An Assessment of the South Bay Historical Tidal-Terrestrial Transition Zone

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EXECUTIVE SUMMARY

San Francisco Bay wetland managers are looking landward for ways to accommodate accelerated sea level rise due to climate change. A major concern is that sea level rise will drown existing tidal marshes except for a narrow ring of marshland between the Bay and the built environment. This would eliminate many of the Bay's ecological services, as well as many of the ecological connections to the terrestrial environment upon which these services depend. Emerging plans therefore call for the conservation and reconnection of a tidal-terrestrial transition zone (T-zone) where tidal marshes and their terrestrial connections can be created or allowed to naturally evolve.

Planning the future T-zone requires knowledge of its natural form and structure – how its physical dimensions and habitat composition varied around the Bay due to natural drivers such as climate and topography, and how they might respond to future conditions. However, the T-zone was severely and extensively altered in this region during the early stages of Euro-American colonization. Information about its historical character – its width, the diversity and relative amount of habitat types that comprised it, the associated ecological functions, and the physical drivers that controlled these patterns – is fragmented and scattered among many sources within the region and elsewhere. Historical ecology can be a useful tool to assemble this information into a coherent and scientifically-sound picture of historical conditions to inform T-zone planning for the future.

In this pilot project we investigated several aspects of historical T-zone form and structure for a subset of the Bay. We found that the South Bay tidal-terrestrial interface was dominated (nearly 70%) by low-gradient seasonal wetlands grading into high marsh. Within this overall pattern, however, the T-zone was quite diverse. Seasonal wetlands included wet meadow, alkali meadow, and vernal pool complexes – each with distinct ecological characteristics and functions. Willow thickets, depressional wetlands (freshwater marsh), and alluvial grassland and riparian forests also contributed to the diversity of the T-zone. Relatively steeply-sloped grasslands bordering tidal marsh – the historical interface type most similar in composition to the levee faces that constitute most of the T-zone observed today in the South Bay – comprised less than 10% of the South Bay tidal-terrestrial interface. The T-zone included variation on the tidal side as well, with fresh-brackish tidal marshes associated with major creek mouths interspersed within a broad salt marsh context. Our study also suggests that the width of the T-zone varied dramatically with physical setting, from several meters to thousands of meters. The zone was broadest in areas with significant fluvial influence and in the most gently-sloping portions of the region.

The findings from this study suggest several immediate and longer-term management implications. For example, it will be important to consider the variability in and relative proportions of T-zone types in Bay restoration planning to conserve the full range of the T-zone's ecological services. In addition, a regional approach will be necessary to match local settings with the most appropriate T-zone types. Because distinctive soil characteristics play a key role in forming many T-zone habitat types, it will be important to preserve and enhance the areas scattered throughout the region with soils that retain this potential.

To develop this adaptive design capacity, several next steps are recommended. Extension of the historical T-zone analysis to the rest of the Bay will be important to develop the full T-zone restoration palette. For example, research in the North Bay has documented additional T-zone types that may be applicable to other parts of the Bay (e.g., valley oak savanna-tidal marsh transitions on coarse soils may be applicable to engineered slopes; Grossinger 2012). In addition, it will be useful to develop this understanding into a set of conceptual models linking T-zone types to physical drivers and target ecological functions (as has been initiated through the Baylands Ecosystem Habitat Goals Update). Relating these T-zone types to their geophysical setting – e.g., soils, slope, groundwater and surface water hydrology – will allow their translation into landscape designs using a combination of natural and engineered processes. The emerging understanding of the character and function of the Bay's T-zone can help us re-integrate it into the contemporary and projected future landscape.

INTRODUCTION

Mr. G.F. Beardsley, who spent part of his childhood in the Mountain View area during late 1860s, described the progression of habitats from the salt marsh ringing the Bay inland toward his home:

> First there was the great salt marsh, with all its winding sloughs and creeks, covered with samphire grass [*Salicornia*] and tufts of Grindelia; next was a line of natural salt pan; next again was a strip of land of varying width, from a few hundred yards to one fourth mile, with a short wiry hard grass *[Distichlis]*… (Beardsley, in Cooper 1926)

What Beardsley observed – a gradient from pickleweed-dominated salt marsh to salt pans to saltgrass – is one example of the broad ecotone, or transition zone, found between the San Francisco Estuary and non-tidal upland habitats. This *tidal-terrestrial transition zone* (T-zone) occupies the gradient between the intertidal zone and terrestrial (i.e., levee faces, valleys, hillsides, alluvial fans, and bluffs) and/or fluvial (i.e., rivers and streams) environments. The T-zone includes intertidal areas whose character is influenced by freshwater processes (e.g., groundwater, diffuse surface runoff, and stream discharge), as well as terrestrial areas whose character is influenced by tidal processes (e.g., the usual flood and ebb of tidal waters, tidal surges, waves and ship wakes generated in the Bay). It can be defined by biotic indicators (e.g., the distribution of vegetation communities or the presence of certain wildlife) as well as by physical factors (e.g., topographic slope, geomorphological patterns and features, or soils and conditions) (Fortin et al. 2000).

The tidal-terrestrial T-zone provides a number of valuable ecosystem functions and services. These services are being described by the T-zone Workgroup of the Baylands Ecosystem Habitat Goals Update (BEHGU). The T-zone supplies habitat for feeding, breeding, refuge and dispersal or migration for both aquatic (tidal and non-tidal) and terrestrial wildlife (including a number of threatened and endangered species). It provides refuge for wildlife during droughts or floods (aquatic/terrestrial species; Collins et al. 2007) and extreme high tides (estuarine species; Josselyn 1983:47). The T-zone has also been shown to often support high plant species richness (Traut 2005) and diversity (Goals Project 1999:78, Baye 2008). In addition, broad T-zones may serve as critical accommodation space for estuarine transgression and flood water dispersal or storage as sea level rises in the future (Collins et al. 2007, BCDC 2009, Whitcraft et al. 2011, Grossinger 2012).

The tidal-terrestrial T-zone is one of the most heavily impacted areas of the Bay ecosystem (Collins and Grossinger 2004:10). With some exceptions, today most of the T-zone consists of a narrow area between the upper limits of tidal marsh and the steep faces of artificial levees (Baye 2008, Collins and Goodman-Collins 2010). Ecological restoration of the T-zone based on "natural models and reference sites" (Goals Project 1999:A-16) is recognized as a conservation and restoration priority (ESA PWA 2013). Significant efforts are currently being considered to reestablish the T-zone using a combination of natural and engineered topography and hydrology. However, since most of the T-zone was impacted so significantly during the early stages of Euro-American colonization in the region and before systematic documentation, information about the natural condition of the T-zone is fragmented and broadly scattered. This information must be assembled and interpreted to understand the most basic aspects of the natural T-zone, such as its form, structure, and ecological composition. While it has been recognized that the T-zone was likely much broader in many places than observed today (Collins and Grossinger 2004, Baye 2008), there have been no quantitative regional assessments of the distribution or condition of the historical or present-day T-zone to inform planning efforts.

This study seeks to partially address this information gap by reconstructing the historical (ca. 1850) extent and character of the tidal-terrestrial T-zone in the South Bay. The project study area (hereafter referred to as "South Bay") extends from San Francisquito Creek in Palo Alto to approximately the current location of Highway 92 in the East Bay. Research was funded by the California Coastal Program of the U.S. Fish and Wildlife Service in support of their San Francisco Bay Transition Zone Conservation and Management Decision Support System (Fulfrost and Thomson in prep), designed to identify opportunities to protect and restore the T-zone.

METHODS

This project draws from four independent historical ecology studies: *Baylands and Creeks of South San Francisco Bay* (Grossinger and Askevold 2005), *Coyote Creek Watershed Historical Ecology Study* (Grossinger et al. 2006), *Historical Vegetation and Drainage Patterns of Western Santa Clara Valley* (Beller et al. 2010), and *Historical Ecology of the Alameda Creek Watershed* (Stanford et al. 2013). Each study included detailed mapping of historical habitat types in GIS. These four GIS layers were merged to create a seamless depiction of 19th century historical habitat types in the South Bay (fig. 1). For more information on the mapping process, please see the individual reports.

Two new products were generated for the current T-zone study using this historical South Bay synthesis map. First, we used it to estimate the landward limit of the intertidal environment, termed the estuarine backshore (Ellis 1978), and to characterize this interface between adjacent estuarine and fluvial/terrestrial habitat types. Second, we used physical indicators to delineate an approximate T-zone around the South Bay. Methods for each of these products are briefly described below.

Mapping the Estuarine-Terrestrial Interface (Backshore)

We represented the approximate position of the backshore with a continuous line (fig. 2). This boundary was derived from the historical South Bay synthesis map, whose characterization of the backshore location was in turn based largely on the early U.S. Coast Survey Topographic sheets ("T-sheets"). T-sheet surveyors mapped the marsh boundary based on tidal marsh vegetation indicators (Shalowitz 1964). As a result, this line represents an approximation of the landward boundary of areas dominated by tidal marsh vegetation. The boundary would not have been as distinct on the ground as the map would suggest. On the contrary, even for the most experienced government surveyors delineating the backshore was sometimes very difficult and somewhat subjective: surveyor Ferdinand Westdahl described the environment just inland of the tidal marsh as he mapped it on the T-sheet as "the debatable area immediately adjoining the Salt-marsh, which is sometimes covered at high tides" (Westdahl 1897). The backshore could be especially challenging to identify in gently sloping areas, where occasional extreme high tides interacted with runoff to create diffuse gradients in soil salinity.

This line was used as a tool to quantify the total linear extent of each major historical terrestrial and intertidal habitat type that composed the T-zone, and to estimate the relative proportions of different types of tidal-terrestrial interfaces. We attributed segments of the line with both the adjacent tidal habitat type (on the bayward side of the line) and the adjacent terrestrial habitat type (on the landward side of the line) (fig. 2). Habitat types and features included in this analysis are listed in Table 1.

The historical South Bay included a number of rivers and streams that crossed this interface, draining to the Bay through tidal marsh. These were challenging to include in the analysis of backshore composition, since they were originally mapped as single lines or thin polygons lacking realistic width and therefore without appropriate representation along the interface line. To adequately represent these features as components of the backshore, we mapped their intersection with the tidal-terrestrial interface and separated them into two stream classes: primary fluvial inputs (San Francisquito Creek, Guadalupe River, Coyote Creek, and Alameda Creek)

Table 1. Historical habitat types (ca. 1850) adjacent to the ecotone line. These habitat types are depicted in Figure 1 (following page).

Intertidal Habitat Types	Terrestrial Habitat Types
Salt Flat / Panne	Seasonally Flooded Wetland (mapped separately as Alkali Meadow, Vernal Pool Complex, and Wet Meadow)
Tidal Channel	Riparian Grassland (and forest)
Tidal Marsh	Hillslope Grassland
	Freshwater Marsh
	Willow Thicket

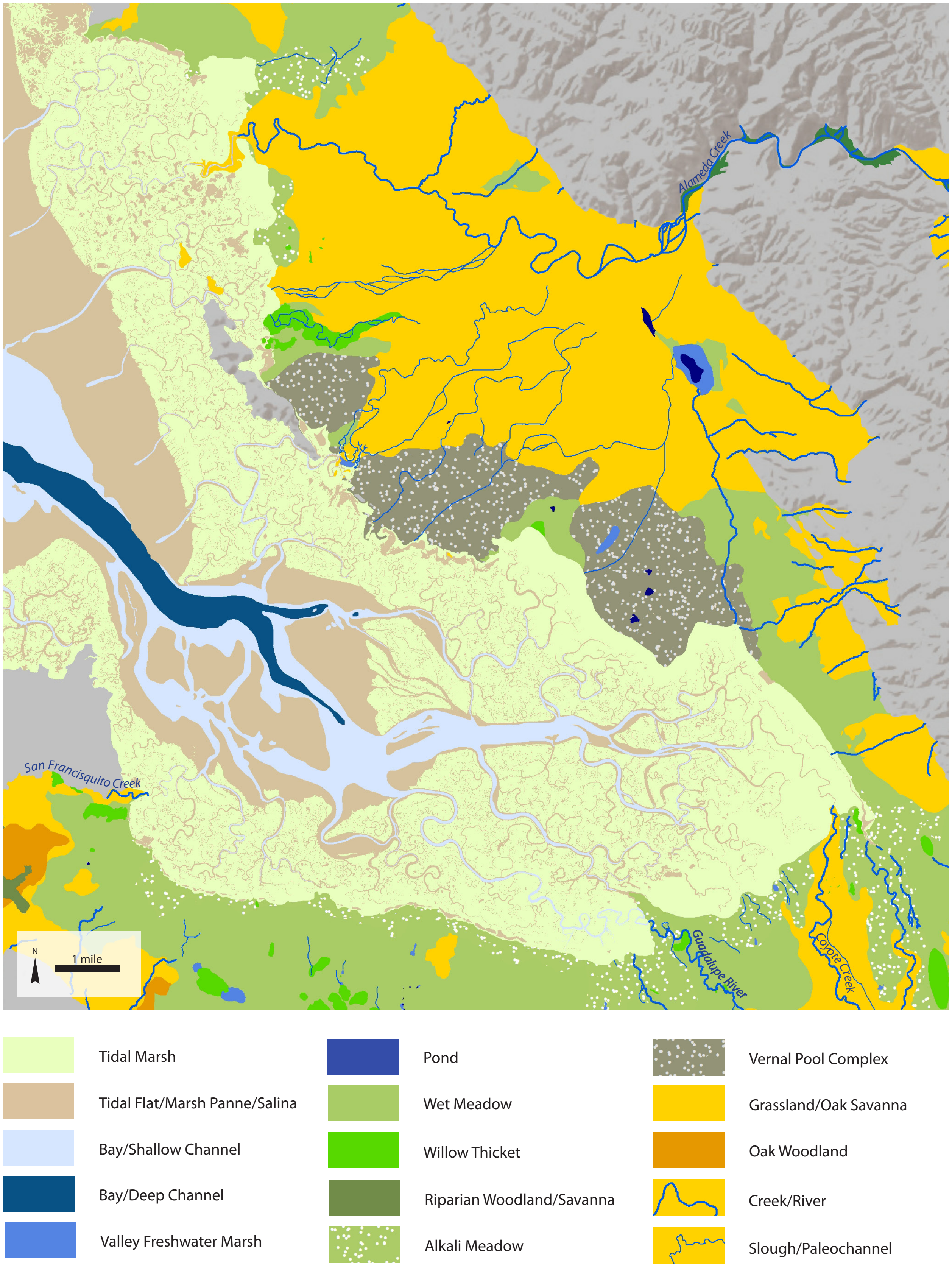


Figure 1. The project study area extends from San Francisquito Creek in Palo Alto to approximately the current location of Highway 92 in the East Bay. Historical ecology mapping was synthesized from four separate South Bay studies to create a seamless depiction of 19th century historical habitat types in the region.

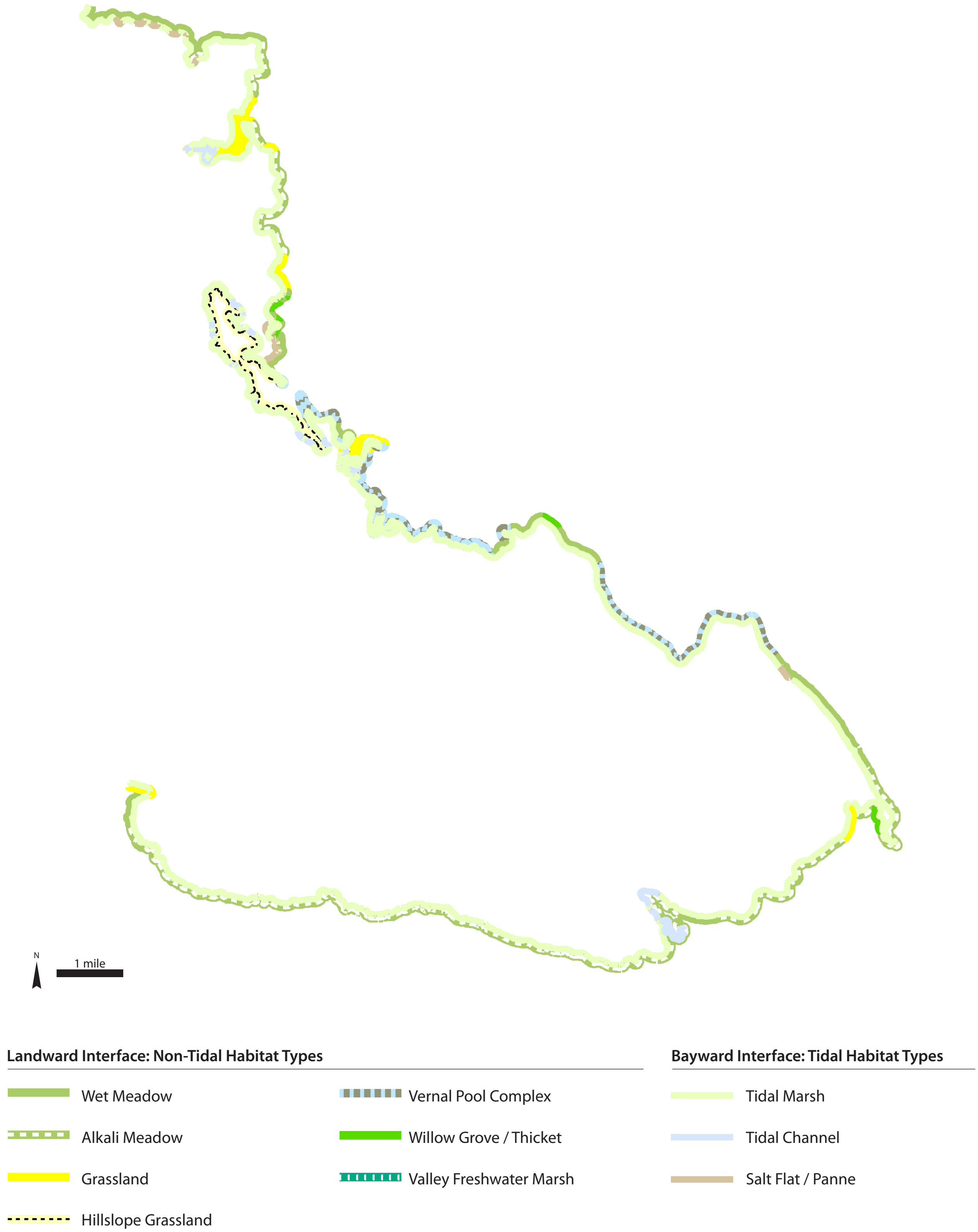


Figure 2. A line was digitized to capture the interface between tidal and terrestrial habiat types in the South Bay. This line was then coded with the adjacent tidal and terrestrial habitat types in order to estimate the relative proportions of each type of interface.

and secondary fluvial inputs. Primary fluvial inputs drained comparatively large watersheds and probably provided relatively significant inputs of water and sediment into the Bay ecosystem, whereas secondary streams had much smaller drainage areas and therefore yielded smaller water and sediment inputs. Primary fluvial inputs were used to delineate the width of the T-zone (see page 8).

Mapping the Transition Zone

In addition to mapping and characterizing the historical South Bay tidal-terrestrial/fluvial interface, we also estimated the width of the South Bay transition zone. The intent was to create a conceptual representation of the approximate historical width of the T-zone, including the bayward extent of the influence of terrestrial and fluvial processes and the landward extent of the influence of tidal processes. This representation is meant to provide a sense of the former range of widths of the T-zone in the South Bay, as well as to establish a standard means to compare the relative width of the zone across the region (i.e., where the T-zone would be expected to have been relatively narrow or broad). It also offers a way to describe the habitat composition of the historical T-zone. These analyses are discussed further in the Results section.

Few data have been synthesized that explicitly delineate the upland limit of the tidal-terrestrial T-zone. Instead, we defined the landward boundary of the T-zone as the elevation contour that likely coincided with the landward limit of interactions between tidal and fluvial or terrestrial processes that would affect the distribution, abundance, or mosaics of habitat types. Since data are not available to directly assess the historical (19th century) extent of extreme high tides, we used 20th century measurements of highest observed tide levels from a number of South Bay stations in or near the study area to estimate the approximate inland extent of the highest tides (table 2). These data support the use of the 10 foot NAVD 88 contour as a standard proxy for the historical inland extent of the physical T-zone. In some places, this approach is likely to underestimate the width of the T-zone based on physical processes (Collins and Goodman-Collins 2010). The approach certainly underestimates the width of the T-zone relative to the maximum bayward and landward limits of its ecological services (BEHGU 2013). Nevertheless, it provides a general demarcation between tidal and non-tidal influence and therefore a convenient and useful approximation of the inland extent of the T-zone.

In most places, we adopted the 10 foot contour as mapped on the USGS DRG (georeferenced contemporary topographic quadrangles, generally based on 1948-1961 surveys and photography) to delineate the landward T-zone boundary. This contour was then compared to the historical (ca. 1900) USGS topographic quadrangles and 2010 LiDAR to ensure their general consistency. The contemporary USGS DRG was used instead of historical USGS maps because the latter do not include a 10 foot contour. In some areas, we determined that grading, filling, or other land use activities had significantly altered the topography of the T-zone, such that the DRG does not represent historical conditions. For example, there has been significant subsidence of lands near San José due to groundwater withdrawal. In these modified areas (as well as in areas where the 10 foot contour is not shown on the DRG; e.g., near the Coyote Hills), the 10 foot contour was estimated from the LiDAR and historical USGS quadrangles. Artificial levees and channels were disregarded in our estimates of T-zone width.

Table 2. Highest observed still-water levels for selected South Bay stations. While these likely underestimate the actual upper limit of tidal flooding, they provide a standard proxy for the historical inland extent of the T-zone. Mean Lower Low Water (MLLW) measurements from NOAA's National Ocean Service benchmark sheets. Conversions from MLLW to NAVD 88 for Coyote Creek, Gold Street Bridge, and San Mateo Bridge from PWA (2006), and for Redwood City from Sea Surveyor Inc. (2007).

Station	Coyote Creek, Alviso Slough (#9414575)	Gold Street Bridge, Aviso Slough (#9414551)	Redwood City (#9414523)	San Mateo Bridge, West (#9414458)
Date	11/24/1984	12/28/1974	12/03/1983	01/27/1983
Highest observed water level (feet, MLLW)	10.76	10.99	10.80	10.71
Highest observed water level (feet, NAVD88)	9.25	9.02	9.73	9.95

We defined the bayward T-zone boundary based on several historical physical factors and indicators. With regard to the tidal marsh plain, we note that shallow, elongate natural salt ponds or pannes (sometimes called *salinas*) were present at the upland tidal marsh edge across much of the South Bay in the 19th century (Collins and Grossinger 2004:27; fig. 3). These features are characteristic of the intertidal portion of the South Bay T-zone. They are associated with portions of the high marsh plain removed from frequent tidal flooding (Goals Project 1999:79) and that have little direct freshwater influence from creeks and springs (Collins and Grossinger 2004:27, although some ponds may have been seasonally brackish as a result of emerging groundwater and/or non-channelized runoff; see Baye 2000:44).

In portions of tidal marsh where these elongate ponds were historically present, we mapped the T-zone boundary as an approximate "drainage divide" between the first order tidal channels (which were excluded from the T-zone) and the ponds (which were included in the zone). The boundary was interpolated in areas where these ponds were not depicted on the historical T-sheets, notably between Mowry Slough and Mud Slough. We believe that this omission reflects differences in mapping protocol rather than an actual absence of ponds, since their mapped extent corresponds to the edge of the T-sheet (Kerr 1857a). This interpretation is supported by the observation that overlapping T-sheets of the same vintage but produced by different surveyors show ponds in one case (Kerr 1857a) but not in the other (Morse and Westdahl 1896).

In some places, the influence of local rivers and streams extended far into the Bay ecosystem. While freshwater inputs derived from a variety of local sources (including springs, seeps, and overland runoff), rivers and streams with channels that reached the Bay were historically the most significant sources of freshwater to the South Bay (SFEI 1999). Listed in order of watershed size, these primary streams are Alameda Creek (1,800 km^2), Coyote Creek (830 km^2), Guadalupe River (440 km^2), and San Francisquito Creek (110 km^2). Grossinger (1995:99) identified map-based indicators of the effects of rivers and streams (including Alameda and San Francisquito creeks) on tidal marsh form, including reduced tidal channel density, reduced channel sinuosity, decreased panne abundance, and increased average panne size. These indicators clearly show zones of freshwater influence

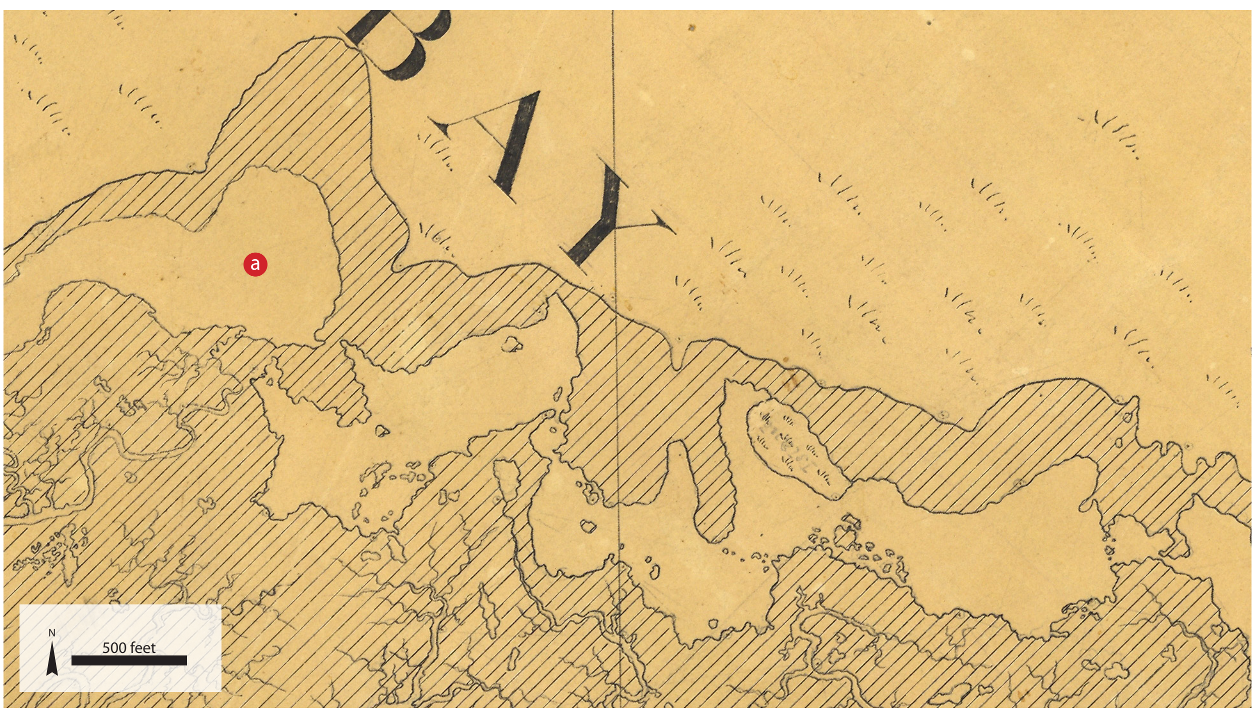


Figure 3. Elongate natural salt ponds, sometimes called *salinas* (a), were found in the upper intertidal zone across much of the South Bay in the 19th century. They formed in areas not drained by tidal channels at the marsh backshore. This detail from an 1857 T-sheet depicts these features near Mowry Slough as large, irregularly shaped unshaded areas. (Kerr 1857a)

near the mouths of these primary streams extending into the marsh. (Most of the secondary South Bay streams did not historically maintain channels that reached the intertidal environment, but instead dissipated into alluvial fans or spread into distributary channels and freshwater wetlands; SFEI 1999, Beller et al. 2010, Stanford et al. 2013.)

To represent the effect of these distinct, widely-spaced zones of freshwater influence on the bayward extent of the T-zone, we created a buffer for each of these four large streams based on the available data (e.g., historical marsh planform patterns and presence of freshwater vegetation in historical records; Grossinger 1995, SFEI 1999). Zones were represented by a 3,000 meter (10,000 ft) buffer for Alameda Creek, Coyote Creek, and Guadalupe River, and a 1,000 meter (3,000 ft) buffer for San Francisquito Creek to reflect its much smaller watershed area (after SFEI 1999 and Goals Project 1999:16). These buffers are intended to be conceptual illustrations rather than precise boundaries. Buffers for each stream were centered at its point of intersection with the tidal-terrestrial interface line. The northern boundary of the Alameda Creek buffer was adjusted slightly to exclude the elongate ponds found along the tidal marsh backshore.

These two boundaries – the landward (10 foot contour) and bayward *(*pond edge/freshwater buffer) – were combined to create a single polygon coarsely depicting the historical extent of the physical T-zone (see fig. 14). This is designed to be only a preliminary depiction of the historical South Bay T-zone; there are many reasons to expect that the accuracy of this map can be improved by finding and interpreting additional local data about salt-affected soils, salt-affected groundwater chemistry and emergence (where less dense non-saline groundwater is forced to the surface by intruding salt water), the landward distribution of salt-tolerant vegetation, and the bayward distribution of vegetation indicative of fresh or brackish conditions. In the absence of thsee data, we generalized such local effects into sub-regional rules for depicting the T-zone. For example, the three largest South Bay streams were assigned identical buffer widths to depict the spatial limits of freshwater influence, and our methods do not directly address the effects of secondary freshwater inputs (including springs and small streams). The head-of-tide was not included in our map of the landward extent of the T-zone for any stream, except to the degree that the 10 foot contour extends upstream along the streams before crossing them. It is likely that the head-of-tide is further upstream than indicated on the T-zone map.

We expect that subsequent research involving additional historical data or refinements of the mapping protocols might substantially change the location and shape of the zone. Nevertheless, we believe that this product provides a meaningful approximation of the relative widths and extents of the T-zone across the South Bay, distinguishing areas that would have supported a relatively narrow T-zone (tens of meters wide) from those that would have supported a much wider T-zone (thousands of meters wide).

RESULTS

Estuarine-Terrestrial Interface (Backshore)

Based on our mapping, we identified five general types of historical estuarine-terrestrial interfaces for the South Bay. These include tidal habitat complexes (including marsh, channel, and ponds/pannes*)* adjacent to seasonal wetlands, perennial freshwater marsh, willow thicket, hillslope grassland (grasses and forbs occupying relatively steep bedrock), and riparian grassland (grasses and forbs occupying alluvial soils, primarily alluvial fans and natural levee deposits). These five types are broadly consistent with types identified by Baye (2008:14), and are further described below.

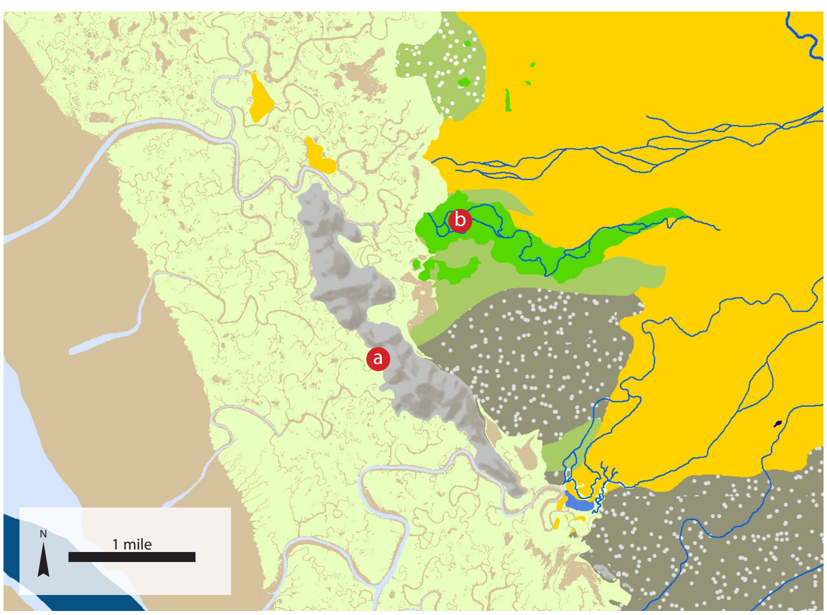
While this is a comprehensive list of the habitat types formerly adjoining the intertidal South Bay environment, additional historical habitat types were also documented within the South Bay T-zone but not immediately adjoining the intertidal environment (most notably valley oak woodland/savanna). These same habitat types adjoin the intertidal environment elsewhere in the Bay Area.

HILLSLOPE GRASSLAND Steep, grassy upland areas immediately adjacent to tidal marsh were classified as hillslope grassland. These grasslands generally had thin soils compared to grasslands on alluvial plains. We distinguish this habitat from other lower-lying grassland habitat types, in particular the grasslands which historically occupied parts of the natural levees formed by the larger local creeks (see Riparian Grassland section below). Hillslope grassland accounted for 10% of the total interface length in the South Bay (11,390 m/37,380 ft).

Tidal marsh-hillslope grassland T-zone was found in only one location in the study area, at the Coyote Hills (figs. 4 and 5). Stratton (1862) described the northern Coyote Hills as "isolated hills surrounded by the salt marsh…they are sometimes called islands, but not properly so, because they are only surrounded by water at the Spring tides." Springs were formerly found along the western edge of the hills (DWR 1960:26).

RIPARIAN GRASSLAND (AND FOREST) The riparian grassland T-zone includes grassland as well as riparian woodland/forest on the well-drained natural levees of a number of South Bay creeks. While these portions of the T-zone were primarily characterized by low grasses and forbs (Minnich 2008), there was also a narrower riparian forest component of indeterminate width along the channel. In addition to the natural levees of active creeks, this category also includes grassland (and potentially some trees) on old (inactive) natural levees that were slightly higher and better-drained than the surrounding landscape. This type of T-zone accounted for 18% of the total interface length in the South Bay (19,120 m/62,720 ft).

Riparian grassland was found contacting tidal marsh where the natural levees of Alameda Creek (historical route) and Coyote and San Francisquito creeks protruded into the baylands. On Alameda Creek, for example, a narrow corridor of willows lined the creek far into the tidal marsh, and was flanked by grassland on the stream's natural levee (Stanford et al. 2013:207; fig. 6). Willow thickets were also found within the T-zone at the Alameda Creek mouth: historian C.H. Shinn (1907:23) described Union City as "in the willow-swamps at the edge of salt water." Lower Coyote Creek was also flanked by a narrow corridor of willow-dominated riparian forest and was incised within a broad, grassy natural levee (Grossinger et al. 2006:II-5). Riparian grassland on relict natural levees was found at Crandall and Newark sloughs.



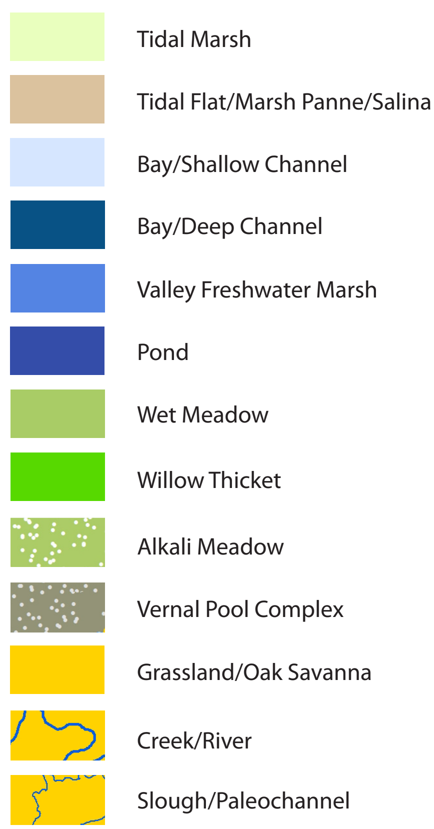


Figure 4. Tidal marsh-hillslope grassland transition zone at the Coyote Hills (a). This was the only location in the South Bay study area where this transition zone type was documented. (Since the hills themselves were not included in the historical land cover layer, they appear as grey hillshade in the above map.) The Willows (see page 10) is also visible east of the Coyote Hills (b).

Figure 5. A panoramic view taken from the Coyote Hills in fall 1916 shows the transition from steep hillslope grassland to tidal marsh. The image looks north across Coyote Hills Slough, now the mouth of Alameda Creek. In addition to the channels, small pannes, or ponds, are visible within the marsh. (AD-1005-1009, © San Francisco Public Utilities Commission)

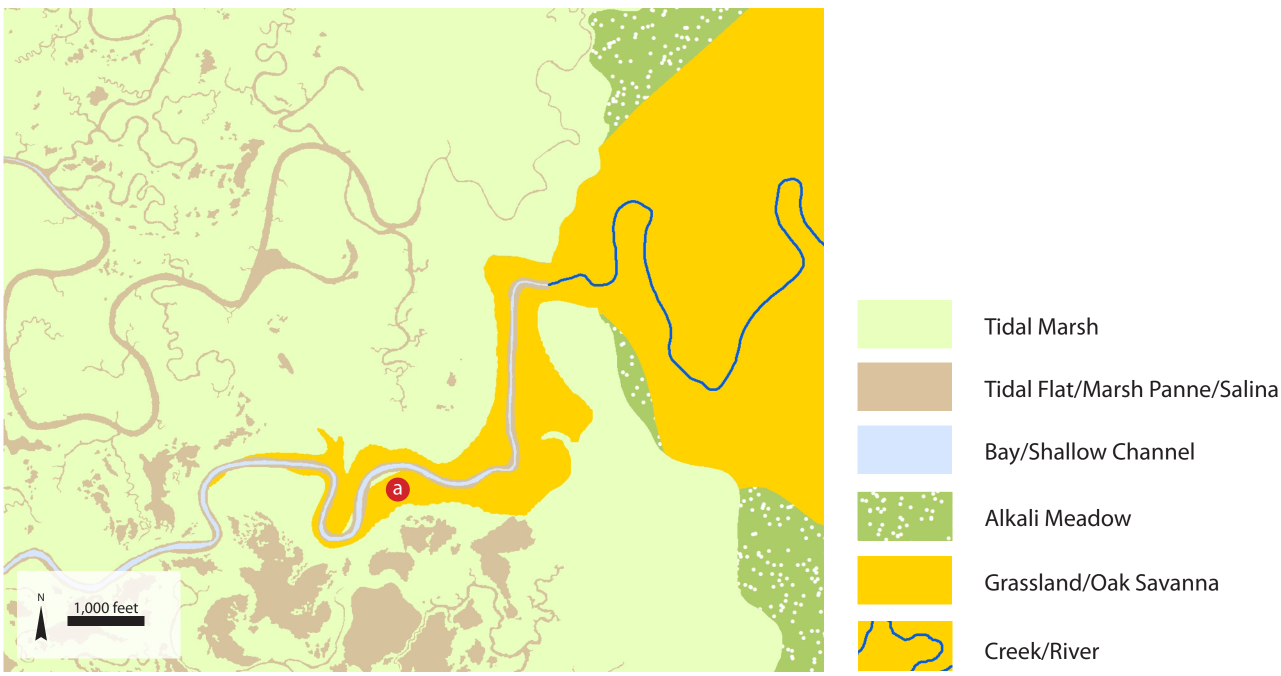


Figure 6. The natural levee of Alameda Creek's historical route (a) protruded over two kilometers into the baylands, creating higher ground that supported riparian grassland and willows.

WILLOW THICKET Willow thickets are palustrine forested wetlands that occur in large, broad stands not directly associated with a stream (as opposed to linear riparian features along channels). The presence of willow groves or thickets indicates the temporary or seasonal availability of fresh surface water and a consistently high water table. In the South Bay willow thickets frequently occurred in areas of emergent groundwater, and were often associated with springs and spring runs (Beller et al. 2010:37). The dominant tree in local willow thickets was arroyo willow, though other tree species (such as cottonwood, box elder, and Oregon ash) were also present, in addition to an often dense understory of wild rose, blackberry, and ninebark (Cooper 1926; see Coyote II-30). These relatively rare areas of prominent freshwater woody vegetation on open plains were likely nodes of biodiversity, as suggested by accounts of wildlife at the Willows (see below). These features are largely absent from the landscape today (Collins and Grossinger 2004).

Willow thickets immediately adjacent to tidal marshland were relatively rare in the South Bay, documented in only a few places. The most notable instance was a 400 acre grove known as the Willows, east of Coyote Hills and

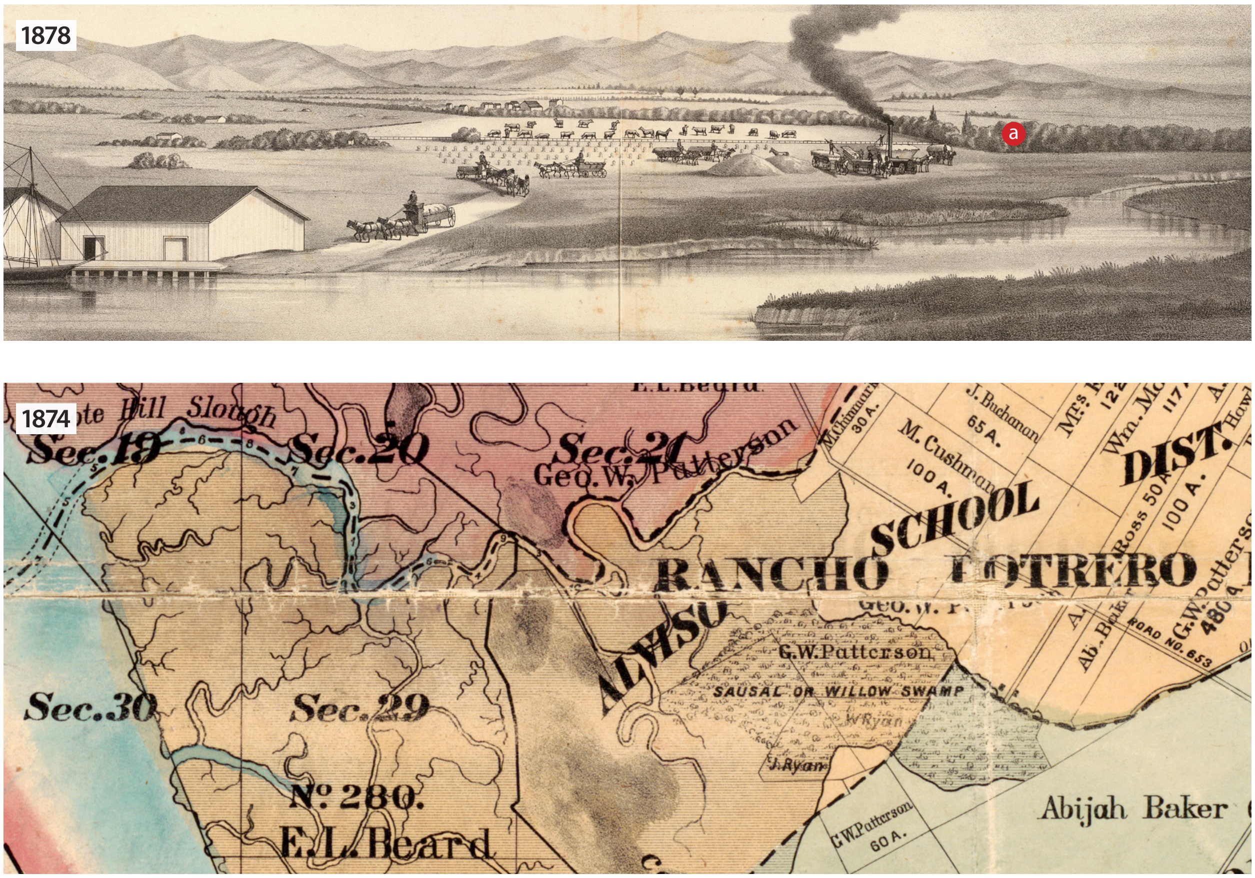


Figure 7. A 400 acre willow thicket known as "the Willows" was documented east of Coyote Hills. This 1878 lithograph (top) shows the Willows (a), as well as a few additional isolated willow clumps scattered to the north. The feature was also captured in numerous 19th century maps of the area, including the 1874 map reproduced here (bottom). (Top: Thompson and West 1878, courtesy David Rumsey Map Collection; bottom: Allardt 1874, courtesy The Bancroft Library, UC Berkeley)

just south of the present-day Flood Control Channel (Stanford et al. 2013:172; fig. 7, see also fig. 4). The Willows was laced with swales and springs, and supported cottonwood, alder, sycamore, and oak in addition to the willows (Westdahl 1896, Country Club of Washington Township [1904]1956:100, Grinnell 1919). The complex included at least one willow patch fully surrounded by tidal marsh and ponds/pannes (Kerr 1857b).

In total, willow thicket-tidal marsh T-zone accounted for only 2% of the total interface length in the South Bay (2,750 m/9,020 ft). However, in many places (such as south of the mouth of San Francisquito Creek; fig. 8) extensive additional willow thickets were found within a dozen to a couple hundred meters upslope of the interface, within the T-zone albeit not directly contiguous to tidal marsh.

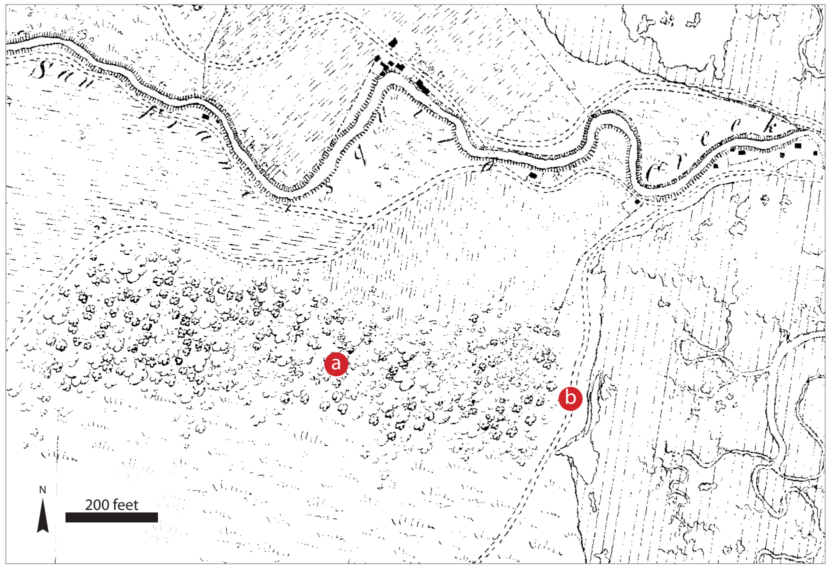


Figure 8. Willow thicket south of San Francisquito Creek (a), within the T-zone though not directly adjoining tidal marsh. On this 1857 map, a road (b) is shown in the narrow gap between the willow thicket and the tidal marsh. (Rodgers and Kerr 1857)

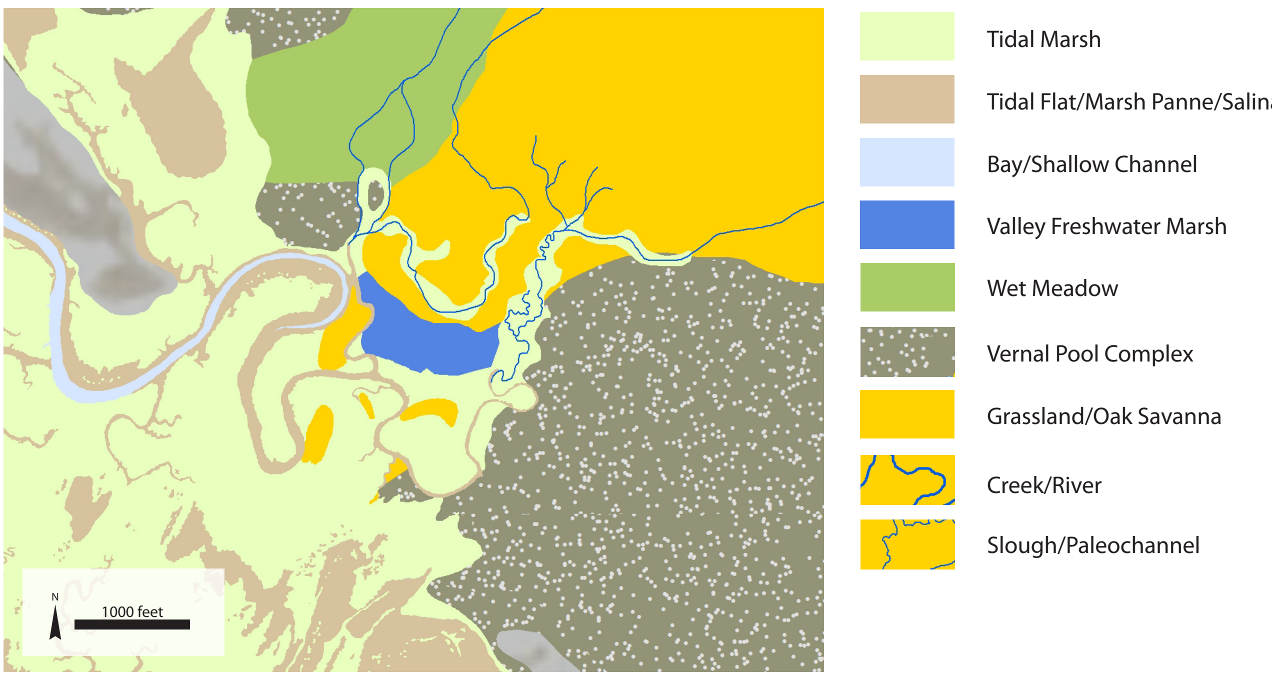
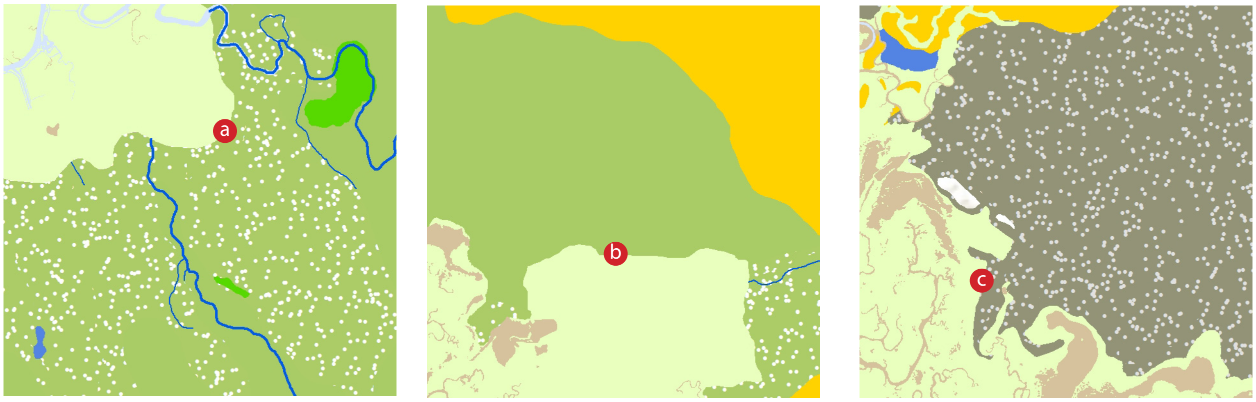


Figure 9. Freshwater marsh historically adjoined tidal marsh south of Coyote Hills near Newark Slough. This is the only area where this transition type was documented in the South Bay in the historical mapping.

FRESHWATER MARSH Valley freshwater marshes are persistent emergent freshwater wetlands typically dominated by bulrushes, cattails, sedges, and rushes. Freshwater marsh was documented adjacent to tidal marsh by our South Bay historical ecology mapping in only one area, near Newark Slough (fig. 9), though additional areas may have occurred near Alvarado (Baye pers. comm.). As a result, these wetlands represent the smallest proportion of T-zone interface in the South Bay, just 1% (750 m/2,440 ft) of total length. Limited additional patches of freshwater marsh were found in the T-zone near the interface west of Coyote Creek.

SEASONALLY FLOODED WETLAND As the name implies, seasonally flooded wetland is a composite type comprising a suite of temporarily or seasonally saturated or flooded herbaceous communities. These wetlands are characterized by higher desiccation frequencies compared to freshwater marsh and are subject to dry season desiccation (Whipple et al. 2012:73). They generally have high groundwater and poor drainage conditions associated with dense, clay-rich soils and nearly flat topography.

Seasonally flooded wetland habitat types include alkali meadow (saltgrass-dominated, greater than 0.2% residual salt content in the first six feet of the soil column), wet meadow (likely rhizomatous ryegrass-dominant,



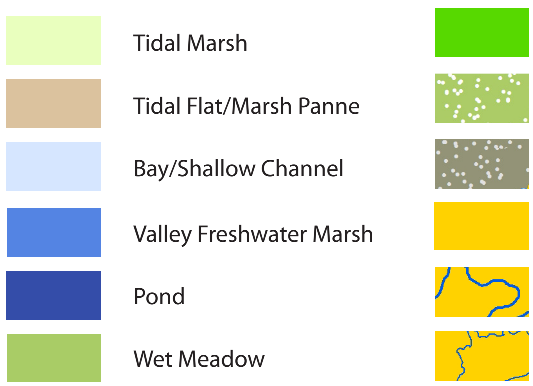


Figure 10. These details from the historical habitat map show the three types of seasonal wetland-tidal marsh transition zone: alkali meadow (a) at Alviso, wet meadow (b) north of the old Alameda Creek channel, and vernal pool complex (c) south of the Coyote Hills.

no evidence of alkali), and vernal pool complexes (depressional wetlands characterized by hummocky "hog wallow" microtopography underlain by claypans or hardpans and supporting a distinctive vegetation community). Vernal pool complexes were only mapped where we found evidence of distinctive patterns associated with vernal pools; as a result, smaller vernal pool complexes within other seasonal wetland types are likely undermapped. For more information on vegetation communities associated with these habitat types, see Stanford et al. (2013:39).

These wetlands dominated the lowlands bordering the South Bay, and in total accounted for 69% (75,030 m/246,170 ft) of the region's tidal-terrestrial interface length (fig. 10). Alkali meadow (36,060 m/118,310 ft) was particularly prevalent in Santa Clara County, where it often occurred in low-lying areas between tidal marsh and wet meadow (Beller et al. 2010). Stephens (1856) described this T-zone north of San Francisquito Creek, noting that "the precise demarcation between the Tide Marsh and the firm land is well defined by the growth of a peculiar species of aquatic plant, a salt grass which covers the flat along the edges of the Bay, and on its inner margin grows slightly above the elevation of ordinary high tide." Reed (1862) explained that east of San José, the alkali meadows were "a medium" between terrestrial and tidal habitat types: "it was neither like the upland nor like the Salt marsh, but it partook of the character of both." In some areas, this in-between character made these lands difficult to classify; surveyor Westdahl (1897) described the zone as "the debatable area immediately adjoining the Salt-marsh, which is sometimes covered at high tides."

Wet meadow (17,950 m/58,890 ft) occupied similar poorly-drained, clay-rich soils but without the distinctive soil chemistry or microtopography of alkali meadow/vernal pool. It was documented in broad areas adjacent to tidal marsh throughout the region, with substantial additional acreage in the T-zone upslope of bands of alkali meadow. The vegetation structure of wet and alkali meadow would have had only limited high canopy, with the tallest canopy provided by creeping wildrye (*Elymus triticoides*; Baye pers. comm.).

Vernal pool complex (21,020 m/68,970 ft) was documented exclusively in Alameda County on the Niles Cone, in extensive tracts bordering the tidal marsh. The gently-sloped transition from tidal marsh to vernal pool

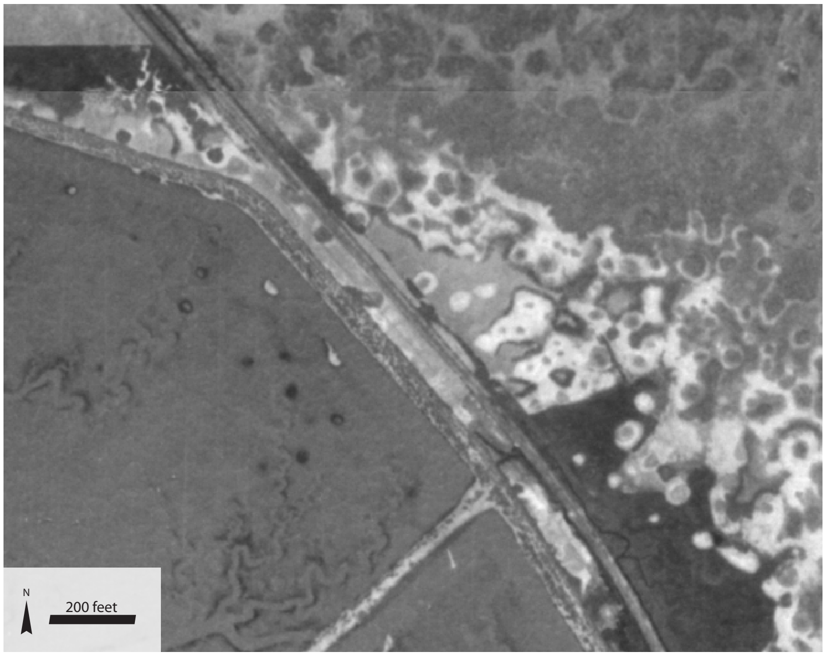


Figure 11. Vernal pools (identifiable by the indicative textured pattern of small circles surrounded by lighter-colored areas) are visible at the tidal marsh backshore in this 1939 aerial photograph. (USDA 1939)

complex was not always clearly defined; historical aerial imagery shows the hummocky vernal pool topography intergrading with tidal marshland south of Coyote Hills near Warm Springs (Stanford et al. 2013; fig. 11). In 1895, botanist Joseph Burtt Davy described the tidal marsh-vernal pool T-zone near Newark in detail:

> this stretch of about 8 miles is the richest in flowers of the whole 52 miles from Alameda [illegible] to San José and shows how gorgeous the whole plain bordering the marshes probably was before the introduction of foreign weeds and the grazing of cattle and horses. …The general impression in color is a mass of yellow owing to the abundance of *Lasthenia* and *Blepharipappus [Layia, likely L. conjugens],* though in places this gives way to the masses of green and white of *Trifolium fucatum.* In places the yellow is dotted with the white heads of *Navarretia cotulaefolia…Bolelia [Downingia] pulchella* (Lindl) Greene. Dried out pools…*Lasthenia conjugens.* (Burtt Davy 1895)

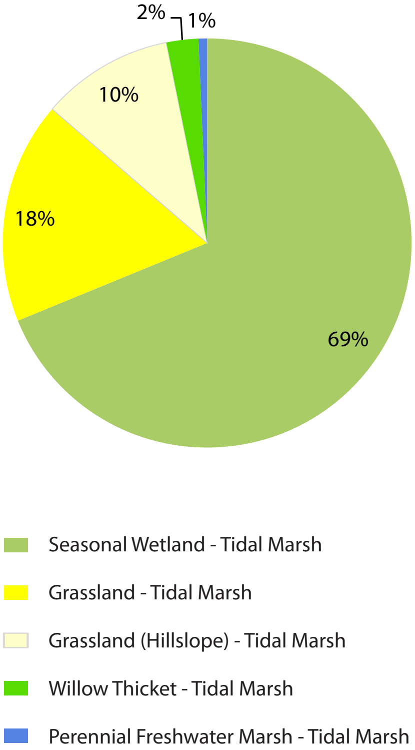


Figure 12. Percentage of each T-zone type occupying the historical tidal-terrestrial interface in the South Bay (see fig. 2). The estuarine backshore was dominated by seasonally flooded wetland habitat types, which accounted for nearly 70% of the total tidal-terrestrial interface length.

In summary, the estuarine backshore was dominated by seasonally flooded wetland habitat types, which accounted for over two-thirds of the total tidal-terrestrial interface length (fig. 12). In contrast, hillslope grassland only composed about 10% of total interface length.

Though in the above discussion we have lumped all tidal marsh categories together, there were notable differences in tidal marsh character across the region that are worth noting. In particular, terrestrial areas with relatively large quantities of surface and subsurface fresh water inputs entering the marsh would have shaped the character of these tidal marshes, supporting different plant communities than neighboring areas with less freshwater input. While most of the South Bay baylands were characterized by salt marsh, localized areas of fresh and brackish tidal marsh were documented in the region associated with freshwater influence from adjacent creeks (see Grossinger et al. 2006:III-15). An

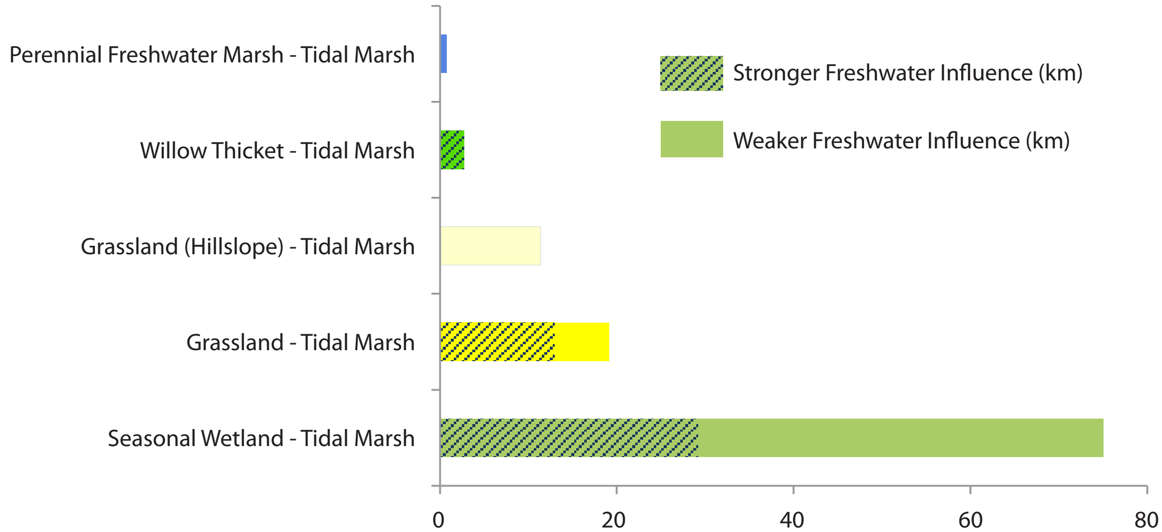


Figure 13. Linear extent of each T-zone type occupying the historical tidal-terrestrial interface in the South Bay, coded by degree of freshwater influence. Over 40% of the T-zone interface was coded as having significant freshwater influence.

approximation of the proportion of each terrestrial habitat type interfacing with freshwater-influenced tidal marsh is provided here (fig. 13). Overall, about 42% of the linear extent of tidal marsh at the terrestrial interface was coded as having significant freshwater influence.

Transition Zone Width and Character

In total, we mapped about 9,840 ha (24,320 ac) of tidal-terrestrial T-zone habitat (fig. 14). The T-zone as depicted includes habitat types and features found bayward of the tidal-terrestrial interface (e.g., tidal salt marsh, fluvially-influenced tidal freshwater/brackish marsh, ponds/pannes, tidal channels, and tidal flats) as well as habitat types and features found landward of the interface, as described above. A few additional terrestrial habitat types not represented by the interface line were also found in the T-zone, including oak savanna and seasonal and perennial freshwater ponds. While none of these compose a significant proportion of the mapped T-zone, they may be ecologically significant as habitat for amphibians and sources of water for many birds and other terrestrial wildlife. On the other hand, a number of terrestrial habitat types were not documented in the South Bay T-zone, including chaparral, coastal scrub, and oak savanna.

T-zone width varied widely across the South Bay, from only a few meters wide to about five kilometers. The character of adjoining tidal and terrestrial habitats influenced T-zone width, as did slope (Watson 2012). The narrowest T-zones were found between tidal marsh and hillslope grassland at Coyote Hills, where they were on the order of only a few to tens of meters wide. The broadest T-zones were found at creek mouths, where fluvial influence extended deep into the tidal marsh and T-zones were often several kilometers wide. Intermediate T-zone widths, on the order of about one kilometer, were found in the relatively flat areas where seasonally flooded wetlands contacted tidal marsh and ponds. Average T-zone width was approximately 2,100 meters.

These results also provide an approximation of the proportion of the T-zone area occupied by each habitat type (fig. 15). Tidal marsh habitat types and features (tidal flat and marsh, channels, pannes and salt flats) occupied a little over 50% of the T-zone as mapped, while seasonal wetland habitat types (alkali and wet meadow and vernal pool complex) cumulatively covered about 40% of the total area. Smaller areas of grassland, willow thicket, and valley freshwater marsh composed the remainder.

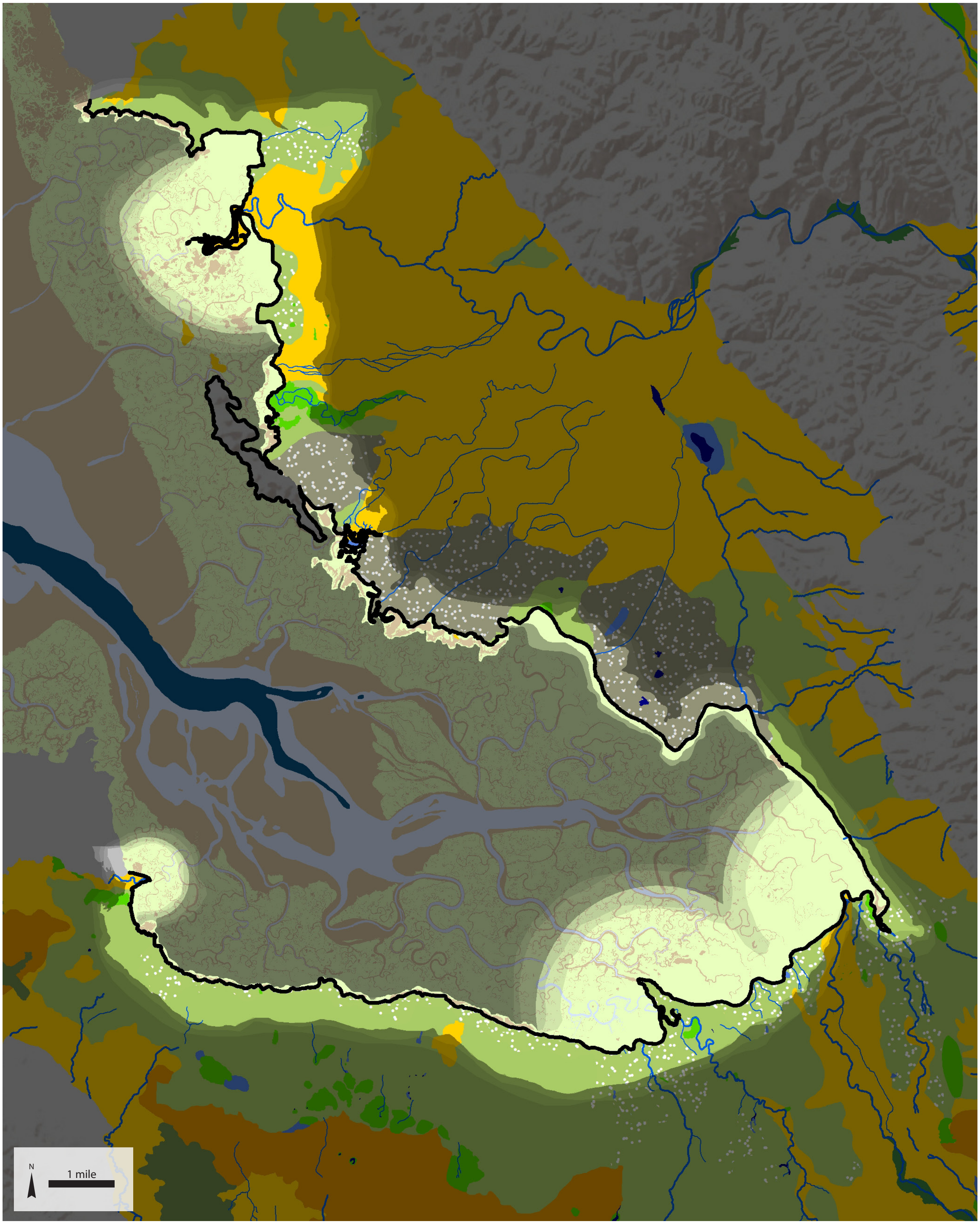


Figure 14. Approximation of historical T-zone width in the South Bay, extending both bayward and landward from the estuarine backshore. The T-zone was widest in areas with low slopes and significant freshwater influence, where it could extend to several kilometers wide.

DISCUSSION

The ecotonal landscape summarized here is almost unrecognizable when compared to the contemporary tidal-terrestrial transition zone in the South Bay. Most of the former ecotone area has been leveed, filled, or converted to other land uses (e.g., industrial areas or salt ponds) (Collins and Goodman-Collins 2010). However, these data do suggest a few areas where remnant or representative regenerated habitat types persist (e.g., hillslope grassland around parts of the Coyote Hills and the abandoned quarry near Don Edwards San Francisco Bay National Wildlife Refuge headquarters, alkali grassland/vernal pools at Warm Springs; Baye pers. comm. and see BEHGU 2013 for more details). Our research suggests that some of these areas might serve as conservation priorities or nodes for future restoration activities.

In particular, the transition between high marsh and low-gradient, seasonally flooded wetland types formerly dominated the South Bay T-zone, representing nearly 70% of the interface. These zones were broad areas with gentle slopes, high groundwater, and fine sediment (Baye 2008, Beller et al. 2010), and they are not well represented today. These seasonally flooded wetlands were themselves quite diverse, including alkali meadow, wet meadow, and vernal pool complexes – each with distinct ecological characteristics and functions. Smaller amounts of other T-zone types such as willow thicket, freshwater marsh, and riparian grassland/forest also contributed to the diversity of the T-zone. Relatively steeply-sloped grasslands bordering tidal marsh – the historical interface type most similar to the dominant T-zones observed today – comprised less than 10% of the South Bay interface. The T-zone included variation on the tidal side as well, with fresh-brackish marshes associated with major creek mouths interspersed within a broad salt marsh matrix. Over 40% of the linear extent of tidal marsh at the terrestrial interface was coded as having significant freshwater influence.

More generally, our research indicates that the South Bay T-zone was quite broad in many areas, much more so than previously reported. The Goals Project (1999:78) noted that the T-zone could be "hundreds of yards" wide, and Collins and Grossinger (2004) noted that the T-zone could be up to 1,000 m in some places. These figures appear to underestimate ecotone width across much of the South Bay: we calculated T-zone width to be on average about 2,200 m, suggesting that a 1,000 m wide T-zone would have represented a below-average ecotone width rather than an extreme. The broadest T-zone regions were associated with freshwater inputs from creeks. It is not clear whether these conclusions are applicable to other parts of the Estuary; further research would contextualize these patterns.

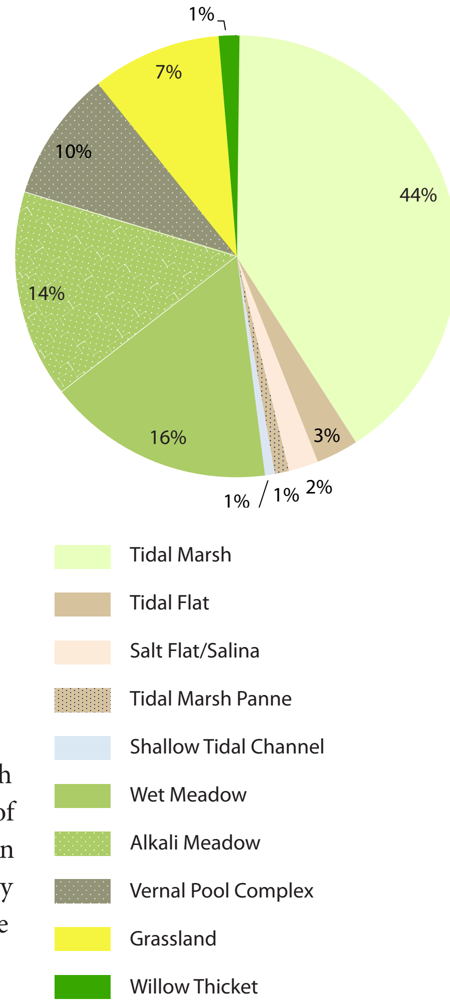


Figure 15. Percentage of historical South Bay T-zone area occupied by each habitat type. Tidal marsh habitat types and features occupied just over 50% (about 5,000 ha) of the mapped T-zone, while seasonal wetland habitat types accounted for about 40% (about 4,300 ha) of total T-zone area. Hillslope Grassland, Valley Freshwater Marsh, and other habitat types are each less than 1% of the mapped T-zone.

CONCLUSIONS AND NEXT STEPS

The tidal-terrestrial transition zone has been recognized as an important component of the San Francisco Bay, and has been identified as a high priority for restoration in the South Bay (SCVWD 2006:6-4) and for the Bay as a whole (Goals Project 1999:A-16). Our research reconstructs the approximate extent of the South Bay T-zone and characterizes it in terms of the adjoining terrestrial and intertidal habitat types and features that were historically prevalent in the region, some of which are no longer common. These findings can assist scientists and managers in identifying appropriate objectives for T-zone conservation and restoration in the context of projected changes in land use and climate, especially with regard to sea level rise.

These findings have several immediate and longer-term management implications. First, in order to maximize the benefits to biodiversity and ecological function, it will be important to consider the full palette and relative proportions of T-zone types in Bay restoration planning. A regional approach will be necessary to match T-zone type (i.e., the form, structure, and plant community of the T-zone) to local setting, based on factors such as topographic slope, elevations, width and length of available and suitable lands, groundwater heights, and land use constraints. The role of soil characteristics in the formation and long-term sustainability of different T-zone types must also be carefully considered; it will be important to preserve and enhance the few areas in the South Bay and elsewhere that retain relatively intact T-zone soils.

To develop an adaptive approach to T-zone conservation and design, several next steps are recommended:

- We hope that this research will help precipitate a more geographically and technically comprehensive study of historical T-zone form, structure, distribution, and function across the San Francisco Bay, using as much local data as possible. Future research extending this analysis to the Central and North Bay is important to develop the full T-zone palette and identify all the relatively intact areas of the T-zone that should be protected. For example, historical transitions between tidal marsh and valley oak savanna on loam soils may provide insights on the design of T-zones for engineered slopes (Grossinger 2012). Additional local historical data in the South Bay will help refine this current effort.
- There should be an effort to develop conceptual models linking T-zone types to physical setting, physical drivers, and target ecological functions and ecosystem services (as has been initiated through the Baylands Goals Update). The models should identify which drivers might be managed to enhance selected T-zone services.
- The next effort to map the historical or existing T-zone should incorporate the heads-of-tide of rivers and streams. The head-of-tide is an important component of the T-zone relating to flood control, anadromous fish support, and the protection of historical and prehistoric cultural resources (BEHGU 2013). A current research project being conducted by BCDC and SFEI is focused on defining head-of-tide and developing methods to map it throughout the Bay Area.
- For each major type of T-zone, a comprehensive list should be compiled of closely associated or dependent plant and animal species, including analysis of how these species are supported by the T-zone. This will help planners identify the ecological objectives of T-zone conservation and creation.

The emerging scientific understanding of the character and function of the Bay's T-zone developed through this and subsequent efforts will greatly improve the chances that efforts to conserve, restore, and create the T-zone will be successful.

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