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MARSH PLANT ASSOCIATIONS OF SOUTH SAN FRANCISCO BAY: 2002 COMPARATIVE STUDY

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EXECUTIVE SUMMARY

Large-scale plant community changes in the remaining marshes of South San Francisco Bay were first observed in the 1970's. Early studies conducted for the South Bay Dischargers Authority in 1984 confirmed those habitat changes. In 1989, as part of a monitoring program required by the San Francisco Bay Regional Water Quality Control Board, the City of San Jose commissioned a more detailed study of the marshes potentially affected by the freshwater discharge from the Water Pollution Control Plant (WPCP). Subsequent mapping studies were conducted in 1991, 1994, and annually thereafter. These studies documented changes in the distribution and aerial extent of salt, brackish and freshwater marsh. This study is the continuation of the WPCP monitoring program.

The 2002 plant association mapping was done on digital ortho-photos created from georectified, color-infrared aerial photography. All vegetation mapping was done by plant biologists in the field and spot-checked by senior biologists. Acreage calculations by plant associations, dominant species and habitat type were done in Geographic Information Systems (GIS) software, and maps were produced. Comparisons were made between the 2002 mapping and previous years' mapping.

The total marsh area mapped in 2002 was 1650 acres for the Main Study Area and 255 acres for the Reference Site. Brackish marsh plant associations dominated the Upper Reaches of the Main Study Area as well as the Reference Area. The Lower and Transition Reach segments are primarily dominated by salt marsh plant species; the Lower Reach has only 16 acres of brackish marsh habitat. Although a similar distribution of habitats is noted in the Reference Area, brackish marsh habitats comprise a much greater proportion of the area than in the Main Study Area.

The surface area of marsh habitat has increased by 231.5 acres (17%) between 1989 and 2002 within the Main Study Area. During the same period, 62.9 acres (37%) of new marsh has formed in the Reference Area. A total of 10.5 acres of salt marsh habitat has converted to brackish marsh habitat from 1989 to 2002 in the Main Study Area. During the same period, 28.7 acres of salt marsh habitat has converted to brackish marsh in the Reference Area.

The entire study area has become less saline since 1989. Newly-forming freshwater marsh habitat in both the Reference Area and the Main Study Area indicates that freshwater influences are affecting all marshes in the vicinity. From 1989 - 2001, the net salt marsh acreage within the Main Study Area was relatively stable during this period of increased freshwater impacts. During the past year, brackish marsh conversion to salt marsh has increased the total area of salt marsh habitat and tipped the balance. Most of the conversion of brackish marsh to salt marsh has occurred in the Transition and Lower Reaches and in the Reference Reach.

Between 1989 and 1999 the relative change in habitat types through time was less in the Main Study Area than in the Reference Area although the rate of new marsh formation in the Main Study Area had exceeded that of the Reference Area. This indicates that much of the conversion of salt marsh habitats within the South San Francisco Bay area was likely driven by large-scale

influences affecting the entire system. However, in 2001 small gains in salt marsh habitat occurred and in 2002 even greater gains in salt marsh habitat were observed. This trend further highlights the influence of multiple factors affecting changes in marsh vegetation communities in South San Francisco Bay.

The WPCP has had past influences on the plant species distribution in the South Bay Marshes. For example, the majority of Artesian Slough, a slough that dead ends at the discharge point for the WPCP, is freshwater marsh habitat. Without the WPCP discharge we would predict that Artesian Slough would consist of a mixture of brackish and salt marsh habitats. However, WPCP discharges have been relatively constant since 1990 and only 10 acres of salt marsh conversion occurred in the Main Study Area in 13 years. It is likely that much of the interannual variation in habitats within the South Bay marshes is due to large scale environmental factors (e.g. changes in annual rainfall patterns and bay salinity due to delta outflows).

INTRODUCTION

Large-scale plant community changes in the marshes of South San Francisco Bay were first observed in the 1970's (H. T. Harvey & Associates 1984). Brackish marsh plants were colonizing areas that had previously been vegetated with salt marsh plants. Based upon those observations, causal mechanisms for the vegetation change were reviewed. A potential cause of that change was freshwater input from the San Jose/Santa Clara Water Pollution Control Plant (WPCP).

Early studies confirmed the observed changes in plant species composition (H. T. Harvey & Associates 1984). Efforts were made to determine the extent of changes through time by examining historical aerial photography (CH2MHill 1989). These studies relied on historical aerial photographs of different scales, and since they were historical, could not be field-truthed. However, the data indicated that large-scale vegetation changes (both marsh type conversion and new marsh formation) were occurring in the marshes of South San Francisco Bay.

In 1989, as part of a monitoring program required by the San Francisco Bay Regional Water Quality Control Board (RWQCB), the City of San Jose commissioned a more detailed study of the marshes potentially affected by the freshwater discharge from the WPCP (H. T. Harvey & Associates 1989). Simultaneously, and also at the behest of the RWQCB, the Sunnyvale WPCP commissioned a study of the vegetation of the marshes in Guadalupe and Alviso Sloughs. Both of these studies included the collection of new aerial photography and detailed mapping of dominant plant species in the field. These data now provide the baseline for comparison of changes in plant species distribution in the marshes of South San Francisco Bay.

Subsequent mapping studies were conducted by the City of San Jose in 1991, 1994, and annually thereafter. These studies documented changes in the distribution and extent of salt, brackish and freshwater marsh (CH2MHill 1989, H.T. Harvey & Associates 1990a, 1990b, 1991, 1995, 1996, 1997, 1998, 1999, 2000 and 2001a). Starting in 1994 it was recognized that the Alviso Slough mapping, conducted for the Sunnyvale WPCP, could serve as a reference area for the City of San Jose's vegetation mapping. To use Alviso Slough as a reference area for these studies, it was assumed that discharges from the San Jose/Santa Clara WPCP did not flow 'upstream' into Alviso Slough, and directly impact its marshes. This assumption is addressed in the mapping analysis. Furthermore, Alviso Slough does receive direct freshwater discharge from the Guadalupe River; just as the main study area receives freshwater discharge from Coyote Creek. Therefore, all mapping efforts since 1995 have included the main study area and this additional reference area (Alviso Slough).

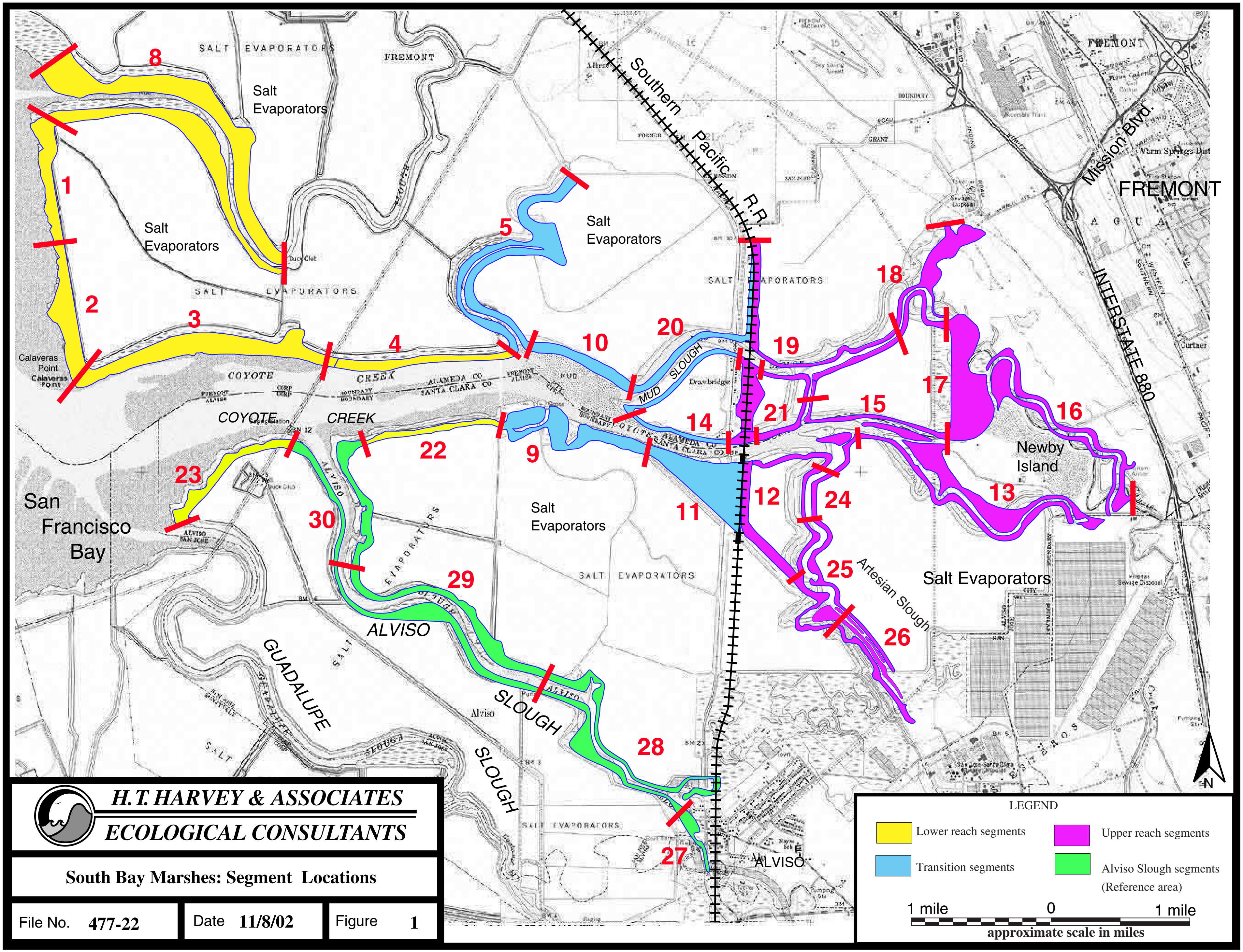
The dominant plant species of tidal salt marshes in South San Francisco Bay include pickleweed (mainly *Salicornia virginica*) and cordgrass (*Spartina* sp.). Pickleweed dominated salt marsh provides habitat for a unique assemblage of animal species including the federally and state-endangered salt marsh harvest mouse (*Reithrodontomys raviventris raviventris)* and California Clapper Rail (*Rallus longirostris obsoletus*). Therefore, it is important to determine the area of vegetation change as well as to identify the factors responsible for the observed conversion of salt marsh habitat to brackish and freshwater marsh habitats. Furthermore, it is important to understand to what extent this conversion is caused by natural, region-wide environmental change versus anthropogenic changes such as freshwater discharge from the San Jose/Santa Clara WPCP and dry-weather releases from local reservoirs.

Research has shown that a number of variables control the distribution of plant species in coastal marshes. The most obvious of these factors, surface water and soil salinity, correlate significantly with vegetation distributions (Callaway and Sabraw 1994, Allison 1992, Callaway et al. 1989, Zedler 1983, 1986). For example, Zedler (1983) documented the conversion of a pickleweed-dominated salt marsh to a cattail-dominated (*Typha dominguensis*) freshwater marsh along the San Diego River. She found that the conversion was highly correlated with prolonged reservoir discharges that continued well beyond the normal rainy season, thereby decreasing salinities.

However, many other factors also influence marsh species composition including: depth and duration of flooding over the marsh surface (Webb and Mendelssohn 1996, Webb et al. 1995, Pennings and Callaway 1992, Mendelssohn and McKee 1988), accumulation of phytotoxins such as hydrogen sulfide in marsh soils (Webb and Mendelssohn 1996, Webb et al. 1995, Koch and Mendelssohn 1989, DeLaune et al. 1983, King et al. 1982), interstitial nutrient concentrations (Koch et al. 1990, Bradley and Morris 1980, Koch and Mendelssohn 1989, Morris 1980) and soil mineral and organic matter content (Nyman et al. 1990, DeLaune et al. 1979). Natural variability in abiotic factors such as precipitation, tidal fluctuation, and evapotranspiration, as well as anthropogenic changes to those factors such as freshwater discharges, non-point source pollution (nutrients and sediments), and regional/global climate changes (drought, temperature, sea level) influence these variables. Warren and Niering (1993) found increased flooding frequency, from sea level rise, altered tidal marsh plant associations in the northeastern United States.

Competition between different plant species (interspecific) with similar environmental tolerances also influences their distributions. Although environmental tolerance and competitive ability are inversely related (Grace and Wetzel 1981, Zedler 1982, Bertness 1991), competition still plays a role among species with similar tolerances. For example, Zedler (1982) found that competitive interactions occur in salt marshes, and concluded that pickleweed does compete with cordgrass for light and to some extent, nutrients.

This study continues the vegetation monitoring of the marshes in South San Francisco Bay that began in 1989. The vegetation mapping conducted by this study determines the spatial location and extent of change in plant communities. This study does not monitor or experimentally manipulate variables that can be responsible for the observed changes. Therefore, the vegetation mapping of the marshes in South San Francisco Bay tracks any changes over time; comparisons are limited to interannual rates of change between the main study area and a reference area.



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South Bay Marshes: Segment Locations

File No. 477-22 | Date 11/8/02 | Figure 1

SURVEY METHODS

STUDY AREA

For the purposes of data collection and analysis, we divided the study area into 28 segments as defined in the 1989 study (H. T. Harvey & Associates 1990a; Figure 1). We then sub-divided the study area into four reaches (Upper Reach segments, Transition Reach segments, Lower Reach segments, and Reference Reach) to provide a more easily comprehensible method of analyzing the data and presenting the results (Figure 1). The Upper (approximately 440 acres), Transition (approximately 390 acres), and Lower Reach (approximately 740 acres) segments, referred to as the Main Study Area are located within the Coyote Creek watershed and include Segments 1-5 and 8-26 (Figure 1). Segments 27-30 (Reference Area - approximately 225 acres) are located along the lower Guadalupe River, also known as Alviso Slough (Figure 1). This study assumes that the WPCP discharge does not significantly influence the Reference Area, and therefore provides a suitable control site for documenting vegetation changes in South San Francisco Bay.

AERIAL PHOTOGRAPHY AND ORTHORECTIFICATION

The subconsultant responsible for aerial photography acquisition and digital imagery production, HJW Geospatial, Inc., took color-infrared (CIR) aerial photographs of the entire study area. These aerial photographs were taken on July 30, 2002. Photographs were taken from an altitude of 8500 feet using a 6-inch camera lens. The flight was scheduled during negative tidal elevation and 30 to 45 degree solar angle.

The photographs were orthorectified to remove any distortion of the scale across the image caused by various factors including curvature of the earth's surface, topographic changes, and tilt of the camera lens. The use of orthorectified photographs adds greater accuracy to the estimation of polygon areas on the vegetation map.

The ortho processing procedure involved several consistent production steps, each including important inspections. First the film diapositive was scanned and thereby converted into a computer rasterized image. Scanning diapositives were made from the photography prior to any editing or other handling of the film. These diapositives were placed in individual sleeves to be kept free of dust, scratches, and any other blemishing agents. HJW maintains an environmentally controlled clean room for performing all photo scans to help eliminate airborne dust. The diapositives were scanned on a high precision Vexcel VS4000 scanner at the aperture of 25 microns. No pixels were resampled to convert to a finer resolution.

To correct an aerial photo for distortion caused by terrain; a digital terrain model (DTM) must be included in the ortho processing. HJW produced a DTM, not only capable of accurately generating the orthophotos, but sufficient for generating the digital elevation model (DEM) as well. Once scanned, HJW used OrthoView™ software to orthorectify the images and orient them into the California State Plane Coordinate System through the sensor orientation process. Control from the aerotriangulation and ground survey data from existing control points in HJW's database was used to tie the digital images to real world coordinates. The DTM collected from the stereo photography was used during the digital orthorectification process to adjust each image pixel into its correct position. HJW used a cubic convolution algorithm to perform the ortho processing. This technique provides a much more accurate solution than nearest neighbor methods.

Each image was visually checked and radiometrically enhanced if needed. Neighboring images were viewed and if problems were detected, they were featured, or blended, along their edges to reduce radiometric differences. Where two adjoining images contain water (i.e., without land features) at the junction, radiometric differences were not removed. Sun angles on water can result in severe tonal discontinuities that are quite labor intensive to repair. All digital orthophotographs were visually compared with the original unrectified image to verify radiometric accuracy.

VEGETATION ASSOCIATION MAPPING AND AREA CALCULATIONS

Field surveys and analysis of vegetation followed a protocol that began with mapping plant associations (comprised of either a single dominant individual plant or two dominant plants) onto clear acetate overlays that were placed directly over the digital images of the orthorectified CIR photos (1:200 projection). These associations were subsequently assigned to one of three marsh types (i.e. salt marsh, brackish marsh or freshwater marsh) based upon the relative salinity tolerance of these species following the protocol established in the baseline study (H. T. Harvey & Associates 1990a). In order to facilitate comparison of results between monitoring years, vegetation associations were assigned to dominant species categories (as defined below). Dominant species categories, marsh types and vegetation associations are presented in Appendix F.

Topographic features, marsh boundaries, and obvious (but tentative) vegetation associations (based on color signatures and experience) were mapped in the office prior to field visits. Complete ground-truthing of both the preliminary mapping and all field mapping was then conducted during site visits from 12 August to 30 August 2002. Marsh vegetation was observed primarily from areas directly adjacent to the marshes in order to maintain consistency with the methods employed in previous years and also follow U.S. Fish and Wildlife Service (USFWS) guidelines and regulations. Marshes were, therefore, observed primarily from levee roadways, railroad beds, unimproved salt pond levees and Pacific Gas and Electric (PG&E) walkways. Only when necessary and allowed by USFWS regulations were vegetation associations verified by walking in those marshes areas that were not clearly visible from adjacent levees and upland areas. Access to the Study Area was obtained from the USFWS San Francisco Bay National Wildlife Refuge (Ms. Joy Albertson 510.792.0222) and Cargill Salt Division, Newark, CA., (Mr. Chuck Taylor 510.797.1820).

The field vegetation mapping (acetate overlays) were scanned and electronically digitized by Geographic Computer Technologies (Kenner, LA). The maps were then linked to the digital orthos images. Plant association acreages and color-coded figures for the entire Study Area were generated by GIS systems ArcInfo and ArcView.

VEGETATION ASSOCIATION CATEGORIZATION METHODS

Any species that occurred as a dominant, co-dominant or sub-dominant in any portion of the study area was mapped. For the purposes of this study a dominant species had a percent cover of 51-100%, co-dominant species have roughly equal percent coverage, and sub-dominant species have between 15 and 49 percent cover.

Each species was then assigned to a vegetation association comprised of one dominant, a dominant and subdominant, or two or more co-dominant species. The three types of vegetation associations are described below:

Dominant - An area that consists of one dominant species that comprises approximately 85-100% of the cover is named solely for that species, so that the vegetation association called Pickleweed consists of from 85-100% Pickleweed and less than 15% of other unspecified species.

Dominant/sub-dominant - If one species comprises between approximately 51-85% of the cover in a particular area, and another species comprises 15-49% cover in that same area, then this is dominant/sub-dominant vegetation association. The association is named for both species, with the more abundant species listed first. The category called Pickleweed/Alkali bulrush could therefore consist of 51-85% cover of Pickleweed and 15-49% cover of Alkali bulrush.

Co-dominant - Two co-dominant associations were identified: Pickleweed-Cordgrass (*Spartina foliosa*) Mix and Saltgrass (*Distichlis spicata*)-Gumplant (*Grindelia* sp.) Mix. The species mixes represent approximately equal amount of each species and their combined total coverage exceeds 85%.

The upland species category consists of species not considered by the USACE to be wetland indicators. These include ruderal species such black mustard (*Brassica nigra*), ripgut grass (*Bromus diandrus*), bristly ox-tongue (*Picris echioides*), sweet fennel (*Foeniculum vulgare*), and coyote brush (*Baccharis pilularis*). The peripheral halophyte category consists of a patchwork of species that occur along salt marsh edges, such as levee slopes. This mixture, in which no one species generally exceeds 15% of the cover, includes pickleweed and various peripheral halophyte species such as alkali heath (*Frankenia salina*), Australian salt-bush (*Atriplex semibaccata*) and slender-leaved iceplant (*Mesembryanthemum nodiflorum*).

Plant species associations were grouped into 15 dominant species categories (e.g. alkali bulrush/peppergrass association is an alkali bulrush dominant species category). These dominant species categories were then assigned to one of four habitat types: salt marsh, brackish marsh, freshwater marsh and upland. A number of assumptions about grouping dominant species into appropriate habitat types were made. These include:

- Relative salt tolerance of dominant plant species;
- Edaphic characteristics of the South Bay Marshes that may control plant species distribution;

- Historic relationships within this study, and;
- Relationships between dominant plant species and wildlife use.

Certain plant species for which salinity tolerance data are lacking (e.g. peppergrass) were categorized into habitat types based on relative location in the marsh plain or known wildlife use. This assumption and the potential uncertainties related to assigning plant species to habitat type categories has been understood throughout the study period and was stated in the 1989 (baseline) study (H. T. Harvey & Associates 1990a). The habitat classification scheme first used in the baseline study is carried through to this study to collect comparable data.

DIGITIZATION OF BASELINE DATA (1989)

To improve area comparisons and the precision of the baseline data, the 1989 data was digitized and rectified to the 2001 orthophotos (H. T. Harvey & Associates 2001a). The original 1989 maps of the plant species association were used for digitization. Initially polygons by species were colored by hand. Specific colors were chosen to represent different plant associations. The maps were scanned and colors were amplified and gaps in coloring filled in Adobe Photoshop. Topology was then built using Image Analysis 1.1a for ArcView. The images were georectifed to the 2001 data using ImageAnalysis. SeedTool was used to select the colors and all like colors are attributed and turned into polygons. This step was completed for all colors. Area calculations were conducted in ArcView.

AREA COMPARISONS

Analysis of potential marsh conversion within the Main Study and Reference Areas involved a multi-step process that began at a total marsh area level and proceeded to a more specific, segment-level analysis. The first task involved comparing the relative acreage change in marsh type and dominant species categories between years. The current year's results are compared to baseline year 1989. When a significant shift in marsh acreage occurred, the dominant species categories responsible for that shift were also identified.

In order to identify where significant acreage changes had occurred, the marsh was divided into four areas based upon segment location: Upper, Transition, Lower and Reference (Alviso Slough) (Figure 1) as described earlier. These are outlined in Table 1.

Table 1. South Bay Marsh Segments and Their Reaches.

Segment	Reaches
Lower (Mouth of Coyote Creek)	1, 2, 3, 4, 8, 22 and 23
Transition (Draw Bridge)	5, 9, 10, 11, 14 and 20
Upper (Newby Island)	12, 13, 15, 16, 17, 18, 19, 21, 24, 25 and 26
Reference (Alviso Slough)	27, 28, 29 and 30

A comparison of marsh habitat acreage data from all years (1989, 1991, 1994, 1996, 1997, 1998, 1999, 2000, 2001, and 2002) by location (reach) was also conducted to compare trends between reaches. The final step in the analysis overlaid the data from the 1989 mapping onto 2002 data in ArcView to determine, with confidence, the location and size of change in marsh area and habitat type.

Dominant species and habitat maps were produced for each of the four segment locations. The maps were produced from an ArcView database and the full mapping for all segments by plant species association is available electronically.

RESULTS

GENERAL SPECIES DISTRIBUTION, DOMINANT SPECIES CATEGORY AND HABITAT ACREAGES FOR 2002

Main Study Area

The spatial distribution of dominant plant species and habitat types for the 2002 data are presented in Appendix B for each of the three segment locations within the Main Study Area (figure scales vary). The area of habitat types and associated dominant plant species for the Main Study Area are shown in Table 2. The dominant plant species within the Main Study Area are alkali bulrush and pickleweed (Table 2); these two species comprise approximately 68% of the marsh within the Main Study Area. In the past several years, the total acreage of salt marsh habitat and brackish marsh habitat within the Main Study Area were nearly equal. However, in 2002, the area of salt marsh is substantially greater than the area of brackish marsh habitats within the Main Study Area.

The Upper Reach segments (Figure 1, Appendix B) consist primarily of brackish marsh associations dominated by either pure stands or mixtures of alkali bulrush and peppergrass (*Lepidium latifolium*). The Lower Reach segments (nearest San Francisco Bay, Figure 1, Appendix B) are comprised primarily of single-species stands or mixtures of the salt marsh plant species dominated by pickleweed and cordgrass. Although cordgrass and pickleweed are most abundant in the Lower Reach segments, both occur at low abundance even in the furthest upstream segments (although sometimes in patches too small to map). Conversely, peppergrass is most abundant in the Upper Reach segments, but is found throughout most of the Main Study Area (Appendix B). Alkali bulrush occurs throughout the Main Study Area and is the dominant plant species of brackish marsh associations in South San Francisco Bay. The Transition Reach, intermediate to the furthest upstream and downstream reaches, supported significant amounts of both salt and brackish species, which sometimes occurred in mixed associations (both brackish and salt marsh plant species).

Table 2. Summary of Acreages of the Main Study Area by Dominant Species Categories for Each Habitat Type for 2002.

DOMINANT SPECIES CATEGORY	2002
Salt Marsh Categories	
Cordgrass	97.62
Pickleweed	685.59
Pickleweed-Cordgrass Mix	112.78
Saltgrass	0.40
Alkali Heath	7.44
Gumplant	36.71
Peripheral Halophytes	19.14
Misc. Others	0.68
Sub-Total	**960.36**
Brackish Marsh Categories	
Alkali Bulrush	435.29
Peppergrass	154.00
Spearscale	17.66
Misc. Others	0.33
Sub-Total	**606.89**
Freshwater Marsh Categories	
California Bulrush	74.64
Cattail	6.69
Misc. Others	1.38
Sub-Total	**82.71**
TOTAL	**1649.95**

Reference Area (Alviso Slough)

The spatial distribution of dominant plant species and habitat types in the Reference Area are presented in Appendix B. The 2002 plant association areas for Alviso Slough are presented in Table 3. Plant species within the Reference Area have a general distribution similar to the Main Study Area in terms of a progression from freshwater to brackish and salt marsh species extending from upstream to the confluence with Coyote Creek. However, instead of pickleweed, alkali bulrush is the dominant plant species within the Reference Area. During the past several years brackish marsh habitat comprised nearly three times the area of salt marsh habitat.

However, in 2002, the ratio between brackish and salt marsh habitat has decreased and brackish marsh habitat is now only about twice the area of salt marsh habitat.

Brackish marsh associations occur throughout Alviso Slough. Patches of alkali bulrush occur as far downstream as Segment 30 (near the confluence with Coyote Creek). Freshwater marsh associations are concentrated in the upstream portions of the slough (nearest the Union Pacific Railroad crossing) and salt marsh associations dominate the downstream areas.

Table 3. Summary of Acreages of the Reference Area (Alviso Slough) by Dominant Species Categories for Each Habitat Type for 2002.

Dominant Species Category	2002
Salt Marsh Categories	
Cordgrass	21.20
Pickleweed	47.39
Peripheral Halophytes	5.51
Misc. Others	0.8
Sub-Total	**74.9**
Brackish Marsh Categories	
Alkali Bulrush	117.14
Peppergrass	36.52
Spearscale	0.07
Misc. Others	0.00
Sub-Total	**153.73**
Freshwater Marsh Categories	
California Bulrush	16.48
Cattail	9.62
Misc. Others	0.45
Sub-Total	**26.45**
TOTAL	**255.18**

Summary

Brackish marsh plant associations dominated the Upper Reach of the Main Study Area as well as the Reference Reach. The Transition Reach is comprised of both salt and brackish marsh habitats. Only the lower reach segments remain primarily dominated by salt marsh plant species. Although a similar distribution of habitats is noted in the Reference Area, brackish marsh habitats comprise a much greater proportion of the area than in the Reference Area.

TEMPORAL AND SPATIAL CHANGES IN MARSH HABITAT ACREAGES FROM 1989 THROUGH 2002

This comparison does not include data from segments 24, 25 and 26 (Artesian Slough) of the Main Study Area and segment 27 (vicinity of the Gold Street Bridge) of the Reference Area since they were not mapped in 1989. Additionally, the Reference Area was not mapped in 1994, therefore only data from the Main Study Area in 1994 is included in the temporal and spatial evaluation. Data from 1991, 1994 and 1996 – 1999 are not derived from orthophotos.

New Marsh Formation (Salt, Brackish, and Freshwater Marsh Combined)

The surface area of marsh habitat has increased by 231.5 acres between 1989 and 2002 within the Main Study Area (Upper, Transition and Lower Reaches Combined) (Table 4). During the same period, 62.9 acres of new marsh has formed in the Reference Area (Table 5). This equates to a 17% increase in marsh acreage in the Main Study Area and a 37% increase in marsh acreage in the Reference Area between 1989 and 2002.

Marsh area remained relatively stable from 1989 to 1996 in the Main Study Area (Figure 2). The formation of new marsh habitat in the Main Study Area has occurred primarily between 1996 and 2002 in the Lower Reach and between 1996 and 1998 in the Transition Reach (Figure 2). Gains in marsh area between 1989 and 2002 were greatest in the Lower Reach (nearly 200 acres), while only 30 acres of new marsh formation has occurred in the Transition Reach. The majority of new marsh formation has occurred in the Lower Reach along the north side of Coyote Creek, immediately upstream of Calaveras Point. Marsh area has increased steadily in the Lower Reach from 1996 through 2002 however a slight decrease occurred between 1999 and 2000 (Figure 2). In contrast, in the Transition Reach marsh area increased in 1997 and 1998 but decreased slightly in 1999, 2000 and 2001 (Figure 2). There was only a slight increase in marsh area in the Transition Reach between 2001 and 2002. Compared to the Lower and Transition Reaches, the surface area of marsh in the Upper Reach has remained relatively stable throughout this 13 year study (Figure 2).

A trend of increasing marsh area is apparent from 1989 through 1999 in the Reference Area (Figure 2). However, a decline in total marsh acreage in the Reference Area occurred between 1999 and 2001 followed by a slight increase in area between 2001 and 2002.

Table 4. Summary of Acreages of the Main Study Area by Dominant Species Categories for Each Habitat Type for 2002.*

Dominant Species Category	1989	2002	Change	Percent Change
Salt Marsh Categories				
Cordgrass	84.15	97.62	13.47	16%
Pickleweed	669.07	684.79	15.72	2%
Pickleweed-Cordgrass Mix**	0.00	112.78	-	-
Alkali Heath**	0.00	7.44	-	-
Gumplant**	0.00	36.71	-	-
Peripheral Halophytes	25.60	19.02	-6.58	-25%
Misc Others	0.13	1.08	0.95	731%
Sub-Total	**778.95**	**959.44**	**180.49**	**23%**
Brackish Marsh Categories				
Alkali Bulrush	489.64	427.56	-62.08	-13%
Peppergrass	66.10	139.16	73.06	111%
Spearscale**	0.00	17.30	-	-
Misc. Others	0.00	0.33	0.33	-
Sub-Total	**555.74**	**584.35**	**28.61**	**5%**
Freshwater Marsh Categories				
California Bulrush	0.00	18.74	18.74	-
Cattail	0.00	3.67	3.67	-
Misc. Others	0.00	0.02	0.02	-
Sub-Total	**0.00**	**22.43**	**22.43**	**-**
TOTAL	**1334.69**	**1566.22**	**231.53**	**17%**

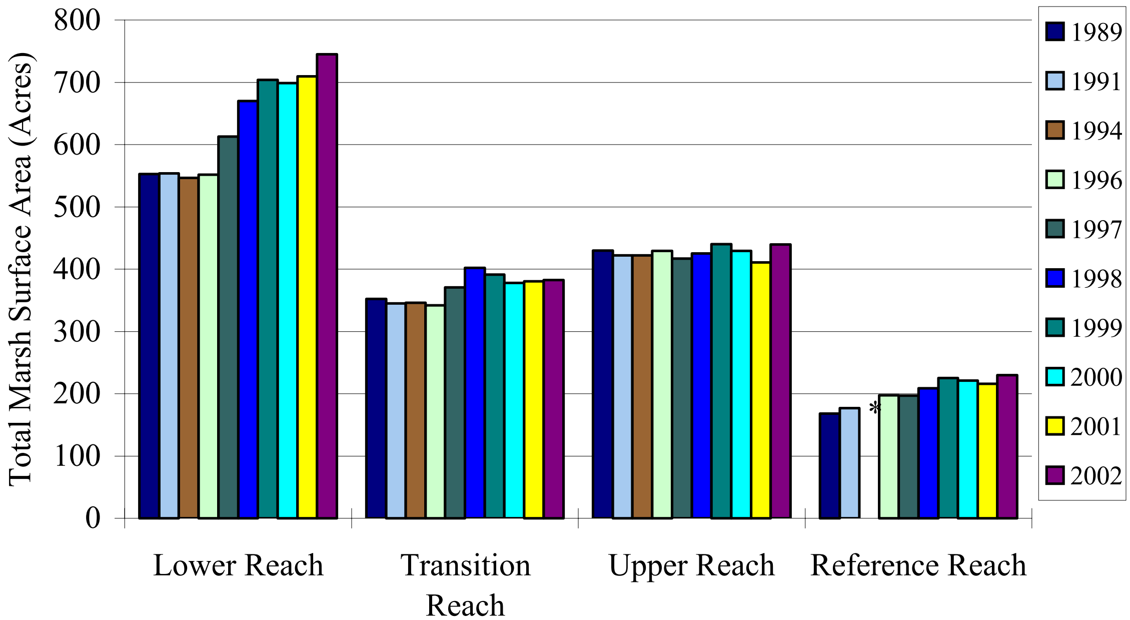
* Comparison consists of segments 1-5, 8-23 only since segments 24-26 were not mapped in 1989
** Not a dominant species category in 1989

Table 5. Summary of Acreages of the Reference Area (Alviso Slough) by Dominant Species Categories for Each Habitat Type for 2002.*

Dominant Species Category	1989	2002	Change	Percent Change
Salt Marsh Categories				
Cordgrass	28.32	21.95	-6.37	-22%
Pickleweed	43.61	46.62	3.01	7%
Peripheral Halophytes	3.06	5.51	1.80	59%
Misc. Others	0.00	0.80	0.80	-
Sub-Total	**74.99**	**74.88**	**-0.11**	**No Change**
Brackish Marsh Categories				
Alkali Bulrush	72.31	109.24	36.93	51%
Peppergrass	20.40	34.58	14.18	70%
Spearscale**	0.00	0.00	-	-
Misc. Others	0.00	0.00	-	-
Sub-Total	**92.71**	**143.82**	**51.11**	**55%**
Freshwater Marsh Categories				
California Bulrush	0.25	10.99	10.74	4296%
Cattail	0.00	0.94	0.94	-
Misc. Others	0.00	0.21	0.21	-
Sub-Total	**0.25**	**12.14**	**11.89**	**4756%**
TOTAL	**167.95**	**230.84**	**62.89**	**37%**

* Comparison consists of segments 28-30.
** Not a dominant species category in 1989.

Figure 2. Total Marsh Acreage Comparison between 1989 and 2002, by Reach



***No data collected in 1994 within Reference Area.**

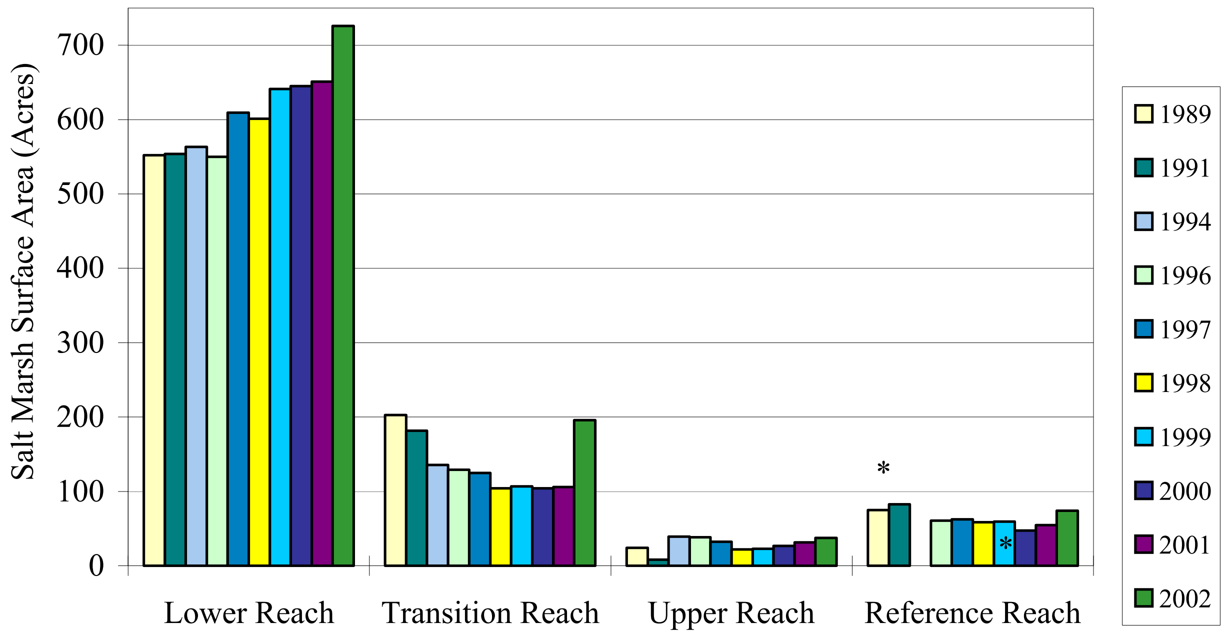
Changes in Surface Area of Salt, Brackish, and Freshwater Marsh Habitats

Salt Marsh. Figure 3 presents the total acreage of salt marsh habitat by year and location (reach). Salt marsh area decreased in the Transition Reach from 1989 through 2001; the rate of decrease in salt marsh area was greatest between 1989 and 1994 (Figure 3). However, a significant increase in salt marsh habitat occurred between 2001 and 2002 in the Transition Reach.

Conversely, salt marsh area increased in the Lower Reach from 1989 through 2002 with most of the increase occurring between 1996 - 1999 and 2001 - 2002. Much of this increase was due to new marsh formation along the north side of Coyote Creek within segments 3 and 4. There has been a significant net change in salt marsh habitat area from 1989 to 2002 (+180.5 acres) within the Main Study Area (Table 4). For the first time the study has found substantial gains in salt marsh habitat from both new marsh formation (which has been occurring steadily since 1997) and conversion of brackish marsh habitat to salt marsh habitat.

Although there is substantial interannual variation, no change in salt marsh habitat has occurred in the Reference Area between 1989 and 2002 (Table 5). The Reference Reach pattern of salt marsh habitat change remains similar to the pattern in the Transition Reach. The majority of salt marsh decline in the Reference Reach occurred early in the study period between 1991 and 1996 (Figure 3), including a slight decline in 2001 with a strong rebound in salt marsh area in 2002.

Figure 3. Salt Marsh Acreage Comparison between 1989 and 2002, by Reach.



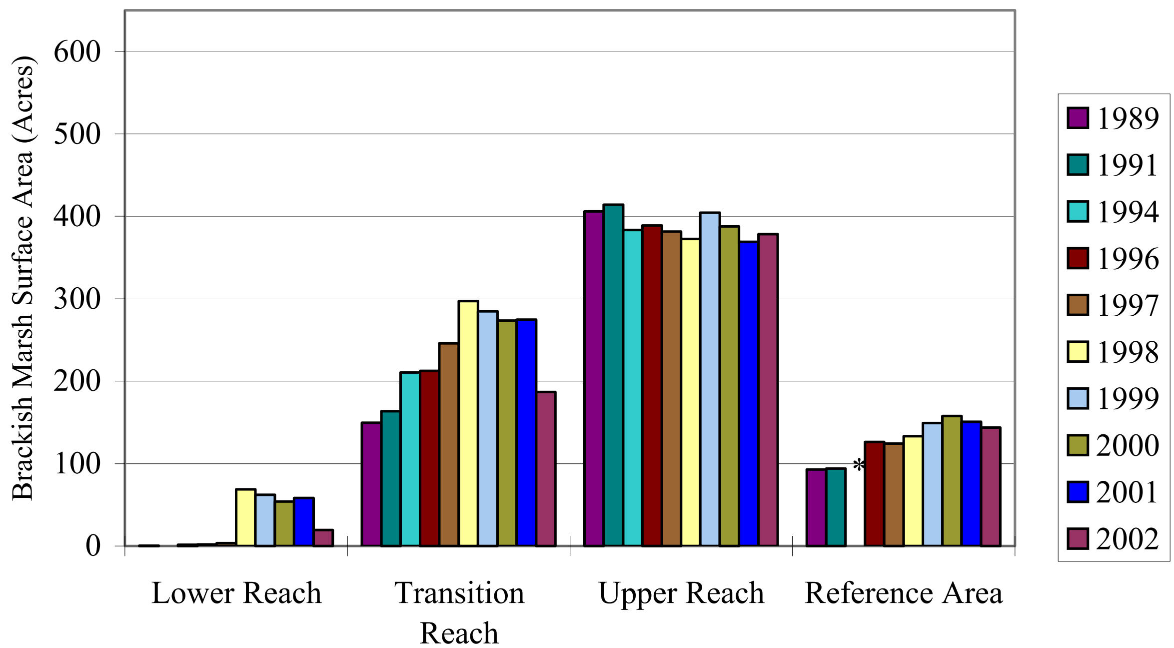
***No data collected in 1994 within Reference Area.**

Brackish and Freshwater Marsh. Figures 4 and 5 present the total acreage of brackish and freshwater marsh habitats by year and location. Relatively minor increases in brackish marsh area occurred in the Main Study Area between 1989 and 2002 (Table 4). The Reference Area has experienced much greater increases in brackish marsh habitat during the same 13 years (Table 5). During this period, brackish marsh increased by 28.6 acres (5% increase) and 51.1 acres (55% increase) in the Main Study and Reference Areas, respectively (Tables 4 and 5). This is due mostly to marsh conversion (from salt to brackish) in the Reference Area. However, a combination of marsh conversion in the Transition Reach and new brackish marsh formation in the Lower Reach accounts for most of the new brackish marsh in the Main Study Area since 1989. Furthermore, freshwater marsh has increased in the Main Study and Reference Areas during the past 13 years (Tables 4 and 5).

In the Main Study Area, gains in brackish marsh were most dramatic from 1989 to 1998 in the Lower and Transition Reaches. Since 1998 there has been a trend of decreasing brackish marsh areas within the Lower and Transition Reaches (Figure 4). The area of brackish marsh has been relatively stable (with only a slight decrease since 1989) in the Upper Reach (Figure 4).

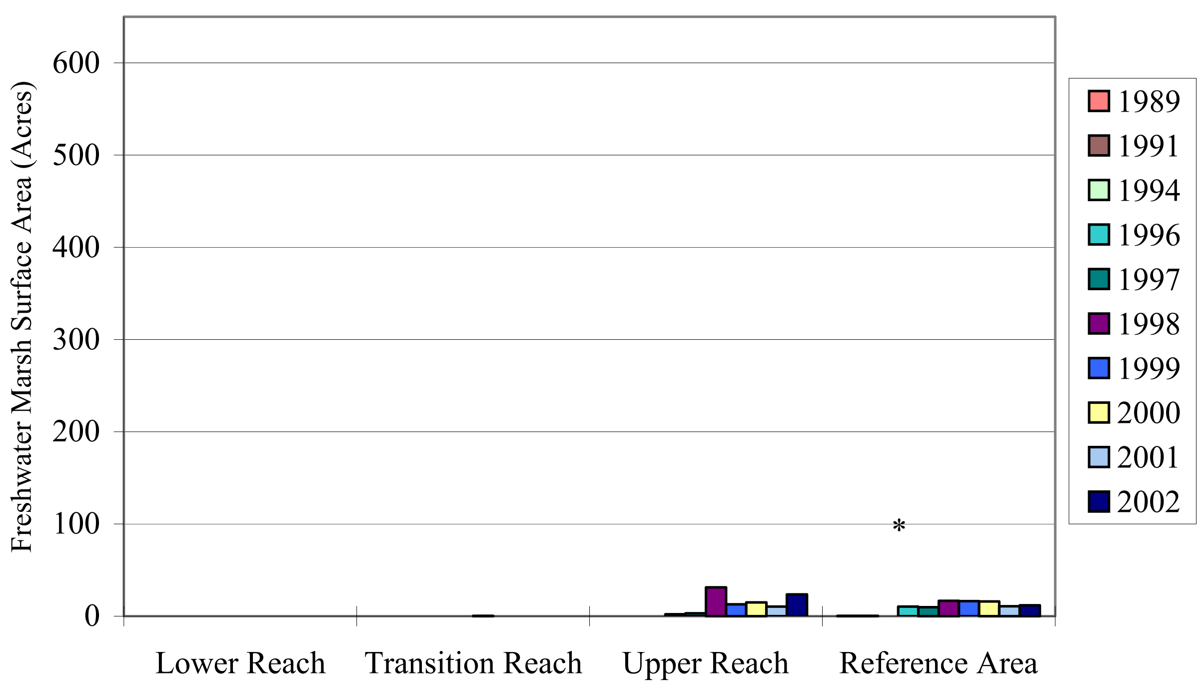
The Reference Area exhibited a steady trend of increasing brackish marsh area from 1991 through 2000 but has been declining since 2000 (Figure 4). Increases in freshwater marsh habitat have only occurred in the Upper Reach and Reference Area (Figure 5).

Figure 4. Brackish Marsh Acreage Comparison between 1989 and 2002, by Reach.



***No data collected in 1994 within Reference Area.**

Figure 5. Freshwater Marsh Acreage Comparison between 1989 and 2002, by Reach.

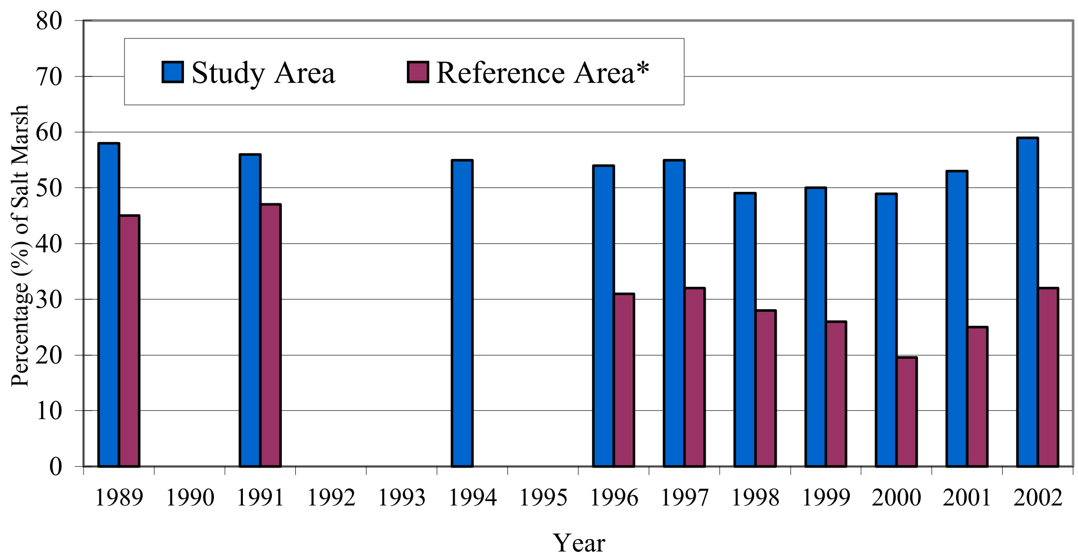


***No data collected in 1994 within Reference Area.**

Temporal Changes in Proportional Area of Salt and Brackish Marsh between the Main Study and Reference Areas

The proportion of salt marsh and brackish marsh area relative to total marsh area was compared between the Main Study and Reference Areas from 1989 through 2002 (Figures 6 and 7). This analysis was performed to control for the difference in size between the Main Study and Reference Areas. The percentage of salt marsh in the Main Study Area remained relatively stable from 1989 through 1997 with a decline between 1997 and 2000 (Figure 6). An increase in the percentage of salt marsh occurred from 2000 to 2002 with a return to 1989/1991 salt marsh area proportions. The relative decline in the percentage of salt marsh was greater in the Reference Area compared to the Main Study Area (Figure 6) and follows a similar temporal pattern.

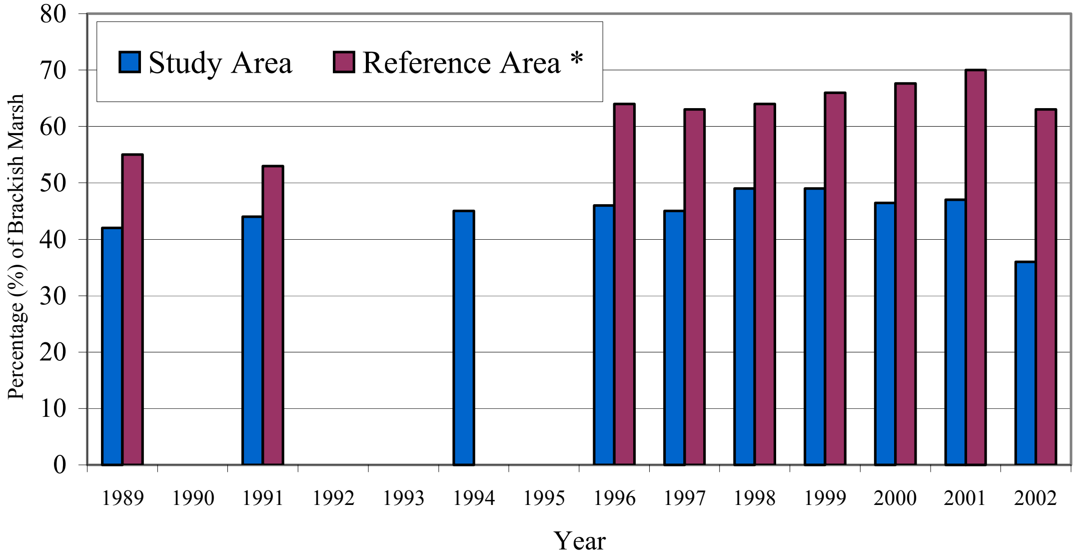
Figure 6. Temporal Comparison of the Proportion of Salt Marsh Area between the Main Study and Reference Areas



***No data collected in 1994 within Reference Area.**

The proportion of the Main Study Area that is brackish marsh has been increasing annually until this year (Figure 7). The 2002 sampling was the first significant decrease in the percentage (10%) of brackish marsh since the study began. The Reference Area has followed a similar pattern over the monitoring years, however prior to 2002, a larger increase in the percentage of brackish marsh was observed in the Reference Area than in the Main Study Area (Figure 7) between 1989 and 2001. This increase in the proportion of brackish marsh area to total marsh area in the Reference Area occurred primarily between 1991 and 1996 and between 1999 and 2000 (Figure 7) during the same time that the percentage of salt marsh declined (Figure 6).

Figure 7. Temporal Comparison of the Proportion of Brackish Marsh Area Between the Main Study and Reference Areas



***No data collected in 1994 within Reference Area**.

Habitat Type Conversion

Detailed comparisons by segment location were done by overlaying the 2002 data on the 1989 data in ArcView. Table 6 provides a summary of the segment locations and shifts in acreage by marsh type from 1989 to 2002. This table differs from Tables 5 and 6, in that the changes are defined by reach. The area calculations in Table 6 were derived from a segment reach level analysis in ArcView (Appendix C).

A total of 68.54 acres of salt marsh habitat has converted to brackish marsh habitat from 1989 to 2002 in the Main Study Area. During the same period, 28.65 of salt marsh habitat converted to brackish marsh in the Reference Area. However, during the same time period, 58.07 acres of brackish marsh has converted to salt marsh habitat in the Main Study Area and 5.03 acres in the Reference Area. Therefore, within the Main Study area only 10.47 acres of net conversion from salt marsh habitat to brackish marsh habitat has occurred since 1989. In the Reference Area the net conversion was substantially greater; 23.62 acres of salt marsh habitat converted to less Salt Marsh types.

Table 6. Detailed Evaluation of Conversion in Acreage for Segment Locations by Habitat Type, 1989 to 2002.

Segment Location	Salt to Brackish/Fresh	Brackish to Fresh	Brackish to Salt	Salt Marsh Conversion Summary
Lower	3.29	0.00	0.16	-3.13
Transition	51.79	0.00	36.25	-15.54
Upper	13.46	5.95	21.66	+8.2
Reference	28.65	1.52	5.03	-23.62

DISCUSSION

New Marsh Formation

There has been a net increase of 231.5 acres of overall marsh area (new marsh formation less marsh loss) since 1989 in the Main Study Area. The majority of this increase is due to sediment accretion along slough and river channels and subsequent vegetation colonization to form new marsh area. The majority of all new marsh formation in the Main Study Area occurred in the Lower Reach (Segments 2, 3 and 4) located near the mouth of Coyote Creek. It appears that substantial sedimentation along Coyote Creek has raised the elevations to a level that will support the growth of emergent plant species. This newly formed mud flat continues to be colonized by a mixture of cordgrass and annual pickleweed (*Salicornia europaea*). Only a small portion of the new marsh formation in the Lower Reach is dominated by alkali bulrush. All of the alkali bulrush polygons have pickleweed as a subdominant. It should be noted that the entire brackish marsh habitat (approximately 16 acres) within the Lower Reach is newly formed marsh. Furthermore, much of the newly formed alkali bulrush-dominated marsh in the Lower Reach mapped in 2001 has converted to salt marsh habitat dominated by pickleweed.

New marsh formation in the Lower Reach occurred rapidly beginning in 1997 and continued through this year. The mud flats at Calaveras Point likely reached an elevation that would support wetland plant species in 1996/97 and were rapidly colonized thereafter. It should be noted that the large mud flat in Coyote Creek just upstream of the confluence with Alviso Slough is nearing an elevation that will support wetland plant species. Numerous patches of cordgrass were noted on the mud flats during the past two years however, the patches are scattered and are not large enough to map. We predict that this mud flat will rapidly colonize with a mixture of alkali bulrush, cordgrass and annual pickleweed within the next few years. This would again dramatically increase the area of vegetated marsh within the Main Study Area.

Marsh Conversion

From 1989 to 2001, losses in salt marsh habitat (in the Main Study Area) from conversion to other habitat types were balanced by increases in salt marsh habitat via new marsh formation. The majority of salt marsh habitat conversion during the past thirteen years is attributed to losses of pickleweed and cordgrass dominated associations and increases in alkali bulrush and peppergrass associations. During the past year, brackish marsh conversion to salt marsh has increased the total area of salt marsh habitat and has tipped the balance. Most of this conversion is due to the dieback of alkali bulrush and replacement by pickleweed and cordgrass as dominant plant species. Most of the conversion of brackish marsh to salt marsh has occurred in the Transition and Lower Reaches; areas that had been rapidly converting from salt to brackish marsh habitat during the past six years.

The only segments where conversion (either from salt to brackish or brackish to salt) has not occurred during the last 13 years are those segments located immediately adjacent to San Francisco Bay (Segments 1, 2 and 8). These marshes are likely outside of the immediate influence of Coyote Creek and Alviso Slough flows but are instead influenced directly by San Francisco Bay hydrology. The lack of salt marsh conversion adjacent to San Francisco Bay and in the bayward portion of Mowry Slough (Segment 8) within the Main Study Area may indicate that the factors affecting marsh conversion are limited to the Coyote Creek and Alviso Slough reaches. The two factors that differ between these areas are freshwater input and channel morphological variation.

Historically, the channel-side vegetation in the transition segments may have been dominated by brackish (alkali bulrush) and freshwater species (tules), based on observations dating as far back as the mid-1800s (SFEI 1999). Salt marsh habitat dominated by pickleweed and saltgrass likely occurred inland of the channel-side vegetation (SFEI 1999). Those areas that were historically salt marsh have largely been converted to salt ponds. Many of the existing marshes, located between the levees of the salt ponds and the channels, have formed more recently. The present day channel-side brackish marshes are likely similar to the edges of the historical marshes that at one time contained patches of lower salinity marshes within a larger matrix of salt marsh habitat (SFEI 1999). The formation of new alkali bulrush-dominated marshes in a matrix of salt marsh habitats has been observed in the Lower Reach in this study. This is further evidence of the highly dynamic nature of vegetation trends in South San Francisco Bay. These changes from historical conditions appear driven by large-scale environmental factors such as changes in local freshwater inputs and landscape-scale changes such as salt pond construction (SFEI 1999) and subsequent changes in channel morphology

From 1989 to 2001 the entire study area was becoming less saline. For example, no freshwater marsh habitat was mapped prior to 1996 in the Main Study Area or Alviso Slough (except in Segments 25 to 27, which are not part of the 10-year analysis) but now accounts for approximately 70 acres within the Main Study area. However, the majority of the freshwater marsh observed on site is in those segments (25 to 27) that are excluded from the comparisons to the 1989 data, as these areas were not mapped until later years. In 2001, Segments 25, 26 and 27 (the most upstream reaches of Alviso and Artesian Sloughs) comprised the majority of the freshwater marsh habitat within the study.

Newly forming freshwater marsh habitat in both the Reference Area and the Main Study Area indicates that freshwater influences (e.g. channel discharges) are affecting all marshes in the vicinity. Additionally, the net salt marsh acreage within the Main Study Area has been relatively stable during this period of increased freshwater impacts but increased this year due to brackish marsh conversion. The conversion of brackish marsh to salt marsh indicates that freshwater from channel discharges has likely decreased over the past several years in response to a decrease in annual precipitation since 1998.

Between 1989 and 1999, the relative change in habitat types through time was less in the Main Study Area than in the Reference Area although the rate of new marsh formation in the Main Study Area had exceeded that of the Reference Area. This indicates that much of the conversion of salt marsh habitats within the South San Francisco Bay area was likely driven by large-scale influences (both environmental and anthropogenic) that were affecting the entire system. In 2001 small gains in salt marsh habitat occurred in both the Main Study Area and Reference Area. In

2002 even greater gains in salt marsh habitat were observed. This trend seems to further highlight the influence of multiple factors affecting changes in marsh vegetation communities in South San Francisco Bay.

Physical Effects

The direct impacts to coastal marshes from the WPCP plant can only be determined from a study that includes both physical and biological variables that could be influenced by the freshwater flows. To better understand the causes of habitat conversion, monitoring of water levels, salinities and selected edaphic characteristics began in August 1999 (H.T. Harvey & Associates 2001b). Information from that study indicates that soil salinities are correlated with dominant plant species distribution and subsequent habitat types.

Interstitial soil salinities and soil bulk density were significantly different between habitat types (H. T. Harvey & Associates 2001b). Freshwater marshes had the lowest interstitial salinities and salt marshes the highest; brackish marsh habitats had intermediate interstitial salinities. Soil bulk densities were the highest in salt and brackish marsh habitats and were significantly lower in fresh marsh habitats. The reference area and the Upper Reach had mean interstitial salinities significantly lower than the remainder of the Main Study Area. The Transition and Lower Zones had significantly higher mean interstitial salinities than the Reference Area (H. T. Harvey & Associates 2001b). This indicates that similar freshwater flows influence the Reference Area and the Upper Zone of the Main Study Area. Furthermore, it can be extrapolated from this study that decreases in freshwater influences will cause an increase in soil salinities leading to a conversion of brackish marsh to salt marsh habitat, as occurred in the past year.

Alkali bulrush distribution does not appear to be directly related to interstitial salinities. However its distribution is likely related to a combination of environmental stress factors including interstitial salinities, interspecific competition and depth and duration of flooding over the marsh surface, all of which may be dramatically altered by increases in freshwater discharge. Alkali bulrush was found growing and thriving as the dominant plant species in locations where the interstitial salinities were as low as 1.1 ppt and as high as 51.8 ppt. Furthermore, alkali bulrush is a dominant plant species in the colonization of new marsh in the high salinity zones of the Lower Reach.

The WPCP has had past influences on the plant species distribution in the South Bay Marshes. For example, the majority of Artesian Slough, a slough that dead ends at the discharge point for the WPCP, is freshwater marsh habitat. Without the WPCP discharge we would predict that Artesian Slough would consist of a mixture of brackish and salt marsh habitats. However, WPCP discharges have been relatively constant since 1989 (120 mgd) and only 10 acres of conversion has occurred in the Main Study Area in 13 years. It is likely that much of the interannual variation in habitats within the South Bay marshes is due to large scale environmental factors (e.g. changes in annual rainfall patterns).

Although the WPCP has had an effect upon portions of the system, discharges from Guadalupe River (Alviso Slough), Coyote Creek and the Sacramento/San Joaquin Delta also play a role in marsh conversion and formation. For example, the Reference Area has experienced a greater rate of salt marsh conversion than the Main Study Area and the Reference Area is hydrologically disconnected from the WPCP discharge (H. T. Harvey & Associates 2001b). Also, conversion of brackish marsh habitats to salt marsh habitats occurred in all reaches during the past year including the Upper Reach, the reach closest to the WPCP discharge point. In the past thirteen years, there has been only a minimal conversion of salt marsh to brackish marsh habitat (approximately 1 acre) in the Lower Reach segments, and therefore it can be assumed that the influence of the WPCP discharge does not extend beyond the Transition Zone of the Main Study Area. Furthermore, the continued decrease in brackish marsh habitats and concurrent increases in salt marsh habitats since the last El Nino (1997 – 1998) indicates that freshwater discharges and incident rainfall have a dramatic effect on the plant species distribution of the South Bay marshes.

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