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RESTORATION OF A COASTAL WETLAND AT PRISONERS HARBOR, SANTA CRUZ ISLAND, CHANNEL ISLANDS NATIONAL PARK, CALIFORNIA

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ABSTRACT.—Prisoners Harbor of Santa Cruz Island, California, was historically the site of a 4.86-ha coastal wetland and riparian system—the largest on the California Channel Islands. The site was occupied by native people for 3000 years until the 1830s. During the late 1800s, ranchers filled about half of the wetland area to build livestock corrals and other facilities. They also rerouted the main stream channel, Cañada del Puerto, and built a stone wall and earthen berm along its west bank. This disconnected the stream from its floodplain and inadvertently caused erosion of a Native American archeological site. The National Park Service developed a wetland and riparian restoration design for Prisoners Harbor based on topographic and hydrologic analyses and on relationships between vegetation community and depth to water table estimated from neighboring reference wetlands. In 2011, Channel Islands National Park and The Nature Conservancy restored 1.25 ha of coastal wetland and reconnected the stream to its floodplain by removing the earthen berm. This restoration was accomplished by excavating 7645 m^3 of fill material and planting the site with over 15,000 native wetland and riparian plants. Postproject vegetation monitoring showed that only one of the 8 planted wetland species had a significant increase in abundance between 2012 and 2013, likely due to severe drought conditions that began soon after project implementation. However, hydrologic monitoring in the first year after restoration showed that the restored marshes met federal criteria for wetland hydrology just before the drought began. These data provide early but promising evidence that our approach to restoration will convert the filled corral area at Prisoners Harbor to functional coastal wetland habitat as more-typical (wetter) precipitation levels return. The restoration also helped to protect the archeological site and is expected to provide an enjoyable and educational destination for visitors.

RESUMEN.—Prisoners Harbor de la Isla Santa Cruz, California, era históricamente el sitio de 4.86-ha de humedal costero y un sistema ripario—el más grande de las Islas del Canal de California. El sitio estuvo ocupado por gente nativa durante 3000 años hasta 1830. A finales del siglo diecinueve, los rancheros llenaron casi la mitad del área de humedal para construir corrales de ganado y otras instalaciones. Ellos también desviaron la corriente principal del canal, Cañada del Puerto, y construyeron un muro de piedra y un terraplén de barro a lo largo de la orilla oeste, lo que desconectó la corriente de su planicie aluvial e inadvertidamente causó la erosión de un yacimiento arqueológico Nativo Americano. El Servicio del Parque Nacional desarrolló un diseño de restauración del humedal y del sistema ripario de Prisoners Harbor, basado en análisis topográficos e hidrológicos y en las relaciones de la profundidad de la comunidad de vegetal desarrolladas para humedales adyacentes de referencia. En 2011, el Parque Nacional de las Islas del Canal y The Nature Conservancy restauraron 1.25 ha de humedales costeros y recanalizaron la corriente hasta su planicie aluvial al eliminar el terraplén de barro. Esto se consiguió al excavar 7645 m^3 de material de relleno y al plantar el lugar con más de 15,000 plantas nativas de sistemas riparios y humedales. El proyecto posterior de monitoreo de la vegetación mostró que sólo una de las ocho especies de humedal plantadas tuvieron un aumento significativo en su abundancia entre 2012 y 2013, probablemente debido a condiciones severas de sequía que empezaron a darse muy pronto tras la implementación del proyecto. Sin embargo, el monitoreo hidrológico del primer año, tras la restauración, mostró que los humedales restaurados reunían los criterios hidrológicos federales para los pantanos justo antes de que empezara la sequía. Esto proporcionó pruebas tempranas, pero prometedoras, de que nuestro enfoque de restauración convertirá el área de corrales de Prisoners Harbor en un hábitat funcional de humedal costero en cuanto regresen los niveles normales de precipitación (más húmedo). La restauración también contribuyó a proteger el yacimiento arqueológico y se espera que proporcione un destino agradable y educativo para los visitantes.

Since the 1850s, an estimated 90% of California's original coastal wetlands have been altered or filled, reducing habitat for untold numbers of birds, amphibians, fish, and other wildlife (California Coastal Commission 1987). This habitat reduction has threatened with extinction numerous wetland-dependent species: 55% of the animals and 25% of the plants designated as threatened or endangered by the State of California depend on wetlands for their survival (Ferren et al. 1995). Remaining coastal wetlands are the most biologically diverse, productive, and densely populated habitats on the Pacific coast

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(USDI 1994). For example, during peak annual migration, hundreds of thousands of birds migrating along the Pacific Flyway—one of the 4 principal bird migration routes in North America—utilize coastal wetlands for refuge and food on their long migratory journeys (California Coastal Commission 1987). Remaining coastal wetlands in southern California are at risk due to climate change and associated rise in sea level.

In this paper, we describe the restoration of the coastal wetland and riparian system at Prisoners Harbor, Santa Cruz Island, California. In 2011, Channel Islands National Park and The Nature Conservancy, which co-own and comanage the island, restored 1.25 ha of this coastal wetland and riparian habitat. Restoration objectives included (1) reestablishment of natural wetland, stream, and floodplain hydrologic processes by excavating fill material from buried wetlands and removing the berm to reconnect the Cañada del Puerto stream with its floodplain; (2) restoration of wetland and riparian wildlife habitat and biological diversity; (3) protection of archeological resources at the Chumash Village site and historic structures of the sheep-ranching era; and (4) improvement of visitors' natural and cultural resource experience at Prisoners Harbor.

METHODS

Site Description

Channel Islands National Park preserves natural and archeological resources on 5 islands off the coast of southern California. These islands support nearly 100 endemic plant and animal species (Schoenherr et al. 1999), significant archeological sites associated with the Chumash people of southern California, and historic buildings and landscapes associated with California's early sheep-ranching industry. The largest of the Channel Islands at 25,000 ha, Santa Cruz Island is rugged and physiographically diverse. It contains the park's largest watershed—a 33.7-km^2 basin that drains the island's central valley. Runoff flows from the central valley to the Pacific Ocean through Cañada del Puerto, a 4-km long canyon with a seasonally dry cobble streambed. As it approaches the coast, the canyon opens onto an alluvial fan, forming what historically was a 4.86-ha system of freshwater wetland, stream channel, riparian area, and back barrier—all lagoon features of Prisoners Harbor. Such systems develop where streams terminate behind coastal beaches or bars that block discharge to the ocean most of the year, forming back-barrier lagoons. The lagoons may become brackish from saltwater intrusion or storm-driven wave overflow from the ocean. During high-rainfall events, floodwaters historically would overtop the Cañada del Puerto stream bank and deliver sediment, nutrients, and organic matter to wetlands and riparian areas on the floodplain. When flows are large enough, the channel erodes through the cobble beach at the coast and discharges floodwaters to the ocean. However, this direct connection to the ocean is temporary, and the cobble beach reforms soon after flood events.

Prisoners Harbor has a long history of development to meet the needs of island residents (Fig. 1). Chumash people occupied the island for at least 7000–10,000 years and the Prisoners Harbor area for more than 3000 years. During the Prisoners Harbor occupation, a large midden formed near the mouth of the Cañada del Puerto stream channel (Glassow 1980, Schoenherr et al. 1999, Arnold 2001). Early European explorers described the Chumash village there as one of the most highly populated sites in the region (Arnold 2001). However, by the 1830s no Chumash lived on Santa Cruz Island. A decade later, the island was used briefly by the Mexican government as a penal colony, hence the name Prisoners Harbor (Mason 1883). Today Prisoners Harbor is the location of one of 2 piers servicing the island, where more than 8000 visitors to the park disembark each year.

Beginning in the 1860s, residents of European descent settled the island's interior valley to produce sheep for mainland consumption. During the late 19th or early 20th century, ranchers rerouted the Cañada del Puerto channel to the east side of the valley floor and built a stone wall on its west bank as it approached the coast at Prisoners Harbor. The wall helped maintain the new channel location, prevented at least some flood flows from spreading out over the floodplain, and directed more flow volume and erosive force toward the valuable archeological resources at the Chumash Village site. Rock and sand were used to fill 1.25 ha of wetlands at Prisoners Harbor

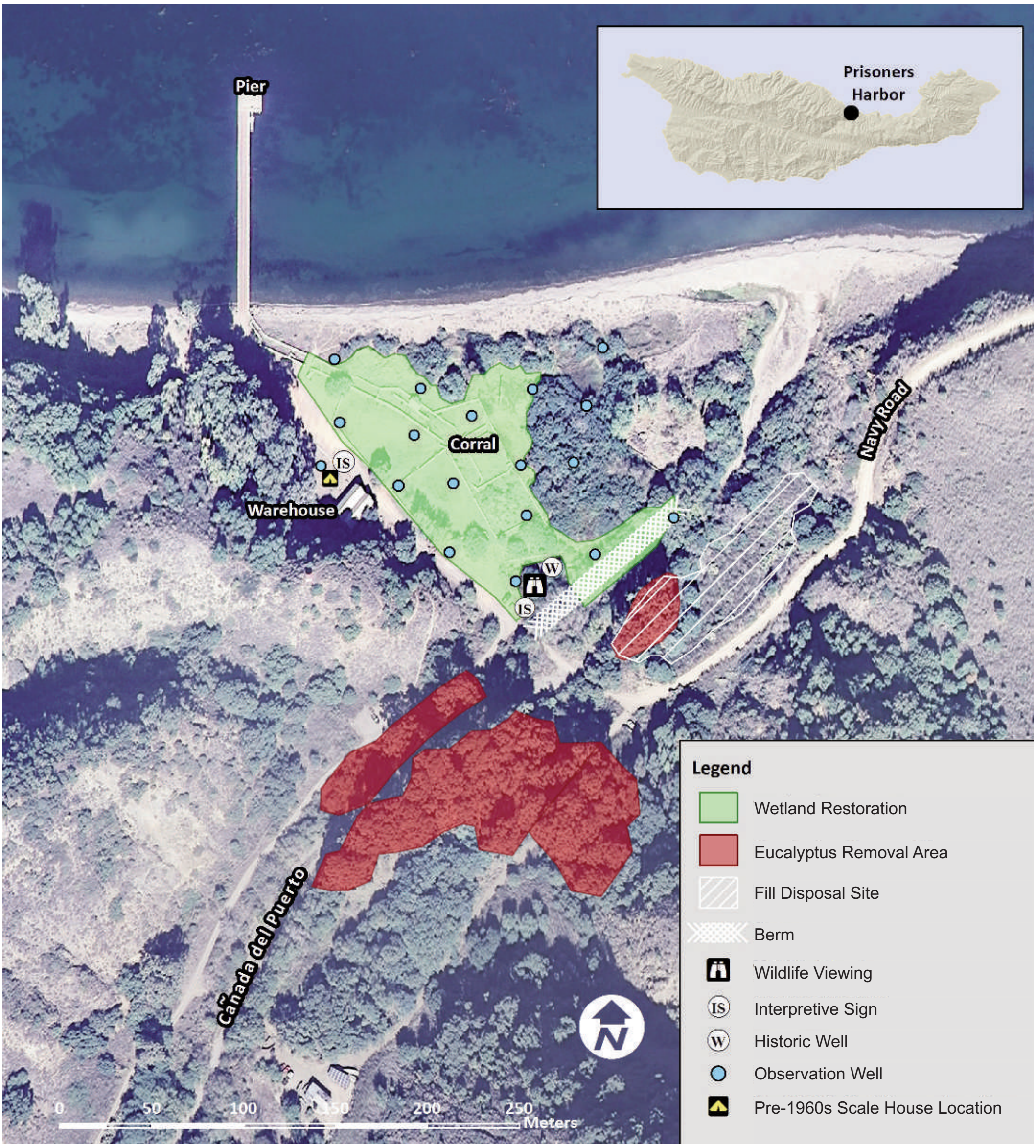

Fig. 1. Aerial view of Prisoners Harbor, Santa Cruz Island, California. Photo was taken prior to project implementation. Inset shows the location of restoration on Santa Cruz Island.

(approximately half of the total predevelopment wetland area) to create dry land suitable for livestock export operations. In the mid-20th century, a new generation of ranchers constructed cattle corrals on the filled wetland and moved the historic scale house from its original upland site to the former wetland area. The ranchers also augmented the rock wall by bulldozing alluvium into a nearly 1-m high berm along the western bank of the stream, completely severing the connection between the stream channel and its floodplain. These actions disrupted or eliminated many of the natural ecological functions provided by wetland-riparian systems, including sequestration of carbon in wetland soils; attenuation of flood flows; filtration of nutrients, sediment, and organic matter delivered from the watershed; and maintenance of diverse and high-quality wildlife habitat.

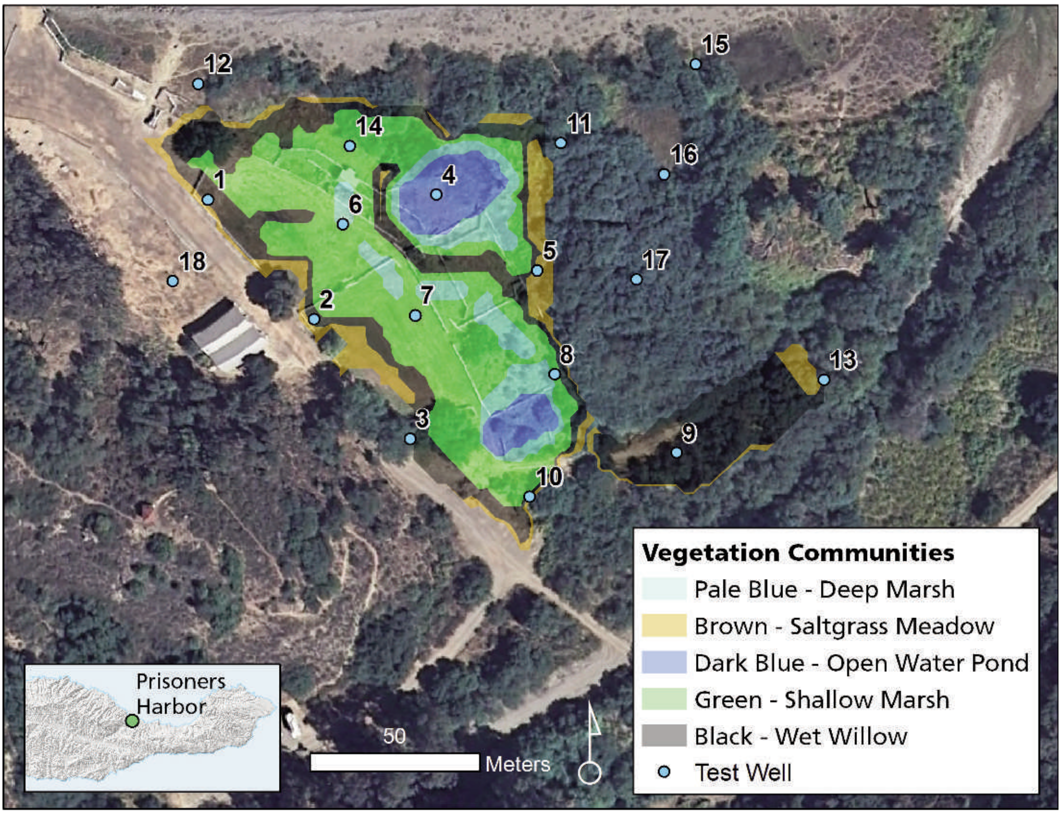

Fig. 2. Final design plan including specified elevations for 5 vegetation community types. Data from 15 observation wells (wells 1–14, 18) and 3 reference wells (wells 15–17) were used to develop the restoration design plan. Reference transect extended from well 15 through well 16 to well 17. Photo was taken after project implementation. Inset shows the location of restoration on Santa Cruz Island.

Project Planning and Design

Our approach to wetland and riparian restoration design was to develop a thorough understanding of site topography and hydrology and to use relationships between vegetation community and depth to water table in nearby, undisturbed "reference wetlands" as a guide. We completed a detailed topographic survey of the area and used spatial analysis software (Surfer®) to create a digital topographic contour map for the prerestoration land surface. To evaluate hydrology, we installed 18 shallow observation wells throughout the project site in December 2004 (Figs. 1, 2). The wells were made from 5-cm-diameter, slotted PVC pipes inserted 1.3–2.6 m into the ground. We logged soils at each borehole during well installation to identify depths of fill material, buried wetland surfaces, and other characteristics. Fifteen of the wells were installed in the filled wetland areas. The other 3 wells (15–17 in Fig. 2) were installed in an adjacent, undisturbed reference area along a transect that passed through a saltgrass (*Distichlis spicata*) meadow (well 15), a marsh dominated by California bulrush (*Schoenoplectus californicus*, well 16), and a wet willow (*Salix lasiolepis*, well 17) forest. The well network allowed us to evaluate daily, seasonal, and interannual variation in water table depths, ground water gradients, and specific conductance in both the disturbed and reference areas. Water-level data collected during 2005–2010 showed that all wells had nearly identical hydrographs, rising and falling in the same way in response to seasonal rainfall patterns. The difference was that the water table in the disturbed area was buried under approximately 1 m of fill. This finding confirmed that our design method was appropriate: we could determine relationships

TABLE 1. Abundance (percent frequency) of target herbaceous plant species in 1-m^2 quadrats in 2012 and 2013, including the type and percentage of designed plant community in which each species was planted.

	Community		Year		
Target species	Type	% of designed community	2012	2013	*P* value
Baccharis douglasii	Wet willow	18%	1.3%	4.4%	0.01
Distichlis spicata	Saltgrass meadow	12%	15.2%	19.5%	0.11
Juncus mexicanus	Shallow marsh	46%	15.2%	18.8%	0.18
Juncus patens	Wet willow	18%	29.6%	20.2%	0.002
Juncus xiphioides	Wet willow	18%	1.3%	0%	0.02
Schoenoplectus californicus	Deep marsh	9%	8.4%	8.9%	0.80
Schoenoplectus maritimus	Shallow marsh	46%	0.8%	0.2%	0.29
Schoenoplectus pungens	Shallow marsh	46%	9.7%	7.4%	0.25

between vegetation community and depth to water table in the reference area and reproduce those same relationships at the restoration site by excavating to depths that would support the desired wetland types.

We began the design process by calculating and plotting mean water table elevations along the reference transect for November 2005–November 2006, a period of near-normal precipitation at the Santa Cruz Island RAWS weather station (WRCC 2008). We then determined the depth-to-mean-water-table range for each reference transect plant community as an initial restoration guide. We supplemented this information with literature on plant species' tolerances for saturated conditions and observations at other Santa Cruz Island wetlands to refine the depth-to-mean-water-table ranges for 4 target wetland and riparian plant communities. Saltgrass meadow was 53 to 34 cm above the mean November 2005–November 2006 water table; wet willow habitat was 34 cm to 15 cm above the mean water table, shallow marsh was 15 cm to 0 cm (exactly at the mean water table), and deep marsh was 0 cm to 76 cm below the mean water table. We developed a plan view conceptual design (Fig. 2) that included these 4 habitat types, with the plant palette for each shown in Table 1. We also incorporated 2 open water ponds (76–180 cm below the mean water table) to provide perennial freshwater sources for wildlife and habitat for waterfowl.

To produce a grading plan that would achieve these habitat types, we used Surfer® software to contour mean November 2005–November 2006 water table elevations across the filled area. Then, based on the relationship between plant community and depth to water table, we either added or subtracted increments of elevation from the water table contours to reach grades that corresponded to target habitat types across the site. Visitor use at Prisoners Harbor also influenced the final design. For example, to screen waterfowl that would use the restored ponds and marshes from human activity, we lined the visitor access road adjacent to the wetlands with willows. Two secluded vistas were incorporated into the design to provide visitors with opportunities for wildlife viewing and interpretation.

One of our objectives was to restore natural floodplain processes by reconnecting the lower Cañada del Puerto stream channel to its immediate floodplain. We quantified potential success of this objective through standard hydraulic modeling. We used the U.S. Army Corps of Engineers water surface profile model, HEC-RAS, to investigate the effects of removing the berm on both the archeological site and on frequency of overbank flooding (United States Army Corps of Engineers 2010). We surveyed a total of 6 channel and floodplain cross sections, beginning at the cobble beach and extending about 700 ft. upstream to completely encompass the study reach. After formatting the survey data into HEC-RAS, we ran a series of design floods through the channel with the levee both in place and removed to evaluate the discharge required to inundate the adjacent floodplain and to quantify channel velocities in the vicinity of the archeological site.

Based on these analyses, we prepared final design specifications, drawings, and cost estimates for earthmoving, erosion control, and revegetation. To estimate the volume of fill to be removed during the construction phase, we used the Surfer® program to calculate the difference in volume between the prerestoration topographic surface and the final design surface.

We contracted for plant nursery services based on the species mix (Table 1) and planting densities specified for each community type. We contracted for a Native American monitor and an archeological monitor to look for cultural material during ground-disturbing activities.

Project Implementation

After consulting with the State Historic Preservation Office, we worked with partners to dismantle the corral system and remove old concrete piles and other debris from the filled area. Salvageable lumber from the corrals was used to construct an interpretive corral adjacent to the historic warehouse (Fig. 1). The interpretive corral incorporated a scale house, squeeze shoot, loading shoot, and water troughs. Invasive eucalyptus trees (*Eucalyptus globulus, E. camaldulensis*), kikuyugrass (*Pennisetum clandestinum*), and fennel (*Foeniculum vulgare*) were removed or treated prior to earthmoving activities. Downed eucalyptus wood was chipped, and chips were also used as a demarcation layer to separate the native soil surface at the fill disposal area from the capping material (Fig. 1).

Between 2008 and 2011, NPS staff collected plant material (seeds, plugs, stakes) of 8 herbaceous species (Table 1) and willows (*S. lasiolepis*) for propagation and planting. To preserve the integrity of island genotypes and to reduce risk of transporting nonnative species in nursery pots, we collected plant material from on-island populations as near to the project area as possible and propagated plants on-island. The number of plants propagated for each herbaceous species was based on the areas of the target plant communities, an on-center spacing of 46 cm, and availability of propagules. We collected enough willow stakes to achieve a planting density of one stake per 1 m^2 in willow zones.

Approximately 30 kg of seed from native upland species was collected from island locations between 2004 and 2010. These seeds were held in a constant-temperature environment (approximately 22 °C) until the earthmoving phase was complete and then were broadcast evenly over the 0.44-ha upland fill disposal area. Approximately 4.5 kg of *Quercus agrifolia* acorns and *Marah macrocarpus* seeds were planted directly into the soil in the fill disposal area.

Design specifications called for excavating over 7645 m^3 of fill to reestablish coastal wetlands and reconnect the Cañada del Puerto stream channel to its floodplain. Earthmoving was scheduled for early fall, when the water table is normally low. Prior to excavation, we worked with the earthmoving contractor to install grading stakes per design specifications. A water truck, bulldozer, skip loader, loader, and excavator were transported to the island, and the excavation crew began work on 20 September 2011.

We checked grades throughout each day to ensure that design elevations were achieved within ±3 cm. Excavated material was transported by loader bucket to the fill disposal site and smoothed to match natural contours. A row of eucalyptus logs was placed approximately 9 m from the stream, creating a stable wall against which fill was placed. The fill was compacted only by the wheels of the vehicles passing over it. When fill placement was complete, the site was smoothed and native upland seed was evenly broadcast across the area. The fill disposal site, excavated wetland, and former berm area were then covered with a biodegradable erosion-control fabric, Curlex Netfree®, composed of aspen shavings. NPS project staff, the construction supervisor, the Native American monitor, and the archeological monitor were present during all earthmoving operations.

Two unanticipated discoveries made during the earthmoving phase caused us to modify the design. While removing the 1950s-era berm, the excavator operator contacted the historic, dry-laid stone wall, and construction was immediately stopped. Park staff directed exposure of a section of the wall, mapped its location using GPS technology, and photographed it before reburying it under a veneer of fill. Although we ultimately lowered the berm by almost a meter, we left the final elevation 33.5 cm higher than the original design to preserve the historic wall. This adaptation would still allow high flows to overtop the stream bank and spread out over the floodplain during future high-flow events, though at a somewhat reduced frequency than originally anticipated.

We made a second field adaptation after discovering midden material at the planned location of the southern pond. We halted excavation work and called in the park archeologist to document the midden material. We then modified the shape of the southern pond to protect the midden site and maintain the same pond surface area as originally designed (Fig. 2).

We scheduled the revegetation phase to coincide with the arrival of late fall rains. Project staff collected approximately 1325 willow stakes, ranging from 1.3 cm to 3.8 cm in diameter, from the riparian corridor near the project area. Cuttings were tied into 25-stake bundles and placed in water to soak prior to planting. The excavator with a "stinger" attachment was used to install the stakes in willow zones along the access road and on the stream bank where the berm had been removed. The stinger operated like scissors, pushing into the ground to a depth of 1.2 m and then opening at a pivot point. A willow stake was then dropped into the resulting hole, the stinger removed, and dirt tamped around the stake to maximize soil contact.

Next, approximately 15,000 plants were planted in their appropriate depth-to-water-table zones during 29 November–6 December 2011 (Table 1). Seedlings grown in 5-cm and 7.6-cm containers, 3.8-L pots, and flats were installed on 46-cm centers. The resulting 1.25 ha of restored wetland included about 0.19 ha of open-water pond habitat, 0.23 ha of wet willow forest, 0.58 ha of shallow marsh, 0.11 ha of deep marsh, and about 0.15 ha of saltgrass meadow. Planting was a cooperative effort among NPS project staff, Los Angeles Conservation Corps members, and volunteers.

Some adaptive vegetation management was necessary. We irrigated higher-elevation areas 4 times during the much-drier-than-average 2012 growing season. We also managed aggressive weeds including white sweetclover (*Melilotus albus*), lotus (*Lotus corniculatus*), Italian ryegrass (*Lolium multiflorum*), and kikuyugrass (*Pennisetum clandestinum*) by hand pulling, chemical application, and weed flame technology.

Postproject Monitoring

We developed a vegetation monitoring design using square nested frequency plots to sample abundance and cover of target (planted) species over time. We established a 195-m baseline parallel to the road along the southwest margin of the restoration site, and created transects approximately perpendicular to the baseline, systematically placed every fifth meter with a random start. The purpose of the transects was to establish a basic structure on which we could randomly but systematically place sampling points that would be well dispersed throughout the excavated area. During 16–18 October 2012 and 27–29 August 2013, NPS staff and partners recorded the abundance of target species along the transects using quadrats sizes 0.1 × 0.1 m, 0.25 × 0.25 m, 0.5 × 0.5 m, and 1 × 1 m. The monitoring design incorporated multiple quadrat sizes to better track changes in target species within the sampling area (Elzinga et al. 1998). We analyzed the data for changes between 2012 and 2013 using the Pearson's chi-square test for independence with $\alpha = 0.05$. Vegetation monitoring will continue through 2016.

To monitor postrestoration hydrology, we installed continuous water-level recorders (pressure transducers) in 4 of the original 18 shallow observation wells. The transducers were programmed to collect hourly data at wells 6 and 7 in the restored shallow marsh zone, at well 9 along the west stream bank (former berm site), and at well 16 within a reference transect marsh (Fig. 2). Wells 6 and 7 will provide data to determine whether the restored shallow marsh meets federal technical standards for wetland hydrology. Well 9 will be used to determine whether larger flows overtop the stream bank and spread out over the floodplain. Well 16 will allow us to compare hydrologic conditions between the restored and reference wetlands. Water table depths at these wells are also measured by hand through the year to calibrate the transducer data, as well as at 11 other shallow wells throughout the restoration and reference areas. NPS hydrologists will use the larger well data set to create postproject water table elevation maps. These maps will be evaluated in conjunction with vegetation monitoring data to assess the relationships between water table elevation and vegetation abundance (by species) at the restored site. Hydrologic monitoring will continue through at least 2016.

Precipitation is recorded hourly at the Santa Cruz Island Main Ranch RAWS Station (WRCC 2008), located approximately 3.9 km from the project site. Long-term monthly data are available for this location beginning in January 1904 (Channel Islands National Park unpublished precipitation data).

We established a series of photo-monitoring points to document changes in dominant landscape features prior to and following project

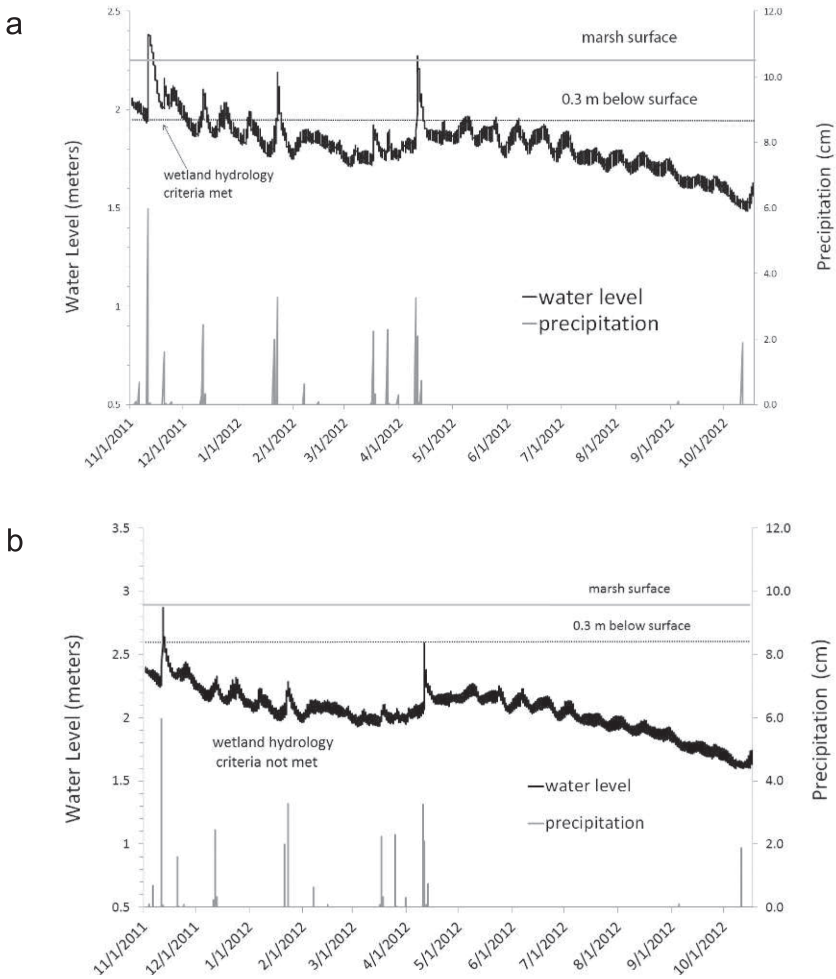

Fig. 3. Postrestoration water-level response to precipitation during November 2011–October 2012: **a,** well 6 (shallow marsh); **b,** well 9 (floodplain west of stream channel, former location of earthen berm).

implementation. These points include a total of 27 views, 4 of which are based on photos taken between 1880 and 1920. For each photo, UTM coordinates, tripod height, camera tilt angle, compass direction, date, and time are recorded. Photos were taken quarterly for the first year after restoration and will be taken once per year for 4 years and as needed in subsequent years.

RESULTS

Hydrology

Precipitation during the 2-year period after construction was far below average, creating a "severe drought" condition for the region according to the U.S. Drought Monitor website (National Drought Mitigation Center 2013). During November 2011 to October 2012, precipitation totaled only 30.9 cm compared to the long-term average of 50.4 cm (61% of average). After a relatively wet November, precipitation for December to March, normally the wettest 4 months of the year, totaled only 14.2 cm (36% of normal). In the following year (November 2012–October 2013) drought conditions persisted, with only 22 cm of precipitation (44% of average).

Figure 3 shows how water levels at well 6 (shallow marsh) and well 9 (the former berm location) responded to precipitation during the first year after construction. According to

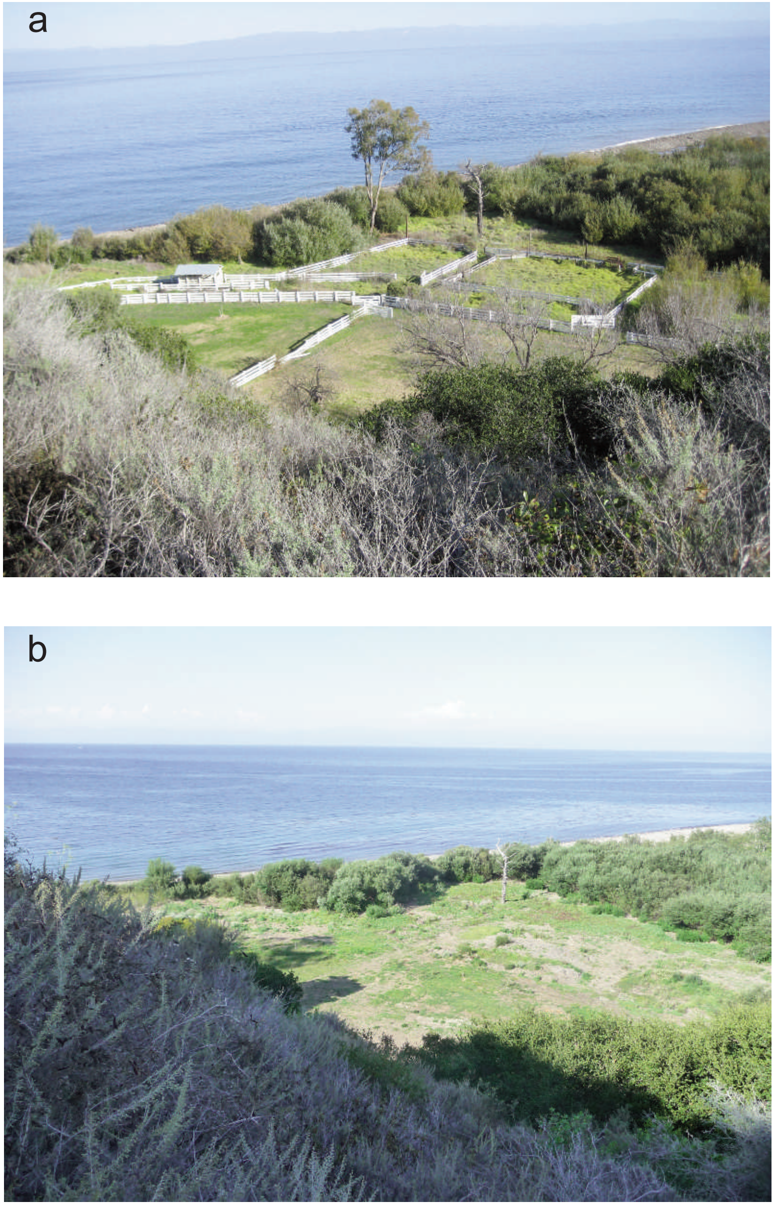

Fig. 4. Prisoners Harbor restoration area looking northeast: **a,** prior to project implementation in January 2010; **b,** prior to excavation in September 2011; **c,** immediately after native plant installation in December 2012; **d,** 18 months after project implementation in June 2013.

the federal technical standard for wetland hydrology, wetland areas must be ponded or have a water table within 0.3 m of the ground surface for 14 or more consecutive days during the growing season, at a minimum frequency of 5 years in 10 (United States Army Corps of Engineers 2005). The dashed lines on the graphs in Fig. 3 represent 0.3 m below the ground surface. Well 6 data show that the shallow marsh met the high–water table duration requirement of the wetland hydrology standard in the relatively wet month of November 2011—the only time this occurred during the 2011–2012 wet season. The water table again rose to within 0.3 m of the marsh surface following rain events in December,

Fig. 4. Continued.

January, and April but not long enough to meet the 14-day duration requirement. A second shallow marsh monitoring site at well 7 produced the same results. Drought conditions were so severe during the 2012–2013 wet season that these shallow marsh wells were dry (no data) much of the time, and neither location had a water table within 0.3 m of the surface. The hydrograph for well 9, located at an upland floodplain site between the stream channel and the restored wetland area, shows that the water table fluctuated in a pattern similar to well 6 in the first year after restoration. Although the water table rose briefly to within 0.3 m of the ground surface on 2 occasions during this period, the water table is generally deeper than at well 6 by design, and this site did not come close to meeting the high–water table requirement of the federal wetland hydrology standard. Well 9 was dry during most of the 2012–2013 wet season and produced little useful data.

Results from the HEC-RAS modeling indicated that removal of the berm would allow more frequent overbank flows to access the adjacent floodplain, reestablishing natural stream-floodplain processes that support wetland and riparian areas. More specifically, with the berm in place, the stream channel was capable of containing a flow of about 73.3 $m^3 \cdot s^{-1}$ before spilling out at a road crossing upstream of the berm. With the berm removed, model results showed that flows $\geq$15.6 $m^3 \cdot s^{-1}$ would spill over the left bank where the berm once stood and access the adjacent floodplain/wetland system. Additionally, removing the berm would substantially reduce the hydraulic pressure of these flows at the archeological site immediately downstream (Fig. 1). Average channel velocities during extreme events would decrease by about 40%, from about 3 $m \cdot s^{-1}$ to $<$1.8 $m \cdot s^{-1}$.

Vegetation

Table 1 shows the results for 1 × 1-m quadrat vegetation monitoring in 2012 compared to 2013. Of the 8 herbaceous species planted, abundance (% frequency) of one species, *Baccharis douglasii,* increased significantly from 1.3% to 4.4% (chi-square value $P = 0.01$). There was no significant change in *D. spicata, Juncus mexicanus, S. californicus, Schoenoplectus maritimus,* and *Schoenoplectus pungens. Juncus patens* declined in abundance significantly, and *Juncus xiphioides* was not observed during 2013 monitoring (chi-square value $P = 0.02$ and $P = 0.00$, respectively). Photomonitoring also documented vegetation change on a landscape scale over this period (Fig. 4).

DISCUSSION

A main project objective was to reestablish natural wetland, stream, and floodplain conditions and processes at Prisoners Harbor. One way of evaluating project success is to determine whether the restored wetland communities meet federal wetland definitions and standards. Under Corps of Engineers Wetlands Delineation Manual procedures (Environmental Laboratory 1987), positive indicators of wetland hydrology, hydrophytic vegetation, and hydric soil must be confirmed for a site to be a wetland. Though it is too soon to make this determination for the Prisoners Harbor restoration, especially with regard to vegetation cover and soil characteristics, which take time to establish, our postproject hydrologic monitoring provides some early evidence of success.

In the first year after construction, wells 6 and 7 showed that the shallow marsh (the largest community type in the restoration) met the high water table requirement of the federal wetland hydrology standard. In the second year, the shallow marsh did not meet this requirement due to severe drought conditions (44% of average precipitation). However, with the return of historic precipitation levels, we expect that the restored wet willow zones, marshes, and ponds will meet the high water table requirement with sufficient frequency (at least 5 years in 10) to satisfy the federal technical standard for wetland hydrology.

Postrestoration drought conditions have not produced sufficient runoff to determine whether removing the berm has reconnected the stream to its floodplain at Prisoners Harbor. However, HEC-RAS modeling results showed that removal of the earthen berm has opened a broad path for overbank flows to reach the floodplain and wetland areas when they do occur in the future, beginning when stream flows exceed about 16 $m^3 \cdot s^{-1}$. The retention of approximately 33.5 cm of berm material above the original design grade to protect the historic stone wall will contain a very narrow range of overbank flows within the stream channel. However, most flows that would have been contained by the former earthen berm will now be able to spread out over the adjacent floodplain and wetlands. In addition to more frequent floodplain inundation, removal of the berm has reduced the potential erosive forces in the vicinity of the archeological site. In the prerestoration channel, high-magnitude flows would be contained by the berm, producing a much higher stream stage and leading to excessive velocities and stream power values immediately downstream at the archeological site. Removal of the berm has reduced potential velocities by about 40% and stream power values by about 75%.

Four vegetated community types were designed into the project: saltgrass meadow, wet willow, shallow marsh, and deep marsh.

Monitoring results showed mixed results for species and vegetation communities. Wet willow species *Baccharis douglasii* increased significantly ($P = 0.01$) in abundance between 2012 and 2013 and continues to expand in the wet willow zone. *Schoenoplectus californicus,* planted in the deep marsh zone, grew into robust plants approximately 3–4 m in height on the banks of the open water ponds, where soil moisture is high in spite of drought conditions. This species' slight increase in abundance was not significant. *Juncus patens,* planted broadly in the wet willow and shallow marsh zones, significantly declined in abundance during the same time period ($P = 0.002$). This species persisted primarily at the boundary between the 2 zones, under the canopy of other species, and in finer soils. Note that soil texture was highly variable across the site. Soil on the northwest edge of the excavated area was coarse sand and gravel, whereas soil on the southeastern side of the excavated area was a finer texture. Shallow marsh species *Juncus mexicanus* and *S. pungens* increased slightly in abundance ($P = 0.18$) and decreased slightly ($P = 0.25$), respectively. Species planted in the shallow marsh zone depend on water close to the surface, and establishment and expansion of these species was likely negatively impacted by extreme drought conditions. *Juncus xiphioides* and *Schoenoplectus maritimus* exhibited evidence of plant rust and were in poor condition at the time of planting. They did not recover under the exceptionally dry conditions and by 2013 disappeared entirely.

We expect that species whose abundance increased or remained the same between 2012 and 2013 will become more robust over time, but we do not expect them to expand beyond their depth-to-water-table tolerances. Species that declined in abundance, such as *S. pungens* and *J. patens,* may have different tolerances for saturated conditions, neighbor effects, or soil type than expected. They may become established in narrower bands or may disappear entirely as longer-term hydrologic conditions prevail and neighboring plant species compete for resources over time.

Despite the limited spread of the planted species during severe drought conditions, postproject hydrologic data provide early but promising evidence that we successfully converted much of the site from upland pasture to wetlands, according to federal definitions and standards. Our approach of analyzing prerestoration groundwater and topographic data, developing relationships between plant community and depth to water table for adjacent reference wetlands, and grading the filled area to recreate these relationships for target communities appears to be an effective wetland restoration method that could be applied successfully to other projects of this kind. With the eventual return of more typical (wetter) precipitation levels, we expect the site to continue to develop into quality aquatic habitat, provide a perennial water source for island wildlife, serve as an important resource for migratory birds that use southern California's few remaining coastal wetlands, protect cultural resources, and serve as an enjoyable and educational destination for park visitors.

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