Factors Affecting Marsh Vegetation at the Liberty Island Conservation Bank in the Cache Slough Region of the Sacramento–San Joaquin Delta, California

Open-File Report 2017–1077

U.S. Department of the Interior
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Front cover. North Little Holland Tract marsh.
Back top. U.S. Geological Survey personnel collecting samples at the Liberty Island Conservation Bank.
Back bottom. Vegetation at the Liberty Island Conservation Bank.

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By James L. Orlando and Judith Z. Drexler

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Conversion Factors

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
micrometer (µm)	0.0003937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Area	
hectare (ha)	2.471	acre
square meter (m^2)	0.0002471	acre
	Volume	
liter (L)	33.81402	ounce, fluid (fl. oz)
liter (L)	0.2642	gallon (gal)
liter (L)	61.02	cubic inch (in^3)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F = (1.8 \times °C) + 32.$$

Datum

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Supplemental Information

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 °C).

Concentrations of chemical constituents in water are given in either milligrams per liter (mg/L) or nanograms per liter (ng/L).

Abbreviations

3,4-DCA	3,4-dichlooraniline
ANOVA	analysis of variance
CUP	Current-use Pesticide
DCPMU	N-(3,4-Dichlorophenyl)-N′-methylurea
GC/MS	gas chromatograph mass spectrometer
LC/MS/MS	liquid chromatography tandem mass spectrometry
LICB	Liberty Island Conservation Bank
OCRL	Organic Chemistry Research Laboratory
QC	quality control
RTK-GPS	real-time kinematic global positioning system
USGS	U.S. Geological Survey

Factors Affecting Marsh Vegetation at the Liberty Island Conservation Bank in the Cache Slough Region of the Sacramento–San Joaquin Delta, California

By James L. Orlando and Judith Z. Drexler

Abstract

The Liberty Island Conservation Bank (LICB) is a tidal freshwater marsh restored for the purpose of mitigating adverse effects on sensitive fish populations elsewhere in the region. The LICB was completed in 2012 and is in the northern Cache Slough region of the Sacramento–San Joaquin Delta. The wetland vegetation at the LICB is stunted and yellow-green in color (chlorotic) compared to nearby wetlands. A study was done to investigate three potential causes of the stunted and chlorotic vegetation: (1) improper grading of the marsh plain, (2) pesticide contamination from agricultural and urban inputs upstream from the site, (3) nitrogen-deficient soil, or some combination of these. Water samples were collected from channels at five sites, and soil samples were collected from four wetlands, including the LICB, during the summer of 2015. Real-time kinematic global positioning system (RTK-GPS) elevation surveys were completed at the LICB and north Little Holland Tract, a closely situated natural marsh that has similar hydrodynamics as the LICB, but contains healthy marsh vegetation.

The results showed no significant differences in carbon or nitrogen content in the surface soils or in pesticides in water among the sites. The elevation survey indicated that the mean elevation of the LICB was about 26 centimeters higher than that of the north Little Holland Tract marsh. Because marsh plain elevation largely determines the hydroperiod of a marsh, these results indicated that the LICB has a hydroperiod that differs from that of neighboring north Little Holland Tract marsh. This difference in hydroperiod contributed to the lower stature and decreased vigor of wetland vegetation at the LICB. Although the LICB cannot be regraded without great expense, it could be possible to reduce the sharp angle of the marsh edge to facilitate deeper and more frequent tidal flooding along the marsh periphery. Establishing optimal elevations for restored wetlands is necessary for obtaining the full suite of ecosystem services provided by tidal wetlands. A better system of tidal benchmarks throughout the delta is needed to help restoration practitioners correctly grade the elevation of newly restored wetlands.

Introduction

Background

The Liberty Island Conservation Bank (LICB) is in the Cache Slough region of the Sacramento–San Joaquin Delta (fig. 1). The project is a fish mitigation bank, which is a wetland area restored for the purpose of providing compensation as required by state or federal law for unavoidable, adverse effects on sensitive fish populations from projects in the region. It was created with two primary goals: (1) to preserve, restore, and enhance 67.2 hectares of wildlife habitat and (2) to provide improvements to flood capacity and levee stability (Wildlands, Inc., 2009). As part of the restoration, the project included grading of 21.8 hectares to construct channels (2.7 hectares), emergent marsh (13.8 hectares), and riparian habitat (1.1 hectares). In addition, 366 linear meters of levee were graded to sustain wetland vegetation (Wildlands, Inc. 2009). The project was completed in 2012.

In August of 2014, we noticed that dominant wetland plants at the LICB were shorter than those in nearby natural marshes and were yellow, or “chlorotic,” in contrast to the deep-green plants in neighboring marshes. In September of 2014, we compared the stem height and diameter of *Schoenoplectus californicus* (*S. californicus,* California bulrush), a common tidal marsh species throughout Cache Slough, in the LICB to that of bulrushes in three nearby marshes (north Little Holland Tract, south Little Holland Tract, and south Prospect; fig. 1). We collected five plants from each of three well-dispersed 1-square meter (m^2) plots in each of the three nearby marshes. Because of the extensive presence of *Typha* species (cattails) at the LICB, we could not find enough *S. californicus* to measure plant height and diameter in plots, so we measured plants along three transects through the marsh. We analyzed the stem length and diameter data using one-way analysis of variance (ANOVA) and did post hoc pairwise comparisons using the Bonferroni method.

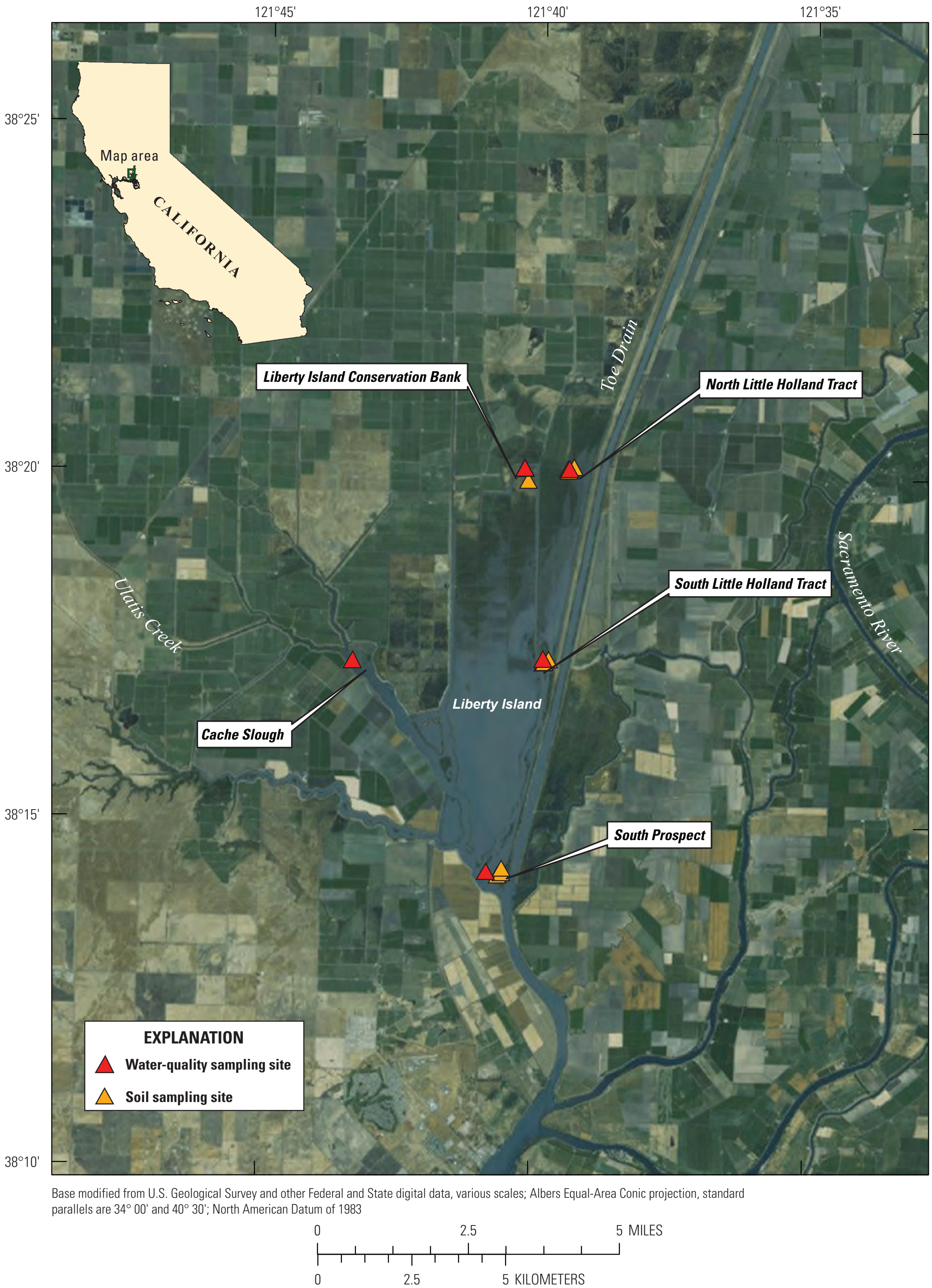

Figure 1. Marsh soil and water-quality sampling sites in the Cache Slough region of the Sacramento–San Joaquin Delta.

For both parameters, the one-way ANOVA was significant (*p* less than 0.0001), and the post hoc analyses indicated that shoot length and stem diameter of *S. californicus* plants were less at the LICB than at the other three sites (figs. 2, 3). In addition, vegetation at the LICB was chlorotic (of a yellow color) compared to the green (healthy) vegetation at the other nearby sites.

Purpose and Scope

The observations made in 2014 spurred a new study that is described in this report to determine the cause for the stunted and chlorotic vegetation at the LICB. Although we considered many possibilities, this report explains the stunted and chlorotic vegetation at LICB in relation to three potential causes: (1) improper grading of the marsh plain, (2) contamination by pesticides applied to agricultural and urban areas upstream from the site, and (3) nitrogen-deficient soil. We focused on these potential causes for the following reasons. We chose improper grading because, during flood tide, the marsh plain was not flooded to the same depth as in nearby marshes, indicating that the LICB is likely to have a different hydroperiod (the frequency and extent of tidal inundation during a season or longer) compared with that of nearby marshes. Hydroperiod is the chief variable determining the elevation suitable for plant growth in a tidal marsh (Mitsch and Gosselink, 2000). We considered the effect of herbicides on marsh vegetation because of the intensity of pesticide use upstream from the LICB (California Department of Pesticide Regulation, 2015). Lastly, we considered the nitrogen content of the soil, because chlorotic marsh vegetation could be a sign of nitrogen deficiency (Pilbeam, 2015). The study used soil and water samples collected in 2014 or 2015 from four marshes and analyzed for carbon and nitrogen in soil and for pesticides in water. Topographic data for the LICB and a nearby marsh also were measured.

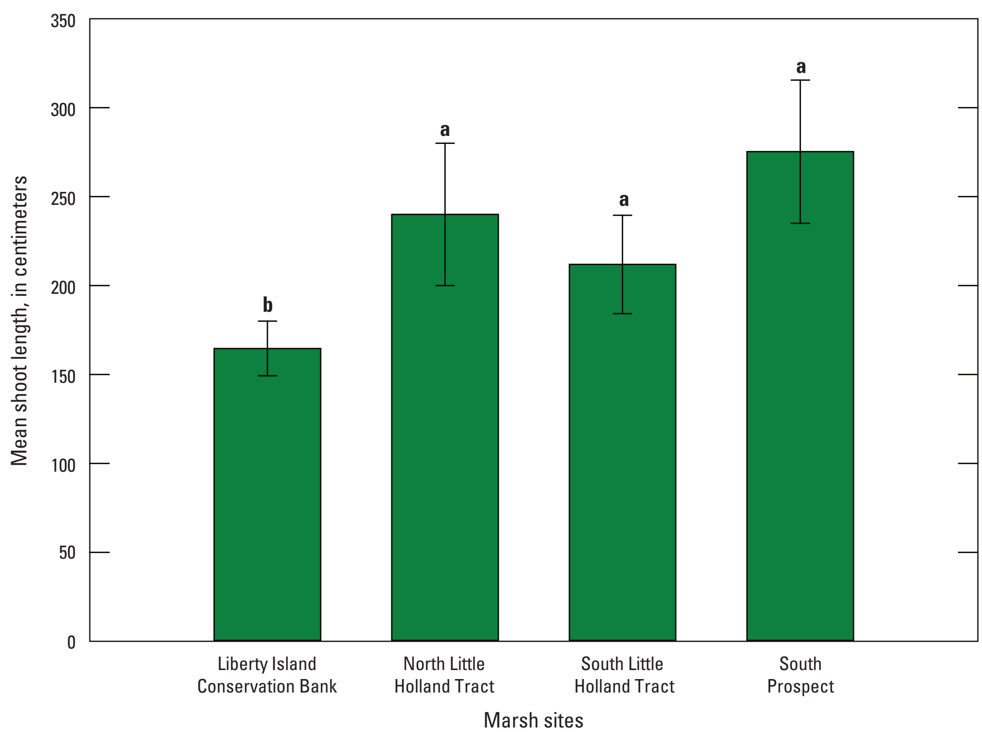

Figure 2. Mean shoot length of California bulrush (*Schoenoplectus californicus*) collected from four marsh sites in the Cache Slough region of the Sacramento–San Joaquin Delta during September 2014. Letters indicate significant differences among sites from a one-way analysis of variance (ANOVA) and post hoc pairwise comparisons by the Bonferroni method (*p* less than 0.0001 for the one-way ANOVA and post hoc comparisons. Vertical bars represent plus and minus one standard deviation error).

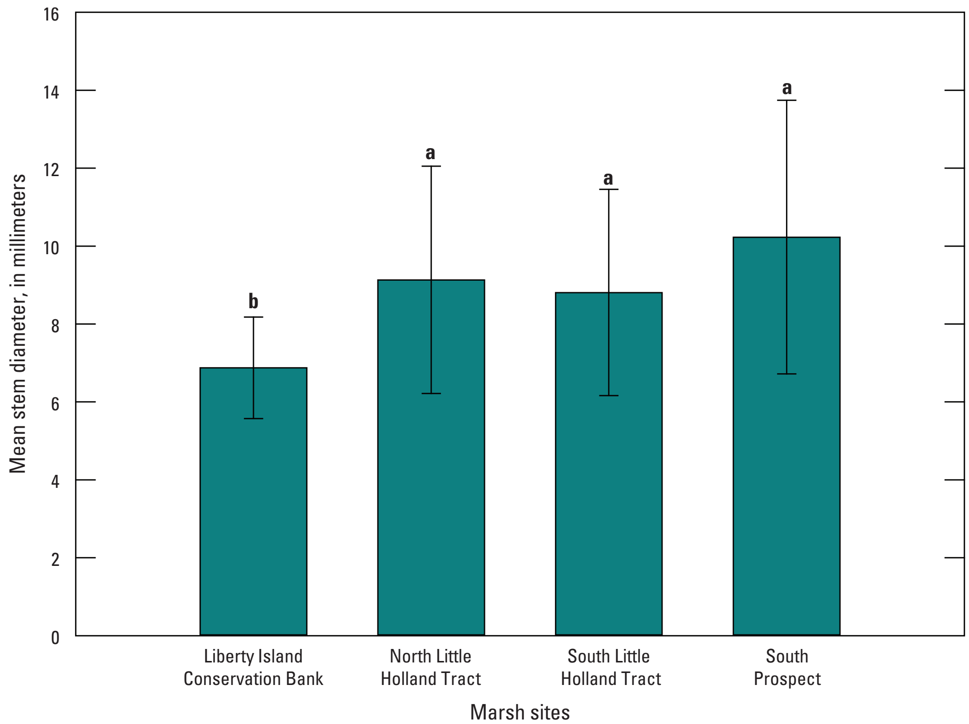

Figure 3. Mean stem diameter of California bulrush collected from four marsh sites in the Cache Slough region of the Sacramento–San Joaquin Delta during September 2014. Letters indicate significant differences among sites from a one-way analysis of variance (ANOVA) and post hoc pairwise comparisons by the Bonferroni method (p less than 0.0001 for the one-way ANOVA and post hoc comparisons. Vertical bars represent plus and minus one standard deviation error).

Field and Laboratory Methods

The approach for this study included three parts: (1) an elevation survey of the marsh plain in the LICB and north Little Holland Tract (the closest marsh in the most similar hydrodynamic setting in northern Cache Slough region), (2) an analysis of carbon and nitrogen in soil samples collected in each of the four wetland sites in September 2014, and (3) water sampling and analysis for pesticides during the summer of 2015.

Elevation Survey

An elevation survey was carried out in November 2015 using RTK-GPS (real-time kinematic global positioning system) in north Little Holland Tract and the LICB. A Trimble R7 GNSS receiver and Zephyr model 2 antenna on a 2-meter, fixed-height tripod were used to collect static data (base station), and a Trimble R8 GNSS model 3 receiver on a 2-meter, fixed-height, carbon-fiber rod (rover unit) was used to collect location data at the marsh sites. A Trimble TDL450H was used for radio communication between the base station and rover units, and data were collected using a Trimble TSC3 hand-held unit. Location and elevation measurements were collected at approximately 3-meter intervals on multiple transects at two marsh sites (north Little Holland Tract and the LICB). Each transect extended from the marsh and waterway interface to the marsh plain, and each transect varied in length. At north Little Holland Tract, 4 transect lines were sampled for a total of 41 measurement points, whereas at the LICB, 5 transect lines were sampled for a total of 72 measurement points.

Soils

The top 4 centimeters (cm) of soil were collected in 9-cm-diameter, aluminum sample containers in three locations in each of the four sites (LICB, north Little Holland Tract, south Little Holland Tract, and south Prospect marshes; table 1) during September 2014. The sample container was pushed 4 cm into the soil surface, and a metal spatula was used to dig into the soil and cut away the bottom of the sample from the underlying soil. Soil samples were sealed in their containers and transported on wet ice to the U.S. Geological Survey (USGS) laboratory in Sacramento, California, where they were stored at 3 degrees Celsius (°C). Soil samples were then dried in ovens at 60 °C, weighed, and subsequently ground to 2 millimeters.

Total percentages, by weight, of carbon, organic carbon, nitrogen, and organic nitrogen were determined using a Perkin Elmer CHNS/O elemental analyzer (Perkin Elmer Corporation, Waltham, Mass.), which was calibrated with blanks and acetanilide standards before use, according to a modified version of U.S. Environmental Protection Agency Method 440.0 (Zimmerman and others, 1997).

Table 1. Surface-water and soil sampling sites in the Cache Slough region of the Sacramento–San Joaquin Delta, California.

[dd, decimal degrees; NA, not applicable; NAD 83, North American Datum of 1983; USGS, U.S. Geological Survey]

USGS station number	USGS station name	Marsh	Marsh type	Sample types collected	Latitude (dd)	Longitude (dd)	Horizontal datum
381719121432301	Cache Slough at Hass Slough near Liberty Farms, CA	NA	NA	Surface water	38.28838	–121.72302	NAD 83
382006121401601	Liberty Island at Liberty Cut near Courtland, CA	Liberty Island Conservation Bank (LICB)	Restored marsh	Surface water	38.33501	–121.67111	NAD 83
382006121401701	Liberty Island Marsh Site 1 near Courtland, CA	Liberty Island Conservation Bank (LICB)	Restored marsh	Soil	38.33487	–121.67148	NAD 83
381955121401301	Liberty Island Marsh Site 2 near Courtland, CA	Liberty Island Conservation Bank (LICB)	Restored marsh	Soil	38.33203	–121.67025	NAD 83
382006121401602	Liberty Island Marsh Site 3 near Courtland, CA	Liberty Island Conservation Bank (LICB)	Restored marsh	Soil	38.33502	–121.67123	NAD 83
382005121392801	Little Holland Tract near Courtland, CA	North Little Holland Tract	Remnant natural marsh	Surface water	38.33486	–121.65780	NAD 83
382005121392901	Little Holland Tract Marsh Site 1 near Courtland, CA	North Little Holland Tract	Remnant natural marsh	Soil	38.33478	–121.65813	NAD 83
382004121392801	Little Holland Tract Marsh Site 2 near Courtland, CA	North Little Holland Tract	Remnant natural marsh	Soil	38.33443	–121.65780	NAD 83
382007121392301	Little Holland Tract Marsh Site 3 near Courtland, CA	North Little Holland Tract	Remnant natural marsh	Soil	38.33532	–121.65625	NAD 83
381721121395301	Prospect Slough near Liberty Farms, CA	South Little Holland Tract	Remnant natural marsh	Surface water	38.28920	–121.66483	NAD 83
381721121394701	Prospect Slough Marsh Site 4 near Liberty Farms, CA	South Little Holland Tract	Remnant natural marsh	Soil	38.28915	–121.66307	NAD 83
381718121395301	Prospect Slough Marsh Site 5 near Liberty Farms, CA	South Little Holland Tract	Remnant natural marsh	Soil	38.28833	–121.66477	NAD 83
381718121395201	Prospect Slough Marsh Site 6 near Liberty Farms, CA	South Little Holland Tract	Remnant natural marsh	Soil	38.28845	–121.66445	NAD 83
381418121405301	Prospect Slough at Cache Slough near Rio Vista, CA	South Prospect	Remnant natural marsh	Surface water	38.23829	–121.68128	NAD 83
381414121403901	Prospect Slough Marsh Site 1 near Rio Vista, CA	South Prospect	Remnant natural marsh	Soil	38.23730	–121.67763	NAD 83
381416121403601	Prospect Slough Marsh Site 2 near Rio Vista, CA	South Prospect	Remnant natural marsh	Soil	38.23788	–121.67658	NAD 83
381420121403501	Prospect Slough Marsh Site 3 near Rio Vista, CA	South Prospect	Remnant natural marsh	Soil	38.23897	–121.67643	NAD 83

Pesticides

Water samples were collected at one site in each marsh (table 1) and in Cache Slough downstream from Ulatis Creek, a known source of pesticides to the region (Orlando and others, 2004; Weston and Lydy, 2010), in June, July, and August of 2015. Sites were accessed, and samples were collected, by boat on the ebb tide at each site. Samples were collected by submerging 1-liter (L), baked, amber-glass bottles 0.1 meter below the water surface. Two 1-L bottles were collected at each site. Additional bottles were collected for field, quality-control (QC) samples during the study (one each of a trip blank, replicate, matrix spike, and matrix-spike replicate). After collection, all water samples were chilled on wet ice and delivered the same day to the USGS Organic Chemistry Research Laboratory (OCRL) in Sacramento, California. All water samples were processed at the OCRL laboratory within 24 hours of collection to remove suspended material by filtering through 0.7-micrometer glass-fiber filters (Grade GF/F, Whatman, Piscataway, New Jersey) into pre-cleaned glass bottles. After filtering, the pre-weighed filter papers and captured suspended sediment were allowed to air dry in a fume hood, then placed in aluminum foil, sealed in zip-lock bags, and stored at −20 °C for no longer than 30 days following collection prior to extraction and analysis.

Water samples (1 L each) were analyzed for pesticides (table 2) using two published analytical methods. Samples were analyzed for 124 current-use pesticides (CUPs) using a gas chromatograph/mass spectrometer (GC/MS) following the method described in Hladik and others (2008). Water samples were also analyzed for an additional 25 CUPs using liquid chromatography tandem mass spectrometry (LC/MS/MS) following the method described in Hladik and Calhoun (2012). Suspended sediments filtered from the water samples were analyzed for 124 CUPs using GC/MS following the method described in Hladik and McWayne (2012).

Field water-quality parameters (temperature, specific conductance, dissolved oxygen concentration, and pH) were measured at the time of sample collection using a YSI 6920-V2 multi-parameter meter that was calibrated with appropriate standards immediately prior to sampling (table 3).

Table 2. Method detection limits for pesticides in water measured by the U.S. Geological Survey Organic Chemistry Research Laboratory.

[GC/MS, gas chromatography/mass spectrometry; LC/MS/MS, liquid chromatography/tandem mass spectrometry; ng/L, nanograms per liter; NWIS, National Water Information System]

Compound	NWIS parameter code	Pesticide type	Chemical class	Method detection limit (ng/L)	Analytical method	Matrices analyzed
Acetamiprid	68302	Insecticide	Neonicotinoid	3.3	LC/MS/MS	Water
Acibenzolar-S-methyl	51849	Fungicide	Benzothiadiazole	3.0	GC/MS	Water and sediment
Alachlor	65064	Herbicide	Chloroacetanilide	1.7	GC/MS	Water and sediment
Allethrin	66586	Insecticide	Pyrethroid	6.0	GC/MS	Water and sediment
Atrazine	65065	Herbicide	Triazine	2.3	GC/MS	Water and sediment
Azoxystrobin	66589	Fungicide	Strobilurin	3.1	GC/MS	Water and sediment
Benefluralin	51643	Herbicide	Dinitroaniline	2.0	GC/MS	Water and sediment
Bifenthrin	65067	Insecticide	Pyrethroid	4.7	GC/MS	Water and sediment
Boscalid	67550	Fungicide	Pyridine	2.8	GC/MS	Water and sediment
Butralin	68545	Herbicide	Dinitroaniline	2.6	GC/MS	Water and sediment
Butylate	65068	Herbicide	Thiocarbamate	1.8	GC/MS	Water and sediment
Captan	68322	Fungicide	Phthalimide	10.2	GC/MS	Water and sediment
Carbaryl	65069	Insecticide	Carbamate	6.5	GC/MS	Water and sediment
Carbendazim	68548	Fungicide	Benzimidazole	4.2	LC/MS/MS	Water
Carbofuran	65070	Insecticide	Carbamate	3.1	GC/MS	Water and sediment
Chlorantraniliprole	51856	Insecticide	Anthranilic diamide	4.0	LC/MS/MS	Water
Chlorothalonil	65071	Fungicide	Chloronitrile	4.1	GC/MS	Water and sediment
Chlorpyrifos	65072	Insecticide	Organophosphate	2.1	GC/MS	Water and sediment
Chlorpyrifos oxon	68216	Degradate	Organophosphate	5.0	GC/MS	Water and sediment
Clomazone	67562	Herbicide	Isoxazlidinone	2.5	GC/MS	Water and sediment
Clothianidin	68221	Insecticide	Neonicotinoid	3.9	LC/MS/MS	Water
Coumaphos	51836	Insecticide	Organophosphate	3.1	GC/MS	Water and sediment
Cyantraniliprole	51862	Insecticide	Anthranilic diamide	4.2	LC/MS/MS	Water
Cyazofamid	51853	Fungicide	Azole	4.1	LC/MS/MS	Water
Cycloate	65073	Herbicide	Thiocarbamate	1.1	GC/MS	Water and sediment
Cyfluthrin	65074	Insecticide	Pyrethroid	5.2	GC/MS	Water and sediment
Cyhalofop-butyl	68360	Herbicide	Aryloxyphenoxypropionate	1.9	GC/MS	Water and sediment
Cyhalothrin	68354	Insecticide	Pyrethroid	2.0	GC/MS	Water and sediment
Cymoxanil	51861	Fungicide	Unclassified	3.9	LC/MS/MS	Water
Cypermethrin	65075	Insecticide	Pyrethroid	5.6	GC/MS	Water and sediment

Table 2. Method detection limits for pesticides in water measured by the U.S. Geological Survey Organic Chemistry Research Laboratory.—Continued

[GC/MS, gas chromatography/mass spectrometry; LC/MS/MS, liquid chromatography/tandem mass spectrometry; ng/L, nanograms per liter; NWIS, National Water Information System]

Compound	NWIS parameter code	Pesticide type	Chemical class	Method detection limit (ng/L)	Analytical method	Matrices analyzed
Cyproconazole	66593	Fungicide	Triazole	4.7	GC/MS	Water and sediment
Cyprodinil	67574	Fungicide	Pyrimidine	7.4	GC/MS	Water and sediment
DCPA	65076	Herbicide	Benzenedicarboxylic acid	2.0	GC/MS	Water and sediment
p,p’-DDD	65094	Degradate	Organochlorine	4.1	GC/MS	Water and sediment
p,p’-DDE	65095	Degradate	Organochlorine	3.6	GC/MS	Water and sediment
p,p’-DDT	65096	Insecticide	Organochlorine	4.0	GC/MS	Water and sediment
Deltamethrin	65077	Insecticide	Pyrethroid	3.5	GC/MS	Water and sediment
Desthio-Prothioconazole	51865	Fungicide	Azole	3.0	LC/MS/MS	Water
Desulfinylfipronil	66607	Degradate	Phenylpyrazole	1.6	GC/MS	Water and sediment
Desulfinylfipronil amide	68570	Degradate	Phenylpyrazole	3.2	GC/MS	Water and sediment
Diazinon	65078	Insecticide	Organophosphate	0.9	GC/MS	Water and sediment
Diazinon oxon	68236	Degradate	Organophosphate	5.0	GC/MS	Water and sediment
3,4-Dichloroaniline (3,4-DCA)	66584	Degradate	Urea	3.2	LC/MS/MS	Water
3,5-Dichloroaniline (3,5-DCA)	67536	Degradate	Aniline	7.6	GC/MS	Water and sediment
3,4-Dichlorophenylurea (DCPU)	68226	Degradate	Urea	3.4	LC/MS/MS	Water
Difenoconazole	67582	Fungicide	Triazole	10.5	GC/MS	Water and sediment
(E)-Dimethomorph	67587	Fungicide	Morpholine	6.0	GC/MS	Water and sediment
Dinotefuran	68379	Insecticide	Neonicotinoid	4.5	LC/MS/MS	Water
Dithiopyr	51837	Herbicide	Pyridine	1.6	GC/MS	Water and sediment
Diuron	66598	Herbicide	Urea	3.2	LC/MS/MS	Water
EPTC	65080	Herbicide	Thiocarbamate	1.5	GC/MS	Water and sediment
Esfenvalerate	65081	Insecticide	Pyrethroid	3.9	GC/MS	Water and sediment
Ethaboxam	51855	Fungicide	Unclassified	3.8	LC/MS/MS	Water
Ethalfluralin	65082	Herbicide	Aniline	3.0	GC/MS	Water and sediment
Etofenprox	67604	Insecticide	Pyrethroid	2.2	GC/MS	Water and sediment
Famoxadone	67609	Fungicide	Oxazole	2.5	GC/MS	Water and sediment
Fenamidone	51848	Fungicide	Imidazole	5.1	GC/MS	Water and sediment
Fenarimol	67613	Fungicide	Pyrimidine	6.5	GC/MS	Water and sediment
Fenbuconazole	67618	Fungicide	Triazole	5.2	GC/MS	Water and sediment
Fenhexamide	67622	Fungicide	Anilide	7.6	GC/MS	Water and sediment
Fenpropathrin	65083	Insecticide	Pyrethroid	4.1	GC/MS	Water and sediment

Table 2. Method detection limits for pesticides in water measured by the U.S. Geological Survey Organic Chemistry Research Laboratory.—Continued

[GC/MS, gas chromatography/mass spectrometry; LC/MS/MS, liquid chromatography/tandem mass spectrometry; ng/L, nanograms per liter; NWIS, National Water Information System]

Compound	NWIS parameter code	Pesticide type	Chemical class	Method detection limit (ng/L)	Analytical method	Matrices analyzed
Fenpyroximate	51838	Insecticide	Pyrazole	5.2	GC/MS	Water and sediment
Fenthion	51839	Insecticide	Organophosphate	5.5	GC/MS	Water and sediment
Fipronil	66604	Insecticide	Phenylpyrazole	2.9	GC/MS	Water and sediment
Fipronil sulfide	66610	Degradate	Phenylpyrazole	1.8	GC/MS	Water and sediment
Fipronil sulfone	66613	Degradate	Phenylpyrazole	3.5	GC/MS	Water and sediment
Flonicamid	51858	Insecticide	Unclassified	3.4	LC/MS/MS	Water
Fluazinam	67636	Fungicide	Pyridine	4.4	GC/MS	Water and sediment
Fludioxinil	67640	Fungicide	Pyrrole	7.3	GC/MS	Water and sediment
Flufenacet	51840	Herbicide	Anilide	4.7	GC/MS	Water and sediment
Flumetralin	51841	Plant growth regulator	Dinitroaniline	5.8	GC/MS	Water and sediment
Fluopicolide	51852	Fungicide	Pyrimidine	3.9	GC/MS	Water and sediment
Fluoxastrobin	67645	Fungicide	Strobilurin	9.5	GC/MS	Water and sediment
Fluridone	51864	Herbicide	Unclassified	3.7	LC/MS/MS	Water
Flusilazole	67649	Fungicide	Triazole	4.5	GC/MS	Water and sediment
Flutolanil	51842	Fungicide	Anilide	4.4	GC/MS	Water and sediment
Flutriafol	67653	Fungicide	Triazole	4.2	GC/MS	Water and sediment
τ-Fluvalinate	65106	Insecticide	Pyrethroid	5.3	GC/MS	Water and sediment
Fluxapyroxad	51851	Fungicide	Anilide	4.8	GC/MS	Water and sediment
Hexazinone	65085	Herbicide	Triazone	8.4	GC/MS	Water and sediment
Imazalil	67662	Fungicide	Triazole	10.5	GC/MS	Water and sediment
Imidacloprid	68426	Insecticide	Neonicotinoid	3.8	LC/MS/MS	Water
Indoxacarb	68898	Insecticide	Oxadiazine	4.9	GC/MS	Water and sediment
Iprodione	66617	Fungicide	Dicarboxamide	4.4	GC/MS	Water and sediment
Kresoxim-methyl	67670	Fungicide	Strobilurin	4.0	GC/MS	Water and sediment
Malathion	65087	Insecticide	Organophosphate	3.7	GC/MS	Water and sediment
Malathion oxon	68240	Degradate	Organophosphate	5.0	GC/MS	Water and sediment
Mandipropamid	51854	Fungicide	Mandelamide	3.3	LC/MS/MS	Water
Metalaxyl	68437	Fungicide	Phenylamide	5.1	GC/MS	Water and sediment
Metconazole	66620	Fungicide	Azole	5.2	GC/MS	Water and sediment
Methidathion	65088	Insecticide	Organophosphate	7.2	GC/MS	Water and sediment
Methoprene	66623	Insecticide	Terpene	6.4	GC/MS	Water and sediment

Table 2. Method detection limits for pesticides in water measured by the U.S. Geological Survey Organic Chemistry Research Laboratory.—Continued

[GC/MS, gas chromatography/mass spectrometry; LC/MS/MS, liquid chromatography/tandem mass spectrometry; ng/L, nanograms per liter; NWIS, National Water Information System]

Compound	NWIS parameter code	Pesticide type	Chemical class	Method detection limit (ng/L)	Analytical method	Matrices analyzed
Methoxyfenozide	68647	Insecticide	Diacylhydrazine	2.7	LC/MS/MS	Water
Methylparathion	65089	Insecticide	Organophosphate	3.4	GC/MS	Water and sediment
Metolachlor	65090	Herbicide	Chloroacetanilide	1.5	GC/MS	Water and sediment
Molinate	65091	Herbicide	Thiocarbamate	3.2	GC/MS	Water and sediment
Myclobutanil	66632	Fungicide	Triazole	6.0	GC/MS	Water and sediment
N-(3,4-Dichlorophenyl)-*N'*-methylurea (DCPMU)	68231	Degradate	Urea	3.5	LC/MS/MS	Water
Napropamide	65092	Herbicide	Amide	8.2	GC/MS	Water and sediment
Novaluron	68655	Herbicide	Benzoylurea	2.9	GC/MS	Water and sediment
Oryzalin	68663	Herbicide	2,6-Dinitroaniline	5.0	LC/MS/MS	Water
Oxadiazon	51843	Herbicide	Oxadiazolone	2.1	GC/MS	Water and sediment
Oxyfluorfen	65093	Herbicide	Nitrophenyl ether	3.1	GC/MS	Water and sediment
Paclobutrazol	51846	Fungicide	Triazole	6.2	GC/MS	Water and sediment
Pebulate	65097	Herbicide	Thiocarbamate	2.3	GC/MS	Water and sediment
Pendimethalin	65098	Herbicide	Aniline	2.3	GC/MS	Water and sediment
Penoxsulam	51863	Herbicide	Triazolopyrimidine	3.5	LC/MS/MS	Water
Pentachloroanisole (PCA)	66637	Insecticide	Organochlorine	4.7	GC/MS	Water and sediment
Pentachloronitrobenzene (PCNB)	66639	Fungicide	Organochlorine	3.1	GC/MS	Water and sediment
Permethrin	65099	Insecticide	Pyrethroid	3.4	GC/MS	Water and sediment
Phenothrin	65100	Insecticide	Pyrethroid	5.1	GC/MS	Water and sediment
Phosmet	65101	Insecticide	Organophosphate	4.4	GC/MS	Water and sediment
Picoxystrobin	51850	Fungicide	Strobilurin	4.2	GC/MS	Water and sediment
Piperonyl butoxide	65102	Synergist	Unclassified	2.3	GC/MS	Water and sediment
Prodiamine	51844	Herbicide	Dinitroaniline	5.2	GC/MS	Water and sediment
Prometon	67702	Herbicide	Triazine	2.5	GC/MS	Water and sediment
Prometryn	65103	Herbicide	Triazine	1.8	GC/MS	Water and sediment
Propanil	66641	Herbicide	Anilide	10.1	GC/MS	Water and sediment
Propargite	68677	Insecticide	Sulfite ester	6.1	GC/MS	Water and sediment
Propiconazole	66643	Fungicide	Azole	5.0	GC/MS	Water and sediment
Propyzamide	67706	Herbicide	Benzamide	5.0	GC/MS	Water and sediment
Pyraclostrobin	66646	Fungicide	Strobilurin	2.9	GC/MS	Water and sediment
Pyridaben	68908	Insecticide	Pyridazinone	5.4	GC/MS	Water and sediment

Table 2. Method detection limits for pesticides in water measured by the U.S. Geological Survey Organic Chemistry Research Laboratory.—Continued

[GC/MS, gas chromatography/mass spectrometry; LC/MS/MS, liquid chromatography/tandem mass spectrometry; ng/L, nanograms per liter; NWIS, National Water Information System]

Compound	NWIS parameter code	Pesticide type	Chemical class	Method detection limit (ng/L)	Analytical method	Matrices analyzed
Pyrimethanil	67717	Fungicide	Pyrmidine	4.1	GC/MS	Water and sediment
Quinoxyfen	51847	Fungicide	Quinoline	3.3	GC/MS	Water and sediment
Resmethrin	65104	Insecticide	Pyrethroid	5.7	GC/MS	Water and sediment
Simazine	65105	Herbicide	Triazine	5.0	GC/MS	Water and sediment
Tebuconazole	66649	Fungicide	Azole	3.7	GC/MS	Water and sediment
Tebupirimfos	68693	Insecticide	Organophosphate	1.9	GC/MS	Water and sediment
Tebupirimfos oxon	68694	Degradate	Organophosphate	2.8	GC/MS	Water and sediment
Tefluthrin	67731	Insecticide	Pyrethroid	4.2	GC/MS	Water and sediment
Tetraconazole	66654	Fungicide	Azole	5.6	GC/MS	Water and sediment
Tetradifon	51651	Insecticide	Bridged diphenyl	3.8	GC/MS	Water and sediment
Tetramethrin	66657	Insecticide	Pyrethroid	2.9	GC/MS	Water and sediment
Thiabendazole	67161	Fungicide	Benzimidazole	3.6	LC/MS/MS	Water
Thiacloprid	68485	Insecticide	Neonicotinoid	3.2	LC/MS/MS	Water
Thiamethoxam	68245	Insecticide	Neonicotinoid	3.4	LC/MS/MS	Water
Thiazopyr	51845	Herbicide	Pyridine	4.1	GC/MS	Water and sediment
Thiobencarb	65107	Herbicide	Thiocarbamate	1.9	GC/MS	Water and sediment
Tofenpyrad	51866	Insecticide	Pyrazole	2.9	LC/MS/MS	Water
Triadimefon	67741	Fungicide	Triazole	8.9	GC/MS	Water and sediment
Triadimenol	67746	Fungicide	Triazole	8.0	GC/MS	Water and sediment
Triallate	68710	Herbicide	Carbamate	2.4	GC/MS	Water and sediment
Tribufos	68711	Herbicide	Organophosphate	3.1	GC/MS	Water and sediment
Trifloxystrobin	66660	Fungicide	Strobilurin	4.7	GC/MS	Water and sediment
Triflumizole	67753	Fungicide	Azole	6.1	GC/MS	Water and sediment
Trifluralin	65108	Herbicide	Aniline	2.1	GC/MS	Water and sediment
Triticonazole	67758	Fungicide	Azole	6.9	GC/MS	Water and sediment
Zoxamide	67768	Fungicide	Benzamide	3.5	GC/MS	Water and sediment

Table 3. Field water-quality parameter data measured at collection sites in 2015 during water-sample collection in the Cache Slough region of the Sacramento–San Joaquin Delta, California.

[Numbers in brackets are U.S. Geological Survey (USGS) National Water Information System (NWIS) parameter codes. **Abbreviations**: hh:mm, hours:minutes; mg/L, milligrams per liter; NA, data not collected; °C, degrees Celsius; µS/cm, microsiemens per centimeter]

USGS station number	USGS station name	Short site name	Sample time (hh:mm)	Water temperature (°C) [00010]	Specific conductance (µS/cm at 25 °C) [00095]	Dissolved oxygen (mg/L) [00300]	pH [00400]
Sample date: June 3, 2015							
381719121432301	Cache Slough at Hass Slough near Liberty Farms, CA	Ulatis Creek	10:45	NA	217	NA	7.6
382006121401601	Liberty Island at Liberty Cut near Courtland, CA	Liberty Island Conservation Bank (LICB)	11:30	20.6	350	NA	7.3
382005121392801	Little Holland Tract near Courtland, CA	North Little Holland Tract	11:50	22.1	263	NA	7.5
381721121395301	Prospect Slough near Liberty Farms, CA	South Little Holland Tract	13:00	20.8	221	NA	8.4
381418121405301	Prospect Slough at Cache Slough near Rio Vista, CA	South Prospect	12:35	20.0	207	NA	7.8
Sample date: July 6, 2015							
381719121432301	Cache Slough at Hass Slough near Liberty Farms, CA	Ulatis Creek	10:40	21.0	201	9.0	8.3
382006121401601	Liberty Island at Liberty Cut near Courtland, CA	Liberty Island Conservation Bank (LICB)	11:10	21.4	255	6.8	7.6
382005121392801	Little Holland Tract near Courtland, CA	North Little Holland Tract	11:25	20.1	219	8.6	8.0
381721121395301	Prospect Slough near Liberty Farms, CA	South Little Holland Tract	11:45	21.2	209	8.9	8.2
381418121405301	Prospect Slough at Cache Slough near Rio Vista, CA	South Prospect	12:10	22.2	217	9.0	7.9
Sample date: August 13, 2015							
381719121432301	Cache Slough at Hass Slough near Liberty Farms, CA	Ulatis Creek	10:30	21.4	206	9.4	8.5
382006121401601	Liberty Island at Liberty Cut near Courtland, CA	Liberty Island Conservation Bank (LICB)	11:00	21.6	320	6.1	7.5
382005121392801	Little Holland Tract near Courtland, CA	North Little Holland Tract	11:15	22.9	253	7.7	7.9
381721121395301	Prospect Slough near Liberty Farms, CA	South Little Holland Tract	11:35	21.8	207	8.5	8.1
381418121405301	Prospect Slough at Cache Slough near Rio Vista, CA	South Prospect	11:52	22.0	192	8.3	8.0

Quality Assurance and Quality Control

Soil Samples

Replicates and standards were analyzed every five samples to assess instrument stability. Replicate samples were re-analyzed if the relative percentage difference between the two replicates was greater than 20 percent. The method detection limits were 0.15 percent by weight for carbon and 0.10 percent by weight for nitrogen. Statistical analysis of the organic carbon and nitrogen (percentage by weight) in soils was done with one-way ANOVA and post hoc pairwise comparisons using the Bonferroni method.

Pesticides

Four quality-control samples (a trip blank, replicate, matrix spike, and matrix-spike replicate) were collected and analyzed. The trip blank consisted of a 1-L amber-glass bottle filled with pesticide-grade blank water, which was taken into the field (chilled on ice) during the August sampling and opened to the atmosphere while water samples were collected at one field site. The trip blank was processed in the same manner as the environmental samples and was then analyzed by GC/MS. There were no pesticides detected in the trip blank.

One replicate sample was collected during the June 2015 sampling (Liberty Island at Liberty Cut near Courtland, Calif.) and analyzed by GC/MS. Eight pesticides were detected in the replicate sample as well as the corresponding environmental sample. The relative standard deviations of the paired detections ranged from 1 to 7 percent, which met the data-quality objective of less than 25 percent. There were no unpaired detections of any pesticides either in the environmental or replicate sample.

One matrix-spike sample and one matrix-spike replicate sample were collected during the July sampling (Prospect Slough near Liberty Farms, Calif.) and analyzed by LC/MS/MS. Both samples were spiked with the full range of analytical compounds (table 2). Recoveries for all compounds ranged from 72 to 119 percent, which met the data-quality objective of 70–130 percent. The relative standard deviations between the matrix spike and matrix-spike replicate samples for all compounds ranged from 2 to 6 percent, which met the data quality objective of less than 25 percent. In addition to the four QC samples described previously, analyte recovery was assessed in all samples by the addition of surrogate compounds in the laboratory. Recoveries for all surrogate compounds met the data-quality objective of 70–130 percent.

Results

Elevation Survey

Elevation data for north Little Holland Tract and the LICB are shown in tables 4 and 5, respectively, and in figure 4, which shows the elevation of survey points at both sites. The mean elevation of the marsh plain was determined to be 1.42 meters relative to the North American Vertical Datum of 1988 (NAVD 88) at north Little Holland Tract, whereas at the LICB, the mean elevation of the marsh plan was 1.68 meters relative to the NAVD 88. Marsh elevations could not be directly compared to mean tide elevation because the closest reliable tidal benchmark is at Port Chicago, Calif., which is more than 43 kilometers from the sites. This distance is too great for conversion of the NAVD 88 elevations to tidal elevations without unacceptable error. Regardless, the mean difference of 26 cm between the elevations at the LICB and north Little Holland Tract represents 25 percent of the 1-meter habitable range of elevation for marsh vegetation in the delta region (Swanson and others, 2015). This result indicates that the elevation of the LICB is too high for the formation of a fully functional micro-tidal marsh in this region of the delta.

Soil Samples

The results of the soil analyses showed that there were no statistically significant differences among the four sites for total carbon, organic carbon, total nitrogen, or total organic nitrogen in the top 4 cm of the soil (table 6; fig. 5). This indicates that soil nitrogen in the surface of the marshes is not likely to be limiting plant growth at the LICB. Because we did not sample deeper in the soil, however, we cannot be sure that nitrogen, or some other nutrient, is not lacking at a greater depth in the soils at the LICB. We also did not measure bulk density, which could have shown effects from compaction following restoration at the LICB compared with the other marsh sites, which were not disturbed by heavy machinery (Sloey and Hester, 2016).

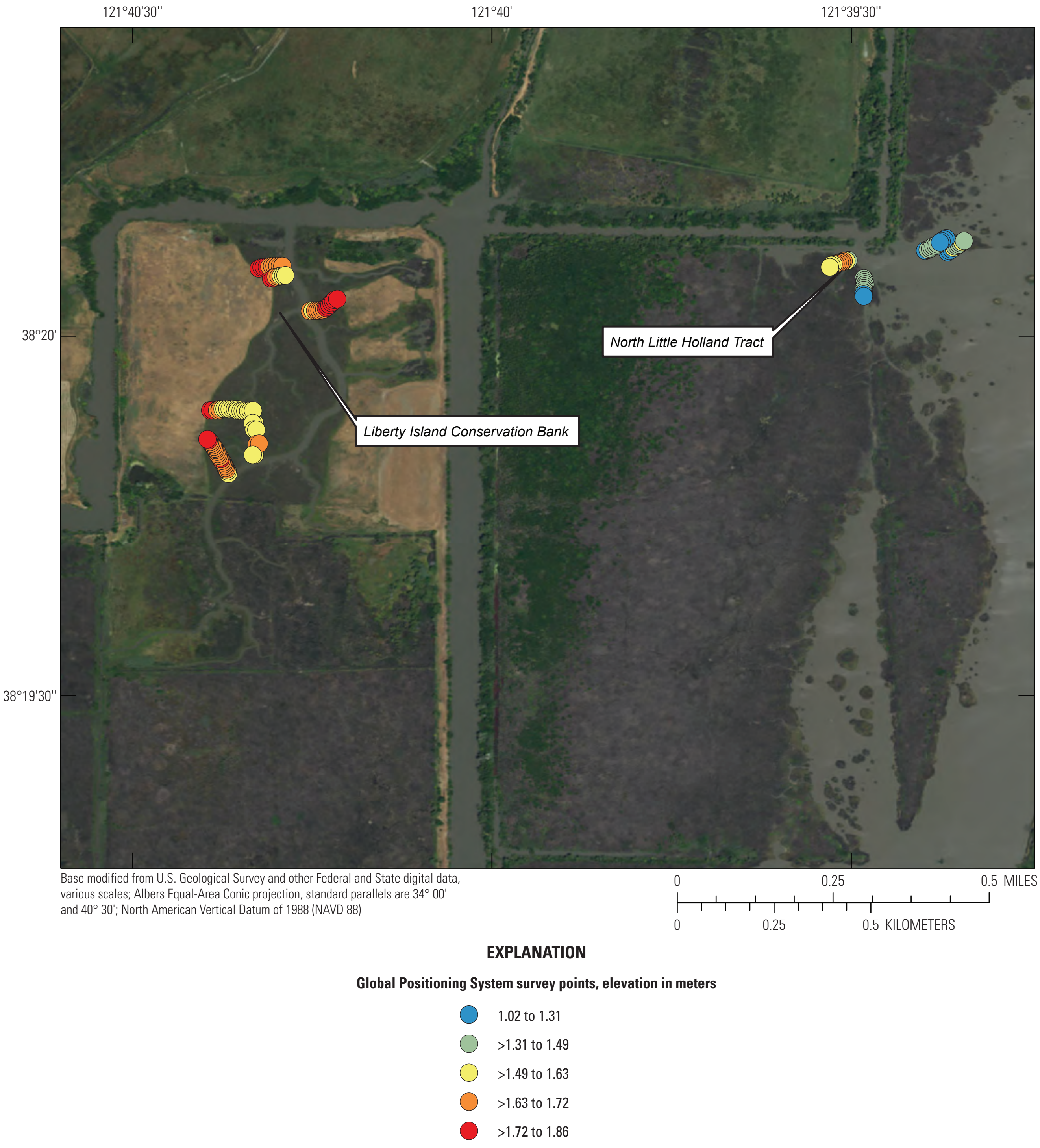

Figure 4. The RTK-GPS (real-time kinematic global positioning system) survey-point elevations, relative to the North American Vertical Datum of 1988, for two marsh sites in the Cache Slough region of the Sacramento–San Joaquin Delta, November 2015.

Table 4. Elevation and coordinate data from the Global Positioning System survey at the north Little Holland Tract marsh site, November 2015.

[Horizontal coordinates are reported using the North American Datum of 1983; NAD 83. Elevation data is reported in meters (m) referenced to the North American Vertical Datum of 1988; NAVD 88. **Abbreviation**: dd, decimal degrees]

Site number	Transect	Latitude (dd)	Longitude (dd)	Elevation (m)
1	1	38.33509	–121.65840	1.49
2	1	38.33507	–121.65845	1.56
3	1	38.33506	–121.65851	1.65
4	1	38.33504	–121.65855	1.66
5	1	38.33503	–121.65860	1.67
6	1	38.33502	–121.65865	1.68
7	1	38.33500	–121.65870	1.71
8	1	38.33499	–121.65875	1.62
9	1	38.33497	–121.65879	1.62
10	1	38.33493	–121.65883	1.58
11	2	38.33467	–121.65804	1.42
12	2	38.33462	–121.65803	1.36
13	2	38.33457	–121.65803	1.41
14	2	38.33453	–121.65801	1.34
15	2	38.33448	–121.65803	1.34
16	2	38.33444	–121.65804	1.37
17	2	38.33439	–121.65804	1.39
18	2	38.33434	–121.65804	1.34
19	2	38.33430	–121.65805	1.31
20	2	38.33425	–121.65804	1.29
21	3	38.33531	–121.65662	1.23
22	3	38.33533	–121.65656	1.46
23	3	38.33536	–121.65650	1.46
24	3	38.33539	–121.65646	1.41
25	3	38.33541	–121.65642	1.47
26	3	38.33543	–121.65637	1.44
27	3	38.33546	–121.65633	1.40
28	3	38.33550	–121.65627	1.29
29	3	38.33553	–121.65623	1.22
30	3	38.33557	–121.65617	1.25
31	3	38.33559	–121.65613	1.16
32	4	38.33528	–121.65610	1.02
33	4	38.33531	–121.65606	1.19
34	4	38.33534	–121.65600	1.29
35	4	38.33538	–121.65596	1.51
36	4	38.33541	–121.65593	1.43
37	4	38.33543	–121.65588	1.45
38	4	38.33545	–121.65584	1.48
39	4	38.33548	–121.65580	1.47
40	4	38.33551	–121.65576	1.54
41	4	38.33554	–121.65572	1.39

Table 5. Elevation and coordinate data from the Global Positioning System survey at the Liberty Island Conservation Bank marsh site, November 2015.

[Horizontal coordinates are reported using the North American Datum of 1983; NAD 83. Elevation data is reported in meters (m) referenced to the North American Vertical Datum of 1988; NAVD 88. **Abbreviation**: dd, decimal degrees]

Site number	Transect	Latitude (dd)	Longitude (dd)	Elevation (m)	Site number	Transect	Latitude (dd)	Longitude (dd)	Elevation (m)
1	1	38.33495	–121.67153	1.69	37	3	38.33091	–121.67324	1.75
2	1	38.33495	–121.67159	1.69	38	3	38.33094	–121.67327	1.76
3	1	38.33495	–121.67165	1.66	39	4	38.33161	–121.67315	1.79
4	1	38.33495	–121.67171	1.69	40	4	38.33161	–121.67310	1.74
5	1	38.33495	–121.67177	1.69	41	4	38.33161	–121.67304	1.71
6	1	38.33494	–121.67183	1.69	42	4	38.33162	–121.67298	1.70
7	1	38.33493	–121.67189	1.76	43	4	38.33163	–121.67292	1.69
8	1	38.33493	–121.67196	1.74	44	4	38.33164	–121.67286	1.62
9	1	38.33492	–121.67201	1.78	45	4	38.33164	–121.67281	1.63
10	1	38.33490	–121.67208	1.76	46	4	38.33164	–121.67274	1.61
11	2	38.33467	–121.67179	1.79	47	4	38.33163	–121.67269	1.61
12	2	38.33468	–121.67174	1.74	48	4	38.33164	–121.67262	1.61
13	2	38.33470	–121.67168	1.71	49	4	38.33163	–121.67257	1.56
14	2	38.33471	–121.67162	1.64	50	4	38.33159	–121.67250	1.62
15	2	38.33472	–121.67156	1.60	51	4	38.33159	–121.67244	1.59
16	2	38.33473	–121.67151	1.62	52	4	38.33159	–121.67239	1.63
17	2	38.33474	–121.67146	1.62	53	4	38.33159	–121.67233	1.63
18	3	38.33014	–121.67278	1.59	54	4	38.33159	–121.67226	1.62
19	3	38.33019	–121.67280	1.62	55	4	38.33160	–121.67221	1.63
20	3	38.33023	–121.67283	1.66	56	4	38.33131	–121.67217	1.63
21	3	38.33027	–121.67285	1.67	57	4	38.33116	–121.67214	1.57
22	3	38.33032	–121.67287	1.64	58	4	38.33083	–121.67207	1.65
23	3	38.33036	–121.67289	1.67	59	4	38.33058	–121.67216	1.60
24	3	38.33040	–121.67291	1.71	60	5	38.33391	–121.67084	1.66
25	3	38.33044	–121.67294	1.70	61	5	38.33392	–121.67077	1.54
26	3	38.33048	–121.67296	1.76	62	5	38.33392	–121.67072	1.66
27	3	38.33052	–121.67298	1.69	63	5	38.33392	–121.67067	1.67
28	3	38.33056	–121.67301	1.71	64	5	38.33393	–121.67061	1.70
29	3	38.33060	–121.67303	1.70	65	5	38.33395	–121.67056	1.66
30	3	38.33065	–121.67305	1.65	66	5	38.33398	–121.67052	1.76
31	3	38.33069	–121.67308	1.64	67	5	38.33401	–121.67048	1.80
32	3	38.33072	–121.67310	1.69	68	5	38.33405	–121.67044	1.75
33	3	38.33076	–121.67312	1.66	69	5	38.33410	–121.67039	1.74
34	3	38.33080	–121.67315	1.67	70	5	38.33413	–121.67035	1.78
35	3	38.33084	–121.67318	1.68	71	5	38.33417	–121.67032	1.83
36	3	38.33088	–121.67321	1.72	72	5	38.33419	–121.67026	1.86

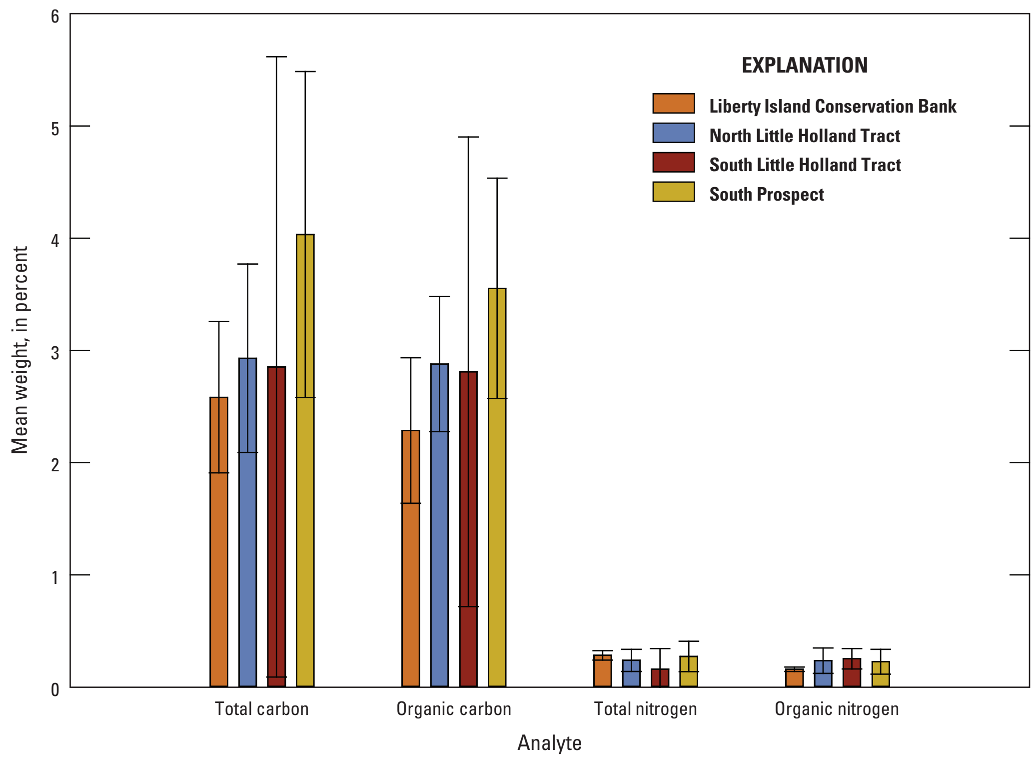

Figure 5. Mean weight as percentages of total carbon, organic carbon, total nitrogen, and total organic nitrogen measured in soil samples collected from four marsh sites in the Cache Slough region of the Sacramento–San Joaquin Delta, September 2014. Vertical bars represent plus and minus one standard deviation error.

Table 6. Organic carbon and nitrogen measured in soil samples collected from marsh sites in the Cache Slough region of the Sacramento–San Joaquin Delta, September 2014.

[Numbers in brackets are U.S. Geological Survey (USGS) National Water Information System (NWIS) parameter codes. **Abbreviations**: hh:mm; hour:minute; mm/dd/yyyy; month/day/year; NAD 83, North American Datum of 1983]

USGS station number	USGS station name	Marsh site	Sample date (mm/dd/yyyy)	Sample time (hh:mm)	Total carbon (percent) [46247]	Organic carbon (percent) [01423]	Total nitrogen (percent) [01471]	Organic nitrogen (percent) [52760]
382006121401701	Liberty Island Marsh Site 1 near Courtland, CA	Liberty Island Conservation Bank (LICB)	09/23/2014	12:30	1.90	1.68	0.27	0.16
381955121401301	Liberty Island Marsh Site 2 near Courtland, CA	Liberty Island Conservation Bank (LICB)	09/23/2014	13:05	3.25	2.97	0.33	0.18
382006121401602	Liberty Island Marsh Site 3 near Courtland, CA	Liberty Island Conservation Bank (LICB)	09/23/2014	13:45	2.60	2.21	0.25	0.14
382005121392901	Little Holland Tract Marsh Site 1 near Courtland, CA	North Little Holland Tract	09/23/2014	14:20	2.91	2.89	0.13	0.22
382004121392801	Little Holland Tract Marsh Site 2 near Courtland, CA	North Little Holland Tract	09/23/2014	16:00	2.10	2.27	0.26	0.13
382007121392301	Little Holland Tract Marsh Site 3 near Courtland, CA	North Little Holland Tract	09/23/2014	16:15	3.78	3.48	0.33	0.36
381721121394701	Prospect Slough Marsh Site 4 near Liberty Farms, CA	South Little Holland Tract	09/23/2014	11:05	1.68	1.98	0.32	0.35
381718121395301	Prospect Slough Marsh Site 5 near Liberty Farms, CA	South Little Holland Tract	09/23/2014	11:25	6.01	5.19	0.36	0.24
381718121395201	Prospect Slough Marsh Site 6 near Liberty Farms, CA	South Little Holland Tract	09/23/2014	11:50	0.87	1.26	0.12	0.17
381414121403901	Prospect Slough Marsh Site 1 near Rio Vista, CA	South Prospect	09/23/2014	09:15	2.70	2.60	0.14	0.11
381416121403601	Prospect Slough Marsh Site 2 near Rio Vista, CA	South Prospect	09/23/2014	09:45	5.58	4.56	0.41	0.33
381420121403501	Prospect Slough Marsh Site 3 near Rio Vista, CA	South Prospect	09/23/2014	10:20	3.82	3.50	0.27	0.24

Pesticide Analyses

A total of 18 pesticides and degradates were detected in water samples. Five fungicides (azoxystrobin, boscalid, carbendazim, fluxapyroxad, and pyrimethanil), eight herbicides (clomazone, dithiopyr, diuron, fluridone, hexazinone, metolachlor, penoxsulam, and simazine), two herbicide degradates (3,4-DCA, and DCPMU), two insecticides (carbaryl and chlorantraniliprole), and one insecticide degradate (desulfinylfipronil) were detected (table 7). All water samples contained mixtures of 10–15 pesticides (fig. 6). Pesticide detection frequencies ranged from 7 to 100 percent, and eight pesticides (azoxystrobin, boscalid, clomazone, DCPMU, 3,4-DCA, diuron, hexazinone, and metolachlor) were detected in every water sample (table 8).

Pesticide concentrations ranged from below the method detection limits for some compounds up to 140.9 nanograms per liter (ng/L) for the fungicide azoxystrobin (table 7). Compounds detected at the highest concentrations included azoxystrobin and clomazone (two compounds applied to rice) as well as the herbicide hexazinone and the fungicide boscalid, both of which have a variety of agricultural applications. In general, insecticide concentrations were near or below method detection levels. Total detected pesticide mass per sample (the sum of all individual pesticide concentrations) ranged from 169.6 to 396.8 ng/L. In general, herbicides and fungicides contributed nearly all of the total pesticide mass per sample. No pesticides were detected at concentrations greater than published Environmental Protection Agency aquatic-life benchmarks (U.S. Environmental Protection Agency, 2016).

The spatial distribution of pesticides was generally consistent among the five sites. In the few instances where a detected pesticide was not present at all five sites, the detections were generally at or below the respective method detection limits listed in table 2. Pesticide concentrations were also generally similar for the five sampling sites during a particular sampling date. In those cases in which a pesticide was detected at all five sampling sites during a particular site visit (32 instances), the relative standard deviation in concentration for the five sites sampled on a particular date ranged from 6 to 105 percent and averaged 26 percent. The highest concentration for a particular pesticide was most often (12 out of 32) detected at the Ulatis Creek input site (Cache Slough at Hass Slough near Liberty Farms), followed by the LICB restored marsh site (8 out of 32). No pesticides were detected in suspended sediment filtered from any of the water samples analyzed during this project.

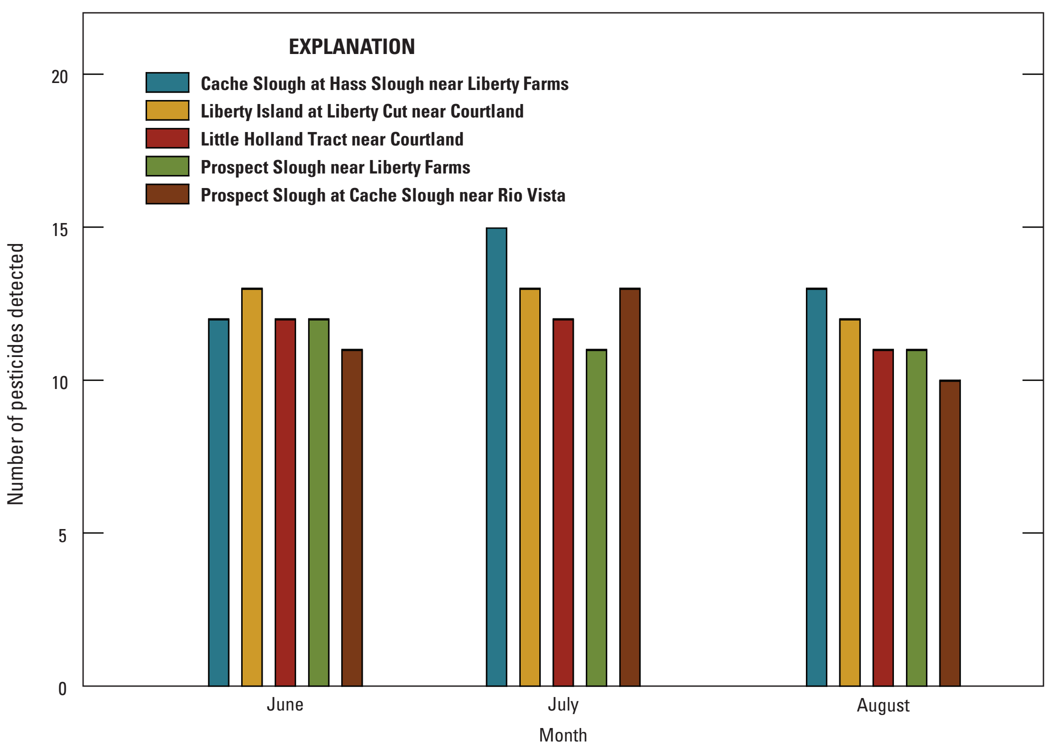

Figure 6. Number of current-use pesticides detected at five surface-water sites in the Cache Slough region of the Sacramento–San Joaquin Delta, 2015.

Table 7. Pesticide concentrations measured in environmental water samples collected from the Cache Slough region of the Sacramento–San Joaquin Delta, California, 2015.

[Numbers in brackets are U.S. Geological Survey (USGS) National Water Information System (NWIS) parameter codes. Concentrations are in nanograms per liter. Results in parenthesis ( ) are below method detection limits and are estimates. **Abbreviations**: hh:mm, hours:minutes; —, not detected]

USGS station number	USGS station name	Short site name	Sample time (hh:mm)	Azoxystrobin [66589]	Boscalid [67550]	Carbaryl [65069]	Carbendazim [68548]
		Sample date: June 3, 2015					
381719121432301	Cache Slough at Hass Slough near Liberty Farms, CA	Ulatis Creek	10:45	77.9	29.0	—	4.2
382006121401601	Liberty Island at Liberty Cut near Courtland, CA	Liberty Island Conservation Bank (LICB)	11:30	136.8	60.9	17.2	13.6
382005121392801	Little Holland Tract near Courtland, CA	North Little Holland Tract	11:50	99.0	34.5	—	5.7
381721121395301	Prospect Slough near Liberty Farms, CA	South Little Holland Tract	13:00	44.1	22.9	—	18.3
381418121405301	Prospect Slough at Cache Slough near Rio Vista, CA	South Prospect	12:35	72.0	31.8	—	—
		Sample date: July 6, 2015					
381719121432301	Cache Slough at Hass Slough near Liberty Farms, CA	Ulatis Creek	10:40	74.9	16.0	—	18.8
382006121401601	Liberty Island at Liberty Cut near Courtland, CA	Liberty Island Conservation Bank (LICB)	11:10	50.3	18.8	—	12.2
382005121392801	Little Holland Tract near Courtland, CA	North Little Holland Tract	11:25	55.1	16.0	—	(4.1)
381721121395301	Prospect Slough near Liberty Farms, CA	South Little Holland Tract	11:45	49.4	8.7	—	—
381418121405301	Prospect Slough at Cache Slough near Rio Vista, CA	South Prospect	12:10	41.8	10.3	—	15.2
		Sample date: August 13, 2015					
381719121432301	Cache Slough at Hass Slough near Liberty Farms, CA	Ulatis Creek	10:30	119.6	16.0	—	13.2
382006121401601	Liberty Island at Liberty Cut near Courtland, CA	Liberty Island Conservation Bank (LICB)	11:00	112.5	25.3	—	6.2
382005121392801	Little Holland Tract near Courtland, CA	North Little Holland Tract	11:15	121.7	25.2	—	11.0
381721121395301	Prospect Slough near Liberty Farms, CA	South Little Holland Tract	11:35	140.9	20.8	—	15.3
381418121405301	Prospect Slough at Cache Slough near Rio Vista, CA	South Prospect	11:52	137.2	14.0	—	—

Table 7. Pesticide concentrations measured in environmental water samples collected from the Cache Slough region of the Sacramento–San Joaquin Delta, California, 2015.—Continued

[Numbers in brackets are U.S. Geological Survey (USGS) National Water Information System (NWIS) parameter codes. Concentrations are in nanograms per liter. Results in parenthesis ( ) are below method detection limits and are estimates. **Abbreviations**: hh:mm, hours:minutes; —, not detected]

USGS station number	USGS station name	Short site name	Sample time (hh:mm)	Chlorantraniliprole [51856]	Clomazone [67562]	DCPMU [68231]	3,4-DCA [66584]	Dithiopyr [51837]
Sample date: June 3, 2015								
381719121432301	Cache Slough at Hass Slough near Liberty Farms, CA	Ulatis Creek	10:45	—	56.9	17.1	6.5	—
382006121401601	Liberty Island at Liberty Cut near Courtland, CA	Liberty Island Conservation Bank (LICB)	11:30	—	26.1	(2.8)	5.8	—
382005121392801	Little Holland Tract near Courtland, CA	North Little Holland Tract	11:50	—	31.5	4.2	11.2	—
381721121395301	Prospect Slough near Liberty Farms, CA	South Little Holland Tract	13:00	—	75.6	3.6	6.1	—
381418121405301	Prospect Slough at Cache Slough near Rio Vista, CA	South Prospect	12:35	—	59.7	(2.1)	6.6	—
Sample date: July 6, 2015								
381719121432301	Cache Slough at Hass Slough near Liberty Farms, CA	Ulatis Creek	10:40	(3.7)	45.1	4.6	12.0	—
382006121401601	Liberty Island at Liberty Cut near Courtland, CA	Liberty Island Conservation Bank (LICB)	11:10	4.0	34.6	4.2	7.8	—
382005121392801	Little Holland Tract near Courtland, CA	North Little Holland Tract	11:25	(3.5)	31.9	4.4	10.5	—
381721121395301	Prospect Slough near Liberty Farms, CA	South Little Holland Tract	11:45	(3.9)	37.0	4.6	16.2	—
381418121405301	Prospect Slough at Cache Slough near Rio Vista, CA	South Prospect	12:10	(3.4)	31.1	(3.2)	14.4	—
Sample date: August 13, 2015								
381719121432301	Cache Slough at Hass Slough near Liberty Farms, CA	Ulatis Creek	10:30	6.9	7.0	(3.2)	5.0	2.0
382006121401601	Liberty Island at Liberty Cut near Courtland, CA	Liberty Island Conservation Bank (LICB)	11:00	(3.0)	6.3	(2.3)	5.9	—
382005121392801	Little Holland Tract near Courtland, CA	North Little Holland Tract	11:15	—	7.0	(3.4)	6.5	—
381721121395301	Prospect Slough near Liberty Farms, CA	South Little Holland Tract	11:35	—	7.4	(3.2)	6.2	—
381418121405301	Prospect Slough at Cache Slough near Rio Vista, CA	South Prospect	11:52	—	6.8	(2.0)	7.7	—

Table 7. Pesticide concentrations measured in environmental water samples collected from the Cache Slough region of the Sacramento–San Joaquin Delta, California, 2015.—Continued

[Numbers in brackets are U.S. Geological Survey (USGS) National Water Information System (NWIS) parameter codes. Concentrations are in nanograms per liter. Results in parenthesis ( ) are below method detection limits and are estimates. **Abbreviations**: hh:mm, hours:minutes; —, not detected]

USGS station number	USGS station name	Short site name	Sample time (hh:mm)	Diuron [66598]	Desulfinylfipronil [66607]	Fluridone [51864]	Fluxapyroxad [51851]
		Sample date: June 3, 2015					
381719121432301	Cache Slough at Hass Slough near Liberty Farms, CA	Ulatis Creek	10:45	45.3	—	6.1	5.3
382006121401601	Liberty Island at Liberty Cut near Courtland, CA	Liberty Island Conservation Bank (LICB)	11:30	8.4	—	3.9	13.6
382005121392801	Little Holland Tract near Courtland, CA	North Little Holland Tract	11:50	13.6	—	5.1	6.2
381721121395301	Prospect Slough near Liberty Farms, CA	South Little Holland Tract	13:00	10.1	—	5.4	5.3
381418121405301	Prospect Slough at Cache Slough near Rio Vista, CA	South Prospect	12:35	10.9	—	5.2	5.9
		Sample date: July 6, 2015					
381719121432301	Cache Slough at Hass Slough near Liberty Farms, CA	Ulatis Creek	10:40	7.3	3.8	3.7	—
382006121401601	Liberty Island at Liberty Cut near Courtland, CA	Liberty Island Conservation Bank (LICB)	11:10	6.2	—	(3.0)	—
382005121392801	Little Holland Tract near Courtland, CA	North Little Holland Tract	11:25	7.3	—	3.7	—
381721121395301	Prospect Slough near Liberty Farms, CA	South Little Holland Tract	11:45	9.8	—	6.1	—
381418121405301	Prospect Slough at Cache Slough near Rio Vista, CA	South Prospect	12:10	5.8	—	4.2	—
		Sample date: August 13, 2015					
381719121432301	Cache Slough at Hass Slough near Liberty Farms, CA	Ulatis Creek	10:30	4.5	2.5	—	(3.6)
382006121401601	Liberty Island at Liberty Cut near Courtland, CA	Liberty Island Conservation Bank (LICB)	11:00	3.2	2.6	—	(4.4)
382005121392801	Little Holland Tract near Courtland, CA	North Little Holland Tract	11:15	3.6	2.7	—	(4.6)
381721121395301	Prospect Slough near Liberty Farms, CA	South Little Holland Tract	11:35	4.1	3.0	—	(4.4)
381418121405301	Prospect Slough at Cache Slough near Rio Vista, CA	South Prospect	11:52	4.1	2.6	—	(3.6)

Table 7. Pesticide concentrations measured in environmental water samples collected from the Cache Slough region of the Sacramento–San Joaquin Delta, California, 2015.—Continued

[Numbers in brackets are U.S. Geological Survey (USGS) National Water Information System (NWIS) parameter codes. Concentrations are in nanograms per liter. Results in parenthesis ( ) are below method detection limits and are estimates. **Abbreviations**: hh:mm, hours:minutes; —, not detected]

USGS station number	USGS station name	Short site name	Sample time (hh:mm)	Hexazinone [65085]	Metolachlor [65090]	Penoxsulam [51863]	Pyrimeth-anil [67717]	Simazine [65105]
		Sample date: June 3, 2015						
381719121432301	Cache Slough at Hass Slough near Liberty Farms, CA	Ulatis Creek	10:45	99.4	29.6	—	—	6.5
382006121401601	Liberty Island at Liberty Cut near Courtland, CA	Liberty Island Conservation Bank (LICB)	11:30	76.8	23.6	—	—	7.3
382005121392801	Little Holland Tract near Courtland, CA	North Little Holland Tract	11:50	56.5	22.1	—	—	6.9
381721121395301	Prospect Slough near Liberty Farms, CA	South Little Holland Tract	13:00	45.2	22.6	—	—	6.0
381418121405301	Prospect Slough at Cache Slough near Rio Vista, CA	South Prospect	12:35	53.7	24.6	—	—	6.2
		Sample date: July 6, 2015						
381719121432301	Cache Slough at Hass Slough near Liberty Farms, CA	Ulatis Creek	10:40	27.6	15.3	4.3	5.5	(2.6)
382006121401601	Liberty Island at Liberty Cut near Courtland, CA	Liberty Island Conservation Bank (LICB)	11:10	24.0	11.2	4.4	(2.6)	—
382005121392801	Little Holland Tract near Courtland, CA	North Little Holland Tract	11:25	19.8	9.4	—	(3.9)	—
381721121395301	Prospect Slough near Liberty Farms, CA	South Little Holland Tract	11:45	19.3	15.8	—	4.8	—
381418121405301	Prospect Slough at Cache Slough near Rio Vista, CA	South Prospect	12:10	17.5	13.1	5.4	5.4	—
		Sample date: August 13, 2015						
381719121432301	Cache Slough at Hass Slough near Liberty Farms, CA	Ulatis Creek	10:30	29.6	8.7	—	—	—
382006121401601	Liberty Island at Liberty Cut near Courtland, CA	Liberty Island Conservation Bank (LICB)	11:00	34.8	6.6	—	—	—
382005121392801	Little Holland Tract near Courtland, CA	North Little Holland Tract	11:15	33.8	7.5	—	—	—
381721121395301	Prospect Slough near Liberty Farms, CA	South Little Holland Tract	11:35	32.9	8.5	—	—	—
381418121405301	Prospect Slough at Cache Slough near Rio Vista, CA	South Prospect	11:52	27.0	8.5	—	—	—

Table 8. Detection frequencies of pesticides in water samples collected from the Cache Slough region of the Sacramento–San Joaquin Delta, California, 2015.

Pesticide	Pesticide type	Detection frequency (percent)
Azoxystrobin	Fungicide	100
Boscalid	Fungicide	100
Clomazone	Herbicide	100
N-(3,4-Dichlorophenyl)-*N*'-methylurea (DCPMU)	Herbicide degradate	100
3,4-Dichloroaniline (3,4-DCA)	Herbicide degradate	100
Diuron	Herbicide	100
Hexazinone	Herbicide	100
Metolachlor	Herbicide	100
Carbendazim	Fungicide	80
Fluridone	Herbicide	67
Fluxapyroxad	Fungicide	67
Chlorantraniliprole	Insecticide	47
Desulfinylfipronil	Insecticide degradate	40
Simazine	Herbicide	40
Pyrimethanil	Fungicide	33
Penoxsulam	Herbicide	20
Carbaryl	Insecticide	7
Dithiopyr	Herbicide	7

A comparison of pesticide detections for only the restored and remnant natural marsh sites (Ulatis Creek input-site data excluded) showed that the number of pesticides detected during a particular sampling was greatest at the LICB during June and August and tied for greatest during July (fig. 6). A similar comparison of total pesticide concentrations showed that concentrations were highest at the LICB in June and July compared to the natural marsh sites, but were lower at the LICB than at the natural marsh sites in August (table 7). These differences do not in and of themselves support the hypothesis that pesticide contamination is limiting plant growth in the LICB site. Further research is needed to determine whether these compounds could be affecting plant productivity at the LICB, particularly because 2015 was a drought year, when less rice was planted than usual (U.S. Department of Agriculture, 2017), and therefore, overall pesticide use in the region was also likely less than usual.

Conclusions

The Liberty Island Conservation Bank (LICB) contains vegetation that is of short stature and chlorotic relative to neighboring marshes in the Cache Slough region. This study tested whether (1) improper grading of the marsh plain, (2) contamination by pesticides from urban and agricultural sources upstream from the site, or (3) nitrogen-deficient soil could be responsible for these differences. The data showed no differences in total or organic carbon and nitrogen in the surface-soil layers among the marshes. Although we did not sample the full soil profile, the results indicated that differences among soils were not likely to be the main reason for the short and chlorotic vegetation at the LICB. An analysis of pesticides in water and suspended sediments collected during the summer of 2015 showed no major differences among sites. Because 2015 was a drought year, however, less rice than usual was planted, likely resulting in less pesticide use in the region compared with prior years. More research needs to be done to determine whether pesticides could be affecting plant growth at the LICB.

Lastly, an RTK-GPS elevation survey was carried out to determine whether there is an elevational difference between the constructed marsh at LICB and a natural marsh, also in the northern Cache Slough region (north Little Holland Tract), that has similar hydrodynamics. The results of the survey showed that, on average, the marsh plain is 26 centimeters higher at the LICB than at the north Little Holland Tract marsh. This result indicates that the higher elevation of the marsh plain at the LICB is altering its hydroperiod, resulting in decreased flooding and leading to reduced growth and vigor of marsh vegetation. Although the LICB cannot be regraded at this point without great expense, it could be possible to reduce the sharp angle of the marsh edge to facilitate tidal flooding on the marsh periphery. Grading the marsh plain at the correct elevation range is necessary for the establishment of marsh vegetation and the development of the full suite of ecosystem services that marshes provide. A better system of tidal benchmarks and more research on the elevation range required for successful colonization of herbaceous and scrub-shrub wetlands in the delta is needed to improve the success of wetland restoration in the region.

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