferred to the same land cover classes across different images, and vegetated areas are especially variable among scenes, due to differences in spectral properties of vegetation in winter versus summer and in vegetation vigor over different years. There was no static band combination that represented particular species such as cattail (*Typha*) or common reed (*Phragmites*) because their spectral properties changed with seasons and years.

To surmount this problem, we used the Red and NIR bands to calculate Normalized Difference Vegetation Index (NDVI) values:

$$NDVI = (NIR - Red)/(NIR + Red) \quad (1)$$

NDVI reduces the image to a single layer with NDVI values from -1.0 to +1.0, with water having strongly negative values, soils slightly negative to slightly positive, and vegetation having positive values. NDVI of vegetation is strongly sensitive to chlorophyll absorption of Red and scattering and reflection of NIR by cell walls and stacked layers of cells in leaves, and provides a measure of canopy "greenness" at the time of measurement (Glenn et al., 2008).

NDVI and other vegetation indices have been highly successful in assessing vegetation condition, foliage, cover, phenology, and processes such as evapotranspiration (ET) and primary productivity, related to the fraction of photosynthetically active radiation absorbed by a canopy (Glenn et al., 2007; Kerr and Ostrovsky, 2003; Pettorelli et al., 2005). Vegetation indices are robust satellite data products computed the same way across all pixels in time and space, regardless of surface conditions. As ratios, they can be easily cross-calibrated across sensor systems, ensuring continuity of data sets for long-term monitoring of ecosystems by different satellites and sensor systems (Baldi et al., 2008; Verbesselt et al., 2010). Hence we used NDVI as a first step in the classification protocol for QuickBird and WorldView 2 images, to produce standardized products that can be easily compared.

Nagler et al. (2009) developed empirical methods to interconvert vegetation index values among different satellite systems and over different time periods in the riparian and wetland areas of the Colorado River Delta. This biome allows some simplification of the normal processing procedures for imagery used in change detection (Song et al., 2003). For example, the flat terrain means that orthorectification (correction for topography) of images is not necessary. The generally clear skies mean that haze and cloud and aerosol corrections are not necessary. Furthermore, reflectance and Digital Number (DN) NDVI values can be interconverted using a simple linear regression based on common features on images, without the need to calculate absolute reflectance values for Red and NIR bands separately. We used the experience gained in those studies to process and classify the Ciénega QuickBird images, using both unsupervised and supervised classification programs in ERDAS Imagine (Atlanta, Georgia).

b) Procedure

We used QuickBird images acquired September 2008; February 2009; April 2009; August 2009; January 2010; and October 2011; and WorldView2 images from April 2010; July 2010; and April 2011. We used images from several years preceding the YDP pilot operation in order to estimate the seasonal and year-to year variability in the system in the absence of YDP operations and arranged water activities. Both QuickBird and WorldView2 satellites are owned by Digital Globe, Inc., and sensor systems are inter-calibrated so satellite data can be used interchangeably. The radiometric corrections applied to these products include relative radiometric response between detectors, non-responsive detector fill, and a conversion for absolute radiometry. The sensor corrections account for internal detector geometry, optical distortion, scan distortion, any line-rate variations, and mis-registration of the multi-spectral bands. Hence, digital number (DN) values are accurately related to at-satellite reflectance values, but do not account for effects of atmospheric conditions on band values. In the absence of atmospheric data, bands can be inter-calibrated among images using pseudoinvariant objects on images, such as clear deep water, bright sand, rock or dense vegetation (Song et al., 2003). In the present study, minimum (water), mean, and maximum (dense vegetation) NDVI values were similar for spring and summer images, with standard errors less than 5% for minimum and maximum values among images (Figure 4-1). Hence, further corrections were not necessary.

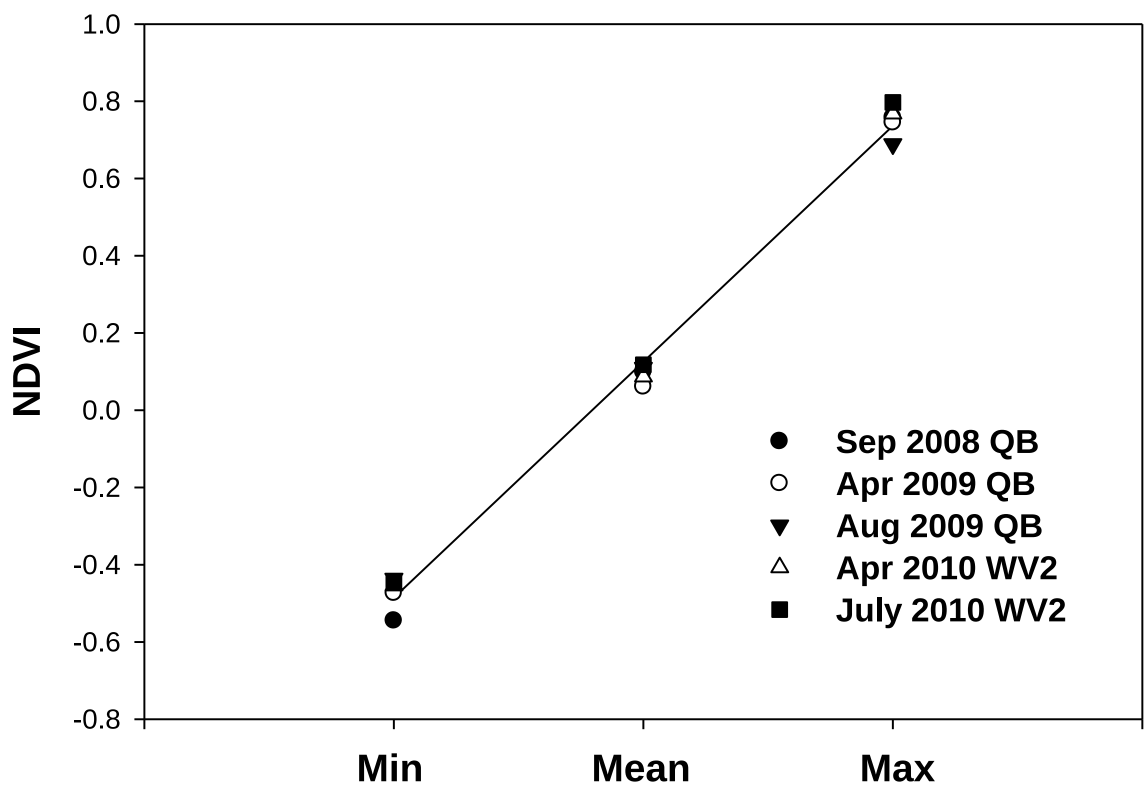


Figure 4-1. Stability of NDVI values among QuickBird (QB) and WorldView2 (WV2) images used in the Ciénega change detection analyses. Values are minimum, mean and maximum relative values for all pixels on each image.

The classification procedure we developed was based on consultations with John Pollard and Jeff Dooley, remote sensing specialists at ERDAS Imagine, via their support line. We first converted pixels on all four QuickBird images to NDVI values using the spectral enhancement tool in ERDAS. We tried both supervised and unsupervised classification procedures, using from 6 to 30 subclasses per image. We finally used the unsupervised classification program to generate classified images, dividing each image into 12 NDVI subclasses. To get the maximum separation between classes, it was necessary to change the convergence factor from the preset 0.95 to 0.98. The classification program required about 20 iterations to achieve this convergence factor.

The unsupervised program uses a nearest-neighbor analysis to bin the pixels into a user-specified number of subclasses, grouping pixels into natural clusters. This was preferred over the supervised classification, which requires either use of a common signature file across images, or sampling within known cover types on each new image. It was difficult to sample enough vegetation pixels to assign them to discrete classes, whereas the unsupervised procedure does an analysis of variance of all pixels then determines the most parsimonious distribution of pixels within classes. Furthermore, using a common signature file across images can result in misclassifications if the NDVI ranges of images differ greatly (Jeff Dooley, private communication). A signature file produced from the August 2009 image did not adequately separate the different land cover classes on the other images.

The 12 subclasses defined on each image were assigned to land cover classes defined by NDVI values. The NDVI ranges were determined by comparison of the classified images with NDVI images and with the original panchromatic ("normal" color) images. Using tiled viewers and locked images, 60-100 pixels per image were sampled in areas of water, soil, and vegetation. NDVI values were sampled within each subclass. Based on NDVI values and visual inspection of the panchromatic images, of the original twelve subclasses, two to four corresponded to water (depending on image); two or three corresponded to soil or dry or dormant *Typha*; and five to eight corresponded to different intensities of green vegetation. Based on these results, we combined subclasses to produce six classes corresponding to the following: water; soil or dry *Typha* (when dormant); low-density vegetation; medium density vegetation; high density vegetation; and highest intensity vegetation. The NDVI ranges that define these classes across images are in Figure 4-2. There was minimal overlap between soil, water and vegetation NDVI values. On the other hand, the different subclasses of water and soil were not consistent among images, though they seemed to be related to depth of water in the water subclasses, and to color and wetness of soils.

Table 4-2 displays the number of hectares in each class on each image. Figures 4-3 to 4-11 display the classified images for each date. Note that the green areas on the February and April images appear to represent *Phragmites australis*, which is green in winter whereas *Typha* is dormant (Figure 4-12). Note also that dormant *Typha* falls into the soil category in some winter scenes due to overlapping NDVI values. Only summer images should be used to compare vegetation vigor over different years, but winter images are useful in determining the distribution of *Phragmites* in the marsh.

Class	Sept 2008	Feb 2009	April 2009	Aug 2009	Jan 2010	April 2010	July 2010	April 2011	Oct 2011
Water	1007	958	869	543	759	569	465	478	588
Soil/Dry Veg	1736	2249	1581	1509	1483	474	1682	1087	1228
Brown-yellow-vegetation	1886	3027	3786	1335	3991	2569	1442	1952	940
Brown-green vegetation	726	313	257	1311	250	1949	1535	1380	836
Green vegetation	779	92	0	1421	0	820	1261	1296	2535
Greenest vegetation	406	0	45	419	50	154	150	337	407
Total vegetated area	3,797	3,432	4,088	4,486	4,241	5,492	4,388	4,965	4,718
Total area	6540	6639	6538	6538	6533	6535	6534	6530	6534

Table 4-2. Number of hectares in each cover class in QuickBird or World View2 images of Ciénega de Santa Clara. Classes of vegetation refer to intensity of greenness of the vegetation. Note: In the summer, the "soil/dry veg" class is predominantly soil, because the vegetation is green at that time. They are labeled "soil/dry veg" for other months as the NDVI values for dormant veg and soil overlap.

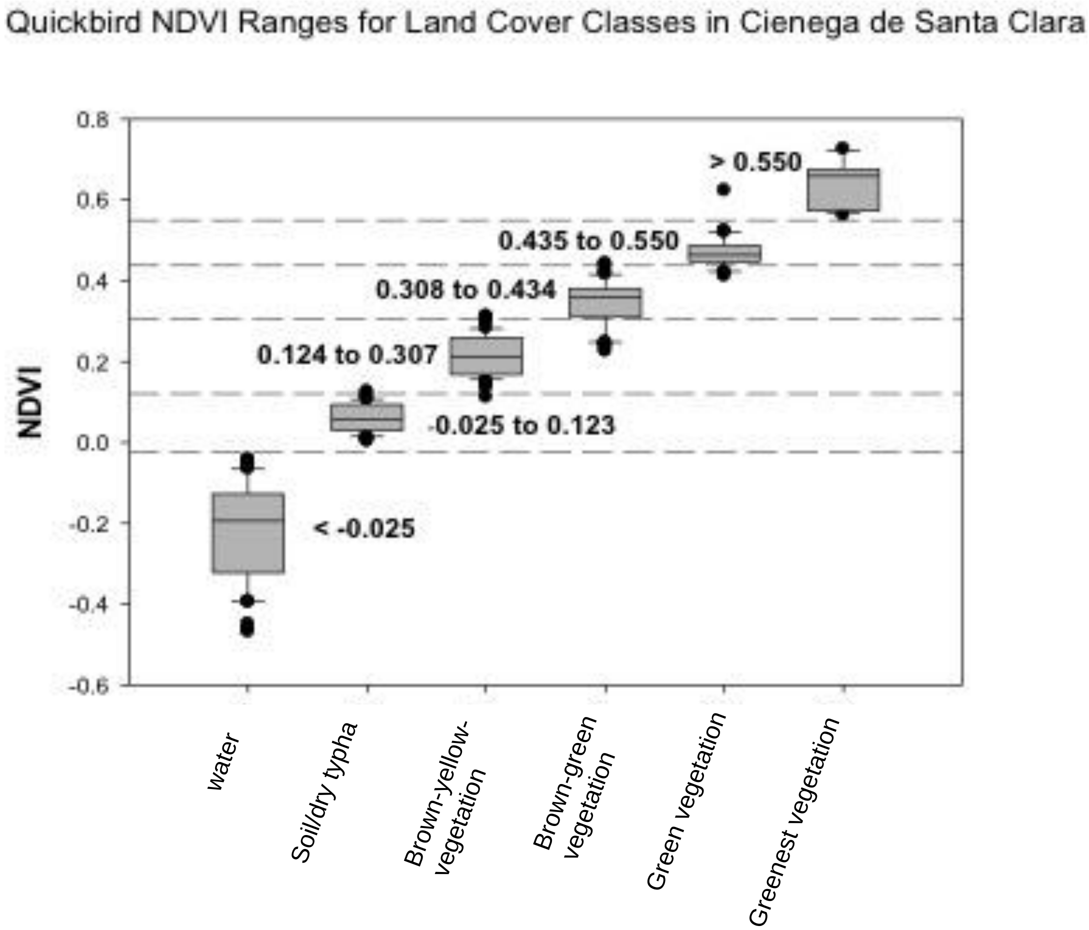


Figure 4-2. The August 2009 QuickBird image was converted to an NDVI layer using the Red and NIR bands. Then an unsupervised classification program was used to divide the pixels into 12 subclasses using nearest-neighbor analysis. Six final classes were identified by comparing NDVI values across images. Box plots show the median, 25% quartiles for each class, and a description of what each class represents. Each box represents 60-100 pixels.

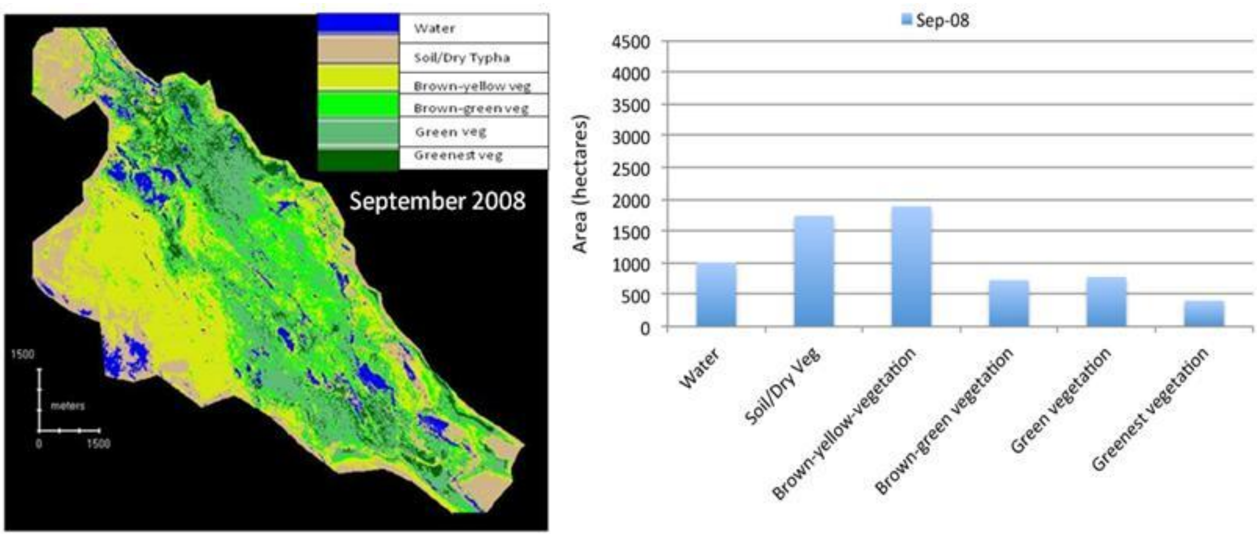


Figure 4-3. Ciénega classified image and histogram, September 2008. The Soil/Dry *Typha* class was nearly all soil in this September scene.

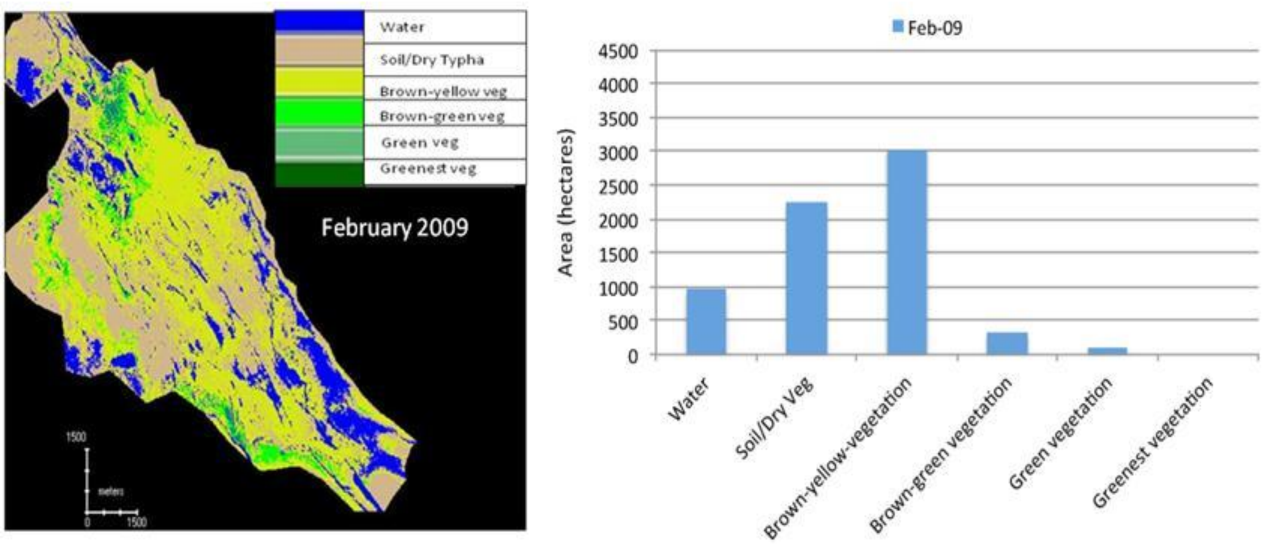


Figure 4-4. Ciénega classified image and histogram, February 2009. The Soil/Dry *Typha* class was a mix of bare soil on the periphery and dormant *Typha* inside the Ciénega in this winter scene.

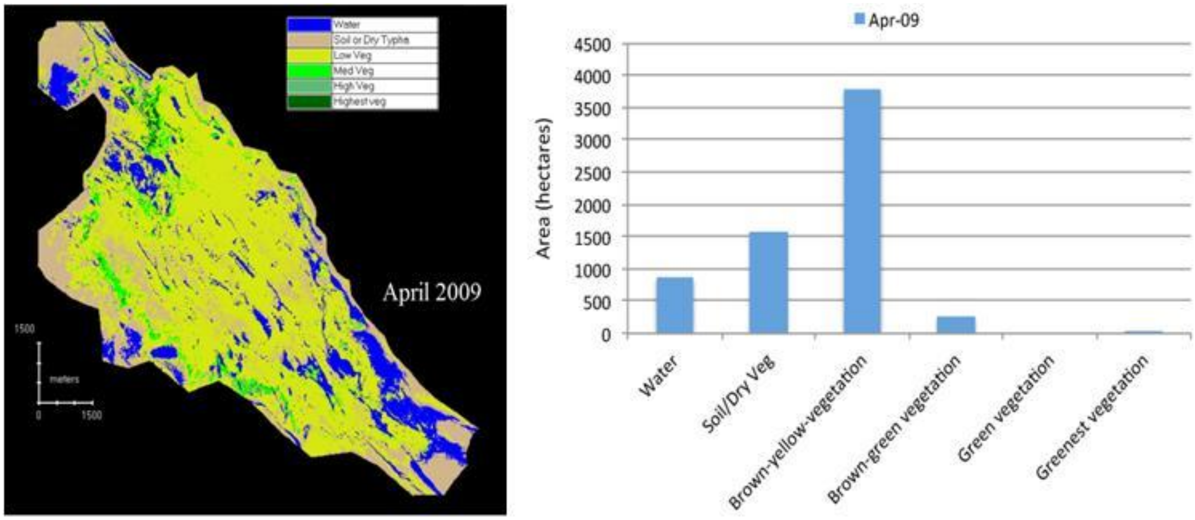


Figure 4-5. Ciénega classified image and histogram, April 2009. The Soil/Dry *Typha* class was a mix of soil on the periphery and dormant *Typha* in this spring scene.

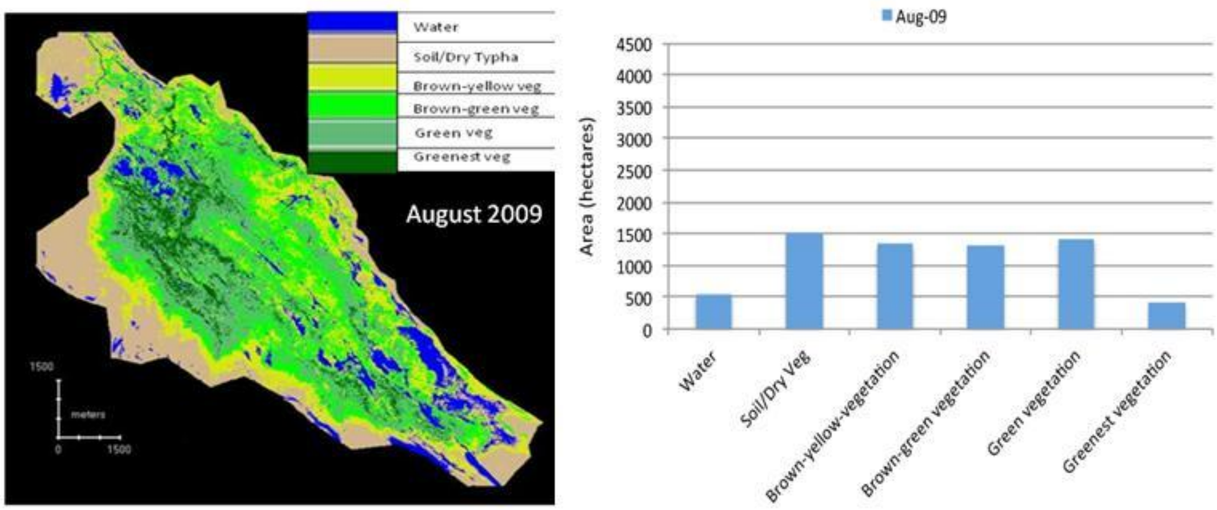


Figure 4-6. Ciénega classified image and histogram, August 2009. The Soil/Dry *Typha* class was nearly all bare soil in this summer scene.

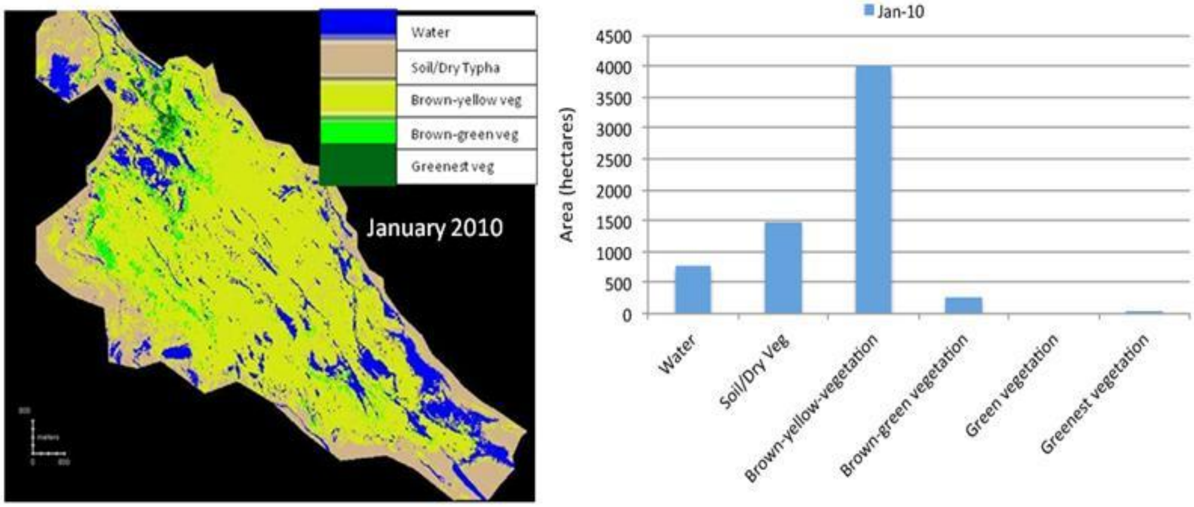


Figure 4-7. Ciénega classified image and histogram, January 2010. The Soil/Dry *Typha* class was nearly all bare soil in this winter scene.

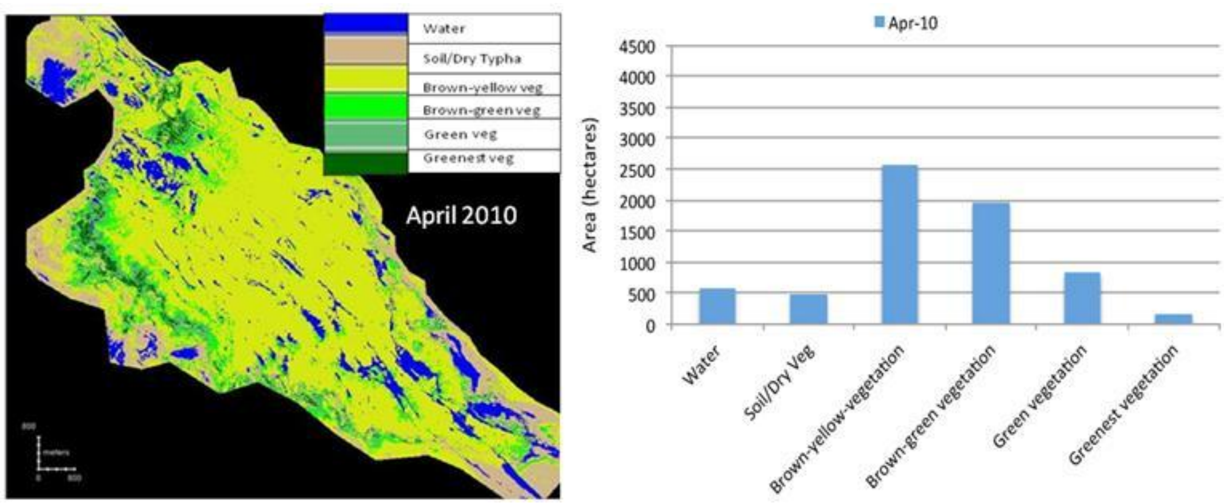


Figure 4-8. Ciénega classified image and histogram, April 2010. The Soil/Dry *Typha* class was nearly all bare soil in this spring scene.

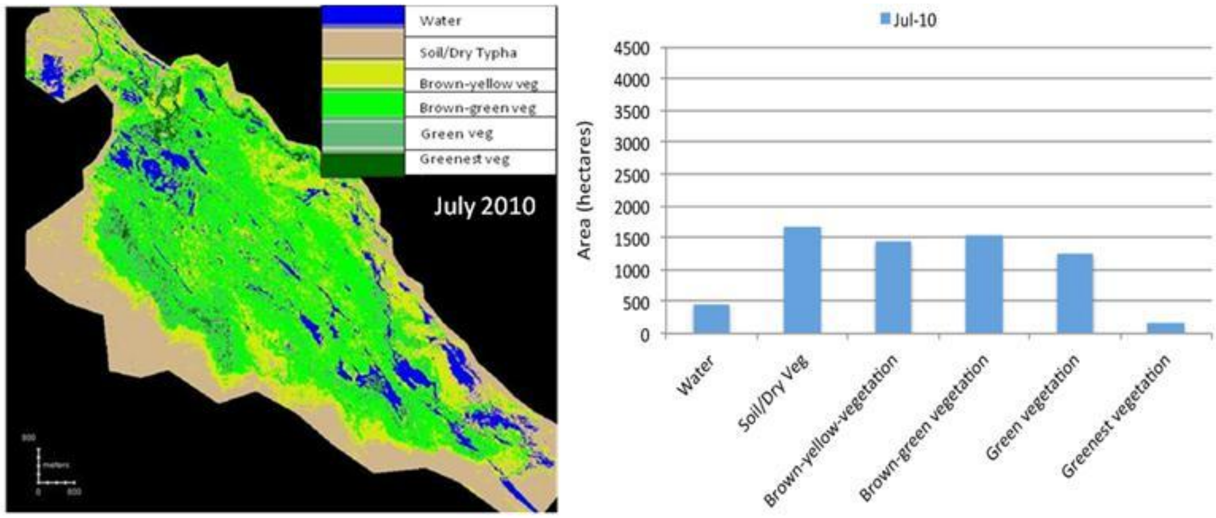


Figure 4-9. Ciénega classified image and histogram, July 2010. The Soil/Dry *Typha* class was nearly all bare soil in this summer scene.

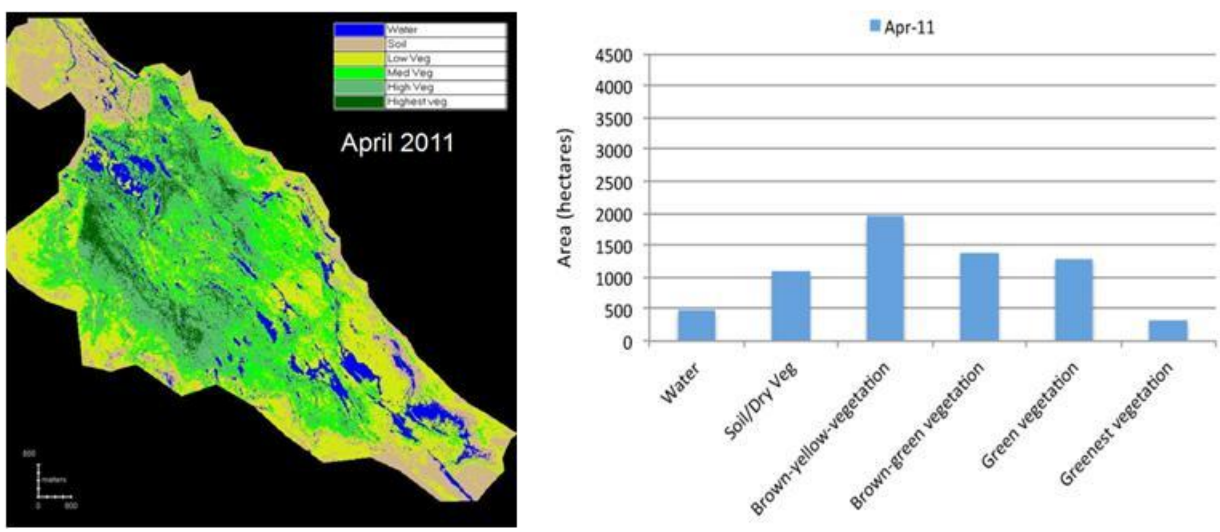


Figure 4-10. Ciénega classified image and histogram, April 2011. The Soil/Dry *Typha* class was a mixture of bare soil and dormant *Typha* in this spring scene.

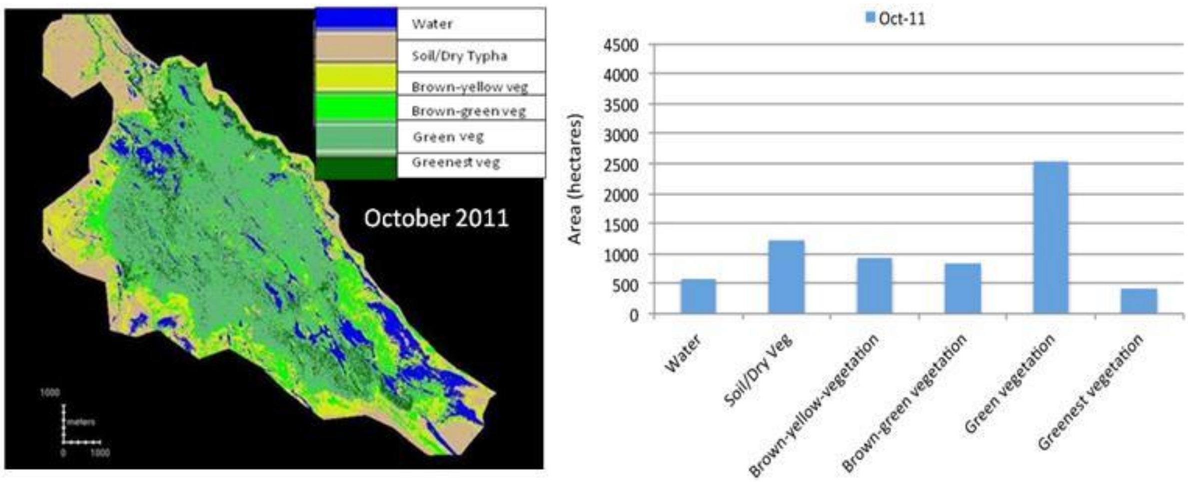


Figure 4-11. Ciénega classified image and histogram, October 2011. The Soil/Dry *Typha* class was mostly bare soil in this fall scene.

Figure 4-12. Aerial photograph taken by Francisco Zamora-Arroyo in January 2010, showing green *Phragmites* amidst dormant *Typha* in the Ciénega de Santa Clara.

c) Accuracy Assessment

The classification scheme was tested by sampling an additional 480 pixels (10 per subclass per image) to determine the accuracy of pixel assignment into the six main classes. Accuracy of the classification was assessed based on the number of sampled pixels assigned visually to a class based on the panchromatic image and ground knowledge but that fell outside the NDVI class range in Figure 4-13. Misclassification percentages were 1.3% for water; 5.5% for soil; 0.0% for Brown-yellow vegetation; 23.3% for brown-green vegetation; 15.0% for green vegetation; and 10.0% for greenest vegetation. The classification procedure clearly separates soil and water from each other and from vegetated areas. The higher misclassification rates for vegetation classes reflects the fact that vegetation density as measured by NDVI varies continuously over the marsh area, and any arbitrary division of the vegetation density into classes is bound to produce some overlap among classes.

Table 4-3 compares mean NDVI values of vegetation classes across images. Means were not equal to the midpoint NDVI value of each class because the pixel values were not necessarily normally distributed within each class. NDVI values were fairly consistent among images. These classes are reasonable to use for visual display of vegetation change and for semi-quantitative analyses. However, for quantitative comparison of NDVI values of different classes among images, we recommend using the weighted mean NDVI value of each class as determined by sampling 10 or more pixels within each class. For example, to compare the mean NDVI of vegetation at different dates, the formula for each image would be:

Veg Mean NDVI = [(Mean NDVI brown-yellow vegetation x number of hectares) + (Mean NDVI brown-green vegetation x no. hectares) + (Mean NDVI green vegetation x no. hectares) + (Mean NDVI greenest vegetation x no. hectares)]/(no. hectares brown-yellow vegetation + no. hectares brown-green vegetation + no. hectares green vegetation + no. hectares greenest Vegetation) (2)

Class	**Sept 08**	**Feb 09**	**Apr09**	**Aug 09**	**Jan 10**	**Apr 10**	**July 10**
Water	-0.205	-0.244	-0.187	-0.182	-0.278	-0.283	-0.158
Soil	0.060	0.074	0.066	0.063	0.052	0.004	0.082
Brown-yellow vegetation	0.239	0.216	0.193	0.228	0.198	0.196	0.226
Brown-green vegetation	0.393	0.308	0.355	0.396	0.318	0.334	0.387
Green vegetation	0.472	0.535	NA	0.468	NA	NA	0.500
Greenest Vegetation	0.678	NA	0.605	0.589	0.558	0.592	0.714

Table 4-3. Mean NDVI of cover classes on different QuickBird images. No pixels were classified as greenest vegetation in February or green vegetation in April 2009 and January 2010.

d) Combining QuickBird and MODIS for Change Detection

QuickBird has high spatial resolution (0.6 m in the panchromatic band and 2.6 m in the multispectral bands), but provides only a snapshot at the time of satellite overpass. On the other hand, the MODIS sensors on the Terra satellite provide nearly daily coverage at 250 m resolution. Both types of image are valuable in assessing changes in the Ciénega. Furthermore, MODIS NDVI can be used as a check on the accuracy of the QuickBird classification procedure. We compared NDVI values calculated for each QuickBird image by Equation (2) with NDVI sampled in vegetated areas of the Ciénega by MODIS (Figure 4-13). The MODIS samples included the vegetated Ciénega as well as the southern, unvegetated basin which had a dry down in 2008. Both MODIS and QuickBird produced similar results. Hence, QuickBird images can be used for detailed spatial comparisons among dates, while MODIS can be used to track the time course of vegetation dynamics (see section on water budget of this report).

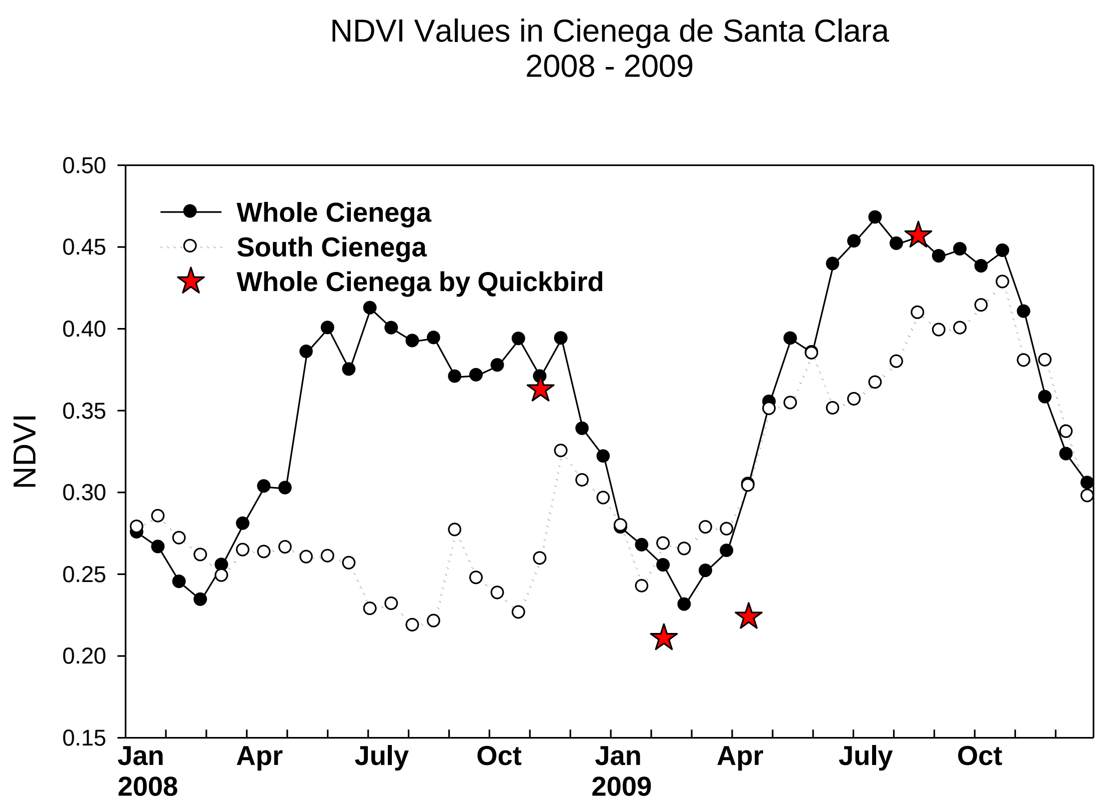


Figure 4-13. NDVI values in vegetated areas of the Ciénega determined by MODIS and QuickBird. MODIS values were from blocks of pixels sampling the whole Ciénega or sampling the southern portion of the Ciénega, which dried down in 2008 (see Figure 4-26). QuickBird values were from classified images using Equation (2) for the four vegetation class on September 2008; February 2009; April 2009; and August 2009 images.

2. Supervised Classification

a) *Data and methodology*

For the supervised classification we used one of the most commonly used tools for land cover classification, the Classification and Regression Tree (CART) model, which was applied for this classification using the CART/See5 tool developed for ERDAS Imagine software. The Classification and Regression Tree model is a non-parametric technique that is being used more often in land cover classifications. What the CART model does is help select from a set of variables those variables that better explain a particular output. In other words, it provides us with a significant amount of information that is generated from the combination of the different spectral information in the satellite images, and thus helps us identify the different land cover classes. We performed the CART Analysis in the ERDAS Imagine, using a set of independent variables and the dependent variable (training points) to automatically generate an output of the classified image.

After applying this method to a subset of the image showing the Ciénega marsh only, we decided to apply it to the entire image and then extract the information for the marsh if necessary. After classifying the images, and because the marsh area of the Ciénega changes through time, we decided to present results here for the entire image (16,719 hectares) without trying to extract the information for the marsh area using one polygon that could be applied to all images.

From all images available, we used those for spring and summer dates, which was a total of six images: September 2008; August 2009; April 2010, July 2010, April 2011, and October 2011. To conduct the classification, we generated a number of information layers from the original 8-band WorldView2 and the 4-band QuickBird (QB) image data. A total of 21 variables (Table 4-4) were created using ERDAS Imagine for the WorldView images. Only 13 variables could be created for the QuickBird images because QuickBird only has 4 bands available. The following is a description of the variables used for the WV2. We used the same procedure but adjusted it to create the variables using the 4-band QB image. All data were output as, or converted to, signed 16-bit.

- WorldView2 reflectance in 8 bands: Blue, Green, Red, NIR1, NIR2, Coastal, Yellow, Red edge. This is created by simply multiplying input by 10000 and choosing Signed 16-bit data type for output.

- Normalized Difference Vegetation Index: Standard procedure to detect vegetation responses based on WV2 bands 5 and 7, red, and NIR1 reflectance data respectively. NDVI = (NIR1-Red)/(NIR1+Red).

- Soil Adjusted Vegetation index (SAVI): Similar to NDVI but uses a coefficient (L=0.5) that seeks to minimize the effects of soil spectral properties in the signal (Huete, 1988).

- SAVI = ((NIR1-Red)(1+L))/(NIR1+Red+L).

- Enhanced Vegetation Index (EVI): The EVI was developed to minimize the vegetation signal with improved sensitivity in high biomass regions and improved vegetation monitoring through a de-coupling of the canopy background signal and reduction in atmosphere influence (Huete et al., 2002). EVI = (G*(NIR1-Red))/(NIR1+C1*Red-C2*Blue+L).

  Where the coefficients adopted in the EVI algorithm are, L = 1, C1 = 6, C2 = 7.5, and G = 2.5

- Enhanced Vegetation Index 2 (EVI2): EVI2 is computed without a blue band, and it remains functionally equivalent to the EVI, although slightly more prone to aerosol noise (Jiang et al., 2008).

  EVI2 = (2.5*(NIR1-Red))/(NIR1+2.4Red+1)

- Principal components analysis is a technique that transforms the original remotely sensed dataset into a substantially smaller and easier to interpret set of uncorrelated variables that represents most of the information present in the original dataset. We applied this technique to our images with 8 Principal Components (PC).

- Image texture: The image texture attribute was created from the WorldView2 images using a 3 by 3 variance filter, with the variance of the nine pixels being assigned to the central pixel.

Attribute name	**Acronym**	**Reference**	**# bands**
WorldView2 reflectance	n/a	n/a	8
Normalized Difference Vegetation Index	NDVI	Tucker 1979	1
Soil Adjusted Vegetation Index	SAVI	Huete 1988	1
Enhanced Vegetation Index	EVI	Huete et al. 2002	1
Enhanced Vegetation Index 2	EVI2	Jiang et al. 2007	1
Principal Components	PC	Fung and LeDrew 1987	8
Texture Analysis	Texture	Franklin et al. 2001	1

Table 4-4. List of images and derived attributes, and number of bands or layers associated with each used for classification using WV2 images.
Note: each band counts as one variable in the classification algorithm.

b) Training points

The supervised classification method is based on the image analysis software information of the different classes present at the area being analyzed. The classification algorithm then uses this information to classify the image. For the Ciénega de Santa Clara, we first developed a tentative set of land cover (vegetation) classes using expert knowledge of the Ciénega's land cover. We later aggregated these classes into 6 classes: green vegetation; brown-green vegetation; brown-yellow vegetation; shallow water; open water; bare soil; and for some images a burned area class. For each image we selected a minimum of fifty training points, or representative pixels. The selection of training sites was based on extensive aerial photography taken close to the date the image was taken (See section on repeat aerial photography). Coordinates *(UTM, Zone-11, and Datum-WGS84*) for each point were extracted from ArcGIS and imported into an Excel spreadsheet for use by the See5 CART model.

c) Results

Using the CART model approach, we generated classified land cover maps for six satellite images. We only used those images for spring and summer, as we found these are the best time of the year to better capture the conditions of the Ciénega, particularly vegetation. Table 4-5 shows a summary of the area in each cover class for each image as well as the total vegetated area. The three classes of vegetation represent the biomass intensity conditions. For example, green vegetation is that class having the highest biomass intensity (or greenness) as measured by the variables used in the analysis. The brown-green vegetation class is vegetation in good condition but which shows less biomass intensity. Finally, the brown-yellow vegetation class was used to identify vegetation that is dormant during winter months, which is something expected for cattail, or senescent vegetation. In summer months, this class also represents vegetation that is not green. It is important to notice that since we used the entire image for the classification, the biomass intensity of vegetation captured by these vegetation classes also applies to terrestrial vegetation, though terrestrial vegetation is very stable.

The open water class usually represents areas of more than one to two feet of water, whereas the shallow water class represents areas that are very shallow, usually less than one foot of water. The bare soil class includes dry and wet soil, with no vegetation. In April 2011 we added one class to captured burned areas after the extensive fire that reached most of the wetland marsh area.

Land Cover Class/Image Date	Sep-08	Aug-09	Apr-10	Jul-10	Apr-11	Oct-11
Green vegetation	944	2,523	552	579	3,480	1309.6
Brown-green vegetation	1,657	474	1,245	2,736	0	2,547
Brown-yellow vegetation	3,521	1,562	2,734	1,441	1,797	2,388
Total vegetation (ha)	**6,122**	**4,559**	**4,531**	**4,756**	**5,277**	**6,245**
Open water	383	571	457	277	267	366
Shallow water	456	851	1,169	276	523	734
Bare soil	3,562	4,543	4,372	5,218	3,721	3184.1
Burned area	0	0	0	0	737	0
Total Area (ha)	**10,523**	**10,524**	**10,529**	**10,527**	**10,525**	**10,529**

Table 4-5. Results of the land cover classification in hectares by land cover class.

i. September 2008

Given the temperature and sunlight conditions, it is expected that the vegetation in the Ciénega would be the greenest in the summer. For 2008, the only image available was for September 8. After evaluating this image (Figure 4-14), we determined it is still showing summer conditions with the greenest vegetation depicted in red color. It also shows the western portion of the Ciénega with an extensive brown-colored area which we know, based on ground surveys by Osvel Hinojosa and Jaqueline García during the months before September, was senescent vegetation was caused by a lack of water flowing to the area due to a plug at the end of the Bypass Drain.

Figure 4-14 also shows the land cover map for September 8, 2008 and figure 4-15 shows the area in each land cover class. The classification overall captured the different classes in the Ciénega. For example, most of the western portion of the Ciénega is classified as brown-yellow vegetation representing the die-back vegetation that was confirmed through field surveys in 2008 (die-back vegetation means loss of part of the above ground vegetation, and that the plant is not completely dead). However, one year later this vegetation came back, as the results for 2009 show.

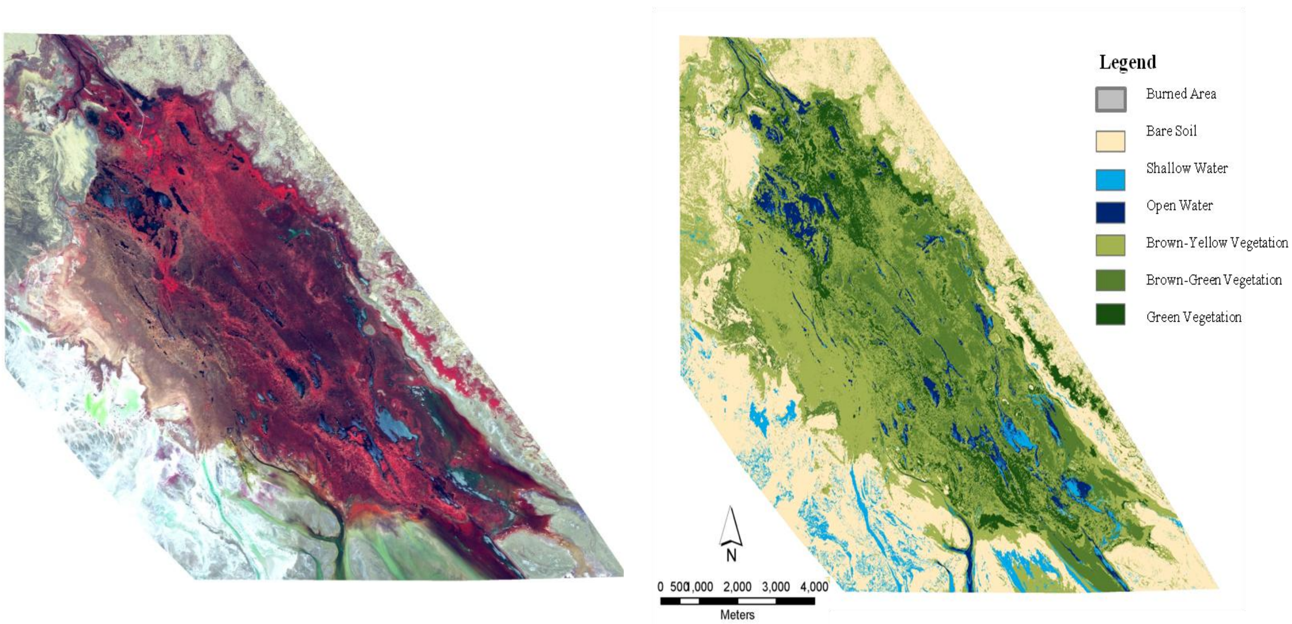


Figure 4-14. Left image is the Satellite image
using bands 4, 3, and 2. Right image is the vegetation map for September 8, 2008.

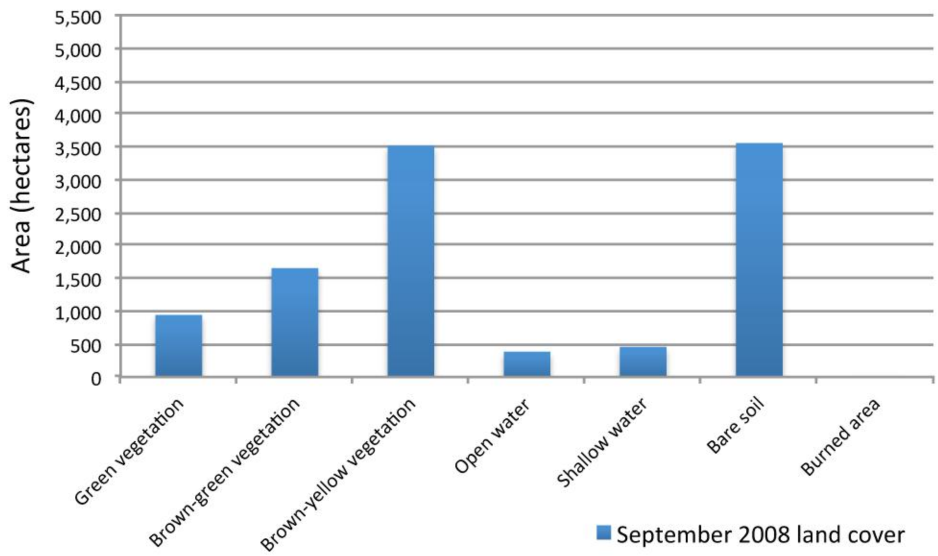


Figure 4-15. Number of hectares per land cover class for the Ciénega de Santa Clara in September 8, 2008.

ii. August 2009

Figure 4-16 shows the satellite image and the land cover map for August 19, 2009. Results show that by 2009 the western portion of the Ciénega had rejuvenated. For example, the number of hectares classified as brown-yellow vegetation decreased from 3,521 in September 2008 to 1,562 in August 2009 (Table 4-5). The recuperation is also reflected in the increase of green vegetation from 944 hectares in 2008 to 2,523 hectares in 2009. Figure 4-17 shows that after bare soil, the class with the largest number of hectares is green vegetation, while in 2008 brown-yellow vegetation was the class with the largest area after bare soil (Figure 4-15). Although the Ciénega is a dynamic system, the images for 2008 and 2009 provide some indication of the summer conditions in the Ciénega prior to the pilot run of the Yuma Desalting Plant, particularly the 2009 image, when water in the Ciénega was reaching the western portion once again after the dredging of sediments accumulated at the end of the Bypass Drain.

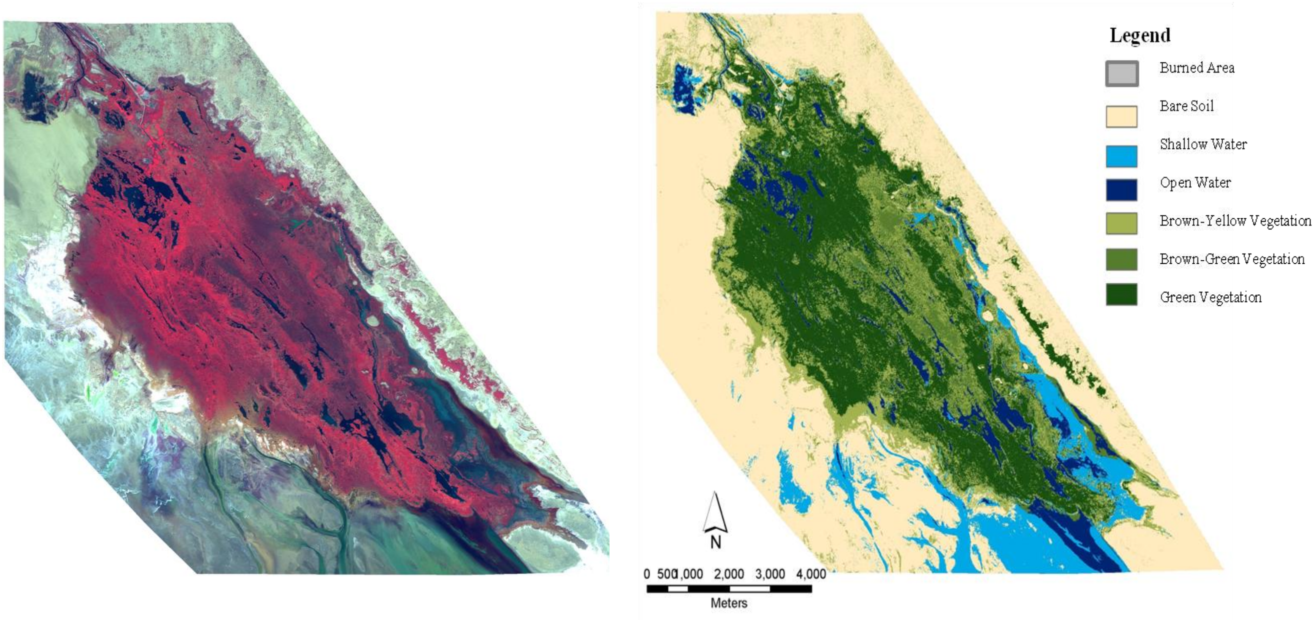


Figure 4-16. Left image is the Satellite image using bands 4, 3, and 2. Right image is the vegetation map for August 19, 2009.

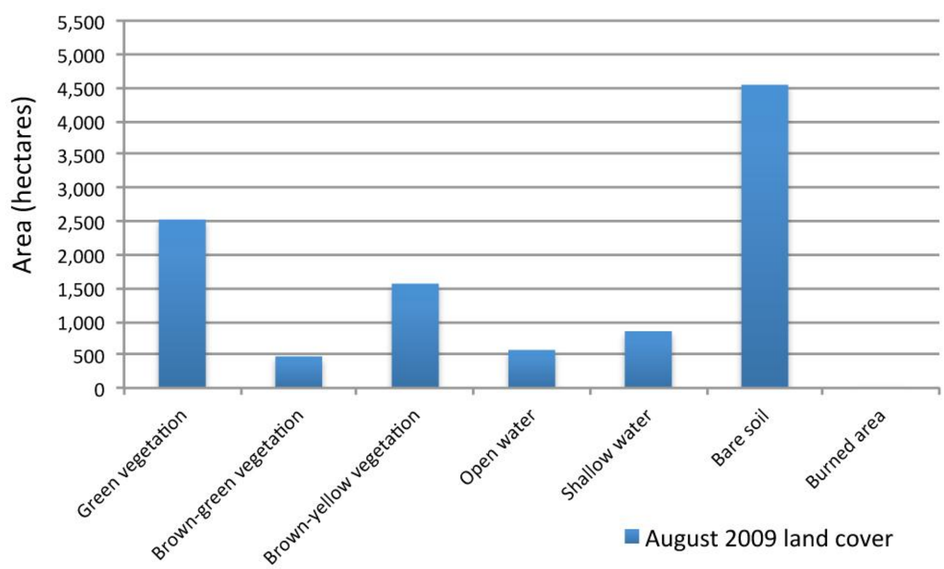


Figure 4-17. Number of hectares per land cover class for the Ciénega de Santa Clara in August 2009.

iii. April 2010

The image for April 7, 2010 provides us with an opportunity to identify the conditions of the vegetation in the Ciénega before the YDP pilot run started in May 2010. This also was the first WorldView2 image we acquired for this project and the initial image for which we apply the classification methodology described above; this methodology was later adjusted to classify QuickBird images. The image is from early spring, which is still too early to show the emergent vegetation as green as in the summer months. This is reflected in the land cover map (Figure 4-18), which shows that most of the vegetation is either brown-yellow (2,734 hectares [ha]) or brown-green (1,245 ha), with only 552 ha of green vegetation (Table 4-5). This can also be seen in Figure 4-19, where brown-yellow vegetation dominates the Ciénega.

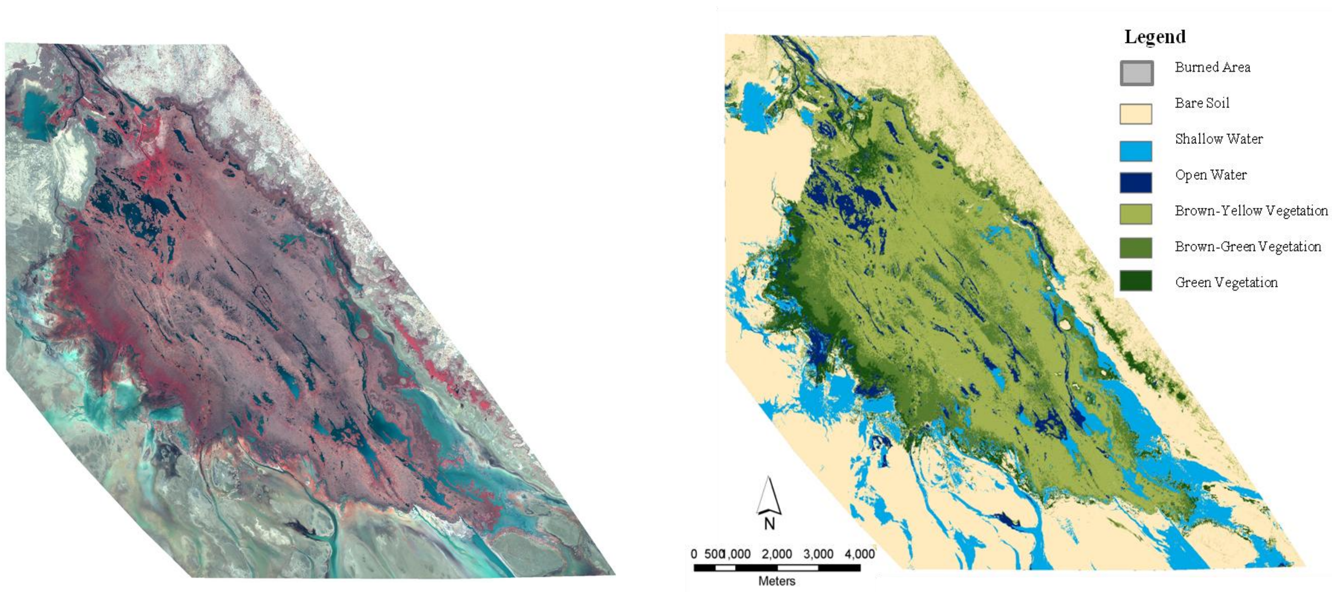


Figure 4-18. Left image is the Satellite image using bands 4, 3, and 2. Right image is the vegetation map for April 7, 2010.

The April image was taken only a few days after the earthquake that hit the Mexicali valley on April 4th. Apparently the area to the west of the Ciénega subsided after the earthquake (Steve Nelson, personal communication) and that is one reason we see additional areas of shallow water in that western portion (see Figure 4-19 and Table 4-5).

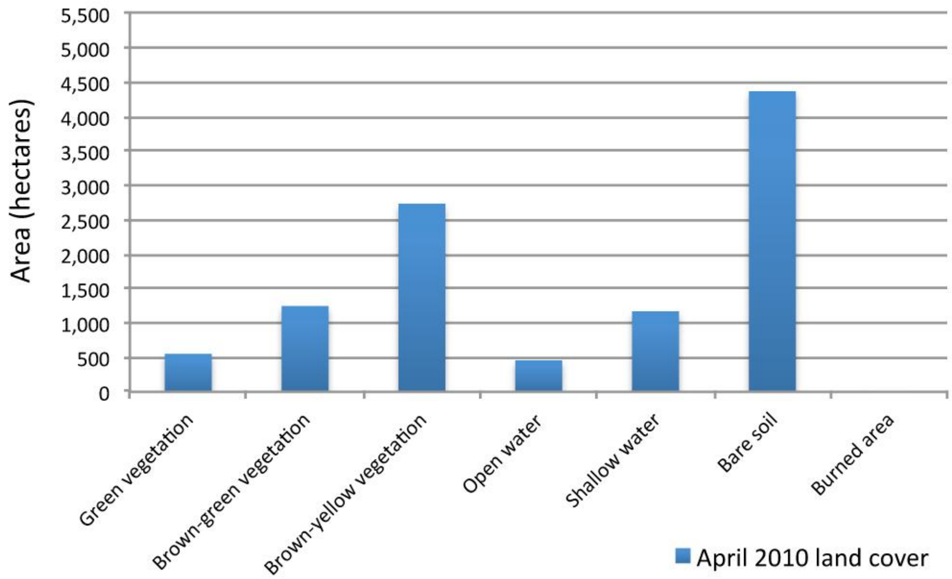


Figure 4-19. Number of hectares per land cover class for the Ciénega de Santa Clara for April 2010.

iv. July 2010

The image for July 2010 was taken approximately two months after the operation of the YDP began (Figure 4-20). The land cover map shows approximately the same vegetated area, but with an increase in green and brown-green vegetation and a decrease in brown-yellow vegetation from April 2010.

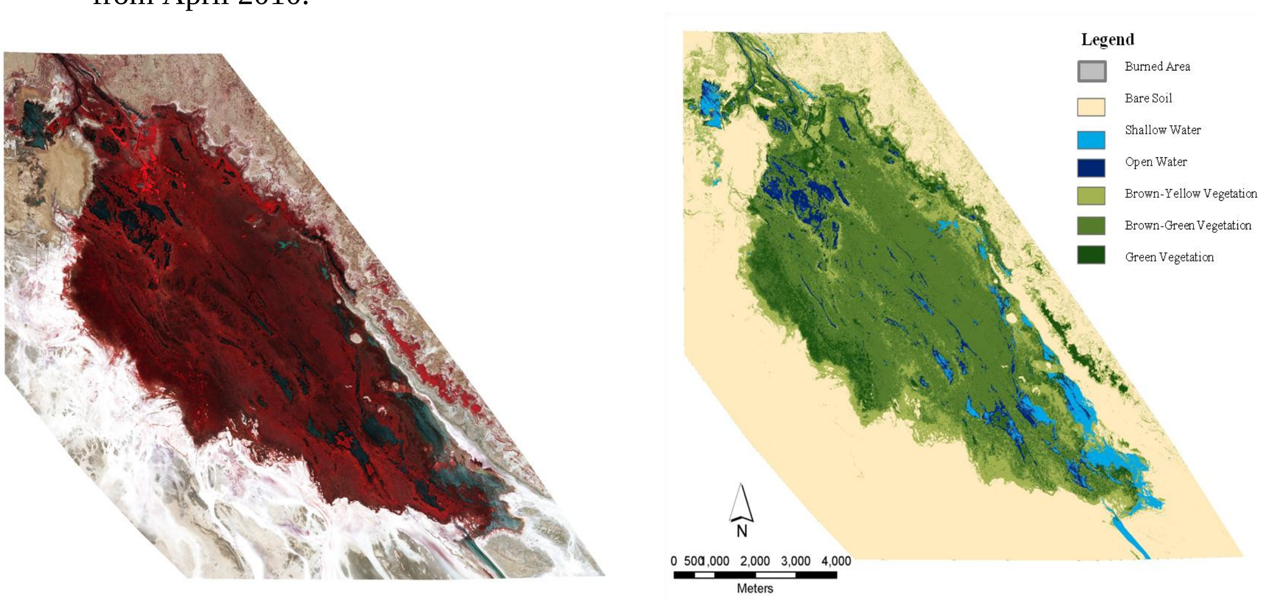


Figure 4-20. Left image is the Satellite image using bands 4, 3, and 2. Right image is the vegetation map for July, 2010.

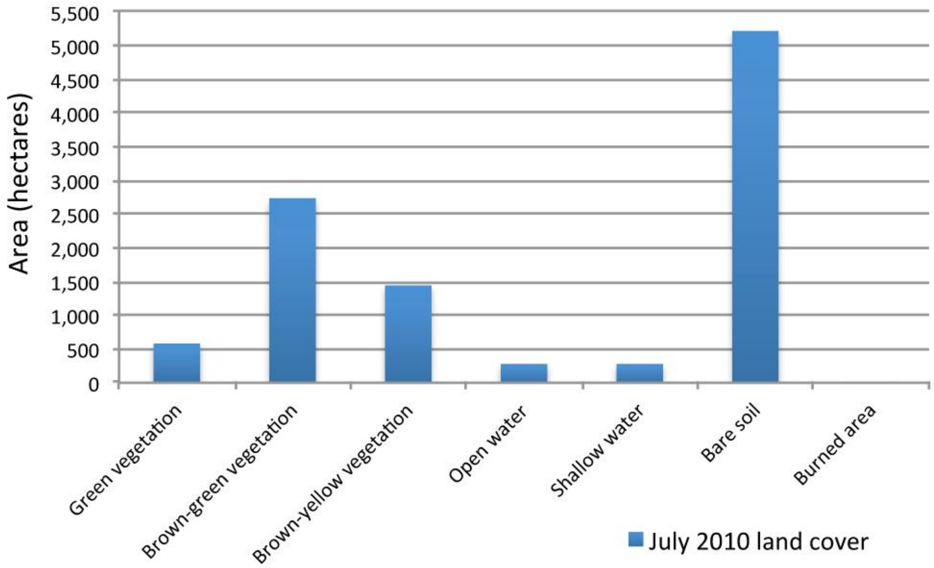


Figure 4-21. Number of hectares per land cover class for the Ciénega de Santa Clara for July 2010.

v. April 2011

The image for April 2011 was taken only three weeks after the extensive fire that occurred in the Ciénega on March 26-27, 2011. Figure 4-22 shows that the Ciénega responded very quickly and most of the area that was burned came back vigorously with new vegetation. Table 4-5 shows that 3,480 hectares were of green vegetation, most of which is in the marsh area. The burned areas that remained with no vegetation account for about 800 hectares, with most of these surrounding the end of the Bypass Drain and the Santa Clara-Riito Drain. Vegetation in these areas used to be terrestrial vegetation, which does not come back as quickly as emergent vegetation. The areas shown as brown-yellow vegetation represent those areas that did not burn. Also by April 2011 the shallow lagoons adjacent to the Santa Clara-Riito drain have disappeared as a result of dredging of the drain by CONAGUA.

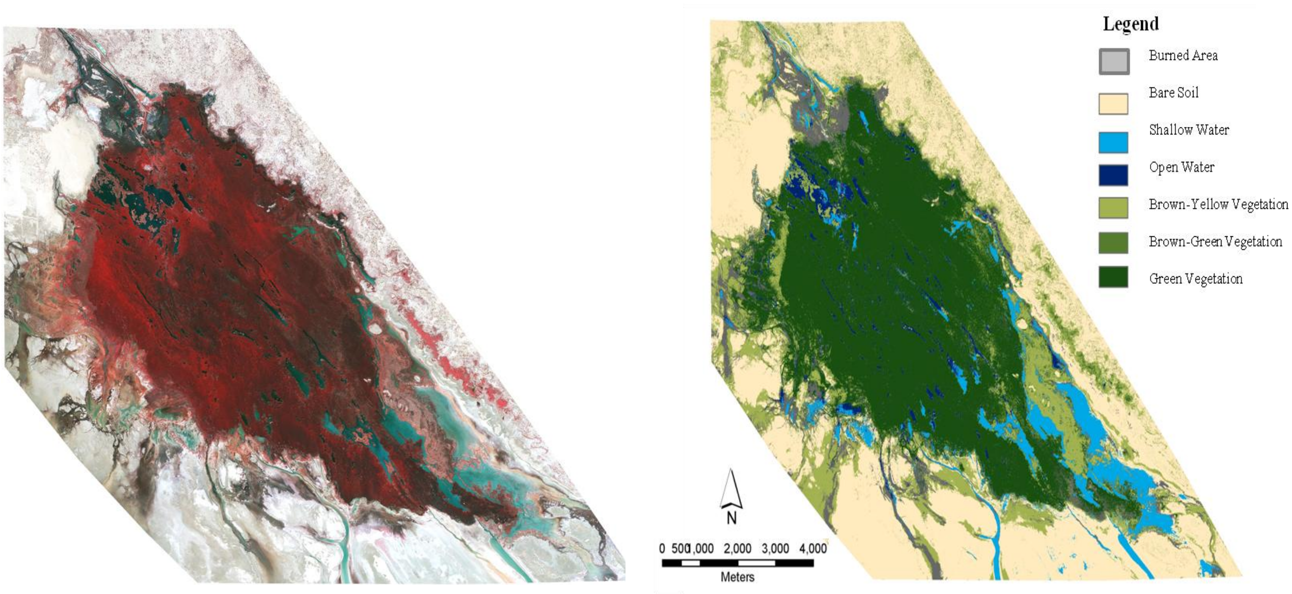


Figure 4-22. Left image is the Satellite image using bands 4, 3, and 2. Right image is the vegetation map for April, 2011.

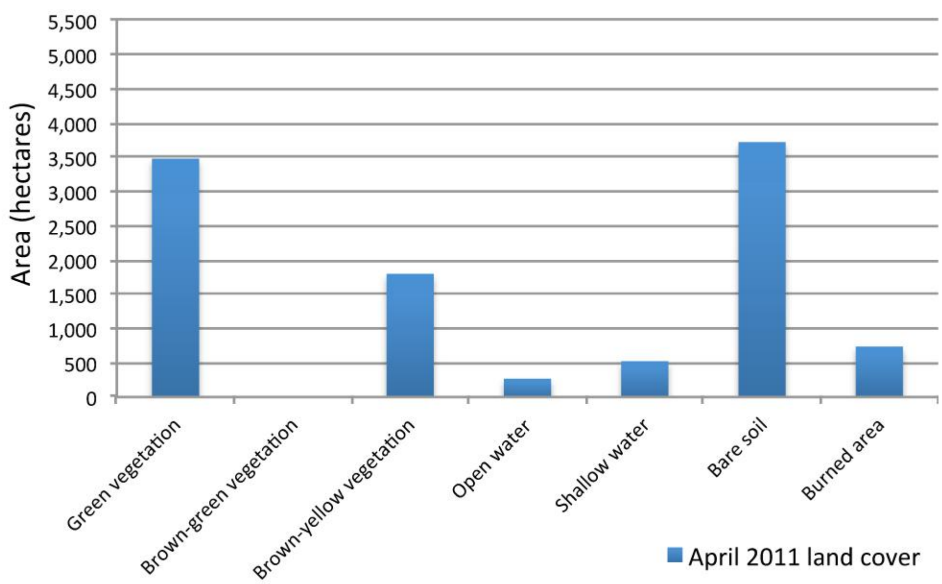


Figure 4-23. Number of hectares per land cover class for the Ciénega de Santa Clara for April 2011.

vi. October 2011

The image for summer of 2011 took longer for the provider to acquire due to high demand of the satellite during the summer months. Although taken in early fall, the image still represents summer conditions for 2011. Figure 4-26 and Table 4-5 show that total vegetation is the greatest among all satellite images from 2008 to 2011. It is important to notice that some of this vegetation in the western edge of the Ciénega may be algae on wet soil or very shallow water and not emergent vegetation. Burned areas around the Bypass Drain and Santa Clara-Riito drain are also misclassified as shallow water. We estimate that approximately 30-50% of 737 hectares of burned area remained without vegetation in October 2011.

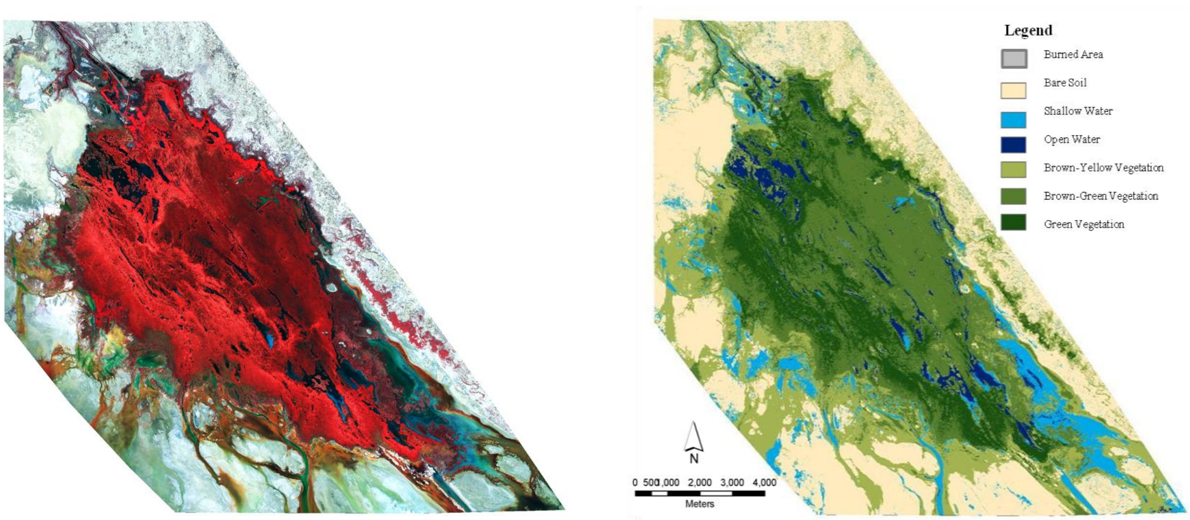


Figure 4-24. Left image is the Satellite image using bands 4, 3, and 2. Right image is the vegetation map for October, 2011.

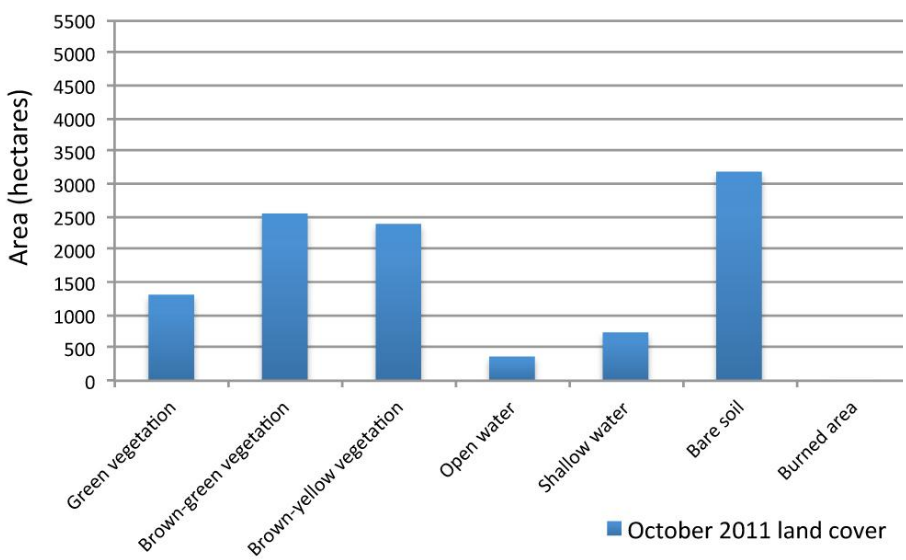


Figure 4-25. Number of hectares per land cover class for the Ciénega de Santa Clara for April 2011.

vii. Possible effects of the May-July 2010 flow reductions on EVI values

One of the objectives of the remote sensing study was to detect possible effects of flow reductions and salinity increases on the vegetation in the Ciénega. As described elsewhere, arranged water was provided for most of the Yuma Desalting Plant test run, but there was a marked reduction in flows and increase in salinity during May-August 2010 (see Figure 2-32). We plotted EVI values from 2008-2011 (Figure 4-26) to determine if the May-August 2010 period was anomalous compared to previous years. Summer EVI values were higher in 2009 than in either 2008 or 2010. In 2008, this was due to silt buildup in the inflow channel, which reduced flows to the western edge of the Ciénega. This was repaired by dredging, restoring full flows to the western edge in 2009. In 2010 silt buildup was not a factor, but inflows were reduced from May to August and peak ET values were lower in 2010 than in 2009. However, factors other than flow reductions might have contributed to lower EVI values. For example, the April 2010 earthquake produced subsidence in the intertidal area to the west of the Ciénega, which opened up a pathway for ocean water to enter the western edge when high tides exceeded 5 m. The sharp increase in EVI in 2011 following a fire event shows that the Ciénega is resilient, and that the accumulation of thatch over time is perhaps the single most important factor controlling green foliage density and ET from year to year.

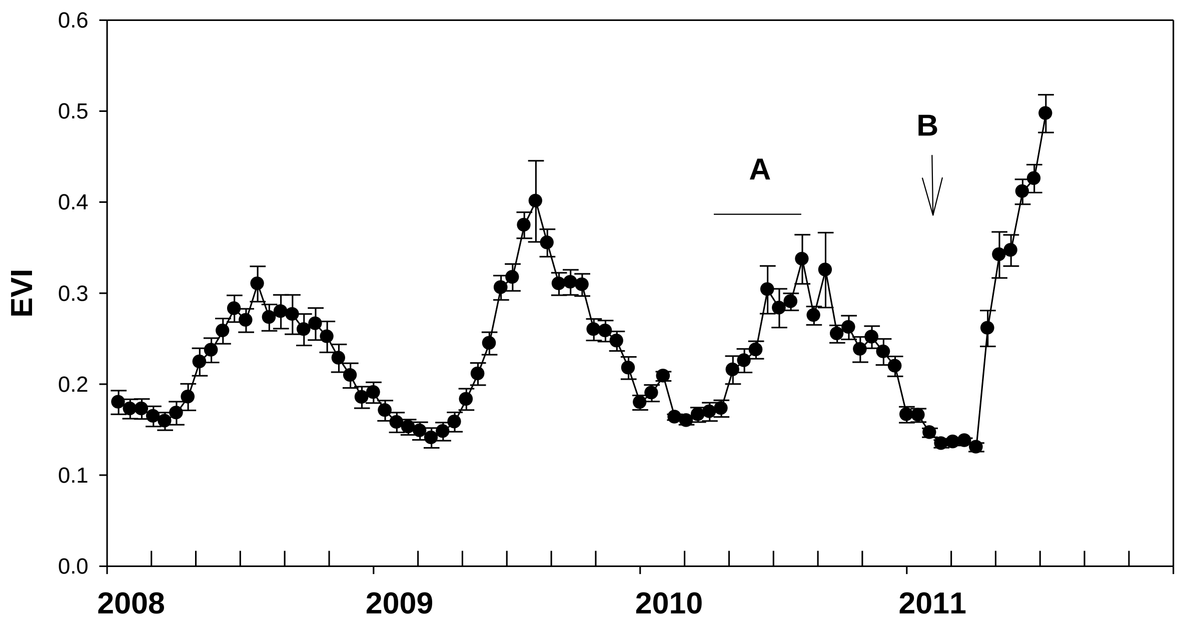


Figure 4-26. EVI values for the Ciénega, 2008-2011. Bar A shows the period of lower flows and higher salinities in May-August 2010. Point B shows when a major fire occurred in March 2011.

The finding that *Typha* can support ET rates equal to ETo was also supported in a study of a restored marsh in the San Joaquin Valley, California (Drexler et al., 2008). On the other hand, Goulden et al. (2007) reported lower ET rates for an unmanaged marsh in Irvine, California, with peak summer ET rates of 3-4 millimeters per day (mm/day), similar to rates measured in the Ciénega during non-fire years. Differences in levels of thatch were the primary cause of ET reductions in the study of Goulden et al. (2007), similar to our conclusions for the Ciénega.

C. Summary

1. The extent of the vegetated marsh area in the Ciénega was stable (6530-6540 ha using the unsupervised method) but the density of vegetation showed changes. The September 2008 image shows an area of low vegetation density in the western arm of the Ciénega. This was also noted in ground surveys and was thought to be due to a change in water flow from buildup of silt in the entry canal. CONAGUA subsequently dredged the canal.

2. The winter images used in the unsupervised classification (February 2009 and January 2010 images) show stable patches of green vegetation at the entry point of the Bypass Drain and along the western perimeter of the vegetated area. Aerial photographs show these are mostly due to patches of *Phragmites australis* (common reed), which remain green in winter, whereas the dominant *Typha domengensis* (southern cattail) is dormant in winter.

3. The July 2010 image shows apparent diminished vegetation intensity based on the supervised classification. The highest-vegetation category was reduced from 406 ha in September 2008 and 419 ha in August 2009, to 150 ha in July 2010. This change is not as evident in the supervised classification.

4. A fire burned nearly all of the dormant *Typha* by March 23, 2011. Nevertheless, the WorldView2 image acquired April 27, 2011 showed rapid re-greening of the marsh vegetation, similar to earlier April images. The October 2011 image showed that the full area of the Ciénega was once again vegetated, illustrating the resilience of the vegetation in this wetland.

5. The accumulation of thatch over time is perhaps the single most important factor controlling green foliage density and ET from year to year.

Chapter V: Repeat Aerial Photography

A. Introduction

In this project we employed several methods to monitor the presence of water and detect changes in vegetation in the Ciénega de Santa Clara. One of those methods was repeat oblique aerial photography. We conducted this photographic aerial monitoring nine times between February 2010 and September 2011 and collected aerial photos of fifteen distinct sites throughout the Ciénega. Below is a table of the dates of flights taken in 2010 and 2011 (Table 5-1).

	2010				2011				
Date of flight	Feb 18	May 5	Jul 8	Oct 26	Feb 17	Mar 16	Apr 13	Sept 2	Sept 30

Table 5-1. Dates of flights taken 2010-2011

Each over-flight followed the same route around the Ciénega and that route is replicated in the order of the pages below. The flights began at the northern edge of the Ciénega and continued clockwise around its perimeter. A few of the sites are in the center of the Ciénega, while the majority of the sites are situated towards the edges. Because photographs were taken from a moving airplane it was difficult to capture the sites from the same orientation and angle each time. Therefore photos of a particular site may have been taken from multiple perspectives and were not looking straight down over the site. Flight elevation was relatively the same during each flight but was not monitored. Our intention was not to match each photograph from a given site perfectly to the one previous, but to provide an aerial representation of each monitored area as a supplement to on-the-ground monitoring. In conjunction with this, since flights were scheduled in advance and could not always be scheduled at consistent times, we could not always have the same weather or angle of sunlight on each monitoring day. Environmental factors such as overcast skies and morning versus afternoon light played an inevitable role in the outcome of the photographs.

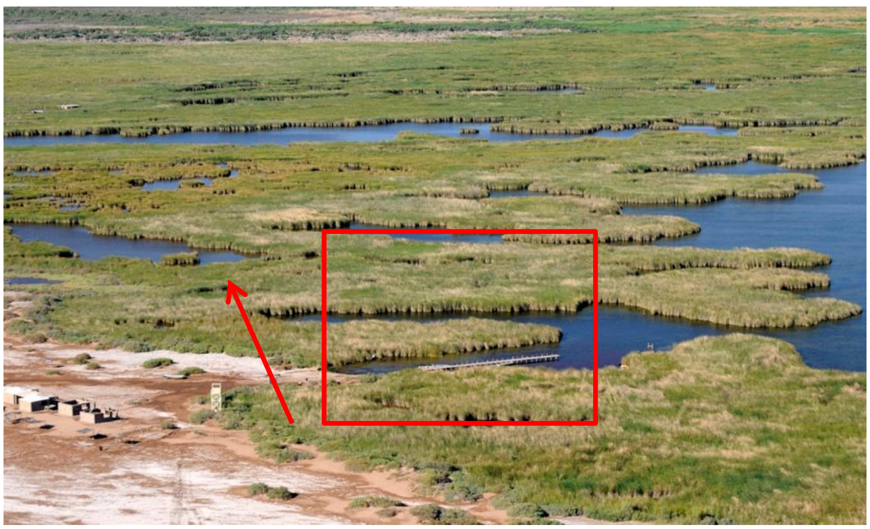
B. Aerial Photos

Below you will find a red reference box and an arrow in each photo. The reference box highlights the key reference point of each monitoring site while the arrow points approximately toward north to help orient each picture.

1. Cabins

The cabins are multiple one-story structures located on the northwest edge of the Ciénega. They are situated a couple hundred meters from a boat ramp and dock, all of which provide amenities for ecotourism in the Ciénega. The photographs for this site contain the dock as a reference point. They are located near monitoring site 23.

February 18 2010



July 8 2010

October 26 2010

Cabins

February 17 2011

March 16 2011

April 13 2011

Cabins

September 2 2011

September 30 2011

Summary of Observations

In February of 2010, just at the end of winter, the vegetation surrounding the cabin site was dry which is typical for winter. By July the vegetation was mainly green with a few dry-looking patches. October appeared to be the most verdant month of the 2010 monitoring season with vegetation lining the banks of the Ciénega to the north and south of the dock and cabins. February and March of 2011 showed dry vegetation. Between the March and April photos there was a large fire in this area which; the green portion of the April 13, 2011 photo was burned in that fire. The photo shows the rejuvenation of the cattail within weeks of the fire. September 2011 showed verdant vegetation returning to both sides of the dock. Water was present in all surrounding lagoons between the first and latest aerial monitoring sessions.

2. Buoys- Passageway

The Buoys-Passageway site is located near the cabins on the northwest side of the Ciénega. The site reference is a narrow passageway between two lagoons, noted on the ground by two buoys on either side and from the air by landmarks including a narrow triangle lagoon leading to the passageway. This site is located near monitoring site 3.

February 17 2011

April 13 2011

September 2 2011

Summary of Observations

The vegetation surrounding the buoys appeared dry in February of 2011. In April 2011, as seen at the "cabin" site, some of the vegetation remains very dry while some has turned quite green. Again, this is likely attributed to the fires that burned in the Cienega in March 2011 and promoted rejuvenation of cattail in the verdant areas. September 2011 was predominantly verdant.

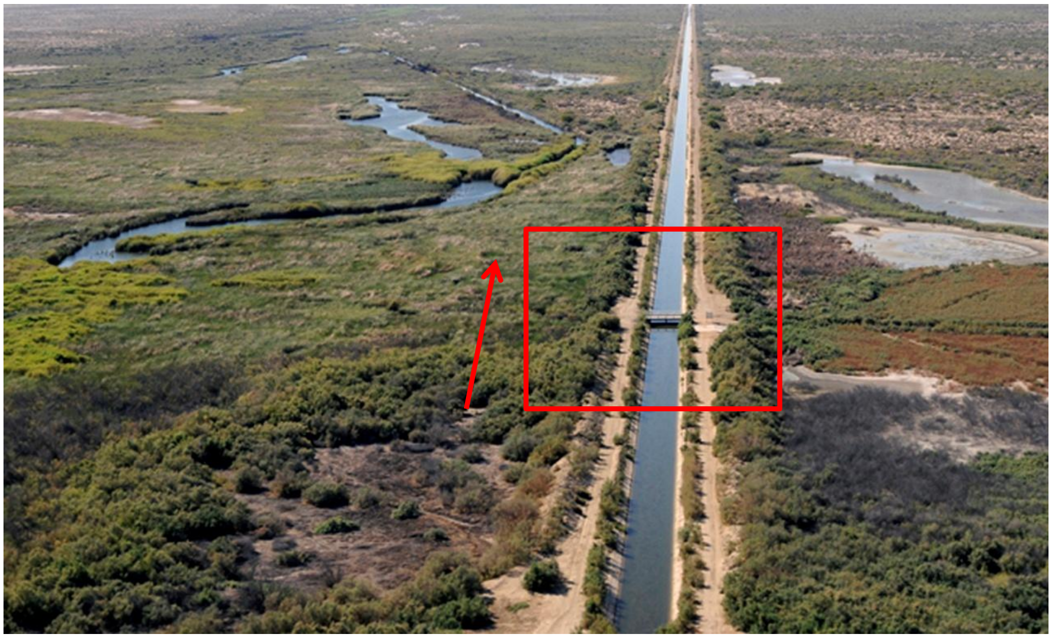
3. Bypass Drain

The Bypass Drain is the main source of water for the Ciénega. It carries agricultural runoff from the Wellton-Mohawk Irrigation and Drainage Districts (WMIDD) in Arizona and empties into the Ciénega de Santa Clara. The canal comes in from the north and eventually runs parallel to a Mexican drainage ditch called the Santa Clara-Riito drain, which carries agricultural runoff from the Mexicali Valley in Mexico. Photographs of this site contain a small access bridge that crosses the canal as a reference point. The site is located near monitoring site 8 and is 0.5 miles (0.8 kilometers) from the terminus of the Bypass Drain.

February 18 2010

May 5 2010

Bypass Drain



July 8 2010

February 17 2011

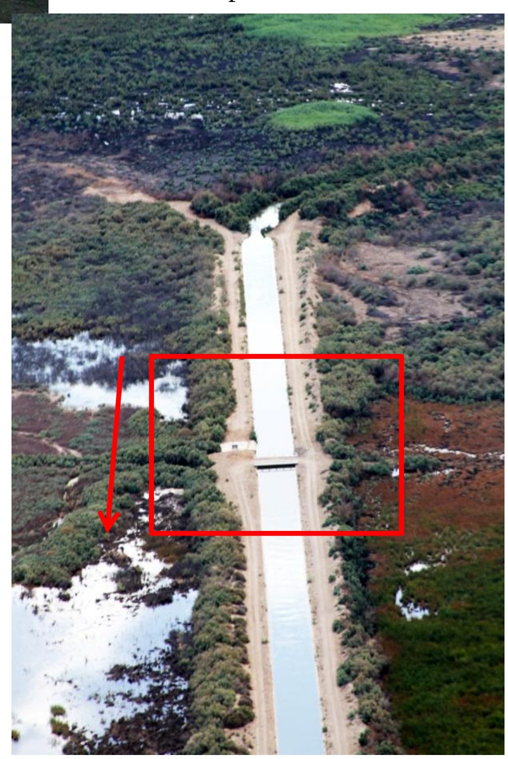
March 16 2011

Bypass Drain

April 13 2011

September 2 2011

September 30 2011



Summary of Observations

In February and May of 2010 the area surrounding the bypass drain was a patchwork of dry and verdant vegetation. There were areas of bare ground as well as standing water just outside the canal walls. July shows a similar patchwork as well as standing water outside the canal. February of 2011 jumps back to a relatively dry state of vegetation surrounding the canal and standing water is still visible. March, April and September 2011 also maintain patchworks of dry and verdant vegetation and standing water outside the canal; however, September 2 and 30 appear to have more patches of verdant vegetation than the spring months. Water was present in the canal during all overflights.

4. The End of the Bypass Drain

The end of the Bypass Drain is where the drainage canal dumps into the Ciénega. The site is characterized by the end of the built canal and often by the presence of sediment settling at the mouth of the canal. This site is located near monitoring site 17.

February 17 2011

March 16 2011

April 13 2011

End Bypass Drain

September 2 2011

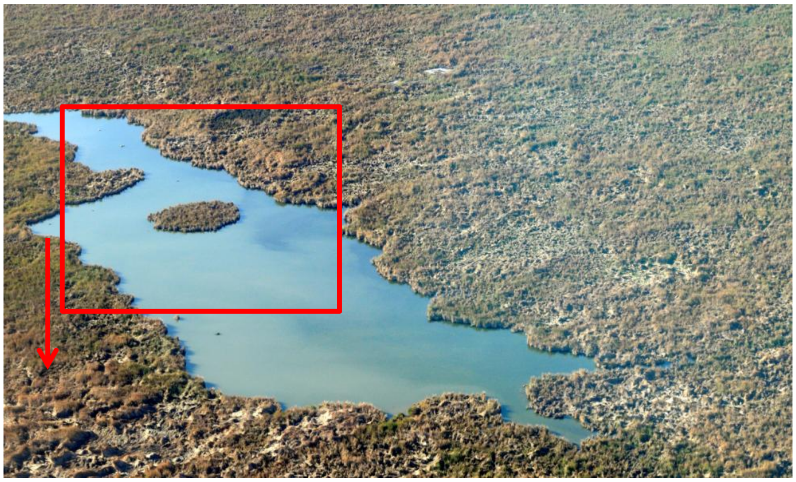
September 30 2011

Summary of Observations

While the February 2011 photograph does not show the sediment deposit at the end of the canal, it does show relatively dry vegetation surrounding the site, which is normal for that season. April 2011 shows the general greening of the surrounding vegetation after the fire in March 2011 as well as increasing build up of sediment. In September 2011 the vegetation is still verdant and the sediment deposit has increased significantly. Beginning in this month, CONAGUA/CILA conducted dredging at the end of the Bypass Drain, where the sediment deposit is seen in the photos.

5. Turtle Lagoon

The turtle lagoon is located in the very northeast corner of the Ciénega and is characterized by a small island at the south end of the lagoon reminiscent of an eye. This leads into a narrow section of the lagoon that hooks south-eastward. The site is located southwest of monitoring site 16.



February 18 2010

July 8 2010

February 17 2011

Turtle Lagoon

March 16 2011

April 13 2011

Turtle Lagoon

September 2 2011

September 30 2011

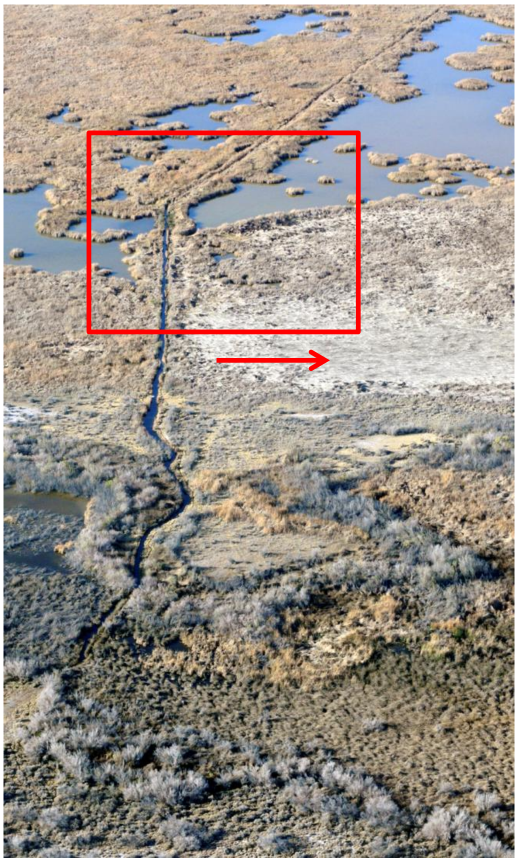
Summary of Observations

February 2010 showed mainly dry and vegetation with verdant patches around the lagoon's edge while July 2010 showed increased verdant vegetation, which is normal for the season. February and March of 2011 showed predominantly dry vegetation, while April and September 2011 show a predominantly verdant landscape on-site. Water remained present in the lagoon through all overflights.

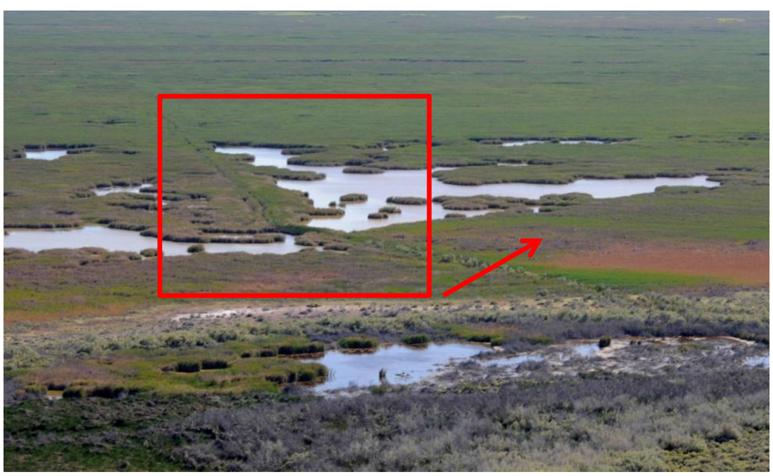
6. La Flor

La Flor is located on the east side of the Ciénega in the north-central region. It is characterized by an entrance road leading into the Ciénega and a canal running straight into the middle of the wetland. This site is also our monitoring site 7.

February 18 2010



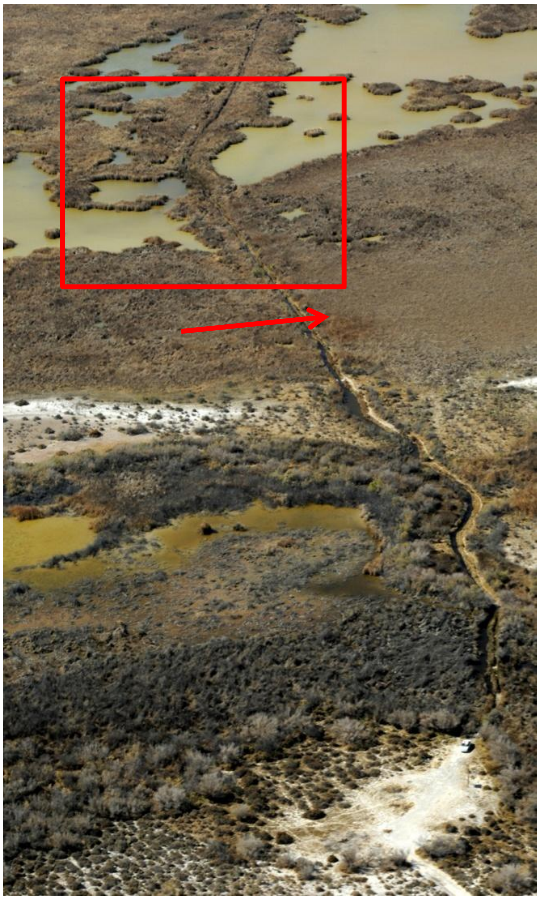
May 5 2010



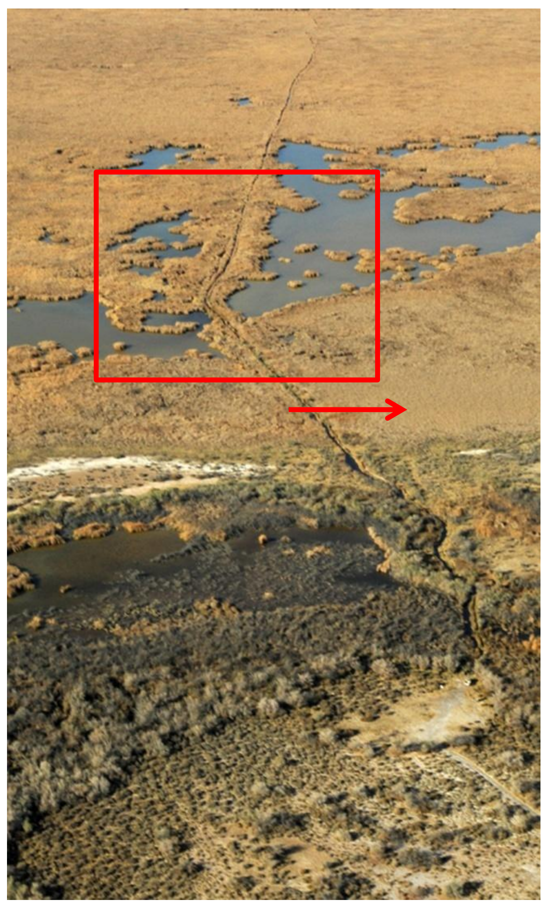
July 8 2010

La Flor

February 17 2011

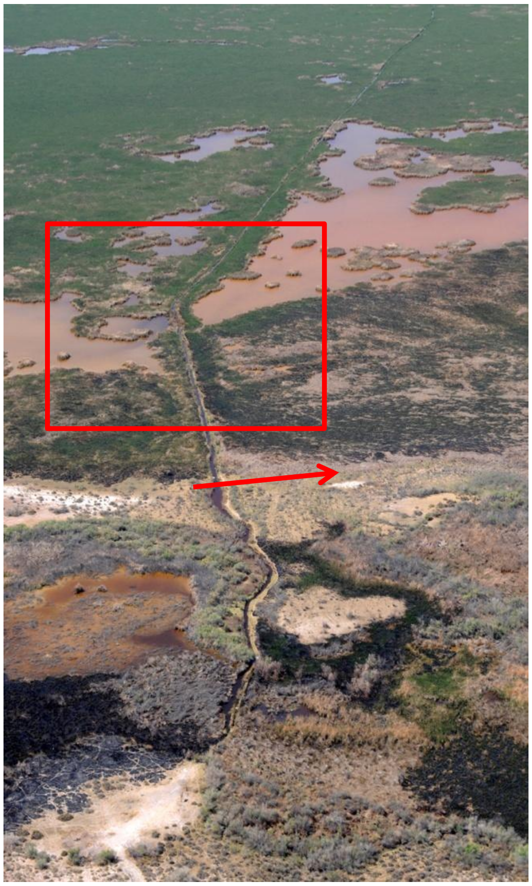


March 16 2011

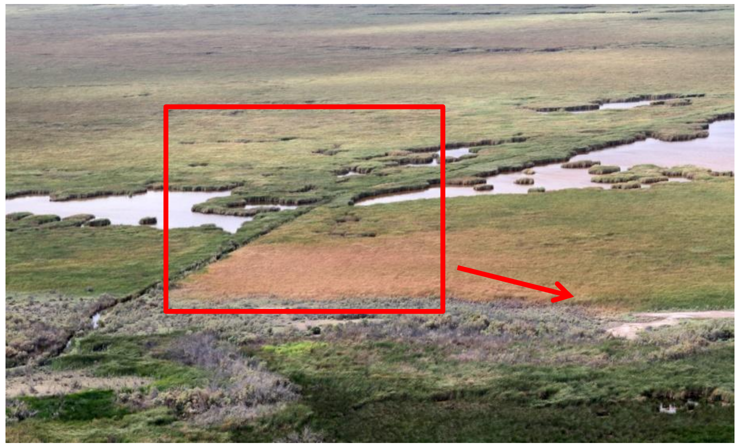


La Flor

April 13 2011



September 2 2011



September 30 2011

Summary of Observations

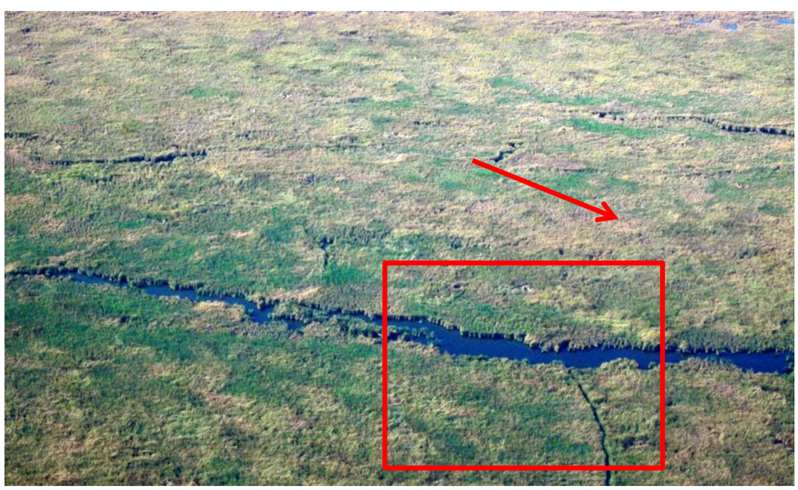
The vegetation at this site in February of 2010 appeared very dry, which is normal for the season. May and July 2010 showed the return of verdant vegetation, particularly toward the heart of the Cienega. February and March of 2011 showed predominantly dry vegetation while April 2011 showed a return of verdant vegetation, particularly toward the heart of the Cienega. September 2011 showed predominantly verdant vegetation at the site, with an area north of the canal entrance that has not greened up. Water remained present in the surrounding lagoons throughout all overflights.

7. End Canal at La Flor

The end canal at La Flor is located west of the La Flor site toward the center of the Cienega. This site is characterized by a skinny canal that T's with a long and narrow lagoon. This is also the location of our monitoring site 6.

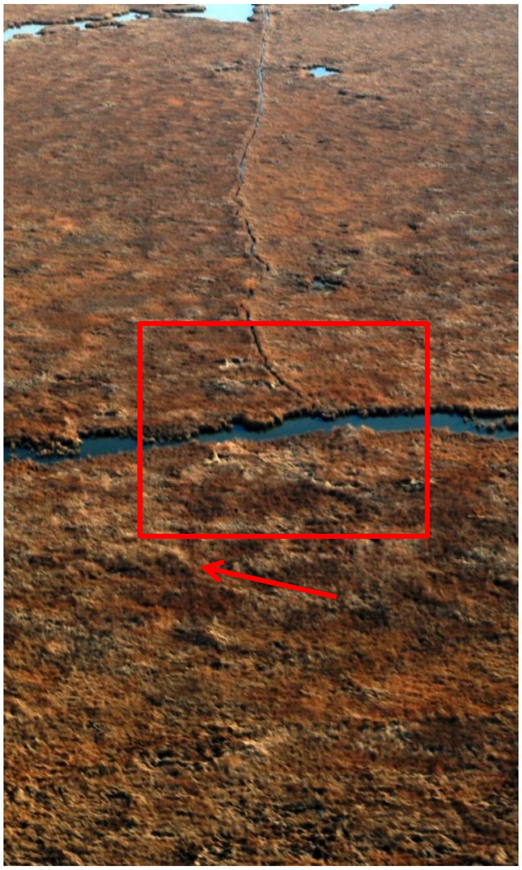
July 8 2010

October 26 2010

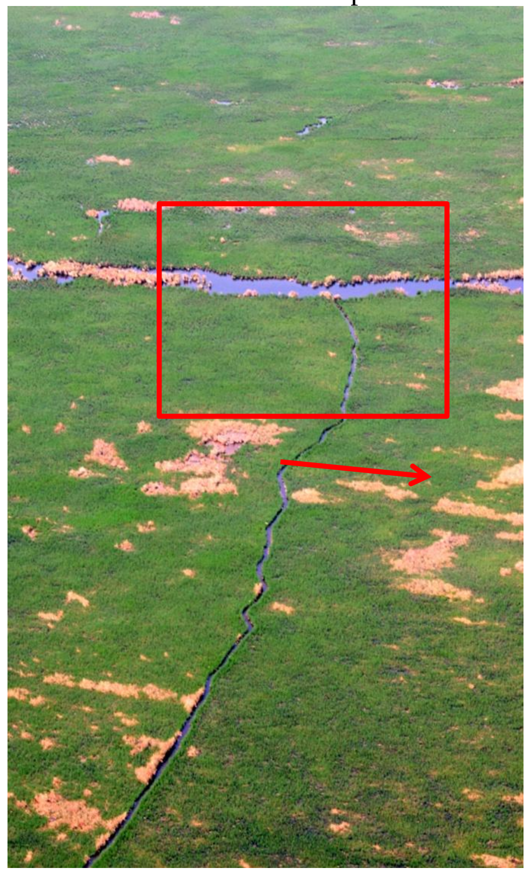


End Canal at La Flor

March 16 2011



April 13 2011



September 30 2011

Summary of Observations

In July of 2010 the vegetation surrounding the end canal appeared very verdant with a few brown patches visible. October of 2010 showed a wider swath of land and increased patchy vegetation between verdant and brown. March 2011 showed almost purely dry vegetation, which is normal for winter months, while April 2011 showed a predominance of green vegetation. September showed patchy dry and verdant vegetation. The effect of the fire that took place at the end of March 2011 is clearly shown in the March and April 2011 pictures. Within only a few weeks, new cattail started to grow. While it cannot be determined through the photos if water remained in the canal throughout all overflights, water did remain present in the end lagoon throughout all overflights.

8. Area Near Site 13

This site is located on the east side of the Ciénega in the central region. It is a large circular area with pock marks of vegetation dotting its center. Lagoons surround the flat to the north, west, and east sides. This is also near the location of our monitoring site 13.

May 5 2010

July 8 2010

October 26 2010

Area near Site 13

February 17 2011

March 16 2011

April 13 2011

Area near Site 13

September 2 2011

September 30 2011

Summary of Observations
From May through October 2010 the vegetation at this site remained varied, with a mix of different tones of verdant vegetation with a few brown patches assumed to be drier vegetation. February and March 2011 appeared very dry while April showed a mix of dry and verdant vegetation following the March 2011 fire, with the more verdant areas located on the western side—as opposed to the desert side—of the flat. In September 2011 the vegetation immediately surrounding the site was predominantly green while dry patches remained on the outskirts of the photos. The center of the island itself did not change over time but remained dry with a few pock marks of vegetation. Water remained at the site throughout all overflights.

9. Peninsula

The peninsula site is a narrow peninsula located in the southeast corner of the Ciénega and points approximately northwest. There is a small round flat just to the west of the peninsula which helps mark its location. It is located just north of monitoring site 11.

July 8 2010

February 17 2011

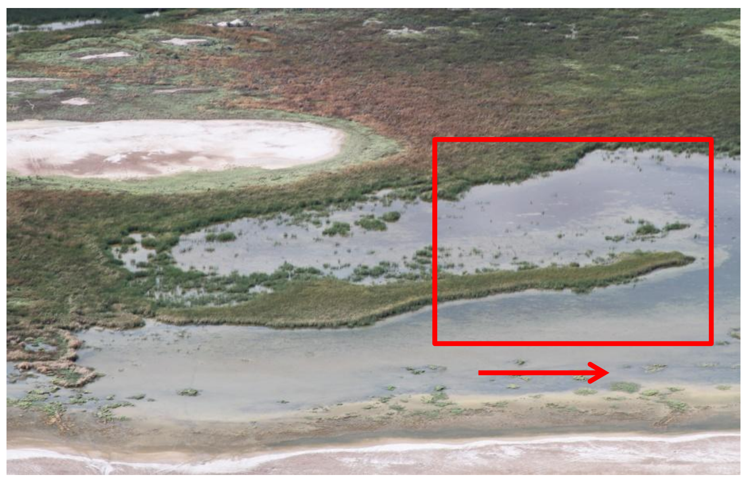
October 26 2010

March 16 2011

Peninsula

April 13 2011

September 2 2011



September 30 2011

Summary of Observations

In July of 2010 the peninsula and surrounding vegetation appeared quite verdant while the vegetation slightly farther from the bank of the lagoon appeared relatively dry. In October 2010 the peninsula and the surrounding vegetation appeared predominantly dry, which is slightly abnormal relative to photographs taken in October of other sites. October, however, still showed patches of verdant vegetation. February and March of 2011 appeared very dry. In April 2011 the peninsula was just barely visible at the bottom of the picture and the area appeared predominantly dry with a verdant area in the background. September 2011 showed green vegetation returning to the peninsula and its surrounding area with a few dry patchy areas near the flat. Water remained in the lagoon throughout all overflights; however, its color changed over time.

10. Chain Islands

The chain islands are located in the very south tip of the Ciénega. They run northwest-southeast across a lagoon and are characterized by a number of small vegetated islands in a line. Often one of the surrounding desert edges of the Ciénega is seen in the photographs since this site lies where the Ciénega narrows significantly in the south. This site is located near monitoring site 10.

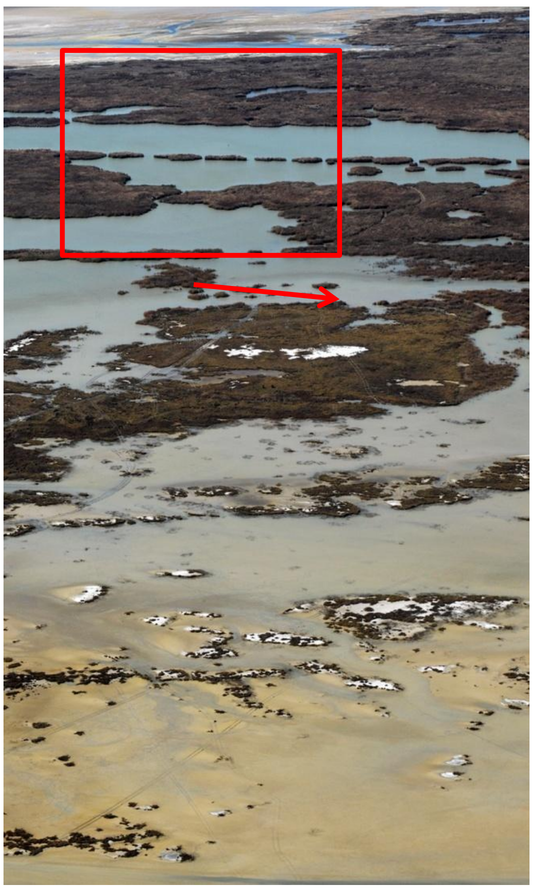
February 18 2010

May 5 2010

Chain Islands

July 8 2010

February 17 2011



March 16 2011

Chain Islands

April 13 2011

September 2 2011

September 30 2011

Summary of Observations

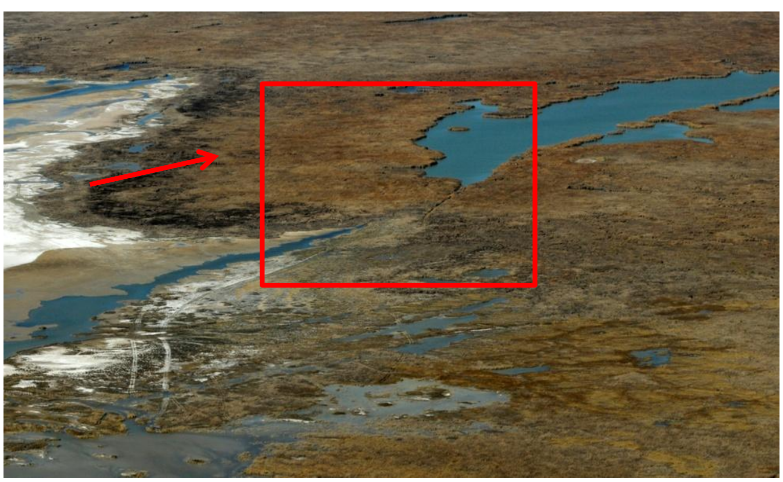
The vegetation of the chain islands in February of 2010 appeared predominantly dry while in May of 2010 verdant patches of vegetation had emerged. In July of 2010 the chain islands themselves were very green while some areas in the bottom portion of the photograph appeared dry or at least brown in color. February and March of 2011 showed almost ubiquitous dry vegetation at the site. In April 2011 the western section of the site (top of the photo) had become quite verdant and in September 2011 the vegetation on the eastern portion of the islands (bottom of the photos) had also become quite green. Relatively equivalent amounts of water appeared to remain in the lagoons throughout all overflights.

11. View from the South

This site offers a larger view of the Ciénega from the south end. The landmark used to identify this site is where a lagoon in the Cienega and a waterway on the south edge of the wetland just barely come together, like the points of two needles meeting. This site includes monitoring site 10.

February 18 2010

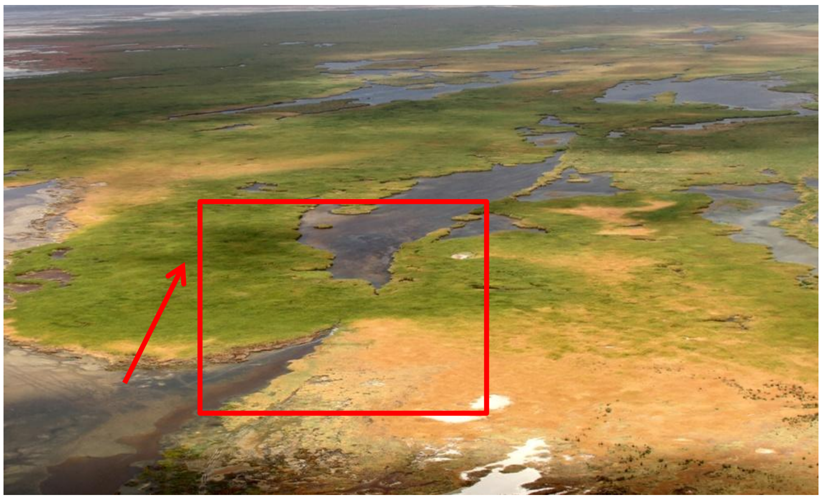
July 8 2010



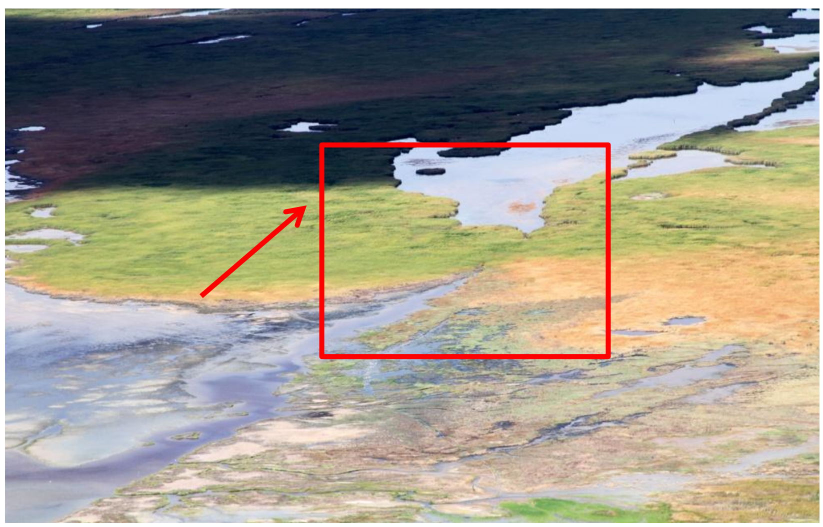
February 17 2011

View from South

April 13 2011



September 2 2011



September 30 2011

Summary of Observations

February 2010 showed predominantly dry vegetation while July 2010 showed a patchwork of dry and verdant vegetation. February 2011 appeared predominantly dry while April 2011 showed heavy patches of verdant vegetation in areas. September 2011 also showed predominantly verdant vegetation on the Cienega side (top of photos) with expanded verdant vegetation in the top right-hand corner of the September 2 photo (dark area in upper left of September 30 photo is cloud shadow). Water remained present throughout all overflights.

12. Narrows

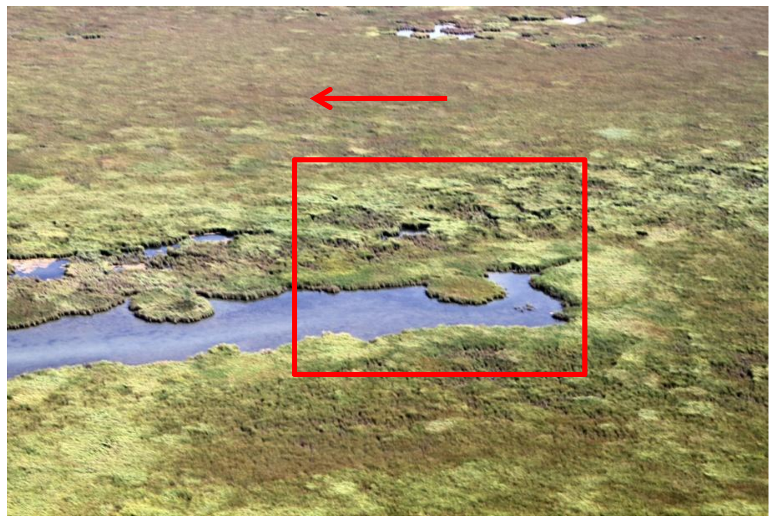
The "narrows" is located in the very center of the Cienega, straight west and slightly south of La Flor. This area is characterized by a lagoon with two knobs on its eastern edge. The site is located near monitoring sites 5 and 21.

July 8 2010

February 17 2011

Narrows

March 16 2011



September 30 2011

Summary of Observations

July of 2010 showed almost ubiquitous verdant vegetation at the site. February and March 2011 showed almost ubiquitous dry vegetation at the site. September 30, 2011 showed verdant vegetation surrounding the lagoon with patchy drier-looking vegetation farther from the lagoon. Both states (dry and verdant) are normal for their respective seasons. Water remained in the monitored lagoon throughout all of the overflights.

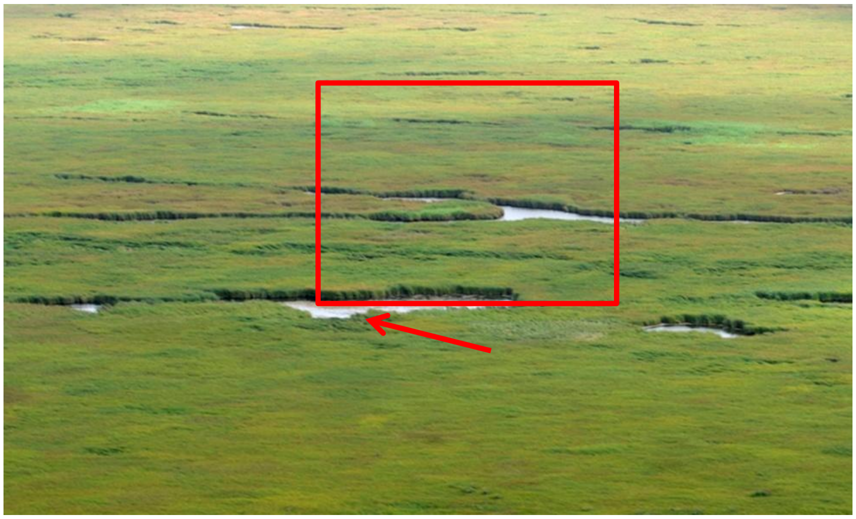
13. "Y"

The Y is s a "Y" shaped lagoon in the west-central region of the Ciénega. The two arms of the "Y" run north while the stem runs south. It is located northeast of monitoring site 15.

March 16 2011

April 13 2011

Y



September 2 2011

September 30 2011

Summary of Observations
This site fits the pattern of dry and verdant vegetation. March 2011 appeared predominantly dry whereas April 2011 appeared predominantly verdant. September 2011 continued in that direction and the site remained surrounded predominantly by verdant vegetation. Water remained in the "Y" lagoon throughout all of the overflights.

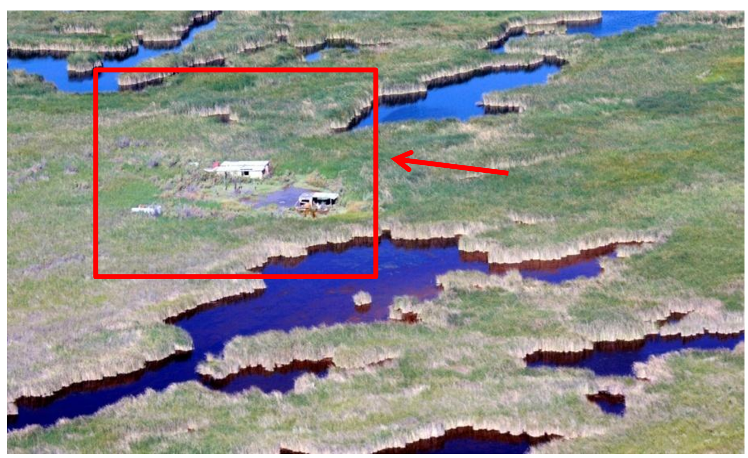
14. Hut

The hut is located in the northwest corner of the Ciénega and consists of three small structures seated on the edge of a small lagoon. A portion of these structures is visible in each of the photos below.

February 18 2010

May 5 2010

July 8 2010



Hut

March 16 2011

September 2 2011

September 30 2011

Summary of Observations
In February 2010 the vegetation surrounding the "hut" site appeared predominantly dry. With the onset of summer, May and July 2010 showed an increase in verdant vegetation. March of 2011 showed predominantly dry vegetation, as is normal for that time of year. September 2011 appeared predominantly verdant; however a large brown patch of vegetation can be seen to the northwest of the huts in both photos. Water remained present throughout all overflights.

C. Summary

Repeat oblique aerial photography from a small plane documented the spring and summer green-up and the fall and winter brown-up of the cattail. This method greatly assisted in documenting features observed in high-resolution satellite images, and was invaluable in assessing the extent and health of vegetation in areas not accessible by boat or on foot.

Chapter VI: Marsh Birds

Pronatura Noroeste conducted the marsh bird surveys in the Ciénega de Santa Clara as part of the binational monitoring program in this wetland. The overall objective of the marsh bird surveys is to detect changes in population trends and distribution of secretive marsh birds. This effort is particularly focused on the Yuma Clapper Rail, an endemic marsh bird of the Lower Colorado River and Delta, protected as endangered in the U.S. (Conway 2002) and as threatened in Mexico (DOF 2002). Surveys were conducted in 2010 and 2011 to estimate the density, abundance, population trend and distribution changes of Yuma Clapper Rails and other marsh birds in the Ciénega. This chapter presents the results from this effort.

A. Methods

In general the procedures established by the Standardized North American Marsh Birds Monitoring Protocols (Conway 2002) were followed. Since 1999 Pronatura Noroeste has been implementing the marsh bird surveys, with a monitoring design that consists of 15 transects (a total of 75 survey points; Figure 6-1; Hinojosa-Huerta et al. 2008). In addition to these existing monitoring sites, in 2010 11 new transects were added (for a total of 26 transects and 130 survey points) to create better coverage of the Ciénega (Figure 6-2).

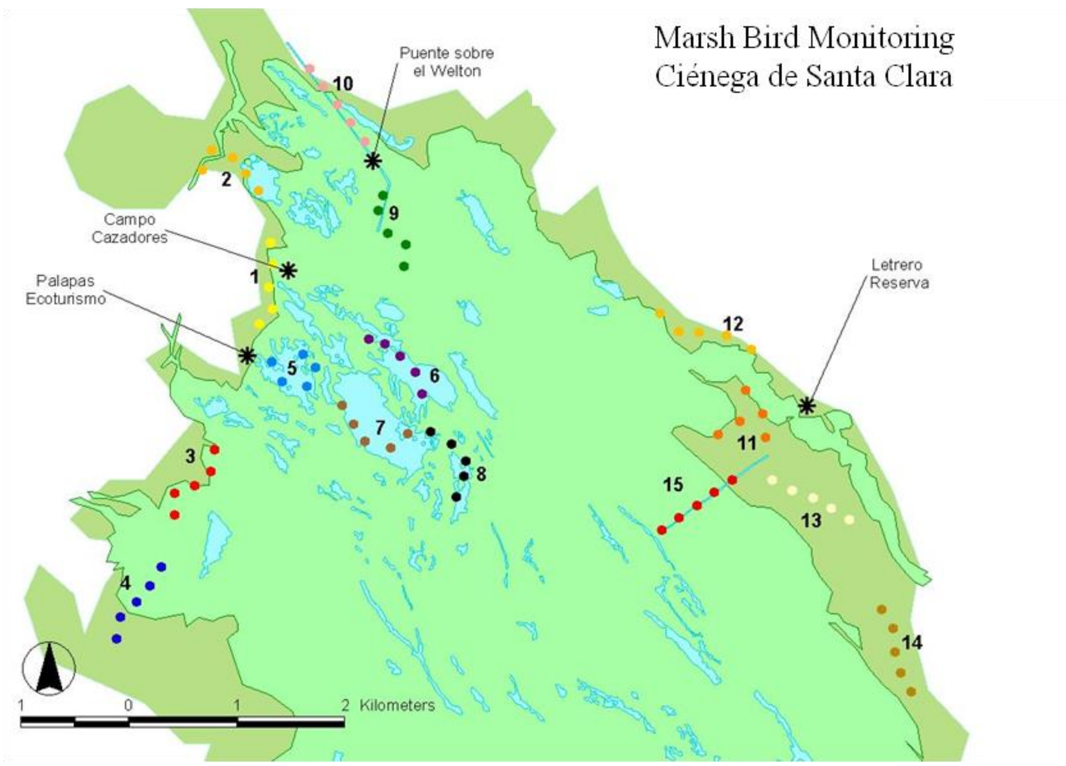


Figure 6-1. Pre-existing (1999-2009) marsh bird monitoring sites in the Ciénega de Santa Clara

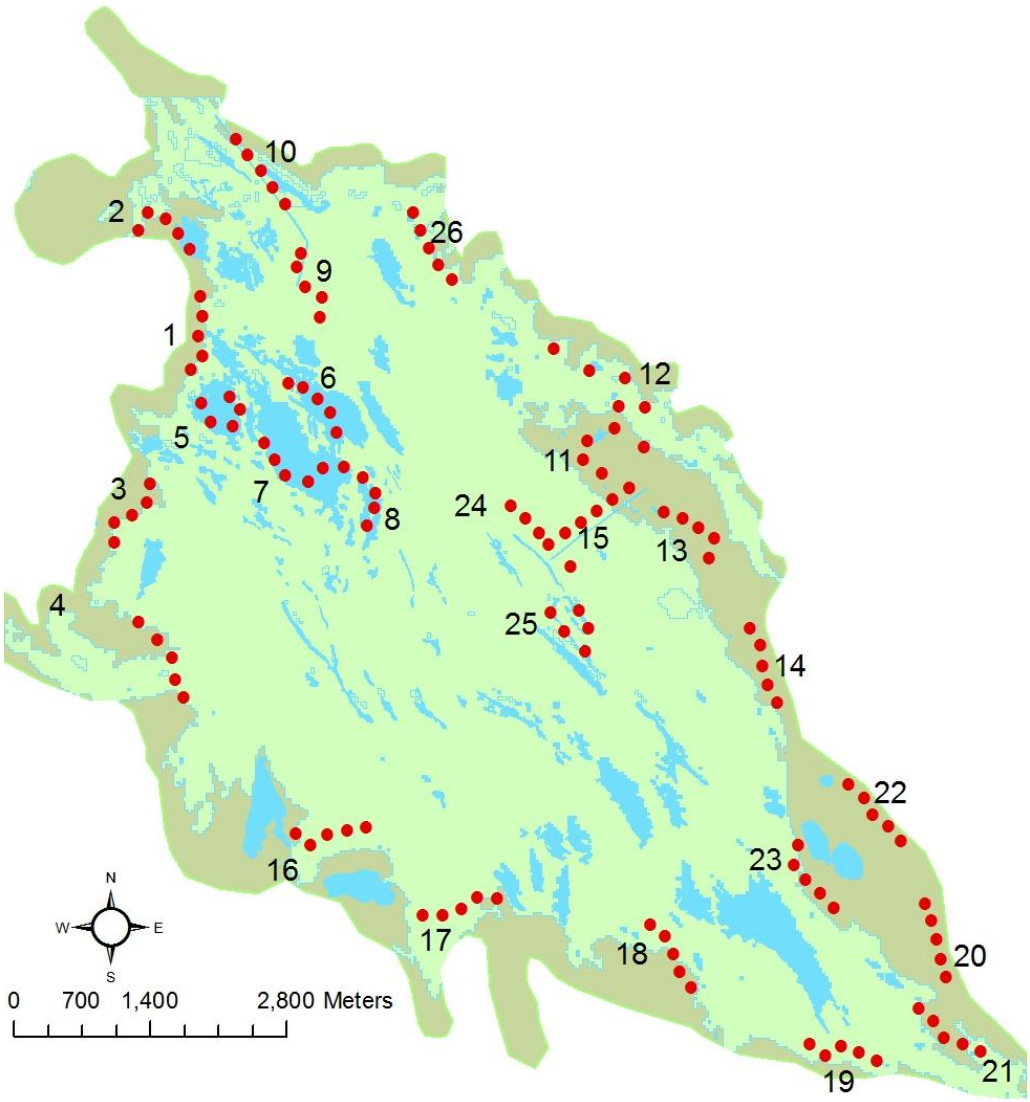


Figure 6-2. Marsh bird monitoring sites in the Ciénega de Santa Clara in 2010 and 2011.

Each site was visited three times during the 2010 breeding season: 1) March 20-April 10, 2) April 20-May 10, and 3) May 20-June 10. During the first visit only 25 transects were surveyed because cattail clumps that collapsed over a channel after the April 4, 2010 earthquake blocked access to one of the survey areas. During the second visit, only the original 15 transects were surveyed due to time constraints. During the third visit all sites were surveyed.

During 2011, each site was visited twice: 1) March 20-April 10 and 2) May 20-June 10. This frequency is the standard that we have been using since 1999, based on a statistical power analysis (Gibbs and Melvin 1997), which concluded that for the Ciénega de Santa Clara, having 15 transects visited twice per year was sufficient to detect population changes <3% per year, with a confidence level of 95% and a statistical power of 99% (Hinojosa-Huerta 2000). Contrasting the 2010 data with the 10 year dataset it was found that conducting 3 visits did not increase the statistical ability to detect population trends in the Ciénega de Santa Clara, and it was decided to continue with only 2 visits per breeding season.

B. Data Integration and Analysis

After each survey visit, the field data was integrated into a relational database in Microsoft (MS) Access. The number of Clapper Rails detected per point was used to estimate population trends, averaging the data for each transect from both early and late in the breeding season. A linear regression analysis was conducted using detections of Clapper Rails per year. A similar analysis was conducted with a particular focus on the southwestern portion of the Ciénega, where large variations in Clapper Rail abundance during the last 10 years have been detected in association with changes in water level and vegetation in the area.

The program DISTANCE (Thomas et al. 2002) was used to estimate densities of Clapper Rails, Virginia Rails and Least Bitterns. Distance models were selected using a combination of Akaike's Information Criterion (AIC), Goodness of Fit test, and the coefficient of variation in the parameter estimates (Williams et al. 2001). Estimates of abundance were obtained based on the study area of the Ciénega de Santa Clara (5,800 ha), and the 95% confidence intervals of the density estimates from DISTANCE. This estimate assumes a 100% response rate from Clapper Rails to the call-response surveys. The response rate is certainly <100%, but since no precise estimate has been obtained, we decided to use this conservative estimate.

Distribution maps for Clapper Rails, Virginia Rails, Black Rails and Least Bitterns in the Ciénega de Santa Clara were created for the sole purpose of visualizing bird densities for different species and through time. Bird densities were estimated by interpolating the point count data (average detections per point for each year), using the IDW (Inverse Distance Weighted technique) Interpolation function of Spatial Analyst Tools in ArcGis (McCoy and Johnston 2001, Fortin and Dale 2005). For each species, a raster file was generated with a cell size of 100 m, using the data from 15 neighboring points. The datum for each cell is a rough estimate that allows for a general observation of the patterns of marsh birds distribution at the Ciénega throughout the study.

C. Results

1. 2010 Breeding Season (see Appendix XI-a)

During the three surveys, 1,822 marsh birds were detected, of which 36.9% were Yuma Clapper Rails (674 individuals), 25.4% were Least Bitterns (463 individuals) and 24.8% were Virginia Rails (452 individuals, Table 6-1). During the monitoring, 23 Black Rails were detected (1.26% of detections), which is the highest number of this species ever detected in the Ciénega de Santa Clara.

Of the 328 points that were surveyed, marsh birds were detected in 313 points (95.4% of all survey points) and Yuma Clapper Rails in 239 points (72.8%). Virginia Rails were detected in 145 points (44.6%) and Least Bitterns in 178 points (54.26%). In contrast, Black Rails were detected in only 18 points (5.4%).

	Visit				
Species	I	II	III	Total	%
American Bittern	18	5	1	24	1.32
Black Rail	11	1	11	23	1.26
Clapper Rail	224	148	302	674	36.99
Least Bittern	43	99	321	463	25.41
Sora	140	45	1	186	10.21
Virginia Rail	195	88	169	452	24.81
Total	631	386	805	1822	100.00
Points with no birds	12	2	1	15	4.57

Table 6-1. Total detections of marsh birds in the Ciénega de Santa Clara during the 2010 breeding season (March-June 2010).

During the first visit, 224 Clapper Rails were detected, 148 during the second visit (in only 15 transects), and 302 during the third visit (Table 6-1). The overall average of Clapper Rails per point was 2.01 (± 0.18), with a maximum of 2.32 (± 0.25) rails per point during the third visit and a minimum of 1.72 (± 0.35) during the first visit. Considering only those transects that have been monitored since 1999, the average number of detections was 2.12 rails per point (± 0.22).

Based on the estimation with DISTANCE modeling (4 intervals at 50 m each, truncated at 200 m; Probability of Detection Model based on Half-Normal Distribution with Cosine adjustment, 2 parameters), the density of Yuma Clapper Rails in the Ciénega de Santa Clara during 2010 was 0.94 rails per ha (95% C.I. 0.73 - 1.21; GOF Chi-p=0.35, AIC=782.95). Considering that the transects are located within a study area of 5,800 ha, the estimated abundance of Yuma Clapper Rails for 2010 was 5,438 (95% C.I. 4,229 - 6,993).

2. 2011 Breeding Season (see Appendix XI-b)

During the two surveys in 2011, 1,478 marsh birds were detected of which 42.7% were Yuma Clapper Rails (631 individuals), 23.3% were Virginia Rails (345 individuals), and 20.2% were Least Bitterns (298 individuals, Table 6-2). 16 Black Rails were also detected (1.08% of detections).

Of the 250 points that were surveyed, marsh birds were detected in 238 points (95.2% of all survey points) and Yuma Clapper Rails in 202 points (77.69%), Virginia Rails were detected in 112 points (43%) and Least Bitterns in 130 points (50%).

	Visit			
Species	I	II	Total	%
American Bittern	12	26	38	2.57
Black Rail	4	12	16	1.08
Clapper Rail	257	374	631	42.69
Least Bittern	55	243	298	20.16
Sora	149	1	150	10.15
Virginia Rail	159	186	345	23.34
Total	636	842	1478	100.00
Points with no birds	7	5	12	4.61

Table 6-2. Total detections of marsh birds in the Ciénega de Santa Clara during the breeding season of 2011 (March-June 2011).

During the first visit, 257 Clapper Rails were detected while 374 were detected during the second visit (Table 6-2). The overall average of Clapper Rails per point was 2.42 (± 0.21), with a maximum of 2.87 (± 0.29) rails per point during the second visit and a minimum of 1.97 (± 0.27) during the first visit. Considering only those transects that have been monitored since 1999, the average number of detections was 2.74 rails per point (± 0.26).

Based on the estimation with Distance modeling (5 intervals at 80 m each, truncated at 400 m; Probability of Detection Model based on Half-Normal Distribution with Simple Polynomial adjustment, 3 parameters), the density of Yuma Clapper Rails in the Ciénega de Santa Clara during 2011 was 1.49 rails per ha (95% C.I. 1.33 - 1.67; GOF Chi-p=0.77, AIC=583.36). Considering that the transects are located within a study area of 5,800 ha, the estimated abundance of Yuma Clapper Rails for 2011 was 8,642 (95% C.I. 7,714- 9,686).

3. Population Trends

The number of detections, estimates of density and abundance estimates for 2010 and 2011 are within the higher range for Yuma Clapper Rails in the Ciénega. 2011 was the year with highest number of detections per point since the monitoring program was started in 1999. Considering the monitoring data from 1999 to 2011, there was no significant change in the population of Yuma Clapper Rails in 2010-2011. Yuma Clapper Rail numbers have been increasing since 2007, when there was a 30% decline from 2006 (Figure 6-3).

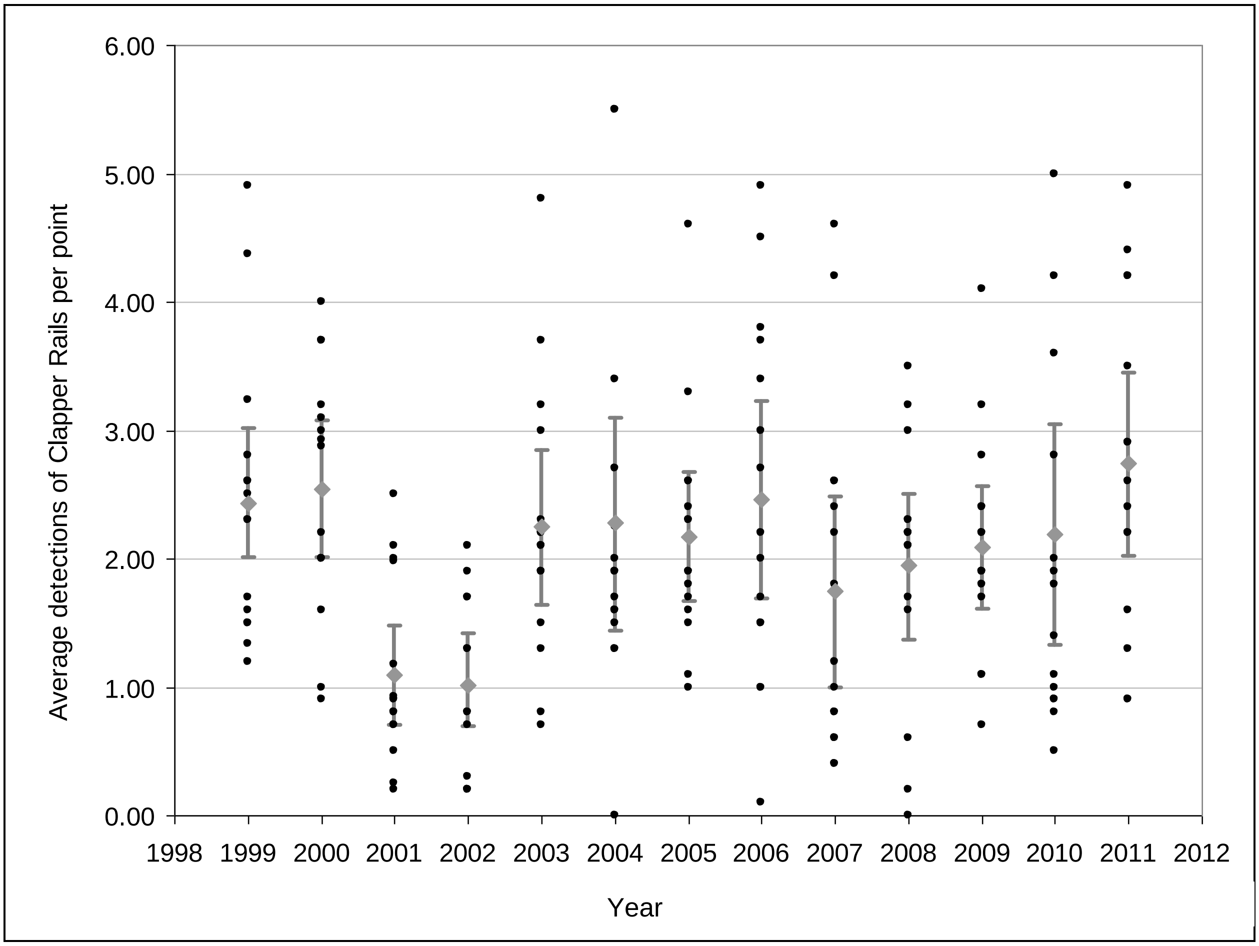


Figure 6-3. Detections of Yuma Clapper Rails in the Ciénega de Santa Clara from 1999 to 2011. Black circles indicate detections at survey transects, gray diamonds indicate the average number of detections per year, with SE bars.

Despite this relative stability in the overall number of rails in the Ciénega de Santa Clara (except during 2001 and 2002), there have been significant changes in the distribution of Clapper Rails within the Ciénega (Figure 6-4). These changes are related to fluctuations in water levels and the dynamics of the cattail vegetation, including desiccation, colonization of new patches, senescence, and rejuvenation by fire.

One evident change is in the central portion of the Ciénega, where Clapper Rail densities were reduced 54.99% from 1999-2002 (95% C.I. 33.53 – 76.45; $P < 0.001$, $\beta = 0.99$), apparently in relation to cattail senescence. This area again showed a high density in 2008, after the vegetation was rejuvenated after large fires in 2003 and 2004.

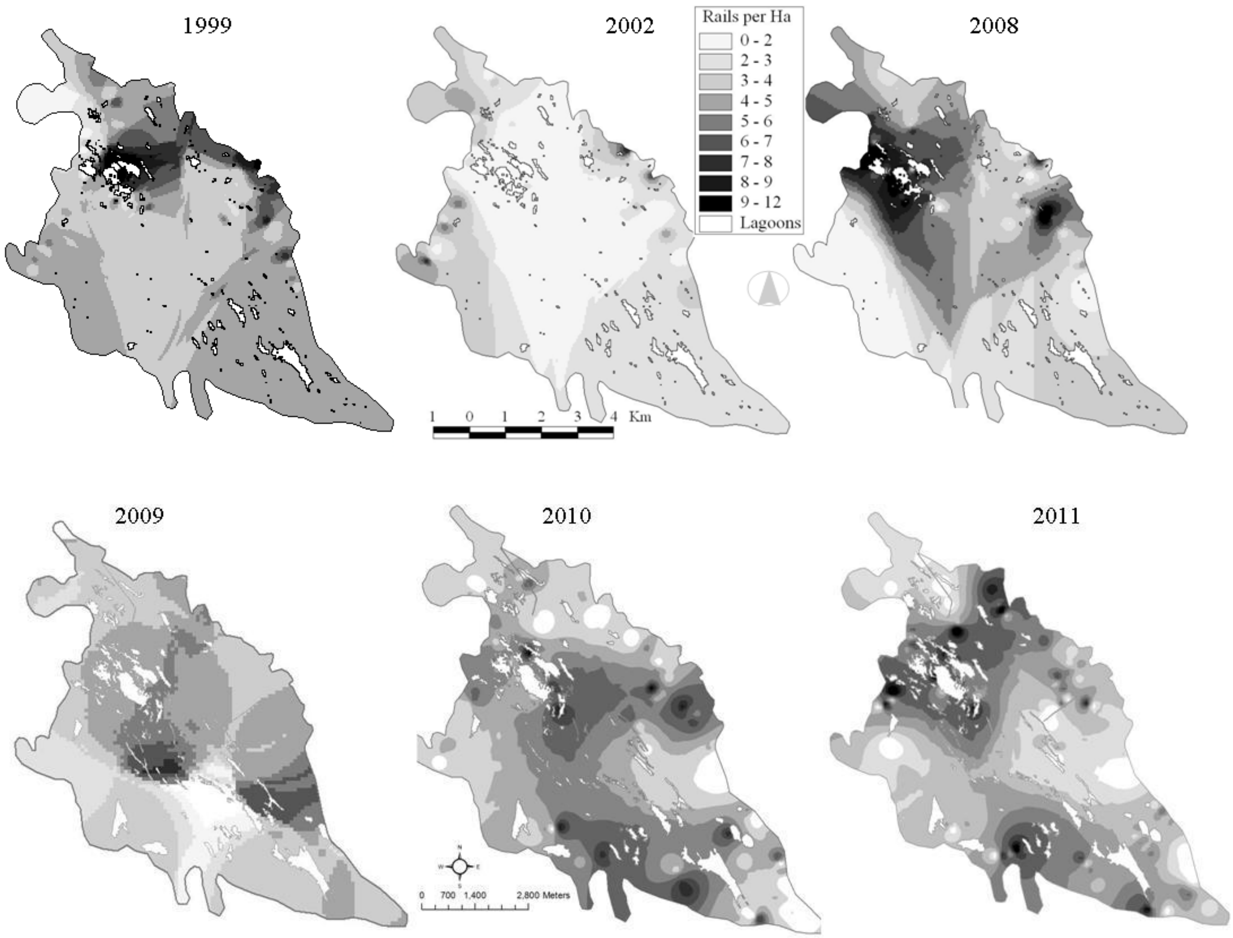


Figure 6-4. Density distribution of Yuma Clapper Rails in the Ciénega de Santa Clara from 1999 to 2011. Clapper Rail densities were interpolated from count data using ArcGIS.Maps for 1999-2009 are based on transects in the northern portion of the Ciénega only (see Figure 6-1). The interpolations are estimates that allow for a general observation of the patterns of Clapper Rail distribution at the Ciénega throughout the study.

Another change has been occurring in the southwestern portion of the Ciénega. From 1999 to 2008 there was a reduction of Clapper Rails in this area at a rate of 23% per year (± 4.10, $r^2 = 0.79$, $p < 0.0001$, $\beta = 0.99$); this dropped from an average detection of 2.56 rails per point in 2000 to an average detection of 0.10 rails per point in 2008 (Figure 6-5).

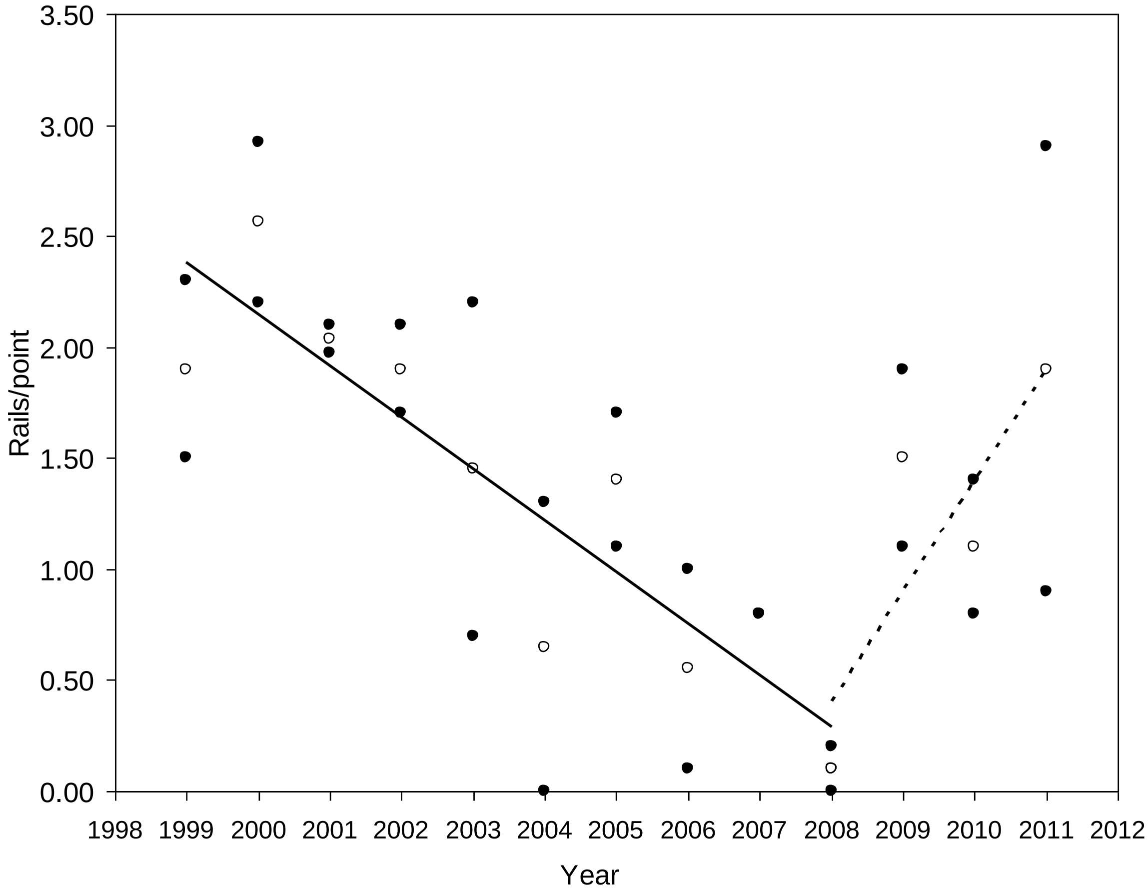


Figure 6-5. Population trend of Yuma Clapper Rails in the southwestern portion of the Ciénega de Santa Clara (transects 3 and 4). The solid line indicates the regression curve of the population trend between 1999 and 2008. The dotted line indicates the regression curve of the population trend between 2008 and 2011.

This change was related to a decrease in water levels due to sediment build up at the discharge point of the Bypass Drain, which caused the local desiccation of the marsh (Figure 6-6). The vegetation analysis conducted by E.P. Glenn indicates that 940 ha dried up in this portion between 2005 and 2008. Based on our estimates of changes in Clapper Rail densities in the area, this probably represented a localized population decrease between 730 and 1,220 rails.

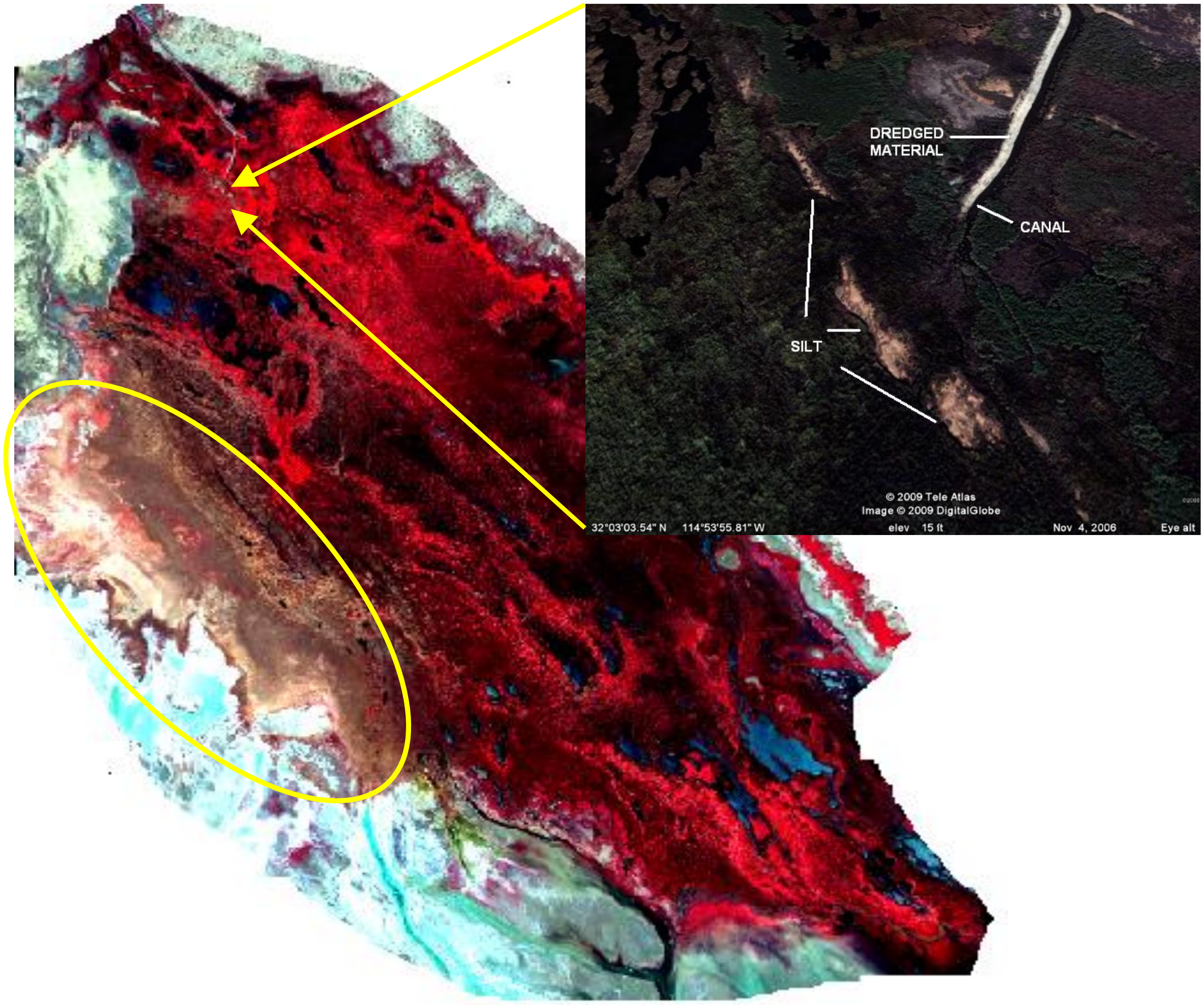


Figure 6-6. Landsat image of the Ciénega de Santa Clara (July 2006), showing the local desiccation of the marsh on the western portion of the Ciénega (inside circled area). The smaller picture shows the sediment build-up that was removed in 2009.

The sediment build-up was removed in the winter of 2008-2009 and additional dredging was conducted during 2010 in the MODE canal and Santa Clara drain. These actions allowed more water to reach the southwestern portion of the Ciénega. Since then the vegetation and population of Yuma Clapper Rails has been recovering at a rate of 50% per year (± 14.79, $r^2 = 0.23$, $p < 0.0017$, $\beta = 0.91$), with average detections of 1.10 and 1.90 rails/point in 2010 and 2011 respectively (Figure 6-5).

During 2010, the highest densities of Yuma Clapper Rails were detected in the lagoons of the western-central part of the Ciénega; in the eastern section in the area known as Flor del Desierto; and in the south edge, tending towards the east (Figure 6-7). The pattern was similar during 2011, although higher densities were observed towards the north-central portion of the Ciénega.

D. Status of Other Marsh Birds in the Ciénega

The Ciénega de Santa Clara also provides important habitat for other marsh birds, including Virginia Rails, Black Rails and Least Bitterns. Both Virginia Rails and Least Bitterns are abundant in the Ciénega. Virginia Rails increase their numbers with winter migrants, but there is a local resident population. Their estimated abundance is 7,150 individuals (95% C.I. 5,831 - 8768). Although they are abundant, the species could be more vulnerable to changes in water levels, as they prefer shallower habitats in the edge of the marsh (Figure 6-7). The Virginia Rail is listed as threatened in Mexico and is a priority species in the LCR MSCP (DOF, 2002, Lower Colorado River Multi-Species Conservation Program, 2004).

Least Bitterns prefer the central portions of the Ciénega near deeper water (Figure 6-7). Their estimated abundance is 8,652 individuals (95% C.I. 7,238 - 10,342). Least Bitterns are breeding visitors in the Ciénega and migrate south during winter. The species is a priority in the LCR MSCP (Lower Colorado River Multi-Species Conservation Program, 2004).

California Black Rails are one of the rarest marsh birds in North America. Their populations in all of North America have decreased drastically in the last decades, especially the inland populations that are limited to the Lower Colorado and its delta (Eddleman et al. 1994). This subspecies is listed as endangered in Mexico and is a priority in the LCR MSCP (DOF, 2002, Lower Colorado River Multi-Species Conservation Program, 2004). In general, Black Rails prefer wetland sites with shallow (0-5 cm) and stable water levels, with short emergent vegetation (bulrush and sedges instead of cattail) and near upland vegetation (Flores and Eddleman 1995). In the Ciénega, this is limited to a few places which are vulnerable to flow fluctuations and the presence of cattle (Figure 6-7). Black Rails are resident in the delta and their estimated abundance in the Ciénega is 405 individuals (95% C.I. 205-800

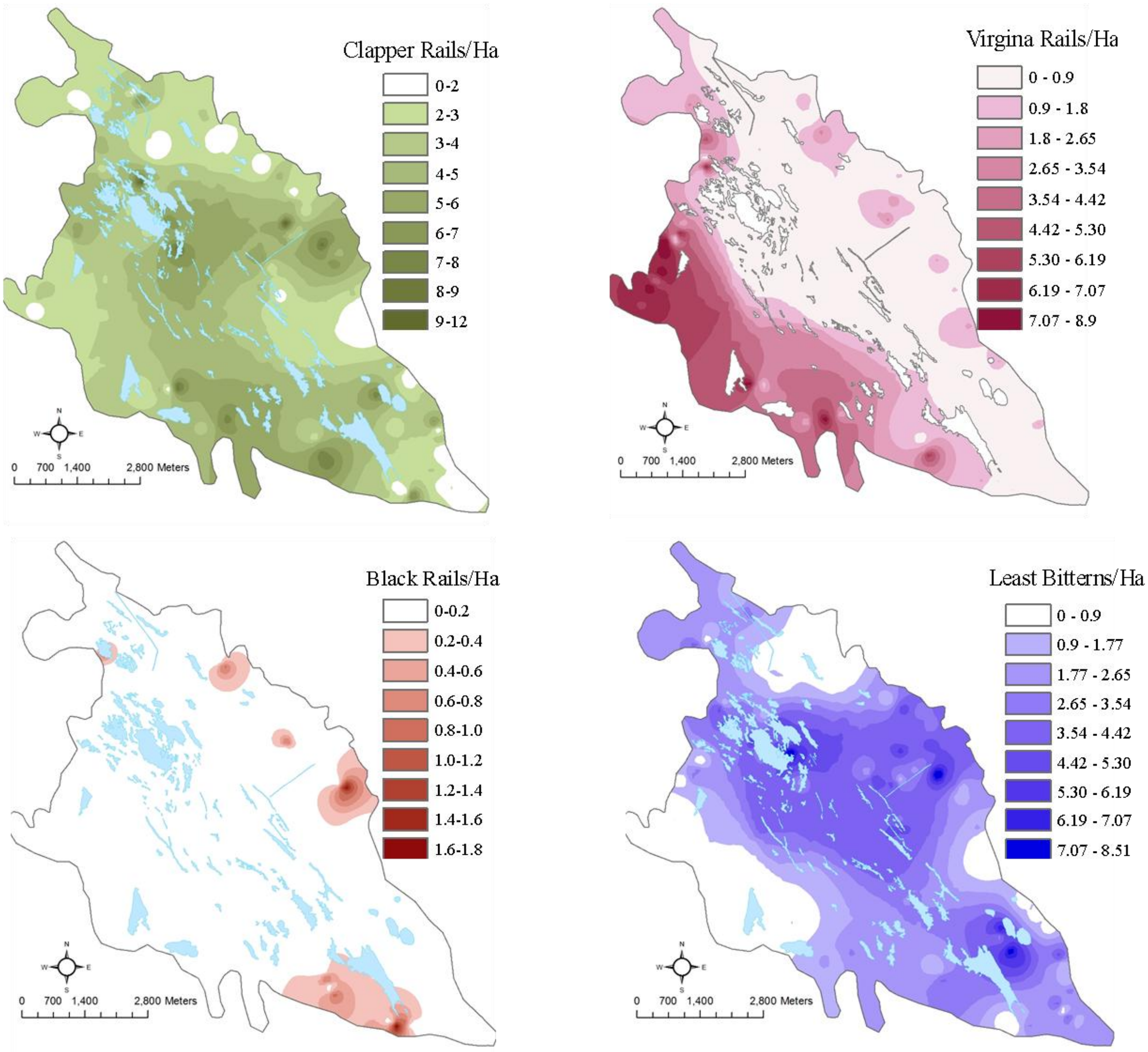


Figure 6-7. Density distribution of Yuma Clapper Rails, Virginia Rails, Black Rails and Least Bitterns in the Ciénega de Santa Clara during 2010. Bird densities were interpolated from count data using ArcGIS.

E. Summary

This report provides information on the status and trends of marsh birds from 1999 to 2011 in the Ciénega de Santa Clara. The detections of Yuma Clapper Rails, and therefore population estimates, were higher during 2011 than in any other year during the monitoring period, and numbers have been increasing since 2007. During this time, several events have occurred in the Cienega, including the dredging of sediments, an earthquake, variations on input flows from the Bypass Drain, and a major fire. It is difficult to pinpoint the exact significance of each event on the population of marsh birds, but at least it is apparent that this level of disturbance creates a dynamism in the marsh that promotes the regeneration and diversity of the emergent vegetation, which in turn results in greater densities of Yuma Clapper Rails.

For these species, changes in the wetland ecosystem are not usually reflected in their populations at the time the changes occur, but are reflected in the population numbers in subsequent years. This occurs because changes such as fire, fluctuations in water levels, or wetland desiccation usually represent a low mortality risk for adult birds, but might cause the degradation or improvement of breeding habitat quality, with positive or negative effects on nesting success and mortality rates of chicks and juvenile birds (Eddleman and Conway 1998).

In this sense, the effects of the earthquake, the operation of the Yuma Desalting Plant, the allocation of replacement water, the dredging projects and the fire may not have been fully expressed during 2010 and 2011, but rather may become apparent as changes in populations in subsequent years. Monitoring efforts are planned to continue in order to track these changes.

Chapter VII: Summary of Results

The Ciénega de Santa Clara is a wetland in the Colorado Delta in Sonora, Mexico that receives brackish groundwater from the Wellton-Mohawk Irrigation and Drainage District (WMIDD) in Arizona via the Main Outlet Drain Extension (MODE) and Bypass Drains. The Ciénega de Santa Clara provides habitat for fish and for migratory and resident birds. Two listed species inhabit the Ciénega de Santa Clara: the Yuma Clapper Rail (Endangered in the U.S.; threatened in Mexico) and the desert Pupfish (Endangered in both the U.S. and Mexico). The Ciénega de Santa Clara lies within the boundaries of a protected area in Mexico – the Upper Gulf of California and Colorado River Delta Biosphere Reserve.

We monitored a ~6,000 hectare area of the Ciénega de Santa Clara characterized by emergent vegetation and associated open-water areas in the vicinity of, and south of, the ends of the Bypass and Santa Clara-Riito drains. Monitoring was conducted from December 2009 until June 2011 – from about three months before until three months after the pilot operation of the Yuma Desalting Plant (YDP). During this pilot run, some water that would have gone to the Ciénega de Santa Clara was diverted to the YDP and brackish effluent was delivered to the Ciénega de Santa Clara via the Bypass Drain in exchange for the YDP diversions. Other events that may have affected the Ciénega de Santa Clara during that time included an earthquake, ~30,000 acre-feet (37 mcm) of arranged water and an extensive fire.

Our binational monitoring program characterized the topography and bathymetry of the Ciénega de Santa Clara, monitored water flow, water elevation, water quality, vegetation extent, seasonal and other changes in vegetation, and marsh bird populations.

A. Bathymetry and Hydrology

The study area consists of a shallow (generally less than 1 m deep), NNW-SSE trending basin that is sharply defined along its eastern margin by an upland area and slopes gently toward a low divide with marine tidal flats to the west. Within the basin, bathymetry is irregular, consisting of small connected basins and vegetated divides draining to the SSE. At least 90% of the annual inflow to the Ciénega de Santa Clara is delivered by the Bypass Drain. Inflow from the Santa-Clara-Riito Drain is approximately 10% of the total inflow.

Three different approaches to estimating evapotranspiration yield estimates of 86,000 af (106 mcm), 58,098 af (73 mcm) or 69,153 af (85 mcm) lost to evapotranspiration each year. Considering an average annual flow of 110,000 af [136 mcm] these estimates suggest that approximately 78%, 53% or 62%, respectively, of the total inflow to the Ciénega is lost to evapotranspiration. This suggests that from 22% to 47% of the incoming water exits the Ciénega into the adjacent mudflats and especially into the tidal basin at the southern end of the Ciénega. Much of this discharge occurs in winter when *Typha* plants are dormant and ET is low. This wintertime drainage prevents the buildup of salts in the Ciénega by flushing the more saline water into the basin to the south.

B. Water Quality

Total Dissolved Solids (TDS) values were lower in the Bypass Drain than in the Santa Clara-Riito Drain. Within the Ciénega de Santa Clara, TDS values varied at several sites during the monitoring period. The most common pattern was an increase in the spring and summer of 2010. Spring and summer increases of these magnitudes were not observed at the same sites in spring and summer periods dating back to summer 2006. This pattern occurred both at sites in the interior of the Ciénega and sites near the Ciénega's margin. The increases were roughly coincident with the operation of the YDP when little or no arranged water was delivered to the Bypass Drain.

Water temperatures increased during summer and dissolved oxygen deceased. pH did not vary with seasons.

Some sites showed elevated (>chronic; U.S. National Oceanographic and Atmospheric Administration standards) selenium values in both February 2010 and February 2011. Mercury concentrations were below the U.S. National Irrigation Water Quality (NIWQP) toxicity threshold values in sediment and fish tissue in both February 2010 and 2011, but all ten sediment values were above NIWQP toxicity thresholds established for habitats of a different clapper rail species in San Francisco Bay. Arsenic concentrations in water were not above the NIWQP toxicity threshold in any sites in 2010 but were above them in five of ten sites in 2011. Arsenic in sediment was below the NIWQP toxicity threshold in all ten sites in February 2010 but exceeded the threshold in two out of ten sites in 2011.

Selenium values in water at some localities exceeded chronic (6 localities out of 10) or acute (3 out of 10) thresholds in February 2010. Selenium values in water at seven localities (out of 10) exceeded the chronic threshold but none exceeded the acute threshold in February 2011. Selenium concentrations in edible tissue of largemouth bass were all below the 4 mg/kg toxicity threshold.

Concentrations in largemouth bass tissue were under US (FDA) and Mexican toxicity thresholds. Lead, cadmium and copper were under detection limits in water, sediment and largemouth bass tissue at all sites in both February 2010 and February 2011. The pesticides most frequently detected in water were pp-DDT, endosulfan sulphate, heptachlor and the BHC´s and in sediment they were trans-chlordane, heptachlor epoxide, pp-DDT, endosulfan sulphate, pp-TDE, and BHC alpha. The organophosphate pesticides, pyrethroid pesticides and PCBs were under detection limits in samples of water, sediment and fish. No organochlorine compounds were detected in edible tissue of largemouth bass, although they were detected in other species at low concentrations in 2010. *E. coli* concentrations above U.S. EPA water quality standards were detected in Bypass Drain water at one sampling. Nutrient (N, P) concentrations decreased inside the Ciénega and the water was generally clear.

C. Changes in Vegetation over Seasons and Years 2008–2011

The extent of the vegetated marsh area in the Ciénega was stable (6530-6540 ha using the unsupervised method) but the density of vegetation showed changes. The September 2008 image shows an area of low vegetation density in the western arm of the Ciénega. This was also noted in ground surveys and was thought to be due to a diversion of water flow caused by the buildup of silt at the end of the Bypass Drain. CONAGUA subsequently dredged the area and restored flow to the west.

The winter images used in the unsupervised classification (February 2009 and January 2010 images) show stable patches of green vegetation at the end of the Bypass Drain and along the western perimeter of the vegetated area. Aerial photographs show these are mostly due to patches of *Phragmites australis* (common reed), which remain green in winter, whereas the dominant *Typha domengensis* (southern cattail) is dormant in winter.

The July 2010 image shows apparent diminished vegetation intensity based on the supervised classification. The most intensely green vegetation category was reduced from 406 ha in September 2008 and 419 ha in August 2009, to 150 ha in July, 2010. This change is not as evident in the supervised classification.

A fire burned nearly all of the Ciénega de Santa Clara the few days around March 23, 2011. By April 27, the WorldView2 satellite image showed rapid re-greening of the marsh vegetation, similar to April images in earlier years. The October 2011 image showed that the full area of the Ciénega was once again vegetated, illustrating the resilience of the vegetation in this wetland.

The accumulation of thatch (dormant and dried cattail) is one of the most important factors controlling green foliage density and ET from year to year. As thatch increases, ET and green foliage density decrease. Buildup of thatch provides fuel for fires that re-invigorate the vegetation.

D. Oblique Aerial Photography

Repeat oblique aerial photography from a small plane documented the spring and summer green-up and the fall and winter brown-up of the cattail, greatly assisted in documenting features observed in high-resolution satellite images, and was invaluable in assessing the extent and health of vegetation in areas not accessible by boat or on foot.

E. Marsh Birds

This report provides information on the status and trends of Ciénega de Santa Clara marsh birds from 1999 to 2011. Population size of Yuma Clapper Rails – as measured by the number of detections, were higher during 2011 than in any other year during the monitoring period. Numbers have been increasing since 2007. Disturbances of various kinds have occurred during this time, including the dredging of sediments, an earthquake, variations of inflows, and a major fire. Although it is difficult to pinpoint the significance of each event on the population of marsh birds, it appears that disturbance can promote the regeneration and diversity of the emergent vegetation, which in turn results in greater densities of Yuma clapper rails.

With regards to marsh birds that breed in the Ciénega de Santa Clara, changes in the environment may not immediately cause changes in population size. Changes may occur in subsequent years. This occurs because changes such as fire, fluctuations in water levels, or wetland desiccation my not significantly affect mortality in adult birds, but cause degradation or improvement of breeding habitat quality, with positive or negative effects on nesting success and mortality rates of chicks and juvenile birds.

For this reason, the effects of the earthquake, the operation of the Yuma Desalting Plant, the arranged water, the dredging projects and the fire may not have been fully expressed during 2010 and 2011, but could occur in subsequent years. Pronatura Noroeste plans to maintain the marsh bird monitoring efforts in order to track any such changes.

F. Conclusion

The short-term changes associated with the pilot operation of the YDP accompanied by the ~30,000 af of arranged water did not cause significant changes to the features of the Ciénega de Santa Clara monitored during the period of this study. The Ciénega de Santa Clara appears to be an ecosystem that is resilient in the face of short-term disturbances and minor changes in water quality and quantity, minor changes in drainage resulting from earthquakes, and fire.

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