Suisun Marsh Vegetation Mapping
Change Detection 2003

A Report to the California Department of Water Resources

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Executive Summary

This document summarizes the methods and results for vegetation change detection in Suisun Marsh conducted by the Wildlife and Habitat Data Analysis Branch of the California Department of Fish and Game. This effort is the continuation of a habitat monitoring and assessment program undertaken in 1999 and reported in *Vegetation Mapping of Suisun Marsh, Solano County: A Report to the California Department of Water Resources* (Keeler-Wolf et al. 2000).

The change detection process uses the existing 1999 digital vegetation map and classification, 2003 aerial photograph interpretation, database functions, and geographic information systems (GIS) editing and processing. Field data was collected to strengthen the existing classification and improve map accuracy. The method is based on a set of rules defining vegetation change (defined in Keeler-Wolf et al. 2000), which are applied along with expert aerial photo interpretation to quantitatively identify and record changes in vegetation distribution over the study period. The results are summarized in tabular form using basic statistics and as a digital GIS map.

The study area is bounded by the 10-foot elevation contour surrounding Suisun Marsh on the west, north and east, and extends into the open water beyond the tidal flats and marsh vegetation in Suisun Bay to the south; the Potrero Hills are excluded. In total, 69,316 acres were assessed for vegetation change. Within this area 98 rapid assessment plots were collected over the summer of 2003 and 31,218 vegetation polygons were examined against aerial photography. Over the 4-year study period, 16.8% of the study area was interpreted to have changed. There was no additional accuracy assessment completed in conjunction with this project, but see results from the original survey (Keeler-Wolf et al. 2000).

Introduction

<u>Background</u>

The Suisun Marsh (**Figure 1**) is one of the largest contiguous brackish marshes remaining in the United States, covering over 69,000 acres of tidal and managed seasonal wetlands. This marsh is a key wintering area for waterfowl and supports a number of sensitive plant and animal species. In 1977 the Suisun Marsh Preservation Act was legislated and required that the marsh be managed for its wildlife resources. Consequently, the Plan of Protection for the Suisun Marsh (Plan of Protection) was developed. In 1981 the U.S. Fish and Wildlife Service produced a Section 7 Biological Opinion for the Plan of Protection. Their Biological Opinion accepted the monitoring program in the Plan of Protection and added specific conservation measures to protect salt marsh harvest mouse (SMHM) habitat.

As part of the monitoring program in the Plan of Protection, a Triennial Vegetation Survey was developed to document the overall vegetation composition of the marsh and to monitor SMHM habitat by the use of aerial photography in combination with ground verification. Prior to the final Plan of Protection, a baseline vegetation survey was conducted in 1981. However, since completion of the Suisun Marsh Salinity Control Gates as described in the Plan of Protection was delayed until 1988, the 1988 vegetation survey was the closest to the start of facility operations. The Triennial Vegetation Survey was conducted in Suisun Marsh in 1981, 1988, 1991, and 1994 to document any changes in vegetation composition over time.

There were concerns about the methodology used and the lack of useful maps from the 1988, 1991, and 1994 surveys. In 1996 an interagency technical committee was convened to review the current survey methodology and recommend a more detailed monitoring system for vegetation changes in the marsh. Consequently, in July 1997 the committee agreed to implement a new survey methodology for the 1998 vegetation survey.

The new methodology and results for the 1999 survey are described in detail in *Vegetation Mapping of Suisun Marsh, Solano County: A Report to the California Department of Water Resources* (Keeler-Wolf et al. 2000). The survey methodology is designed to meet the goal of documenting changes in preferred habitat for the Salt Marsh Harvest Mouse as well as to gather vegetation information such that it can be used for a variety of other purposes. These may include correlating management activities with vegetation changes, gathering data to support the use of a GIS format that will allow queries and overlaying of additional information, and creation of a base map for future studies. This methodology is based on work by the Department of Fish and Game, Wildlife and Habitat Data Analysis Branch. It has been conducted at Anza-Borrego Desert State Park, Point Reyes National Seashore, Yosemite National Park, Sequoia-King's Canyon National Park, Joshua Tree National Park, and the Mohave Desert.

In 2000 an exploratory change detection study was implemented (Vaghti & Keeler-Wolf 2001). The goals of the change analysis were to define significant change for vegetation in the Suisun Marsh ecosystem, quantify and spatially identify such changes, improve map accuracy, and make recommendations for future revisions of the map to best support management efforts for endangered species habitat, waterfowl and other wildlife.

The 2003 change detection analysis described herein uses the 1999 vegetation map as the baseline and follows the 2000 change detection methodology. The 2000 vegetation map was not used due to the poor quality of that year's aerial photography. Please refer to *Vegetation Mapping of Suisun Marsh, Solano County: A Report to the California Department of Water Resources* (Keeler-Wolf et al. 2000) and *Suisun Marsh Vegetation Mapping: Change Detection 2000* (Vaghti & Keeler-Wolf 2001) for further details. A CD version of all three reports and related data is available from:

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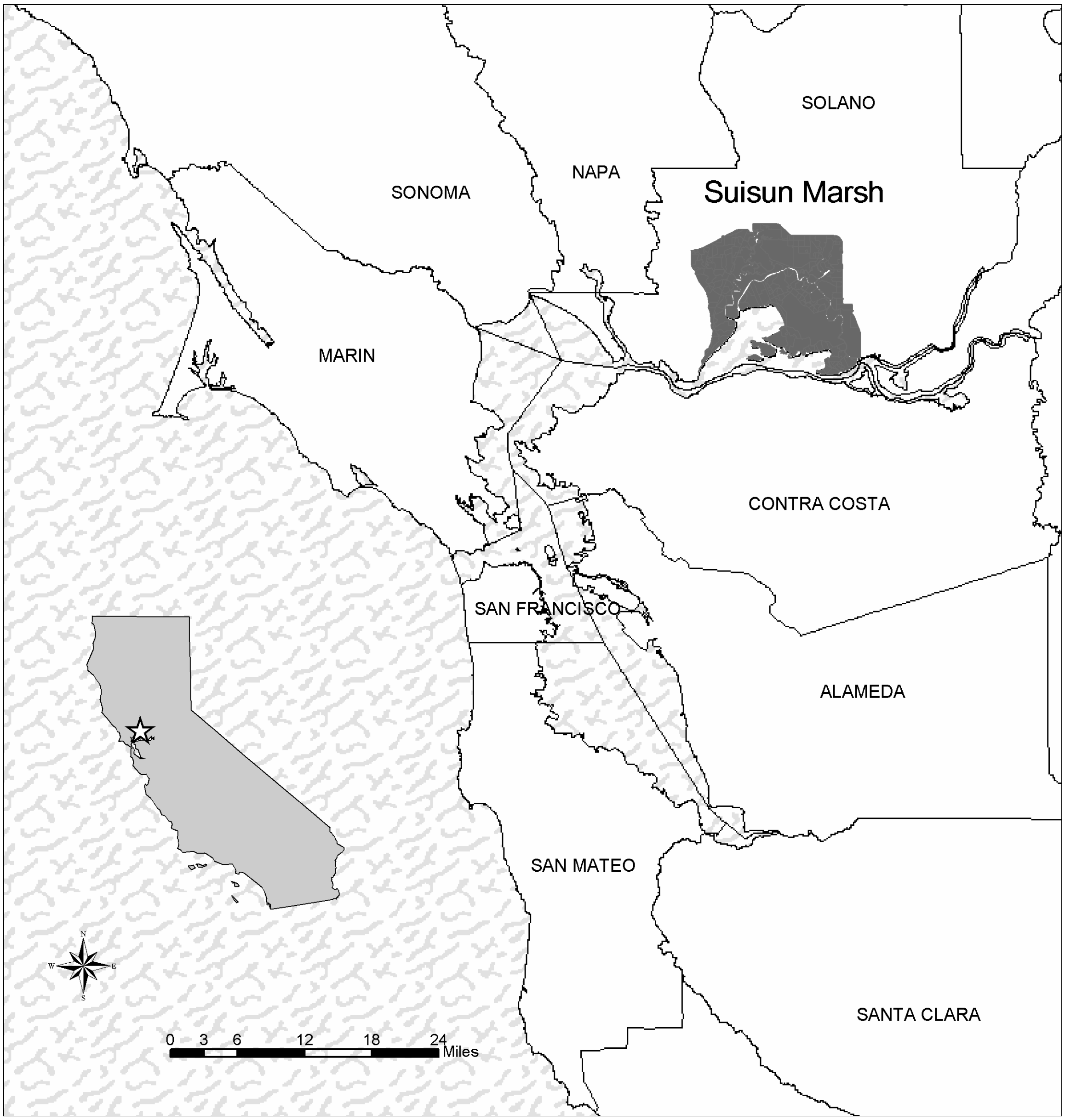
http://iep.water.ca.gov/suisun/

Figure 1 – Location of Suisun Marsh, Solano County, California.



Methods

Additional technical details of the methods used in the aerial photo interpretation and analysis can be found in Appendix B.

2003 Field Data Collection

To support the current aerial photo interpretation and strengthen the existing vegetation classification for the Suisun Marsh study area, additional field data was collected from June through September, 2003.

The 2003 field effort was directed at specific vegetation types determined by the authors of the original map as being in need of further verification (less than 5 plots per type). A list of targeted types is given in **Table 3**. A randomized subset of all possible 1999 vegetation polygons was selected using GIS technology. Polygons visited were limited by accessibility and ownership constraints. Field sampling followed the California Native Plant Society's Rapid Assessment Protocol (CNPS 2003). Collected field data were entered into an Access (2002, Microsoft Corporation) database administered by CNPS.

Aerial Photograph Interpretation

True color aerial photographs of the study area were taken on June 16, 2003 at 1:9600 scale. The timing, scale and quality of the photography mimicked the 1999 product as much as possible to minimize variation in vegetation stage, moisture and photo quality. These photographs were delivered to DFG in two formats: as scanned, georeferenced, mosaiced digital images; and as a set of 10"x10" diapositives.

The existing 1999 vegetation map was reprojected from Teale Albers (NAD 27, meters) to State Plane Zone II (NAD 83, feet) and rubbersheeted (Lo & Yeung 2002) to match the 2003 digital aerial photography. These adjustments resulted in a 0.24 acre discrepancy between the 1999 and 2003 study area. It was determined that direct on-screen assessment of change was not possible due to the fine scale of the investigation and the lack of contrast in photo signatures between many of the vegetation units involved. Furthermore, the photo interpreter had training and experience using diapositives.

The study area was divided into six sections, each approximately 22,000 acres, to best match the plotter print area. The 1999 vegetation polygons, labeled with polygon number and vegetation code, were printed onto 34 x 44 inch mylar sheets at 1:9600 scale.

The mylar printouts, the 2003 aerial diapositives, a magnification tool (Magnabrite 4x Magnifier) and a light table were used in the photo interpretation process. The 1999 vegetation polygons on mylar were overlaid onto the 2003 aerial diapositives and each polygon was assessed for vegetation change as defined below. If vegetation change was determined for a polygon, height, cover and disturbance were also recorded. Only those polygons otherwise noted as candidates for change, using the principle criteria identified below were further investigated for changes in height, cover or disturbance.

Definition of Change

The following changes were considered significant and consistently interpretable, and were assessed:

- A greater than 20% change in acreage of an exiting small polygon (<1 acre)
- A greater than 10% change in acreage of a mid-sized polygon (1-5 acres)
- A greater than 5% change in a large polygon (>5 acres)
- A type conversion of a vegetation polygon dominated by perennial species. Type conversion as defined here, occurs when a previously mapped vegetation type dominated by perennial species has changed based on the decision rules set forth in the vegetation mapping unit key defined in Table 5 of *Vegetation Mapping of Suisun Marsh, Solano County* (Keeler-Wolf et al. 2000), or when an annual species dominated vegetation type is converted to a perennial vegetation type.
- A persistent physical change has altered any vegetation polygon and partially or entirely replaced it with a non-vegetated area (non-vegetated areas include buildings, dredged ditches, new levees, roads, or other human engineered structures).
- A change in management style, which includes a conversion or restoration from an actively managed situation (annual burning, disking, plowing, flooding, or other management practice which annually disturbs the vegetation) to a passively or non-managed situation.

The following changes were considered non-significant and/or unreliably interpretable and were not assessed:

- Annual to annual type conversion were not considered because of the vagaries of climate on annual vegetation. **Table 1** lists these excluded types.
- Polygons that are regularly heavily managed by annual burning, disking, flooding, or other means were not considered. These changes, unless they show some direction (e.g., from passive management to active, or vice versa), are considered regular management perturbations and maintain the same general vegetation pattern through regular disturbance.

Table 1 – List of Annual Type Changes Excluded From Assessment

The following is a list of annual dominated vegetation types not assessed if one changed to another. Please refer to Keeler-Wolf et al. (2000) for identification and discussion of these types.

142	*Distichlis*/Annual Grasses	312	*Atriplex/Distichlis*
153	*Distichlis/Cotula*	315	*Atriplex/Scirpus maritimus*
155	*Crypsis schoenoides*	315	*Atriplex/Sesuvium*
218	*Lolium* (generic)	329	*Polygonum-Xanthium-Echinochloa*
220	*Lolium/Lepidium*	336	*Rumex* (generic)
222	*Lolium/Rumex*	337	*Atriplex*/Annual Grasses
225	Cultivated Annual Graminoid	339	*Atriplex triangularis* (generic)
227	Annual Grasses/Weeds	342	*Cotula coronopifolia*
230	Short Upland Graminoids	357	*Sesuvium verrucosum**
231	Annual Grasses (generic)	358	*Sesuvium/Distichlis**
232	*Bromus* ssp/*Hordeum*	359	*Sesuvium/Lolium**
234	*Hordeum/Lolium*	405	*Raphanus sativus* (generic)
235	*Vulpia/Heterotheca*	406	*Brassica nigra*
238	*Polypogon monspeliensis* (generic)	413	*Centaurea* (generic)
311	*Atriplex triangularis*		

* *Sesuvium verrucosum* is a perennial species, however common management styles in Suisun Marsh result in an annual life cycle.

Current vegetation composition was determined by assessing vegetation signatures, primarily through color and texture. The presence of standing water was also considered. Information collected on species composition and environmental factors during the 2003 field season was used to update specific polygons and verify vegetation signatures. In many instances, areas of managed wetlands exhibited recent vegetation growth following disturbance that was not possible to identify beyond basic vegetation structure. Thus, mapping units, such as Medium Wetland Graminoids or Short Wetland Herbs, were applied.

All determined changes were recorded directly on the mylar overlays, and then entered into an Access database and a GIS shapefile using the digitized aerial photographs as a background. The 1999 vegetation map was copied, renamed and manipulated in the GIS to reflect changes in vegetation polygon boundaries. Internal functions in Access were used to incorporate the table of changed polygons into the existing complete database. All polygons identified as mislabeled in the 2000 change detection effort were updated in the current database; this update was identified by a “U” in the Id field. **Table 2** describes the attributes included in the database and shapefile.

Table 2 – Attributes of Vegetation Polygons for the 2003 Change Detection

Field Name	Data Type	Description
Poly_ID	Number	Unique polygon identifier
Veg_99	Number	Assessed vegetation code in 1999
Legend_99	Text	Vegetation code description
Ht_99	Number	Assessed height class in 1999; 0=N/A, 1=(<0.5m), 2=(0.5-1m), 3=(1-2m), 4=(2-5m), 5=(5-10m), 6=(>10m)
Cov_99	Number	Assessed cover class in 1999; 0=N/A, 1=(<2%), 2=(2-10%), 3=(10-25%), 4=(25-50%), 5=(50-75%), 6=(>75%)
Dist_99	Number	Assessed disturbance class in 1999; 0=N/A, 1=Not evident, 2=Low, 3=Medium, 4=High
Id	Text	How assessment was determined; P=photo interpretation, R=reconnaissance, S=sampled '99, S03=sampled '03, U=updated
Who	Text	Who made the assessment
QC_who	Text	Who quality controlled the assessment
Acres_99	Number	Acres in 1999
Poly_size	Text	Size class of polygon in 1999; 1=(<1ac), 2=(1-5ac), 3=(>5ac)
Veg_03	Number	Assessed vegetation code in 2003
Legend_03	Text	Vegetation code description
Ht_03	Number	Assessed height class in 2003; 0=N/A, 1=(<0.5m), 2=(0.5-1m), 3=(1-2m), 4=(2-5m), 5=(5-10m), 6=(>10m)
Cov_03	Number	Assessed cover class in 2003; 0=N/A, 1=(<2%), 2=(2-10%), 3=(10-25%), 4=(25-50%), 5=(50-75%), 6=(>75%)
Dist_03	Number	Assessed disturbance class in 2003; 0=N/A, 1=Not evident, 2=Low, 3=Medium, 4=High
Acres_03	Number	Acres in 2003
Chnge_veg	Number	0=no change in vegetation type from 1999 to 2003; 1=change
Chnge_%	Number	Percent change in acreage from 1999 to 2003
Chnge_cls	Text	Change class; 0=none, 1=(5-10%), 2=(10-20%), 3=(20-50%), 4=(>50%), 999=eliminated
Area_99	Number	Area in 1999, in square feet
Perim_99	Number	Perimeter in 1999, in square feet
Area_03	Number	Area in 2003, in square feet
Perim_03	Number	Perimeter in 2003, in square feet

Quality control of the Access database and GIS shapefile were performed to eliminate duplicate polygons, nonsensical labels and other errors.

Analysis

Calculations of basic statistics were performed in Access using query functions. To determine change in acreage per vegetation type over the study period, two steps were used. First, the data table was grouped by the 1999 assessed vegetation (Veg_99) and the associated 1999 acreages (Acres_99) were summed. This was repeated with the 2003 assessed vegetation (Veg_03) and the associated 2003 acreages (Acres_03). Second, the 1999 acreage was subtracted from the 2003 acreage for each vegetation type.

Percent change in acreage from 1999 to 2003 was calculated as:

$$\frac{(2003\,Acreage - 1999\,Acreage)}{1999\,Acreage} * 100$$

Salicornia virginica has been identified as important habitat for the salt marsh harvest mouse (Shellhammer et al. 1982, Goals Project 2000), thus the specific dynamics of *Salicornia* vegetation were investigated. *Salicornia* vegetation is represented by the following ten vegetation types or map units: (1) *Scirpus maritimus/Salicornia*; (2) *Distichlis spicata/Salicornia*; (3) *Salicornia*; (4) *Salicornia*/Annual Grasses; (5) *Salicornia/Atriplex triangularis*; (6) *Salicornia/Crypsis schoenoides*; (7) *Salicornia/Sesuvium verrucosum*; (8) *Salicornia* (generic); (9) *Salicornia/Echinochloa crus-gali-Polygonum lapathifolium-Xanthium strumarium*; and (10) *Salicornia/Cotula coronopifolia*. First, these 10 types were selected from the 1999 assessed vegetation (Veg_99) but limited to polygons that had changed (Chnge_veg = 1). These polygons were grouped by the 2003 assessed vegetation type (Veg_03) and the 1999 acreages (Acres_99) were summed. This represented vegetation changes <u>from</u> *Salicornia* types. Second, these 10 types were selected from the 2003 assessed vegetation (Veg_03) but limited to polygons that had changed (Chnge_veg = 1). These polygons were grouped by the 1999 assessed vegetation type (Veg_99) and the 2003 acreages (Acres_03) were summed. This represented vegetation changes <u>to</u> *Salicornia* types. Finally, the changes <u>to</u> *Salicornia* types were subtracted from the changes <u>from</u> *Salicornia* types.

Because the initial results indicated a significant decrease in *Distichlis spicata* vegetation over the study period, this species was also specifically examined. To determine the dynamics of *Distichlis* vegetation types, the same procedure used for *Salicornia* was applied to the following fourteen types: (1) *Typha angustifolia/Distichlis*; (2) *Distichlis*; (3) *Distichlis*/Annual Grass; (4) *Distichlis/Juncus balticus*; (5) *Distichlis/Lotus corniculatus*; (6) *Distichlis/Salicornia virginica*; (7) *Distichlis/Scirpus americanus*; (8) *Distichlis/Cotula coronopifolia*; (9) *Distichlis/Scirpus maritimus*; (10) *Distichlis* (generic); (11) *Atriplex triangularis/Distichlis*; (12) *Frankenia salina/Distichlis*; (13) *Lepidium latifolium/Distichlis*; and (14) *Sesuvium verrucosum/Distichlis*.

Spatial statistics were performed in ArcView (Version 3.3, ESRI Inc.) To determine vegetation acreage for tidal wetlands within the study area, the 1999 and 2003 vegetation maps were clipped with an EcoAtlas (1998-2002 San Francisco Estuary Institute) shapefile of tidal areas using the Geoprocessing Wizard. Tidal areas identified by the EcoAtlas file were checked against the 2003 aerial photography for accuracy. Polygons less than 10 acres were eliminated from the analysis. These polygons were strips of vegetation occurring outside of levees along sloughs. Because the EcoAtlas did not capture all such vegetation only the larger areas were retained. There was a slight but unquantified spatial error between the vegetation files and the EcoAtlas file, probably due to reprojection variability.

Vegetation acreage for leveed wetlands was calculated by subtracting the tidal wetland acreages from the total acreages for each vegetation type.

The dynamics of nine non-native species of concern, which were also mapped as individual vegetation units due to their reliable photo signature and their tendency to dominate in cover, were investigated for tidal and leveed wetlands. Total acreage in 1999 and 2003, acreage change and percent acreage change for the entire study area, tidal wetlands and leveed wetlands were calculated. These species, *Arundo donax, Carpobrotus edulis, Centaurea solstitialis, Conium maculatum, Cortaderia selloana*, *Eucalyptus* species, *Foeniculum vulgare, Lepidium latifolium,* and *Phragmites australis*, were represented by the following vegetation types or map units: (1) *Arundo donax*; (2) *Carpobrotus edulis*; (3) *Centaurea solstitialis*; (4) *Conium maculatum* (generic); (5) *Juncus balticus/Conium*; (6) *Cortaderia selloana*; (7) *Eucalyptus* (generic); (8) *Eucalyptus globulus*; (9) *Foeniculum vulgare*; (10) *Lepidium latifolium* (generic); (11) *Lepidium/Distichlis spicata*; (12) *Scirpus americanus/Lepidium*; (13) *Juncus balticus/Lepidium*; (14) *Lolium multiflorum/Lepidium*; (15) *Phragmites australis*; (16) *Phragmites/Scirpus (acutus or californicus)*; (17) *Phragmites/Xanthium strumarium*; and (18) *Typha* spp.*/Phragmites*. It was not possible to distinguish the native *Phragmites* from the invasive genotype; for a discussion of *Phragmites* invasion, see Saltonstall (2002).

Results

2003 Field Data Collection

A total of 99 rapid assessment surveys were conducted. **Figure 2** shows sample locations relative to property ownership. The majority of surveys were in the *Distichlis spicata* and *Salicornia virginica* alliances. **Table 3** compares the targeted vegetation types with the actual set of plots collected. Overall, the targeted and collected samples do not match well, implying a discrepancy between the 1999 polygon labels and the vegetation on the ground in 2003. This was likely the result of both vegetation changes in the intervening years and errors in the 1999 aerial photo interpretation. Many of the targeted vegetation types were intentionally selected due to low accuracy in 1999.

Preliminary Vegetation Map Unit Identified

The collected field data allowed for the addition of a vegetation map unit: *Calystegia sepium/Euthamia occidentalis* (vegetation code 330). This vegetation occurs in tidally influenced areas of the marsh, typically along slough edges. Dominant species are *Calystegia sepium* and *Euthamia occidentalis*. Typical associates may include *Typha* species, *Scirpus americanus*, *S. acutus*, *S. californicus, Rosa californica* and *Helianthus californicus*. *Lathyrus jepsonii* var *jepsonii* and *Lilaeopsis masonii* may also be present. Identification of the associated vegetation signature resulted in 107 acres of this map unit added to the map and analysis. *Calystegia sepium/Euthamia occidentalis* largely replaced polygons previously labeled as *Scirpus* (*californicus* or *acutus*)/Wetland Herbs and can be regarded as a map update. This preliminary map unit is potentially an association within the *Scirpus acutus-S. californicus* or *Scirpus acutus-S. californicus-Typha* spp alliance. Formal classification analysis may result in changes to this preliminary description. This description was based on the following five plots: SUISR503, SUISR509, SUISR590, SUISR592, and SUISR593.

Vegetation Changes

The Suisun Marsh vegetation mapping study area covers 69,316 acres delineated into approximately 31,200 polygons. From 1999 to 2003, there were changes to 5177 vegetation polygons representing 11,641 acres in 2003. Changed polygons were well distributed throughout the marsh (**Figure 3**). Of these, 4763 polygons totaling 10,491 acres occurred in leveed wetlands. Thus, 16.8% of the entire study area and 16.7% of leveed wetlands were interpreted to have changed. Polygon changes included in the analysis are described above (see Methods) and may be the result of vegetation type conversions, vegetation expansion, and/or the splitting of a polygon into two or more vegetation types. Vegetation decreases were not explicitly identified (though implicitly may be accounted for by split polygons) and therefore were not included in these calculations.

Figure 2 – Location of 2003 Field Data Collection Points

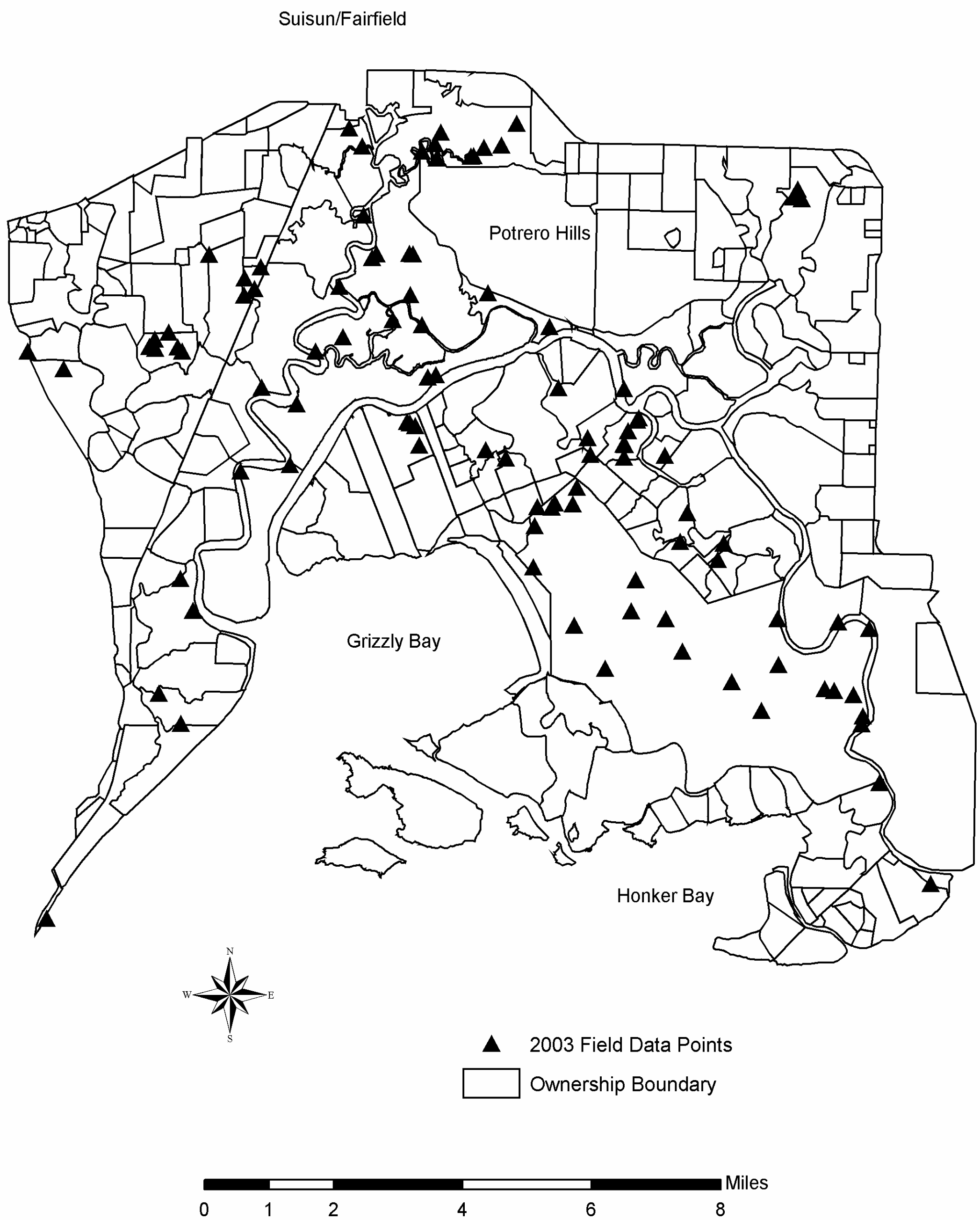
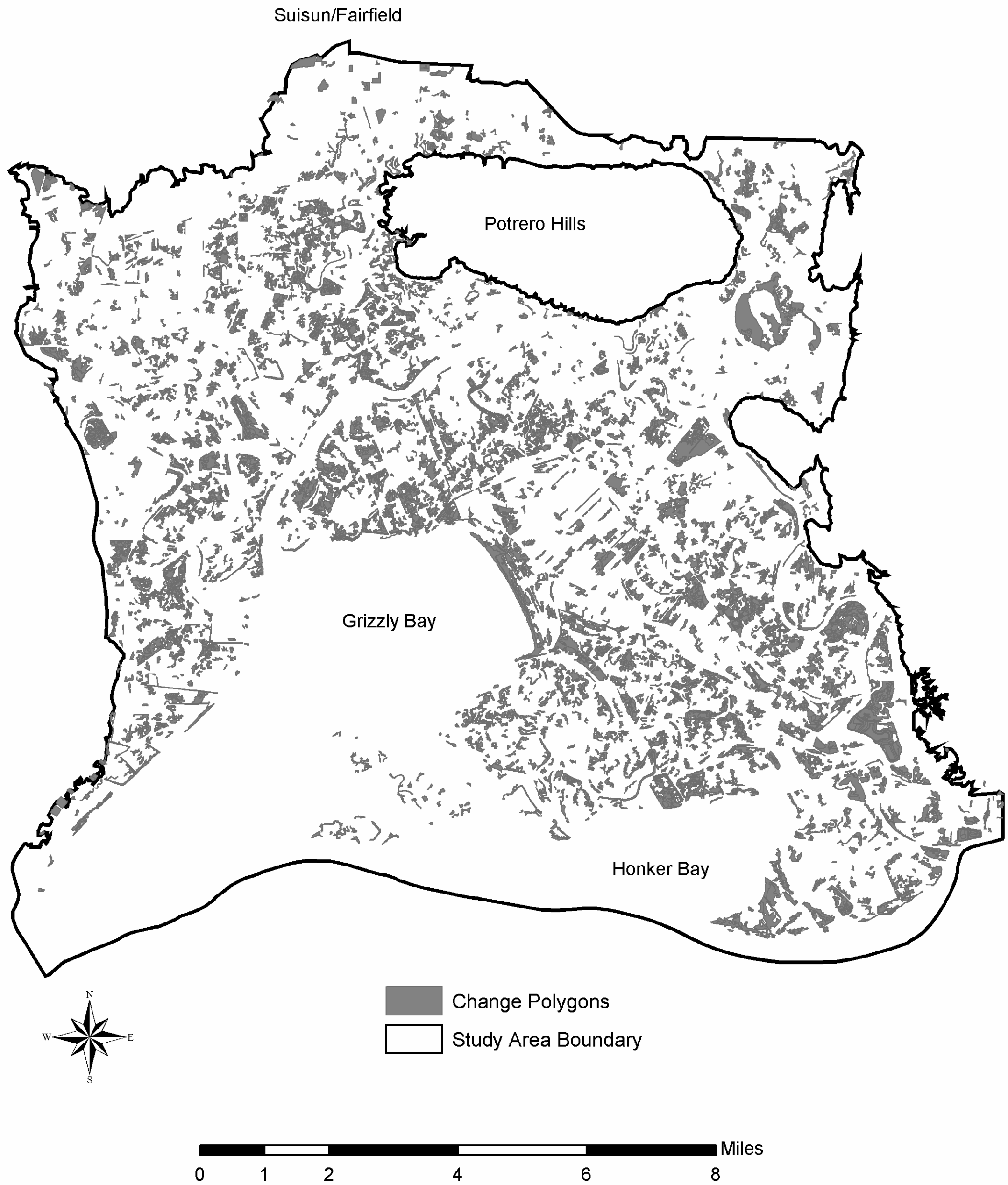


Table 3 – Targeted and Collected Vegetation Types for 2003 Field Effort

Vegetation Type	Targeted #	Collected #
001 Bare Ground		5
103 Phragmites australis		2
104 Phragmites/Scirpus	3	1
112 Scirpus americanus/Potentilla	4	1
113 Scirpus americanus/S. Californicus-S. acutus	4	
116 Scirpus californicus/S. acutus		1
121 Typha angustifolia/S. americanus		1
123 Typha species (generic)		7
127 Scirpus americanus/Lepidium	4	
132 Juncus balticus	2	5
134 Juncus balticus/Lepidium	2	
135 Juncus balticus/Potentilla	3	
137 Scirpus maritimus	7	6
138 Scirpus maritimus/Salicornia		1
139 Scirpus maritimus/Sesuvium	2	
141 Distichlis spicata	10	2
142 Distichlis/Annual Grasses		2
148 Distichlis/Salicornia		3
149 Distichlis/S. americanus	2	
155 Crypsis schoenoides		1
156 Distichlis (generic)		3
157 Scirpus (californicus or acutus)-Typha sp.		1
160 Distichlis-Juncus-Triglochin-Glaux	4	2
162 Scirpus (californicus or acutus)/Rosa		1
232 Bromus spp/Hordeum		1
311 Atriplex triangularis	10	1
312 Atriplex/Distichlis	16	3
315 Atriplex/S. maritimus	21	
318 Frankenia/Distichlis	3	2
320 Frankenia (generic)	2	1
324 Lepidium (generic)		5
329 Polygonum-Xanthium-Echinochloa		1
330 Calystegia/Euthamia		4
339 Atriplex triangularis(generic)		3
342 Cotula coronopifolia	5	
344 Lotus corniculatus	6	1
346 Salicornia virginica	4	14
348 Salicornia/Atriplex	10	2
356 Salicornia/Sesuvium	10	1
357 Sesuvium verrucosum	10	3
361 Salicornia (generic)	4	4
365 Salicornia/Cotula	2	
403 Foeniculum vulgare		1
514 Atriplex lentiformis (generic)	4	3
603 Baccharis/Annual Grasses	2	2
604 Rosa californica	10	2

Figure 3 – Spatial Distribution of Changed Polygons



These changes were not evenly distributed over the 133 vegetation types. **Table 4** lists total acreage in 1999, total acreage in 2003 and change in acreage from 1999 to 2003 by vegetation type. Medium Wetland Graminoids, *Scirpus maritimus*, Short Wetland Herbs, Medium Wetland Herbs and *S. maritimus/Salicornia virginica* were the five types with the greatest increase in acreage. *Distichlis spicata*, *Salicornia*, *Distichlis*/Annual Grasses, *Distichlis/Salicornia*, and Flooded Managed Wetlands were the five types with the greatest decrease in acreage over the study period.

Urban areas increased by 103 acres, primarily due to construction in Benicia and Cordelia. Construction of new levees in the eastern portion of the marsh and on Joice Island contributed to 54 acres of new roads/levees and 44 acres of new ditches.

There was an overall 682 acre (5.2%) decrease in all *Salicornia virginica* types from 1999 to 2003. *Salicornia* was represented by 10 vegetation types or map units (see Table 5). **Table 5** details which vegetation types or map units replaced *Salicornia* types and which vegetation types or map units changed to *Salicornia* types from 1999 to 2003. There was a 7.4 acre error associated with this analysis, calculated as the difference in acreage change for *Salicornia* types from Table 4 and those from Table 5. The five types and map units with the most acreage replacing *Salicornia* types were; *Scirpus maritimus/Salicornia*, Medium Wetland Graminoids, Short Wetland Herbs, Flooded Managed Wetland, and Medium Wetland Herbs.

Distichlis spicata, represented by 14 vegetation types or map units (see Table 6), decreased by 2,064 acres from 1999 to 2003. **Table 6** details which vegetation types or map units replaced *Distichlis* and which vegetation types or map units changed to *Distichlis* over the study period. There was a 23.7 acre error associated with this analysis, calculated as the difference in acreage change for *Distichlis* types from Table 4 and those from Table 6. The five types with the most acreage replacing *Distichlis* types were; Short Wetland Herbs, *Scirpus maritimus*, Annual Grasses, Medium Wetland Herbs, and *Salicornia* (generic).

Several non-native species of concern increased in cover over the study period. Nine non-native species represented by 18 vegetation types or map units (see Table 7) increased by a total of 537 acres. These species were: *Arundo donax, Carpobrotus edulis, Centaurea solstitialis, Conium maculatum, Cortaderia selloana, Eucalyptus* species, *Foeniculum vulgare, Lepidium latifolium,* and *Phragmites australis*. **Table 7a** summarizes total acreage in 1999 and 2003, acreage change, and percent acreage change for these species. **Table 7b** provides the same summary for the leveed areas of the marsh. Despite evidence of successful control measures, *Phragmites australis* showed the greatest increase in acreage over the entire study area. *Lepidium latifolium*, *Conium maculatum* and *Eucalyptus* species also showed significant acreage increases. *Arundo donax* showed the greatest percent change increase. These patterns were also observed in the leveed wetlands.

Table 4 – Vegetation Acreage 1999-2003 Sorted by Acreage Change

Vegetation Type		Acres 1999	Acres 2003	Change Acres*
130	Medium Wetland Graminoids	4.40	1,138.59	1,134.19
137	Scirpus maritimus	1,796.59	2,766.35	969.76
340	Short Wetland Herbs	65.29	709.64	644.35
310	Medium Wetland Herbs	309.90	866.93	557.03
138	Scirpus maritimus/Salicornia	541.04	1,015.35	474.31
361	Salicornia (generic)	556.62	847.21	290.59
158	Scirpus (californicus or acutus)/Wetland Herb	426.24	643.26	217.02
154	Distichlis/S. maritimus	363.51	504.46	140.95
129	Typha angustifolia/Phragmites	170.47	288.46	117.99
324	Lepidium (generic)	649.27	757.26	107.99
330	Calystegia/Euthamia	0.00	107.36	107.36
014	Urban Area	341.97	444.78	102.81
002	Fallow Disced Field	171.56	271.32	99.76
103	Phragmites australis	549.73	624.34	74.61
101	Tall Wetland Graminoids	46.46	103.88	57.42
004	Road	1,062.08	1,115.71	53.63
009	Ditch	1,534.66	1,579.12	44.46
133	Juncus balticus/Conium	62.88	99.80	36.92
402	Conium maculatum	247.60	276.60	29.00
134	Juncus balticus/Lepidium	16.06	42.20	26.14
211	Elytrigia pontica	86.47	108.27	21.80
156	Distichlis (generic)	792.03	813.10	21.07
801	Eucalyptus globulus	204.74	225.79	21.05
102	Arundo donax	4.73	23.81	19.08
139	Scirpus maritimus/Sesuvium	234.03	252.88	18.85
226	Perennial Grass	444.02	462.46	18.44
231	Annual Grasses generic	7,505.90	7,523.08	17.18
003	Parking Lot	259.21	270.87	11.66
401	Upland Herbs	188.86	200.34	11.48
413	Centaurea (generic)	76.91	88.15	11.24
603	Baccharis/Annual Grasses	85.88	96.05	10.17
104	Phragmites/Scirpus	133.86	143.16	9.30
606	Rubus discolor	119.17	126.03	6.86

*Change Acres calculated as Acres 2003 less Acres 1999.

Table 4 (cont.)

Vegetation Type		Acres 1999	Acres 2003	Change Acres*
005	Structure	213.79	220.62	6.83
601	Medium Upland Shrubs	7.11	13.73	6.62
358	Sesuvium/Distichlis	28.76	33.39	4.63
301	Tall Wetland Herbs	8.06	12.42	4.36
155	Crypsis schoenoides	92.45	96.79	4.34
403	Foeniculum vulgare	140.93	145.01	4.08
514	Atriplex lentiformis (generic)	31.35	35.37	4.02
900	Oaks	2.99	6.21	3.22
234	Hordeum/Lolium	1.71	4.06	2.35
800	Eucalyptus	5.15	6.68	1.53
410	Medium Upland Herbs	40.74	41.48	0.74
910	Landscape Trees	10.44	11.16	0.72
161	Cynodon dactylon	16.21	16.75	0.54
230	Short Upland Graminoids	3.27	3.72	0.45
421	Carpobrotus edulis	7.03	7.40	0.37
202	Cortaderia selloana	9.77	9.98	0.21
903	Quercus lobata	1.36	1.36	0.00
013	Water Treatment Pond	4.37	4.37	0.00
406	Brassica nigra (generic)	31.92	31.92	0.00
700	Willow Trees	11.41	11.41	0.00
350	Salicornia/Crypsis	2.12	2.12	0.00
705	Salix lasiolepis/Quercus agrifolia	3.42	3.42	0.00
008	Railroad Track	105.22	105.22	0.00
222	Lolium/Rumex	13.45	13.45	0.00
702	Salix laevigata/S. lasiolepis	4.92	4.92	0.00
901	Quercus agrifolia	10.99	10.99	0.00
235	Vulpia/Euthamia	1.34	1.34	0.00
359	Sesuvium/Lolium	15.70	15.70	0.00
360	Spergularia/Cotula	5.45	5.45	0.00
105	Phragmites/Xanthium	9.59	9.59	0.00
911	Ailanthus altissima	0.74	0.74	0.00
912	Fraxinus latifolia	2.91	2.91	0.00
321	Grindelia stricta var stricta	2.04	2.04	0.00
317	Frankenia/Agrostis	2.07	2.07	0.00
010	Trail	5.14	4.95	-0.19

*Change Acres calculated as Acres 2003 less Acres 1999.

Table 4 (cont.)

Vegetation Type		Acres 1999	Acres 2003	Change Acres*
232	Bromus spp/Hordeum	8.06	7.75	-0.31
215	Leymus (generic)	21.53	20.20	-1.33
502	Salix exigua	1.53	0.00	-1.53
605	Rosa/Baccharis	62.46	60.89	-1.57
012	Freshwater Drainage	35.98	33.42	-2.56
225	Cultivated Annual Graminoid	541.27	537.96	-3.31
315	Atriplex/S. maritimus	64.85	60.76	-4.09
140	Short Wetland Graminoids	19.11	14.96	-4.15
007	Tidal Mudflat	375.57	371.05	-4.52
405	Raphanus sativus (generic)	294.99	290.41	-4.58
223	Phalaris aquatica	24.90	19.76	-5.14
210	Medium Upland Graminoids	141.74	136.07	-5.67
316	Atriplex/Sesuvium	9.51	3.70	-5.81
300	Wetland Herbs	46.94	41.12	-5.82
228	Agrostis avenacea	35.01	29.04	-5.97
365	Salicornia/Cotula	264.30	257.24	-7.06
323	Lepidium/Distichlis	198.82	190.90	-7.92
135	Juncus balticus/Potentilla	11.11	2.91	-8.20
127	Scirpus americanus/Lepidium	41.41	33.13	-8.28
145	Distichlis/Juncus	390.52	381.44	-9.08
344	Lotus corniculatus	252.67	241.66	-11.01
318	Frankenia/Distichlis	53.15	42.12	-11.03
218	Lolium (generic)	247.42	235.65	-11.77
336	Rumex (generic)	20.19	7.95	-12.24
604	Rosa californica	140.02	126.59	-13.43
364	Salicornia/Polygonum-Xanthium-Echinochloa	116.80	103.18	-13.62
320	Frankenia (generic)	114.12	96.16	-17.96
220	Lolium/Lepidium	55.24	36.92	-18.32
113	Scirpus americanus/S. Californicus-S. acutus	149.27	127.33	-21.94
339	Atriplex triangularis(generic)	97.18	73.76	-23.42
238	Polypogon monspeliensis (generic)	54.38	30.50	-23.88
338	Potentilla anserina (generic)	60.47	35.85	-24.62
371	Potamogeton pectinatus	32.55	5.79	-26.76
356	Salicornia/Sesuvium	122.85	95.48	-27.37
160	Distichlis-Juncus-Triglochin-Glaux	343.45	315.70	-27.75

*Change Acres calculated as Acres 2003 less Acres 1999.

Table 4 (cont.)

Vegetation Type		Acres 1999	Acres 2003	Change Acres*
337	Atriplex/Annual Grasses	315.49	277.56	-37.93
132	Juncus balticus	336.28	293.20	-43.08
153	Distichlis/Cotula	180.27	136.31	-43.96
112	Scirpus americanus/Potentilla	265.97	217.68	-48.29
125	Typha angustifolia (dead stalks)	116.20	65.66	-50.54
162	Scirpus (californicus or acutus)/Rosa	373.13	320.99	-52.14
123	Typha species (generic)	4,169.96	4,117.61	-52.35
120	Typha angustifolia/Polygonum-Xanthium-Echinochloa	437.28	381.26	-56.02
342	Cotula coronopifolia	393.98	336.69	-57.29
121	Typha angustifolia/S. americanus	1,133.51	1,075.66	-57.85
147	Distichlis/Lotus	190.98	132.83	-58.15
227	Annual Grasses/Weeds	1,584.96	1,523.98	-60.98
312	Atriplex/Distichlis	406.98	339.55	-67.43
126	Typha angustifolia/Distichlis	971.00	894.92	-76.08
006	Slough	4,203.74	4,124.51	-79.23
114	Scirpus americanus (generic)	704.01	619.44	-84.57
311	Atriplex triangularis	539.90	447.21	-92.69
116	Scirpus californicus/S. acutus	2,026.01	1,933.15	-92.86
149	Distichlis/S. americanus	485.63	384.40	-101.23
157	Scirpus (californicus or acutus)-Typha sp.	2,085.15	1,975.84	-109.31
357	Sesuvium verrucosum	408.85	299.46	-109.39
348	Salicornia/Atriplex	643.10	514.28	-128.82
001	Bare Ground	2,207.06	2,011.59	-195.47
347	Salicornia/Annual Grasses	2,306.50	2,070.10	-236.40
329	Polygonum-Xanthium-Echinochloa	1,271.18	966.29	-304.89
011	Flooded Managed Wetland	3,801.40	3,341.22	-460.18
148	Distichlis/Salicornia	2,409.57	1,903.62	-505.95
142	Distichlis/Annual Grasses	1,982.23	1,458.37	-523.86
346	Salicornia virginica	6,115.42	5,580.38	-535.04
141	Distichlis spicata	2,895.00	2,069.47	-825.53

*Change Acres calculated as Acres 2003 less Acres 1999.

Tidal Wetlands

Based on the modified EcoAtlas shapefile, tidal wetlands cover 6,684 acres, or approximately 10%, of the study area. Change was detected in 414 polygons representing 1150 acres, equivalent to 17.2% of tidal wetlands. The spatial distribution of the tidal areas used in this analysis is depicted in **Figure 4**. Because of the spatial inconsistency between the EcoAtlas and vegetation shapefiles, this analysis was only used to determine the number of changed polygons and the amount of invasion by selected non-native species in the tidal wetlands. **Table 7c** summarizes the total acreage of eight non-native species (see "Vegetation Changes" above) in the tidal wetlands, acreage change and percent acreage change over the study period. *Lepidium latifolium* and *Arundo donax* exhibited the largest increase in acreage; *A. donax* and *Cortaderia selloana* showed dramatic percent change increases.

Table 5 – Dynamics of *Salicornia virginica* Types from 1999 to 2003

Salicornia virginica vegetation types or map units summarized: (1) *Scirpus maritimus/Salicornia*; (2) *Distichlis spicata/Salicornia*; (3) *Salicornia*; (4) *Salicornia*/Annual Grasses; (5) *Salicornia/Atriplex triangularis*; (6) *Salicornia/Crypsis schoenoides*; (7) *Salicornia/Sesuvium verrucosum*; (8) *Salicornia* (generic); (9) *Salicornia/Echinochloa crus-gali-Polygonum lapathifolium-Xanthium strumarium*; and (10) *Salicornia/Cotula coronopifolia*.

Vegetation Type	Net Acreage Changing TO Salicornia Types	Net Acreage Changing FROM Salicornia Types
NET LOSS OF SALICORNIA TYPES		681.96
TOTAL	883.66	1,565.62
001 Bare Ground	65.41	
002 Fallow Disced Field		76.87
003 Parking Lot		0.65
004 Road	5.58	
011 Flooded Managed Wetland		197.48
101 Tall Wetland Graminoids		10.08
103 Phragmites australis		22.00
104 Phragmites/Scirpus		1.18
114 Scirpus americanus (generic)	5.55	
116 Scirpus californicus/S. acutus		2.94
120 Typha angustifolia/Polygonum-Xanthium-Echinochloa	0.54	
121 Typha angustifolia/S. americanus	2.53	
123 Typha species (generic)		46.70
125 Typha angustifolia (dead stalks)	2.61	
126 Typha angustifolia/Distichlis		2.77
129 Typha angustifolia/Phragmites		23.31
130 Medium Wetland Graminoids		225.92
132 Juncus balticus	2.59	
133 Juncus balticus/Conium		3.49
137 Scirpus maritimus		129.12
138 Scirpus maritimus/Salicornia		233.66
139 Scirpus maritimus/Sesuvium		4.90
141 Distichlis spicata	149.40	
142 Distichlis/Annual Grasses	87.05	
145 Distichlis/Juncus	4.51	
147 Distichlis/Lotus	6.10	

Table 5 (cont.)

Vegetation Type		Net Acreage Changing TO Salicornia Types	Net Acreage Changing FROM Salicornia Types
148	Distichlis/Salicornia	241.05	
149	Distichlis/S. americanus	13.16	
153	Distichlis/Cotula	7.91	
154	Distichlis/S. maritimus	1.53	
155	Crypsis schoenoides		4.34
156	Distichlis (generic)		4.29
157	Scirpus (californicus or acutus)-Typha sp.	2.93	
160	Distichlis-Juncus-Triglochin-Glaux	7.41	
210	Medium Upland Graminoids	2.67	
211	Elytrigia pontica		1.42
220	Lolium/Lepidium	2.84	
223	Phalaris aquatica	1.33	
226	Perennial Grass		11.52
227	Annual Grasses/Weeds		26.72
230	Short Upland Graminoids	1.16	
231	Annual Grasses generic	30.67	
234	Hordeum/Lolium		2.35
310	Medium Wetland Herbs		162.68
311	Atriplex triangularis	4.92	
312	Atriplex/Distichlis	9.13	
315	Atriplex/S. maritimus	0.63	
320	Frankenia (generic)	5.21	
323	Lepidium/Distichlis		0.07
324	Lepidium (generic)		17.80
329	Polygonum-Xanthium-Echinochloa	10.52	
337	Atriplex/Annual Grasses	3.36	
339	Atriplex triangularis(generic)		1.16
340	Short Wetland Herbs		205.44
342	Cotula coronopifolia	20.48	
344	Lotus corniculatus	3.10	
346	Salicornia virginica	85.16	
347	Salicornia/Annual Grasses	24.44	
348	Salicornia/Atriplex	35.69	
356	Salicornia/Sesuvium	12.85	

Table 5 (cont.)

Vegetation Type		Net Acreage Changing TO Salicornia Types	Net Acreage Changing FROM Salicornia Types
357	Sesuvium verrucosum	15.89	
358	Sesuvium/Distichlis	0.71	
361	Salicornia (generic)		135.00
365	Salicornia/Cotula		2.82
401	Upland Herbs		3.44
402	Conium maculatum		3.31
403	Foeniculum vulgare	2.82	
410	Medium Upland Herbs		1.00
603	Baccharis/Annual Grasses	4.22	
801	Eucalyptus globulus		1.19

Table 6 – Dynamics of *Distichlis spicata* Types from 1999 to 2003

Distichlis spicata vegetation types or map units summarized: (1) *Typha angustifolia/Distichlis*; (2) *Distichlis*; (3) *Distichlis*/Annual Grass; (4) *Distichlis/Juncus balticus*; (5) *Distichlis/Lotus corniculatus*; (6) *Distichlis/Salicornia virginica*; (7) *Distichlis/Scirpus americanus*; (8) *Distichlis/Cotula coronopifolia*; (9) *Distichlis/Scirpus maritimus*; (10) *Distichlis* (generic); (11) *Atriplex triangularis/Distichlis*; (12) *Frankenia salina/Distichlis*; (13) *Lepidium lapathifolium/Distichlis*; and (14) *Sesuvium verrucosum/Distichlis*.

Vegetation Type	Net Acreage Changing TO Distichlis Types	Net Acreage Changing FROM Distichlis Types
NET LOSS IN DISTICHLIS TYPES		2,039.85
TOTAL	424.35	2,464.20
001 Bare Ground		94.85
002 Fallow Disced Field		16.46
006 Slough		2.84
011 Flooded Managed Wetland		129.90
101 Tall Wetland Graminoids		8.94
102 Arundo donax		0.94
103 Phragmites australis		22.52
104 Phragmites/Scirpus		0.55
113 Scirpus americanus/S. Californicus-S. acutus		0.60
114 Scirpus americanus (generic)	10.26	
116 Scirpus californicus/S. acutus		3.20
120 Typha angustifolia/Polygonum-Xanthium-Echinochloa	10.72	
121 Typha angustifolia/S. americanus		1.74
123 Typha species (generic)		82.96
125 Typha angustifolia (dead stalks)	6.10	
126 Typha angustifolia/Distichlis		22.15
129 Typha angustifolia/Phragmites		13.14
130 Medium Wetland Graminoids		174.31
132 Juncus balticus		7.24
133 Juncus balticus/Conium		5.86
134 Juncus balticus/Lepidium		16.08
137 Scirpus maritimus		261.91
138 Scirpus maritimus/Salicornia		76.17
141 Distichlis spicata	189.03	
142 Distichlis/Annual Grasses	52.85	
145 Distichlis/Juncus		2.70

Table 6 (cont.)

Vegetation Type		Net Acreage Changing TO Distichlis Types	Net Acreage Changing FROM Distichlis Types
147	Distichlis/Lotus	17.87	
148	Distichlis/Salicornia		64.65
149	Distichlis/S. americanus	1.86	
153	Distichlis/Cotula	2.29	
154	Distichlis/S. maritimus		120.51
156	Distichlis (generic)		53.27
157	Scirpus (californicus or acutus)-Typha sp.		11.59
158	Scirpus (californicus or acutus)/Wetland Herbs		1.66
160	Distichlis-Juncus-Triglochin-Glaux	7.93	
161	Cynodon dactylon		0.54
162	Scirpus (californicus or acutus)/Rosa		2.03
210	Medium Upland Graminoids	1.50	
218	Lolium (generic)	1.94	
223	Phalaris aquatica	5.14	
226	Perennial Grass		12.04
227	Annual Grasses/Weeds		13.02
228	Agrostis avenacea	2.77	
230	Short Upland Graminoids		1.61
231	Annual Grasses generic		246.59
310	Medium Wetland Herbs		219.14
311	Atriplex triangularis	6.18	
312	Atriplex/Distichlis		13.70
315	Atriplex/S. maritimus		4.83
316	Atriplex/Sesuvium	3.94	
318	Frankenia/Distichlis	5.79	
320	Frankenia (generic)	5.11	
323	Lepidium/Distichlis		38.55
324	Lepidium (generic)		39.34
329	Polygonum-Xanthium-Echinochloa	65.48	
330	Calystegia/Euthamia		7.72
337	Atriplex/Annual Grasses	2.51	
339	Atriplex triangularis(generic)		0.76
340	Short Wetland Herbs		263.35
342	Cotula coronopifolia		0.31

Table 6 (cont.)

Vegetation Type		Net Acreage Changing TO Distichlis Types	Net Acreage Changing FROM Distichlis Types
344	Lotus corniculatus	11.77	
346	Salicornia virginica		160.70
347	Salicornia/Annual Grasses		2.84
348	Salicornia/Atriplex		2.59
356	Salicornia/Sesuvium	0.16	
357	Sesuvium verrucosum	0.89	
361	Salicornia (generic)		185.64
364	Salicornia/Polygonum-Xanthium-Echinochloa		2.10
365	Salicornia/Cotula		10.85
401	Upland Herbs		14.09
402	Conium maculatum		6.46
403	Foeniculum vulgare	2.78	
405	Raphanus sativus (generic)	8.85	
410	Medium Upland Herbs		1.47
413	Centaurea (generic)		12.49
514	Atriplex lentiformis (generic)	0.63	
603	Baccharis/Annual Grasses		2.16
604	Rosa californica		0.47
801	Eucalyptus globulus		2.07

Table 7 – Acreages of Non-Native Species of Concern in Tidal and Leveed Wetlands

Non-native species *Arundo donax, Carpobrotus edulis, Centaurea solstitialis, Conium maculatum, Cortaderia selloana*, *Eucalyptus* species, *Foeniculum vulgare, Lepidium latifolium,* and *Phragmites australis* represented by the following vegetation types or map units: (1) *Arundo donax*; (2) *Carpobrotus edulis*; (3) *Centaurea solstitialis*; (4) *Conium maculatum* (generic); (5) *Juncus balticus/Conium*; (6) *Cortaderia selloana*; (7) *Eucalyptus* (generic); (8) *Eucalyptus globulus*; (9) *Foeniculum vulgare*; (10) *Lepidium latifolium* (generic); (11) *Lepidium/Distichlis spicata*; (12) *Scirpus americanus/Lepidium*; (13) *Juncus balticus/Lepidium*; (14) *Lolium multiflorum/Lepidium*; (15) *Phragmites australis*; (16) *Phragmites/Scirpus (acutus or californicus)*; (17) *Phragmites/Xanthium strumarium*; and (18) *Typha* spp*./Phragmites*.

7a – Entire Study Area

Vegetation Type	Common Name	Acres 99	Acres 03	Ac Change	% Change
Arundo donax	Giant Reed	4.73	23.81	19.08	403.38
Carpobrotus edulis	Ice Plant	7.03	7.40	0.37	5.26
Centaurea solstitialis	Yellow Star-Thistle	76.91	88.15	11.24	14.61
Conium maculatum (2 types)	Poison Hemlock	310.48	376.40	65.92	21.23
Cortaderia selloana	Pampas grass	9.77	9.98	0.21	2.15
Eucalyptus species (2 types)	Gum Tree	209.89	232.47	22.58	10.76
Foeniculum vulgare	Fennel	140.93	145.01	4.08	2.90
Lepidium latifolium (5 types)	Perennial Pepperweed	960.80	1,060.41	99.61	10.37
Phragmites australis (4 types)	Common Reed	863.65	1,065.55	201.90	23.38

7b – Leveed Wetlands

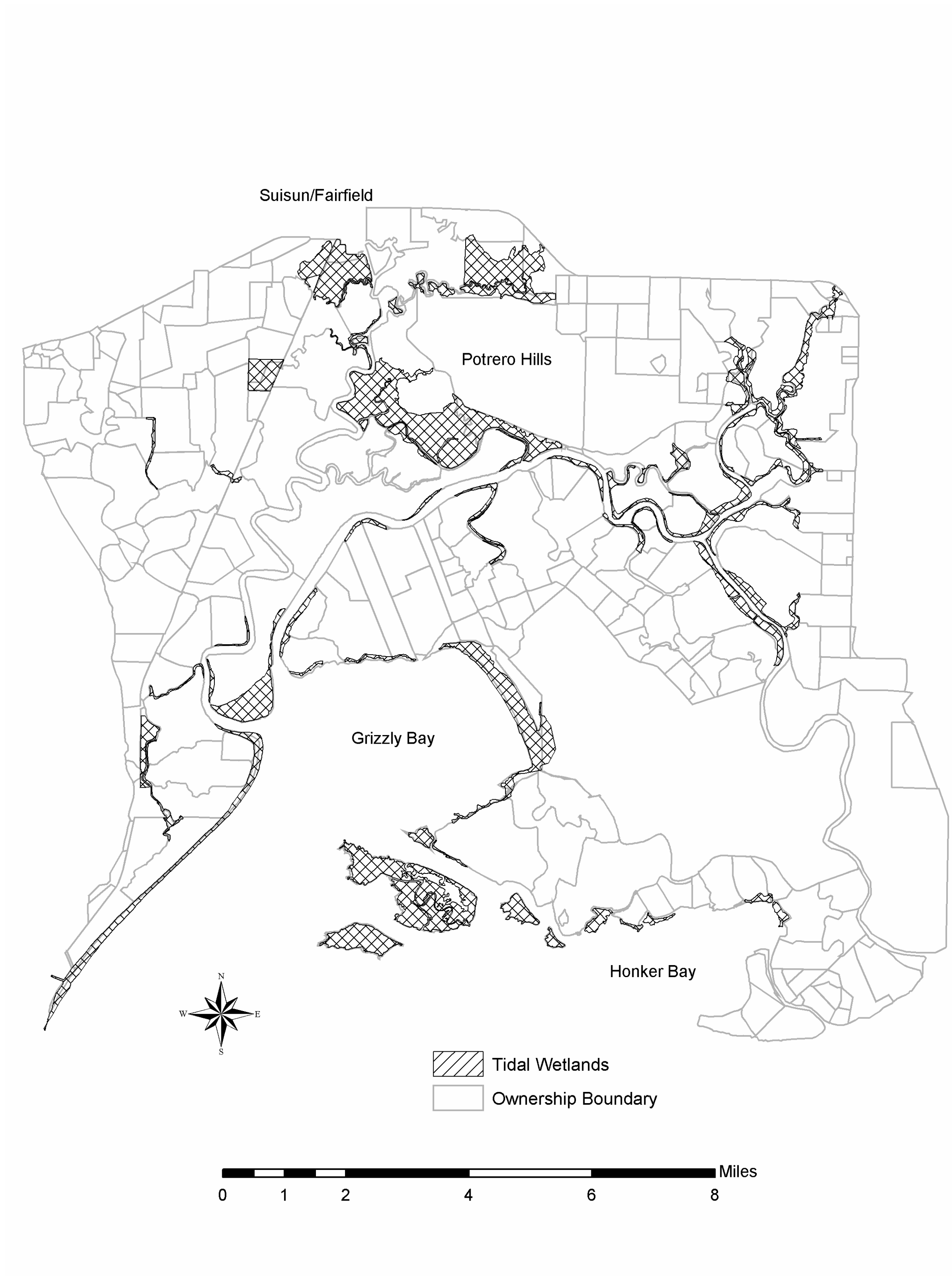
Vegetation Type	Common Name	Acres 99	Acres 03	Ac Change	% Change
Arundo donax	Giant Reed	3.88	10.07	6.19	159.54
Carpobrotus edulis	Pampas Grass	6.81	7.18	0.37	5.43
Centaurea solstitialis	Yellow Star-Thistle	72.83	84.07	11.24	15.43
Conium maculatum (2 types)	Poison Hemlock	299.78	365.32	65.54	21.86
Cortaderia selloana	Pampas Grass	8.88	7.81	-1.07	-12.05
Eucalyptus species (2 types)	Gum Tree	189.59	210.98	21.39	11.28
Foeniculum vulgare	Fennel	128.59	137.37	8.78	6.83
Lepidium latifolium (5 types)	Perennial Pepperweed	797.30	864.95	67.65	8.48
Phragmites australis (4 types)	Common Reed	536.61	753.11	217.50	40.61

Table 7 (cont.)

7c – Tidal Wetlands

Vegetation Type	Common Name	Acres 99	Acres 03	Acr Change	% Change
Arundo donax	Giant Reed	0.85	13.74	12.89	1,516.47
Carpobrotus edulis	Ice Plant	0.22	0.22	0.00	0.00
Centaurea solstitialis	Yellow Star-Thistle	4.08	4.08	0.00	0.00
Conium maculatum (2 types)	Poison Hemlock	10.70	11.08	0.38	3.55
Cortaderia selloana	Pampas Grass	0.89	2.17	1.28	143.82
Eucalyptus species (2 types)	Gum Tree	20.30	21.49	1.19	5.86
Foeniculum vulgare	Fennel	12.34	7.64	-4.70	-38.09
Lepidium latifolium (5 types)	Perennial Pepperweed	163.50	195.46	31.96	19.55
Phragmites australis (4 types)	Common Reed	327.04	312.44	-14.60	-4.46

Figure 4 – Spatial Distribution of Tidal Wetlands Used in the Analysis



Discussion

Comparison with 2000 Change Detection Results

The 2000 (Vaghti & Keeler-Wolf 2001) and 2003 change detection analyses both used the 1999 vegetation map as the reference point for change. The study area and methods were also the same. The 2000 change detection resulted in 167 polygons representing 515 acres of vegetation change. The current analysis resulted in 5177 vegetation polygons representing 11,641 acres of vegetation change. Thus, there was an approximate 23-fold increase in vegetation acreage change over the three years. It is important to note, however, that **poor photo quality in 2000 may have limited the effectiveness of the analysis.**

Observed Trends

The 23-fold increase in vegetation acreage change between the 2000 and 2003 change detection efforts is dramatic. A precise analysis of how much of this change is the result of management style or other modifications in the marsh and how much is due to variance in interpretation style is not possible. Most likely a combination of factors is the cause.

According to Bruce Wickland of the Suisun Resource Conservation District, there were no widespread management trends among private landowners in the marsh over the study period. The majority of landowners continued to manage vegetation for waterfowl cover, feed, and nesting habitats. Common plant species enhanced included *Sciprus maritimus*, *Atriplex triangularis*, *Echinochloa crus-galli*, *Sesuvium verrucosum*, *Cynodon dactylon* and *Salicornia virginica*. There was mention of a *Polygonum* species, referred to as African smartweed, which was new to some landowners and appeared to be spreading. Attention should be given to identify this plant in the near future.

According to Chad Fien of the Grizzly Island Wildlife Area, the Department of Fish & Game continued with typical routine maintenance of its lands over the study period. One exception was the conversion of approximately 100 acres of upland habitat to irrigated facultative wetlands.

Three of the five vegetation types with the greatest acreage increases over the study period were structural map units: Medium Wetland Graminoids, Short Wetland Herbs and Medium Wetland Herbs. These totaled 2,336 acres, or approximately 20% of the total vegetation acreage change. Structural map units were assigned to polygons when the vegetation signature was not interpretable in more detail. Often such mapping unit names were applied to a polygon when vegetation was just beginning to recover from a disturbance or just emerging from a flooded field. The increase in structural map unit acreage is in part due to decreased confidence by the photo interpreter to distinguish between similar vegetation signatures. This conservative approach results in a less precise but more accurate analysis.

Caveats of Interpretability

Manual aerial photo interpretation relies heavily on ocular recognition of vegetation signatures defined by color, texture, and environmental position. Change detection further relies on consistency in interpretation over an extended time period. Vegetation phenology and interpretation style can vary across time and affect interpretation outcome even when care has been taken to hold photographic quality and timing, and interpretation personnel constant.

No formal accuracy assessment was conducted for this change detection effort, however, the accuracy assessment results from the 1999 vegetation mapping process may be used as a guide (see Keeler-Wolf et al. 2000). Accuracy varied across vegetation types and averaged around 80% for the entire study area. It is predicted that the 2003 change detection has a reduced accuracy due to the photo interpreter being less intimately involved with the vegetation of the marsh and the aerial photographs in the intervening years.

Conclusions and Recommendations

There is no single overriding explanation for the observed changes in vegetation over the study period. The majority (approximately 90%) of vegetation in Suisun Marsh occurs as managed seasonal wetlands. Approximately 59,000 acres are under private ownership, managed by over 200 entities. A large proportion of the remaining public 16,000 acres are also actively managed. Given the high level of manipulation by numerous owners it is very difficult to relate cause and effect for vegetation change in the marsh.

Interestingly, the tidal wetlands within the study area exhibited a similar vegetation change percentage as the managed wetlands and the entire study area. Some of these changes were due to the addition of a vegetation type, *Calystegia sepium/Euthamia occidentalis*, which occurs only in tidal areas.

Tidal wetlands are strongly affected by slight alterations in hydrology (Kusler 1999). Global climate change predictions include an accelerated rise in sea level of 2 to 5-fold above the past 100 year average of 1-2 mm per year (Kusler 1999). A recent study on the East Coast documented significant tidal wetland loss over the past 30 years, apparently from inundation (Hartig et al. 2000). Although the data from the 2003 change detection do not exhibit noticeable trends to support effects of increased sea level, it is important to continue to monitor the tidal wetlands for such effects.

The analysis suggests that the large decrease in *Distichlis spicata* types is primarily due to selective management for more hydrophytic species, such as *Scirpus maritimus*. The high salt tolerance of *Distichlis* has been well documented (Smart & Barko 1980, Kemp & Cunningham 1981, Alshammary et al. 2004), however, there is a dearth of information on its competitive ability in freshwater conditions. An increase in *Distichlis* would suggest higher salinities, hence a decrease suggests increased freshwater to the system.

The analysis of non-native species of concern demonstrated an overall increase in acreage of the 9 species investigated. Despite evidence of successful control measures by several landowners, acreage of *Phragmites australis* increased by 40% in leveed wetlands; acreage in tidal wetlands actually decreased by 5%. This decrease was largely influenced by control measures along the east side of Grizzly Bay. The analysis did not distinguish between the native and non-native *Phragmites*; an effort to differentiate the two in the field is worthwhile. *Lepidium latifolium* exhibited greater acreage change in tidal than leveed wetlands, increasing by 20% and 8%, respectively. Such changes could have significant impacts on sensitive plant species found only in tidal wetlands. Although total acreage of *Arundo donax* was relatively small (24 acres), this species exhibited dramatic increases in acreage percent change, particularly in tidal areas where it is typically found on the backside of levees along slough edges.

It is recommended that the vegetation survey continue at a 3-year interval following the methodologies outlined in Keeler Wolf et al. (2000) and in this report. A more extensive temporal data set of vegetation maps is required to distinguish baseline change rates in Suisun Marsh from rates showing trends or uncharacteristic fluctuations.

The following actions would improve the current change detection process:

- A set of 100 permanent plots distributed among key vegetation types and related to the 1999 releve survey would provide ground-based change rates over time;
- The development of a database coding system to distinguish map update changes from signature changes would aid in pinpointing actual change;
- Increased feedback from the field in the form of interpreter reconnaissance and rapid assessment plot data each mapping cycle (particularly for vegetation types with low accuracy) is necessary to maintain the present level of mapping detail.

It is further recommended that future field data collection efforts focus on acquiring data for targeted vegetation types. If, upon arrival at a vegetation polygon, the vegetation is different than expected, brief reconnaissance notes can be taken then the survey team should move on to targeted types. This strategy provides increased probability of gathering the requisite number of samples to strengthen the vegetation classification and improve map accuracy.

There exists a tradeoff between continued interpretation based on the original 1999 linework, such as this change detection process, and a full remapping of the study area. The 1999 linework has three main drawbacks: (1) linear features such as roads and ditches are delineated inconsistently; (2) vegetation delineations do not follow ecological gradients; and (3) the study area is over-delineated. These characteristics make the change detection process more difficult. While a full remap would rectify such drawbacks, the continuity now built on the 1999 map would be lost. Summary data would remain valid but individual polygons could no longer be tracked to 1999. Continued discussion among stakeholders about how to proceed is justified.

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Appendix A – Scientific & Common Names of Referenced Plant Species

Scientific Name	Common Name	Non-Native
Agrostis avenacea	Bent grass	*
Ailanthus altissima	Tree of heaven	*
Apocynum cannabinum	Indian hemp	
Arundo donax	Giant reed	*
Atriplex lentiformis	Big saltbush	
Atriplex triangularis	Fathen	
Baccharis pilularis	Coyote bush	
Brassica nigra	Black mustard	*
Bromus diandrus	Ripgut brome	*
Bromus hordeaceus	Soft chess	*
Carpobrotus edulis	Ice plant	*
Centaurea solstitialis	Yellow star thistle	*
Conium maculatum	Poison hemlock	*
Cortaderia selloana	Pampas grass	*
Cotula coronopifolia	Brass buttons	*
Crypsis schoenoides	Swamp grass	*
Cynodon dactylon	Bermuda grass	*
Distichlis spicata	Salt grass	
Echinochloa crus-gali	Japanese millet	*
Elytrigia pontica	Tall wheatgrass	*
Eucalyptus globulus	Blue gum	*
Foeniculum vulgare	Fennel	*
Frankenia salina	Alkali heath	
Fraxinus latifolia	Oregon ash	
Glaux maritima	Sea milkwort	
Grindelia stricta	Marsh gumplant	
Heterotheca grandifolia	Telegraph weed	
Hordeum marinum	Mediterranean barley	*
Hordeum murinum	Barley	*
Juncus balticus	Baltic rush	
Lathyrus jepsonii var *jepsonii*	Delta tule pea	
Lepidium latifolium	Perennial pepperweed	*
Leymus triticoides	Alkali ryegrass	
Lilaeopsis masonii	Mason’s lilaeopsis	
Lolium multiflorum	Italian ryegrass	*
Lotus corniculatus	Bird’s foot trefoil	*
Phalaris aquatica	Harding grass	*
Phragmites australis	Common reed	*
Polygonum lapathifolium	Willow weed	
Polypogon monspeliensis	Rabbitfoot grass	*
Potamogeton pectinatus	Fennel-leaved pondweed	

Scientific Name	Common Name	Non-Native
Potentilla anserina	Marsh cinquefoil	
Quercus agrifolia	Coast live oak	
Quercus lobata	Valley oak	
Raphanus sativus	Wild radish	*
Rosa californica	California wild rose	
Rubus discolor	Himalayan blackberry	*
Rumex crispus	Curly dock	*
Salicornia virginica	Perennial pickleweed	
Salix exigua	Narrow-leaved willow	
Salix laevigata	Red willow	
Salix lasiolepis	Arroyo willow	
Scirpus acutus	Common tule	
Scirpus americanus	Three-stem	
Scirpus californicus	California bulrush	
Scirpus maritimus	Alkali bulrush	
Sesuvium verrucosum	Western sea purslane	
Spartina foliosa	California cord grass	
Spergularia marina	Saltmarsh sand spurry	
Triglochin maritima	Seaside arrowgrass	
Typha angustifolia	Narrow-leaved cattail	
Vulpia myuros	Rattail fescue	*
Xanthium strumarium	Cocklebur	

Appendix B – Additional Technical Information

The following information is meant to augment the Methods section of the main report by providing details to aid in the reconstruction of the change detection process.

GIS Details

The 2003 digital imagery received by DFG was projected in State Plane Zone II (NAD 83, feet). The existing 1999 vegetation map (Suiun_veg99_attr2.shp) was reprojected from Teale Albers (NAD 27, meters) to State Plane Zone II (NAD 83, feet) using ArcToolbox; datum transformation used the NADCON[9613] method. The reprojected file was named Suisun1999_spft83.shp. The area and perimeter fields were updated using the calculator: Area=[shape].returnarea; Perimeter=[shape].returnlength. The acreage field was then updated using the calculator: Acres=[Area]/43560.

To partially amend the resulting spatial error between the 1999 vegetation map and the 2003 digital imagery, the rubbersheeting editing tool in ArcMap was used. The following points (adjust_link8.txt) were used to rubbersheet the 1999 vegetation polygon linework to the 2003 aerial photo mosaic:

1	6589678.880306	1796887.120971	6589676.319633	1796879.865729
2	6546377.160296	1847997.328249	6546329.398164	1848032.843680
3	6578177.932123	1842463.218099	6578177.932123	1842471.531011
4	6577980.500467	1842479.843923	6577967.338357	1842493.006033
5	6554095.081976	1793711.463085	6554049.279316	1793638.942207
6	6535947.612946	1817305.301093	6535922.656528	1817313.619899
7	6535997.525780	1817430.083180	6535972.569363	1817441.967188
8	6531159.226531	1804090.351989	6531157.424139	1804063.916903
9	6531322.042628	1804054.904942	6531328.651400	1804024.264274
10	6524815.468884	1779316.081785	6524825.038110	1779428.178430
11	6523664.136368	1841475.436516	6523714.077475	1841373.744841
12	6588212.100419	1832402.719045	6588223.703584	1832394.983602
13	6594672.743737	1788836.398983	6594714.270854	1788831.015838
14	6559300.564944	1815267.428575	6559306.568206	1815285.438361
15	6561890.938561	1847859.124053	6561911.293269	1847842.840287
16	6563669.432120	1794197.575450	6563666.509612	1794170.103874
17	6527510.787634	1840132.042307	6527466.811413	1840224.392371
18	6527000.663469	1840134.241118	6526952.289625	1840228.789993
19	6562840.400725	1831991.907064	6562823.760356	1831993.755994
20	6562797.875338	1831995.604923	6562807.119987	1831999.302783
21	6562735.011723	1831897.611641	6562747.954232	1831887.442527
22	6562815.440172	1831892.989316	6562784.008364	1831878.197877
23	6568193.619611	1806431.412936	6568185.834623	1806439.197924
24	6575712.370430	1789763.550299	6575696.633929	1789721.750219
25	6575800.396482	1789741.912610	6575776.299965	1789720.274922

Successful printing of the 1999 vegetation line work at 1:9600 scale onto 34" X 44" mylar sheets was accomplished by using the ArcPress print driver and setting the printer DPI to 600.

During the interpretation process it was most efficient to have a laptop computer easily accessible to lookup polygon details in the GIS.

The 1999 vegetation map was copied and renamed to generate the 2003 vegetation map (Suisun2003_spft83.shp). All attribute fields except the polygon identifier, area and perimeter were eliminated. This file was updated as described in the Methods section. Polygon linework changes were performed in ArcView 3.3 using the polygon splitting and appending tools. Edits which appended parts of one polygon onto a target polygon were done using the "Union" command. New polygons were given a unique identifier starting with 42000.

The 2003 vegetation map attribute table (Suisun2003_spft83.dbf) was exported into Access and the query wizard was used to check for duplicate unique identifiers. Errors were assessed individually in ArcView. After completion of data entry and database updates (see below), SQL connect was used to import the Access attribute file (Change Detection Main Table) into ArcView and was linked through the unique identifier to the vegetation map. The legend was imported from the original 1999 vegetation map.

The tidal wetlands shapefile described in the Methods: Analysis section is named suisun_tidalmarsh.shp (State Plane Zone II, NAD 83, feet) and was based on SFEI_EcoAtlas_tidalmarsh.shp (UTM Zone 10N, NAD 27, meters).

Analysis Details

During the interpretation process it was most efficient to have a laptop computer readily accessible for on-the-fly data entry. A data-entry-only table was established in Access with the following attributes:

Name	Type	Description
Index #	Text	Print index identifier
Photo #	Text	Aerial photograph associated with polygon
Poly_id	Double	Unique polygon identifier
Veg_99	Double	Assessed vegetation code in 1999
Id	Text	How assessment was made in 2003
Poly_size	Text	Size class of polygon
Chnge_cls	Integer	Change class, 1999-2003
Veg_03	Integer	Assessed vegetation in 2003
Ht_03	Integer	Assessed height in 2003
Cov_03	Integer	Assessed cover in 2003
Dist_03	Integer	Assessed disturbance in 2003
Notes	Text	Additional information

Following completion of photo interpretation, the main data table was created by exporting the attribute table of the 1999 vegetation map (Suisun1999_spft83.dbf) from the GIS and importing it into Access. All polygons identified as mislabeled in the 2000 change detection effort were updated in the current database; this update was identified by a "U" in the Id field. Disturbance, cover and height codes were updated such that "Not Applicable" became "0" (zero) in all cases. Thus, for cover and height 7 was replaced by zero; for disturbance 5 was replaced by zero. Additional fields were added to accommodate the 2003 data; all fields are listed in **Table 2**. The "Change Detection Main Table" was updated with data from the data-entry-only table using update queries.

The calculations performed in Access are described in the Methods section. A working knowledge of expression building in query functions is necessary to perform these calculations; a full description is beyond the scope of this report.