



NOVATO CREEK BAYLANDS

HISTORICAL ECOLOGY STUDY

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SAN FRANCISCO ESTUARY INSTITUTE & THE AQUATIC SCIENCE CENTER

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HISTORICAL ECOLOGY STUDY

May 2015



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COVER CREDITS

NAIP 2012; historical synthesis mapping of Novato Creek baylands (developed for this report).

VERSION

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Introduction

Project Background

Over the past century and a half, lower Novato Creek and the surrounding tidal wetlands have been heavily modified for flood control and land reclamation purposes. Levees were built in the tidal portion of the mainstem channel beginning in the late 1800s to convey flood flows out to San Pablo Bay more rapidly and to remove surrounding areas from inundation. Following levee construction, the wetlands surrounding the channel were drained and converted to agricultural, residential, and industrial areas. These changes have resulted in a considerable loss of wetland habitat, reduced sediment transport to marshes and the Bay, and an overall decreased resilience of the system to sea level rise.

In addition to tidal wetland modification, land use changes upstream in the Novato Creek watershed have resulted in several challenges for flood control management. Dam construction and increased runoff in the upper watershed have resulted in elevated rates of channel incision, which have increased transport of fine sediment from the upper watershed to lower Novato Creek. Channelization of tributaries and construction of irrigation ditches have likely increased drainage density in the upper watershed, also potentially contributing to increased rates of channel incision and fine sediment production (Collins 1998). Downstream, sediment transport capacity has been reduced by construction of a railroad crossing and loss of tidal prism and channel capacity associated with the diking of the surrounding marsh. As a result of the increased fine sediment supply from the watershed and the loss of sediment transport capacity in lower Novato Creek, sediment aggradation occurs within the channel, which in turn reduces the flood capacity of the channel, necessitating periodic dredging (fig. 1; Collins 1998, PWA 2002).

Figure 1. Lower Novato Creek. (photo by SFEI, May 29, 2013)



Currently, the Marin County Department of Public Works (MCDPW) is coordinating the Novato Watershed Program, which includes Marin County Flood Control and Water Conservation District, Novato Sanitary District, North Marin Water District, and the City of Novato. Within lower Novato Creek, the Program is seeking to implement a new approach to flood control that includes redirecting sediment for beneficial use, reducing flood channel maintenance costs, restoring wetland habitat, and enhancing resilience to sea level rise. Included as part of this goal is the re-establishment of historical physical processes that existed before major channel modification, which in turn will re-establish historical ecological functions and help to create a tidal landscape that is resilient to increasing sea level.

Study Goal and Objectives

The goal of this study is to develop an understanding of the physical and ecological changes to lower Novato Creek and the surrounding tidal marshes and mudflats (referred to here as “baylands”). The specific objectives of the study are to: 1) reconstruct the historical ecology and hydrography of lower Novato Creek and baylands during the mid-19th century; and 2) assess ecological change over time within lower Novato Creek and baylands through comparisons of reconstructed historical and contemporary conditions. These objectives are met through a detailed analysis of the changes in landscape ecological patterns, or landscape metrics, over the past 150 years. The results from this analysis are intended to provide baseline information that can be used to design restoration and flood control alternatives and develop appropriate restoration targets for lower Novato Creek and baylands.

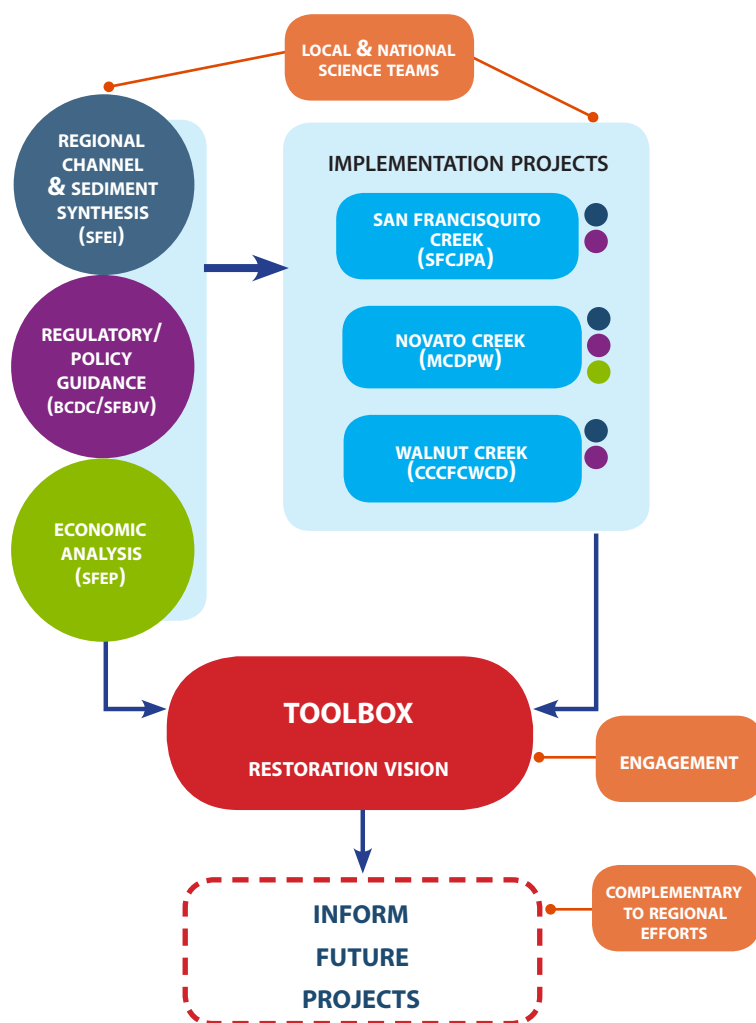
This study is one component of the Flood Control 2.0 project, a regional effort to redesign flood control channels at the Bay interface to improve bayland habitats and provide beneficial uses of sediment while maintaining the required level of flood protection (fig. 2). Emerging strategies for flood protection focus on reconnecting channels to floodplains and tidal marshes and using available dredged sediment as a resource to increase marsh elevations to keep pace with sea level rise. Lower Novato Creek was selected as one of three pilot implementation projects, along with lower San Francisquito Creek in Santa Clara and San Mateo counties and lower Walnut Creek in Contra Costa County, to demonstrate the benefits of this new approach to flood control and habitat management at the Bay interface.

Study Area

This study focuses on lower Novato Creek and surrounding baylands downstream of the City of Novato (fig. 3). The study area was largely defined by the historical extent of tidal marsh, which extended inland to about a third of a mile west of where U.S. Highway 101 crosses the creek today. On the eastern side, the study area encompasses both the historical and current intertidal mudflats (bay flats) between the Novato Creek baylands and San Pablo Bay. The northern and southern boundaries are defined by natural promontories. On the northern end of the Novato Creek baylands, Petaluma Point marks the study area boundary. On the southern end, Hamilton Point is used to separate the Novato Creek baylands from the Miller Creek baylands to the south.

Novato Creek Watershed

Novato Creek originates in the hills to the west of the City of Novato and flows east for approximately 17 miles before emptying into San Pablo Bay (County of Marin 2009). The creek drains an approximately 44 square mile watershed that ranges in elevation from sea level to 1,900 feet (fig. 4; USACE 2003, CDFG 2009). Stafford Dam, constructed in 1951, is located approximately 9 miles west of the mouth of Novato Creek and impounds flow and sediment from approximately 17% (8 square miles) of the watershed (North Marin Water District 2013). Average annual precipitation within the watershed is approximately 28 inches, with the majority of precipitation falling between late fall and early spring (Collins 1998). Flow in Novato Creek generally tracks precipitation, with nearly 90% of the



PROJECT LEADS

- SAN FRANCISCO ESTUARY INSTITUTE (SFEI)
- SAN FRANCISCO ESTUARY PARTNERSHIP (SFEP)
- SAN FRANCISCO BAY CONSERVATION AND DEVELOPMENT COMMISSION (BCDC)
- SAN FRANCISCO BAY JOINT VENTURE (SFBJV)

PROJECT PARTNERS

- SAN FRANCISQUITO CREEK JOINT POWERS AUTHORITY (SFCJPA)
- MARIN COUNTY DEPARTMENT OF PUBLIC WORKS (MCDPW)
- CONTRA COSTA COUNTY FLOOD CONTROL AND WATER CONSERVATION DISTRICT (CCCFCWCD)

Figure 2. Flood Control 2.0 project overview. Lower Novato Creek was selected as one of three pilot implementation projects around the Bay.



Figure 3. The study area (outlined in white) encompasses approximately 13 square miles, including lower Novato Creek and the surrounding baylands. (NAIP 2012)

annual flow volume passing through the creek between December and March (as recorded at USGS gage 11459500 in downtown Novato).

Despite its location in the heavily urbanized San Francisco Bay Area, most of the Novato Creek watershed remains relatively rural. Land uses include open space (60% of the watershed), developed areas (35% of the watershed), and agriculture (5% of the watershed). The open space areas include forested land, rangeland (grassland and shrubland), wetlands, and open water features, with over half of the areas designated as parkland (ABAG 2005). Vegetation in higher elevation open space areas is dominated by annual grassland and interior mixed hardwood forest (oak-bay woodland), while vegetation at lower elevations is characterized by annual grassland and coast live oak woodland/savanna (County of Marin

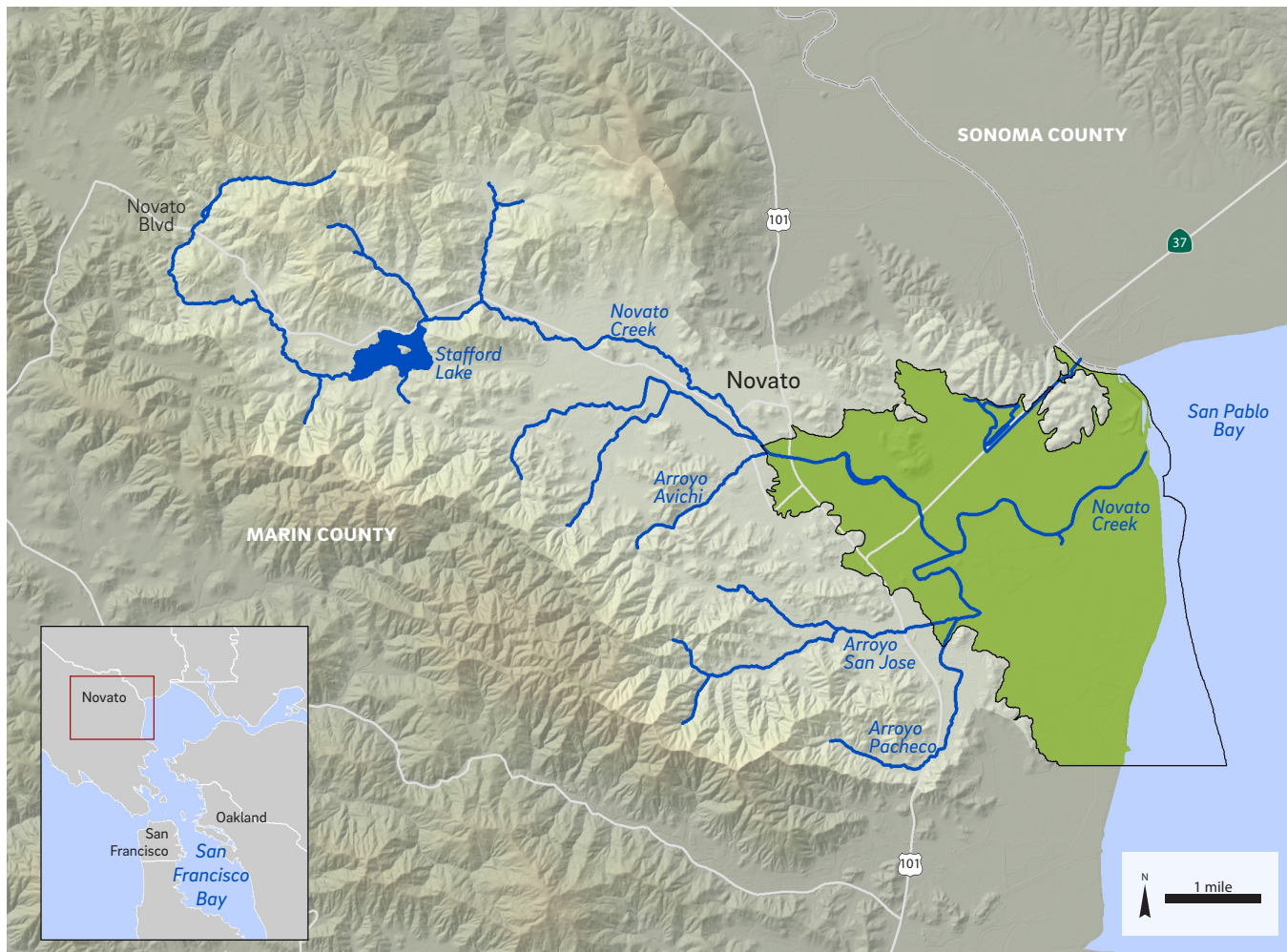


Figure 4. Map of Novato Creek watershed (lighter hillshade) and study area (green).

2009, USDA 2010). The City of Novato, a suburban community with a population of about 53,000, is the main developed area within the watershed (US Census Bureau 2012). Several major transportation corridors cross Novato Creek near the City of Novato, including U.S. Highway 101, State Highway 37, and two railroad lines (fig. 5). The Sonoma-Marín Area Rail Transit (SMART) train now occupies the former Northwestern Pacific Railroad (NWPRR) crossing over the Novato Creek baylands.

Novato Creek Baylands

The historical Novato Creek baylands were low-elevation areas subject to regular tidal influence. Over the past century and half, diking and filling for flood control and land reclamation purposes have eliminated most of the historical baylands. Levee construction along lower Novato Creek and the rerouting of Arroyo San Jose and Pacheco Creek (which entered the baylands from the south) began in the late 19th century and was completed by the early 1920s (Collins 1998). The result was the confining of fluvial and tidal flows, which resulted in sediment accumulation within mainstem Novato Creek, the elimination of the historical tidal channel network that connected lower Novato Creek to its surrounding baylands, and the elimination of the sediment supply that helped maintain and sustain the baylands.



Figure 5. SMART bridge over lower Novato Creek. (photo by Marin County DPW, November 5, 2014)

Today, much of the former baylands are occupied by agricultural land and other urban and developed areas. Major developed features in the historical bayland area include Pacheco Pond, a flood control basin connected to lower Novato Creek by an artificial channel; Bel Marin Keys, a roughly 500 acre development in the central portion of the historical baylands; and State Highway 37, a four lane highway that runs northeast-southwest through the center of the historical baylands west of Bel Marin Keys. In the southernmost portion of the historical baylands, the decommissioned Hamilton Air Force Base and adjacent land are part of an ongoing ecological restoration project covering nearly 2,600 acres. The Novato Sanitary District also operates a series of wastewater treatment ponds and sprayfields around Highway 37.

Over the past two decades, there have been several restoration projects initiated within and adjacent to the study area aimed at improving bayland ecological functions (e.g., Hamilton and Bel Marin Keys Unit V Wetlands Restoration Project). These projects have focused on improving habitat conditions for special status species that are known to occur within the study area, including Ridgway's Rail (*Rallus obsoletus*), California Black Rail (*Laterallus jamaicensis coturniculus*), salt marsh harvest mouse (*Reithrodontomys raviventris*), and steelhead (*Oncorhynchus mykiss*) (Jones & Stokes 2003).

Methods

The use of historical data to study past ecosystem characteristics is an interdisciplinary field called historical ecology (Swetnam et al. 1999, Rhemtulla and Mladenhoff 2007). Historical ecology can allow us to understand relevant landscape drivers and context, document change over time, and suggest appropriate restoration and management targets by identifying constraints and opportunities posed by the contemporary landscape.

Constructing an accurate picture of historical landscape patterns requires the integration, comparison, and interpretation of many independent sources (Grossinger et al. 2007). Where possible we documented each historical landscape feature using multiple sources from varying years and authors to ensure accurate interpretation. This section details how these sources were collected and interpreted, as well as how they were used to create maps of historical habitat types and channels.

Historical Data Collection and Compilation

We retrieved hundreds of records from archives, agencies, libraries, historical societies, and online databases during the course of this study (table 1). The data assembled include written accounts, photographs, and maps (figs. 6 & 7). While our efforts focused on 19th century sources, a few comprehensive data sets from the 20th century, such as United States Department of Agriculture (USDA) 1942 aerial photography and lidar-derived elevation datasets (County of Marin 2013), were also collected. Through this process, we developed a diverse, often overlapping array of historical records providing broad coverage of the study area. Altogether, we assembled approximately 70 maps, 160 photos, and 30 textual sources. Once collected, photographs, maps, and textual data were organized geographically and by topic. We used ERDAS LPS 9.3 to orthorectify the 1942 USDA aerial photos, providing complete historical aerial photo coverage of the study area.

Figure 6. Portion of 1892 map of Marin County. (Dodge 1892, courtesy of David Rumsey Map Collection)

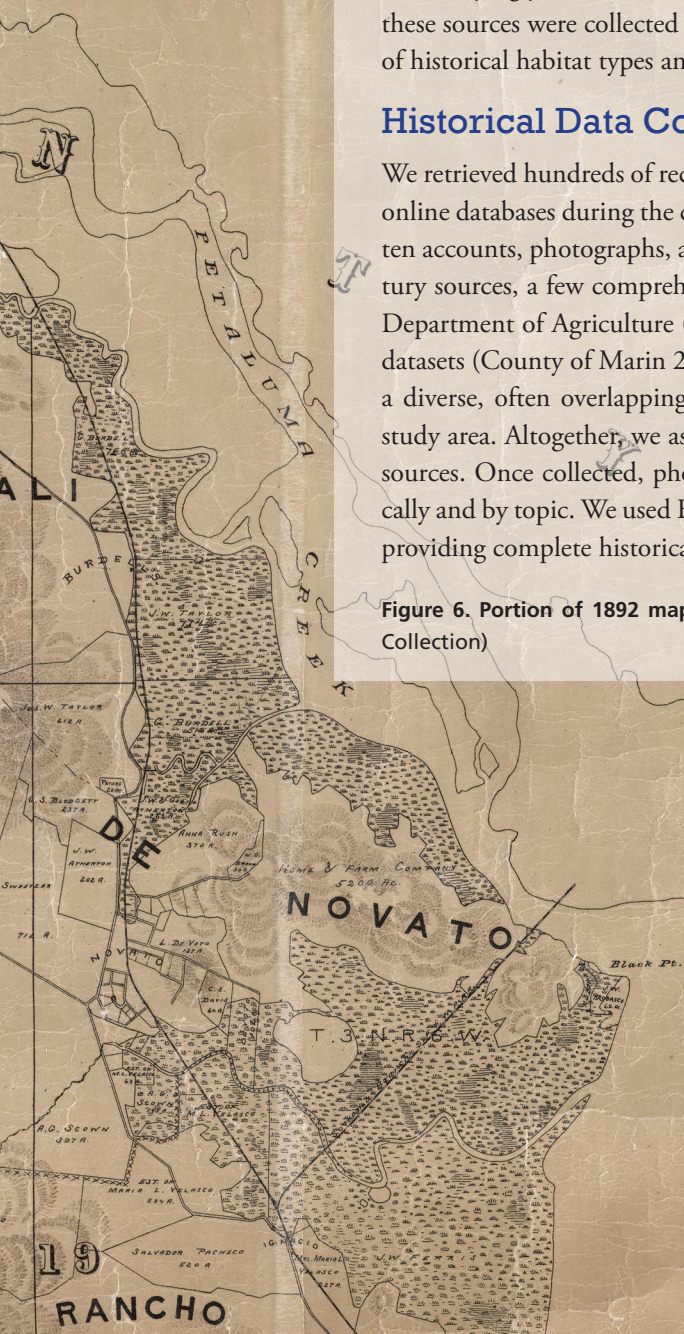




Table 1. Source institutions visited for the Novato Creek Historical Ecology Study.

Source Institution	Location	Relevant Holdings
Bureau of Land Management	Sacramento	General Land Office (GLO) survey notes and plats
Marin County Free Library	San Rafael	Pamphlets, Marin County planning documents, Environmental Impact Reports, newspaper clippings, land titles, diseños, land grant plats, early 20th century photographs
Novato History Museum	Novato	Newspaper clippings, letters, transcriptions of journal entries, county maps, land grant plats, parcel maps, railroad maps, early 20th century landscape photographs
Water Resources Collections and Archives, UC Riverside	Riverside	Congressional report, late 20th century photographs of Novato Creek
The Bancroft Library, UC Berkeley	Berkeley	Land grant court case dockets, land grant plats, diseños, railroad maps, County maps, early landscape photographs
County of Marin: Assessor, Community Development Agency, GIS	San Rafael	Late 19th and early 20th century county and parcel maps, contemporary and historical aerial imagery, lidar-derived DEM and Hillshade
Marin History Museum	Novato	County maps, 20th century flood control maps, land grant plats, mid-20th century aerial and oblique photographs
UC Berkeley Earth Sciences and Map Library	Berkeley	County maps, late 20th century aerial photographs



Black Point culvert circa 1910

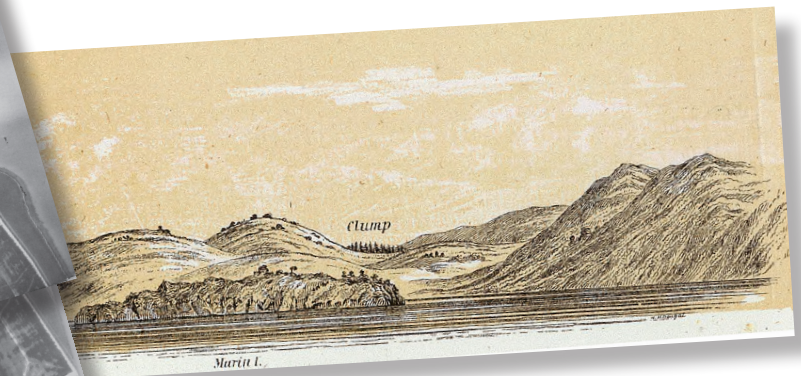


Figure 7. Examples of historical sources.

Opposite: 1873 map of Marin County. Top to Bottom: Photo of flooding at Black Point, February 13, 1938; Photo of flooding at Black Point, ca. 1910; aerial photos of lower Novato Creek and baylands, May 19, 1942; 1852 lithograph of Red Rock Island in San Francisco Bay. (Austin 1873, courtesy of David Rumsey Map Collection; P77-119, Photo File 167, courtesy of Novato History Museum; P81-005, Photo File 167, courtesy of Novato History Museum; COF-04-101 and COF -04-103, USDA 1942; Blunt 1852, courtesy of David Rumsey Map Collection)

Data Synthesis and Mapping

Historical data were synthesized to create GIS layers depicting the historical Novato Creek mainstem and tidal channel network as well as the extent and character of bayland habitat types. We mapped landscape features as they existed, on average, prior to significant Euro-American modification (i.e., early to mid-1800s). This effort built upon mapping layers created through SFEI's EcoAtlas project (SFEI 1998), which produced historical baylands mapping based on U.S. Coast (and Geodetic) Survey (USCS/USCGS) topographic sheets (T-sheets) for the entire Bay Area. Because of the much smaller study area, it was possible to produce a more refined and detailed depiction of the local channel network and habitat types than that shown by EcoAtlas.

Mapping and interpretation efforts drew largely on several of the earliest and most detailed maps acquired. In particular, the three T-sheets produced for the Novato Creek baylands were a key early dataset (Rodgers 1854a,b; Lawson 1887, Dickins 1897-8b). With their large scale, remarkable level of detail, and high scientific standards, the T-sheets are a highly valuable source, often showing features not depicted in other sources such as lower-order tidal channels and marsh pannes. A USCS hydrographic and bathymetric survey (also known as an H-sheet; Cuyler 1856) was used to map the extent of intertidal bay flat.

Though the T-sheets are an early, accurate, and detailed source, unfortunately none of them provide complete coverage of the study area. As a result, additional sources were used to supplement the information provided by the T-sheets, particularly for the western portion of the study area (table 2). These included a number of smaller-scale early maps (e.g., Matthewson 1858, 1859b; Van Dorn 1860; Austin 1873), U.S. Geological Survey (USGS) topographic quadrangles (USGS [1910-12]1914; 1980a,b), orthorectified historical aerial photography (USDA 1942), contemporary aerial photography (USGS 2011), and a lidar-derived digital elevation model (DEM) and hillshade layer (County of Marin 2013).

Channels and habitats were digitized from the most spatially accurate source, with supporting evidence where available attributed to one or more additional historical sources. For each historical habitat type and channel segment, certainty levels for interpretation, size/shape, and location were assigned based

Table 2. Maps and geospatial datasets at a broad range of spatial scales were used to digitize historical habitats and channels.

Digitizing Sources	Description	Spatial Accuracy	Spatial Extent
County of Marin 2013	Lidar-derived hillshade	1 ft (best)	Entire study area
USGS 2011	High resolution (0.5 ft) aerial imagery	1 ft (best)	Entire study area
USGS 1980a,b	Digital version of USGS 7.5-minute topographic quadrangles	20 ft	Entire study area
USDA 1942	Historical aerial orthophotos	20 ft	Entire study area
USGS [1910-12]1914	Historical USGS 15-minute topographic quadrangle	150 ft	Entire study area
Dickins 1897-8b	Later T-sheet	30 ft	Eastern ¾ of study area
Lawson 1887	Later T-sheet	30 ft	Near shoreline and Novato Creek mouth only
Cuyler 1856	Earliest H-sheet including soundings, mean lower low water line	30 ft	Near shoreline only
Rodgers 1854a,b	Earliest T-sheets	50 – 150 ft	Eastern ¾ of study area
Matthewson 1858, 1859b; Van Dorn 1860	Smaller scale 19th century maps and survey plats	300 – 500 ft	Entire study area for most, but small scale

on the methods described in Grossinger et al. (2007). Though some of these sources were produced after the target time period, they often include highly accurate depictions of landscape features documented by less-accurate earlier sources, and can therefore be used to improve mapping accuracy. For example, the 1942 aerial photos show numerous channels which can also be discerned in earlier maps. The maps confirm the historical presence of the features, while the aerial photos (or another spatially accurate source) allow us to map them with a higher level of detail and confidence than would be possible using the early sources alone.

Channel Network

Tidal channels were mapped both as lines and polygons, and were primarily digitized from the T-sheets and aerial imagery. When a T-sheet was the main digitizing source, channels mapped as single lines on the T-sheet were digitized as lines, while larger channels mapped as double lines on the T-sheet were digitized as polygons. When the digitizing source was an aerial photo (USDA 1942, USGS 2011) or lidar-derived hillshade (County of Marin 2013), channels less than 10 m (33 ft) wide were mapped as lines and buffered by 0.5 m (1.6 ft) on each side for channel flat habitat area calculations. Linear traces of the centerlines of larger channels were also created in order to perform channel length calculations. Though the majority of mapped channels were tidal channels, we also mapped the downstream ends of fluvial channels where they entered the tidal marsh. Fluvial channels were not included in calculations of channel length or analyses.

Bayland Habitat Types

Bayland habitat types were mapped as polygons and were primarily digitized from the T-sheets (fig. 8), supplemented by auxiliary sources where they provided additional or more spatially accurate information. Mapped habitat types include tidal marsh, low tidal marsh, salt pond/panne, subtidal channel, channel flat, and bay flat. These habitat types are described briefly below. For more details on bayland habitat types, refer to the Goals Project (1999).

Tidal marsh refers here to vegetated portions of the baylands dominated by pickleweed (*Salicornia pacifica*) and California cordgrass (*Spartina foliosa*). Historical tidal marshes were digitized from georeferenced T-sheets and aerial photography (USDA 1942). Contemporary USGS topographic quadrangles (USGS 1980a,b), and lidar-derived hillshade (County of Marin 2013) were also used to refine the shape of polygons at the upland edge. Low marsh is defined as areas vegetated with California cordgrass interspersed with exposed mud; this habitat type was mapped exclusively based on the Rodgers (1854b) T-sheet, which shows it as a distinct bayland feature occurring between tidal marsh (likely pickleweed-dominated) and bay/channel flat.

Salt pannes are open water or unvegetated areas found on the marsh plain. They are associated with portions of the high marsh plain removed from frequent tidal flooding, and as a result often form along drainage divides (Goals Project 1999). Pannes were primarily digitized from the Rodgers (1854b) T-sheet, and also from the Dickens (1897-8b) T-sheet in a few cases.

Channel flats and Bay flats are the portions of tidal channels and the bay that dewater during low tide. Channel flats include the smaller tidal channels in the study area, as well as relatively wide areas along the edges of the larger channels. The historical extent of bay flat was digitized from an early hydrographic survey (Cuyler 1856).

Subtidal channels are the portions of tidal channels that do not completely drain even at low tide; the deepest parts of Novato Creek and Simmons Slough fall into this category. They were mapped exclusively from the mean lower low water (MLLW) elevation on the Rodgers (1854b) T-sheet, which covers the area to Simmons Slough.

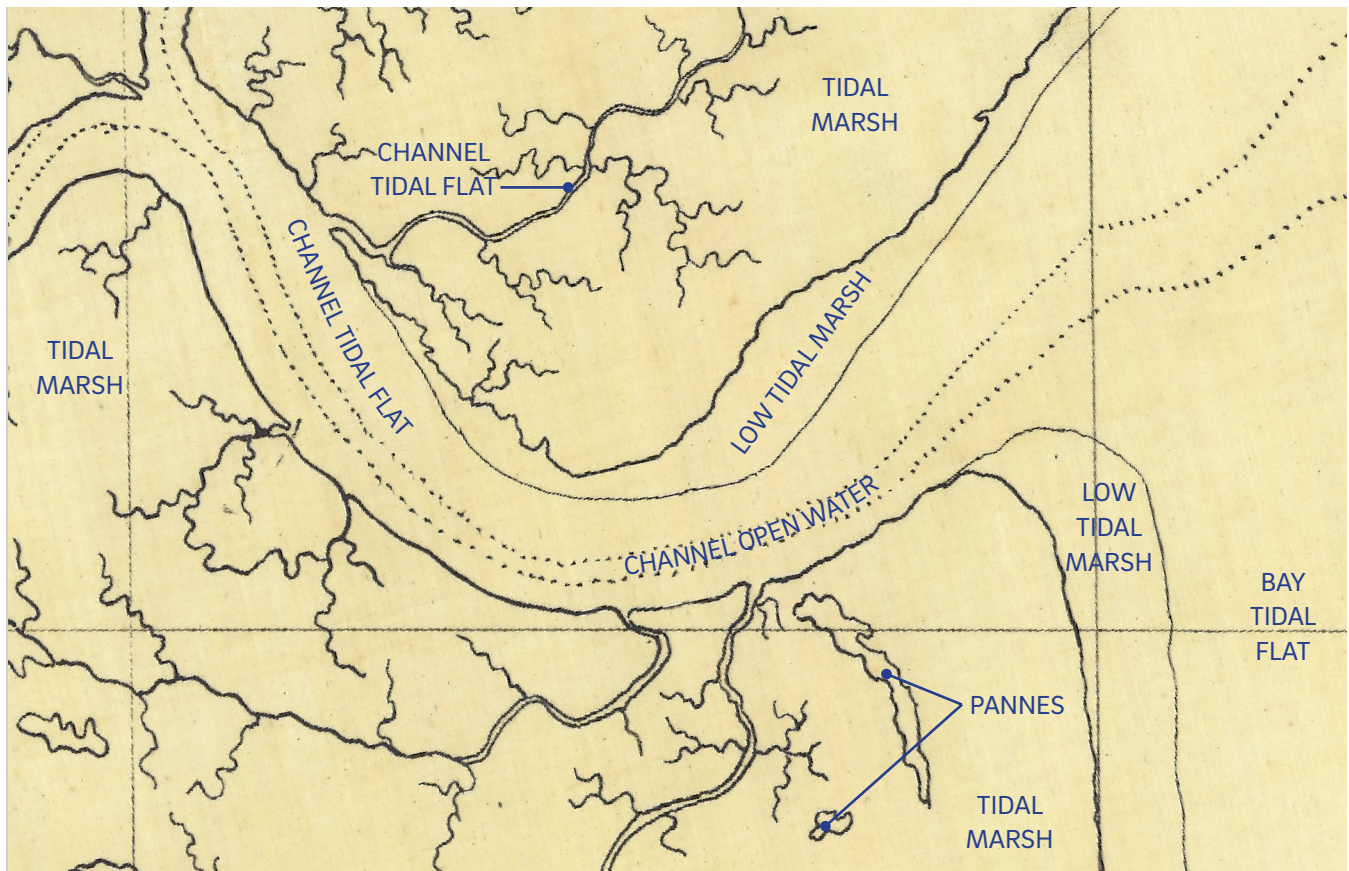


Figure 8. Historical habitat types depicted on an early T-sheet. (Rodgers 1854b, courtesy of NOAA)

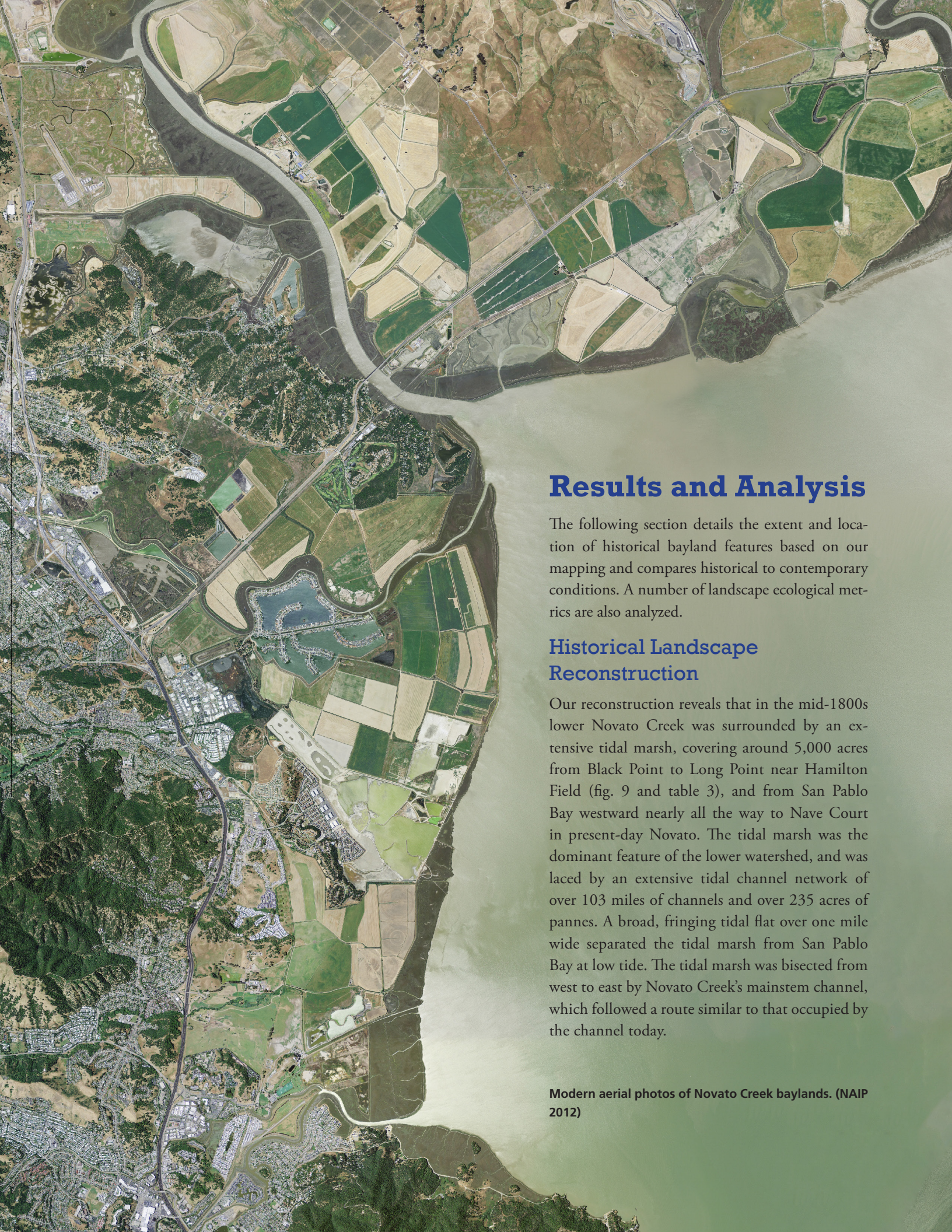


Transition Zone

To characterize the transition zone at the boundary between tidal wetland and terrestrial habitats, we performed a simplified version of the tidal-terrestrial interface analysis described in Beller et al. (2013). A linear interface was extracted from the boundary between tidal and non-tidal habitats, and each segment of this line was attributed with the type of historical habitat present on each side of the line. Since habitat types have not been mapped for the Novato Creek watershed above the historical bayland margin, we used a simplified, binary classification system for the terrestrial interface that distinguished a low-gradient interface (i.e., tidal wetland to alluvial plain) from a high-gradient interface (i.e., tidal wetland to hillslope/bedrock).

Comparison to Contemporary Conditions

We used a series of Bay Area Aquatic Resource Inventory (BAARI) GIS layers (SFEI 2011) to compare historical to contemporary conditions, including BAARI tidal and BAARI wetlands layers. Some modifications were made to the original BAARI layers in order to suit the scale and scope of this study. For the contemporary channel network, channels that were classified as tidal in BAARI were reviewed with high resolution (0.5 ft) imagery available for the study area (USGS 2011) to ensure that the tidal connection was perennial, and not actively managed by tide gates. Some tidal polygons were re-classified as non-tidal based on evidence from this analysis. The BAARI wetlands GIS layer (SFEI 2011) was used to account for non-tidal wetland features now present within the bayland footprint.



Results and Analysis

The following section details the extent and location of historical bayland features based on our mapping and compares historical to contemporary conditions. A number of landscape ecological metrics are also analyzed.

Historical Landscape Reconstruction

Our reconstruction reveals that in the mid-1800s lower Novato Creek was surrounded by an extensive tidal marsh, covering around 5,000 acres from Black Point to Long Point near Hamilton Field (fig. 9 and table 3), and from San Pablo Bay westward nearly all the way to Nave Court in present-day Novato. The tidal marsh was the dominant feature of the lower watershed, and was laced by an extensive tidal channel network of over 103 miles of channels and over 235 acres of pannes. A broad, fringing tidal flat over one mile wide separated the tidal marsh from San Pablo Bay at low tide. The tidal marsh was bisected from west to east by Novato Creek's mainstem channel, which followed a route similar to that occupied by the channel today.

Modern aerial photos of Novato Creek baylands. (NAIP 2012)



-  Fluvial Channel
-  Small Intertidal Channel
-  Tidal Marsh
-  Low Tidal Marsh
-  Salt Pond / Panne
-  Subtidal Channel
-  Channel Flat
-  Bay Flat
-  Shallow Bay

Habitat Type	Historical Acreage
Tidal Marsh	4,490
Low Tidal Marsh	160
Salt Pond / Panne	240
Subtidal Channel	50
Channel Flat	320
Bay Flat (more bay flat existed south of the study area)	2,800
Total	8,060

Figure 9. Historical habitats of the Novato Creek baylands, mid-1800s. An extensive tidal marsh, totaling nearly 5,000 acres, surrounded lower Novato Creek. Within the marsh plain there were over 100 miles of tidal channels and approximately 240 acres of salt pannes. A broad tidal flat, over one mile wide, separated the marsh from San Pablo Bay.

Table 3. Total area (acres) occupied by each habitat type historically.

Novato Creek and Tidal Channel Network

In the 1850s, before the levees were constructed, the tidal channel network in the Novato Creek baylands included over 100 miles of channels. The vast majority of this network (95%) consisted of first- through third-order channels branching from Novato Creek in dendritic systems (see fig. 9). Novato Creek's mainstem made up only 5.4 miles of the historical tidal channel length. Due to a lack of early historical evidence of comparable spatial resolution and detail in the western portion of the study area, some portions of the actual historical channel network were likely undermapped, suggesting even greater historical tidal channel length.

A southern branch of Novato Creek

Today, Novato Creek follows a single channel from Highway 101 to its mouth at San Pablo Bay. East of the Northwestern Pacific Railroad tracks (and the planned route of the SMART train), the alignment largely mirrors the historical route of the mainstem as shown by historical maps (e.g., Dickins 1897-8b). Unfortunately, none of the T-sheets extend far enough westward to provide coverage of this highly-modified reach of Novato Creek. However, some early sources (e.g., Matthewson 1858, 1859a,b; Van Dorn 1860) suggest the presence of a secondary or alternate channel that split off to the south in the vicinity of the Highway 101 bridge and rejoined what is now the mainstem about a mile or two downstream, possibly near the southern tip of Deer Island (fig. 10, top). The exact location of this second channel is not clearly evident, and these maps are not necessarily precise in this regard. Later sources (e.g., Austin 1873, USGS [1910-12]1914) do not show an obvious channel branching off from the Novato Creek mainstem, but do show a blind (terminating) channel that connects to Novato's mainstem in the east and appears to be a remnant of the former course (fig. 10, bottom). Traces of this possible channel appear to be present on the 1942 historical aerial bisected by a railroad berm.

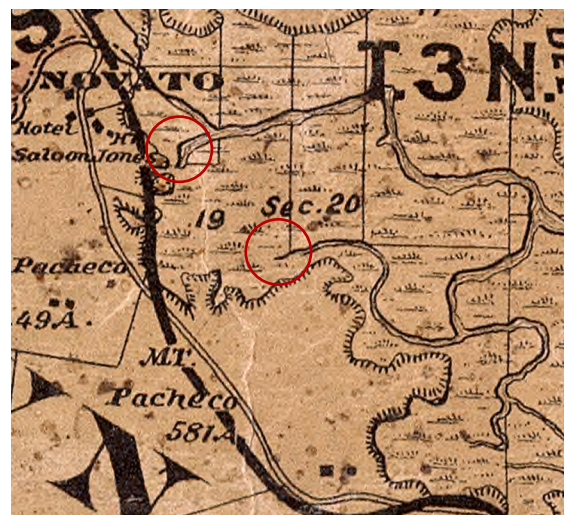


Figure 10. Top: Several early sources, such as this 1859 plat, depict a possible southern branch of Novato Creek's mainstem. Bottom: Later sources, such as this 1873 county map, may depict remnants of this former course further to the east. (Top: Matthewson 1859b, courtesy of The Bancroft Library, UC Berkeley; Bottom: Austin 1873, courtesy of David Rumsey Map Collection)



Navigability of Novato Creek

Novato Creek was historically navigable by scow schooners, flat-bottomed ships which sailed up the creek at high tide to transport goods to and from the Novato Rancho (fig. 11; Peirce 1841, Revere 1849, Dickins 1897-8a). The portion of the creek between the bay and Sweetser's landing, located near the western edge of the historical baylands extent, was declared navigable in 1860 (Sacramento Daily Union 1860). The fact that these vessels were able to travel 5-6 miles inland along the creek at high tide provides some indication of the depth of the creek (at least several feet deep at low tide) and the inland extent of tidal inundation.



Figure 11. Early sources indicate that lower Novato Creek was navigable. Top: This ca. 1910 photograph shows a schooner in "Novato Slough." Bottom: This ca. 1870 lithograph shows schooners navigating Novato Creek's tidal mainstem (circled in red). Several schooners are gathered at the landing, while another is sailing along the mainstem. A third is at the mouth of Novato Creek in San Pablo Bay. (Top: P81-002, Photo File 238, courtesy of Novato History Museum; Bottom: BANC PIC 1963.002:0824-D, courtesy of The Bancroft Library, UC Berkeley)

Bayland Habitat Types

Prior to significant Euro-American modification, the Novato Creek baylands covered over 8,060 acres at the downstream end of Novato Creek (see fig. 9 and table 3). Tidal marsh composed the majority (56%) of this area. The tidal marsh plain covered 4,490 acres and was laced by a network of tidal channels covering 370 acres, including 50 acres of subtidal channel and 320 acres of channel flat. More than one hundred pannes dotted the marsh interior, occupying approximately 240 acres; average panne size was about two acres, though the largest was over 50 acres. Very wide bay flats occurred along the margins of San Pablo Bay, extending south from Novato Creek's mouth all the way to Gallinas Creek. Within the study area, 2,800 acres of bay flat extended about a mile eastwards, adjacent to the tidal marsh. Additional bay flat also occurred south of the study area, with a contiguous wide band extending about 2 miles south to the mouth of Gallinas Creek.

Four distinct zones of the tidal marsh were inferred from historical sources (fig. 12). The largest zone consisted of well-drained tidal marsh (fig. 12, area B), evidenced by a high density of tidal channels and few marsh pannes. To the east of this primary zone, a wave-built berm (fig. 12, area A) along much of the shoreline north and south of Novato Creek's mouth restricted tidal channel connection to the Bay. From this berm, low-order tidal channels drained westward, ultimately emptying into the mainstem of lower Novato Creek (rather than draining eastward toward San Pablo Bay). In the third zone (fig. 12, area C), the presence of pannes and a lower density of tidal channels indicates that tidal flow was more obstructed, resulting in ponding. This area was likely slightly higher in elevation than most of the marsh plain (though not as high as the wave built berms), in part due

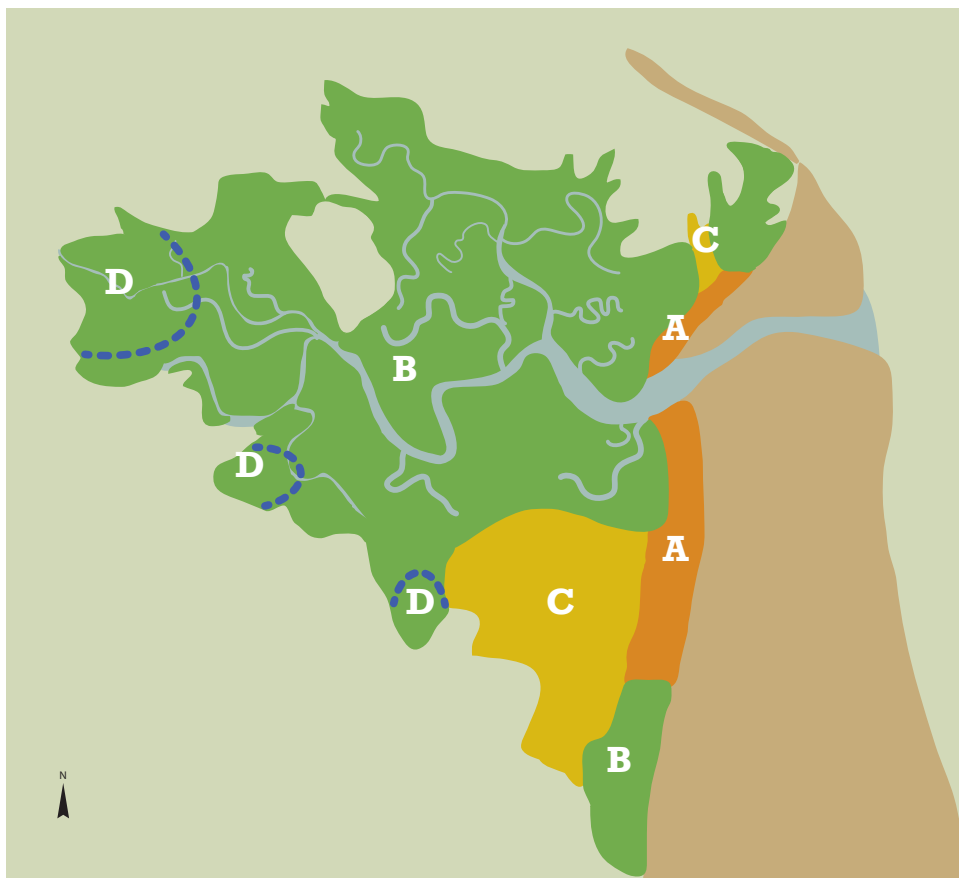


Figure 12. Four distinct zones of the historical tidal marsh in the Novato Creek baylands. (A) A wave built berm, (B) well-drained tidal marsh, (C) less well-drained tidal marsh with an abundance of pannes, and (D) areas of freshwater influence where creeks entered the baylands.

to sediment deposition from smaller creeks (Arroyo San Jose and Arroyo Pacheco) draining into the marsh. The fourth zone of freshwater influence (fig. 12, area D) was associated with areas where Novato Creek and smaller creeks entered the tidal marsh, supplying freshwater and sediment from their respective watersheds. The extent of freshwater influence would have varied annually and seasonally based on streamflow, but there is not sufficient data to quantify the size range of this zone. Ecologically, the zone of freshwater influence was a transition zone between tidal and fluvial habitats.

Transition Zone

The Novato Creek baylands historically supported both a flatter (low-gradient, alluvial plain) and a steeper (high-gradient, hillslope) tidal-terrestrial interface. The low-gradient interface type made up 8.1 miles (36%) of the approximately 23 mile interface, in the lowland areas surrounding where Novato Creek and smaller creeks such as Arroyo San Jose, Arroyo Pacheco, and Ignacio Creek entered the marsh (fig. 13). In contrast, the high-gradient interface (14.5 miles, 64%) was found at the base of hillslopes adjacent to the tidal marsh, including Deer Island and several other hills surrounded entirely by marsh (fig. 14). While they composed the majority of the Novato Creek baylands tidal-terrestrial interface, steep transition zones were not common elsewhere around the Bay. Comparable historical examples of this regionally-uncommon interface include the Coyote Hills near Hayward and the hills of the Richmond Potrero.

Figure 13. (Top) An example of the low-gradient interface type between the Novato Creek baylands and the adjacent non-tidal areas is shown in this ca. 1945 photograph. The photo is showing the “Lynwood area toward South Novato Blvd” and the “entrance to Brazil ranch,” on the southwestern side of the study area. (P76-30, Photo File 240, courtesy of Novato History Museum)

Figure 14. (Bottom) This undated photograph shows an example of the high-gradient interface type that existed around portions of the baylands. Tidal marsh abruptly transitions to relatively steep, densely-wooded hills on the northern side of the study area near Black Point. This was a relatively rare interface type within the larger San Francisco Bay region. (Photo File 240, courtesy of Novato History Museum)



Comparison to Contemporary Conditions

The Novato Creek baylands have experienced a dramatic reduction in tidal extent and habitat area since the mid-1800s, beginning with intensive diking and filling in the second half of the 19th century (fig. 15). The current extent of tidal marsh represents an 87% reduction compared to the historical extent. Marsh is now found mainly in a thin strip along lower Novato Creek and at the mouth of the Creek, in areas historically occupied mainly by tidal channels, bay flats, and shallow bay. Similarly, the once-extensive tidal channel network has been greatly diminished and restricted in drainage area. These losses are associated with corresponding decreases in ecological function provided by the baylands.

Novato Creek and Tidal Channel Network

Today, constructed levees separate Novato Creek from most of its historical tidal drainage area, and the once-extensive tidal channel network has been greatly diminished and restricted in drainage area. In the contemporary Novato Creek baylands, the total channel length is 18 miles, representing a net decrease of 85% compared with historical channel length. The total contemporary length also includes channels in newly formed tidal marsh along the south bank of the Petaluma River and adjacent to San Pablo Bay. Today, lower Novato Creek's mainstem is 6.4 miles long, one mile longer than it was historically (because of the bayward expansion of diked baylands due to hydraulic mining debris). However, the length of Novato Creek's tributaries and side channels has been reduced by 94%, from 98 miles to 6 miles (fig. 16). An additional 5.5 channel miles flow through newly created tidal marsh in the Novato Creek baylands but are not connected to Novato Creek.

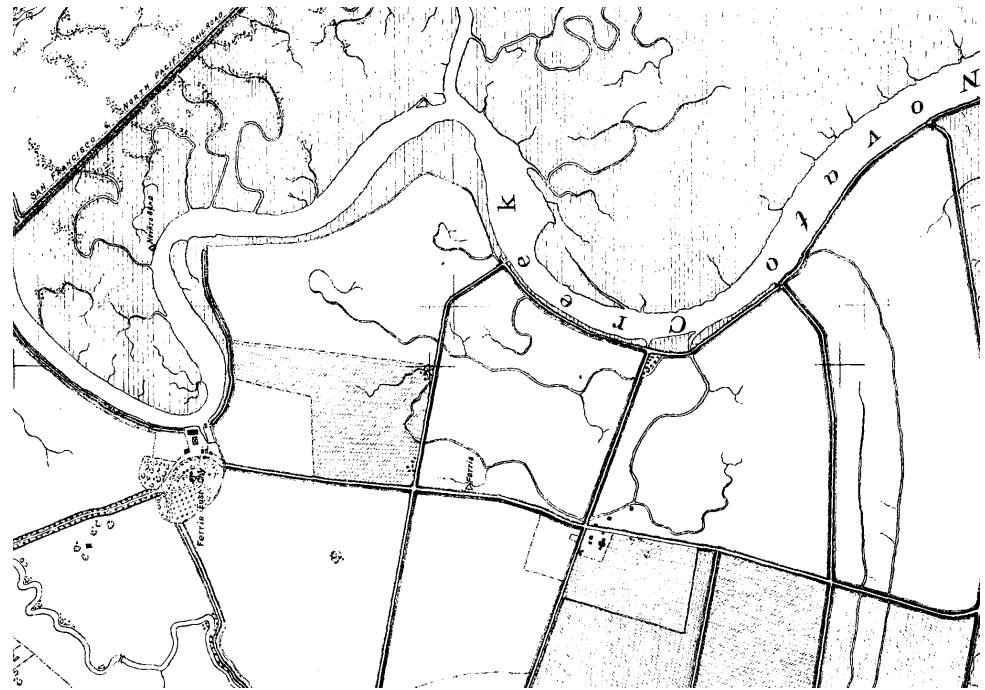


Figure 15. Early modifications to the Novato Creek baylands. By the time of the 1897-8 T-sheet resurvey shown here, much of the tidal marsh south of the Novato Creek mainstem had been diked, and many of the tidal channels in this area had been eliminated. (Dickins 1897-8b, courtesy of NOAA)

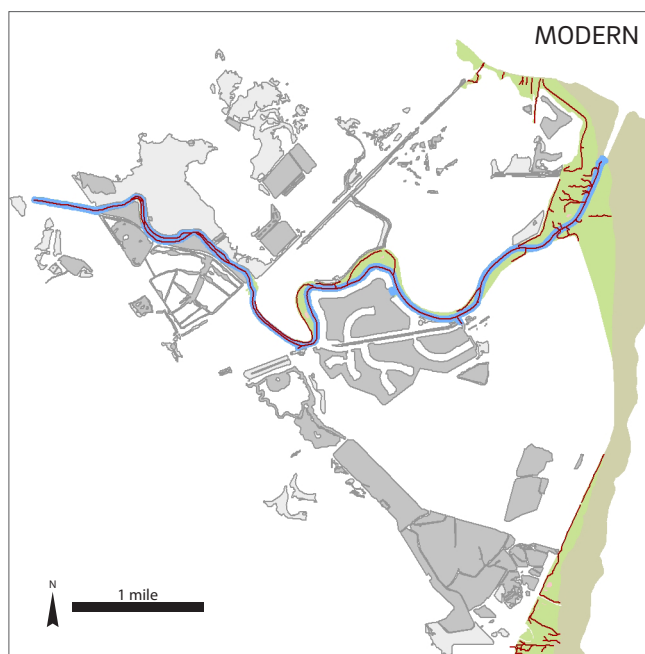
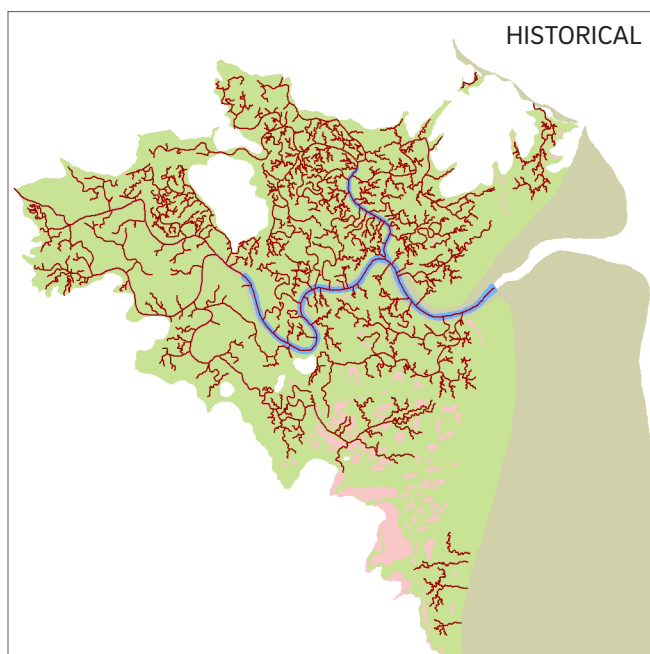
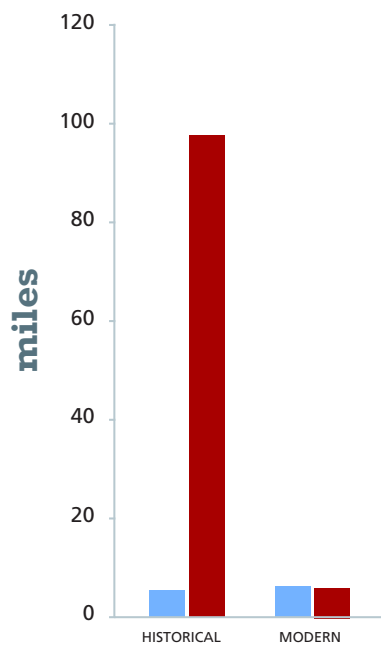


Figure 16. Historical and contemporary channel length for Novato Creek mainstem and tributaries. Novato Creek's mainstem has increased in length somewhat due to progradation of the shoreline, while the total length of tributary channels in the surrounding baylands has been reduced by 94%. See fig. 17 for habitat type legend. (NAIP 2012)

■ Mainstem
■ Tributaries

Bayland Habitat Types

Overall, there has been an 83% loss in estuarine area within the study area, from 8,070 acres to only 1,390 acres (fig. 17). This trend has been largely driven by the near-complete loss of tidal marsh area. Tidal marsh today is present only as narrow features along the shore of San Pablo Bay and along the margins of Novato Creek, restricted to the area between constructed levees. Only 620 acres of tidal marsh are present today compared to 4,490 acres in the mid-1800s, representing a reduction of nearly 90%. In addition, whereas the historical estuary consisted of large, contiguous areas of marsh laced with an extensive channel network, the marsh areas adjacent to Novato Creek today are much smaller and more fragmented.

Habitat types have changed not just in extent, but in location as well. The overwhelming majority (93%) of the contemporary marsh area is found in places where tidal marsh was not historically present. Almost all of the current tidal marsh is located in areas that were historically tidal flats, channels, or shallow bay.

Other historically prevalent habitat types have also been reduced in extent over the past century and a half. Of all the habitat types mapped, salt ponds/pannes have experienced the most dramatic reduction in extent, with a loss of 99% of their former area. In mapping based on 2005 imagery (SFEI 2011), only 19 smaller marsh pannes exist within the contemporary tidal marsh, all of which are less than one acre. Like much of the small strip of marsh surrounding today's Novato Creek, many of these pannes are located in areas that were historically channel or bay flats. The bay flat along the eastern edge of the study area has experienced a 75% reduction in area as a result of the expansion of tidal marsh, (subsequently diked) in the late 19th century.

Hydraulic gold mining in the Sierra foothills produced an extremely high volume of sediment, some of which was ultimately deposited at the Novato Creek baylands, resulting in the rapid shoaling of tidal channels and bay flats (Gilbert 1917, Atwater et al. 1979). These artificial sediment deposits were locked into place by residents through the construction of dikes in an attempt to "reclaim" the new land for agricultural production and other uses. As a result, diked former tidelands extend more than a mile further into the Bay than did tidal marsh in the 1850s. The loss of tidal marsh and bay flat was already well underway by the late 19th century, as Dickins noted in the 1897-8 T-sheet descriptive report:

A large extent of this marsh has been ditched, dyked and reclaimed, a portion of which is now under cultivation, and the balance used as pasture land. After the marsh has been ditched and dyked, the salt water is drained off, and then the land is generally turned over with a large deep plough and allowed to stand about a year. —Dickins 1897-8a

Today, the baylands are dominated by low-lying undeveloped tracts, residential land uses, flood and sanitation infrastructure, and the early stages of major wetland restoration projects. The restoration projects, the flood and sanitation infrastructure, and the artificial lagoons of Bel Marin Keys all comprise non-tidal wetland habitats that have been created within the historical bayland footprint. Although these habitat types were not present historically, they do contribute to the current wetland area. In total, these new wetlands consist of 1,180 acres of non-tidal open water and 850 acres of non-tidal vegetated wetland (see fig. 17). These numbers include wetland areas that are part of habitat restoration projects as well as those managed for flood control and residential amenities. Some of these features have the potential to offset some historical wetland and open water habitat loss.

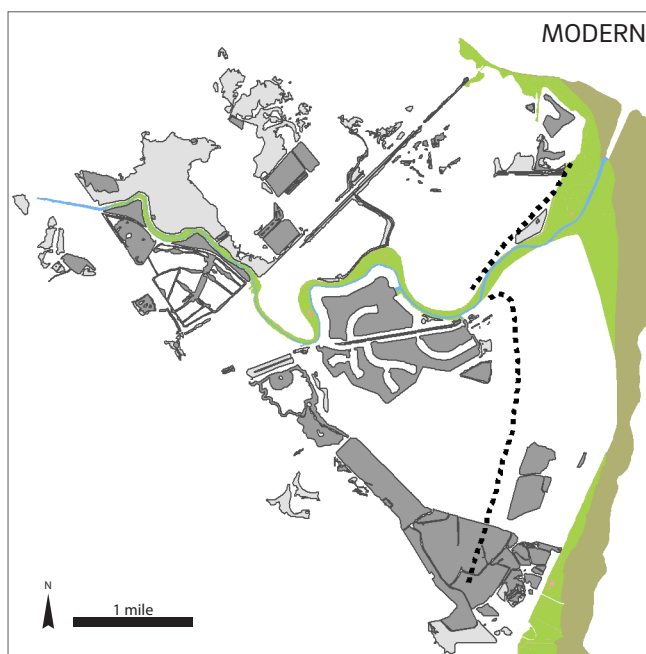
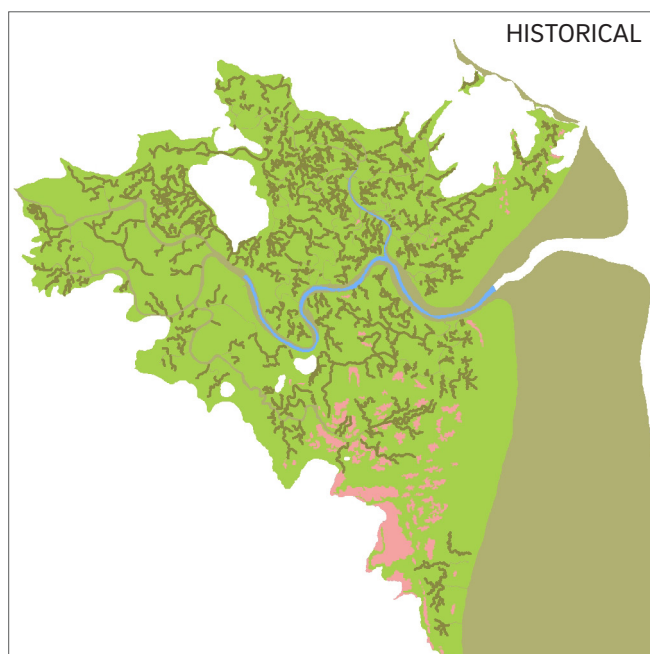
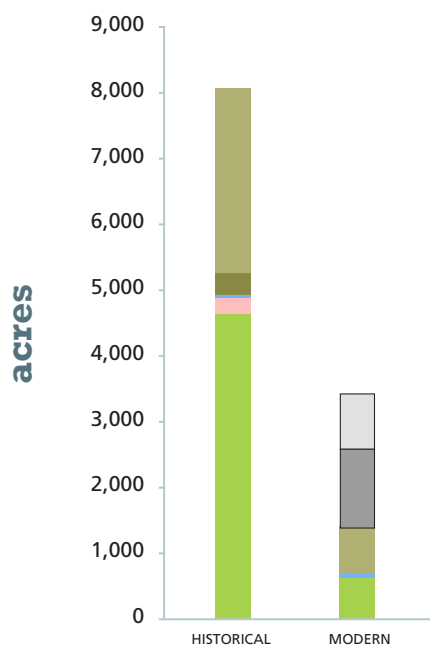


Figure 17. Extent of tidal wetlands has been greatly reduced within the study area.

Overall tidal wetland area has been reduced by 83%, including an 87% loss of tidal marsh area, 99% loss of panne area, and 77% loss of bay flat area. Several non-tidal wetland habitat types can be found in the contemporary baylands that did not exist historically, including non-tidal open water and vegetated wetland. These non-tidal wetlands contribute to the wetland area found in the study area today. Even with the addition of non-tidal open water (1,180 acres) and non-tidal vegetated wetlands (850 acres), however, there has still been a 58% decrease in wetland area compared to historical conditions. (NAIP 2012)

- Historical Shoreline
- Tidal Marsh
- Salt Pond / Panne
- Channel Open Water
- Bay Tidal Flat
- Channel Tidal Flat
- Non-tidal Open Water
- Non-tidal Vegetated Wetland

Transition Zone

The length of the transition zone between tidal marsh and terrestrial or upland habitats has decreased by 94% (from 22.6 miles to 1.4 miles), which includes the complete disappearance of the low-gradient interface (fig. 18). Remnants of the high-gradient interface are located around Black Point and to the north along the marshes on the south bank of the Petaluma River. Today, the tidal marsh is mostly lined by steep-sloped levees constructed to confine Novato Creek and protect surrounding lands from flooding. The habitat value of this artificial transition zone is currently unknown.

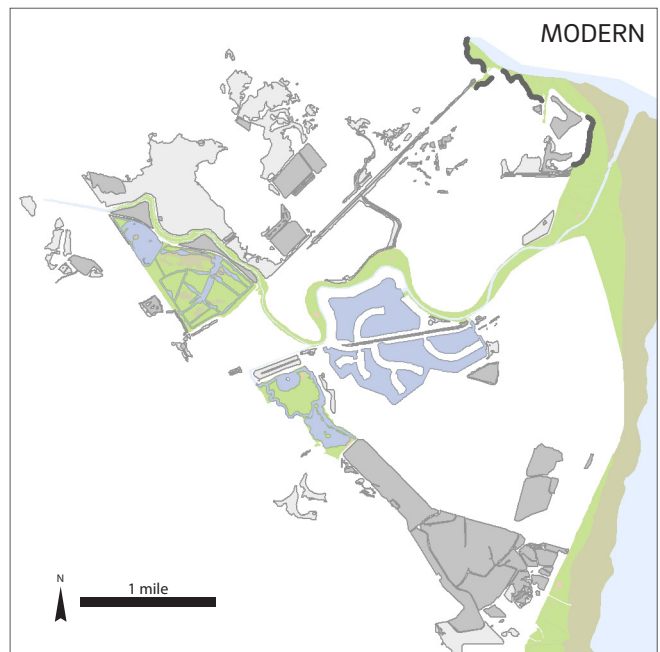
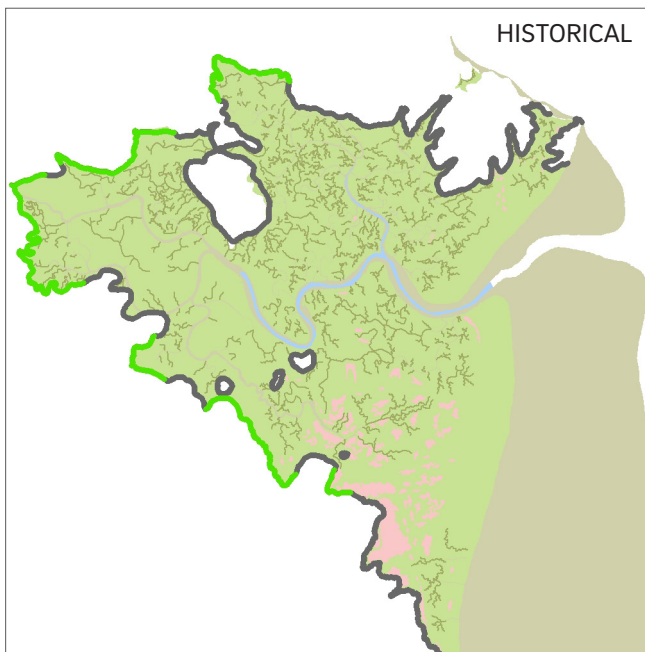
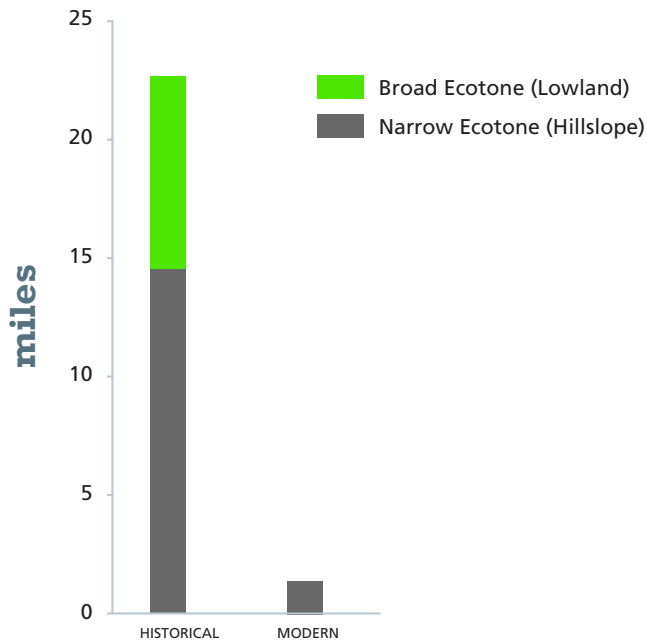


Figure 18. The historical and contemporary linear extent of the two types of tidal-terrestrial interface in the Novato Creek baylands. The length of the high-gradient interface has been reduced by over 90%, while the low-gradient interface has been completely eliminated. Much of the natural interface has been replaced by artificial levees. See fig. 17 for habitat type legend. (NAIP 2012)

Summary and Synthesis

Major Findings

Over the past 150 years, the Novato Creek baylands have been modified for the sake of flood control and land reclamation. This study focused on developing an understanding of the magnitude of change since the mid-19th century through comparisons of key historical and contemporary landscape-scale habitat features. The major findings from the analyses conducted for this study are as follows:

- Historically, the Novato Creek baylands included a mosaic of habitat types, including well-drained tidal marsh with an expansive tidal channel network, poorly-drained tidal marsh with a high density of salt pannes, wave-built berms on the bayward edge of the tidal marsh areas, brackish marshes at mouths of the dominant river channels draining into the baylands, bay flat and channel flat areas above low tide elevation, subtidal channel areas below low tide elevation, and a marsh-upland transition zone.
- Starting in the late 19th century, the baylands were modified for flood control and land reclamation purposes. This included leveeing mainstem Novato Creek and creating a bay levee at the edge of the bay flats, which had recently expanded considerably due to the short-term influx of hydraulic mining sediment from the Sierra Nevada foothills.
- Since the late 19th century, reclamation of the Novato Creek baylands has resulted in a ~75% decrease in bay flat area, ~85% decrease in tidal channel length, ~90% decrease in tidal marsh area, ~95% decrease in marsh-upland transition zone length, and an almost complete disappearance of channel flats and salt pannes. Almost all of the current tidal marsh is located in the narrow areas between the Novato Creek banks and adjacent levees.
- The open freshwater areas, freshwater vegetated wetlands, and levees currently within the historical baylands footprint have the potential to offset some of the historical habitat loss. However, the quality of the habitat provided by these features is currently not well understood.

Recommendations for Landscape-Scale Restoration Design

The findings from this study provide an understanding of how the Novato Creek baylands have changed over time, and can therefore help inform the approach for restoring some of the historical landscape features and ecological functions. Specific restoration design recommendations developed from the study findings are as follows:

- The modifications to lower Novato Creek and adjacent baylands over the past 150 years have primarily resulted in the conversion of marsh land to agricultural land. As such, there are currently large areas within the historical baylands footprint that have a similar degree of connectivity as the historical landscape. These areas present the possibility of large-scale restoration of contiguous landscape patches, which are essential for re-establishing tidal prism and providing higher quality habitat. The restoration vision for this area should therefore target these large, connected areas.

- The historical marsh types in the baylands were located within distinct geomorphic settings. For example, the marsh areas with a well-established tidal network had relatively low elevations and were well-drained, while the marsh areas with salt pannes and relatively few tidal channels had relatively high elevations and were poorly drained. The restoration vision for this area should therefore take local geomorphic setting into account when assessing the types of marsh and associated ecological functioning that will result from restoration within the historical baylands footprint.
- The Bay levee adjacent to the agricultural land south of Novato Creek was built on a mud-flat that had expanded in the mid-19th century due to the short-term influx of hydraulic mining sediment and elevated Bay sediment concentrations. Even with the artificial raising of the ground surface on the landward side of the levee (as is currently proposed in the restoration plan for this area), the relatively high wave power and relatively low sediment concentrations in this part of the Bay may cause the shoreline to migrate inland over time. The restoration vision for this area should include this possible retreat into the projected site evolution.
- The almost complete disappearance of the marsh-upland transition zone and salt pannes within the baylands should make them a high priority within any restoration vision for this area. These rare habitat types provide distinct ecological services and are in dire need of protection and restoration around the Bay. As sea level continues to rise, transition zones will provide space for marshes to migrate inland, and thus their importance will only increase in the future.
- The landscape ecology metrics used in this study were very effective at illustrating the magnitude of bayland habitat change over time. The values for the historical metrics could be used to develop the functional restoration targets for the baylands. Under this approach, the historical values would be considered the optimal condition and would be used to assess the relative ecosystem improvement associated with various restoration approaches.

Acknowledgements

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