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creator	B. F. Atwater, S. G. Conard, J. N. Dowden, C. W. Hedel, R. L. MacDonald, W. Savage
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Abstract

Around 8,000 to 10,000 years ago, sharply rising sea levels nursed a newborn San Francisco Bay estuary whose tidal marshes probably covered less area than open water. Thereafter the rate of submergence decreased about 10-fold, and by 6,000 years ago sediment began to maintain marshes that later spread across marginal parts San Francisco Bay. By thus counteracting or overtaking submergence, sedimentation created marshes that, as of 1850, covered about 2200 km^2, nearly twice as much area as the bays. People have leveed or filled all but approximately 85 km^2 of these marshes during the past 125 years. Concurrently, human activities have caused the delivery of enormous quantities of sediment to the bays and the slackening of tidal currents in sloughs, thereby contributing to the creation of nearly 75 km^2 of marsh, about half of which remains pristine. Plains situated near high-tide levels are the most extensive landforms of both historic and modern marshes. Tides rather than upland tributaries created most sloughs around the bays, but riverine floods erected natural levees that confined tidal water in the Delta. Tidal marshes around San Francisco Bay typically contain13 or 14 species of vascular plants characteristic of salt marshes and are dominated by common pickleweed *(Salicornia pacifica)* and California cordgrass *(Spartinafoliosa).* In the Delta, tidal marshes support about 40 species characteristic of fresh-water marshes and are dominated by tules and bulrushes *(Scirpus* spp.), cat-tails *(Typha* spp.), and common reed *(Phragraites communis).* These contrasting communities overlap around San Pablo Bay, Carquinez Strait, and Suisun Bay. Damage to tules and bulrushes during the drought of 1976-1977 confirms that intolerance of salt causes these plants to disappear toward San Francisco Bay. The disappearance of California cordgrass and common pickleweed toward the Delta, alternatively, may result from unsuccessful competition against tules, bulrushes, and other species. If export equals one quarter of net above-ground productivity, then vascular plants of the tidal marshes collectively contribute about 10 billion grams of carbon per year to other parts of the estuary.

HISTORY, LANDFORMS, AND VEGETATION OF THE ESTUARY'S TIDAL MARSHES

BRIAN F. ATWATER
U. S. Geological Survey, 345 Middlefield Road, Menlo Park, CA 94025
SUSAN G. CONARD
Botany Department, University of California, Davis, CA 95616
JAMES N. DOWDEN
California State Lands Commission, 1807 13th Street, Sacramento, CA 95814*
CHARLES W. HEDEL
U. S. Geological Survey, 345 Middlefield Road, Menlo Park, CA 94025
RODERICK L. MACDONALD
Botany Department, University of California, Davis, CA 95616
WAYNE SAVAGE
Biology Department, San Jose State University, San Jose, CA 95192

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* The views expressed herein are not necessarily those of the California State Lands Commission (CSLC) or of other bureaus of the State.

SAN FRANCISCO BAY

Though initially regarded as wastelands, tidal marshes of the San Francisco Bay estuary have gained considerable human significance during the past 125 years. The monetary value of these marshes derives chiefly from their historical conversion to farmlands, salt ponds, and sites for commerce, industry, recreation, and residence. Areas of former marshland in the Sacramento-San Joaquin Delta, for example, currently yield about $300 million in crops, including one quarter of America's domestic asparagus (Delta Advisory Planning Commission 1976:77, 80). From impounded marshes around San Francisco and San Pablo bays, the Leslie Salt Company annually harvests approximately 400,000 metric tons of crude salt worth $7 million (M. Armstrong pers. comm.). Other leveed areas of former tidal marsh attract hunters, particularly north of Suisun Bay, where the annual duck kill equals about 10% of California's total (Jones and Stokes Associates Inc., and EDAW, Inc. 1975:46).

Few people deliberately maintained tidal marshes in their pristine condition until the 1960's, when concern about human encroachment on the bays led to the creation of the San Francisco Bay Conservation and Development Commission (BCDC) (Gilliam 1969). Since 1969, this regulatory agency has mandated the preservation of most remaining tidal marshes around San Francisco, San Pablo, and Suisun bays. According to the Commission's findings, tidal marshes warrant such protection because, directly or indirectly, they nourish and shelter many estuarine animals (BCDC 1969: 11). Some people also value pristine tidal marshes as sties for outdoor education or recreation. In response to this interest, local governments have established parks that preserve tidal marshes for students, bird-watchers, and strollers.

This chapter reflects the current concern for pristine tidal marshes by providing an overview of their history, landforms, and vegetation. Drawn partly from unpublished observations by the authors, the overview also depends on information from published sources, particularly topographic surveys by the U. S. Coast and Geodetic Survey (USC&GS); geologic investigations by Gilbert (1917), Pestrong (1963, 1972), and Atwater et al. (1977); and botanical studies by Cooper (1926), Marshall (1948), Hinde (1954), Mason (1957), Cameron (1972), Mahall and Park (1976a, b, c) and Conard et al. (1977). Much additional information remains to be gathered and assimilated, so we expect that others will improve many of the ideas put forth in this synthesis.

HISTORY

The discovery of gold at Sutter's mill in 1848 initiated human activities that have worked vast changes in tidal marshes of the San Francisco Bay estuary. Before the Gold Rush, people interfered with few of the natural processes that create, maintain, or destroy tidal marshes. Since the Gold Rush, however, people have leveed or filled most pre-existing marshes, accidentally promoted the erosion of others, and created some new marshes by both accident and design.

Events Before the California Gold Rush

Rates of submergence (rise in sea level relative to the land) and sedimentation largely controlled the areal extent of tidal marshes in the San Francisco Bay estuary between the inception of the estuary and the arrival of the Forty-Niners about 10,000 years later. Known tidal-marsh deposits older than 8,000 years form lenses no more than a few meters thick and underlie sediments that accumulated in open-water bay environments. This distribution implies that 8,000 to 10,000 years ago a discontinuous fringe of tidal marsh retreated from a rising, spreading bay, presumably because sediments accumulated in tidal marshes less rapidly than the level of the Bay climbed.

By about 6,000 years ago, the rate of submergence had slowed by nearly 10-fold to its subsequent average of 1-2 m per millenium (Atwater 1979, Fig. 5), thereby allowing sedimentation to counterbalance submergence in some parts of the estuary. In the western Delta, peat as thick as 20 m indicates that vertical accretion in marshes has kept pace with submergence during the past 4,000-6,000 years (Weir 1950; Schlemon and Begg 1973). A balance between sedimentation and submergence likewise accounts for thick accumulations of tidal-marsh deposits in Massachusetts (Mudge 1858; Davis 1910; Redfield 1972).

The establishment of extensive tidal marshes around southern San Francisco Bay appears to have occurred later than in the Delta, probably close to 4,000 years after the rate of submergence reached 1-2 m per millenium (Atwater et al. 1977). This delay is evidenced by deposits of tidal-flat mud that typically underlie peaty tidal-marsh sediments at elevations close to modern mean tide level (MTL) (Table 1). The boundary between tidal-flat and tidal-marsh sediment records the colonization of mudflats by marsh plants, so it marks the inception of a marsh (Shaler 1886: 364-365). The date at which MTL equalled the elevation of this boundary approximates the minimal ages of the marsh because California cordgrass (*Spartina foliosa*), the pioneer vascular plant of San Francisco Bay's mudflats, colonizes surfaces near MTL (Pestrong 1972; Hinde 1954). Approximately equating MTL with mean sea level, estimating former mean sea levels from radiocarbon-dated marsh deposits elsewhere in southern San Francisco Bay (Atwater 1979, Fig. 5), and correcting elevations for local subsidence due to withdrawal of groundwater (Poland 1971), we infer that marshes such as Palo Alto Baylands originated within the past 2,000 years. The 4,000-yr lag between the inception of a slow rate of submergence and the creation of such marshes probably represents the time required for sedimentation to make up for the effects of earlier, more rapid submergence.

TABLE 1. DATUMS FOR TIDE LEVELS AND HEIGHTS.[a]

Datum	Abbreviation	Definition
Mean higher high water	MHHW	Average height of the higher of the daily high tides
Mean high water	MHW	Average height of all high tides
Mean tide level	MTL	Plane halfway between mean high water and mean low water, also called half-tide level
Mean low water	MLW	Average height of all low tides
Mean lower low water	MLLW	Average height of the lower of the daily low tides. Adopted as plane of reference for hydrographic surveys and nautical charts of the west coast of the United States
Mean sea level	MSL	Average height of the water surface for all stages of the tide, determined from hourly readings
National Geodetic Vertical Datum of 1929	NGVD	The standard datum for heights across the nation. Formerly called the "U.S. Coast and Geodetic Survey sea-level datum of 1929," and originally determined from mean sea levels at 26 tide stations in the United States and Canada. Generally differs from local mean sea level (Fig. 1), so it is best regarded as an arbitrary datum that happens to be close to mean sea level.

[a] Tidal datums are ideally determined from 19 years of measurement, but shorter series of observations may be compared with a long-term record to determine mean values.

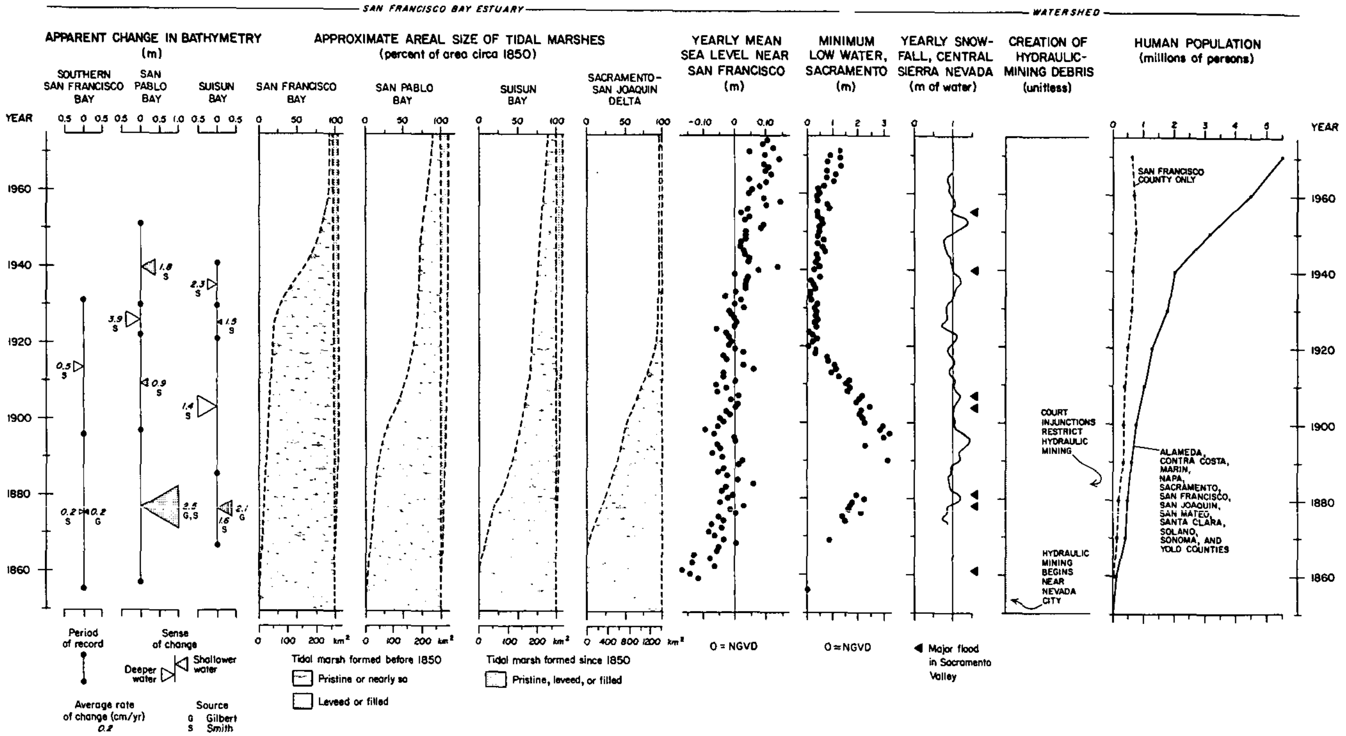

SAN FRANCISCO BAY ESTUARY
WATERSHED
APPARENT CHANGE IN BATHYMETRY (m)
SOUTHERN SAN FRANCISCO BAY
SAN PABLO BAY
SUISUN BAY
APPROXIMATE AREAL SIZE OF TIDAL MARSHES (percent of area circa 1850)
SAN FRANCISCO BAY
SAN PABLO BAY
SUISUN BAY
SACRAMENTO-SAN JOAQUIN DELTA
YEARLY MEAN SEA LEVEL NEAR SAN FRANCISCO (m)
MINIMUM LOW WATER, SACRAMENTO (m)
YEARLY SNOWFALL, CENTRAL SIERRA NEVADA (m of water)
CREATION OF HYDRAULIC-MINING DEBRIS (unitless)
HUMAN POPULATION (millions of persons)
YEAR
1860
1880
1900
1920
1940
1960
0.5 0 0.5
0.5 0 0.5 1.0
0 50 100
-0.10 0 0.10
0 1 2 3
0 1
0 1 2 3 4 5
0.5 S
0.2 S
0.2 G
3.9 S
1.8 S
0.9 S
2.5 G,S
2.3 S
1.5 S
1.4 S
2.1 G
1.6 S
0 100 200 km²
0 400 800 1200 km²
0 = NGVD
0 ≈ NGVD
COURT INJUNCTIONS RESTRICT HYDRAULIC MINING
HYDRAULIC MINING BEGINS NEAR NEVADA CITY
SAN FRANCISCO COUNTY ONLY
ALAMEDA, CONTRA COSTA, MARIN, NAPA, SACRAMENTO, SAN FRANCISCO, SAN JOAQUIN, SAN MATEO, SANTA CLARA, SOLANO, SONOMA, AND YOLO COUNTIES
Period of record
Sense of change
Shallower water
Deeper water
Average rate of change (cm/yr) 0.2
Source
G Gilbert
S Smith
Tidal marsh formed before 1850
Pristine or nearly so
Leveed or filled
Tidal marsh formed since 1850
Pristine, leveed, or filled
◀ Major flood in Sacramento Valley

Fig. 1. Some historic changes in the San Francisco Bay estuary and its watershed.

BATHYMETRY. Apparent changes in water depth are adapted from comparisons of archival hydrographic maps as performed by Gilbert (1917:32-37) and Smith (1965). Few of the average apparent changes in bathymetry can be attributed with confidence to net erosion or deposition on the Bay floor because of possible errors introduced by methods of bathymetric comparison. The average decrease in bathymetry for all of San Pablo Bay during the late 19th century, however, seems too large to ascribe to such errors, particularly because some areas of this bay appear to have shoaled by 1.5-2.5 m (Gilbert 1917:35).

TIDAL MARSHES. Initial size of tidal marshes follows Gilbert (1917:78) and Nichols and Wright (1971). Approximate areas at later dates are compiled and modified from textual and cartographic information of Gilbert (1917:86-88); Matthew and Blackie (1931:96-98); Matthew et al. (1931:158); Cosby (1941: 16); Van Royen and Siegel (1959); Atwater and Hedel (1976); Kingsley et al. (1977:3); archival topographic maps of the USC&GS examined during preparation of Figs. 3, 6; and planning maps of the BCDC (1969). Precision is greatest for changes at the Delta and San Francisco Bay, least for Suisun Bay.

MEAN SEA LEVEL. Dots show yearly mean of the surface elevation of San Francisco Bay at Fort Point (1857-1877), Sausalito (1877-1896), and the Presidio (1897-1974). The compilation was prepared by the NOS for the CSLC. NGVD denotes National Geodetic Vertical Datum (Table 1).

LOW WATER. This statistic denotes the lowest reported level of the Sacramento River at Sacramento as compiled by Gilbert (1917: 29-30) and the U. S. Weather Bureau (1914-1971). Lowest levels occur during the low-flow summer or autumn months. The broad peak centered between 1890 and 1900 reflects changes in the level of the river bed. These changes presumably indicate deposition and subsequent erosion of hydraulic-mining debris, which progressed downriver like a wave (Gilbert 1917:29-31). Some smaller changes may reflect variation in the discharge of water, and others may be artifacts of infrequent (once daily) measurement.

SNOWFALL. The curve, from Curry (1969:28) shows smoothed yearly records of snowfall at Donner Pass. Dates of major floods on the Sacramento River (triangles) follow Thompson (1958:446-467).

MINING DEBRIS. This graph, from Gilbert (1917:36), sketches the relative output of sediment from hydraulic gold mines of the western Sierra Nevada and from Sierran streams that carried debris from these mines.

POPULATION. Graph shows decennial changes in counties surrounding the San Francisco Bay estuary, as reported by the U.S. Census Office (1901: 11) and by the County Supervisors Association of California (1975:22).

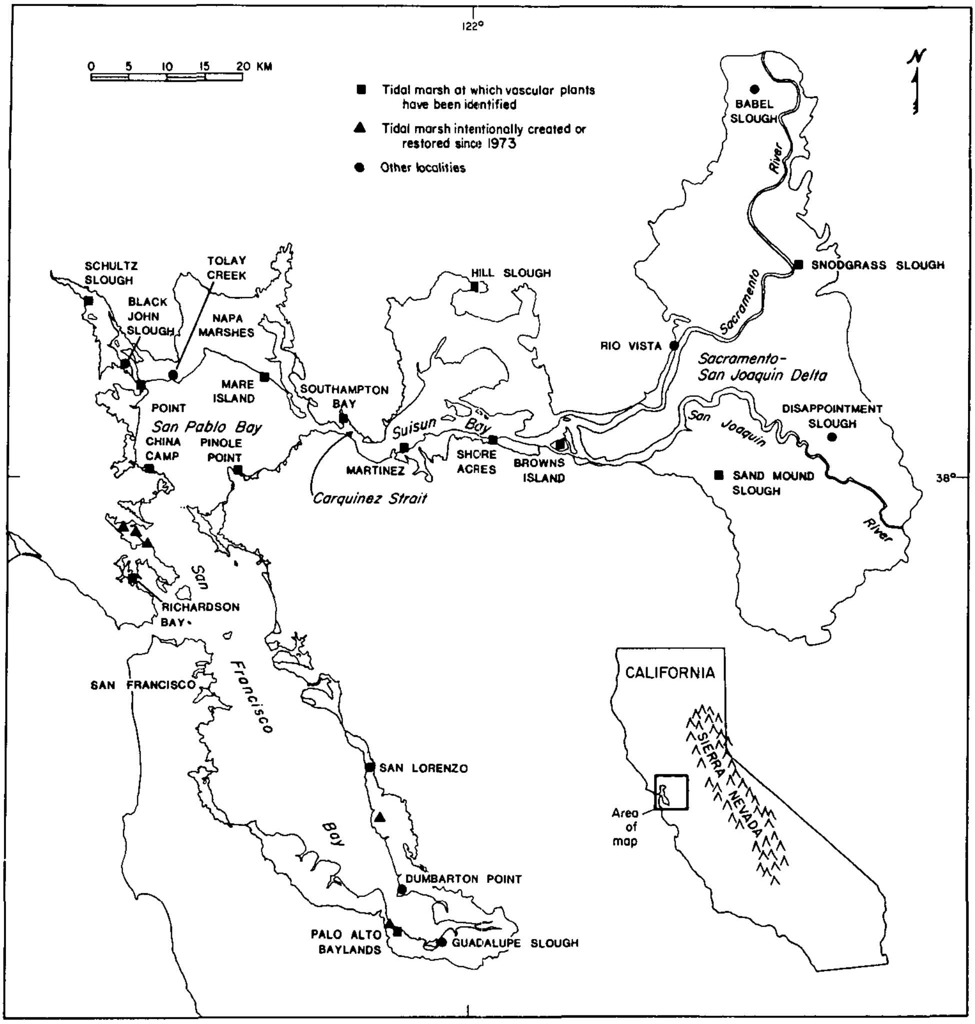


Fig. 2. San Francisco Bay estuary and the Sacramento-San Joaquin River Delta. Locations of newly created marshes follow Kingsley and Boerger (1976), Knutson et al. (1976), and Harvey et al. (1977:85). Thin lines approximate shorelines or margins of tidal marsh ca. 1860 as shown on compilations by Gilbert (1917:76) and Nichols and Wright (1971).

Events since the California Gold Rush

Early surveys by Ringgold (1852) and the USC&GS portray the San Francisco Bay estuary as it appeared during the California Gold Rush. Collectively, the tidal marshes and open-water bays covered about 3400 km^2, an area slightly larger than Rhode Island. The area of tidal marsh was nearly double the area of the bays, with the Delta marshes making up about 1400 km^2 and the marshes bordering San Francisco, San Pablo, and Suisun bays accounting for another 800 km^2 (Gilbert 1917:78).

Approximately 95% of the estuary's tidal marshes have been leveed or filled since the Gold Rush (Figs. 1, 3). The typical age of levees varies with location and appears to depend on the

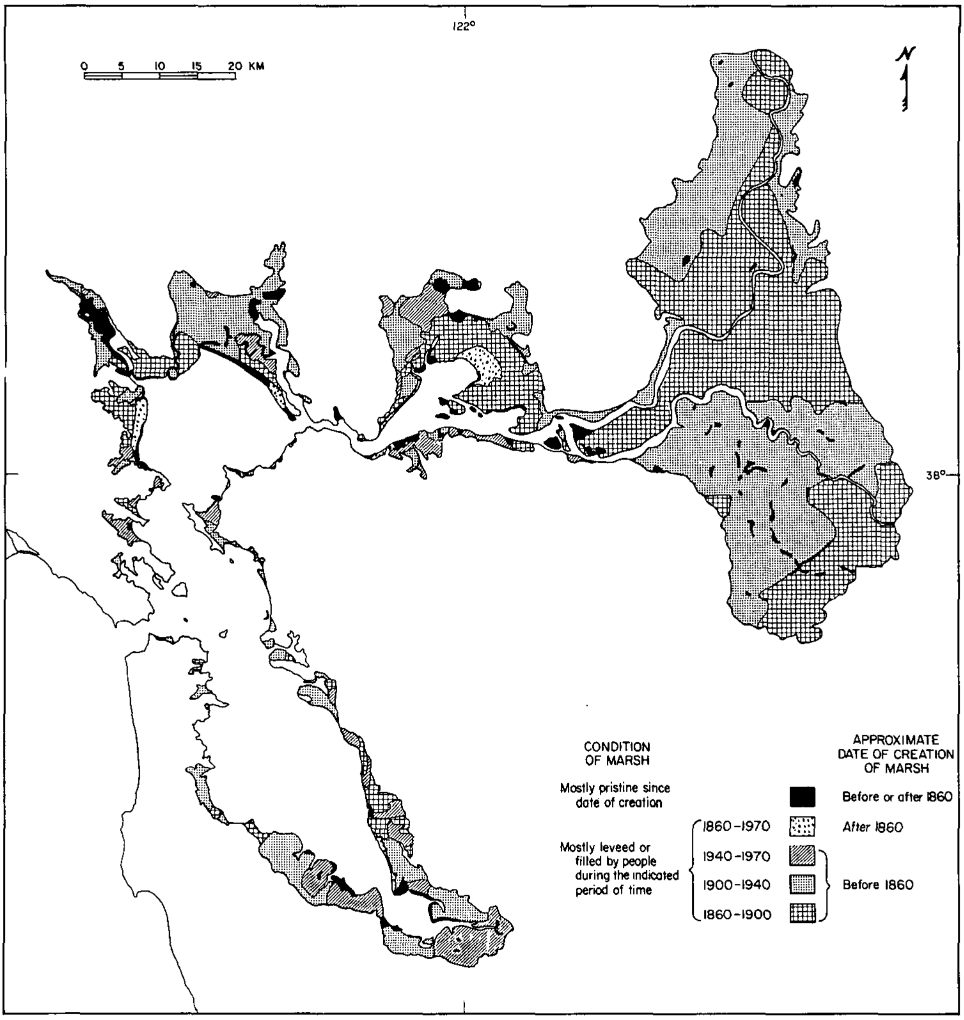


Fig. 3. Generalized and approximate historic changes in aerial distribution of tidal marshes. The map scale requires that patterned areas exceed about 0.5 km in width and about 0.5 km^2 in area. Dates for levees and fill follow Van Royen and Siegel (1959) for San Francisco Bay. Around San Pablo and Suisun Bays, dates are estimated by inspection of archival maps of the USC&GS (scale generally 1:10,000) and the USGS (scale 1:31,680; Suisun Bay only); Van Royen and Siegel incompletely discriminate for these bays between marshes enclosed by levees and marshes subject to natural inundation by tides. Changes in the Delta follow Matthew et al. (1931, pl. 34). Areas of modern tidal marsh are compiled from topographic maps of all areas by the USGS (1968 and 1973 editions, scale 1:24,000), from a landuse map of San Francisco, San Pablo, and Suisun bays by the BCDC (1969; approximate scale 1:250,000), and from maps by the California Department of Fish and Game (CDF&G) showing dominant vascular plants north of Suisun Bay as of 1973 (H. A. George, unpublished map). Some modern marshes have undoubtedly been omitted or misrepresented.

suitability of marshland for agriculture. Fresh-water marshes characterized the pristine Delta, and most of these were leveed for farming before 1920. Marshes nearer the Golden Gate, on the other

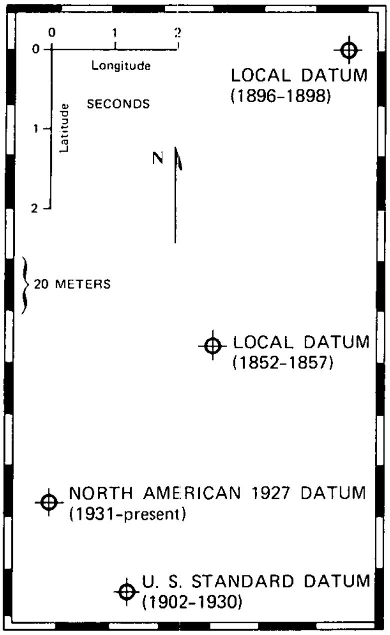


Fig. 4. Horizontal datums for maps of southern San Francisco Bay. The circled crosses locate intersecting lines of the geographic projection for latitude and longitude. For example, the intersection of a latitude and longitude according to the local datum of 1896-1898 is located 176 m N and 117 m E of the intersection of the same latitude and longitude according to the North American 1927 Datum. Such relationships provide precise geodetic means for comparing features shown on archival and modern maps (Fig. 5). The local datums are reconciled to each other and to the nationwide datums by comparing the published positions, as referenced to the various horizontal datums, of persistent triangulation stations. These positions appear in: (1) annual reports of the superintendent of the USC&GS, 1851-1868, 1904, and 1910; (2) "Old Registers" maintained by the Early Drawing Division, U. S. Coast Survey, 1850-1927; and (3) a special publication on triangulation in California (Mitchell 1936). Early geodesists in California, led by George Davidson, established local datums astronomically and projected them according to a mathematical model of the shape of the earth called the Bessel Spheroid of 1841. These datums yielded to others as a result of several advances in geodesy: (1) a more accurate determination of longitude in the 1870's; (2) the application of the Clarke Spheroid of 1866; (3) the completion of the transcontinental triangulation network in the late 1880's, which led to the adoption of the U. S. Standard Datum in 1902; and (4) readjustment of the network during the early 1920's, which resulted in the North American 1927 Datum (Shalowitz 1964:112-114, 141-158).

hand, contained more salt in their soils and sloughs. This salt presumably limited the agricultural value of the marshland and therefore delayed the construction of levees until other human uses were found. For example, whereas agricultural levees in 1900 enclosed about half of the historic marshes of the Delta and Suisun Bay, less than one fifth of the Bay's marshes had been leveed by that time, and these mostly for production of salt. Tidal marshes around the Bay remained largely pristine until later in the 20th century when, coincident with a rapid increase in the population of suburban areas, most of the marshes were converted to salt-evaporation ponds or to sites for residential and industrial structures, transportation facilities, and garbage dumps.

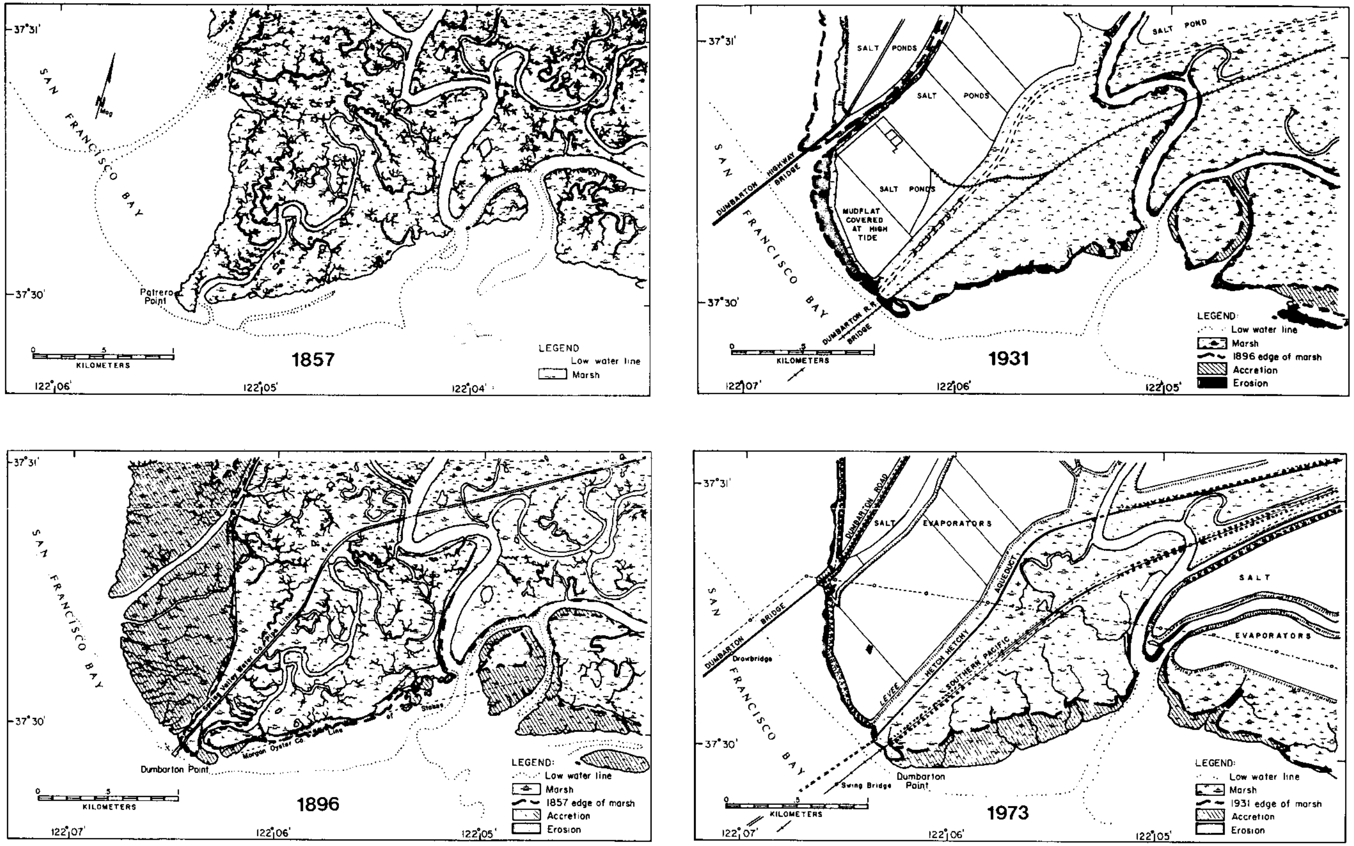
Changes in mapped shorelines (Figs. 3, 5, 6) indicate that approximately 75 km^2 of new tidal marsh have appeared around San Francisco, San Pablo, and Suisun bays since the Gold Rush. It seems likely that humans accidentally created much of this marshland by supplying sediment to the bays and by building levees and jetties that promoted deposition.

The widespread and rapid expansion of marshland during the late 19th century (Fig. 6) probably resulted in large measure from contemporaneous hydraulic mining in the Sierra Nevada. Between 1853 and 1884, gold miners washed prodigious quantities of sediment into Sierran streams. Further downstream, this debris caused damage to farmlands and waterways and thereby led to court injunctions that effectively halted hydraulic mining (Gilbert 1917:11; Briscoe 1979). Much debris travelled even further and entered the San Francisco Bay estuary, as evidenced by the wave of river-bottom sediment, presumably sand and gravel, that crested near the northern end of the Delta between 1890 and 1900 (Fig. 1, "minimum low water"). Clay and fine silt from the hydraulic mines should have reached the estuary sooner because they move in suspension, and deposition of this fine sediment apparently caused both shoaling of subtidal areas in San Pablo and Suisun bays and rapid horizontal expansion of marshlands into mudflats of northern Suisun Bay, western San Pablo Bay, and southern San Francisco Bay during the late 19th century (Gilbert 1917:36, 86-88; Figs. 1, 6). The delivery of mining debris to the margins of southern San Francisco Bay may be doubted because few subtidal areas of this bay shoaled greatly during the late 19th century (Fig. 6; Krone 1979) and because Ferdinand Westdahl, the topographer who mapped much of the expanded marshland, designated commercial oyster shells and Oakland's growing port as the causes of tidal-marsh accretion (Westdahl 1897). Nevertheless, large quantities of silt- and clay-size mining debris certainly reached San Pablo Bay; some of this sediment undoubtedly entered the layer of low-salinity water that, according to McCulloch et al. (1970) and Carlson and McCulloch (1974), spreads across southern San Francisco Bay during periods of high discharge from the Sacramento River; and, once delivered to southern San Francisco Bay, mining debris might have preferentially accumulated on marginal tidal flats as clay and silt appear to be doing today (Conomos and Peterson 1977).

Tidal marshes have probably received additional sediment from farmlands (Gilbert 1917:36), urbanized uplands (Knott 19'/3), and dredged channels and harbors. Moreover, many future marshes may rest entirely on dredged material if, as currently planned, public agencies mitigate the disposal of dredged material by intentionally creating tidal marshes on spoils. Beginning with the experiments of H. T. Harvey during the 1960's, both independent parties and members of the U.S. Army Corps of Engineers have demonstrated that people can establish such marshes by planting seeds, seedlings, and cuttings of California cordgrass in previously barren areas (Knutson et al. 1976; Kingsley and Boerger 1976; Fig. 2).

Levees and jetties have also contributed to the creation of marshlands, particularly during the 20th century. Construction of levees around tidal marshes almost invariably preceded and probably caused the historic appearance of new marshes along the banks of sloughs that formerly served the marshes (K. Dedrick pers. comm.). Presumably, sediment accumulated because the levees prevented exchange of water with the former tidal marshes and thereby slackened currents in the sloughs (Gilbert 1917:102-103). Levees may have also promoted expansion of marshland into the bays by reducing the area in which sediment could accumulate. According to Robert Nadey (pers. comm.), this effect may account for part of the spectacular growth of marshes into western San Pablo Bay during the period of hydraulic mining. Extension of a jetty south of Mare Island during the 20th century coincides with shoaling of nearby tidal flats (Smith 1965) and expansion of nearby marshland. The jetty probably caused these changes because, during the late 19th century, the marsh eroded rather than advanced, even though other parts of San Pablo Bay were trapping large quantities of hydraulic-mining debris (Figs. 6, 7).

Many changes in mapped shorelines indicate erosion rather than deposition at the bayward


1857
37°31'
37°30'
SAN FRANCISCO BAY
Mag
Potrero Point
KILOMETERS
0 .5 1
122°06'
122°05'
122°04'
LEGEND
Low water line
Marsh
1931
SALT PONDS
SALT PONDS
SALT PONDS
SALT POND
MUDFLAT COVERED AT HIGH TIDE
DUMBARTON HIGHWAY BRIDGE
DUMBARTON R.R. BRIDGE
122°07'
122°06'
122°05'
LEGEND
Low water line
Marsh
1896 edge of marsh
Accretion
Erosion
1896
Spring Valley Water Co. Pipe Line
Morgan Oyster Co. Line of Stakes
Dumbarton Point
122°07'
122°06'
122°05'
LEGEND
Low water line
Marsh
1857 edge of marsh
Accretion
Erosion
1973
DUMBARTON ROAD
SALT EVAPORATORS
HETCH HETCHY AQUEDUCT
SOUTHERN PACIFIC
LEVEE
SALT EVAPORATORS
DUMBARTON BRIDGE
Drawbridge
Swing Bridge
Dumbarton Point
122°07'
122°06'
122°05'
LEGEND
Low water line
Marsh
1931 edge of marsh
Accretion
Erosion

margins of tidal marshes (Fig. 6). As inferred by Gilbert (1917:21-22), such retreat may result in part from a rise in sea level relative to the land. Other contributing factors include burrowing by an introduced isopod (Carlton 1979).

Available inventories of the areal size of tidal marshes at a given date employ different means of distinguishing "tidal" from "leveed" and rarely discriminate between marshes formed before and after 1850. These problems, together with the infrequency of such inventories, currently preclude a detailed summary of historic changes in tidal-marsh areas. Even the generalized graphs and maps (Figs. 1, 3) imply unwarranted precision, as the reader can determine by consulting the cited sources. Despite such deficiencies, our estimates justify several conclusions about the effects of levees and fill on the San Francisco Bay estuary: (1) The present area of tidal marsh within the entire estuary is about 125 km^2, one third of which has originated since 1850. Both Van Royen and Siegel (1959) and Nichols and Wright (1971) offer a much higher figure for the total area of marshland because their tallies include many non-tidal leveed marshes. (2) Even excluding the Delta, leveed or filled tidal marshes cover far more area than the 140 km^2 of open-water baylands that have been leveed, filled, or converted to tidal marsh since the Gold Rush (Nichols and Wright 1971). Thus, tidal marshes rather than open-water bays have provided most of the leveed and filled areas of the San Francisco Bay estuary.

LANDFORMS

Natural topographic features of the tidal marshes of the San Francisco Bay estuary include broad, nearly flat surfaces; narrower surfaces that descend into tidal flats, some precipitously; beach ridges and related berms; tidal sloughs; riverine channels and their natural levees; shallow ponds and pans; and islands of pre-existing bedrock and sand dunes. The following discussion emphasizes the principal kinds of marshlands and waterways.

Plains near High-Tide Levels

Around the turn of the century, the "typical tidal marsh" of the San Francisco Bay estuary

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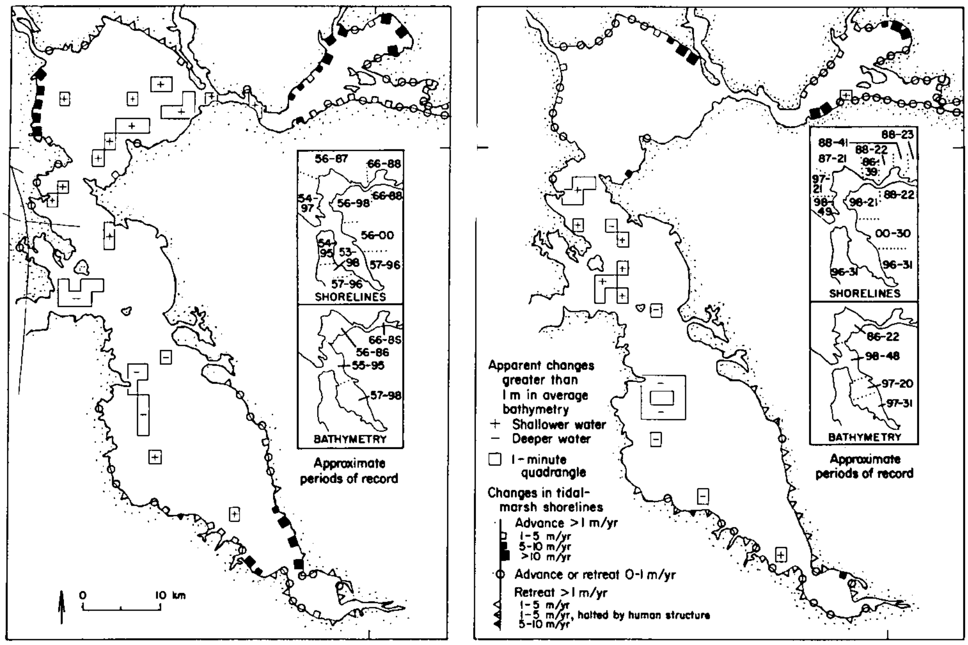
Fig. 5. Historic changes in tidal marshes near Dumbarton Point, southern San Francisco Bay. The archival maps copy lines and names from 1:10,000-scale plane-table sheets of the USC&GS: T-634, surveyed in 1857 by David Kerr; T-2258, surveyed in 1896 by Fremont Morse and Ferdinand Westdahl (low-water line from contemporary hydrographic surveys H-2304 and H-2413); and T-4626, surveyed in 1931 by H. G. Conerly (low-water line from contemporaneous hydrographic survey H-5135). The modern map is traced from a 1:24,000-scale photogrammetric map (Newark 7.5-min quadrangle). Additional symbols show old shorelines and inferred areas of erosion and deposition. Registration of archival maps to the North American 1927 Datum (Fig. 4) controls the comparisons of charted shorelines. Though subject to uncertainties related to method and season of surveying, shorelines approximate the bayward limit of vegetation (Gilbert 1917:86; Shalowitz 1964:177). The density and distribution of sloughs reflects methods of mapping and changes related to human structures. Morse and Westdahl apparently traced Kerr's lines for most of the mid-19th century sloughs (R. Nadey pers. comm.); according to Westdahl's (1896) description of a nearby survey "on the salt marshes only the sloughs used for navigation, the shore-line, the area between the old and new bayshore, and improvements, such as dykes, houses, and saltworks, have been surveyed." Conerly apparently neglected all but the largest sloughs. Differences between modern sloughs and those mapped by Kerr imply that the railroad and salt ponds have disrupted the original pattern of drainage.



A. LATE NINETEENTH CENTURY

B. LATEST NINETEENTH AND EARLY TWENTIETH CENTURIES

Fig. 6. Historic changes in tidal-marsh shorelines and subtidal bathymetry (A) during the late 19th century and (B) during the latest 19th century and early 20th centuries.

SHORELINES. Changes in shoreline area measured by comparing archival topographic maps that were prepared by the USC&GS. Comparisons make use of 1:24,000-scale photographic reductions of the CSLC. Most maps are registered to one another by matching persistent features such as hills, rocky shorelines, intricately meandering sloughs, railroad tracks, and occasional triangulation stations. Precise geodetic registration (Figs. 4, 5) is limited to the southern and eastern shores of San Francisco Bay. Elsewhere the uncertainties in registration, together with errors in surveying, possible distortion of original map paper, and possible differences in notation for tidal-marsh shorelines (Gilbert 1917:86), prevent resolution of changes that average less than 1 m·yr^{-1} over 20- to 40-yr intervals.

BATHYMETRY. Changes in bathymetry for subtidal areas excluding sloughs are adapted from Smith's (1965) comparison of archival hydrographic maps. Smith compared average depths within 1/8-min quadrangles and reported the sum of changes for 1-min quadrangles. The distribution of areas showing large changes in bathymetry must be interpreted with reference to index maps because the magnitude of change depends partly on the length of the period of record. Dates on index maps omit numerals for century and millennium.

resembled "a plain traversed by a branching system of sloughs" (Gilbert 1917:75). Excluding sloughs, the relief on such "plains" must have been slight because topographers such as Ferdinand Westdahl (1897) used "the level of the salt-marsh in its natural state" as a datum plane for upland elevations.

Nearly flat surfaces appear to remain the most extensive landforms of the tidal marshes of the San Francisco Bay estuary (Fig. 7; Bodnar et al. 1975: Figs. 32, 33; Hinde 1954). These plains characterize marshland formed both before and after 1850, and they cross historic shorelines without appreciable change in level or relief (China Camp and Mare Island marshes, Fig. 7).

Within uncertainties of measurement[1], most of the broad surfaces (Fig. 7) are probably situated within a few decimeters of MHHW. This coincidence implies a widespread tendency of tidal-marsh surfaces to approach high-tide levels. Presumably, such heights equilibrate deposition, erosion, and subsidence (Pestrong 1972).

Differences in elevation between some tidal-marsh plains, however, exceed probable errors in measurement. The flat surface of the marsh at Richardson Bay appears to be situated about 0.2 m below MHHW (Fig. 7), and broad parts of several tidal marshes also occupy elevations below MHHW along the western shore of southern San Francisco Bay northwest of Palo Alto Baylands (K. Dedrick, pers. comm.). Typical elevations near Point Pinole, on the other hand, approximately equal MHHW according to third-order leveling (Bodnar et al. 1975: Figs 32, 33), and less precise measurements at the nearby China Camp marsh (Fig. 7) suggest similar elevations. Furthermore, marshland near Mare Island appears to rise 0.2-0.5 m above MHHW (Fig. 7). Both here and at Palo Alto Baylands, however, probable but unmeasured subsidence of the bench mark at the origin of the transect (Table 2, footnotes 3, 5) may erroneously heighten the measured elevations.

These geographic variations in the elevation of marshlands with respect to tidal datums imply that local conditions influence topography. The entrapment of suspended sediment in San Pablo and Suisun bays (Conomos and Peterson 1977), for example, may partly explain why post-1850 marshes at Richardson Bay have reached lower levels than contemporaneous marshes at China Camp. Anomalously high elevations near Mare Island may reflect not only such entrapment but also southerly high winds, which potentially pile water above normal high-tide levels, and the nearby jetty, which has promoted intertidal deposition (see above discussion of levees and jetties). Finally, subsidence due to withdrawal of groundwater (Poland 1971) dropped the tidal marsh at Palo Alto Baylands to a lower level between 1954 and 1965, as evidenced by the spread of cordgrass into areas whose former elevation may have excluded this plant (Harvey 1966). Most of this marsh is nevertheless situated at or near MHHW (Fig. 7), so it seems likely that sedimentation has, on the average, largely maintained the level of the marsh against subsidence, which amounts to nearly 1 m since 1931 (Table 2, footnote 3).

Uncertainties and geographic variation in the elevations of modern tidal-marsh plains compound the problems of defining, relative to tidal datums, the "level of salt-marsh in its natural state" as of the 19th century. One possible solution presumes similarity between the elevations of modern and historic marshes and therefore must allow for differences between localities. Additional complications arise if marshlands have reached unnaturally high levels because of human activities such as hydraulic gold-mining, disposal of dredge spoils, and construction of levees and jetties. A remark by Gilbert (1917:77) indirectly supports this hypothesis by equating areas vegetated by tules (*Scirpus* spp.) and California cordgrass with the "broader parts" of marshes. Currently, these plants mostly grow along narrow surfaces that descend into mudflats or sloughs (Fig. 7), so it seems possible that the few remaining pristine marshlands have risen to extraordinary heights during this century, perhaps by trapping hydraulic-mining debris and dredge spoils. Alternatively, Gilbert erred, perhaps by attributing to all marshlands the characteristics of those that spread across mudflats during the late 19th century (Figs. 5, 6) and initially supported California cordgrass and tules rather than common

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[1] With respect to tide levels, the elevations of modern surfaces reported in Fig. 7 may err by 0.1 m or more because of undetermined changes in the published elevations of bench marks and tidal datum planes (Table 2), extrapolation or interpolation of datums from distant tide stations, and imprecise methods of leveling. The leveling generally fails to meet several of the National Ocean Survey's (NOS) standards for third-order work (NOS 1974): (1) maximum length of sights–some sights exceed the 90-m standard by 10-30 m; (2) difference in length of forward and backward sights–the 10-m standard is met for turning points, but most elevations along transects represent unbalanced forward and backward sights between turning points; and (3) minimum error in closure–complete closure was not attempted at marshes shown in Fig. 7, and partial closure at China Camp and Palo Alto Baylands indicate cumulative errors of about 5 cm, roughly three times as large as the standard.

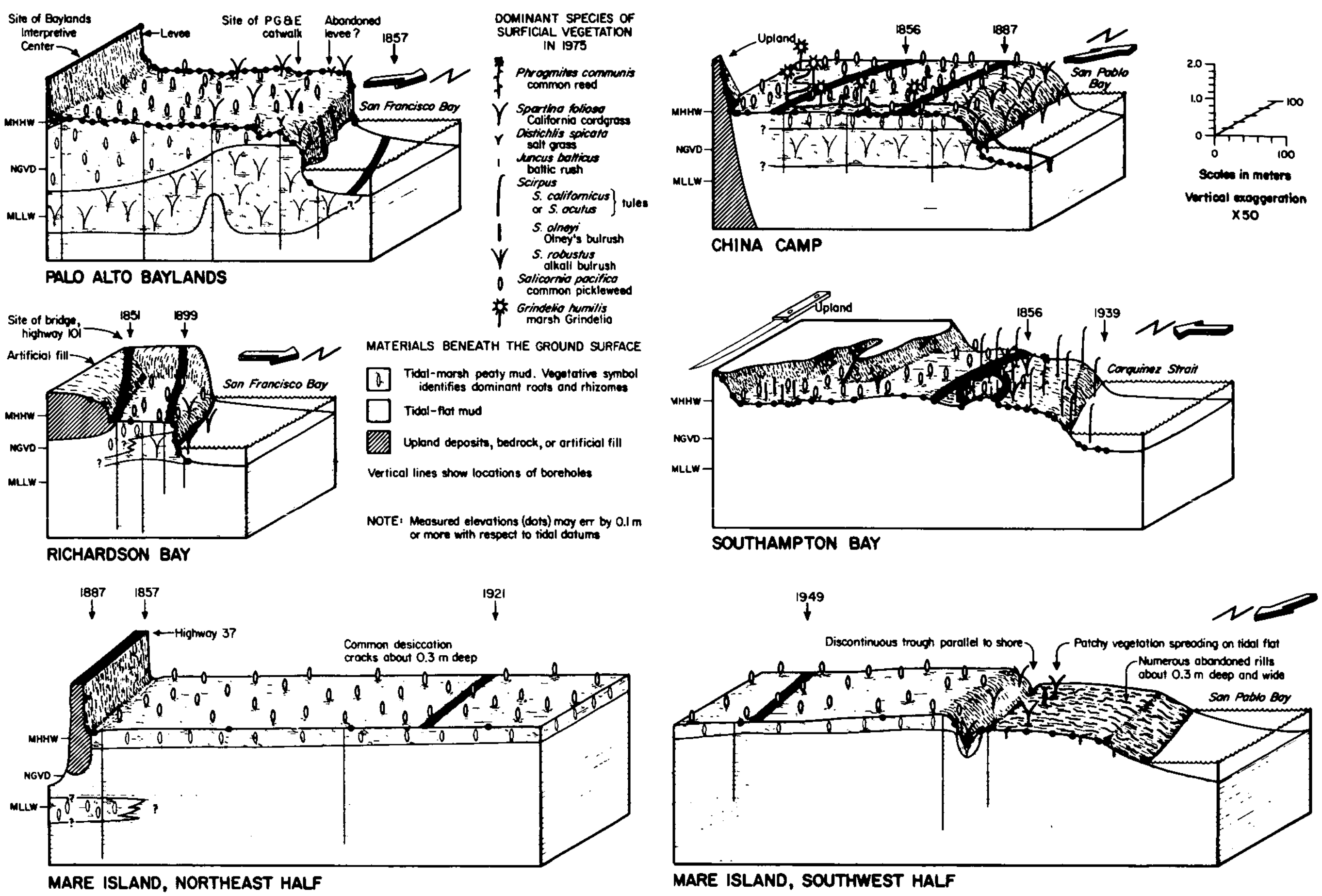
Site of Baylands Interpretive Center
Levee
Site of PG&E catwalk
Abandoned levee ?
1857
San Francisco Bay
MHHW
NGVD
MLLW
PALO ALTO BAYLANDS
DOMINANT SPECIES OF SURFICIAL VEGETATION IN 1975
Phragmites communis common reed
Spartina foliosa California cordgrass
Distichlis spicata salt grass
Juncus balticus baltic rush
Scirpus
S. californicus or S. acutus } tules
S. olneyi Olney's bulrush
S. robustus alkali bulrush
Salicornia pacifica common pickleweed
Grindelia humilis marsh Grindelia
MATERIALS BENEATH THE GROUND SURFACE
Tidal-marsh peaty mud. Vegetative symbol identifies dominant roots and rhizomes
Tidal-flat mud
Upland deposits, bedrock, or artificial fill
Vertical lines show locations of boreholes
NOTE: Measured elevations (dots) may err by 0.1 m or more with respect to tidal datums
Upland
1856
1887
San Pablo Bay
CHINA CAMP
2.0
1.0
0
100
0
100
Scales in meters
Vertical exaggeration X50
Site of bridge, highway 101
Artificial fill
1851
1899
San Francisco Bay
RICHARDSON BAY
Upland
1856
1939
Carquinez Strait
SOUTHAMPTON BAY
1887
1857
Highway 37
Common desiccation cracks about 0.3 m deep
1921
MARE ISLAND, NORTHEAST HALF
1949
Discontinuous trough parallel to shore
Patchy vegetation spreading on tidal flat
Numerous abandoned rills about 0.3 m deep and wide
San Pablo Bay
MARE ISLAND, SOUTHWEST HALF

TABLE 2. REFERENCE STATIONS FOR ELEVATIONS AND TIDAL DATUMS SHOWN IN FIG. 7

MARSH	BENCH MARK[a]			TIDAL DATUMS				
				Location of gauge		Elevations at gauge (m)[b]		
	Designation	Elevation (m)	Year of leveling	Place name	Distance from marsh (km)	MLLW	MTL	MHHW
Palo Alto Baylands	Tidal No. 1	1.09[c]	1965	Palo Alto Yacht Harbor	1	-1.3	0.2	1.4
Richardson Bay	R481	2.60[d]	1955	San Francisco (Presidio)	10	-0.8	0.1	0.9
China Camp	D552	12.56[d]	1956	Pinole Point	11	-0.9	0.2	1.0
Mare Island	N466	1.21[e]	1956	Hercules	11	-0.8	0.2	1.0
Southampton Bay	C467	4.94[d]	1951	Crockett	4	-0.8	0.2	1.0

[a] From "Vertical Control Data" compiled by the National Geodetic Survey. Datum is NGVD.

[b] Compiled by the National Ocean Survey (1977a, 1977b) and referenced to leveling completed in 1956 or, for Palo Alto, 1967. Datum is NGVD. See Table 1 for definition of reference planes.

[c] Repeated leveling by the U. S. Coast and Geodetic Survey indicates that the elevation of Tidal No. 1 decreased 0.76 m between 1931 and 1965, chiefly because of regional subsidence accompanying ground-water withdrawal (Poland: 1971). Hinde (1954: 217) apparently used the initial elevation of the benchmark, and his measured elevations may therefore be too high by 0.5 m, the change in elevation of Tidal No. 1 between 1931 and 1955. Changes in elevation since the 1965 leveling are ignored here because they are probably 0.2 m or less; artificial recharge of ground water halted subsidence near Palo Alto by 1971 (Poland: 1971).

[d] Leveled only once by the U. S. Coast and Geodetic Survey. Changes in elevation since year of leveling presumably do not exceed 0.05 m because monument rests on bedrock (D552, C467) or on a concrete pier supporting a 10-lane bridge (R481).

[e] According to repeated leveling by the U. S. Coast and Geodetic Survey, bench mark N466 subsided 0.04 m between 1951 and 1956. No correction for unmeasured, subsequent movement is attempted here, but at least 0.10 additional subsidence seems likely because the road embankment beneath the monument overlies compressible estuarine sediments and because fill has been added to the embankment or adjacent road since 1956.

Fig. 7. Generalized landforms, vegetation, and subsurface sediments of some salt- and brackish-water tidal marshes. (Vertical exaggeration 50X). Dots on profiles denote places where elevation was surveyed in 1975 or 1976. Elevations were transferred with a rod and tripod-mounted level from the nearest geodetic or tidal bench mark (Table 2). No correction is made for probable but unmeasured subsidence of bench marks near Palo Alto Baylands and Mare Island. Methods of surveying meet only some of the standards for third-order leveling (see footnote 1 in text). Tidal datums are extrapolated from the nearest long-term tide gauge for which the relationship between MLLW and NGVD has been determined (Table 2). Collectively, these procedures may cause measured elevations to err by 0.1 m or more with respect to tidal datums. Elevations away from dots are estimated by extrapolation, chiefly with reference to vegetation. Small channels are generally omitted. The water surface is at MTL. Gray bands approximate the horizontal position of the bayward limit of vascular plants at the indicated date, as interpreted from archival maps (Figs. 5, 6). The distribution of vascular plants on the surface shows approximate conditions in 1975 (Fig. 10). Appendix A lists native species at all localities except Mare Island. Fossil rhizomes (below-ground stems) and roots are tentatively identified by macroscopic examination of core samples. Most of the tidal-flat mud lacks roots or rhizomes in growth position. The Mare Island diagrams join at center.

pickleweed (*Salicornia pacifica*) and salt grass (*Distichlis spicata*) (see description by Westdahl 1896).

Sloping Surfaces Bordering Mudflats

Marshes unquestionably vary in the slope of surfaces that descend into tidal mudflats. Near China Camp and at Southampton Bay, marshland dips gently into adjacent mudflats (Fig. 7). At Palo Alto Baylands and Richardson Bay, on the other hand, most of the bayward edge of the marsh drops precipitously.

Gently sloping margins imply net deposition and precipitous margins imply net erosion. Several lines of evidence support these inferences: (1) gently sloping margins correspond with shorelines that typically migrated toward the Bay during the late 19th and early 20th centuries, and precipitous margins characterize shorelines that generally retreated during this period of time (Fig. 6); and (2) precipitous slopes locally correlate with ongoing erosion, as indicated around parts of southern San Francisco Bay by blocks of tidal-marsh mud that slump from vertical or overhanging scarps onto the adjacent mudflat.

Low beach ridges historically bordered some tidal marshes of the San Francisco Bay estuary (Gilbert 1917:86), and a few ridges remain today. Beach ridges apparently impounded marshlands near San Lorenzo and thereby created natural salt ponds (Fig. 8). By analogy with sandy barriers that fringe marshes of Delaware Bay (Kraft et al. 1976:98-104), these ridges may have contained sand that had been derived from eroding headlands, particularly the ancient dune sands near Oakland (Atwater et al. 1977). Other beach ridges of the San Francisco Bay estuary are made of shell (Westdahl 1897). A possibly related feature of unknown origin is the broad berm of mud that currently appears to rise above MHHW at the bayward margin of a marsh near Mare Island (Fig. 7). A similar berm probably forced sloughs near this locality to drain away from San Pablo Bay in 1856 (Fig. 8).

Waterways

Patterns of tidal-marsh drainage around San Francisco, San Pablo, and Suisun bays depend partly on the age of surrounding marshland. Whereas prominent meanders characterize the sloughs of marshes created before 1850, the sloughs of younger marshes follow relatively straight paths that trend nearly perpendicular to the bayward edge of the marsh. Such direct paths cross modern marshlands (Fig. 7, China Camp) as well as their 19th-century ancestors (Fig. 5; Westdahl 1897) and therefore appear to have gained little sinuousity since formation. The contrast between straight and meandering sloughs may reflect differences in the rate of formation of marshland if, as seems likely from enormous changes in historic shorelines (Fig. 6), marshes drained by straight channels initially spread and rose at an extraordinarily rapid pace during the late 19th century.

Tidal water rather than the discharge of upland creeks controls the dimensions of most sloughs around the bays. Pestrong (1965:32-33) and Gilbert (1917:102-103) implicitly advocated such control, Pestrong by adopting Chapman's (1960:30) conclusion that sloughs grow because of the flow of tidal water to and from an upward-building marsh, and Gilbert by proposing that reduction of this flow, owing to impoundment of marshland behind levees, caused shoaling of a slough near Mare Island. Moreover, although the widths of waterways commonly increase with discharge (Myrick and Leopold 1963), the widths of historic tidal sloughs north of San Pablo Bay greatly tapered toward upland creeks (Nichols and Wright 1971), so it seems likely that the widths of these sloughs depended mainly on the areas of their tidal-marsh drainage basins. Such drainage basins must also account for the considerable widths of sloughs near Guadalupe Slough and Mare Island (Fig. 8) that drained no major upland creeks.

Riverine floods, on the other hand, probably restricted the reach of tides in the northern

Delta by creating natural levees along the channels of rivers and distributaries. Near Babel Slough, the Sacramento River built natural levees about 1 km wide and up to 5 m high (Fig. 9). Such levees diminished in height toward Suisun Bay but extended as far downstream as the confluence of the Sacramento and San Joaquin Rivers (Thompson 1958:26; Ringgold 1852). At autumnal low stages of the rivers, high tides probably could not surmount many of the levees in the northern Delta, so perhaps only riverine floods inundated low-lying marshes that were enclosed by naturally leveed channels. Thus, some areas designated as historical tidal marsh in Figs. 1-3 may have actually been isolated from autumnal tides.

Natural levees in the southern Delta generally reached much lower elevations, as evidenced by archival records (Thompson 1958:37), by tidal sloughs that transect levees of the San Joaquin River (Fig. 9), and by peaty soils along the San Joaquin River that contrast with the bands of inorganic soil bordering waterways of the northern Delta (Cosby 1941). Consequently, it seems probable that the southern part of the pristine Delta was flooded and drained more nearly like tidal marshes of the bays than like the naturally leveed marshes near the Sacramento River.

VEGETATION

Vascular plants[2] visually dominate the vegetation of tidal marshes and distinguish the marshes from mudflats. Our discussion of these plants considers their distribution with respect to geographic location, elevation, and other environmental variables. In addition, we attempt to estimate the quantity of organic material that vascular plants of tidal marshes export to the rest of the estuary.

Distribution of Species

Geographic and vertical trends. About 125 species of vascular plants have been reported from tidal marshes of the San Francisco Bay estuary. Most of these species are native to California (Appendix A), but some have been introduced from other parts of the world (Table 3).

Diversity generally increases from San Francisco Bay to the Delta. Whereas individual marshes around San Francisco Bay typically contain 13 or 14 species of native plants, specific sites in the Delta contain about 40 species. Composite regional lists imply even greater differences in diversity: only 15 native species reportedly live in tidal marshes around San Francisco Bay, but about 30 reportedly live around San Pablo Bay and Carquinez Strait, 40 around Suisun Bay, and 80 in the Delta.

San Francisco Bay and the Delta differ in kinds as well as numbers of tidal-marsh plants. Inhabitants of San Francisco Bay's marshes belong to the group of plants that characterize California salt marshes (Macdonald 1977). Few species from San Francisco Bay, however, have also been reported from tidal marshes of the Delta. Rather, the Delta's marshes are dominated by other plants that typically inhabit low-altitude fresh-water marshes in California (Mason 1957).

Common pickleweed (*Salicornia pacifica*) and California cordgrass (*Spartina foliosa*) dominate the tidal-marsh vegetation around San Francisco Bay. Common pickleweed generally monopolizes tidal-marsh plains at elevations near and above MHHW (Hinde 1954:218). Excepting salt-marsh dodder (*Cuscuta salina,* a parasite on common pickleweed), additional species on tidal-marsh plains typically grow in scattered patches next to sloughs, natural uplands, and man-made levees. These plants include salt grass (*Distichlis spicata*), marsh Grindelia (*Grindelia humilis*), halberd-leaved saltbush (*Atriplex patula* ssp. *hastata*), alkali heath (*Frankenia grandifolia*), and

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[2] Vascular plants (Phylum *Tracheophyta*) contain veinlike channels that convey metabolic materials between roots, stems, and leaves. Other kinds of tidal-marsh plants, such as diatoms, are not described in this chapter.

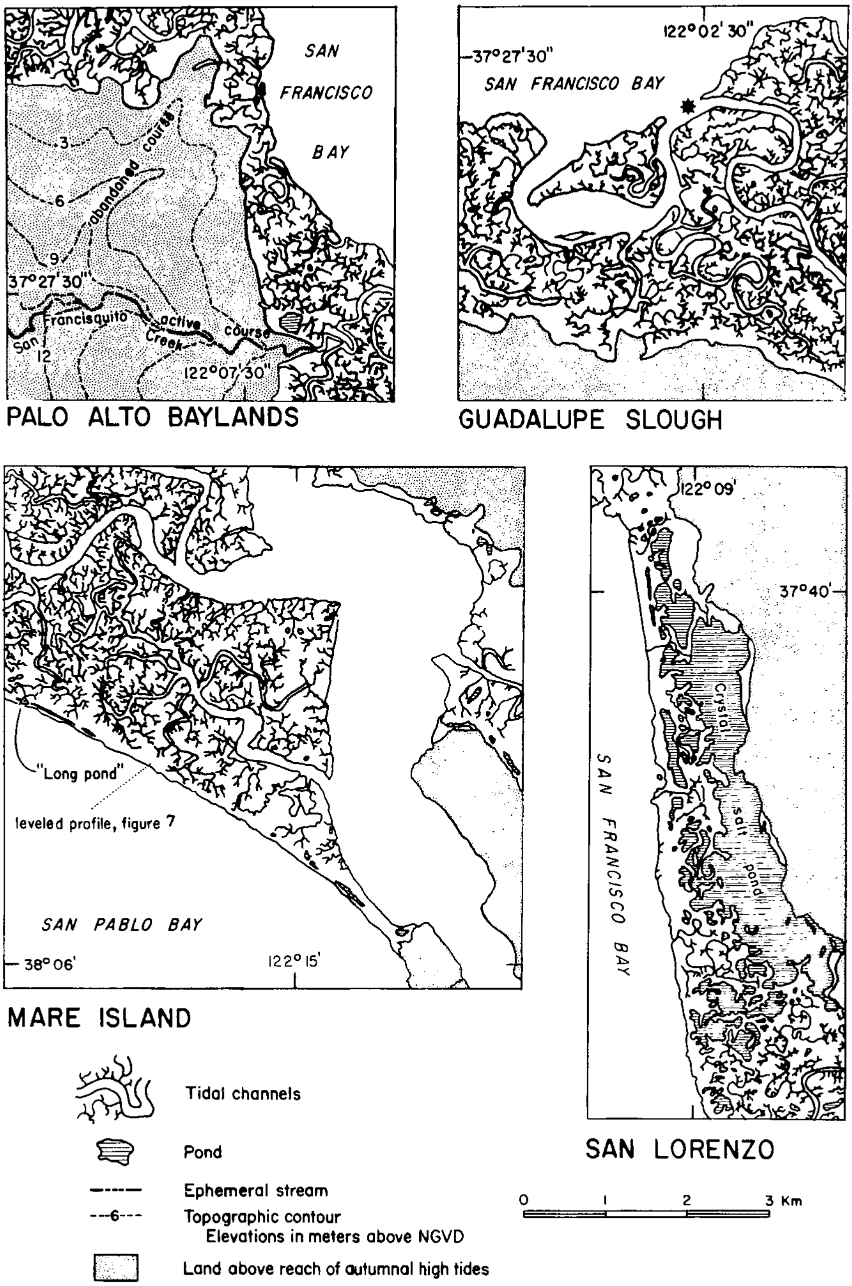
Fig. 8. Marshes of San Francisco and San Pablo bays as mapped before significant human disturbance. Locations on Fig. 2.

SOURCES OF INFORMATION. Channels and ponds are traced from unpublished 1:62,500-scale compilations, by D. R. Nichols and N. A. Wright, of 1:10,000-scale topographic maps prepared shortly after the California Gold Rush by A. F. Rodgers and David Kerr of the U. S. Coast Survey. Topographic contours, shown near Palo Alto Baylands only, are generalized from a modern 1:24,000-scale topographic map.

INTERPRETATIONS. Sloughs near Palo Alto Baylands, surveyed in 1857, show relation of tidal-marsh channels to active and abandoned mouths of an ephemeral fresh-water stream, San Francisquito Creek. The active mouth of this stream joins an average-size slough. The abandoned mouth lacks a comparable connection with San Francisco Bay, and a finger of marsh occupies a vestige of the old stream channel. Natural levees of both the active and abandoned courses of San Francisquito Creek, built by the stream when it overtopped its banks (Westdahl 1897; Gerow and Force 1968:24-27), cause the topographic contours to point downstream, as on a ridge, rather than upstream, as in a valley.

Guadalupe Slough followed a shortcut to San Francisco Bay when Rodgers and Kerr surveyed its course in 1857. At some earlier time, marshland presumably intervened between the starred meander and the bay (K. Lajoie pers. comm.). Erosion along the edge of the Bay probably removed this marsh. Similar erosion took place in this area during the late 19th century despite the *predominance of deposition along most other shorelines* (Fig. 6).

Ridges at the bayward margins of marshland may have caused water to collect in large ponds near San Lorenzo and to drain away from San Pablo Bay near Mare Island. Ponds near San Lorenzo appear on maps as old as F. W. Beechey's chart of San Francisco Bay, surveyed in 1827-1828 (Harlow 1850:64). When Kerr mapped them in detail 30 years later, he labelled the largest, "crystal salt pond." Predictably, commercial production of salt from San Francisco Bay began in this area (Ver Planck 1958:107). The berm along the bayward edge of a modern marsh near Mare Island (see Fig. 7) probably resembles the landform that caused the sloughs to drain northward when A. F. Rodgers surveyed them in 1856. A possible ancestor of the discontinuous trough at the southern edge of the modern marsh supplied Rodgers with a name, "Long Pond", for the triangulation station at left.



PALO ALTO BAYLANDS

GUADALUPE SLOUGH

MARE ISLAND

SAN LORENZO

Fig. 9. Marshes of the Sacramento-San Joaquin Delta as mapped before significant human disturbance. Locations on Fig. 2.

SOURCES OF INFORMATION. The USC&GS prepared no detailed maps of pristine marshes in the Delta until 1930-1940. Most channels and topographic contours on these diagrams are based on 1:31,680-scale plane-table sheets surveyed in 1906-1908 by the USGS. Some marshes had been leveed (Fig. 3) and some channels modified before these maps were made. Allowing for errors in map-making, the courses of river channels match the meanders shown on a 1:250,000-scale map by Ringgold (1852). The approximate courses of tributaries to Disappointment Slough are sketched from Cosby's (1941) 1:63,360-scale base map and, where highlighted by tonal differences between soils, from modern aerial photographs. Additional waterways probably existed before construction of dikes, but tall, dense stands of tules (*Scirpus* spp.) and other plants undoubtedly prohibited detailed mapping by plane-table methods. Elevations of natural levees along the Sacramento and San Joaquin rivers are consistent with verbal descriptions assembled by Thompson (1958: 36-37).

INTERPRETATIONS. The Sacramento River created most of the landforms near Babel Slough. The complex lobes of high ground, the largest of which enclosed Babel Slough, were built by sediment-laden flood waters that surged over or through the broad natural levees that flank the Sacramento River. In the bird-foot delta of the Mississippi River, such lobes are called crevasse or overbank splays (Coleman and Gagliano 1964). Paired fingers at the distal ends of the lobes represent the narrow levees of distributaries. Floods converted the Yolo Basin into a lake or river (Gilbert 1917:14-15) that accommodated so much more water than its parent that, on occasion, the discharge from the Yolo Basin transected and hydraulically dammed the Sacramento River near Rio Vista (Thompson 1958:448, 453). The 1.5-m contour locates the approximate northern limit of tidal water in the historic Yolo Basin during times of low Sacramento River discharge. During such low river stages, tides in Yolo Basin probably communicated with the rest of the estuary via the basin's outlet near Rio Vista. The top edge of the map approximates the northern boundary of tidal marsh as mapped in 1906-1908 and as generalized in Figs. 2, 3. Additional marshes covered higher parts of the Yolo Basin according to the USGS plane-table sheets.

Disappointment Slough and its tributaries more nearly resemble the typical drainages of tidal marshes bordering the bays. Lacking a river at its head, Disappointment Slough was probably created and maintained by tidal water that flowed in and out of nearby marshes. Low levees apparently forced some adjoining marshes to drain away from the San Joaquin River but, unlike the high borders of the Sacramento River near Babel Slough, these levees allowed tidal water to traverse the banks of the river in such channels as Disappointment Slough and Twenty-one-mile Slough.

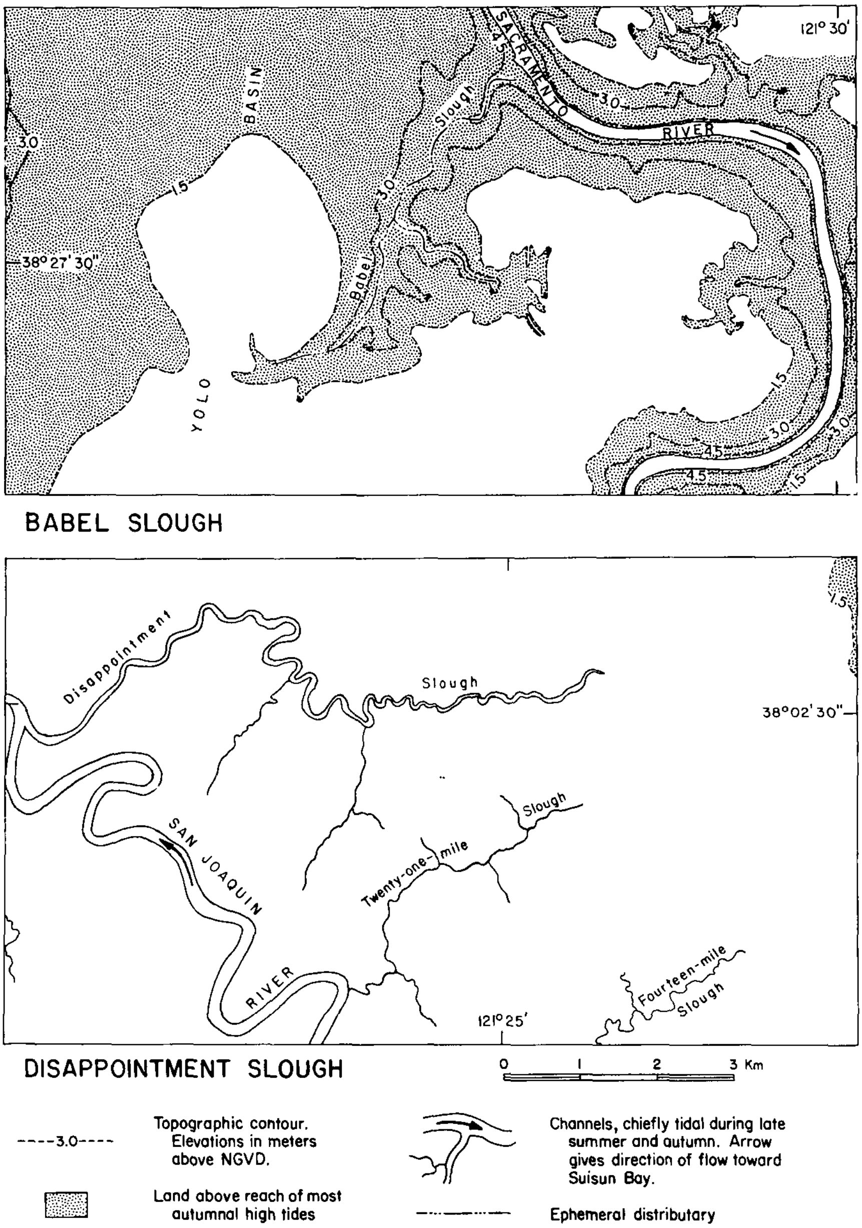

121° 30'
SACRAMENTO
RIVER
4.5
3.0
1.5
Slough
Babel
BASIN
YOLO
38° 27' 30"
BABEL SLOUGH
Disappointment
Slough
1.5
38° 02' 30"
SAN JOAQUIN
RIVER
Twenty-one-mile
Slough
Fourteen-mile
Slough
121° 25'
DISAPPOINTMENT SLOUGH
0
1
2
3 Km
----3.0----
Topographic contour. Elevations in meters above NGVD.
Land above reach of most autumnal high tides
Channels, chiefly tidal during late summer and autumn. Arrow gives direction of flow toward Suisun Bay.
Ephemeral distributary

TABLE 3. COMMON INTRODUCTIONS IN TIDAL MARSHES OF THE SAN FRANCISCO BAY ESTUARY.[a]

FAMILY	SPECIES	
	Linnean name	Common name
(Monocotyledons)		
GRAMINEAE Grass family	*Bromus diandrus* Roth var. *gussonei* (Parl.) Coss & Durieu	Gussone's ripgut grass
	B. mollis L.	Soft chess
	Cortaderia selloana (Schult.) Asch. & Graebn.	Pampas grass
	Festuca elatior L.	Meadow fescue
	Hordeum leporinum Link.	Hare barley
	Polypogon monspeliensis Buckl.	Rabbit's-foot grass
	Spartina patens (L.) Greene	Salt hay
(Dicotyledons)		
CAROPHYLLACEAE Chickweed family	*Spergularia media* (L.) Presl.	Sand-spurrey
CHENOPODIACEAE Goosefoot family	*Atriplex semibaccata* R. Br.	Australian saltbush
	Chenopodium album L.	Lamb's quarters
COMPOSITAE Sunflower family	*Cirsium vulgare* (Savi) Ten.	Common thistle
	Cotula australis (Sieber) Hook.	Australian Cotula
	C. coronopifolia L.	Brass buttons
CRUCIFERAE Mustard family	*Lepidium latifolium* L.	Broad-leaved pepper-grass
DIPSACACEAE Teasel family	*Dipsacus fullonum* L.	Fuller's teasel
LABIATAE Mint family	*Mentha piperita* L.	Peppermint
LEGUMINOSEA Pea family	*Melilotus albus* Desr.	White sweet clover
PLANTAGINACEAE Plantain family	*Plantago major* L.	Common plantain
POLYGONACEAE Buckwheat family	*Rumex crispus* L.	Curly dock
PONTEDERIACEAE Pickerel-weed family	*Eichhornia crassipes* (Mart.) Solms.	Water hyacinth
SOLANACEAE Nightshade family	*Solanum dulcamara* L.	Climbing nightshade
	S. nodifolium Jacq.	Small-flowered nightshade
UMBELLIFERAE Carrot family	*Apium graveolens* L.	Celery
	Conium maculatum L.	Poison-hemlock
	Foeniculum vulgare Mill.	Sweet fennel
VERBENACEAE Vervain family	*Lippia nodiflora* Michx. var. *rosea* (D. Don) Munz	Garden Lippia

[a] The list draws from the same sources as Appendix A. In addition, it includes R. E. Mall's report of salt hay at Southampton Bay (Munz 1968:195), a find which we have not duplicated either at Southampton Bay or anywhere else in the estuary. Among grasses other than salt hay, all commonly inhabit the landward fringes of tidal marshes around San Pablo and Suisun Bays except for pampas grass, which grows mainly in the Delta. The principal species among dicotyledons include Australian saltbush (all bays), curly dock (San Pablo and Suisun bays in 1975 but not, with a few exceptions, in 1977), brass buttons (wet places near high-tide levels around Suisun Bay), and garden Lippia (the Delta).

fleshy Jaumea (*Jaumea carnosa*). California cordgrass fringes tidal-marsh plains where they descend into mudflats. Near MTL it forms pure stands, but midway between MTL and MHHW it intermingles with red pickleweed (*Salicornia rubra*), and at higher elevations it yields to common pickleweed. Subsidence due to ground-water withdrawal probably accounts for the anomalous presence of California cordgrass on the tidal-marsh plain at Palo Alto Baylands (Fig. 7; Harvey 1966).

Common tule (*Scirpus acutus*), Olney's bulrush (*Scirpus olneyi*), cat-tails (*Typha* spp.), common reed (*Phragmites communis*) and arroyo willow (*Salix lasiolepis*) dominate islands of pristine marsh in the Delta. Typical associates of these plants include swamp knotweed (*Polygonum coccineum*), broadfruited bur-reed (*Sparganium eurycarpum*) and Pacific silverweed (*Potentilla egedei*) (*Scirpus-Phragmites-Typha* association, Table 4). Another associated species is marsh bindweed (*Calystegia sepium*), a morning glory that twines around tules and reeds. Below MTL these plants yield to monotonous stands of tules (*Scirpus acutus* and *Scirpus californicus*) and, in areas of quiet water, to floating aquatic species (*Ludwigia* association, Table 4).

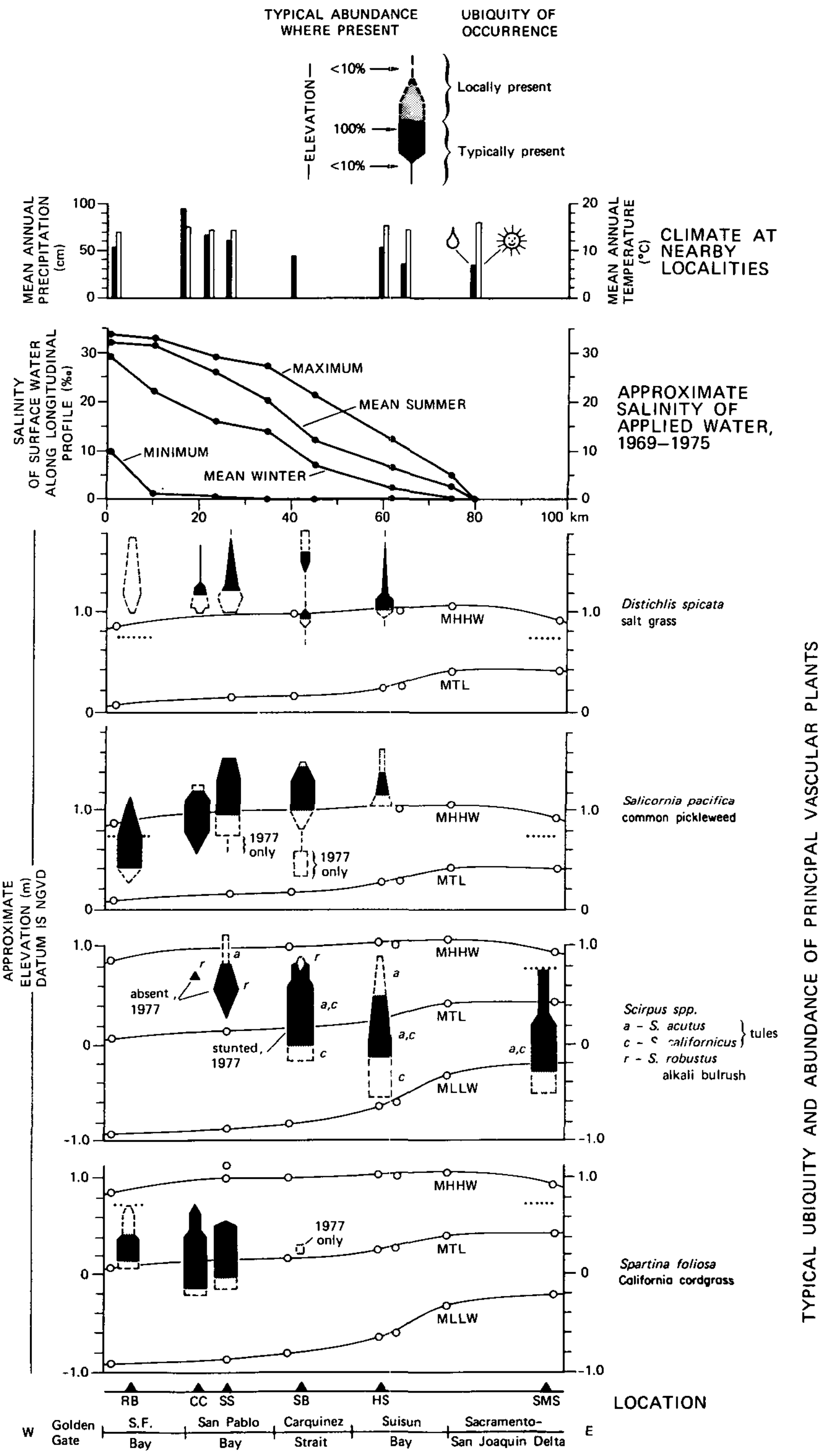
Tidal-marsh plants of San Pablo Bay, Carquinez Strait, and Suisun Bay provide an intricate, mutable transition between salt marshes of San Francisco Bay and freshwater marshes of the Delta (Table 4, Appendix A; Figs. 7, 10). Details of this transition include: (1) Species from opposite ends of the spectrum overlap to varying degrees in the middle. Most salt-marsh plants of San Francisco Bay live around San Pablo Bay and Carquinez Strait (*Spartina* and *Salicornia pacifica* associations, Table 4) and also around Suisun Bay (Appendix A). Salt grass and marsh Grindelia even grow in the western Delta. Neither California cordgrass nor red pickleweed, however, appear to grow east of Carquinez Strait. Cosmopolitan species of the Delta include tules and bulrushes (*Scirpus acutus, S. californicus, S. olneyi*), cat-tails, and common reed. All of these plants range as far west as the large sloughs north of San Pablo Bay. East of San Pablo Bay they generally supplant California cordgrass (Fig. 10; *Scirpus californicus* association, Table 4). (2) Some common plants of San Pablo and Suisun bays are scarce or absent in tidal marshes of the Bay and Delta. These species include alkali bulrush (*Scirpus robustus*), sea milkwort (*Glaux maritima*), and soft bird's beak (*Cordylanthus mollis*). (3) The vertical range and relative abundance of many species vary with geographic location. Common pickleweed, for instance, shortens its vertical range and reduces its ubiquity and abundance from west to east (Fig. 10). (4) Plant communities change not only from the Pacific Ocean to the Sacramento and San Joaquin rivers but also from mouths to heads of sloughs that drain major upland creeks north of San Pablo and Suisun bays. (5) The vertical and geographic ranges of some species, most conspicuously the tules and bulrushes, can change significantly within one or two years (Figs. 10, 11).

Reasons for trends. Environmental variables that may influence the distribution of vascular plants in tidal marshes include the reproductive methods of the plants, the frequency and duration of tidal flooding, and characteristics of the soil such as particle size, salinity, aeration, moisture, and nutrients (Chapman 1960). Competition between species may also restrict the ranges of some plants. Available evidence from the San Francisco Bay estuary used to test several of these possibilities implies that soil salinity, tidal inundation, and interspecific competition largely control the distribution of local species.

High soil salinity related to saline tidal water causes many plants to disappear toward San Francisco Bay. Too much salt inhibits growth, as evidenced in the case of bulrushes and tules west of the Delta by the decrease in their size and abundance during the drought of 1976-1977 (Figs. 10, 11). The damage or demise of these plants mostly reflects the increased salinity of tidal water rather than the decreased local rainfall because daily high tides inundate the soils of most bulrushes and tules. Excessive salt likewise appears to discourage the growth of bulrushes, cattails, and rushes (*Juncus* spp.) in leveed marshes north of Suisun Bay (Mall 1969:36). Consistent with its reduced seed production in tidal marshes during 1976 and 1977, alkali bulrush produces few seeds in these leveed marshes if vernal soils contain more than 24 °/oo salt (Mall 1969:38).

The salinity of soils may also contribute to the vertical zonation of vascular plants if, as reported from north of San Pablo Bay, salinity during the growing season increases with elevation (Fig. 12). According to field and greenhouse studies by Mahall and Park (1976b), salt rather than aeration or nutrients probably favors pickleweed over cordgrass at high elevations near Black John Slough and Mare Island. Similar considerations may account for the scarcity of tules and bulrushes above high-tide levels around San Pablo Bay, Carquinez Strait, and Suisun Bay.

SAN FRANCISCO BAY



The frequency and duration of tidal flooding commonly correlate with vertical ranges of vascular plants in tidal marshes (Johnson and York 1915; Purer 1942; Hinde 1954). For the San Francisco Bay estuary, this correlation implies causation according to two lines of evidence: (1) the scarcity of cordgrass, tules, and bulrushes above MHHW (Fig. 10) may indirectly result from tidal inundation, if, as seems likely, the vertical increase in salinity reflects more prolonged desiccation at higher elevations; and (2) tidal water may prevent pickleweed from growing at low elevations by dislocating, suffocating, or leaching seeds and seedlings (Chapman 1960:45-49; Mahall and Park 1976c).

Though the disappearance of species toward the Golden Gate reflects the physiological hardships of saline water, the disappearance of species toward the Delta may represent a sociological consequence of fresh water. According to greenhouse experiments, the principal vascular plants of San Francisco Bay's tidal marshes grow better in fresh water than in saline water (Barbour and Davis 1970; Barbour 1970; Phleger 1971). The paradoxical disappearance of these species toward the Delta therefore implies either that saline soils uniquely contain vital nutrients or that other species competitively exclude salt-marsh plants from brackish- and fresh-water areas. The vertical ranges of coexisting, potential competitors (Fig. 10) suggest a role for competition. California cordgrass, for instance, seems to yield to alkali bulrush at elevations greater than 0.5 m at Schultz Slough, but below 0.5 m the abundance of California cordgrass remains the same as at more saline marshes such as China Camp. Similarly, bulrushes and tules appear to eliminate

Fig. 10. Regional and vertical distribution of the principal vascular plants in six tidal marshes of the northern San Francisco Bay estuary. SYMBOLS FOR UBIQUITY AND ABUNDANCE OF PLANTS (top). Solid lines and black shading indicate widespread occurrence at or near a given elevation; dashed lines and stippled shading show relatively sparse occurrence. The width of each figure represents abundance and ranges from 1-10% (one line-width) to 100% (broadest part of figure). Abundance approximates the area, relative to other vascular plants, covered by the projected canopy of the live individuals of a given species within a 3-m^2 circle centered at a point of measured elevation. Symbols depict conditions as of autumn 1975, and principal changes observed in autumn 1977. DISTRIBUTION OF PLANTS WITH RESPECT TO APPROXIMATE TIDE LEVELS, BAY-WATER SALINITY, AND CLIMATE (main figure). All localities are projected to the nearest point along a longitudinal profile of the estuary. This procedure generalizes the comparison of vegetation with longitudinal trends in environmental variables; for example, the water serving the marsh near Schultz Slough can contain less salt (Matthew et al. 1931:340-364) and rise to slightly higher levels (see MHHW for Lakeville, identified elsewhere in this caption) than water at the nearest point along the longitudinal profile in southeastern San Pablo Bay. Vertical ranges of plants were measured along or near leveled transects (Fig. 7; Atwater and Hedel 1976). With respect to tidal datums these ranges may err by 0.1 m or more (see text). Horizontal rows of dots show the highest elevation of pristine tidal marsh near transects at Richardson Bay and Sand Mound Slough; plants above this level are rooted in artificial levees. Marshes are abbreviated as follows: RB, Richardson Bay; CC, China Camp; SS, Schultz Slough; SB, Southampton Bay; HS, Hill Slough, SMS, Sand Mound Slough (see Fig. 2 for locations). Open circles along lines for tidal datums represent gauges for which differences between various planes of reference have been determined by the NOS (1977a, 1977b; Table 1). Locations of tide gauges are, from west to east: Presidio (San Francisco); Pinole Point and, for the higher MHHW, on the bottom graph, Lakeville (3 km SE of SS); Crockett (4 km W of SB); entrance of Suisun Slough (about 13 km SW of HS); Port Chicago (between Martinez and Shore Acres), Pittsburg (3 km W of SMS); and Old River at Orwood (10 km SE of SMS). Surface-water salinities follow Conomos and Peterson (1977). Climatic data (U. S. Department of Commerce 1964) refer to the following localities, listed from west to east: downtown San Francisco; San Rafael (between RB and CC); Hamilton Air Force Base (2 km N of CC); Petaluma (3 km NW of SS); Crockett; Port Chicago; Fairfield (3 km W of HS); and Antioch (15 km W of SMS).

TABLE 4. Groups of principal vascular plants in nine tidal marshes of the northern San Francisco Bay estuary during 1976. Symbols in the body of the matrix denote the approximate percentage of the ground surface covered by the projected canopy of species within areas (stands) of 10-20 m² having a roughly homogeneous distribution of species: R, single individual; +, 1%; 1, 1-5%, 2, 6-25%; 3, 26-50%; 4, 51-75%; 5, 76-100%. Stands were subjectively located and described in 1976 by the "Braun-Blanquet" or "releve" method (Mueller-Dombois and Ellenberg 1974:45-66). Upper case headings indicate localities (Fig. 2): BI, Browns Island; BP, Black Point; CC, China Camp; MI, Mare Island (stands located approximately 5 km WNW of square on figure); SB, Southampton Bay; SGS, Snodgrass Slough; SMS, Sand Mound Slough; SS, Schultz Slough. Lower-case headings label individual stands. Species and stands are grouped by similarity in occurrence and species composition, respectively, with the assistance of a computer program developed by Ceska and Roemer (1971) and adapted by David Randall and Dean Taylor (University of California, Davis). Associational groups at bottom designate the five tabular groups at left by their diagnostic species, and subgroups suggest several divisions of the *Salicornia* group. Most species inhabit at least 40% of the stands in their indicated associational group and less than 25% of the stands in other groups. Each stand in the Delta contains more than 50% of the species in the corresponding associational group, but more flexible criteria arrange stands from Carquinez Strait and San Pablo Bay because most contain a small number of species or a large percentage of cosmopolitan species.

GENERAL LOCATION																																			SACRAMENTO-SAN JOAQUIN DELTA																		
																		CARQUINEZ STRAIT																																				
	SAN PABLO BAY																																																				
MARSH	MI		PP	MI		CC		CC		BP		MI			CC		CC					SB					CC		BP	PP			SS		SB			SMS		SB	BI						SMS						SGS
		CC					SS							PP		BP																					SGS																
STAND	f	i	e	e	d	h	d	f	c	a	h	g	c	c	a	d	e	i	e	c	b	k	j	h	f	d	g	d	b	f	d	f	g	e	l	g	c	b	j	m	b	a	m	l	i	h	e	g	d	c	n	k	b
Species																																																					
Ludwigia peploides																																					+	1			+										+	5	2
Myriophyllum spicatum																																						1													+	1	2
Azolla filiculoides																																																			+	2	-
Potamogeton pectinatus																																																			+		2
Elodea canadensis																																																					2
Scirpus acutus																																						2	3				2	2	5	1	1	2	1	3			
Scirpus olneyi																		1	2	1		1		2		2						2			+	1				2			1	1	1	3	5	3	2	1			
Phragmites communis																																									3	4	4	5	1	4	1						
Typha domingensis																																				3							1	+	1	1	1	1	4	3			
Polygonum ssp.																			+																				2				1	1	1	2			2	1	1		
Potentilla egedei																		1	1				1		1											+							1	1		2	2	3	1				
Sparganium eurycarpum																																							1									2	1	1			
Scirpus californicus																																			+	1	1	3	3	2	3	2											
Typha spp.																																								4	2												
Salicornia pacifica		+	3	2	4	4	5	5	5	5	5	5	5	3	3	3	1	3	3	3	5	3	2	5	3	1	5	5	5	5	5	4	2	1	5	3				1													
Distichlis spicata					+											3	5	2	2	4	1	2				2	2				1		3	5							2												
Atriplex patula									+	+	2	2	1						1	2	+		1		2	1							+	+		+																	
Scirpus robustus																	+					2				1		+				2																					
Frankenia grandifolia															3		1								1			R						2																			
Lythrum hyssopifolia														2					2							+				2			+																				
Juncus balticus									1						2		+									3																											
Cuscuta salina											1												+		1																												
Achillea borealis																			+				2		1	1								1	+																		
Grindelia humilis																								+	3	1	1	+	1	2	1	2	+	2																			
Limonium californicum																	+							1	1								2			+																	
Jaumea carnosa																		+		1		3					1	1				+			+																		
Spartina foliosa	3	2	2	3	2	1																						2																									
Salicornia rubra		1																																																			
Associational group			*Spartina*																*Salicornia pacifica*																				*Scirpus californicus*								*Scirpus-Typha-Phragmites*						*Ludwigia*
										Salicornia									*Salicornia-Distichlis*										*Salicornia-Grindelia*																								

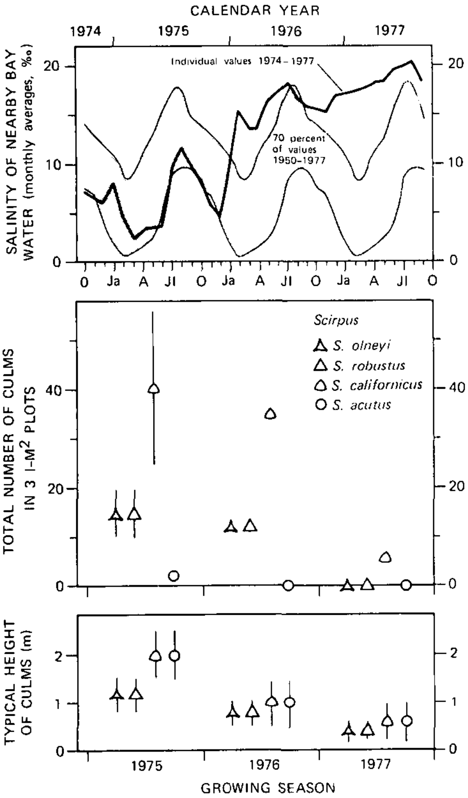


Fig. 11. Decrease in size and abundance of *Scirpus* spp. (bulrushes and tules) bordering Carquinez Strait during the drought of 1976-1977. The plots are located near the leveled transect at Southampton Bay (Fig. 7) at approximate elevations of 0.9 m, 0.4 m, and -0.5 m. Conditions in 1975 are estimated by comparing (qualitatively) living culms (above-ground stems) in plots along the transect in October 1975, with dead culms in September 1976. Measurements and counts of dead culms attempt to exclude those that grew before 1975, but similarities among dead culms of differing vintage result in large uncertainties, particularly for *S. californicus*. Conditions in 1976 and 1977 were determined from measurements and counts of living plants within the plots, excepting heights for 1977, which had to be scaled elsewhere because of the scarcity and absence of *Scirpus* within the plots. Vertical bars approximate the range of observed or estimated values. The top graph shows monthly averages of salinity of near-surface water at the eastern end of Carquinez Strait (USBR station D-6). The shaded area spans 1 SD (approximately 70%) of the monthly averages from October 1974 to September 1977. Data show that Carquinez Strait contained unusually saline water during the winter and spring of 1976 and 1977.

common pickleweed from the lower part of its salt-water range, as confirmed by the reciprocal spread of common pickleweed into low-lying areas denuded of tall tules and bulrushes during the drought of 1976-1977 (Fig. 10).

Productivity

According to classic investigations in the southeastern United States, the vascular plants of extensive tidal marshes supply most of the organic material on which local estuarine animals depend (Teal 1962; Day et al. 1973). Recent studies in Georgia and Holland, however, point to estuarine algae and riverine or marine debris as principal sources of estuarine food (Haines 1976, 1977; Wolff 1976). Given current controversy about these studies and shortcomings of related information about the San Francisco Bay estuary, we can hardly guess what percentage of food in this estuary originates in the vascular plants of its tidal marshes. In the following discussion we merely assemble information about the production of food in tidal marshes, estimate how much of this food enters other parts of the estuary, and offer a tentative comparison with the production of food by floating algae.

Conventional methods equate export by tidal-marsh plants with a calculated or arbitrary percentage of their net productivity. Net productivity refers to the quantity of organic matter that living plants store in excess of what they respire (Odum 1971:43). Bacteria, insects, and other organisms may consume some of this organic matter in the marsh, and high tides may move another fraction toward upland areas; hence, only a fraction of net productivity in a marsh can reach other parts of the estuary. The simplest measure of net productivity is the seasonal peak in the weight of live, above-ground, annual tissues (peak standing crop). Peak standing crop underestimates net productivity, however, because living tissue disappears during the growing season (Hardisky and Reimold 1977; Reimold and Linthurst 1977:87; Kirby and Gosselink 1976).

Local measurements of standing crop (reported herein as grams of dry plant material per

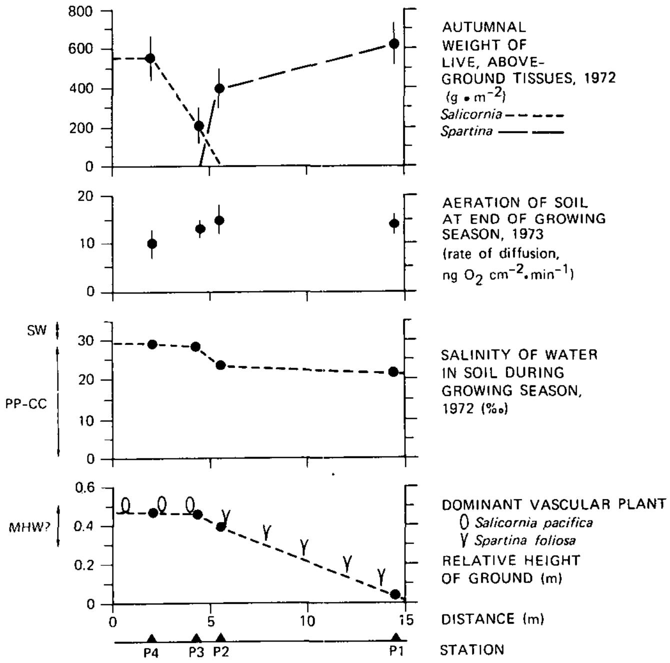


Fig. 12. Autumnal weight (dry) of above-ground tissues of *Spartina foliosa* and *Salicornia pacifica* and environmental variables of a profile near Black John Slough. Aeration of soil (upper 30 cm) at end of 1973 growing season and salinity of water in soil (upper 35 cm) in 1972 are data of Mahall 1974 and Mahall and Park 1976a, c. These data are compared with normal ocean salinities (SW) and the range of salinity of Bay water between Pinole Point (PP) and China Camp (CC) during 1969-75 (station 14 of Conomos and Peterson 1977). Topographic profile is referenced to estimated MHW datum. Vertical bars represent 1 SD of the measurements at each station; the diameter of dots on lower two graphs exceeds the length of bars.

square meter, g·m^{-2}) suggest that vascular plants of the San Francisco Bay estuary produce at least as much organic material as their counterparts in the eastern United States (Fig. 13). Peak standing crops of California cordgrass (*Spartina foliosa*) range from 300 to 1700 g·m^{-2}, comparable with its eastern relative, smooth cordgrass (*Spartina alterniflora*). Common pickleweed (*Salicornia pacifica*) creates standing crops of 500-1200 g·m^{-2}, likewise similar to the salt hay (*Spartina patens*), salt grass (*Distichlis spicata*), and short variety of smooth cordgrass which commonly inhabit high parts of Atlantic-coast marshes. The largest reported above-ground standing crop in North American tidal marshes may belong to tules in the Sacramento-San Joaquin Delta which, at low elevations along sloughs, grow 3-4 m tall and weigh about 2500 g·m^{-2}.

Adjusted for slight loss during the growing season and extrapolated to other species and localities, the standing crops of plants from a variety of marshes (Fig. 13) imply that net above-

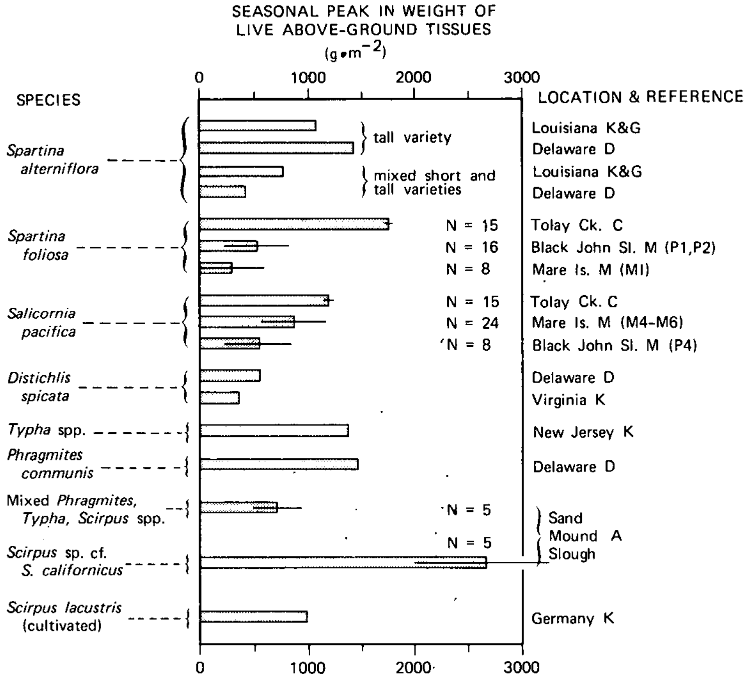


Fig. 13. Comparison of peak above-ground standing crops (dry weight) for some tidal-marsh plants. Weights refer to annual tissues that were harvested from multiple plots near the end of the growing season. Error bar shows 1 SD and N denotes the number of plots. Abbreviations for references: A—Brian Atwater unpublished data. Harvests were made in October 1977. Plots, 0.50 m^2 for mixed vegetation and 0.12 m^2 for *Scirpus*, are located on a remnant of pristine marsh near the transect of Atwater and Hedel (1976, pl. 8). Elevations relative to NGVD are 0.6±0.2 m for mixed plots and -0.4±0.2 m for *Scirpus*. Brown leaves attached to green *Phragmites* are included with live standing crop. Samples were oven-dried to constant weight at 100° C. Infertile flowers prevented definite identification of *Scirpus* sp. C—Cameron (1972:61, 64, 66; pers. comm.). Graph shows harvests of July 1969. Peak standing crops at Tolay Creek in autumn 1968 were 1400 g·m^{-2} (dry weight) for *Spartina* and 1050 g·m^{-2} for *Salicornia*. D—Compilation by Daiber et al. (1976:76, 78, 82). K—Compilation by Keefe (1972). K & G—Kirby and Gosselink (1976). M—Mahall and Park (1976a). Harvests made in 1972. Weights for *Salicornia* exclude living stems from previous years. Symbols in parentheses denote stations. Mahall's Mare Island marsh is located a few kilometers west of the locality plotted on Fig. 2.

ground productivity by the vascular plants of our estuary's tidal marshes averages between 500 and 1500 $g \cdot m^{-2} \cdot yr^{-1}$. Selecting 800 $g \cdot m^{-2} \cdot yr^{-1}$ as a typical value and multiplying by the present area of tidal marsh yields an estimated net above-ground productivity of $10^{11} g \cdot yr^{-1}$. Tides and rain flush approximately half of such organic material from cordgrass marshes (Teal 1962; Day et al. 1973; Cameron 1972:60), but the average fraction that enters the waterways and bays of the San Francisco Bay estuary is probably smaller because of the proximity of most tidal-marsh surfaces to high-tide levels (Fig. 7), which reduces the frequency of tidal flushing relative to the lower areas dominated by California cordgrass. If one fourth of net above-ground productivity enters other parts of the estuary, then annual export equals 2.5×10^{10} g (dry weight), which in turn equals 10^{10} gC because carbon constitutes about 40% of the dry organic matter (Keefe 1972). We therefore estimate that the vascular plants of tidal marshes annually contribute 10 billion grams of carbon to the rest of the San Francisco Bay estuary.

Several perspectives aid in conceptualizing 10 billion grams of carbon. (1) Net productivity of floating algae in the bays, chiefly diatoms and flagellates, averaged about 200 $gC \cdot m^{-2} \cdot yr^{-1}$ in 1976-77 (Peterson 1979), all of which is available to other aquatic organisms. The bays currently cover approximately 100 km^2 (Conomos and Peterson 1977), so these algae produced 2×10^{11} g of carbon, roughly 20 times our estimate of export by vascular plants of tidal marshes. (2) Historic destruction of tidal marshes (Figs. 1, 3) has probably caused a 10- to 20-fold reduction in their export of organic material. (3) At 10^{10} gC, export from vascular plants of tidal marshes translates into roughly 5 lbs. of carbon per year for each of the 5 million human inhabitants who surround the San Francisco Bay estuary.

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APPENDIX A

COMMON VASCULAR PLANTS IN TIDAL MARSHES OF THE SAN FRANCISCO BAY ESTUARY.

The list excludes introduced species denoted by Munz and Keck (1959). Asterisk designates rare or endangered plant according to Powell (1964). Scientific names follow Munz (1968) and Munz and Keck (1959) excepting nomenclature for *Athyrium, Cornus* and *Salicornia*, which follows Mason (1957). Many of the common names are taken from Abrams (1923-1960), and parenthetical descriptions of principal taxonomic groups are abridged from Mason (1957). Abbreviated headings refer to localities (Fig. 2): Palo Alto Baylands; RB, Richardson Bay; CC, China Camp; SS, Schultz Slough; NA, Napa marshes; SB, Southampton Bay; MZ, Martinez, SA, Shore Acres; HS, Hill Slough; SN, marshes N of Suisun Bay; BI, Browns Island; SMS, Sand Mound Slough; SGS, Snodgrass Slough; DL, marshes and sloughs in the Delta.

Sources of information:

PA–Cooper (1926), Hinde (1954), and observations by Atwater in 1976.

RB, CC, SS, SB, SA, HS–Collections by Savage in 1975 (SA), 1976 (RB, CC, SS, SB), and 1977 (HS), and supplemental observations by Conard and Macdonald in 1976 (SS, SB) and by Atwater in 1975 (CC) and 1977 (SB).

NA–Kingsley et al. (1977, Appendix A), lower-marsh and higher-marsh communities.

MZ–Observations by H. L. Mason in 1974.

SN, DL–Observations by H. L. Mason ca. 1970, supplemented with reference to earlier collections. Listed species belong to the following communities of Mason (undated, pp. 57-59, 71-75): palustrine, *Salicornia,* and *Distichlis* (SN); and neuston, buoyan, palustrine, and willow-fern (DL).

BI, SMS, SGS–Reconnaissance by Conard and Macdonald in 1976.

[N. B.: During 1978 and 1979 Atwater collected 40 species at SMS and 38 at SGS, many more than listed here, and also observed widespread *Salicornia pacifica, Jaumea carnosa,* and *Triglochin maritima* in pristine marshland at BI. Mason's *Eupatorium occidentale* is probably *Pluchea purpurascens* (Sw.) DC. (marsh-fleabane).]

FAMILY	SPECIES		KNOWN DISTRIBUTION OF SPECIES IN TIDAL MARSHES													
			San Francisco Bay		San Pablo Bay			Carquinez Strait	Suisun Bay				*Sacramento* - *San* Joaquin Delta			
	Linnaean Name	Common Name	PA	RB	CC	SS	NA	SB	MZ	SA	HS	SN	BI	SMS	SGS	DL
POLYPODIACEAE Fern family	*Athyrium filix-femina* (L.) Roth	Lady fern														X
SALVINIACEAE Salvinia family	*Azolla filiculoides* Lam.	Fern-like azolla														X
	A. mexicana Presl.	Mexican azolla														X
(Anthophytes – plants producing true flowers and seeds. Monocotyledons – plants with leaves usually parallel-veined; flowers usually with parts in multiples of three)																
ALISMATACEAE Water-plantain family	*Sagittaria latifolia* Willd.	Broad-leaved arrow-head													X	
CYPERACEAE Sedge family	*Carex* spp.	Sedge												X		
	Cyperus spp.	Umbrella sedge												X		
	Eleocharis acicularis (L.) R. & S.	Needle spike-rush														X
	E. sp.	Spike-rush									X				X	
	Scirpus acutus Muhl.	Common tule				X	X	X	X	X	X	X		X	X	X
	S. americanus Pers.	Three-square					X									
	S. californicus (C.A. Mey.) Steud.	California bulrush, tule					X	X	X		X	X	X	X	X	X
	S. cernuus Vahl. var. *californicus* (Torr.) Beetle	Low club-rush					X				X					
	S. olneyi Gray	Olney's bulrush				X	X	X	X	X	X	X		X		X
	S. robustus Pursh	Alkali bulrush			X	X	X	X	X	X						
GRAMINEAE Grass family	*Deschampsia caespitosa* (L.) Beauv.	California hair-grass					X				X					
	Distichlis spicata (L.) Greene var. *stolonifera* Beetle	Salt grass	X	X	X	X	X	X	X	X	X	X	X			
	Elymus triticoides Buckl.	Alkali rye-grass			X	X		X								
	Phragmites communis Trin. var. *berlandieri* (Fourn.) Fern.	Common reed						X				X	X	X	X	X
	Spartina foliosa Trin.	California cordgrass	X	X	X	X	X	X								
HYDROCHARITACEAE Frogbit family	*Elodea canadensis* Michx.	Waterweed													X	
	E. densa Planch.															X
JUNCACEAE Rush family	*Juncus balticus* Willd.	Baltic rush			X	X	X	X		X	X		X			X
	J. leseurii Bol.	Salt rush					X	X			X					
	J. effusus L. var. *pacificus* Fern. & Wieg.												X			
	J. sp.														X	
JUNCAGINACEAE Arrow-weed family	*Triglochin concinna* Davy	Slender arrow-grass	X	X												
	T. maritima L.	Seaside arrow-grass	X		X	X		X	X	X	X	X				
LEMNACEAE Duckweed family	*Lemna* ssp. (four species)	Duckweed														X
	Spiradela polyrhiza (L.) Schleid.	Greater duckweed														X
	Wolfiella lingulata (Hegelm.) Hegelm	Tongue-shaped Wolfiella														X
NAJADACEAE Water-nymph family	*Najas guadalupensis* (Spreng.) Morong.	Common water nymph														X
POTAMOGETONACEAE Pondweed family	*Potamogeton pectinatus* L.	Fennel-leaved pondweed												X	X	X
	P. spp. (seven species)															X
SPARGANIACEAE Bur-reed family	*Sparganium eurycarpum* Engelm.	Broad-fruited bur-reed												X		

FAMILY	SPECIES		KNOWN DISTRIBUTION OF SPECIES IN TIDAL MARSHES													
			San Francisco Bay		San Pablo Bay			Carquinez Strait	Suisun Bay				Sacramento - San Joaquin Delta			
	Linnaean Name	Common Name	PA	RB	CC	SS	NA	SB	MZ	SA	HS	SN	BI	SMS	SGS	DL
TYPHACEAE	*Typha angustifolia* L.	Narrow-leaved cat-tail												X		
	T. domingensis Pers.	Domingo cat-tail							X	X	X	X	X	X		
	T. glauca Godron	Blue-flag							X	X		X				
	T. latifolia L.	Broad-leaved cat-tail					X	X	X	X		X			X	X
(Dicotyledons–Plants with leaves not usually parallel-veined; flowers with parts usually in multiples of two, five, or many)																
AIZOACEAE Carpet-weed family	*Sesuvium verrucosum* Raf.	Lowland purslane										X				
CARYOPHLLACEAE Chickweed family	*Spergularia macrotheca* (Hornem.) Heynh.	Large-flowered sand spurry		X												
	S. marina (L.) Griseb.	Salt-marsh sand spurry	X		X	X	X	X	X	X	X					
CERATOPHYLLACEAE Hornwort family	*Ceratophyllum demersum* L.	Hornwort														X
CHENOPODIACEAE Goosefoot family	*Atriplex patula* L. ssp. *hastata* (L.) Hall & Clem.	Halberd-leaved saltbush	X	X	X	X	X	X	X	X	X					
	Salicornia pacifica Standl.	Common pickleweed (perennial)	X	X	X	X	X	X	X	X	X	X				
	Salicornia rubra A. Nels.	Red pickleweed (annual)	X	X	X											
COMPOSITAE Sunflower family	*Achillea borealis* Bong. ssp. *californica* (Pollard) Keck	Common yarrow					X	X	X				X			
	Artemisia douglasiana Bess.	Douglas' mugwort					X						X		X	
	Aster chilensis Nees.	Common California aster					X								X	X
	Baccharis douglasii DC.	Salt-marsh Baccharis						X								
	B. pilularis DC. ssp. *consanguinea* (DC.) B. C. Wolf	Coyote brush			X	X	X							X		
	Bidens frondosa L.	Stick-tight												X		
	B. laevis (L.) BSP.	Bur-marigold											X		X	X
	Eupatorium occidentale Hook.	Western Eupatorium														X
	Grindelia humilis H. & A.	Marsh Grindelia	X	X	X	X	X	X	X	X		X	X			
	Helenium bigelovii Gray	Bigelow's sneezeweed					X				X					
	Jaumea carnosa (Less.) Gray	Fleshy Jaumea	X	X	X	X	X	X	X	X	X	X				
	Solidago occidentalis (Nutt.) Torr. & Gray	Western goldenrod											X			X
CONVOLVULACEAE Morning-glory family	*Calystegia sepium* (L.) R. Br. ssp. *limnophila* (Greene) Brummitt	Marsh hedge bindweed												X	X	X
	Cressa truxillensis HBK. var. *vallicola* (Heller) Munz	Alkali weed						X								
CORNACEAE Dogwood family	*Cornus stolonifera* Michx. var. *californica* (C. A. Mey.) McMinn	Creek dogwood													X	X
CRASSULACEAE Stonecrop family	*Tillaea aquatica* L.	Water pigmy-weed														X
CUSCUTACEAE Dodder family	*Cuscuta salina* Engelm.	Salt-marsh dodder	X	X		X	X	X			X					
FRANKENIACEAE Frankenia family	*Frankenia grandifolia* Cham. & Schlecht.	Alkali heath	X	X	X	X	X	X			X	X				
HALORAGACEAE Water-milfoil family	*Myriophyllum braziliense* Camb.	Parrot's feather														X
	M. spicatum L. ssp. *exalbescens* (Fern.) Hult.	American milfoil												X	X	

FAMILY	SPECIES		KNOWN DISTRIBUTION OF SPECIES IN TIDAL MARSHES													
			San Francisco Bay		San Pablo Bay			Carquinez Strait	Suisun Bay				Sacramento - San Joaquin Delta			
	Linnaean Name	Common Name	PA	RB	CC	SS	NA	SB	MZ	SA	HS	SN	BI	SMS	SGS	DL
LABIATAE Mint family	*Lycopus americanus* Muhl.	Cut-leaved water-horehound												X	X	X
	Stachys albens Gray															X
LEGUMINOSAE Pea family	*Lathyrus californicus* Doug. ex. Lindl.	Beach pea										X				X
	* *L. jepsonii* Greene	Jepson's pea							X			X	X			X
	Lotus salsuginosus Greene	Coastal lotus									X					
	Vicia sp.	Vetch											X			
LYTHRACEAE Loosestrife family	*Lythrum hyssopifolia* L.	Hyssop loosestrife				X		X						X		
MALVACEAE Mallow family	* *Hibiscus californicus* Kell.	California Hibiscus												X	X	X
	Sida hederacea (Dougl.) Torr.	Alkali mallow										X				X
NYMPHAEACEAE Water-lily family	*Nuphar polysepalum* Engelm.	Yellow pond lily														X
ONAGRACEAE Evening primrose family	*Epilobium* spp.	Willow-herb												X	X	
	E. watsonii Barb.	Watson's willow-herb														X
	Ludwigia peploides (HBK.) Raven	Yellow water-weed											X	X	X	X
PLANTAGINACEAE Plantain family	*Plantago maritima* L. ssp. *juncoides* (Lam.) Hult.	Pacific seaside plantain	X	X												
PLUMBAGINACEAE Plumbago family	*Limonium californicum* (Boiss.) Heller	California marsh rosemary	X	X	X	X	X	X								
POLYGONACEAE Buckwheat family	*Polygonum aviculare* L.	Common knotweed						X								
	P. coccineum Muhl.	Swamp knotweed													X	
	P. hydropiperoides Michx. var. *asperifolium* Stauf.	Mild-water pepper												X		X
	P. lapathifolium L.	Pale persicaria												X		
PRIMULACEAE Primrose family	*Glaux maritima* L.	Sea milkwort					X	X		X						
	Samolus floribundus HBK.	Water pimpernel														X
ROSACEAE Rose family	*Potentilla anserina* L.	Silverweed										X				
	P. egedei Wormsk. var. *grandis* (Rydb.) J.T. Howell	Pacific silverweed						X		X				X		
RUBIACEAE Madder family	*Cephalanthus occidentalis* L. var. *californicus* Benth.	Button-bush											X		X	X
	Galium trifidum L. var. *subbiflorum* Weig.	Bedstraw											X			X
SALICACEAE Willow family	*Populus fremontii* Wats.	Fremont's poplar														X
	Salix gooddingii Ball.	Goodding's willow														X
	S. hindsiana Benth.	Sandbar willow													X	X
	S. lasiolepis Benth.	Arroyo willow											X		X	X
SCROPHULARIACEAE Figwort family	* *Cordylanthus mollis* A. Gray ssp. *mollis*	Soft bird's beak					X	X				X				
	Limosella subulata Ives	Awl-leaved mudwort														X
	Mimulus guttatus Fisch. ex. DC.	Common large monkey-flower											X	X		
	Scrophularia californica Chamb. & Schlecht.	Coast figwort												X		

FAMILY	SPECIES		KNOWN DISTRIBUTION OF SPECIES IN TIDAL MARSHES													
			San Francisco Bay		San Pablo Bay			Carquinez Strait	Suisun Bay				Sacramento - San Joaquin Delta			
	Linnaean Name	Common Name	PA	RB	CC	SS	NA	SB	MZ	SA	HS	SN	BI	SMS	SGS	DL
UMBELLIFERAE Carrot family	*Hydrocotyle umbellata* L.	Many-flowered marsh-pennywort											X		X	
	H. verticillata Thunb. var. *triradiata* (A. Rich.) Fern	Whorled marsh-pennywort									X					X
	Oenanthe sarmentosa Presl.	Pacific Oenanthe											X			
URTICACEAE Nettle family	*Urtica holosericea* Nutt.	Nettle													X	
VERBENACEAE Verbena family	*Verbena hastata* L.	Blue vervain													X	
	V. scabra Vahl.	Rough verbena														X