Distribution of vascular-plant species in six remnants of intertidal wetland of the Sacramento - San Joaquin Delta, California

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ABSTRACT

Six remnants of tidal wetland (marsh and swamp) in the Sacramento - San Joaquin Delta collectively support about 75 species of native plants. Two of the species were heretofore overlooked in the Central Valley: *Salix coulteri* Anderss. and *Scutellaria galericulata* L. Geographic trends in the distribution of species in the Delta's tidal wetlands reflect transition from the natural levees and alluvial flood basins of the Sacramento and San Joaquin Valleys to the brackish-water tidal marshes of Suisun Bay. For example, riparian trees and shrubs progressively disappear toward Suisun Bay, mimicking a trend reported by persons who plied the Sacramento River before erection of artificial levees. Another botanical transition involves vertical zonation of *Scirpus acutus* Muhl. (common tule). This bulrush, the principal native plant of the Delta, inhabits all levels from low point bars to higher interior flatlands of remnant wetlands in the south-central part of the Delta. These wetlands possess neither natural levees, whose woody plants exclude *S. acutus* from banks of tidal sloughs in the northern Delta, nor persistently saline soils, which exclude *S. acutus* from all but the low-lying fringes of tidal marshes served by Suisun Bay and its sloughs. Thus, *S. acutus* is cosmopolitan in the south-central Delta because of a combination of naturally unleveed wetland and generally fresh water that is unique to this part of the San Francisco Bay estuary.

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INTRODUCTION

Today's Sacramento - San Joaquin Delta bears little resemblance to the Delta of 1850. Then, during the California Gold Rush, the Delta[1/] contained nearly 1400 km^2 of marsh and swamp subject to tidal inundation (Gilbert, 1917, p. 78). Almost all of this wetland was leveed, drained, and brought under cultivation by 1930 (Matthew and others, 1931; Thompson, 1957, p. 208-238; Dutra, 1976). Remaining tidal marsh and swamp, covering about 20 km^2 (Cosby, 1941, p. 16), consists mostly of islets that were isolated by dredge-cut channels whose spoils created artificial levees.

Owing to the magnitude of human disturbance and the inaccessibility of surviving wetlands, previous descriptions of the Delta's natural vegetation overlook all but the most obvious trends in geographic and vertical distribution of species. This report elucidates additional trends by listing species for six widely spaced localities, describing the vertical distribution of principal species as observed along leveled transects, and contrasting the Delta's vegetation with that of a riparian swamp in the Sacramento Valley and a brackish-water marsh in Suisun Bay. I thank Charles Arnold, Marion Atwater, Daniel Belknap, Joanne Deane, Frances DeMarco, James Demarest, Robert Doyle, and Donald Sullivan for help with field work; Walter Glooschenko, Helen Halsey, John Thomas Howell, and Walter Knight for plant identifications; Ted and Helen Halsey for field accomodations; Carla Hubbard, Yosh Inouye, and Bruce Rodgers for drafting; and Charlene Fischer for typing.

1/ As used herein, the term "Delta" refers to lands east of the confluence of the Sacramento and San Joaquin Rivers that were covered by autumnal high tides ca. 1850 (fig. 2) and the waterways and natural levees immediately adjacent to those lands.

PHYSICAL SETTING

Streams draining 40 percent of California reach sea level in the Sacramento - San Joaquin Delta, an area centered 80 km northeast of San Francisco. Chief among these are the Sacramento and San Joaquin Rivers, arterial drainages of the Great Valley that receive most of their inflow from the Sierra Nevada (fig. 1). During the last ice age (ca. 15,000 years ago) these two rivers merged about 10 km northwest of "Old River" (fig. 3), flowed through the sites of Suisun, San Pablo, and northern San Francisco Bays, and met the ocean on the exposed continental shelf west of San Francisco. Subsequent rise in sea level caused tidal water to reach the western Delta by 7,000-10,000 years ago. Continued sea-level rise, coupled with vertical accretion in tidal marshes and swamps, accounts for the extensive wetlands and peaty soils of historic times (Shlemon and Begg, 1975; Atwater and Belknap, 1980).

Subject to tidal action and situated along a continuum between the Pacific Ocean and rivers of the Central Valley, the wetlands and waterways of the Delta form part of the San Francisco Bay estuary.

Yearly minimum river flows, occurring during late summer and early autumn, historically allowed slightly brackish water (~2 ppt total dissolved solids) to spread into the western Delta. Extreme drought in 1931 allowed such water to invade nearly all of the Delta and raised salinity in the western Delta to as much as 15 ppt (Matthew and others, 1931, pl. 82, p. 369). Despite such incursions of brackish water, mean annual salinity has rarely exceeded 1 ppt, even in the western part of the Delta (e.g., Matthew and others, 1931, p. 274-376).

The Sacramento River historically delivered about three times more water to the Delta than did the San Joaquin River (inferred from data in fig. 1). During major floods, most water from the Sacramento River entered the Delta via alluvial flood basins (fig. 1) because the Sacramento's channel north of the Delta was too small to accommodate even moderate floods (Grunsky, 1929). Yolo Basin, the largest, merged with the northwestern part of the Delta (fig. 2). Catastrophic flooding of the Yolo Basin covered tidal wetland in this area with as much as 4 m of water (Thompson, 1957, p. 448).

Like most of central California, the Delta experiences a Mediterranean climate. In upland areas this means "a desert in summer, a sodden, dripping landscape in winter," so for plants "the supply of water and the need for water are exactly out of phase" (Major, 1977, p. 21, 34). Tidal wetlands of the Delta, however, have no shortage of water. Thus they offer unusually favorable conditions for growth of vascular plants (Jepson, 1893, p. 21).

PREVIOUS WORK

The earliest botanical descriptions come from maps and diaries of persons who plied the Delta's waterways during the first half of the nineteenth century. Thompson (1957) summarizes these accounts as follows:

> "The delta's dominant native cover during recorded time has been the tule (Scirpus lacustris) [now recognized as S. acutus]...The monotony of the green or brown canebrake-like vegetation was broken by channel and pond surfaces and by strips of alluvial alnd where woody shrubs and trees and herbaceous annuals grew...[S]hrubs appeared among the tules of Sherman, lower Roberts, and other centrally located islands; but a continuity of woody growth probably did not develop until the latitude of Brannan Island and Stockton."
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> "Viewed from the deck of a ship the tule and willow thickets of the central delta offered little of interest. The trip to Stockton on the San Joaquin seemed particularly dull...Clumps of shrubbery broke the continuity [of tule], but there were no trees...The margins of the lowermost Sacramento also were lined by tules and shrubs." (p. 135)

> "Sacramento-bound travelers from more humid lands than California appreciated the appearance of wooded natural levees, probably first encountered at Brannan Island. The banks abounded with a scraggy white oak; these oaks, the sycamores, and other trees became larger upstream. Beyond the line of thckets and timber, the tule backswamps looked like a succession of lakes at high water. They were drained by small sloughs which cut through the wooded riverbank." (p. 135-136)

Two problems limit the botanical usefulness of this archival information. First, it seems doubtful that persons other than trappers routinely ventured into small sloughs. Many archival accounts may therefore apply only to lands near major waterways. Second, the term "tule" as used in vernacular means more than a single taxon. A present-day restaurant in the Delta town of Locke exemplified this ambiguity: the sign out front reads "THE TULES" but illustrates cattails (*Typha* sp.).

Noteworthy studies by botanists began with W. L. Jepson (1893), who catalogued the diverse vegetation of natural levees along distributary branches of the Sacramento River. Jepson's description of contiguous tidal wetlands mentions only "masses of waving tule (*Scirpus lacustris*, var *occidentalis* Wats. [*S. acutus* Muhl.]) which chokes the marsh lands" (Jepson, 1893, p. 242). Nowhere does Jepson imply that he ventured into the "waving tule", so his account probably overlooks other species that might have grown among the *S. acutus*. H. L. Mason's (1957) observations in the Delta focus on taxonomy of aquatic and emergent plants. He has also grouped emergent plants of the Delta's tidal islets into communities labelled "Phytopalustrine" and "willow-fern swamp" (Mason, undated). Mason lists a total of 37 species for these communities without specifying any particular locality. Finally, S. G. Conard, R. L. Macdonald, and R. F. Holland (*in* Atwater and others, 1979) supply numerical measures of the relative abundance of species at 14 stations spread unequally between two sites in the Delta.

METHODS

I have studied the distribution of emergent vascular plants by gathering information about the soils, topography, and botany of six tidal islets in the Delta. The sites (fig. 3) are divided equally among three hydrologic settings: two along sloughs that historically drained flood waters from the Yolo and Sacramento Basins (Lindsey and Snodgrass Sloughs, respectively), two along distributaries of the San Joaquin River (Old and Middle Rivers), and two along the upper reaches of sloughs that have never received much upland runoff at their heads (Fourteenmile and Snodgrass Sloughs). The islets at Fourteenmile and Sand Mound Sloughs provide the closest available approximation to the extensive historic wetlands that were distant from waterways in the south-central Delta. I have also studied two sites outside of the Delta: Browns Island, a tidal marsh at the eastern end of Suisun Bay (fig. 3; Atwater, 1980, fig. 28); and a thicket bordering an unnamed oxbow lake (hereafter, Little Packer Lake) of the Sacramento River near latitude 39°30' (Atwater, 1980, figs. 8, 24). These sites allow comparison of the Delta's wetland with a brackish-water marsh and an upland swamp, respectively.

Soils

The nature and thickness of soft deposits beneath each site were determined from at least two borings. Samples were collected with a steel half-cylinder 2 cm in diameter and 1 m long, and were examined only in the field.

Topography

The shape and elevation of each wetland was determined along one or two transects 150-400 m long (figs. 4-10). At Little Packer Lake I used a self-aligning spirit level, taking a series of foresights from a flood-control levee that overlooks the swamp. This procedure is impractical in the Delta because wide waterways separate such levees from the tidal islets. Furthermore, willow thickets and tall tules prohibit efficient leveling inside the islets. I therefore adopted the following procedure:

(1) Work during a spring tide that rises well above mean higher high water (MHHW).

(2) Measure elevation of water surface at foot of man-made levee (point A) by conventional leveling from nearest bench mark.

(3) Canoe to islet (5-15 minutes), set tide staff at end of transect (point B), and transfer bench-mark datum from A to B via water surface. Adjust for changes during canoe trip by extrapolation of previous tide-staff measurements at A and/or subsequent readings at B.

(4) Near high slack tide, synoptically measure water levels at B and water depths along transect. Space readings along transect by 15 m or less.

(5) Return to bench mark by reversing steps (2) and (3).

This procedure involves three kinds of uncertainty: vertical movement of the bench mark, errors in the transfer of the bench-mark datum to point B, and synoptic differences in water level between point B and some other part of the transect. The first two may affect the reported datum for the profiles, whereas the other may influence their shape.

Bench marks in the Delta generally subside relative to upland monuments (Curtin, 1967). Agents responsible include compaction and displacement of levee foundations on which many marks rest, compaction of deeper sediment accompanying withdrawal of natural gas and/or water, and tectonic movement. Repeated leveling of bench marks used in this study indicate average rates of subsidence of 0.3-2.1 cm/yr (table 1). If these rates are correct, then the marks subsided 2-8 cm between the most recent year of leveling and the time of my work. Except in fig. 12, I have not adjusted reported elevations to correct for this subsidence.

Closure errors range from 1 to 13 cm (table 1). For these I have made adjustments that effectively halve the reported errors. No closure was attempted for Browns Island because of the great distance across which the bench-mark datum was transferred by water. The distance produced a 30-minute delay between points A and B in the arrival of high slack tide (determined from synoptic observation of staffs at both points). To calculate elevations on the island I have assumed no difference between A and B in the elevation of high slack tide. This assumption is expedient but unsubstantiated.

Repeated sounding along several transects revealed synoptic differences in water level along individual transects. Conditions that appear to minimize these differences include slack tide, water depth greater than 5 cm, and distance from a waterway less than 100 m. Not all of these conditions prevailed along parts of some of the transects (table 1). Resulting error at Browns Island equals 1-5 cm, as measured and corrected by conventional leveling. No such correction was attempted for the Delta islets.

Botany

Rudimental work on vegetation involved the identification of species and collection of vouchers at the six islets in the Delta (table 2). The list for each site contains species observed while circumnavigating the islet and while logging the transect(s). Voucher specimens have been deposited in the herbarium of the California Academy of Sciences.

I studied the distribution of dominant species by preparing maps from aerial photographs (figs. 4-9) and by noting the occurrence of species along the topographic transects[1/]. Transects were logged at stations 3 m apart. At each station I recorded the approximate percentage of the ground covered by the projected canopy of each species within an area of 1-2 m^2 having a roughly homogeneous distribution of species. The number of stations for individual islets ranges from 56 to 128 (fig. 11). These numbers fail to ensure representative sampling because the vegetation on most islets varies greatly from one place to another. Moreover, transects at Middle River and Fourteenmile Slough cross anomalously few thickets of willow (Salix spp.; figs. 6, 8). The remedy for these shortcomings involves considerably more labor in the thickets. I am therefore content to offer qualified interpretations of the evidence now in hand.

RESULTS

Soils

Near-surface deposits beneath the wetlands contain more organic material in the central and southern Delta than at northern localities (fig. 11). Near-surface deposits at Sand Mound Slough, Fourteenmile Slough, Old River, and Middle River consist of peat and peaty mud. Corresponding deposits at

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1/ The transect at Little Packer Lake was logged by Donald Sullivan.

Lindsey and Snodgrass Sloughs, however, consist mainly of mud and peaty mud. No islet shows a consistent vertical change in organic content within the top 2 m that is large enough to verify in hand specimen.

Deposits beneath farmland of the Delta also decrease in organic content toward the Sacramento River and its distributaries (Cosby, 1941, p. 44 and soil map). Cosby noted no comparable trend for the tidal distributaries of the San Joaquin River north of the latitude of Stockton. Both this contrast and the similar difference between soils of islets are probably related to differences in discharge between the Sacramento and San Joaquin Rivers (see discussion of topography of natural levees).

The typical thickness of soft deposits exceeds 4 m at Lindsey Slough, Middle River, Old River, Fourteenmile Slough, and Browns Island (fig. 11). Firm and/or sandy sediment rises closer to the surface at the other sites.

Topography

Profiles across the six Delta islets (fig. 10) reveal three major landforms: natural levees, restricted to Snodgrass and Lindsey Sloughs; broad surfaces of low relief near high-tide levels, evident at all localities; and sloping point bars, displayed at Old River, Fourteenmile Slough, and Sand Mound Slough.

Natural levees. Banks having abrupt outer margins and gentle inward slopes rise about 25-30 cm above the wetlands at Snodgrass Slough. A small raised bank also appears at the northwest end of the northwest-southeast transect at Lindsey Slough. I doubt that dredges built any of these banks and therefore interpret them as natural levees. In the case of Snodgrass Slough, the islet has been enveloped by short split in Snodgrass Slough for at least

70 years (USGS topographic map, surveyed 1907-08). Whether or not the split is natural, the small size of the islet would make reclamation uneconomical, so man-made levees are unlikely. As for the site at Lindsey Slough, the dredger cut north of the islet (fig. 5) reflects the common practice of building levees straighter than the adjacent sloughs, thereby leaving unreclaimed, isolated wetlands inside tight meanders. The only major historic change affecting the banks of the meander at Lindsey Slough is erosion by westerly winds. This erosion has removed enough of the bank to produce the irregular shoreline on the northwest side of the islet.

The natural levees bordering Snodgrass and Lindsey Sloughs were probably created by floods. I base this opinion on the following considerations: both of these sloughs drained flood basins of the Sacramento River (Thompson, 1957, p. 447-448); a few such drainages possessed natural levees at least 1 m high (USGS topographic maps, surveyed 1906-10); and strictly tidal sloughs in marshlands at Browns Island and north of Suisun Bay lack natural levees (Atwater and Hedel, 1976, pl. 7; Atwater, 1980, fig. 27). Owing to their low stature and predominance of silt and clay, the levees probably formed in the manner envisioned by Brice (1977, p. 19) for the Sacramento River:

> "...natural levees, rather than being deposited by a sheet of water flowing overbank, may be mostly deposited when water moving at high velocity through a stream channel is flanked by rather deep water on the flood plain."

Flood-control projects of the past 50 years have largely prevented such conditions at Snodgrass and Lindsey Sloughs. It therefore seems likely that natural levees represent relict topography, formed either before or after the hydraulic gold mining of the late nineteenth century.

The absence of raised banks at the other sites in the Delta is consistent with the high organic content of their soils and the historic measurements of elevation assembled by Thompson (1957, p. 37). By the reasoning of the preceding paragraph, the banks of these sites have probably been shaped by tidal rather than riverine flow. A lesser influence of riverine flow along distributaries of the San Joaquin River, versus those of the Sacramento River, seems likely from the three- to four-fold difference in surface-water inflow between the San Joaquin and Sacramento Rivers (fig. 1).

Surfaces of low relief. Flatlands are the most widespread landform at all sites. Elevations of the flatlands, corrected for subsidence of bench marks, generally approach high-tide levels (fig. 12). Similar conditions prevail at salt- and brackish-water tidal marshes of San Pablo and San Francisco Bays (Atwater and others, 1979). Exceptional relief along the profiles at Lindsey Slough probably reflects erosion near beaver trails.

Point bars. Profiles at Old River, Fourteenmile Slough, and Sand Mound Slough each slope more gently toward the inside of meanders than toward the outside (fig. 7-10). The islets therefore possess point bars and cut banks. Reported slopes depend largely on the location of transects and the extent of historic erosion. At Sand Mound Slough, for instance, the great apparent width of the point bar reflects proximity of the transect to the slough (fig. 9), and the sloping cutbank probably reflects erosion (fig. 10) by boat wake and wind waves (cf. False River site of Limerinos and Smith, 1974).

Vegetation

The flora. Collectively, the six Delta islets support no fewer than 78 species of emergent vascular plants (table 2). These plants belong to 64 genera and 37 families. They include a fern and a horsetail as well as angiosperms.

Only four of the listed species were historically introduced to California. Of these only Iris pseudacorus is common in the Delta's islets. Additional introduced plants have probably escaped my notice, but none could cover more than, say, 0.01 percent of any of the islets. This scarcity of ruderal species contrasts with their abundance on artificial levees and farmland (Mason, undated).

Four of the native species have been designated as rare and endangered by the California Native Plant Society: Cicuta bolanderi, Hibiscus californicus, Lathyrus jepsonii, and Lilaeopsis masonii. In addition, two have never before been reported from the Great Valley: Salix coulteri and Scutellaria galericulata (Authorites consulted: Mason, 1957; Munz and Keck, 1959; Munz, 1968. Herbaria consulted: Jepson Herbarium, Univ. Calif., Berkeley; Herbarium of Calif. Acad. Sci., San Francisco).

Only three of the species--Lathyrus jepsonii, Lilaeopsis masonii, and Scirpus cernuus var. californicus--are generally restricted to tidal habitats (Mason, 1957). All of the other species range into upland habitat and therefore appear to need tides only for irrigation during the hot, dry summers of the Delta.

None of the Delta species inhabits salt marshes of San Francisco Bay and, conversely, none of the typical salt-marsh plants of the Bay inhabit tidal wetlands of the Delta (Atwater and others, 1979). But many of the Delta's species--including Phragmites australis, Scirpus acutus, S. californicus, S. californicus, S. olneyi, and Typha spp.--extend into brackish-water marshland bordering Suisun Bay and Carquinez Strait. S. acutus and S. olneyi even inhabit tidal marshes north of San Pablo Bay (Atwater and others, 1979).

Most of the individual islets support about 40-45 species. Exceptions are Old River, where I counted 54 species, and Snodgrass Slough, where I counted 32 species.

Distribution of species. Several relationships between species and habitats are evident from casual observation:

-- _Scirpus californicus_, a tall bulrush resembling _S. acutus_, grows almost exclusively on mudflats near or below MLLW. Locally it shares this habitat with a robust form of _S. acutus_ and with _Ludwigia peploides_, a generally aquatic plant. Examples of such mudflats include parts of Fourteenmile and Sand Mound Sloughs that have aggraded because of capture by nearby dredger cuts (figs. 8, 9).

-- Where free of dense shrubbery, banks of sloughs typically support diverse, multi-storied communities whose member species are largely absent from the interiors of islets (right-hand column, table 2). _Juncus_ and _Carex_ are the most frequent of the bank taxa. Others include the introduced _Iris_ and three of the rare-and-endangered plants, _Hibiscus_, _Lathyrus_, and _Lilaeopsis_.

-- The distribution of species inside most of the islets is extremely patchy (figs. 6-9). The patchiness is probably related to the lack of vertical zonation discussed below.

-- The number of arborescent species decreases toward Suisun Bay (fig. 11). This trend illustrates how the Delta's islets provide a botanical transition between the riparian forests of the Sacramento River and the brackish-water marshes of Suisun Bay. Ten species of trees and shrubs inhabit the islet at Snodgrass Slough: valley oak (_Quercus lobata_), cottonwood (_Populus fremontii_), box elder (_Acer negundo_ var. _californicum_), Oregon ash (_Fraxinus latifolia_), white alder (_Alnus rhombifolia_), creek dogwood (_Cornus stolonifera_ var. _californica_), buttonbush (_Cephalanthus occidentalis_ var. _californicus_), and three kinds of willows (_Salix_ spp.). These plants were among the dominant species in riparian habitats along the Sacramento River north of the Delta (Jepson, 1893; Thompson, 1961). Only the more robust riparian plants--valley oak, cottonwood, and box elder--are missing at the eastern islet of Lindsey Slough, perhaps because firm substrate lies too deep. The Old and Middle River sites lack not only those plants but also Oregon ash and abundant white alder. Sand Mound and Fourteenmile Sloughs further lack creek dogwood and sandbar willow (*Salix hindsiana*). Finally, buttonbush and the remaining willows virtually disappear between Sand Mound Slough and the extensive tract of relatively pristine wetland at Browns Island. The scarcity of arborescent plants in tidal wetlands of Browns Island probably reflects intolerance of brackish water.

Data from transects suggest additional trends in the distribution of species. The main body of fig. 11 summarizes the frequency of occurrence, cover, and vertical range of 13 dominant species along the transects. As noted above, 100 or even 150 stations may not suffice for making a thorough statistical description of the patchwork vegetation of the Delta islets. Nevertheless, the available evidence allows several generalizations concerning the interior parts of these islets:

-- *Scirpus acutus*, the botanist's tule, is the most frequent species at all sites except Sand Mound Slough. Perhaps those nineteenth-century accounts of a sea of tule deserve more credence than I have implied. Nevertheless, the high diversity and frequency of other native herbs (table 2, fig. 11) reinforces the view that the archival tule covers a multitude of taxa.

-- Pronounced vertical zonation of dominant species other than *Scirpus californicus* characterizes only those wetlands having natural levees or routinely brackish water. *S. acutus*, for instance, yields to woody plants on high ground at Snodgrass Slough (figs. 4, 11) and to salt-marsh plants (*Distichlis*, *Salicornia*) on flatlands at Browns Island (fig. 11). But at the four inlets in the south-central Delta its vertical distribution generally matches that of the ground surface along the transect. Willows at these four sites also show no consistent preference for high or low ground, the scatter between sites being an artifact of low frequency of occurrence. The lack of pronounced vertical zonation in the south-central Delta probably reflects a combination of flat wetland and fresh water that is unique to this part of the San Francisco Bay estuary. If the sites historically received flood waters like the more nearly riparian wetlands to the north, then natural levees would border the waterways and allow woody plants to exclude herbs such as _S. acutus_ from high ground. If, on the other hand, the sites received summertime brackish water like the marshes of Suisun Bay, then salt would accumulate by evaporation on the flatlands and thereby restrict _S. acutus_ to better drained, less saline soils on lower surfaces that border sloughs and mudflats (cf. Mahall and Park, 1976; Atwater and others, 1979).

-- _Phragmites australis_, a tall (2-3.5 m) grass that leaves distinctive fossil rhizomes, is common only in the south-central Delta. _Phragmites_ appear to decrease in areal abundance toward the Sacramento River and, like _S. acutus_, inhabits virtually none of the extensive flatlands at Browns Island.

IMPLICATIONS FOR THE BOTANY OF PRE-HISTORIC WETLANDS

Geographic differences in soils, topography, and vegetation, together with scarcity of ruderal plants, suggest that remnant tidal wetlands of the Delta have undergone little change during the past 50-130 years. Islets along drainages of the Sacramento and Yolo Basins possess mainly mineral sediment in their soils, display natural levees, and support robust riparian trees. In contrast, islets near distributaries of the San Joaquin River in the south-central Delta possess more organic matter in their soils, lack natural levees, and support woody plants of lower stature. These geographic differences probably predate the twentieth century and, perhaps, the mid-nineteenth century because (1) surficial deposits of remnant wetlands resemble pre-Gold Rush deposits of nearby reclaimed wetlands, (2) natural levees probably predate flood-control projects of the early twentieth century, (3) vegetation seems to depend partly on soils and topography, and (4) the absence of trees in the south-central Delta and their abundance to the north are consistent with descriptions of early travellers.

If the islets I studied have indeed resisted substantial historic change, then conditions that prevailed during the California Gold Rush can be reconstructed with the aid of modern analogues. By analogy with islets at Snodgrass and Lindsey Sloughs, tidal wetlands contiguous with alluvial flood basins of the ancestral Sacramento River possessed tree- and shrub-covered natural levees along major drainages and a dominance of *Scirpus acutus* elsewhere. By analogy with islets along Old and Middle Rivers, wetlands along predominantly tidal distributaries of the ancestral San Joaquin River supported an irregular, overlapping patchwork of bulrushes (*Scirpus* spp.), willows, cat-tails, lady fern, and many subordinate species. By analogy with islets at Fourteenmile and Sand Mound Sloughs, nearby wetlands along dead-end tidal sloughs supported fewer shrubby species and more stands of common reed (*Phragmites australis*). Similar conditions may have prevailed in adjacent wetlands distant from waterways. Finally, by analogy with Browns Island, seasonally brackish wetlands of Suisun Bay lacked shrubs, supported *Scirpus acutus* and *Phragmites australis* only along the banks of sloughs, and possessed extensive tracts of salt grass (*Distichlis spicata*) and Olney's bulrush (*Scirpus olneyi*).

Uniqueness in the Delta's tidal pristine vegetation of the Delta's tidal wetlands probably derives from communities rather than single species. No species is native solely to the present-day Delta. All dominant species of the islets range into upland habitats, and most of the dominant herbs also inhabit brackish-water tidal marshes. The islets may, however, support endemic communities. The best candidate for endemism is the patchwork of bulrushes, willows, cat-tails, and lady fern in the south-central Delta. Viewed as a single community, the vegetation of these "willow-fern swamps" (Mason, undated) is probably diagnostic of freshwater intertidal conditions within the area tributary to San Francisco Bay.

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Table 1.--Sources of error in vertical control for seven wetlands of the Sacramento - San Joaquin Delta and vicinity

Site	Bench mark: Designation	Bench mark: Year of most recent leveling	Bench mark: Prior subsidence[1] Est. rate (cm/yr)	Bench mark: Prior subsidence[1] Time period	Bench mark: Estimated subsidence since most recent leveling (cm)	Leveling: One-way distances of transfer of vertical control (m) Self-aligning level	Leveling: One-way distances of transfer of vertical control (m) Water	Leveling: Closure error (cm)	Sounding: Date	Sounding: Part of tidal cycle	Sounding: Minimum depth of water (cm)	Sounding: Maximum distance from open water (m)
Snodgrass Slough	26 27.94 (USED)	1974	1.0	1951-74	4	1980	400	13	12/29/78	flood	3	80
Lindsey Slough	E474 reset 1952	1974	2.1	1953-74	8	153	400	3	8/21/78	flood	4	50
Middle River	C1069	1974	1.0	1966-74	4	98	310	6	9/16/78	slack to ebb	0	120
Old River, S transect	66MDC	1974	nd[2]		nd[2]	166	550	8	8/18/78	slack to ebb	6	120
Old River, N transect	66MDC	1974	nd[2]		nd[2]	166	1150	8	12/28/78	flood to slack	3	120
Fourteenmile Slough	K909	1974	1.2	1957-74	5	844	80	6	2/24/79	flood	48	60
Sand Mound Slough	E484	1974	0.6	1951-74	2	534	540	1	11/14/78	flood to slack	5	80
Browns Island	Pittsburgh RM3	1963 or 1964	0.3	1951-64	4	298	2100	nd[2]	1/25/79	flood to slack	15	140

1 Determined from results of repeated leveling by staff of the National Geodetic Survey and by M. D. Cummins, U.S. Geological Survey.

2 nd, not determined

Table 2.--Emergent vascular plants at six intertidal swamps and marshes of the Sacramento - San Joaquin Delta, 1978-1979

FAMILY	SPECIES[1]	KNOWN DISTRIBUTION[2] SMS	FMS	OR	MR	LS	SGS	TYPICAL HABITAT (B, bank of slough; I, interior of island)
ASPIDIACEAE	Athyrium filix-femina (L.) Roth	X	X	X	x			I, patches 2-6 m in diameter
EQUISETACEAE	Equisetum arvense L.			X				I
ALISMATACEAE	Sagittaria latifolia Willd.		x	X	x		x	I, beneath Scirpus acutus
CYPERACEAE	Carex sp. or spp.	x	x	x	x	x	x	B; also I, beneath Salix
	Cyperus sp. or spp.	x	x	x	x	x	x	B
	Eleocharis sp.	x		x				I, beneath Salix
	Scirpus acutus Muhl.	x	X	X	x	x	X	B, I
	S. californicus Pers.	x	x	x	X	x	x	B, rooted near low-tide levels
	S. cernuus Vahl. var. californicus (Torr.) Beetle					X		B, with Lilaeopsis and Hydrocotyle
	S. fluviatilis (Torr.) Gray	x	X					I, beneath Salix lasiolepis
	S. microcarpus Presl.		x	X	x	x		I, largely beneath Salix
	S. olneyi Gray	x	x	x	x			I

1 Authorities for nomenclature: Munz and Keck (1959) as amended by Munz (1968) except for Juncus acuminatus forma sphaerocephalus (Hermann, 1956) and Polygonum hartwrightii (Greene, 1891). # denotes introduced plant.

2 Localities: SMS, Sand Mound Slough; FMS, Fourteenmile Slough; OR, Old River; MR, Middle River; LS, Lindsey Slough (composite for both localities); SGS, Snodgrass Slough. X, voucher deposited in herbarium of Calif. Acad. of Sciences, San Francisco; x, no such voucher.

Table 2.--Continued

FAMILY	SPECIES	KNOWN DISTRIBUTION SMS	FMS	OR	MR	LS	SGS	TYPICAL HABITAT (B, bank of slough; I, interior of island)
GRAMINEAE	#Arundo donax L.	X						B
	#Echinochloa crusgalli (L.) Beauv.	x	X	X			x	B
	Leersia oryzoides (L.) Swartz	X	X		X	x		B, I
	Paspalum distichum L.	x			X			B
	Phalaris arundinacea L.		X	x	X	x		B
	Phragmites australis (Cav.) Trinius ex Steudel	x	x	x	x		X	B, I
IRIDACEAE	#Iris pseudacorus L.	x	X	x	x			B
JUNCACEAE	Juncus acuminatus Michx. forma sphaerocephalus Hermann	X	X	x	X	x		B
	Juncus effusus L. var. pacificus Fern. & Wieg.	x	X	x	X	x	X	B
SPARGANIACEAE	Sparganium eurycarpum Engelm.	X	x	x	x			B, I
TYPHACEAE	Typha sp. or spp.	x	x	x	x	x	x	B, I
ACERACEAE	Acer negundo L. ssp. californicum (T. & G.) Wesmael.					X	X	B
APIACEAE	Cicuta bolanderi Wats.			X				I
	Lilaeopsis masonii Constance	x	X	X		x		B
	Hydrocotyle verticillata Thunb.		X	X	X	x		B, but locally I near B
	Oenanthe sarmentosa Presl.	X						
APOCYNACEAE	Apocynum cannabinum L. var. glaberrimum A. DC.	x	X	X	X	x	x	B, I
BETULACEAE	Alnus rhombifolia Nutt.			X		x	X	B

Table 2.--Continued

FAMILY	SPECIES	KNOWN DISTRIBUTION SMS	FMS	OR	MR	LS	SGS	TYPICAL HABITAT (B, bank of slough; I, interior of island)
CAPRIFOLIACEAE	*Lonicera involucrata* (Richards.) Banks var. *ledebourii* (Esch.) Zabel	x		X				B, I
COMPOSITAE	*Artemisia douglasiana* Bess.			X	X			B
	Aster chilensis Nees.						x	B
	Bidens frondosa L.	x			X			B
	Helenium bigelovii Gray			X	x	x		B
	Helianthus cf. *H. nuttallii* Torr. & Gray				X			I
	Pluchea purpurascens (Sw.) DC.	X				X		B
	Solidago canadensis L. ssp. *elongata* (Nutt.) Keck			X				I
	S. occidentalis (Nutt.) Torr. & Gray		X	x	X	x		I
CONVOLVULACEAE	*Calystegia sepium* (L.) R. Br. ssp. *limnophila* (Greene) Brummitt	x	x	X	X	x	x	B, I; mainly on Scirpus acutus
CORNACEAE	*Cornus stolonifera* Michx. var. *californica* (C. A. Mey.) McMinn			X	x	x	X	B, I
CRASSULACEAE	*Tillea aquatica* L.	x	X	x	X	x		B
FAGACEAE	*Quercus lobata* Nee						X	B, natural levees
LABIATAE	*Lycopus americanus* Muhl.	x	x	X	X	x	X	B
	#? *Mentha arvensis* L.	X						B
	Scutellaria galericulata L.		x	X	X			I
	Stachys albens Gray		X	X	X	x		I
LEGUMINOSAE	*Lathyrus jepsonii* Greene	x		X	X	x	X	B, locally I
	Psoralea macrostachya DC.			X				I

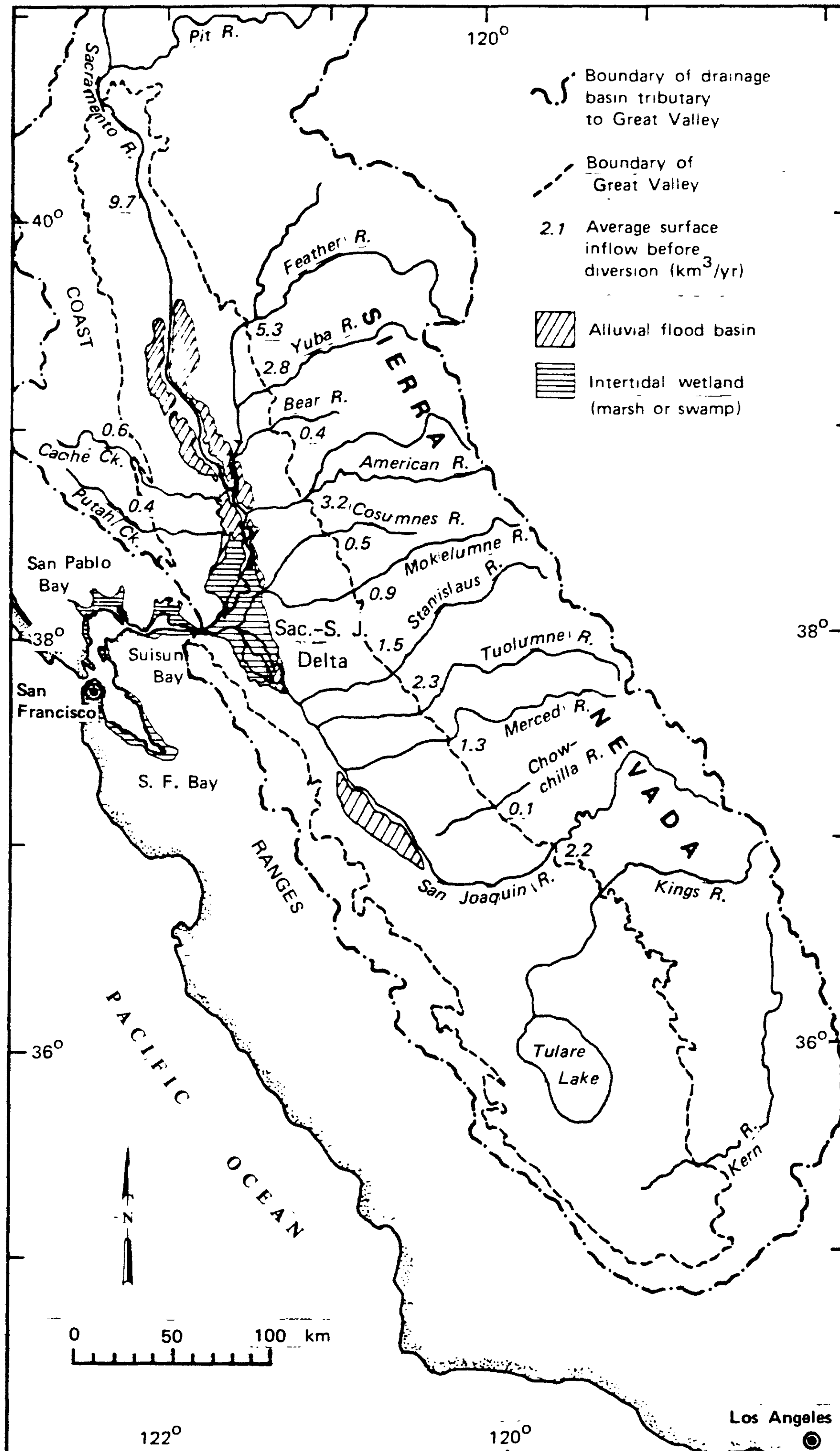
Table 2.--Continued

FAMILY	SPECIES	KNOWN DISTRIBUTION SMS	FMS	OR	MR	LS	SGS	TYPICAL HABITAT (B, bank of slough; I, interior of island)
LORANTHACEAE	Phoradendron flavescens (Pursh) Nutt. var. macrophyllum Engelm. in Rothr.					x	X	B; on Fraxinus, Cornus, Salix
LYTHRACEAE	Lythrum californicum Torr. & Gray			X				B
	L. sp.; either L. californicum or L. hyssopifolia L.	x				x	x	B
MALVACEAE	Hibiscus californicus Kell.	x	x	x	x	x	x	B
NYMPHAEACEAE	Nuphar polysepalum Engelm.				x			B, I
OLEACEAE	Fraxinus latifolia Benth.					X	x	B (LS), I (SGS)
ONAGRACEAE	Epilobium adenocaulon Hausskn.	X	X	X	X	x	X	B, I
	Ludwigia peploides (HBK.) Raven	x	X	x				B, I; mainly among Scirpus acutus
POLYGONACEAE	Polygonum coccineum Muhl.	x		X	x		x	B, I
	P. hartwrightii Gray			X	x	x	x	I
	P. hydropiperoides Michx. var. asperifolium Stauf.	X	X	x		X		I
	P. punctatum Ell.	X			X	x		I
PRIMULACEAE	Samolus parviflorus Raf.				X	X		B
ROSACEAE	Potentilla palustris (L.) Scop.	X			X			near B
	Rosa californica Cham. & Schlecht.					X	X	
	Rubus procerus P. J. Muell.			x			X	B (SMS), I (SGS)
	Rubus vitifolius Cham. & Schlecht.			x	x	X	X	I, locally B

Table 2. Continued

FAMILY	SPECIES	KNOWN DISTRIBUTION SMS	FMS	OR	MR	LS	SGS	TYPICAL HABITAT (B, bank of slough; I, interior of island)
RUBIACEAE	Cephalanthus occidentalis L. var. californicus Benth.	x	X	x	X	x	x	B, but locally I
	Galium trifidum L. var. subbiflorum Weig	x	X	X		x		I
SALICACEAE	Populus fremontii Wats.						x	B
	Salix coulteri Anderss.			X				B, I
	S. gooddingii Ball.	x	x	X	x	X	X	B, I
	S. hindsiana Benth.			X	x	X	X	B (OR, MR); B, I (LS, SGS)
	S. lasiolepis Benth.	x	x	X	x	X	X	B, I
	S. lasiolepis Benth. var. bigelovii (Torr.) Bebb.	x			x	X		B, I
SCROPHULARIACEAE	Mimulus guttatus Fisch. ex DC.	X	X	x				B, I
SOLANACEAE	Solanum nodiflorum Jacq.	x	x					I
URTICACEAE	Urtica holosericea Nutt.		X		X		x	B, I
VERBENACEAE	Verbena hastata L.	x	X	X	X	x	x	B
VITACEAE	Vitis californica Benth.					X		B

Figure 1.--Elements of the hydrology of the Central Valley. Landforms from compilation by Wahrhaftig and Birman (1965, p. 312), modified to show generalized extent of intertidal land at the site of the Delta (from fig. 2). River inflows from Ritchie and others (1960, p. 27) and Boyd (1978, p. 115).



Boundary of drainage basin tributary to Great Valley
Boundary of Great Valley
2.1 Average surface inflow before diversion (km³/yr)
Alluvial flood basin
Intertidal wetland (marsh or swamp)
120°
122°
40°
38°
36°
Pit R.
Sacramento R.
9.7
Feather R.
5.3
Yuba R.
2.8
Bear R.
0.4
American R.
3.2
Cosumnes R.
0.5
Mokelumne R.
0.9
Stanislaus R.
1.5
Tuolumne R.
2.3
Merced R.
1.3
Chowchilla R.
0.1
San Joaquin R.
2.2
Kings R.
Kern R.
Tulare Lake
0.6
Cache Ck.
Putah Ck.
0.4
SIERRA
NEVADA
COAST
RANGES
San Pablo Bay
Suisun Bay
Sac.-S. J. Delta
San Francisco
S. F. Bay
PACIFIC
OCEAN
N
0
50
100 km
Los Angeles

Figure 2.--Generalized distribution of waterways and wetlands in the Delta that were subject to tidal flow or inundation at time of low river discharge circa 1850. Meanders of the smallest sloughs are generally schematic. Drainage interpreted from the charts of Ringgold (1852), USGS topographic maps (editions of 1909-1914 and 1968-1978), and tonal patterns on 1:12,000-scale black-and-white aerial photographs taken 1966. In cases of conflict I generally follow the photos and topograhic maps rther than Ringgold's smaller-scale charts. Distribution of wetlands taken from Gilbert (1917, p. 76) but modified to show prominent natural levees and to omit some northerly areas located above the 5-foot contour shown on 1909-1914 editions of USGS topograhic maps. The distribution of natural levees is interpreted from these maps together with verbal descriptions assembled by Thompson (1957, p. 34-39).

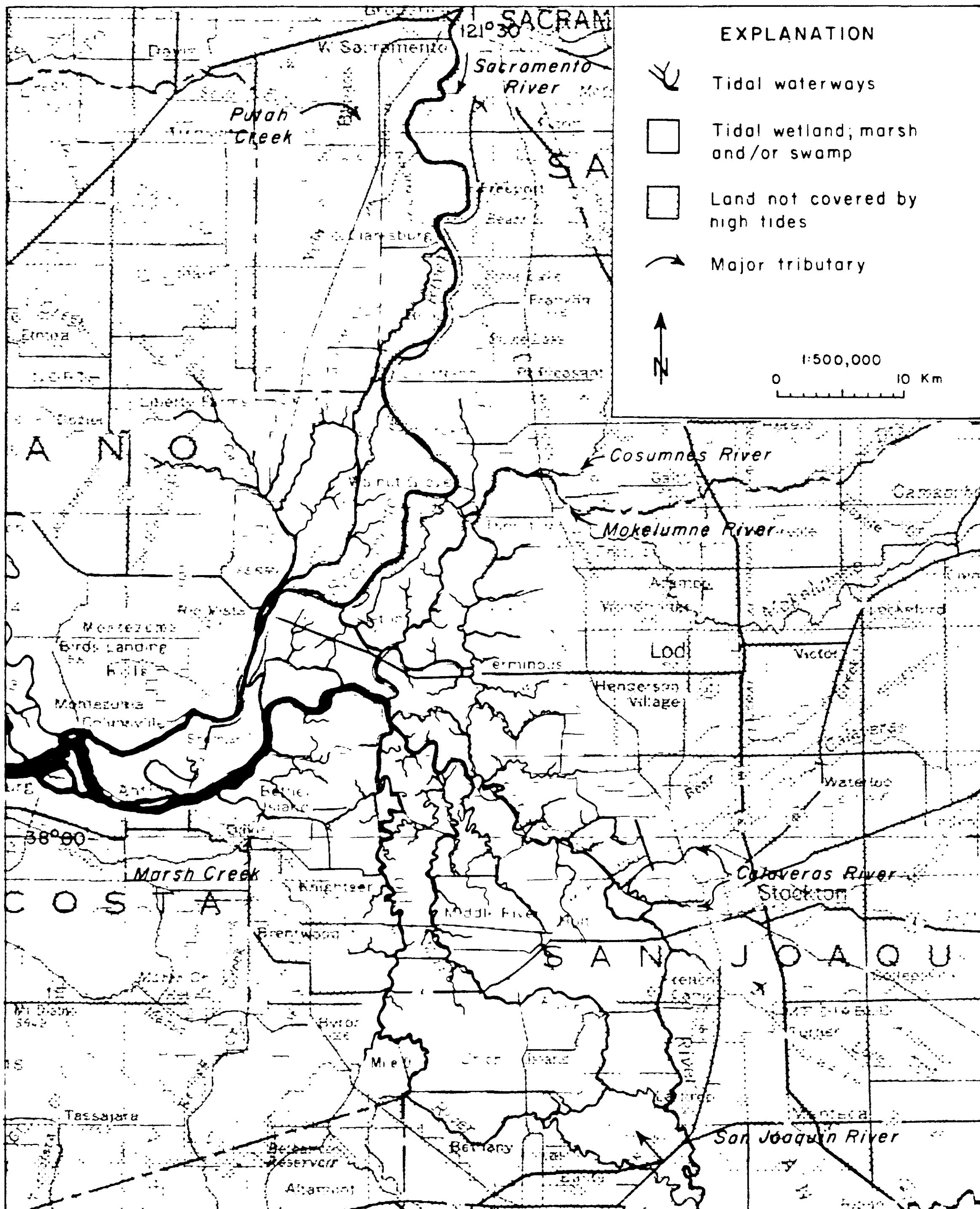

EXPLANATION
Tidal waterways
Tidal wetland, marsh and/or swamp
Land not covered by high tides
Major tributary
N
1:500,000
0 10 Km
SACRAM
121°30'
Sacramento River
Putah Creek
Cosumnes River
Mokelumne River
Lodi
Calaveras River
Stockton
Marsh Creek
38°00'
San Joaquin River
SAN JOAQUI
COSTA
ANO
SA

Figure 3.--Locations of tidal wetlands described in this report and nearest salinity gages operating 1975-1978.

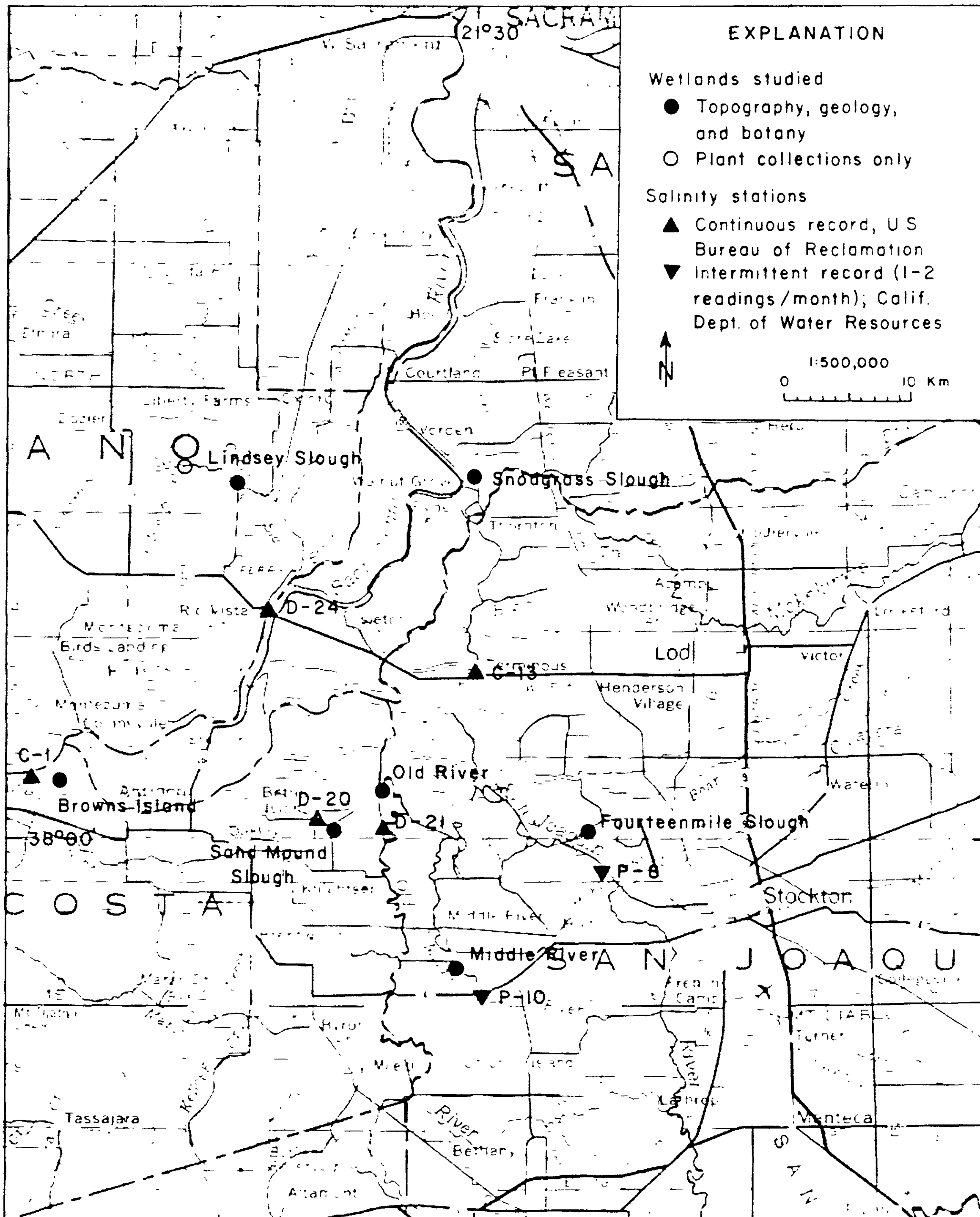
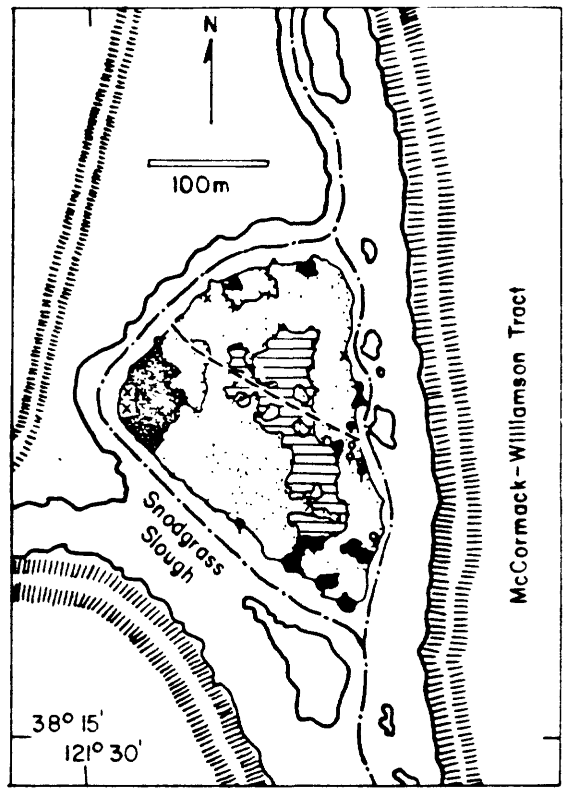

EXPLANATION
Wetlands studied
Topography, geology, and botany
Plant collections only
Salinity stations
Continuous record, U S Bureau of Reclamation
Intermittent record (1-2 readings/month); Calif. Dept. of Water Resources
N
1:500,000
0
10 Km
21°30
SA
Courtland
Pt Pleasant
Lindsey Slough
Snodgrass Slough
Rio Vista
D-24
Lodi
Henderson Village
C-1
Browns Island
38°00
D-20
Sand Mound Slough
Old River
D-21
Fourteenmile Slough
P-8
Stockton
COSTA
Middle River
SAN JOAQU
P-10
Tassajara
River
Bethany
Manteca
Lathrop

Figure 4-9.--Generalized vegetation of tidal islets bordering Snodgrass Slough, Lindsey Slough, Middle River, Old River, Fourteenmile Slough, and Sand Mound Slough. Prepared from 1:6000-scale true-color aerial photographs taken June 26-27 and July 5, 1977, for U.S. Corps of Engineers. Dashed lines represent transects. Tonal patterns related to vegetation by field inspection around magins of islets and along transects. Dot-dash lines in sloughs approximate centerline before erection of levees, as inferred from USGS topographic maps surveyed 1906-1910. Man-made levees shown by double lines of hachures.

F IG. 4



EXPLANATION

x Quercus lobata

Alnus rhombifolia

▲ Acer negundo

\+ Fraxinus latifolia

Cornus stolonifera

Salix spp.

Cephalanthus occidentalis

Cephalanthus occidentalis with Salix hindsiana

Scirpus acutus

FIGURE 5

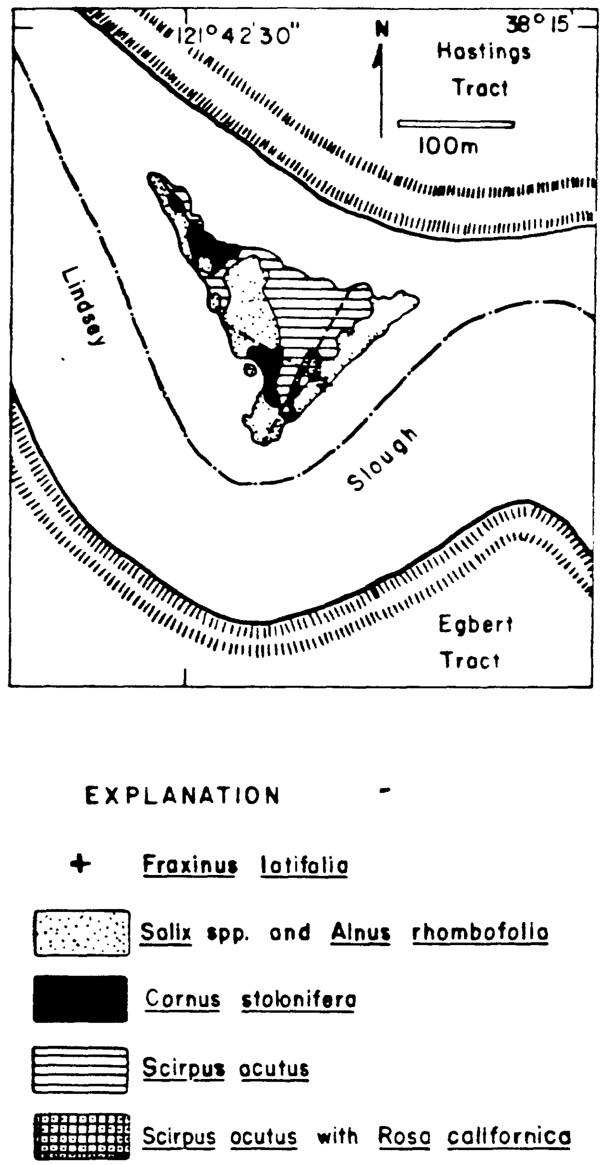

121°42'30"
N
38°15'
Hastings
Tract
100m
Lindsey
Slough
Egbert
Tract
EXPLANATION
Fraxinus latifolia
Salix spp. and Alnus rhombofolia
Cornus stolonifera
Scirpus acutus
Scirpus acutus with Rosa californica

FIGURE 6

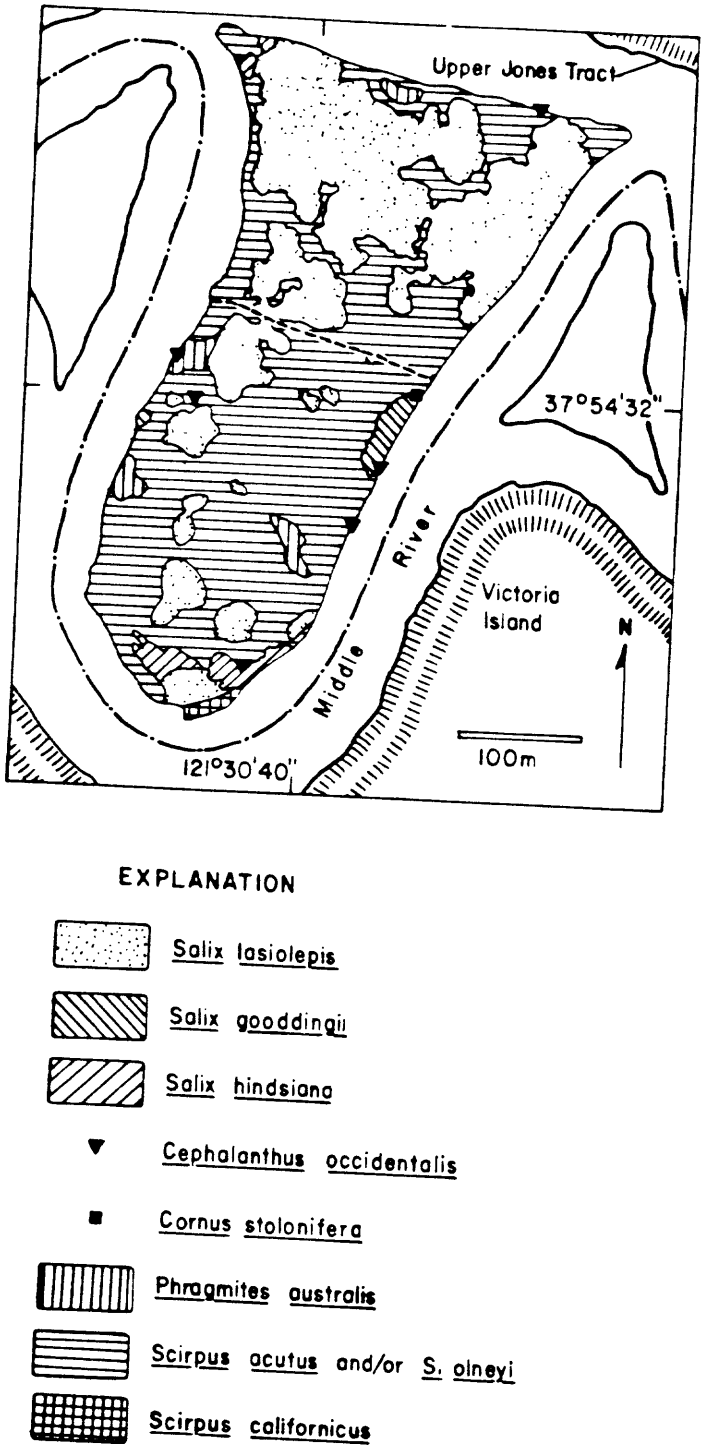
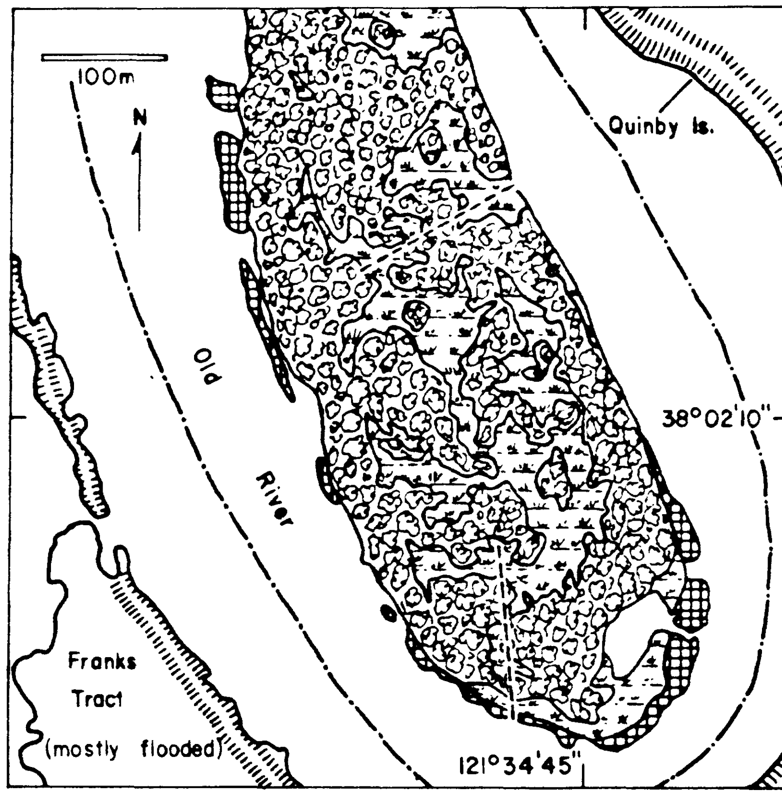

Upper Jones Tract
37°54'32"
Victoria Island
Middle River
N
100m
121°30'40"
EXPLANATION
Salix lasiolepis
Salix gooddingii
Salix hindsiana
Cephalanthus occidentalis
Cornus stolonifera
Phragmites australis
Scirpus acutus and/or S. olneyi
Scirpus californicus

Fig. 7



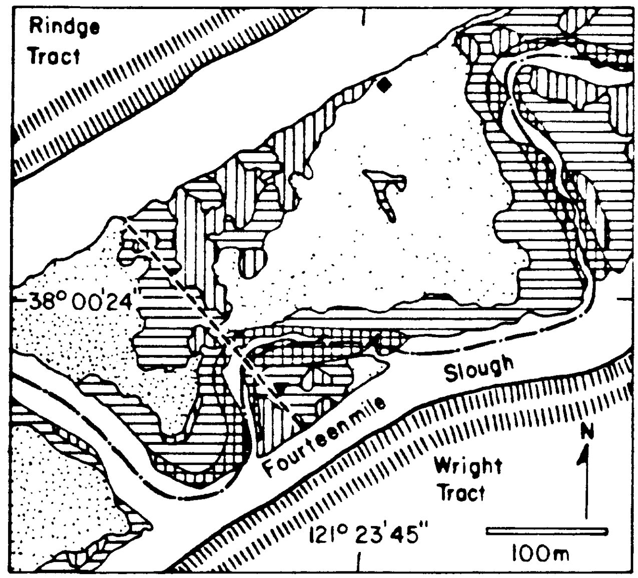
EXPLANATION

Woody plants, largely Salix spp.

Herbaceous plants, largely Scirpus olneyi

Scirpus californicus and robust S. acutus

FIGURE ~~18~~



EXPLANATION

Salix lasiolepis

◆ *Salix gooddingii*

▼ *Cephalanthus occidentalis*

Phragmites australis

Scirpus acutus

Robust *Scirpus acutus* and *S. californicus*

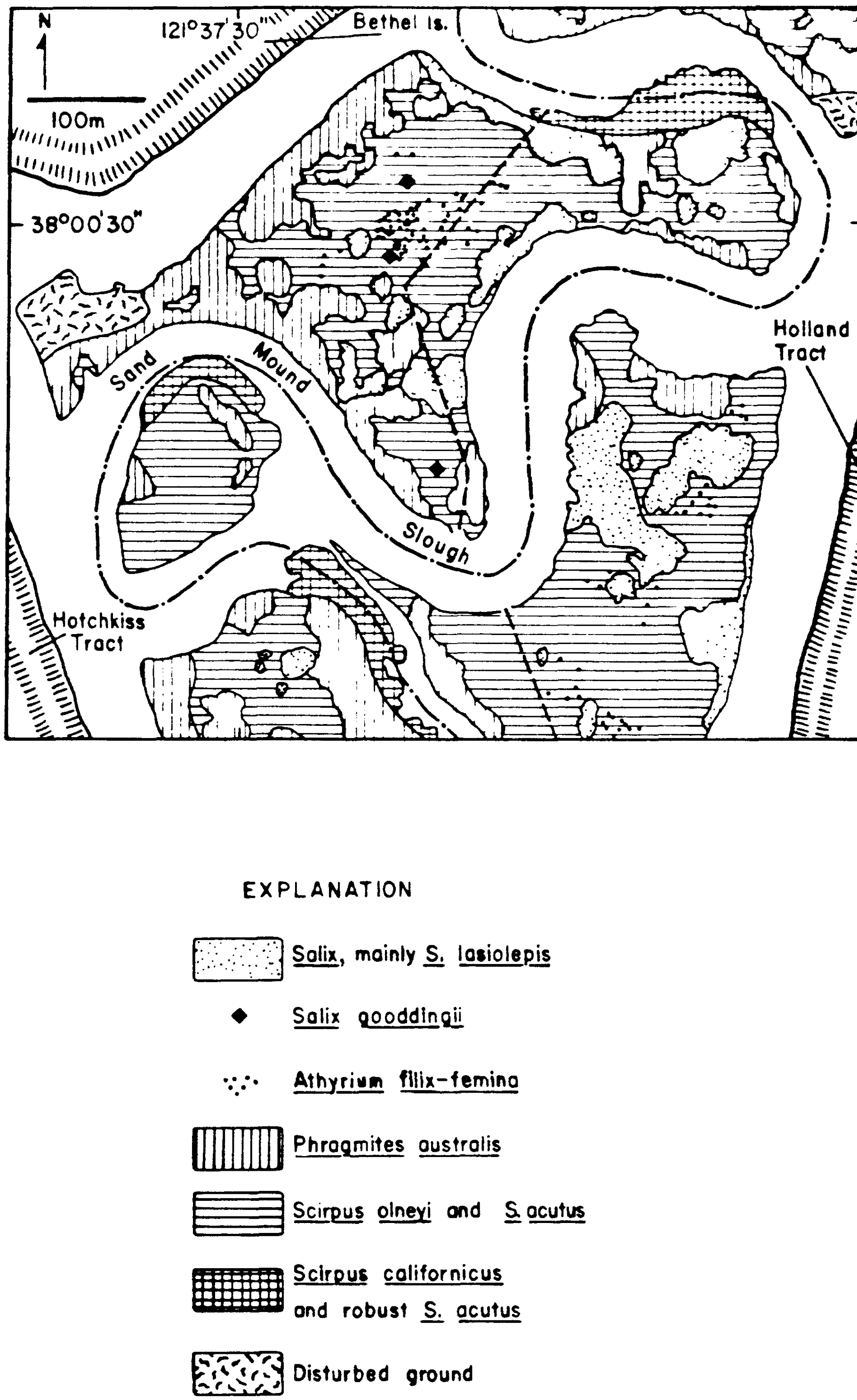
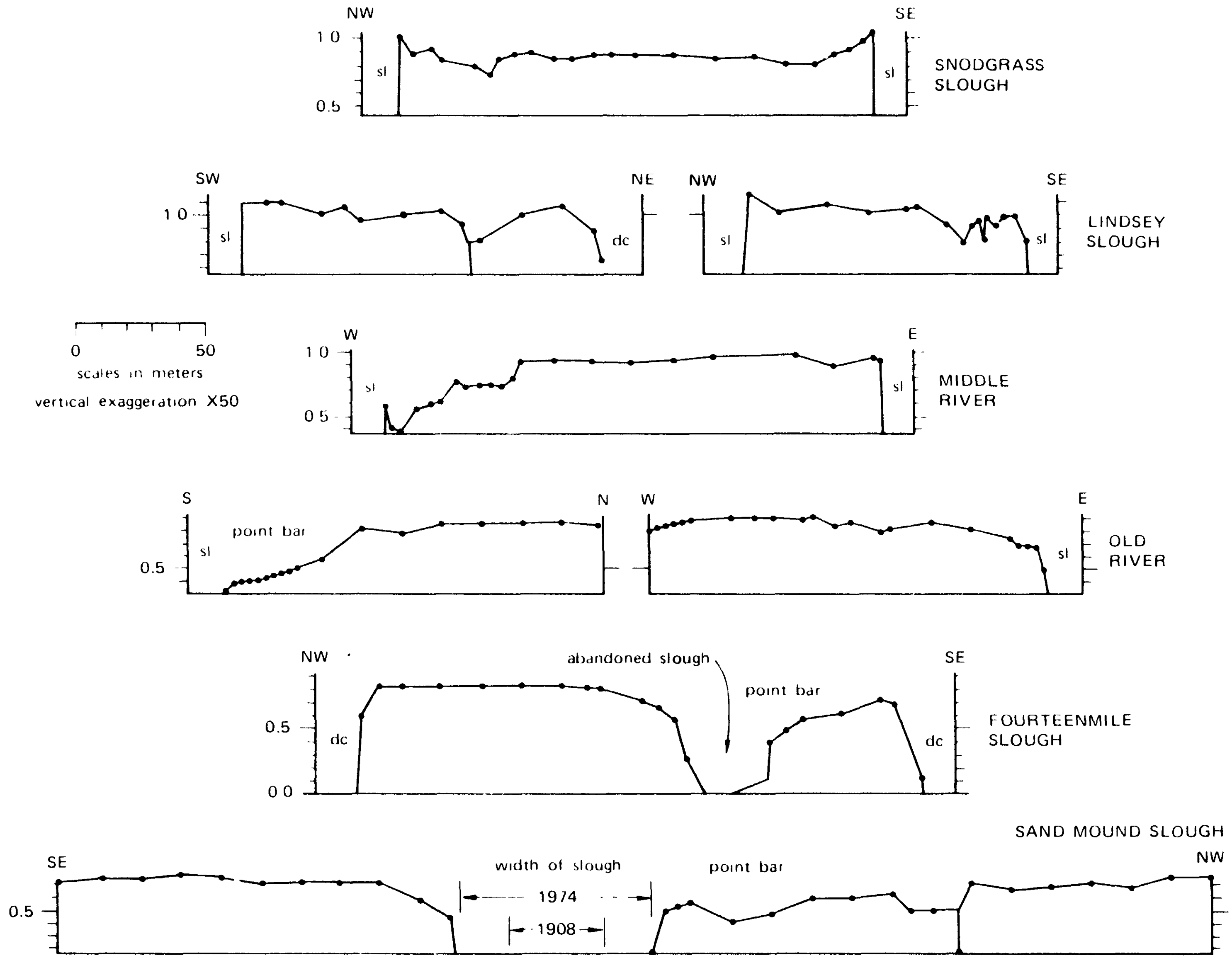

N
121°37'30"
Bethel Is.
100m
38°00'30"
Sand Mound Slough
Holland Tract
Hotchkiss Tract
EXPLANATION
Salix, mainly S. lasiolepis
Salix gooddingii
Athyrium filix-femina
Phragmites australis
Scirpus olneyi and S. acutus
Scirpus californicus and robust S. acutus
Disturbed ground

Figure 10.--Topographic profiles across six tidal islets of the Sacramento - San Joaquin Delta. Dots denote measured elevations. Datum is NGVD. See text for estimation of uncertainties, figs. 12-17 for locations of profiles. Character of waterways bounding profiles as follows: dc, dredger cut, not a natural slough; sl, slough, approximately centered at its pre-Gold Rush location. The profile for San Mound Slough excludes the long northeast-trending dogleg in the transect (fig. 9). Vertical lines on profiles for Lindsey and Sand Mound Sloughs denote channels approx. 0.3 m wide that probably originated as beaver trails.



NW
SE
1.0
0.5
sl
SNODGRASS SLOUGH
SW
NE
NW
SE
dc
LINDSEY SLOUGH
0
50
scales in meters
vertical exaggeration X50
W
E
MIDDLE RIVER
S
N
point bar
OLD RIVER
abandoned slough
0.0
FOURTEENMILE SLOUGH
SAND MOUND SLOUGH
width of slough
1974
1908

Figure 11.--Statistical summary of the occurrence of dominant plants at six tidal wetlands in the Delta and two related localities. Data for Sand Mound Slough from doglegged transect located north of slough. "Mud" at right refers to clay, silty clay, and clayey silt; "peaty mud" to estimated organic contents of 10-50 percent; "peat" to estimated organic contents greater than 50 percent.

Fig. 11.

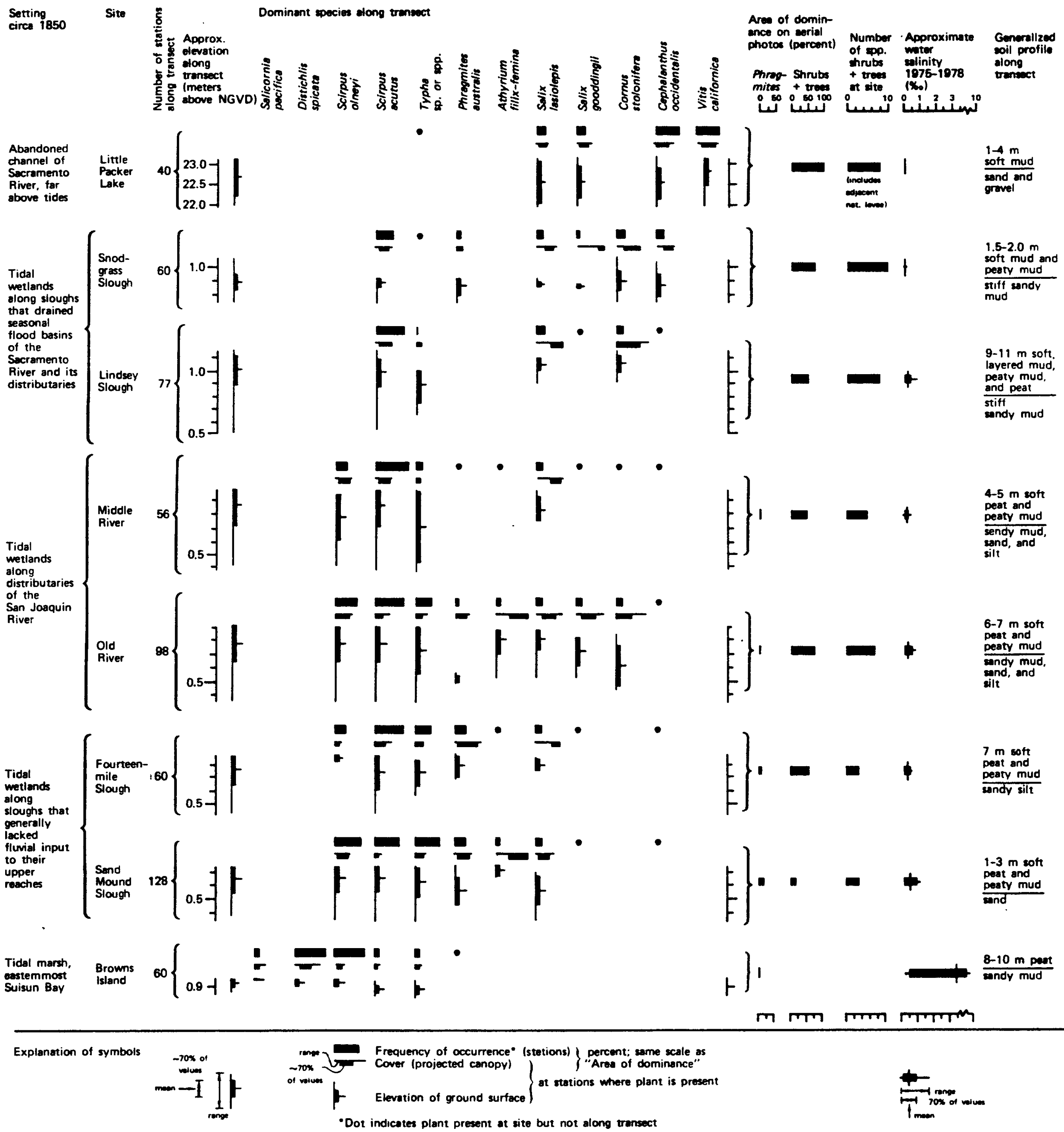
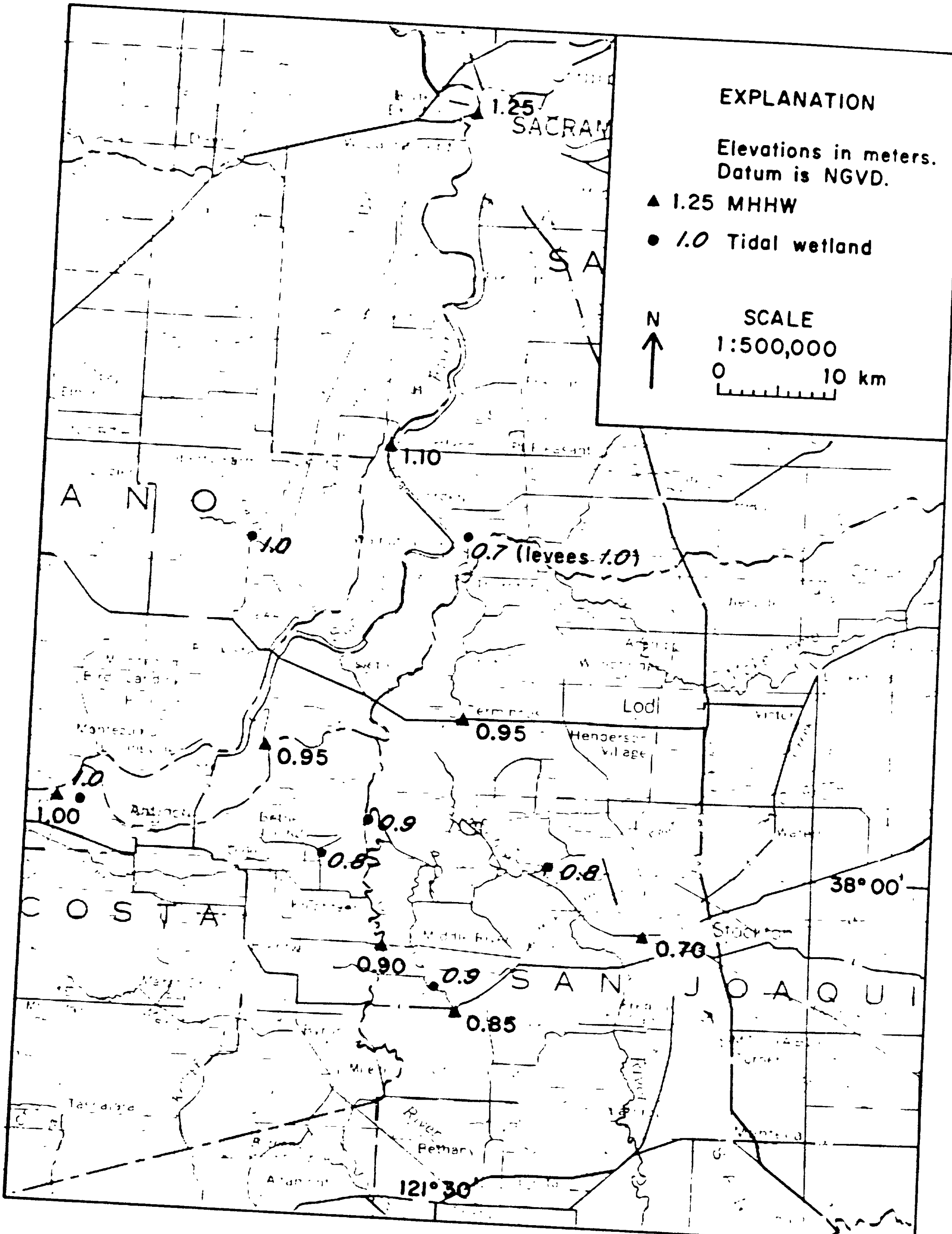

Setting circa 1850
Site
Number of stations along transect
Approx. elevation along transect (meters above NGVD)
Dominant species along transect
Salicornia pacifica
Distichlis spicata
Scirpus olneyi
Scirpus acutus
Typha sp. or spp.
Phragmites australis
Athyrium filix-femina
Salix lasiolepis
Salix gooddingii
Cornus stolonifera
Cephalanthus occidentalis
Vitis californica
Area of dominance on aerial photos (percent)
Phragmites
Shrubs + trees
Number of spp. shrubs + trees at site
Approximate water salinity 1975-1978 (‰)
Generalized soil profile along transect
Abandoned channel of Sacramento River, far above tides
Little Packer Lake
40
23.0
22.5
22.0
(includes adjacent nat. levee)
1-4 m soft mud
sand and gravel
Tidal wetlands along sloughs that drained seasonal flood basins of the Sacramento River and its distributaries
Snodgrass Slough
60
1.0
1.5-2.0 m soft mud and peaty mud
stiff sandy mud
Lindsey Slough
77
1.0
0.5
9-11 m soft, layered mud, peaty mud, and peat
stiff sandy mud
Tidal wetlands along distributaries of the San Joaquin River
Middle River
56
0.5
4-5 m soft peat and peaty mud
sandy mud, sand, and silt
Old River
98
0.5
6-7 m soft peat and peaty mud
sandy mud, sand, and silt
Tidal wetlands along sloughs that generally lacked fluvial input to their upper reaches
Fourteenmile Slough
60
0.5
7 m soft peat and peaty mud
sandy silt
Sand Mound Slough
128
0.5
1-3 m soft peat and peaty mud
sand
Tidal marsh, easternmost Suisun Bay
Browns Island
60
0.9
8-10 m peat
sandy mud
Explanation of symbols
~70% of values
mean
range
Frequency of occurrence* (stations)
Cover (projected canopy)
percent; same scale as "Area of dominance"
Elevation of ground surface
at stations where plant is present
range
70% of values
mean
*Dot indicates plant present at site but not along transect

Figure 12.--Elevations of mean higher high water (MHHW) and of the broad, nearly flat surfaces of tidal wetlands. Tidal data from National Ocean Survey, here rounded to the nearest 0.05 m. Wetland data estimated visually from profiles of figs. 18 and 28, here corrected for probable subsidence of bench marks (see table 2). Uncertainty for most tidal and wetland data is probably close to ±0.1 m.


EXPLANATION
Elevations in meters.
Datum is NGVD.
▲ 1.25 MHHW
● 1.0 Tidal wetland
N
SCALE
1:500,000
0 10 km
1.25
SACRAM
SA
1.10
ANO
1.0
0.7 (levees 1.0)
Lodi
0.95
0.95
Henderson Village
1.0
1.00
0.9
0.8
0.8
38° 00'
COSTA
Stockton
0.70
0.90
0.9
SAN JOAQUI
0.85
River
Bethany
121°30'