South Bay Salt Pond
Restoration Project
Restoring the Wild Heart of the South Bay

Habitat Evolution Mapping Project

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Restoration Project

Final Report
(2009-2011)

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& ASSOCIATES

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Submitted by

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1. Introduction

This report details the results of a three year project aimed at developing methods for tracking long term changes to marsh habitats and mudflats for the South Bay Salt Pond Restoration Project (SBSPRP). We utilized the supervised classifications of satellite imagery to delineate vegetation, mudflats, and other habitats within the study area boundary. The method is designed to reduce the reoccurring cost of tracking habitat development in the restored areas by developing a semi-automated process using remote sensing. A spectral " habitat model" was produced using three years of Ikonos imagery that links spectral values in the satellite data to distinct stands of vegetation. The resulting datasets will assist land managers and the restoration process in tracking changes occurring to these habitats at a variety of scales During the three year period of the project, we visited most marshes south of the San Mateo Bridge, conducting over 1000 vegetation surveys in the field. Our mapping methods focus on ecologically relevant habitat classes that can be differentiated using a pixel based image classification approach, combined with extensive ground truthing. Project deliverables include: methods, habitat type descriptions, standardized field data collection protocols and procedures, spectral habitat model (signature file), and the final habitat datasets for the study period (2009-2011).

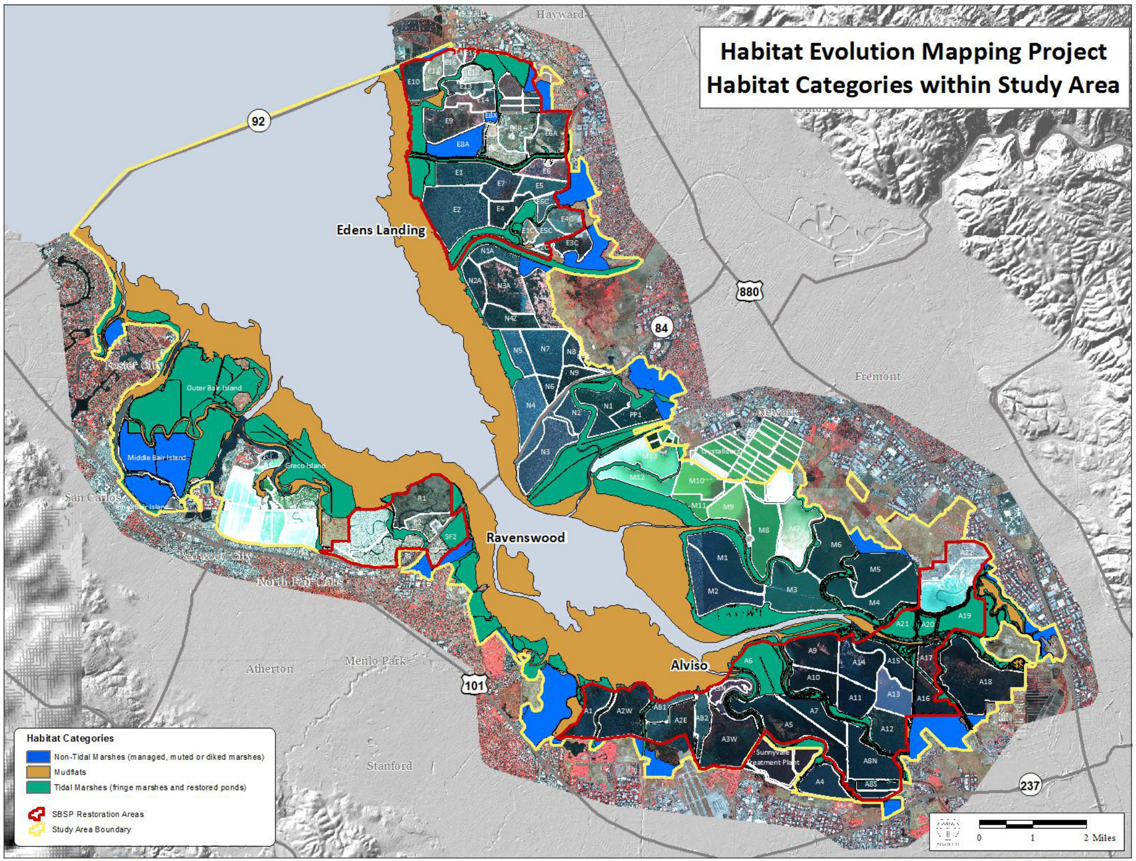
Changes to marsh vegetation and mud flats will play a critical role in the dynamics of the restoration process. The remote sensing of marsh vegetation has proven to be a successful approach to aid with mapping marshes in the SF Bay as well as other locations (Tuxen, Schile, Kelly and Siegel 2008; Belluco et al 2006) and we have found this also to be true in South San Francisco bay. The methods and datasets developed for this study provide the SBSRRP an important set of tools and resources for monitoring long term changes to these habitats. We hope that the products of our research efforts will assist the SBSPRP to make more informed decisions about restoration actions.

This report details the habitats, results and methods produced from our mapping efforts conducted between the summer of 2009 and spring of 2012. Habitats (including biotic and abiotic types) were mapped for all baylands and sloughs in San Francisco Bay south of the San Mateo bridge (see Figure 1). The total area classified was approximately 33,000 acres, more then twice the actual area included in the restoration (~15,000 acres). The project mapped not only habitats within the three restoration project areas, but also all of the tidal marshes (and uplands) designated within the study area boundary. Although the focus was on floral colonization and habitats within restored areas and ponds, we also mapped these additional areas in order to better understand the distribution and extent (and changes) of habitats in the overall estuarine system. Our proposed methods and processes were effective and as a result have been largely preserved in our implementation of the project.

The three habitats datasets provide a strong baseline for describing the distribution and extent of marsh habitats within south San Francisco Bay. The datasets and methods used in their development, will allow the SBSPRP to accurately track changes over time to habitats at the vegetation alliance level – including floral colonization within restored ponds. The model and methods also provide a strong baseline on the distribution and extent of habitats at finer scales (such as Pickleweed /- Gumplant), although overall changes to these specific habitats over the three year project period are less reliable. Some habitat types representing finer vegetation associations were well within (or even above) accuracy requirements (~80% for Pickleweed /- Gumplant), although this also varied from year to year. In addition, changes occurring over longer periods (3-5 years) to specific vegetation associations can also be reliably measured. Some of these limitations can be overcome, by combining habitat classes representing vegetation associations into slightly broader, but ecologically relevant, marsh categories – most notably low, "mid", and high marsh (see Table 1). As a result, changes occurring within the time period of the study can be reliably tracked at the habitat alliance level or the more general marsh types (low, "mid", high marsh). The datasets and methods produced as a result of the mapping project, provide the SBSPRP a valuable set of tools and resources for assisting with long-term management and restoration of marshes within the south bay. These include:

- Baseline data on marsh habitat distributions, extent, and floristic diversity at scales relevant to the restoration process and long term management.
- Methods and tools (i.e. spectral habitat model) that can be reliably used to track changes to marsh habitats now and into the future.

Figure 1: Study Area Map with Habitat Categories



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Ikonos image from July 7th, 2011.

Habitats classified as part of the study were mapped by dominant vegetation alliance and/or association. These habitat classes were analyzed using a range of geographies and scales including biotic and abiotic type (tidal marsh, mudflat, "non-tidal" marsh, levee/upland); as well as by marsh habitat (salt, brackish, and and freshwater marsh); and ecological gradient (low,"mid", high marsh).

2. Habitat Types

Habitats classified within the study area were of two broad land cover types: biotic (i.e. vegetation) and abiotic (e.g. bare earth). This section lists and describes the habitat types that were classified within the study area. It provides background on both the ecological significance of the specific ("Cordgrass") habitat types as well as the more generalized (e.g. "low" marsh) habitat types. The section also included as well as detailed habitat descriptions, based on the Manual of California Vegetation (Keeler-Wolf 2009), to assist both with map interpretation and application of datasets to future restoration and conservation efforts. Details on how the list of habitat types, and associated training sites, were developed for use in the image classification, are described below in Section IV: Methods.

2.1 Overview of Habitat Types

Although the focus of the project is on vegetation, and vegetation associations (e.g. Pickleweed /-Cordgrass), the term "habitat" is being used here to refer to both biotic and/or abiotic land cover classifications. Out list of habitats conform to classifications set by the Manual of California Vegetation (MCV), although they expand on those classes with regards to marsh vegetation associations within South San Francisco bay. Our habitat classes were based on expert review of existing habitat types, the MCV listing of marsh habitats, previous vegetation studies in the south bay and a review of available literature on marsh vegetation. Our primary focus was to create a list of habitat classes that could be distinguished based on the (spatial and spectral) resolution of the satellite imagery and that also met project goals over time.

2.2 Background on Salt, Brackish, and Freshwater Marsh Habitats

At a landscape scale the tidal marsh ecosystem has two major abiotic gradients that influence plant species distributions: dry to wet and fresh to saline. As one travels from the ocean towards the river(s), estuarine conditions generally become less saline; and as one moves from areas of open water towards uplands, conditions generally become drier. The salinity gradient creates distinct salt, brackish, and fresh marsh communities; the inundation gradient creates distinct low, "mid", and high marsh, as well as upland transitional habitats. At the local scale there can also be transitions between salt, brackish, and fresh marshes as well as low marsh, "mid" marsh, high marsh, and upland transitions.

Although we have used the term "mid" marsh, the use of a mid-marsh term for a distinct habitat in this estuary may arise from a misunderstanding of system dynamics; the current marshes are predominantly broad perennial Pickleweed (Sarcocornia pacifica) dominated plains near Mean High Water (MHW), which some refer to as the mid-marsh plain. But these are younger marshes that have developed outside of levees constructed during the last century and have not matured enough to reached equilibrium elevations. At maturity they will stabilize within a decimeter of Mean Higher High Water (MHHW; Atwater 1979), which is the elevation of high marshes.

Along the salinity gradient from saline to fresh marsh up-estuary there are three distinct habitats: *salt, brackish and fresh marsh*. These habitats are denoted by different plant communities that reliably occur where conditions are appropriate. In the study area the vast majority is salt marsh, and where the fresh through brackish to salt marsh ecoclines occur they are driven by wastewater treatment plant outfalls and small rivers. Fresh marsh is rare, restricted to Artesian and Alviso Sloughs within the study area, which is dominated by “Tules” (Schoenoplectus californicus and S. acutus) and broad-leaved Cattails (Typha angustifolia) over six feet in height. Fresh marsh is not known to provide habitat to California Clapper Rail (CCRA) or Salt Marsh Harvest Mouse (SMHM) but they do provide habitat to passerines. Brackish marsh is slightly more common, found in those two sloughs as well as at the Palo Alto Baylands (another wastewater treatment plant outfall), which is dominated by alkali bulrushes (Bolboschoenecutus maritimus, B. robustus, and Schoenoplectus americanus) and brackish marsh cattails (Typha latifolia). Brackish marsh is known to provide some habitat value to SMHM but not CCRA. Although the extent of salt marsh may be greater than brackish, the brackish zone may "reach into" the salt zone per se because Cordgrass extends in the low marsh zone below Alklai Bulrush dominated marshes. Likewise, it may also "reach into" into the fresh zone because Freshwater Bulrush extends in the low marsh below Alkali Bulrush. Although this could be an artifact of the differential salinity vs flooding tolerances of Corgrass and Alkali Bulrush.

Salt marshes dominate the remainder of the tidal marshes in the study area, which are critical habitat for several endangered species. And the majority of these are younger marshes, which have developed in the last century outboard of the levees and other anthropogenic fills. Younger marshes are dominated by Perennial Pickleweed, which is only interrupted in the middle marshes by invasions of the parasitic plant monkey puke (Cuscuta salina). Along the elevation gradient from open water to surrounding uplands, areas above Mean Sea Level are colonized by some annual Pickleweed (Salicornia europaea) but mostly by Pacific Cordgrass (Spartina foliosa), which constitute the low marsh community. Although some might include perennial Pickleweed in the low marsh community its presence intermixed with Pacific Cordgrass may indicate a transition between low and high marsh or the boundary between the two in either a distinct clean edge or the messier in appearance matrix that may denote a transitional zone.

Above the low marshes, which are generally a narrow band adjacent to the mudflats or along the edges of slough channels are the broad high marsh plains. As stated previously, these were reportedly the dominant habitat of the estuary’s tidal marshes due to the tendency for tidal landforms to reach equilibrium within a foot of MHHW (Atwater, 1979). As marshes develop, through accretion via sedimentation from tidal flux, they first vegetate near Mean Sea Level (MSL) with low marsh species, then begin to recruit perennial Pickleweed as they approach MHW. They will remain dominated by perennial Pickleweed for the next century or more as they continue rising towards MHHW, likely due to organic accumulation (a very slow process). Above MHW other species begin out competing perennial Pickleweed, including salty susan (Jaumea carnosa), saltgrass (Distichlis spicata), alkali heath (Frankenia salina), gumplant (Grindelia stricta), seaside arrowgrass (Triglochin concinna & maritima), and California sea lavender (Limonium californicum). Laumeister is arguably the finest remaining example of historic salt marsh in the South Bay. It was never diked and is obviously different than the adjacent Faber Tract, which was restored to tidal action in the 1970s. Together these two small marshes provide habitat for 10% of the entire population of California Clapper Rails.

At the upper limit of the tidal marshes is the upland transition, a zone of mixing between tidal and adjacent upland habitats. Although it is cited as critical habitat for SMHM and CCRA as high tide refuge during extreme high tide events (Shellhammer 1982; Josselyn 1983; Bay Goals 2000; USFWS Tidal Marsh Ecosystem Recovery Plan 2012) it has not been well described. Harvey et al (1978) attempted to create a legally defensible delineation strategy for mapping the tidal marsh-upland boundary during jurisdictional determinations, but their work was not necessarily focused on the tidal marsh ecosystem. Aside from the needs of the dozens of plant species said to once thrive in these transitions (Baye 2000) the two cited functions are extreme high tide refuge and appropriate slope and space for landward transgression during rapid Sea Level Rise events.

2.3 Plant Species Alliance vs. Association

Although the distribution of plant species has been studied since the 19th century, the topic still does not appear as well-understood as some hope (Kent et al. 1997). So the underlying theories of plant communities should not be considered settled. This is particularly true of community boundaries; these borders are rarely sharp or distinct. A “stand” of vegetation is defined by the Manual of California Vegetation (MCV) as a distinct “vegetation type”, which observers perceive as distinct species assemblages that predictably repeat across the landscape in response to abiotic and biotic stressors.

This study mapped significant “stands” of vegetation by species dominance relationships. Dominant species found in the study area’s tidal marsh ecosystem habitats formed the basis for the selection of vegetation “alliances”. The term “series” is used for the upper hierarchical level in the MCV system. Series are defined by the dominant, important or rare species, which is often the species or genera that dominate the upper strata. Stands that have the same dominant(s) but differ in subdominant(s) are called “alliances”. Where there is a significant co or sub-dominant species for a given alliance, these dominance relationships help to define a new “association”.

There are some exceptions to the simple rule of dominance. Certain species, such as marsh Gumplant (Grindelia stricta), are said to provide greater habitat quality than those that lack it, even if all other characteristic are equal. Gumplant’s ability to define a unique “stand” even if it does not provide the highest relative percent cover, is useful in a study of the tidal marsh ecosystem. However, for the purposes of mapping, we have included Gumplant as an association of Pickleweed, since this better reflects the relative percent cover within a given area and the ability for the satellite spectra to distinguish it from other habitats.

We have utilized common names in our habitat types and in the final habitat datasets. However, the habitat type descriptions included below contain details about the species represented for each specific habitat type. The MCV also utilizes common names (instead of scientific) due to the current instability of scientific naming. Recent genetic analyses have led to repeated reclassifications of many species, and we have seen some species be moved between genera only to be moved back again later (e.g.. Pickleweed species). Common names are also relatively well established in California (via the Jepson Manual) and are more currently reliable.

2.4 Habitat Type Descriptions

We mapped 24 unique habitat types, including vegetation at both the a*lliance* and a*ssociation* scale. These are the various biotic (e.g."Pickleweed") and abiotic (e.g. "mud") land cover classes that are mapped as part of the project. The 16 tidal marsh habitat classes include: 9 salt marsh, 4 brackish, and 3 freshwater vegetation specific habitat types. Descriptions for each habitat types are included below starting on the next page.

Table 1: Tidal Marsh Habitat Types (16)

	Salt Marsh
Low Marsh (MTL-MHW)	1. Cordgrass
	2. Pickleweed (annual)
	3. Cordgrass /- Pickleweed (perennial)
"Mid" High Marsh (MHW -MHHW)	4. Pickleweed (perennial)
	5. Saltgrass
	6. Pickleweed /- Jaumea
High Marsh (MHHW)	7. Alkali Heath
	8. Pickleweed /- Gumplant
	9. Pepperweed

Brackish Marsh	***Freshwater Marsh***
10. Alkali Bulrush	14. Tules
11. Alkali Bulrush /- Pickleweed	15. Cattails
12. Alkali Bulrush /- Spearscale	16. Tules /- Cattail
13. Alkali Bulrush /- Pepperweed	
Pepperweed	

Table 2. Other Habitat Types (8)

Upland	***Non-Vegetated***
17. Alkali Grasses	19. Water
18. Mustard	21. Algae
Saltgrass	21. Mud
Alkali Heath	22. Mud with Biofilm
Pepperweed	23. Wrack
	24. Bare Earth

Cordgrass (Spartina sp.) Herbaceous Alliance

California Cordgrass marsh (low marsh / MTL ~ MHW)

Spartina foliosa is dominant in the herbaceous layer with, Salicornia europae, Schoenoplectus californicus, Schoenoplectus maritimus/robustus & americanus, and algae. Herbs <1.5m; canopy is intermittent to continuous.

Habitats: Coastal salt marshes on mudflats, banks, berms, and margins of bays and deltas. The USFWS Wetland Inventory (1996 national list) recognizes Spartina foliosa as an OBL plant.

Elevation: 0.5-1m (provisional)

Membership Rules
Spartina foliosa >50% relative cover in the herbaceous layer (Keeler-Wolf and Vaghti 2000).

Remarks
Spartina foliosa mostly reproduces asexually by rhizomes. Plants are most likely to establish by seed after freshwater flooding (Zedler et al. 1992). Plants grow in pure stands around the upper intertidal creek banks, bay peripheries, or in deeper tidal pools (Zedler et al. 1999) and neighboring bare or open intertidal mudflats.

Pacific cordgrass (*Spartina foliosa*) was mapped as “Cordgrass” due to hybridization with Atlantic cordgrass (*S. alterniflora*), creating cryptic hybrids that require genetic analysis to differentiate. CORD distributions are currently anthropogenically modified due to the estuary-wide Invasive Spartina Project control program. Therefore their current distribution should not be considered ecologically relevant or indicative of their potential spatial extent.

In general S. foliosa is known to occupy the lowest reaches of the emergent macrophyte marshes, near Mean Sea Level (MSL). This is generally a narrow band (although gently sloping mudflats can increase their stand width substantially forming a border between the rest of the marshes and the mudflats or in very narrow bands along the edges of sloughs between the bank and the bottom of the channel if the morphology creates appropriate conditions (i.e. elevation). S. alterniflora was known to colonize lower elevations than S. foliosa, on the mudflats proper creating their characteristic “donut” shaped individual clones until they filled in and became less distinguishable. S alterniflora x foliosa is known to colonize higher elevations than S. foliosa, invading the “mid” marsh plain amongst the Sarcocornia pacifica (perennial pickleweed).

Other species commonly found with S. foliosa are limited to Salicornia europaea (annual pickleweed), although S. pacifica could be considered a component of the low marsh depending on one’s delineation of the transition between low and high-marsh. S. europaea generally occupies elevations just below S. foliosa and is often missed by land-based survey, as the cordgrass obscures it.

Cordgrass /-Pickleweed Herbaceous association

(low -"mid" marsh transitional area)

Sarcocornia Pacifica quickly begins to co-dominate with Spartina foliosa (but not Spartina alterniflora x foliosa hybrids) as elevation rises above MTL towards MHW. Depending on your perceptions of plant communities this could be considered a distinct alliance, an *ecotone* between the Spartina foliosa Alliance and the Sacrocornia pacifica Alliance, or as part of one great *ecocline* continuum between open water-mudflats and adjacent uplands.

Habitats: Coastal salt marshes. The USFWS Wetland Inventory (1996 national list) recognizes Salicornia virginica and Spartina foliosa as OBL plants.

Elevation: 0.15-2.5m.

Membership Rules

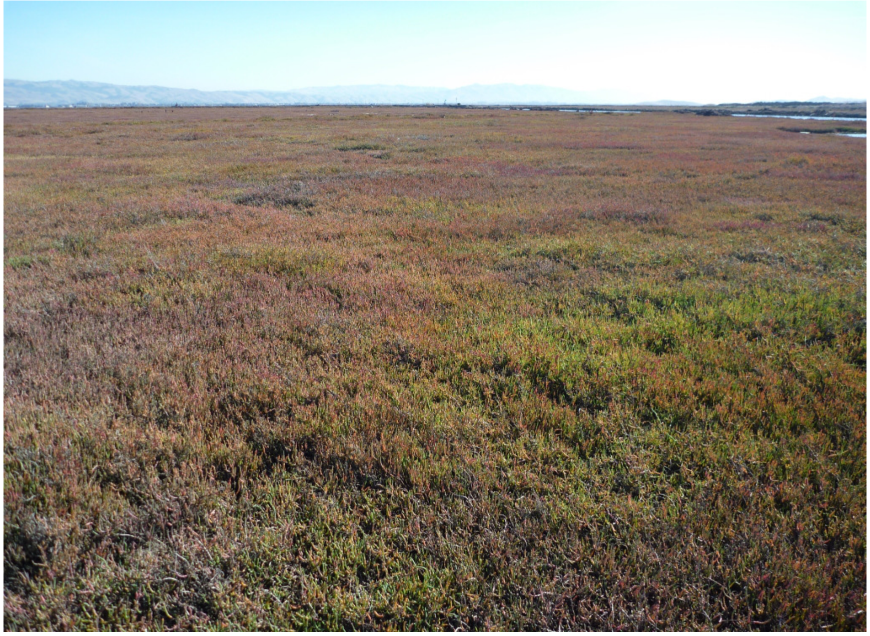
unknown

Remarks

The co-occurrence of S. foliosa and S. pacifica could be considered indicative of a transition zone between low and high-marsh. It could also be found surrounding depressional pannes throughout the high marsh plane. As the actual extent of this transition zone is unclear, requiring further study to clarify, the relative dominance and sub-dominance of Cordgrass and Pickleweed can vary.

Pickleweed (perennial) Herbaceous alliance (Sarcocornia pacifica)

Pickleweed mats (below MHW to above MHHW)



Sarcocornia pacifica or Salicornia depressa is dominant or co-dominant in the subshrub and herbaceous layers with Atriplex patula, A. prostrata, , Bolboschoenus maritimus, Cotula coronopifolia, Cuscuta salina, Distichlis spicata, Frankenia salina, Grindelia stricta, Jaumea carnosa, Lepidium latifolium, Limonium californicum, Spartina foliosa, Triglochin maritima, and algae. Plants 1.5m; canopy is intermittent to continuous.

Habitats: Coastal salt marshes, alkaline flats. The USFWS Wetland Inventory (1996 national list) recognizes Salicornia virginica as an OBL plant.

Elevation: 0.15-2.5m.

Membership Rules

Sarcocornia pacifica >10% absolute cover and sometimes over a higher cover of short annual or perennial grasses; if Distichlis spicata >=50% relative cover, stands are in the DISP alliance (Keeler-Wolf and Vaghti 2000).

Remarks

Taxonomic treatments vary in their determination of pickleweed names. The Jepson Manual (Hickman 1993) used Salicornia virginica for the common perennial pickleweed along the coast of California. A more recent treatment in The Flora of North America (Ball 2003) used Sarcocornia pacifica. This somewhat shrubby perennial has scale-like leaves and fleshy green to reddish stems. It has succulent stems that increase in water content to dilute salts, and plants shed tissues and organs to remove salts (Adams 1990).

Sarcocornia pacifica (perennial pickleweed) was generally mapped as “Pickleweed”, which could include the high marsh species Arthrocnemum subterminale (Parish’s pickleweed) and the low marsh species Salicornia europaea (annual pickleweed). Due to S. pacifica’s broad hydrologic tolerances (both duration of flooding and drying somewhat) it is found from the upper edge of the low marsh, dominating high-marsh elevations, and through the high marsh up into the upland transition zone. In the “mid” high-marsh it grows with Distichlis spicata, Jaumea carnosa, Lepidium latifolium, Triglochin concinna, Atriplex triangularis, and Bolboschoenus maritimus. In the high marsh it grows with Limonium californicum, Grindelia stricta, Frankenia salina, Distichlis spicata, Triglochin maritima, and Arthrocnemum subterminale.

Pickleweed (annual) Herbaceous alliance (Salicornia europaea)

Annual pickleweed marsh (low marsh habitat)

Salicornia europaea is the dominant in the herbaceous layer with Spartina foliosa, S. alterniflora, and their hybrids, as well as Sarcocornia pacifica in some cases. Herbs 0.1-2m. Canopy is intermittent to continuous.

Habitats: coastal salt marsh. The USFWS Wetland Inventory (1996 national list) recognizes Slaiconria europaea as an OBL plant.

Elevation: 0.5-1m.

Membership Rules

Unknown

Remarks

Salicornia europaea is the most flood tolerant of native tidal salt marsh plants. Spartina alterniflora is more tolerant and would be found lower in the tidal profile if present. S. europaea is found adjacent to mudflats, between it and Spartina foliosa. S. europaea is often one of the first species to colonize areas that have reached appropriate elevations (i.e. near MSL), along with the spartinas.

Pickleweed/-Jaumea Herbaceous Association (Sarcocornia pacifica /- Jaumea carnosa)

Jaumea carnosa is usual subdominant to Sarcocornia pacifica in the herbaceous layer with Distichlis spicata, Frankenia salina, Grindelia stricta, Triglochin concinna, and T. maritima. Plants 0.1-0.66m. Canopy is intermittent to continuous.

Habitats: coastal salt marsh. The USFWS Wetland Inventory (1996 national list) recognizes Jaumea carnosa as an OBL plant.

Elevation: 0.15-2.5m.

Membership Rules

Unknown

Remarks

A common species association in the mid-aged and older marshes is perennial pickleweed and salty susan (Jaumea carnosa). Salty susan is often a subdominant, with a patchy distribution amongst the pickleweed, but in a few cases it is more dispersed (older mashes up Newark Slough just south of the Refuge Headquarters hill) or dominant (older marshes on the northern end of Greco Island). Salt susan is the only species known to not provide cover for CCRA (unsure of its utility to SMHM) so its ecological significance remains unknown.

Pickleweed /- Gumplant Herbaceous Association (Sarcocornia pacifica /- Grindelia stricta)

Gumplant patches (high marsh / ~MHHW)

Grindelia stricta or another Grindelia species is co-dominant in the herbaceous layer with Sarcocornia pacifica and dominant with Distichlis spicata, Frankenia salina, jaumea carnosa, Limonium californicum,, Arthrocnenum subterminalis, Triglochin maritime, and T. concinna. Herbs 0.1-1.5m; canopy is intermittent to continuous.

Habitats: Slightly elevated or drier ground that is adjacent to coastal dunes, within salt marshes, or alkaline marshes, including bluffs, levees, and road margins. The USFWS Wetland Inventory (1996 national list) recognizes Grindelia stricta var. angustifolia as an OBL plant. Elevation: 0-200m.

Remarks

Grindelia stricta is a perennial glandular composite with showy, yellow flowers. Plants have a woody caudex and grow along California's coastline. Var. stricta grows along the Northern California coast var. angustifolia is a Central California coast plant, and var. platyphylla occurs along the southern California coast. Varieties have similar ecologies.

Grindelia stricta was mapped as "Pickleweed/-Gumplant", and is generally limited to a narrow elevation band in marshes it is one of the best indicators of high marsh elevations. It is also considered to be one of the most important plant species in high tide refugia for certain marsh obligate fauna, because it is a relatively tall sub-shrub and can provide habitat when the high marsh ground surface is flooded. Its distribution seems to be limited, perhaps by marsh age as many current marshes are young to high-aged (as they have developed outside of our levees in the last 50-100yrs). Usually associated with In the high marsh it grows with Grindelia stricta, Frankenia salina, Distichlis spicata, Triglochin maritima, Limonium californicum, and Arthrocnemum subterminale.

Alkali Heath (Frankenia salina) Herbaceous Alliance

Alkali heath marsh (high marsh/upland transitions / MHHW and up)

Frankenia salina is dominant or co-dominant in the herbaceous and subshrub layers with Arthrocnemum subterminale, Atriplex spp., Cressa truxillensis, Distichlis spicata, Hordeum murinum, Lasthenia spp., Lepidium spp., Limonium californicum, Sarcocornia pacifica, and Suaeda taxifolia. Herbs and subshrubs <60cm; cover is open to continuous.

Habitats: Coastal salt marshes, brackish marshes, alkali meadows, alkali playas. Soils are saline, sandy to clayey alluvium. The USFWS Wetland Inventory (1996 national list) recognizes Frankenia salina as a FACW+ plant. Elevation: <300m.

Membership Rules

Frankenia salina >30% relative cover in the herbaceous layer, sometimes co-dominant with Distichlis spicata or other herbs and subshrubs (Keeler-Wolf and Vaghti 2000, Keeler-Wolf and Evens 2006).

Remarks

Frankenia salina is a perennial or subshrub with pink-purple flowers. It secrets salt from its silvery-gray stems and succulent leaves. The species occurs commonly along the coast of California, inland in the Central Valley, and in the central Mojave Desert.

Frankenia salina was mapped as “Alkali Heath”, and though it does appear to be a good indicator of high marsh elevations it does seem to occupy slightly lower elevations than Gumplant and range well into the upland transitions. While alkali heath does form small mono-typic stands, because each clone appears able to outcompete other species, they are never broad-ranging stands like other marsh dominants. Although it is possible this is due to anthropogenic disturbances that have also reduced the once-broad and dominant distribution of saltgrass in the upland transitions where alkali heath may also have been sub-dominant. Usually associated with In the high marsh it grows with Grindelia stricta, Frankenia salina, Distichlis spicata, Triglochin maritima, Limonium californicum, and Arthrocnemum subterminale.

Saltgrass (Distichlis Spicata) Herbaceous Alliance

Saltgrass flats (high marsh/upland transitions)

Distichlis spicata is dominant or co-dominant in the herbaceous layer with Atriplex prostrata, Bromus diandrus, Cotula coronpifolia, Eleocharis palustris, Frankenia salina, Hordeum brachyantherum, H. murinum, Jaumea carnosa, Juncus arcticus, J. cooperi, Leipdium latifolium, Leymus triticoides, Limonium californicum, Poa secunda, Puccinellia nuttalliana, Sarcocornia pacifica, and Triglochin maritima. Emergent shrubs, such as Atriplex spp., and Suaeda Moquinii may be present at low cover. Herbs <1m; canopy is open to continuous

Habitats: Coastal salt marshes, inland habitats include playas, swales, and terraces along washes that are typically intermittently flooded. Soils are often deep, alkaline or saline, and often have an impermeable layer making them poorly drained. When the soil is dry, the surface usually has salt accumulations. The USFWS Wetland Inventory (1996 national list) recognizes Distichlis spicata as a FACW plant. Elevation: 0-1500m.

Membership Rules

Distichlis spicata >50% relative cover in the herbaceous layer, D. spicata has higher cover than any other single grass species (or) >30% relative cover in the herbaceous layer, Sarcocornia or Salicornia spp. If present <30% relative cover.

Remarks

Distichlis spicata is a rhizomatous, warm-season grass that grows 10-40cm in height. It occurs throughout most of temperate North America. Plants produce little seed annually, but seeds do accumulate in the soil. Seeds require high temperature, low salinity, and moist soil conditions to germinate. Once established, plants grow in soils that vary greatly in salinity (Uchytil 1990f).

Distichlis spicata was mapped as “Saltgrass”, and while it is usually found in the high marsh its range appears to extend lower than GRST or FRSA, and historically it dominated the upland transition. Currently its distribution in most upland transitions is rarer, except for a few locations such as Moffett Field, Warm Springs and the SJ/SC WPCP region. Usually associated with In the high marsh it grows with Grindelia stricta, Frankenia salina, Triglochin maritima, Limonium californicum and upland ecotone species.

Freshwater Bulrush Herbaceous Alliance (Schoenoplectus californicus / acutus)

Tidal Fresh Marsh Tules

The taller "tules" of Schoenoplectus spp. co-occur in the limited tidal fresh marshes of South San Francisco Bay with Typha angustifolia, T. latifolia, (T. x glauca likely), Euthamia occidentalis, as well as S. americanus and Bolboschoenus maritimus/robustus in the fresh-brackish marsh transitions, and a variety of species in the tidal marsh-upland transition. Herbs <4m; cover is intermittent to continuous.

Habitats: along streams; around ponds and lakes; and in sloughs, swamps, freshwater and brackish marshes, and roadside ditches. Soils have a high organic content and are poorly aerated. The USFWS Wetland Inventory (1996 national list) recognizes Schoenoplectus spp. as OBL plants. Elevation: 0-2500m.

Membership Rules

Schoenoplectus acutus/californicus > = 50% absolute cover in the herbaceous layer; Typha spp., if present, can be >30-60% relative cover

Remarks

Schoenoplectus acutus/californicus are robust tules that attains 3m in height. Although S. acutus and S. californicus commonly occur in the same area, S. californicus tends to dominate on the outer, more-exposed edges of marshes adjacent to open water, and S. californicus appears to be more tolerant of brackish water than S. acutus…. S. acutus and S. californicus hybridize (but are sterile). S. acutus is less tolerant of brackish conditions than S. californicus. Mixed stands are often placed in the S. californicus alliance based on analysis of large datasets.

S. acutus/californicus are mapped as "Freshwater Bulrush" as they can be difficult to distinguish in the field and do not play a significantly different habitat role.

Regional Status

Central California Coast (261A). S. acutus frequently dominates in brackish and freshwater marshes of the San Francisco Bay (Josselyn, 1983; Holstein 2000) and the Monterey Bay.

Associations

S. acutus – Typha angustifolia
S. acutus – T. latifolia

Freshwater Bulrush / Cattail Herbaceous Association

(Schoenoplectus californicus|acutus /- Typha latifolia | angustifolia)
Tidal Fresh Marsh & Transition to Brackish Marsh

Schoenoplectus acutus dominates the herbaceous layer, with Typha angustifolia as a subdominant in fresher conditions and T. latifolia as subdominant as they become more brackish. Other species may include Schoenoplectus californica at lower elevations and a variety of peripherial halophytes in the upland transitions.

Habitats: Tidal Fresh Marsh. The USFWS Wetland Inventory (1996 national list) recognizes Schoenoplectus and Typha spp. as OBL plants. Elevation: 0-2500m.

Membership Rules

Unknown

Remarks

While Typha angustifolia is somewhat rare in the fresh marshes of South SF Bay, and usually found as a distinct clone within the tules, T. latifolia presence may be considered an indication of transition to brackish marsh.

Alkali Bulrush (Bolboschoenus maritimus) Herbaceous Alliance

Brackish bulrush marshes (high-low marsh to high marsh)

Bolboschoenus maritimus is dominant or codominant in the herbaceous layer with Lepidium latifolium, Atriplex triangluaris, B. robustus, Cotula coronipfolia, Distichlis spicata, Eleocharis parvula, Sarcocornia pacifica, and Typha latifolia. Herbs <1.5m tall; canopy is intermittent to continuous.

Habitat: Seasonally flooded mudflats; tidal brackish marshes. The USFWS Wetland Inventory (1996 national list) lists Bolboschoenus maritimus as an OBL plant. Elevation: 0-2500m.

Membership Rules

Bolboschoenus maritimus >50% relative cover in the herbaceous layer (Keeler-Wolf and Vaghti 2000).

Remarks

The alliance occurs in tidal marshes with seasonal flooding at intermediate tidal elevations and relatively high salinity (Keeler-Wolf and Vaghti, 2000). Inland marshes in areas with alkali, brackish, and fresh water will contain different associations in this alliance. B. maritimus usually dominates in wetter, tidal brackish to subsaline marshes and ditches, including early successional sites of diked marshes within relict swales and depressions (Baye 2000).

Bolboschoenus maritimus was mapped as “Alkali Bulrush”, to avoid differentiating between it and B. robustus. However, it does appear that D. Thomson may have been mapping Schoenoplectus americanus as alkali bulrush as he was not aware that it was the taller triangular-stemmed bulrush (~2m) and not one of the even taller fresh marsh tules. Significant S. americanus stands include the large marsh just east of A19 and the alkali bulrush mapped this year at the head of Ogilvie Slough that were being classified as cattails. Usually mapped with Atriplex triangularis, Lepidium Latifolium, Sarcacornia pacficia, Frankenia salina, Spartina sp., and Schoenoplectus acutus/californicus.

Alkali Bulrush /- Pickleweed Herbaceous Association

(Bolboschoenus maritimus/- Sarcocornia pacifica)
Brackish-Salt Marsh Transitional Area

Either Bolboschoenus maritimus or Sarcocornia pacifica dominate the herbaceous layer, depending on proximity to brackish or salt marsh, respectively.

Habitats: Coastal salt marshes. The USFWS Wetland Inventory (1996 national list) recognizes Bolboschoenus maritimus and Sarcocornia pacifica as OBL plants.

Elevation: 2.5-3.5m.

Membership Rules
Unknown

Remarks
The salinity gradient created by estuarine conditions creates a transition between salt and brackish marshes, which is indicated by the change in dominance between perennial pickleweed and alkali bulrush. It is assumed that the relative dominance between these two species indicates the salinity gradient, except for at lower elevations, where alkali bulrush appears more flood tolerant and at higher elevations where perennial pickleweed appears more drought tolerant so their relative cover values are likely related to tidal hydrology, which is the other major abiotic gradient in the system.

Alkali Bulrush /- Pepperweed Herbaceous Association

(Bolboschoenus maritimus/- Lepidium latifolium)

Alkali Bulrush /- Perennial Pepperweed invaded brackish marshes where it trades dominance with *Lepidium latofolium*.

Habitats: Tidal brackish marsh. The USFWS Wetland Inventory (1996 national list) recognizes Bolboschoenus maritimus as an OBL plant; Lepidium latifolium is recognized as an FAC plant.

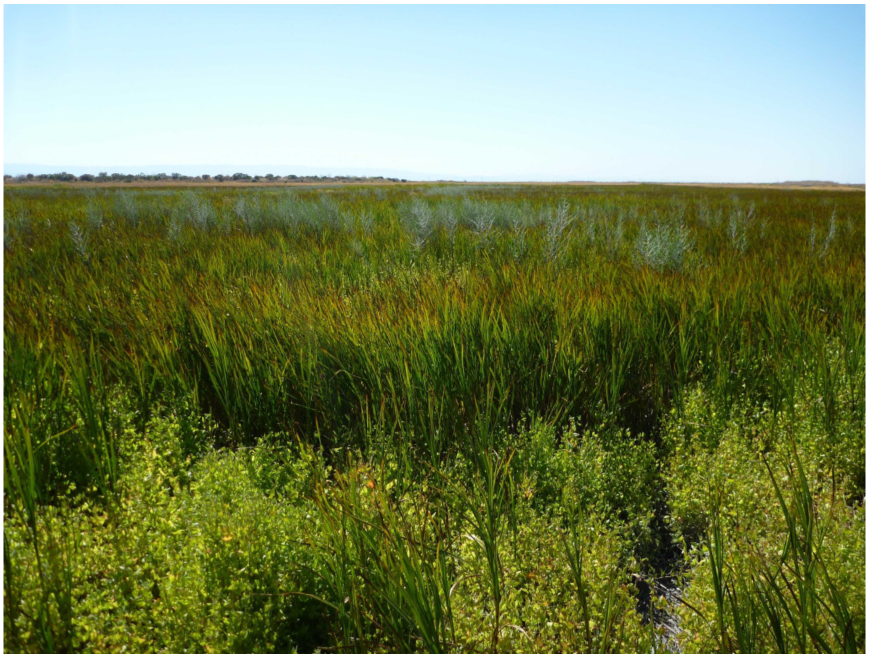
Elevation: 2.5-3.5m.

Membership Rules
Unknown

Remarks
Where *Lepidium latifolium* has invaded Alkali Bulrush dominated brackish marshes and is a sub-dominant in the Alkali Bulrush alliance. This is predominantly along tidal channels, suggesting its mode of invasion (water-borne) or affinity for slightly higher elevations. Once established it will clonally spread into the marsh, which creates a mosaic of dominance relationships between these two species.

Alkali Bulrush /- Spearscale Herbaceous Association
(Bolboschoenus maritimus/- Atriplex triangluaris)

Bolboschoenus maritimus is dominant in the herbaceous layer with Atriplex triangluaris (now considered non-native) as subdominant, except for in the high marsh-upland transition where A. trianglularis can dominate.



Habitats: Tidal brackish marshes. The USFWS Wetland Inventory (1996 national list) recognizes Bolboschoenus maritimus and Atriplex triangluaris as OBL plants.

Elevation: 2.5-3.5 m.

Membership Rules
Unknown

Remarks
ATTR is often found amongst BOMA, able to colonize the open "interstitial" spaces amongst the bulrushes like SASO (Salsola soda – Russian thistle, in Triangle Marsh along Coyote Creek by the RR trestle). Levee-based surveys like those done by HT Harvey for the San Jose's South Bay Marshes study often miss these subdominants because they are not visible from such a perspective. It is unknown what impact these species have on the habitat functions and values, nor does it appear that they out compete BOMA – coexistence seems the best description.

Cattail (Tyhpus angustifolia | latifolia) Herbaceous Alliance

Typha angustifolia Herbaceous Association

Tidal Fresh Marsh Cattails

Typha angustifolia is found with Schoenoplectus acutus and S. californicus. It potentially could be found with Typha latifolia, with which it hybridizes to form Typha x glauca, but this may indicate the transitional type between fresh and brackish marshes. Herbs 3-4m.Cover is continuous.

Habitats: tidal fresh marsh. TYAN and TYLA are OBL species. (3-5m)

Membership Rules

unknown

Remarks

Typha angustifolia seldom dominates the herbaceous layer in tidal fresh marshes of the study area, although it can be found further upstream on several creeks feeding the study area. Typha latifolia is not a common component of the brackish marshes in the study area, and may be an indication of a transition zone between tidal fresh and brackish marsh vegetation types.The only known locations are on Alviso Slough (now the outlet for the Guadalupe River) and along Artesian Slough, which is the outfall for the region's waste water, although there was a small amount of TYLA at the head of Newark Slough

Pepperweed (Lepidium latifolium) Herbaceous Alliance

Perennial Pepperweed

Predominantly found in the Brackish Marsh habitats where it appears to compete well with alkali bulrushes, it also has limited success invading salt marsh, although it does have success in the tidal salt marsh-upland transition zone, but no success invading fresh marsh and does not appears as competitive against other weeds that currently dominate the tidal fresh marsh-upland transitions. It appears to invade via water-borne materials, as it establishes along tidal sloughs, although this may be a function of their slightly higher elevations. As a perennial clonal spreading species, forming large stands via an incredible rooting system, any tiny fraction of which can create a new individual if broken off or unearthed even from depths of many feet or more. It associates with everything found in this study except for the tidal fresh marsh species and perhaps their upland transition weeds. Herbs 0.5-2m; cover is intermittent to continuous (and seasonal).

Habitats: all, except for tidal fresh marsh, tidal mudflat and open water.

Membership Rules

Lepidium latifolium >15% relative cover; more likely mapped as Pepperweed where >25% relative cover.

Remarks

Lepidium latifolium (perennial pepperweed) is a native of Eurasia, likely introduced in the 1960s via a beet shipment to UC Davis. It has since become one of the worst invasive species in the Western US. One of the worst weed in the riparian zones of the Intermountain West, and dominating tens to hundreds of thousands of acres in NE California and the surrounding region, L. latifolium has become one of the worst weed in the tidal marshes of San Francisco Bay.

Lepidium latifolium was mapped as “Pepperweed” and we found they varied substantially both locally and regionally in their phenology It is assumed their invasion reduces habitat values due to their seasonality. Some locations mapping as Pepperweed might also represent other invasive species (see “Mustard” below for list).

Pepperweed /- Alkali Bulrush Herbaceous Association

(Lepidium latifolium /- Bolboschoenus maritimus)

Perennial pepperweed invaded brackish marshes where it trades dominance with Bolboschoenus maritimus.

Habitats: Tidal brackish marsh. The USFWS Wetland Inventory (1996 national list) recognizes Bolboschoenus maritimus as an OBL plant; Lepidium latifolium is recognized as an FAC plant.

Elevation: 2.5-3.5m.

Membership Rules
unknown

Remarks
Where Lepidium latifolium has invaded brackish marshes and dominated the plant community. This is predominantly along tidal channels, suggesting its mode of invasion (water-borne) or affinity for slightly higher elevations. Once established it will clonally spread into the marsh, which creates a mosaic of dominance relationships between these two species.

Alkali Grasses (Leymus triticoides /- Lolium multiflorum) Herbaceous Alliance

Historic Tidal Marsh / Upland Transitional Habitat

In some areas the upland transition were wetter, either due to river flooding, artesian groundwater, or high water tables, and those areas were dominated by grasses such as Leymus triticoides or L. x multiflorus (the hybrid with L. condensatus said to once dominate the bay's margin). Interspersed in these alkali grasslands were alkali vernal pools, seasonal wetlands that once were common.

While this area still contains a significant amount of Leymus triticoides, it has been losing acreage to non-native grasses primarily Lolium multiflorum or Bromus Diandrus. The broadleaf (forb) component of these grasslands has likely been significantly diminished by the prescribed grazing regime used by the refuge to protect the vernal pools from invasion by weeds. The cows do a very good job of keeping the vernal pools from becoming choked by weeds, but the trade-off is they are very hard on parts of the alkali grassland community. And there are broadleaf weeds competing with the natives for space in the grassland.

Common species are similar to halophytic disturbance community: Conium maculatum, Lepidium latifolium, mustards (several species), and thistles (several genera). Natives include many that should be common in the peripherial halophytic community but due to the extent of impacts to them (>90% disturbed) they are not able to self-propagate and are restricted to some historic locations; these are: Malvella leprosa, Lasthenia glabrata, Heliotropium currasavicum, Centromadia pungens, Amsinckia menzieseii, and Suaeda nigra.

Elevation: 0.5-2m; cover is intermittent to continuous (and seasonal)

Membership Rules
Leymus triticoides >30% or Lolium multiflorum >30% or Bromus diandrus >30% cover, with regular interspersion of alkali vernal pools (percentages based on qualitative review of 3 years of ground truthing data).

Mustard (Brassica negra) Herbaceous Alliance

Peripheral halophytic disturbance community

Abundant annual on levees, paths, disturbed soils above tide line. Often associated with Foeniculum vulgare, Conium maculatum, Lepidium latifolium, thistles (several genera), Mesembranthemum nodiflorum, Tetragonia tetragonioides, spearscales (Atriplex spp.), and Chenopodium chenopodioides. Herbs 0.5-4m; cover is intermittent to and continuous (and seasonal)

Habitats: all, but the community varies depending on the adjacent habitats.

Membership Rules

None (too chaotic)

Remarks

We mapped Brassica negra as “Mustard” but it is likely that locations mapped as mustard include other invasive species common to levee flanks, tops, and uplands. The plant communities now are grouped under the moniker “peripherial halophytes”, and are essentially disturbance communities dominated by exotic species.

Although historically the drier upland transitions around the study area would have fit into the Distichlis spicata Alliance, sub-dominated by Frankenia salina, those transitions are now rare (Warm Springs, Artesian Slough, Moffett Field) and all of them are impaired (i.e. diked). What now fits into this category are levee flanks, which are vastly different in landscape and plant communities. Historic transitions were predominantly gently sloping, broad alluvial floodplains, contemporary transitions are steep levee flanks; therefore what was once hundreds to thousands of meters, from tidal marsh to adjacent uplands has become 3-6m wide.

Abiotic Habitat Types

(includes Water, Alage, Mud, Biofilm, Wrack and Bare Earth)

Water within the study area was mapped with a range of training sites throughout the study area. Surface water varies substantially in its appearance and therefore necessarily in its reflected spectral values. From the deeper parts of the open bay, in sloughs, to the shallowest pannes within the marshes or restored ponds, this requires a substantial number of training sites to characterize this variability.

Mudflats were mapped as “*Mud*” and also vary substantially in appearance, from different types of mud, its slope, degree of wetting (as opposed to dry upland dirt, which also varies), presence of wrack or any algae and biofilms (diatoms).

Algae and (mud with) *Biofilm* were also noted to be a component of some emergent macrophyte (vascular) plant stands, so were included as two distinct habitat types in the final model.

Wrack is floating debris deposited by the tides, and often forms a line perpendicular to the shore. Often composed of wood it disturbs the plant communities and may play a role in successional dynamics (temporal variability). But it is most importantly known as habitat for the potentially extirpated (extinct?) salt marsh wandering shrew (vagrant).

Bare Earth is non-wetland soil types, taken from levee tops, or wetland soils that have been piled above the tides (levees). Wrack and bare earth often map as each other.

3. Results (2009-2011)

3.1 Overview of Results

The final habitat dataset(s) produced from the habitat model accurately map (~75% overall accuracy) the distribution and extent of habitat types at the *Alliance* level (including biotic and abiotic habitat types). In addition, the habitat datasets accurately differentiate between salt, brackish and freshwater marshes, as well as low, “mid” and high salt marshes. Accurate results were achieved for all *tidal* marshes, including fringe marshes and restored ponds that are exposed to tidal action, throughout the study area. The classification of habitat types within *non-tidal* marshes , including managed or muted marshes, did not meet accuracy requirements (~60% overall accuracy), likely due to observable differences in the structure, color (i.e. chlorosis in water-stressed plants), and phenology of plants when compared to the same species in fully tidal marshes. Crucially, floral colonization within restored ponds (e.g. Island Ponds, Cooley and Bair Island) within the time period of the study is clearly evident and within accuracy requirements (see Figure 5). The model output, and associated methodology, will allow the SBSPRP to accurately track the development of habitats within restored ponds and overall changes to the estuarine system for all habitat types at the *Alliance* level (see Table 3 for crosswalk between alliance and association habitat types).

The model was also successfully able to map the distribution and extent of vegetation at the association level (e.g. Pickleweed /- Jaumea), although not as accurately (see Tables 11-13). Despite the fact that the overall classification of vegetation associations did not meet accuracy standards, the model did accurately identify the presence, distribution and extent of these vegetation associations. In certain cases, such as Pickleweed /- Gumplant, the habitat datasets were able to meet, if not exceed, accuracy requirements. In addition, our quantitative review of model output combined with extensive ground truthing throughout the study area, indicate that in certain locations (e.g. warm springs) overall habitat classification, including vegetation associations, is likely significantly more accurate then the assessment would indicate. In addition, the distribution and extent of high marsh, which are comprised of habitat types at the vegetation association level, can be clearly differentiated from low and “mid” marsh, despite some inaccuracies in classification. The presence of high marsh is both an indication of marsh age and a factor in the habitat quality of marshes. As a result, the ability to map its presence/absence is important to monitoring the ecology of tidal marshes.

The datasets produced for all three years (2009-2011) provide a strong and accurate baseline for understanding not only the current distribution and extent of habitats but also changes to these distributions. Changes occurring to habitat types at the Alliance level, including all the restored ponds and the overall estuarine system, during the 3 years of the study as well as into the future, can be accurately tracked to assist with adaptive management and restoration. Changes occurring to habitat types that represent vegetation associations that were within accuracy requirements for at least one year (e.g. Pickleweed /- Gumplant in 2011 or 2010), can also be used to track changes to these habitats into the future. Changes occurring to vegetation associations, that were less accurately classified, and that comprise habitat types at broader scales (i.e. low, “mid” and high salt marshes) can also be accurately mapped by lumping these vegetation associations into the broader habitat types that they comprise (see Table 1).

3.2 Overview of Habitat Datasets (2009-2011)

The three habitat datasets (one for each year) map the distribution and extent of all 24 habitat types (at the *association* level) between 2009 and 2011. The study area included all of the mudflats and marshes (as well as levees and uplands) in the baylands and sloughs of San Francisco Bay south of the San Mateo bridge and that were within the project boundary. Between 2009-2011, a single Ikonos satellite image was acquired during June or July (a time of overall peak vegetative growth). The habitat datasets produced therefore represent a “snapshot” of these 24 habitat types for each year.

Spatial Resolution

The final habitat datasets were produced with the following spatial resolution and should be evaluated and utilized within these parameters. Scale variations have to do with the spatial (and spectral) footprint of each habitat type.

- 0.9 meter cell resolution
- Minimum Mapping Unit (MMU): 50 – 100 m^2
- Mapping Accuracy Scale: 1:2400 to 1:4800

Habitat Stratification

In order to best evaluate the datasets and results produced from the habitat model for each year, we stratified the study area into broad habitat categories. All of these areas were included in the final habitat datasets. The 5 broad habitat categories that were the focus of our study, comprise approximately 30,000 acres, and include:

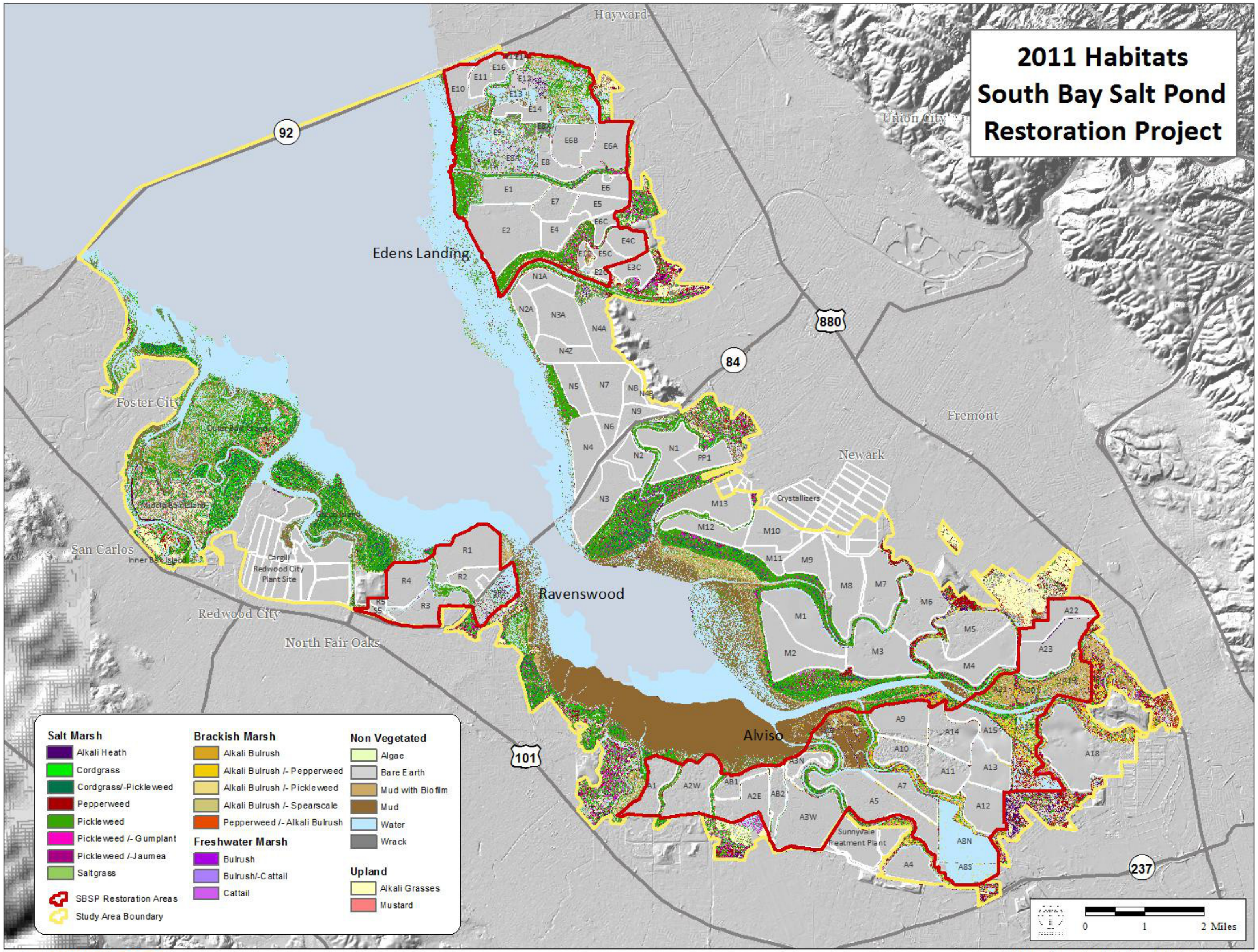
- Mudflats
- Tidal (all marshes exposed to tidal action including fringe marshes and restored ponds)
- Non-Tidal (all managed marshes, muted marshes or non-tidal marshes)
- Levee/Upland

The study area also included three additional categories: unvegetated, developed and water. These areas comprised approximately 3,000 acres within the study area. The vast majority of the unvegetated and developed areas were along the periphery of the project boundary, adjacent to fully developed land uses, and include things like the Alviso Marina. The areas of “water” were either open bay, slough channels or ponds within the restoration area(s) that were still flooded. Although these categories were included in the classification of the satellite imagery they are not included in the analysis of results.

Habitat Results (09-11)

Figures 2 to 4 contain the final mapped results for each year. A comprehensive set of maps, including additional maps not included directly in the report, are included in Appendix 7.5. Qualitative review about habitat trends in specific locations (e.g. restored ponds) or for specific habitat types (e.g. high marsh) are also included below in section entitled “Habitat Trends (2009-2011)”.

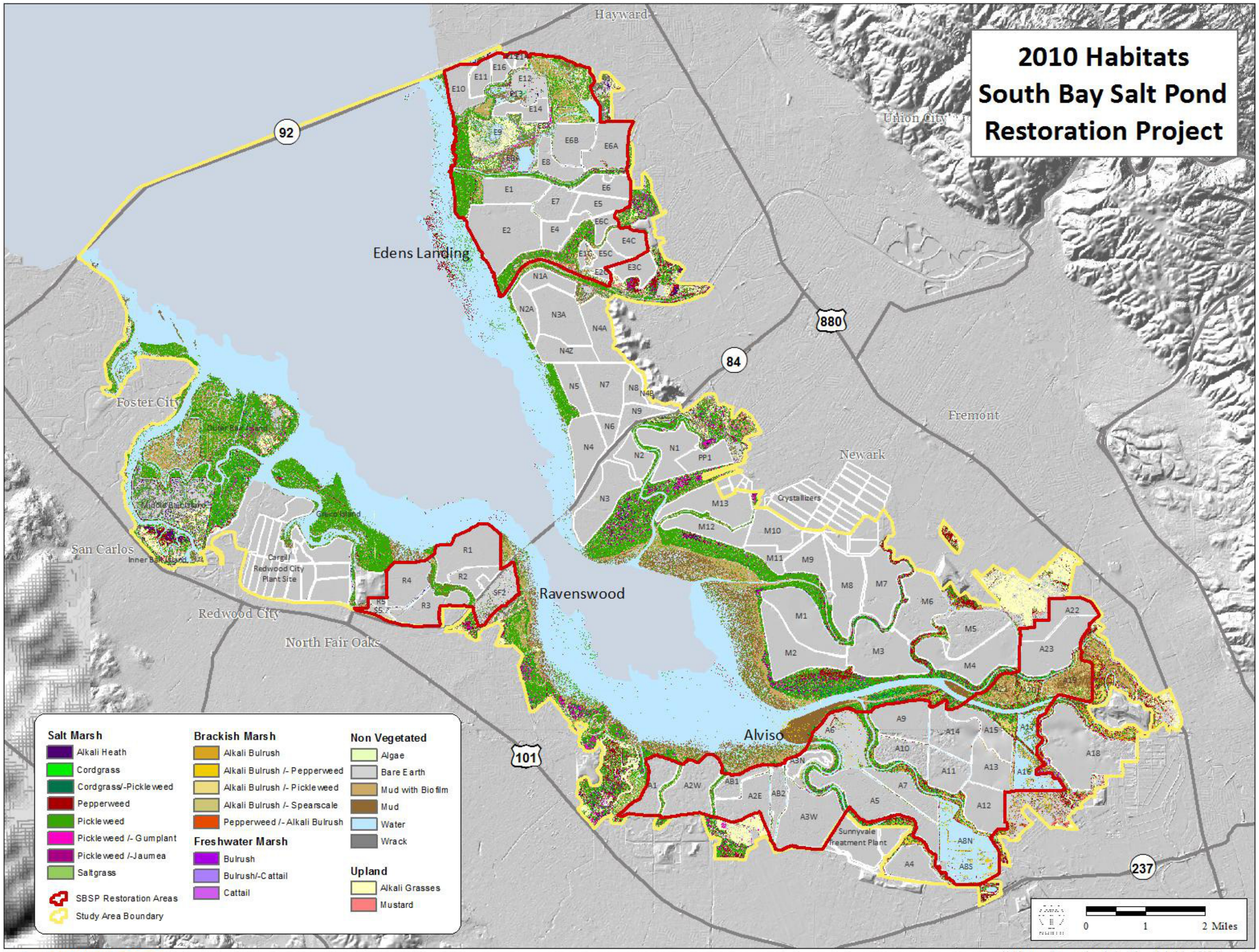
Figure 2: 2011 Final Habitat Dataset



BRIAN FULFROST & ASSOCIATES

Habitats and vegetation derived from July 7th, 2011 (Ikonos).

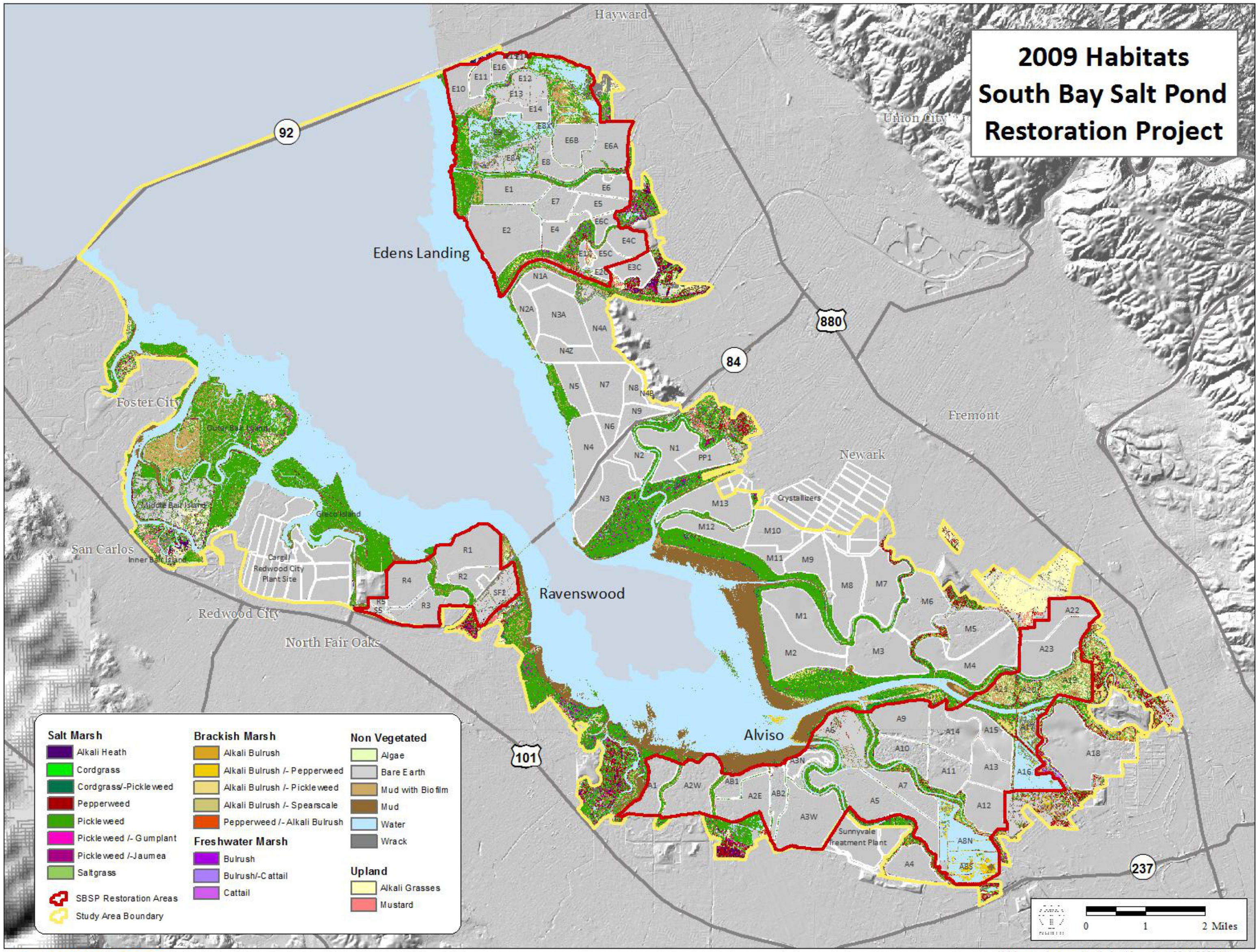
Figure 3: 2010 Final Habitat Dataset



BRIAN FULFROST & ASSOCIATES

Habitats and vegetation derived from July 4th, 2010 (Ikonos).

Figure 4: 2009 Final Habitat Dataset



BRIAN FULFROST & ASSOCIATES

Habitats and vegetation derived from June 23rd, 2009 (Ikonos).

Tidal Marshes & Mudflats

The stratification of acreages of habitat types within *tidal marshes* and *mudflats* (see Figure 1) demonstrate the most accurate and useful data for evaluating the distribution and extent of habitat types as well as changes occurring to these habitats. We have included tables for tidal marshes and mudflats at both the association and alliance level (Tables 4 – 7). The association level tables (Tables 3 and 5) illustrate the acreages and net changes to the 24 specific association level habitat types that were mapped as part of the study. The alliance level tables (Tables 5 and 7) illustrate the acreages and net changes to the 14 “scaled up” alliance level habitat types that were mapped as part of the study. Acreages for mudflats within restored ponds (e.g. A6, island ponds, etc.) are included as part of the tidal marsh acreages (Tables 4 and 6). In addition. although the two categories do not overlap spatially, the mudflats category also includes small amounts of narrow contiguous marsh. Analysis of changes to acreage of habitat types is the most reliable at the alliance level. Values that are indication of misclassification errors (over/under mapping) are indicated in parenthesis and discussed below. We have included a discussion of these tables, organized by biotic and biotic habitat types, within the context of both the accuracy assessment, tidal variation, and 3 years of ground truthing. Table 3 shows the crosswalk used to pool habitat types initially mapped at the association level to the alliance level.

Table 3: Crosswalk of Habitat Associations to Habitat Alliances

Association Level Habitat Types	Alliance Level Habitat Types
Algae	Algae
Alkali Bulrush	Alkali Bulrush
Alkali Bulrush /- Pepperweed	
Alkali Bulrush /- Pickleweed	
Alkali Bulrush /- Spearscale	
Alkali Grasses	Alkali Grasses
Alkali Heath	Alkali Heath
Bare Earth	Bare Earth/ Wrack
Wrack	
Cattail	Cattail
Cordgrass	Cordgrass
Cordgrass /- Pickleweed	
Freshwater Bulrush	Freshwater Bulrush
Freshwater Bulrush /- Cattail	
Mud	Mud
Mud with Biofilm	
Mustard	Mustard
Pepperweed	Pepperweed
Pepperweed /- Alkali Bulrush	
Pickleweed (annual)	Pickleweed
Pickleweed (perennial)	
Pickleweed /- Gumplant	
Pickleweed /- Jaumea (with Saltgrass)	
Saltgrass	Saltgrass
Water	Water
Wrack	Wrack

Overall changes to specific habitat types, such as the Pickleweed alliance, can be best understood and analyzed by combining values for both tidal marshes and mudflats, since floral colonization of mudflats (or alternatively mudflat accretion or erosion) impacts the overall distribution of specific habitat types.

Table 4. Acreage by Association Level Habitat Type in Tidal Marshes (09-11)

Habitat Type	**2009 (acres)**	**2010 (acres)**	**2011 (acres)**	**Net Change (09-11) (percent)**	
Salt Marsh					
Cordgrass	46	159.7	(414.4)	(801.3)	*low marsh*
Cordgrass /- Pickleweed	244.8	378.3	(787.4)	(221.7)	
Pickleweed	4802.8	3902.6	3236.5	-32.6	*mid marsh*
Saltgrass	154.8	285.9	(41.4)	(-73.3)	
Pickleweed /- Jaumea	65.2	155.6	108.7	66.8	*high marsh*
Alkali Heath	31.1	74.8	96	208.5	
Pickleweed /- Gumplant	122.1	239.5	256.7	110.2	
Brackish Marsh					
Alkali Bulrush	60.3	133.5	88.3	46.6	
Alkali Bulrush /- Pepperweed	25.7	57.4	255.8	894.5	
Alkali Bulrush /- Pickleweed	231.3	87.9	40.3	-82.6	
Alkali Bulrush /- Spearscale	44.8	71.6	72.5	61.8	
Pepperweed	300.6	379.4	368.9	22.7	
Pepperweed /- Alkali Bulrush	34.7	29	13.2	-61.8	
Freshwater Marsh					
Freshwater Bulrush	64.8	42.7	55.4	-14.6	
Freshwater Bulrush /- Cattail	21.5	6.9	17.7	-17.8	
Cattail	11.4	8	(103.5)	-810.5	
Upland					
Alkali Grasses	51.4	156.8	173.9	238.5	
Mustard	41.5	62.8	34.9	-15.9	
Non-Vegetated					
Water	549.4	556.8	995.6	81.2	
Algae	175.1	94.6	45.3	-74.1	
Mud	322	348.1	390.1	21.1	
Mud with Biofilm	797.3	789	698.4	-12.4	
Wrack	229.2	218.7	186.2	-18.7	
Bare Earth	400	463.2	150.3	-62	
Total (associations)	*8652*	*8608*	*8586*	*-0.8*	

Table 5. Acreage by Alliance Level Habitat Type in Tidal Marshes (09-11)

Habitat Type	**2009 (acres)**	**2010 (acres)**	**2011 (acres)**	**Net Change (09-11) (percent)**
Salt Marsh				
Cordgrass	290.8	538	**744.6**[a] / 1201.8	**156**[a] / 313.3
Pickleweed	4990	4297	**4487**[a] / 3601	**-10**[a] / -27.8
Saltgrass	154.8	285.9	(41.4)	(-73.3)
Alkali Heath	31.1	74.8	96	**208.5**
Brackish Marsh				
Alkali Bulrush	301.8	217	368.6	**22.1**
Pepperweed	335.3	408.4	382.1	**14**
Freshwater Marsh				
Freshwater Bulrush	86.3	49.6	73.1	**-15.4**
Cattail	11.4	8	(103.5)	(810.5)
Upland				
Alkali Grasses	51.4	156.8	173.9	**238.5**
Mustard	41.5	62.8	34.9	**-15.9**
Non-Vegetated				
Water	549.4	556.8	**565**[a] / 995.6	**2**[a] / 81.2
Algae	175.1	94.6	45.3	**-74.1**
Mud	1119.3	1137.2	1088.5	**-2.8**
Wrack / Bare Earth	629.1	682	336.4	**-46.5**
Total (alliances)	*8767*	*8569*	*8543*	***-2.6***

[a] These numbers were adjusted to account for misclassifications of one habitat type to another (resulting in under or overmapping of a given habitat type) as obtained from the percentage of a given habitat type being misclassified as another in the “mapped data” columns of the error matrices (user's accuracy). Only habitat types that were significantly below acceptable accuracy limits (~75%) were adjusted.

Abiotic

A number of changes seen in both Tables 4 and 5 can be directly related to tidal conditions; including algae, mud, mud with biofilm, water. In 2009, the image was captured at mean tide. As a result, there is a larger presence of algae present in tidal marshes then in the following two years (2010 and 2011), which were captured closer to MLLW. The net decrease (-2.8%) in the Mud alliance (a combination of mud and mud with biofilm) within tidal marshes over the time period and geographic scope of the study is likely due to tidal differences and is not necessarily indicate of overall trends. This is also demonstrated at the association level by the net increase of mud (image caught at lower tide) and net decrease of mud with biofilm (see Table 4). These relative differences are likely evidence of tidal variability and not some other trend. On the other hand, although the 2011 image was captured at MLLW, more water was present within specific marshes (Outer Bair and Cooley) and the resulting large increase of water in the 2011 habitat dataset is very likely these flooded Pickleweed marshes. Although the 2011 image was captured closer to MLLW, it is possible that tidal differences and delays in drainage during low tides within the study area account for the presence of water within these specific restored marshes.

Biotic

The net decrease of both the Pickleweed alliance (and association) needs to be adjusted ([a]) to better understand the actual trend (see Table 5). First, the increased presence of water in 2011 (~430 acres) can be confidently reassigned to Pickleweed, since a number of marshes (notably Bair and Cooley) contained significantly more water in the 2011 image. Second, at least a portion (~456 acres) of the growth in Cordgrass, especially in 2011, can be attributed to overmapping (38% of the Cordgrass alliance assignments were actually part of the Pickleweed alliance). The resulting adjusted value for Pickleweed in 2011 would be 4,487 acres (as opposed to 3601) which still indicates a net decrease of 10%. However, there was also a net increase of Pickleweed [~206 acres: 125% of 165 acres (2009)] on mud flats over the 3 year project period. *If we take this increase into account, the total acreage of Pickleweed in tidal marshes and mud flats in 2011 would be 4,693 for a total net change of 6%.* Some of this net decrease in Pickleweed might also be due to the net decrease of the Mud alliance (-2.8 %) within tidal marshes. It is important to understand that some variance and/or mis-classifications both within and among years over such a large geographic area will occur when mapping at high spatial resolution (~ 1 meter). Although a reduction in Pickleweed classifications amounting to hundreds of acres may seem important, the degree of change between years occurring to the Pickleweed alliance (~6%) is well within within accuracy limits (~75%) and therefore not substantial and likely insignificant.

The significant increase seen in the Cordgrass alliance (see Table 5) is at least partly due to the misclassification of Pickleweed as Cordgrass (or Cordgrass/-Pickleweed), most evidently in 2011, and would account for what appears to be the undermapping of Pickleweed in that same year (2011). The overmapping of Cordgrass in 2011 (and specifically Cordgrass /– Pickleweed) can be at least partially attributed to it's spectral similarity to Dodder (on top of Pickleweed), which was was observed in the field to be widely distributed throughout the study area in 2011. However, even accounting for this misclassification (assuming the rate of growth between 09 and 10 is carried through to 2011), there is evidence of net growth of Cordgrass throughout the study area. In addition, the potential ecotonal nature of Cordgrass/-Pickleweed (between low and “mid” marsh) is still clearly evident in the habitat datasets.

Brackish marsh habitat types had a *net increase* of 22.1% at the *alliance* level. The large difference of the Alkali Bulrush /- Pickleweed association between 2009/10 and 2011 is most likely due to phenologic differences that cause a spectral “shift” from one species association to another species association that are both in the same alliance. At the same time, we see a net increase in brackish marsh habitat types, there is a corresponding *net decrease* of freshwater bulrush at the alliance level (-15.1%). However, cattail is significantly overmapped in 2011 but the acreage values from 2009 and 2010 are likely more consistent with actual acreage values of cattail within the study area.

Alkali Heath is likely undermapped in 2009 (as are many of the high marsh species). At the same time, acreages for this habitat in 2010 and 2011 demonstrate a net increase between the two years. Some of the acreage value in 2010 and 2011 can be accounted for by the misclassification of Alkali Heath. However, the spectral similarity of Alkali Heath with other high marsh species, notably Spearscale (which is not included as a separate habitat type). Although Saltgrass mapped consistently between 2009 and 2010, it is very likely undermapped in 2011 both within tidal marshes and other habitat categories.

Although there is indication that alkali grasses were also under mapped in 2009 (see Table 5), the overall trend over the three years of the study indicate a potential net increase of alkali grasses within tidal marshes. In addition, Pepperweed, which has mapped accurately and consistently, indicates net growth (14%) over the three year period of the study. A reduction in the Pepperweed /- Alkali Bulrush association is also consistent with the growth of both Pepperweed as well as the growth of the Alkali Bulrush /- Pepperweed association.

Table 6. Acreage by Association Level Habitat Type in Mudflats (09-11)

Habitat Type	**2009 (acres)**	**2010 (acres)**	**2011 (acres)**	**Net Change (09-11) (percent)**
Salt Marsh				
Cordgrass	1.8	5.7	8.3	374.3
Cordgrass /- Pickleweed	8.8	6	9	1.5
Pickleweed	162.4	443.8	366.7	125.8
Saltgrass	2	3.9	1.7	-14.1
Pickleweed /- Jaumea	0.5	1	0.8	55.2
Alkali Heath	0.8	1	(23.1)	(2801.9)
Pickleweed /- Gumplant	2	2.8	3.4	70.4
Brackish Marsh				
Alkali Bulrush	1.2	1.3	1.4	23.8
Alkali Bulrush /- Pepperweed	16.6	15.6	16.3	-1.5
Alkali Bulrush /- Pickleweed	1.3	0.7	0.5	-63.7
Alkali Bulrush /- Spearscale	1.2	1.5	0.8	-34.3
Pepperweed	1.3	(64.1)	(15.8)	(1108.5)
Pepperweed /- Alkali Bulrush	0.3	0.3	0.1	-76
Freshwater Marsh				
Freshwater Bulrush	0.4	0.5	0.5	21.8
Freshwater Bulrush /- Cattail	0.1	0.1	0.2	49.3
Cattail	0.2	0.1	1.5	876.9
Non-Vegetated				
Water	8245.2	7587.7	5904.3	-28.4
Algae	51.3	40.8	61.1	19
Mud	1345.2	1022.8	2847.5	111.7
Biofilm	150.4	718.2	449.4	198.8
Wrack	23.8	27.7	151.8	537.9
Bare Earth	30.6	33.6	87	184
Total (associations)	*9998*	*9944*	*9894*	*-1*

Table 7. Acreage by Alliance Level Habitat Type in Mudflats (09-11)

Habitat Type	2009 (acres)	2010 (acres)	2011 (acres)	Net Change (09-11) (percent)
Salt Marsh				
Cordgrass	10.6	11.7	17.3	**63.3**
Pickleweed	164.9	447.5	370.9	**124.9**
Saltgrass	2	3.9	1.7	**-14.1**
Alkali Heath	0.8	1	(23.1)	(2801.9)
Brackish Marsh				
Alkali Bulrush	19.1	17.8	17.6	**-7.8**
Pepperweed	1.6	(64.4)	(15.8)	(891.1)
Freshwater Marsh				
Freshwater Bulrush	0.5	0.5	0.6	**28**
Cattail	0.2	0.1	1.5	**876.9**
Upland				
Alkali Grasses	2.5	6.5	4.5	**78.7**
Mustard	0.1	0.1	0.4	**194.3**
Non-Vegetated				
Water	8245.2	7587.7	5904.3	**-28.4**
Algae	51.3	40.8	61.1	**19**
Mud	1495.6	1741	3296	**120.4**
Bare Earth / Wrack	54.4	61.3	238.8	**338.8**
Total (alliances)	*10048*	*9984*	*9954*	***-0.9***

Abiotic

There is significant variability in mudflat exposure from year to year due to differences in tide at the time of image acquisition for each year (MTL in 2009, near MLLW in 2010, nearest MLLW in 2011). *As a result, acreage numbers for mudflats (2009-2011) can not be used to measure absolute net changes to mudflat extent.* The large increases seen in the Mud alliance is due to the increased exposure of mud flats in 2010 and especially in 2011 over 2009 due to tidal conditions at the time of image acquisition. Although the increased exposure of mudflats in 2010 and 2011 is demonstrated by the increased mudflat acreages for these years, the presence of small amounts of water on mudflats, apparent as you move towards the intertidal zone, exacerbate the classification and mapping of mudflats even when they are exposed in the imagery (e.g. in 2010 and 2011).

Biotic

The large differences between 2009 (164.9 acres) and 2010 (447.5 acres) for the Pickleweed alliance are likely due to tidal conditions between those years (mud flats were covered with more water in 2009). The total *net increase* of the Pickleweed alliance on mud flats was 206 acres. *There is good evidence, from both field observations and model results, of Pickleweed colonization of mud flats in the study area (i.e. net increase) over the three year time period of the study.* This is apparent in review of the habitat datasets themselves in locations such as Calaveres Marsh and the fringe marsh at the top of

A6. These possible expansions of Pickleweed marshes are in addition to floral colonization seen in restored ponds (e.g. A21).

One clear misclassification of a specific habitat class is Alkali Heath in 2011. The acreage in 2011 should therefore be disregarded. The presence of any Alkali Heath on the mudflats is unlikely; however, these occurrences might indicate the presence of other vegetation types since the acreages in 2009 and 2010 are consistent with each other.

For a variety of factors, discussed below, tables for non-tidal marshes, levees, and uplands habitat categories are included in Appendix 7.4. Although there is some useful numbers regarding acreage and change to certain habitats contained in these tables, they also contain potential misleading values and possible inaccuracies.

Non-Tidal Marshes

Less focus was given to non-tidal marshes, levees and uplands. Non-tidal marshes had a significantly reduced sample size relative to tidal marshes over the three year period of the study. Although this might play a role in the lower accuracy figures for these areas, review of model results during development indicated variability in response at those locations due to floristic complexity as well as the impact of differing abiotic conditions (from tidal areas) on plant spectra. As a result, the report does not provide much discussion of non-tidal marshes. See Appendix 7.4 for the table of changes (in acres) to habitats within these non-tidal marshes. Overall there seems to be a reduction in mud and bare earth in these marshes and a general increase in vegetative habitat types. There seems to be a general decrease in Alkali (and Freshwater) Bulrush (-36.9%) with a potential corresponding increase in Alkali Grasses (88%). At the same time, there is a decrease in Pepperweed over the time period of the study (-17%). The degree of increase in Cordgrass and degree of decrease in Pickleweed are likely related to the overmapping of Cordgrass in 2011, but the trends (both increase and decrease) were also apparent between 2009 and 2010, indicating possible shifts between habitat types. Further analysis of these changes and areas is warranted.

Levees

The levee category is defined to consist of levee tops and not levee flanks, which are usually comprised of more alkali tolerant vegetation. Our accuracy assessment of levees was simplified to only measure the presence (or absence) of vegetation. As a result, Levees can also be most consistently mapped by creating 3 distinct categories: “vegetation”, which combines all vegetation classes, “bare earth/wrack/mud” which combines all these abiotic classes; and water. Accuracy for Levees in these two categories was 96%. There is evidence from the changes recorded to habitat types between the three years, that the amount of vegetation overall is growing overall on the levees in the study area while the amount of bare earth (or wrack) is decreasing (see Appendix 7.4). This include increases to Pepperweed (21%) but also increases to other non invasive species including Alklai Bulrush (110%), although increases in Cordgrass (166%) might be attributed to other species and/o overmapping of Cordgrass in 2011. Acreages for water can generally be disregarded as this is likely due to inaccuracies in our stratification mask (that likely included narrow strips of ponds with water).

Uplands

Habitats types included for uplands include alkali grasses and mustard, although other habitat types such as Pepperweed, or possibly even Saltgrass, can be found at these locations. Additional habitat types, such as Coyote Brush were included in the model early in the development process but interfered with model response in tidal marshes and as a result were eventually excluded from model development. The primary function of including these upland specific habitat types is so that Upland areas would map with more appropriate vegetation types and for understanding potential expansion of invasive weeds. In addition, Levee tops, which are fundamentally upland in nature, contain significant amounts of these “upland” habitat types.

3.3 Accuracy Assessment

Results of the accuracy assessment indicate that the overall accuracy of the final habitat datasets performs within acceptable attribute accuracy limits (76% in 2011 and 2010; 70% in 2009) at the dominant vegetation alliance level and less well with habitat types (e.g. Alkali Bulrush /- Spearscale) comprised of sub-dominant species associations (61% in 2011; 66.8% in 2010; 56% in 2009). Certain habitats at the Alliance level also exceeded the accuracy of the overall model. These included Pepperweed (80% in 2011 and 85% in 2010) and Alkali Bulrush (80% in 2010). In addition, Pickleweed /- Gumplant, a habitat type at the species association level, was close to or exceeded (75% in 2011 and 88% in 2010) the overall accuracy of habitats at the alliance level. Levees also had an overall accuracy of 96.5% for differentiating the presence of vegetation from vegetated habitat types (see Table 14).

The distribution and extent of high marsh throughout the study area is evident in all 3 years of imagery, and in the specific case of Pickleweed /- Gumplant, is accurately mapped throughout the study area. In addition, the accuracy of certain vegetation associations in specific locations (e.g. brackish and freshwater marshes around Warms Spring lagoon) in a specific year(s) is likely higher then the overall accuracy for that year (based on qualitative assessment from ground truthing). As a result, the datasets and methods provide accurate baseline data on the distribution and extent of specific vegetation associations (e.g. Pickleweed /Gumplant), at specific locations, as well as by broader habitat type (e.g. low,mid, high marsh).

The lower accuracy of certain species associations can be attributed to a variety of factors including phenologic variability between years, relative phenologic differences between habitats in a given year, as well as significant spectral mixing likely due to the higher relative floristic complexity of these habitat types. Inaccuracies in these mapped vegetation associations were a result of inconsistencies in classification of a given vegetation association in a given location from year to year. For example, in the historic marsh at Faber, the distribution of high marsh, primarily composed of Pickleweed /- Gumplant associations along slough channels, is clearly present in the habitat datasets for all three years. However, in 2010 the Pickleweed/- Gumplant distributions clearly present in 2009 are *partially* classified as Alkali Heath (another high marsh species) and *partially* classified as Cordgrass in 2011. These changes are likely due to phenologic (and related spectral) variability of a given habitat type from year to year as well as spectral mixing (due to higher relative plant diversity) within these habitat types.

Differences in tide between the day and time of satellite acquisition and ground truthing have been accounted for in the accuracy assessment. For example, field ground truthed mudflat might be mapped as water or vice versa due to tidal differences. The same issue can also be seen with algae and wrack, which are heavily influenced by tides. As a result, Algae was considered correct whether it mapped as algae, mud or water (mud was also considered correct if it also mapped as algae).

Error Matrices for Tidal Marshes (09-11)

Included below are the error matrices tables (with Kappa statistics) for tidal marshes (which include mudflats) for 2009-2011. Tables 8 thru 12 are included for habitat types both at the alliance (14 habitat types) and association level (24 habitat types). Validation (and ground truthing overall) datasets focused on tidal marsh systems (including “fringe “marshes” and restored areas open to tidal action) and comprised approximately 88% of the ground truthing over the 3 year period of the project. Ground truthing in non-tidal marshes (accuracy assessment tables for non-tidal marshes are included in Appendix 7.4) and levee tops received significantly less attention over the three year time period of the study, and as a result accuracy assessment on these types was aggregated for all three years.

An overview of the types of statistical accuracy that are measured in the error matrices is included in Table 21. Generally, user's accuracy can be interpreted as identifying if a particular habitat type is *potentially* overmapping if the percentage is low, indicating that other habitat types might be misclassified as that habitat. Producer's accuracy measures the actual field assessed accuracy for each habitat and is what is primarily used to measure “overall accuracy”. Generally, when the sample size increased so did the overall accuracy.

The Pickleweed association (and alliance) classified at generally higher accuracies then the overall model (88% in 2011; 90% in 2010; 89% in 2009). Although the accuracy of validation samples for Pepperweed was generally very high (85% in 2010 and 88% in 2011), it is likely slightly overmapped in all 3 years of imagery (user's accuracy is lower then producer's accuracy). In many locations, both alliance and association level habitats are mapping well, however, in these locations, the correct percent cover is being “swamped” by habitat types that are being overmapped (e.g. Pepperweed). Unfortunately, in the accuracy assessment, many of these locations were scored as “inaccurate” when the model clearly showed the presence of the specific habitat type, but the validation location was dominated by the overmapping species (Pepperweed). Cordgrass is certainly overmapped in 2011 as the user's accuracy is significantly lower in that year (37.9%) then any other year (80% in 2009 and 72% in 2010).

2011 Image Considerations

In the western swath image, the Cordgrass / Pickleweed association often appears where previous years were simply Pickleweed (e.g. Greco Island). This does not necessarily indicate an “error” in the model per se, but the increased spectrally “brightness” of Cordgrass within these Pickleweed marshes that was less apparent spectrally in both the 2009 and 2010 images. This type of phenologic and spectral difference from year to year are inevitable and do not necessarily indicate significant change in those marshes but the varying phenologic and spectral conditions by which the satellites acquired the images on a given day from year to year.

Cordgrass is likely overmapped within high marsh found within and along channels within the marsh plain rather then in high marsh found at the edge of the marsh. There is often cordgrass within these channels but in close proximity to adjacent high marsh species. As a result, in 2011, the “brightness” (indicative of flowering and/or vegetative growth) of healthy cordgrass mixes spectrally with certain species in these locations. Also, Alkali Heath is also likely overmapped, and was found in certain locations to be replacing Cordgrass.

2010 Image Considerations

Overall, the 2010 image was a good balance, both spectrally and phrenologically, between the 2009 and the 2011 images. Most habitat types map relatively accurately at both the alliance and association level, although Cordgrass maps less accurately in 2010 then in 2011, the volume of Cordgrass, represented by the relatively high user's accuracy (72%), is likely a better representation of the overall distribution and extent of this habitat type.

2009 Image Considerations

The 2009 imagery, which formed the base year for our analysis and the foundation for our training sites, mapped very consistently across the study area as well as in specific locations (e.g. in and around A21). The major limitation of the 2009 imagery was the lack of spectral separability (the ability for the training sites to distinguish a given habitat type) for many habitat types comprised of species associations. These associations (e.g. Pickleweed /- Gumplant) were captured more consistently in the 2010 and 2011 imagery, where the spectral signatures of these vegetation was much more apparent.

Table 8: 2011 Alliance Level Error Matrix (based on Dominant Cover Class)

		Mapped (Classified) Data														
		Algae	Alkali Bulrush	Alkali Grasses	Alkali Heath	Bare Earth/ Wrack	Cattail	Cordgrass	Freshwater	Mud	Mustard	Pepperweed	Pickleweed	Saltgrass	Water	TOTAL VISITED	PRODUCER'S ACCURACY (%)
Reference (Ground Truthed) Data	Algae	3											1			4	75
	Alkali Bulrush		21					1				3	4			29	72.4
	Alkali Grasses															0	NA
	Alkali Heath				2	1	1	3				2	3			12	16.7
	Bare Earth/ Wrack			1									1		1	3	0
	Cattail		1				3					2				6	50
	Cordgrass							11					4		1	16	68.8
	Bulrush		2				1	1	2			1				7	28.6
	Mud									18			5			23	78.3
	Mustard											1				1	0
	Pepperweed											8	2			10	80
	Pickleweed		1					11				3	125		1	141	88.7
	Saltgrass							1					2			3	0
	Water							1							3	4	75
	TOTAL MAPPED	3	25	1	2	1	5	29	2	18	0	20	147	0	6	Overall Accuracy 76%	
	USER"S ACCURACY (%)	100	84	0	100	0	60	37.9	100	100	NA	40	85	NA	50		

Observed Accuracy	0.76
Chance Accuracy	0.38
Kappa	0.61

Table 9: 2010 Alliance Level Error Matrix (based on Dominant Cover Class)

		Mapped (Classified) Data															
		Algae	Alkali Bulrush	Alkali Grasses	Alkali Heath	Bare Earth/ Wrack	Cattail	Cordgrass	Bulrush	Mud	Mustard	Pepperweed	Pickleweed	Saltgrass	Water	TOTAL VISITED	PRODUCER'S ACCURACY (%)
Reference (Ground Truthed) Data	Algae	7														7	100
	Alkali Bulrush		25					2				1	3			31	80.6
	Alkali Grasses			1										1		2	50
	Alkali Heath				2								1			3	66.7
	Bare Earth/ Wrack					6							1		2	9	66.7
	Cattail		1													1	0
	Cordgrass	1						8		1			4	1		15	53.3
	Bulrush		4						4			1	6			15	26.7
	Mud									12			6		1	19	63.2
	Mustard										1					1	100
	Pepperweed											6	1			7	85.7
	Pickleweed		1			1		1				4	75	1		83	90.4
	Saltgrass															0	NA
	Water															0	NA
	TOTAL MAPPED	8	31	1	2	7	0	11	4	13	1	12	97	3	3	Overall Accuracy 76.2%	
	USER"S ACCURACY (%)	87.5	80.6	100	100	85.7	N A	72.7	100	92.3	100	50	77.3	0	0		

Observed Accuracy	0.76
Chance Accuracy	0.27
Kappa	0.67

Table 10: 2009 Alliance Level Error Matrix (based on Dominant Cover Class)

		Mapped (Classified) Data															
		Algae	Alkali Bulrush	Alkali Grasses	Alkali Heath	Bare Earth/ Wrack	Cattail	Cordgrass	Bulrush	Mud	Mustard	Pepperweed	Pickleweed	Saltgrass	Water	TOTAL VISITED	PRODUCER'S ACCURACY (%)
Reference (Ground Truthed) Data	Algae												1			1	0
	Alkali Bulrush		6				1						1			8	75
	Alkali Grasses			2									2			4	50
	Alkali Heath				11			1				1	8	4		25	44
	Bare Earth/ Wrack					17						1	1			19	89.5
	Cattail											1	1			2	0
	Cordgrass				1			8		2		1	10			22	36.4
	Bulrush								1			1				2	50
	Mud									8			1			9	88.9
	Mustard			1							1		1			3	33.3
	Pepperweed				1							4	1			6	66.7
	Pickleweed		1					1		1		3	70	2		78	89.7
	Saltgrass				1							1	5	4		11	36.4
	Water									1					1	2	50.0
	TOTAL MAPPED	0	7	3	14	17	1	10	1	12	1	13	102	10	1	Overall Accuracy 70 %	
	USER"S ACCURACY (%)	NA	85.7	66.7	78.6	100	0	80	100	66.7	100	30.8	68.6	40	100		

Observed Accuracy	0.70
Chance Accuracy	0.25
Kappa	0.59

Table 11: 2011 Association Level Error Matrix (based on Dominant Cover Class)

		Mapped (Classified) Data																										
		Algae	Alkali Bulrush	Alkali Bulrush /- Pepperweed	Alkali Bulrush /- Pickleweed	Alkali Bulrush /- Spearscale	Alkali Grasses	Alkali Heath	Bare Earth	Cattail	Cordgrass	Cordgrass /- Pickleweed	Freshwater Bulrush	Freshwater Bulrush /- Cattail	Mud	Mud w/ Biofilm	Mustard	Pepperweed	Pepperweed /- Alkali Bulrush	Pickleweed (annual)	Pickleweed (perennial)	Pickleweed /- Gumplant	Pickleweed /- Jaumea	Saltgrass	Water	Wrack	TOTAL VISITED	PRODUCER'S ACCURACY (%)
Reference (Ground Truthed) Data	Algae	3																			1	1					5	60
	Alkali Bulrush		1	10	1						1							1			1		1				16	6.3
	Alkali Bulrush /- Pepperweed			3																							3	100
	Alkali Bulrush /- Pickleweed				1																1						2	50.0
	Alkali Bulrush /- Spearscale		2	3														2				1					8	0
	Alkali Grasses																										0	NA
	Alkali Heath							2			2											2					6	33.3
	Bare Earth						1														1				1		3	0
	Cattail			1						2								2									5	40
	Cordgrass										1	5									3				1		10	10
	Cordgrass /- Pickleweed											5									1						6	83.3
	Freshwater Bulrush			2						1		1	2					1									7	28.6
	Freshwater Bulrush /- Cattail									1																	1	0
	Mud														4	5											9	44.4
	Mud w/ Biofilm														1	8					5						14	57.1
	Mustard																	1									1	0
	Pepperweed																	8		1		1					10	80
	Pepperweed /- Alkali Bulrush																										0	NA
	Pickleweed (annual)										1																1	0
	Pickleweed (perennial)		1								2	5						1	1		105				1		116	90.5
	Pickleweed /- Gumplant		1									2										12					16	75
	Pickleweed /- Jaumea											3						1			8						12	0
	Saltgrass											1									2						3	0
	Water										1														3		4	75
	Wrack									1		1						1	1		1					1	6	16.7
	TOTAL MAPPED	3	5	19	2	0	1	2	0	5	8	23	2	0	5	13	0	18	2	1	130	17	1	0	6	1	Overall Accuracy 61%	
	USER"S ACCURACY (%)	100	20	15.8	50.0	NA	0	100	NA	40	12.5	21.7	100.0	NA	80	61.5	NA	44.4	0	0	80.8	70.6	0	NA	50	100		

Table 12: 2010 Association Level Error Matrix (based on Dominant Cover Class)

		Mapped (Classified) Data																										
Reference (ground truthed) Data		Algae	Alkali Bulrush	Alkali Bulrush /- Pepperweed	Alkali Bulrush /- Pickleweed	Alkali Bulrush /- Spearscale	Alkali Grasses	Alkali Heath	Bare Earth	Cattail	Cordgrass	Cordgrass /- Pickleweed	Freshwater Bulrush	Freshwater Bulrush /- Cattail	Mud	Mud w/ Biofilm	Mustard	Pepperweed	Pepperweed /- Alkali Bulrush	Pickleweed (annual)	Pickleweed (perennial)	Pickleweed /- Gumplant	Pickleweed /- Jaumea	Saltgrass	Water	Wrack	TOTAL VISITED	PRODUCER'S ACCURACY (%)
	Algae	7																									7	100
	Alkali Bulrush		23								1	1									1						26	88.5
	Alkali Bulrush /- Pepperweed			1														1									2	50
	Alkali Bulrush /- Pickleweed		1																				2				3	0.0
	Alkali Bulrush /- Spearscale																										0	NA
	Alkali Grasses						1																	1			2	50
	Alkali Heath							2													1						3	66.7
	Bare Earth								5												1					1	7	71.4
	Cattail		1																								1	0
	Cordgrass	1									6	1									2	1		1			12	50.0
	Cordgrass /- Pickleweed											1			1						1						3	33.3
	Freshwater Bulrush		4										3	1				1			6						15	20.0
	Freshwater Bulrush /- Cattail																										0	NA
	Mud														5	3					4				1		13	38.5
	Mud w/ Biofilm														2	2					2						6	33.3
	Mustard																1										1	100
	Pepperweed																	6			1						7	85.7
	Pepperweed /- Alkali Bulrush																										0	NA
	Pickleweed (annual)																										0	NA
	Pickleweed (perennial)								1												51		1				53	96.2
	Pickleweed /- Gumplant																					2	1				8	87.5
	Pickleweed /- Jaumea		1								1							4			6	2	4	1			19	21.1
	Saltgrass																										0	NA
	Water																								2		2	100
	Wrack																										0	NA
	TOTAL MAPPED	8	30	1	0	0	1	2	6	0	8	3	3	1	8	5	1	12	0	0	76	10	8	3	3	1	Overall Accuracy 66.8%	
	USER"S ACCURACY (%)	87.5	76.7	100	NA	NA	100.0	100	83.3	NA	75.0	33.3	100	0	62.5	40.0	100	50	NA	NA	67.1	70	50	0	66.7	0		

Table 13: 2009 Association Level Error Matrix (based on Dominant Cover Class)

		Mapped (Classified) Data																										
		Algae	Alkali Bulrush	Alkali Bulrush /- Pepperweed	Alkali Bulrush /- Pickleweed	Alkali Bulrush /- Spearscale	Alkali Grasses	Alkali Heath	Bare Earth	Cattail	Cordgrass	Cordgrass /- Pickleweed	Freshwater Bulrush	Freshwater Bulrush /- Cattail	Mud	Mud w/ Biofilm	Mustard	Pepperweed	Pepperweed /- Alkali Bulrush	Pickleweed (annual)	Pickleweed (perennial)	Pickleweed /- Gumplant	Pickleweed /- Jaumea	Saltgrass	Water	Wrack	TOTAL VISITED	PRODUCER'S ACCURACY %
Reference (ground truthed) Data	Algae																				1						1	0
	Alkali Bulrush		3	1	2					1											1						8	37.5
	Alkali Bulrush /- Pepperweed																										0	NA
	Alkali Bulrush /- Pickleweed																										0	NA
	Alkali Bulrush /- Spearscale																										0	NA
	Alkali Grasses						2														2						4	50
	Alkali Heath							11				1						1			8			4			25	44
	Bare Earth								8									1			1					3	13	61.5
	Cattail																	1			1						2	0
	Cordgrass										3	1			1			1			7						13	23.1
	Cordgrass /- Pickleweed											4				1					3						8	50
	Freshwater Bulrush												1					1									2	50
	Freshwater Bulrush /- Cattail																										0	NA
	Mud														5	3					1						9	55.6
	Mud w/ Biofilm																										0	NA
	Mustard						1										1				1						3	33.3
	Pepperweed							1										4			1						6	66.7
	Pepperweed /- Alkali Bulrush																										0	NA
	Pickleweed (annual)																	1									1	0
	Pickleweed (perennial)				1											1		2			52		1				57	91.2
	Pickleweed /- Gumplant																				6	1		2			11	27.3
	Pickleweed /- Jaumea											1									7	1	1				10	10
	Saltgrass							1										1			5			4			11	36.4
	Water														1										1		2	50.0
	Wrack								1																	5	6	83.3
	MAPPED	0	3	1	3	0	3	13	9	1	3	7	1	0	7	5	1	13	0	0	97	4	2	10	1	8	Overall Accuracy 56.25%	
	USER"S ACCURACY %	NA	100	0	0	NA	66.7	84.6	88.9	0	100	57.1	100	NA	71.4	0	100	30.8	NA	NA	53.6	75	50	40	100	62.5		

3.4 Habitat Trends (2009-2011)

Analysis of trends for the 24 habitat types mapped throughout the study area over the 3 years of the project were most consistent and accurate at the a*lliance* level, since they overcome some of the inaccuracies associated with habitat types at the *association* level. However, we include discussion of association level habitat types since, in many locations throughout the study area, the distribution and extent of these habitat types, especially of habitat types that comprise high marshes, can be clearly distinguished from other habitat types. Even where habitat classes were misclassified in high marsh they were usually misclassified to another habitat types representative of high marsh. Transitions can also be visually interpreted from the imagery, especially between low/mid/high salt marsh as well as between salt, brackish and freshwater marshes.

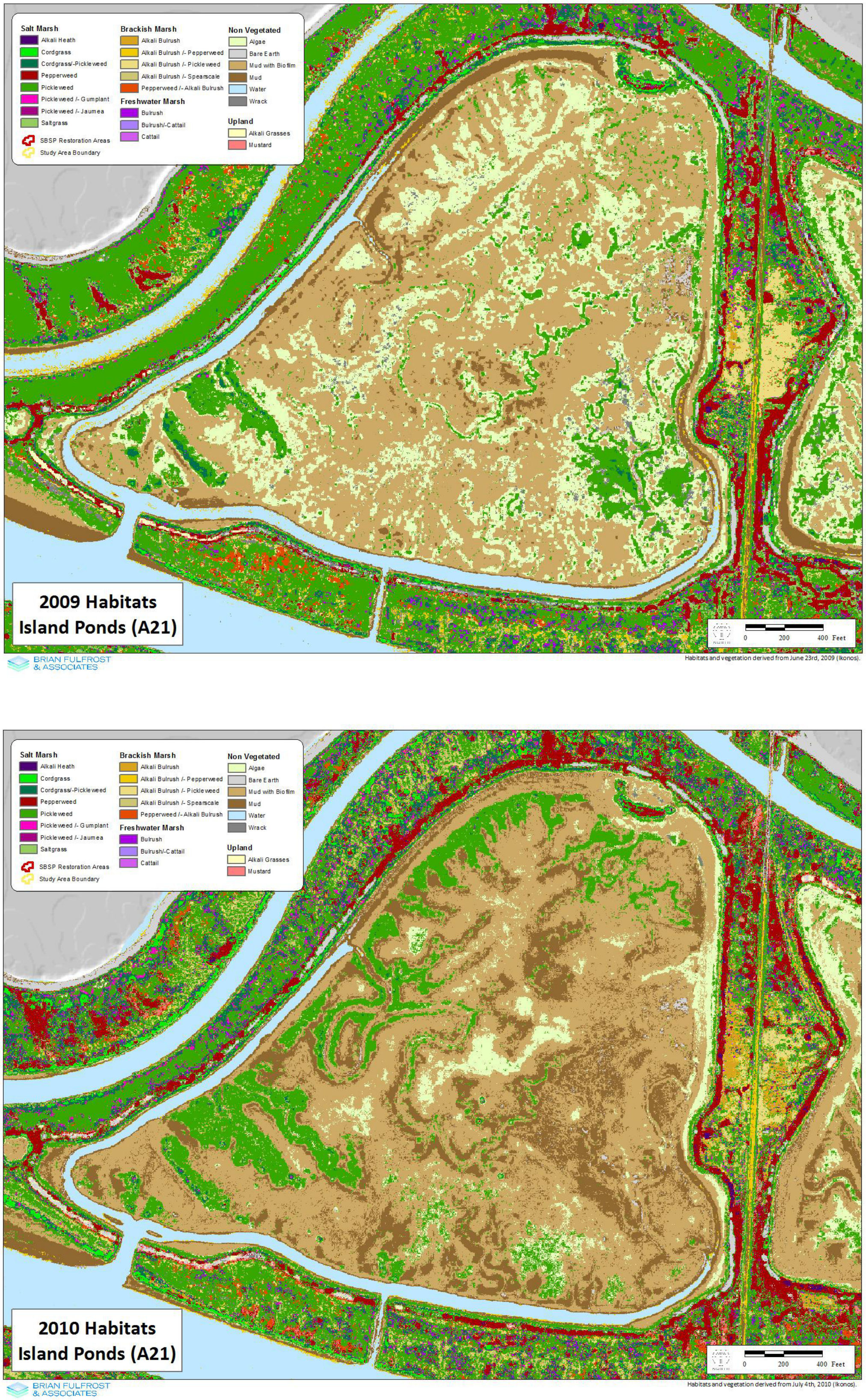
Restored Ponds (pre-Phase I and Phase I)

The habitat model performed exceptionally well within restored ponds, tracking floral colonization over time as well as the accretion of mud (and biofilm on mud) within these ponds. The model(s) behave well when vegetation is developing on mud flats, and there is not already a great deal of vegetative diversity.

Island Ponds

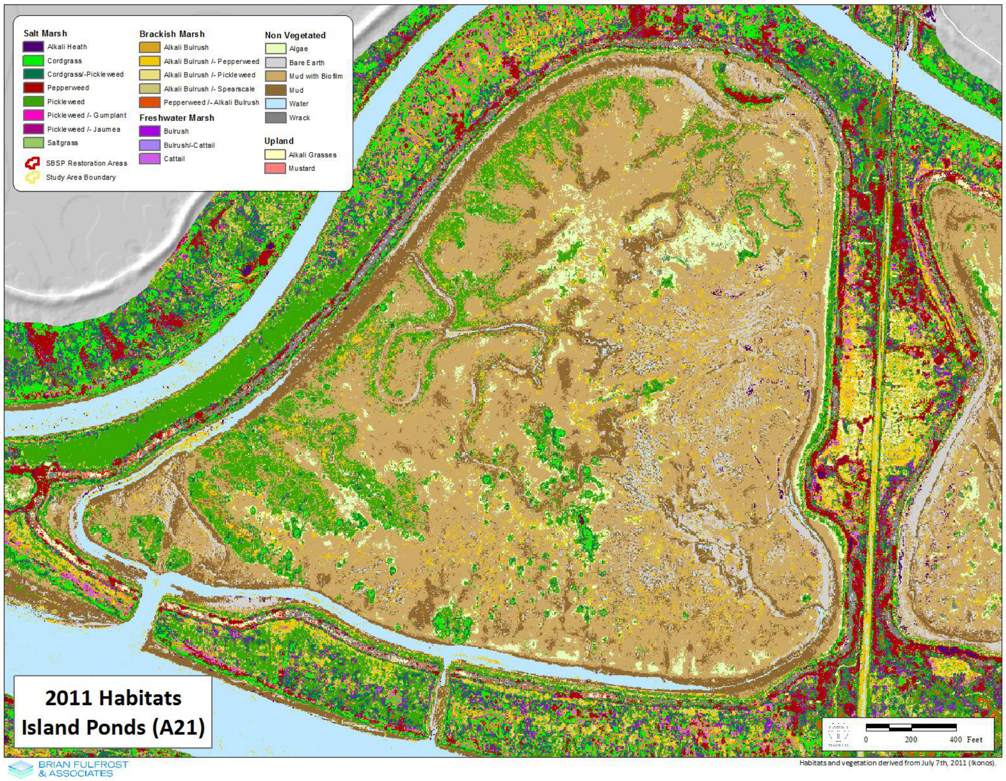
The floral colonization along historic and developing slough channels is readily apparent in all 3 years of imagery. The growth of Pickleweed is most prevalent in Pond A21 between 2009 and 2010 (see Figure 5) as is the emerging presence of Cordgrass between 2010 and 2011. In 2011, there does not appear to be significant increases in Pickleweed or Cordgrass within these ponds. What is apparent in 2011 is the impact of tide variance on model output, specifically the presence of wrack (misclassified as Alkali Bulrush), the “mottled” appearance of vegetation (Pickleweed amd Cordgrass) as compared to 2010 (due to the higher presence of wrack and mud as verified from field observations), and some indication of “shifting” vegetation patterns, likely due to sediment accretion. The differences seen between 2010 and 2011 are evidence of *actual* tidal and phonological variability at the time of image acquisition. Both the growth and distribution of vegetation in A21 is still clearly, and accurately, mapped across the three years of the study. In fact, the growth of Cordgrass (relative to Pickleweed), again verified by field observations, is clearly evident in the 2011 image (see Figure 5). The accurate response of habitats types within restored is also likely due to that the vegetation within these ponds is mostly at the *Alliance* level.

Figure 5: Pond A21 (2009-2010)



Habitats and vegetation derived from June 23rd, 2009 (Ikonos).

Habitats and vegetation derived from July 4th, 2010 (Ikonos).



Habitats and vegetation derived from July 7th, 2011 (Ikonos).

A6

Although the time period of capture for 2011 was not long after the breach in A6, the 2011 imagery (caught at MLLW) shows a clear accretion of sediment (as mud) within the pond, including mud with biofilm, as well as small patches of Pickleweed as it was forming on the bird mounds left on the historic levee tops in the middle of the pond (see Appendix 7.5).

In addition, there is indication that the fringe salt marsh at the top of A6 is expanding slightly by moving onto the mud flat (see Figure 6). There is also some apparent floral colonization of mud flats occurring at Calavares Marsh (see Figure 7). There are also other locations where this type of floral colonization was noticed within the time period of the study – including Ogilvie Island.

Figure 6: Fringe Marsh at Top of Pond A6 (2009-2011)

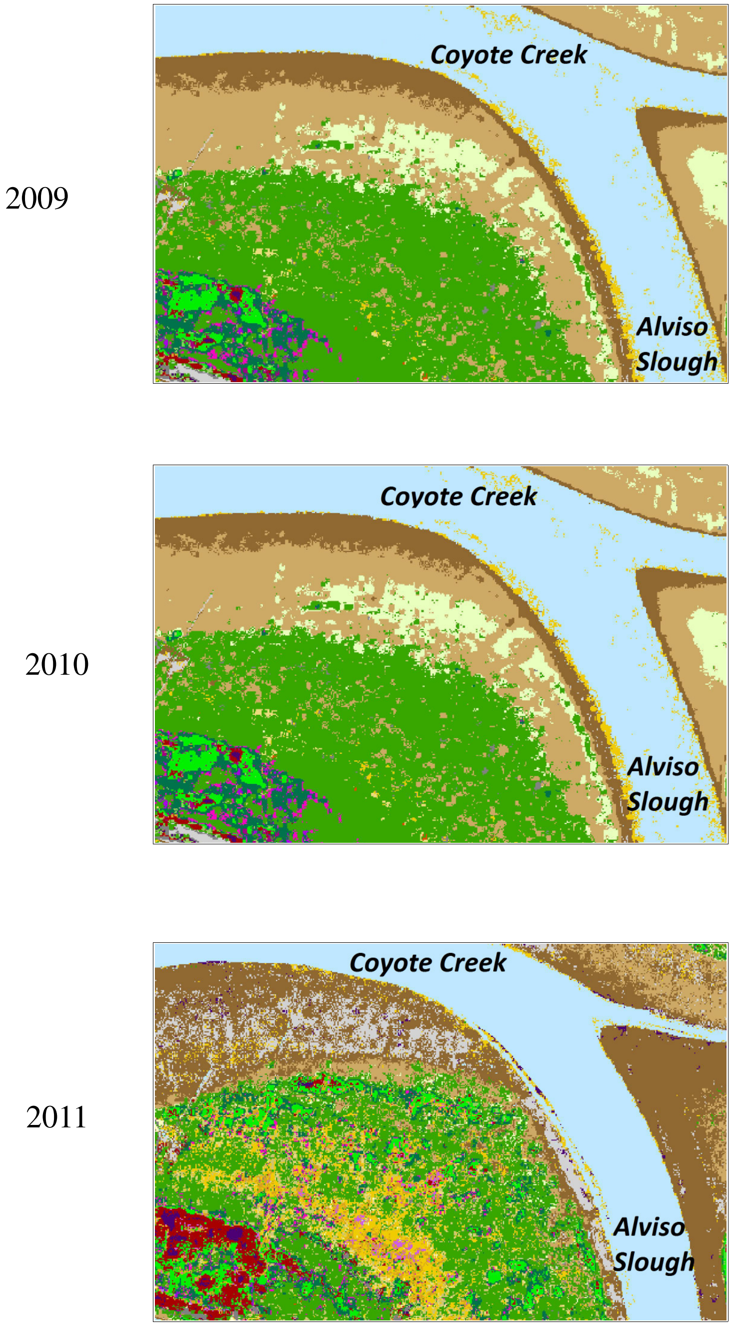
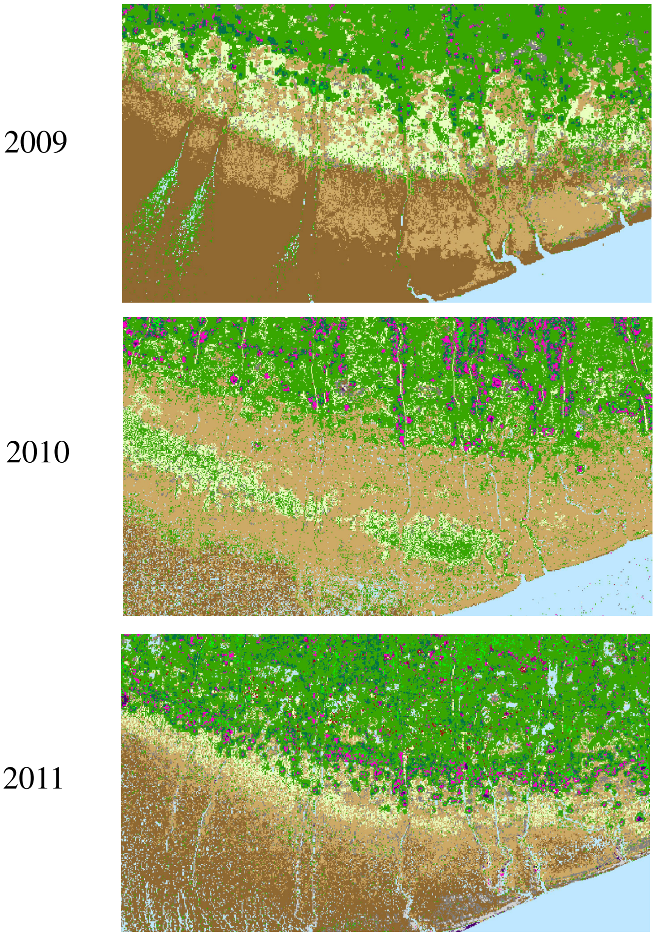


Figure 7: Bottom of Calavares Marsh (2009-2011)



Cooley Landing

Model responses in the restored cooley landing pond, were excellent. The growth of Pickleweed marshes is quite apparent from the model output for all three years (see Figure 8), indicating the continued usefulness of the model for capturing floral colonization within restored ponds. Field based vegetation maps from 2010 (generously provided by HT Harvey and Associates) are extremely similar in distribution and extent to our model and demonstrate additional confirmation of the ability of the model(s) to produce accurate results within restored ponds.


2009 2010

Figure 8: Cooley Pond (2009-2010)

High Marsh

The primary issue with inaccuracies in habitat types that comprise high marsh is the inconsistent classification of habitat types in this marshes from year to year. However, misclassifications from year to year are usually from between one high marsh habitat type to another (e.g. from Pickleweed/-Gumplant to Alkali Heath or vice versa). As a result, the distribution and extent of habitat types that are common to high marshes (e.g. Pickleweed /- Gumplant) are being accurately mapped well enough across years to provide useful baseline data for these marshes (see Figure 9). The scale by which each habitats type is changing can be more reliably expressed in the entire study ares by "scaling up" to broad habitats types (low marsh, mid marsh, high marsh – salt, brackish, fresh). However, at finer scales, change can be detected accurately, but results vary by location and by specific association level habitat type. The most accurate or consistent classification of these specific habitat types can be derived from all years so as to provide a single accurate baseline datasets for tracking changes to these habitats into the future. Gross changes over time, even within lower accuracy standards, might also be possible for broader time periods.

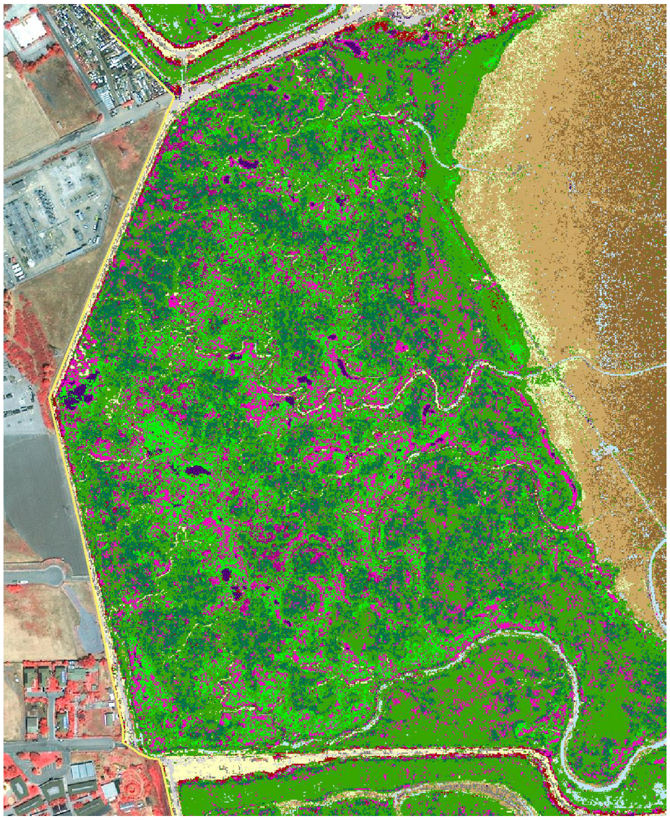


Figure 9: High Marsh (shown in violet) at Laumeister Marsh

Invasives

Both Pepperweed and Mustard were included as habitat types in the model. The Pepperweed alliance mapped very accurately for most years (80% in 2011 and 85% in 2010). Phenological (e.g. senescent Pepperweed vs. flowering from one year to the next in a given location) variability should be considered when analyzing changes within the time period of the study.

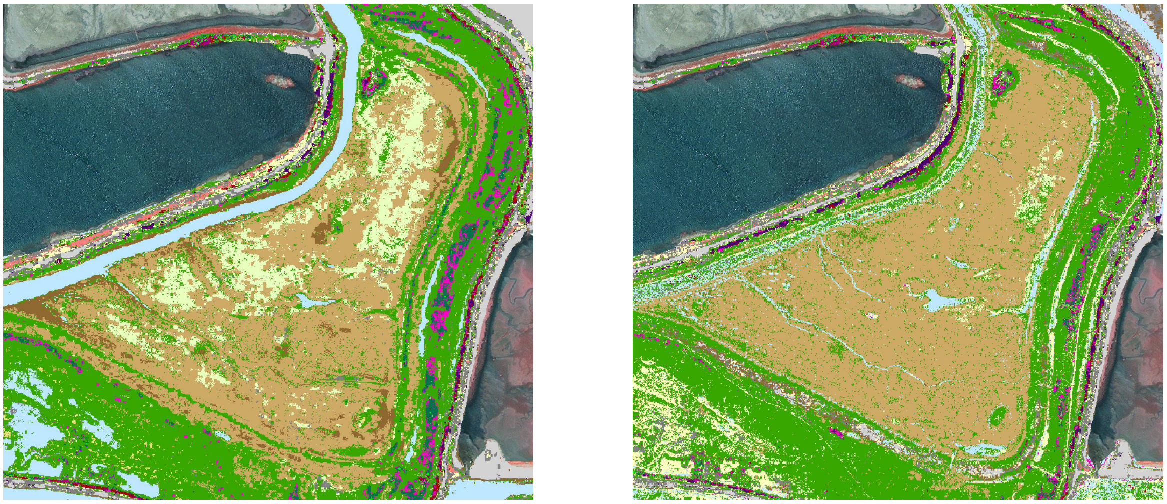
Mud Flats

Overall, mud flats were clearly distinguished from water and biotic habitats. The presence of biofilm on mudflats was also accurately mapped, although there are indications that biofilm was undermapped overall (personal conversation with John Takakewa). The mapping (and ground truthing) of mud flats rests very largely on the matching the satellite acquisition timing with the height of the tide (preferably MLLW). As a result, the extent of mud flats present in the image varied from year to year. In 2009, the satellite image was taken at mean tide (MTL). However, in 2010 the image was captured close to MLLW while 2011 the image was captured even closer to MLLW (as compared to 2010). As a result, the extent of mud flats was significantly more exposed in 2010 and 2010 when compared to 2009.As a result, acreage numbers for mudflats (2009-2011) can not be used to measure absolute net changes to mudflat extent. Other methods should be explored for more accurately mapping changes to mudflat extents (see Section 5).

Mud with biofilm was consistently classified adjacent to the edge of the low marsh, possibly due to either the “relative “density” of biofilm and/or the relationship between water depth and the emergence of diatoms (Kuawe T. et al.2008). After subsequent conversations with the USGS team studying biofilm at Dumbarton shoals, it was clear that (a) the lack of water on top of and exposure of mudflats to the sun resulted in potentially higher probability of biofilm; and (b) there were a range of type of biofilms which could be descriptively characterized by density. We are not confident that our ground truthing locations adequately represent this variability and therefore we can not be certain if the model is mapping the *complete* distribution of biofilm.

There was also a noticeable presence of biofilm in all years on relatively large mud flats within sloughs, including Palo Alto baylands and in Eden's Landing (see Figure 10).

Figure 10: Biofim present on Mudflat (2009-2010) within Eden Landing/Mt. Eden Creek



2009

2010

Sloughs and Channels

Slough and channels were accurately mapped as water and/or mud (including mud with biofilm) depending on tidal conditions. In 2009, the presence of channels is less apparent, again likely due to tidal conditions, but in 2010 and 2011 even small channels, as small as 1 meter wide (see Figure 11) , are captured in the final model datasets.

Figure 11: Sloughs and Channels at Outer Bair Island (2009)

Challenges

Overall Phenological and Spectral Variability

Differences in the spectral values for a given habitat from year to year are a result of a number of factors, including: image details (e.g. elevation angle), radiometric normalization, and phenological differences (spatially and temporally). As a result, there will be slight differences in the mapping of a given habitat in certain locations (local spatial variability) from year to year. Some of this variability represents true phenological differences (dead vegetation one year vs. alive second year) in vegetation and therefore cannot be accounted for through automated methods alone. The variability in phenology and radiometry across the study area and over time proved to a challenge in achieving consistently classification results for specific habitat types at finer spatial and taxonomic scale (e.g. sub-dominance).

Mudflats
Limitations involved with matching dates to which the Ikonos satellite will pass over the study area during (or close to) MLLW limited the efficacy of using the Ikonos imagery for mapping changes to mudflat extent.

Species Associations

Although the spatial and spectral resolution of the imagery demonstrated the capacity to pick up the distribution and extent of species associations, the spectral similarities of some species made mapping consistently over years within specific habitat types more challenging. Where there was a larger relative floristic complexity in addition to the narrow width of these habitats made them generally more difficult to map consistently. As a result, in combination with significant phrenological and radiometric variability, certain high marsh habitats did not map as consistently across years. In those areas where there a mix of habitat types that are inconsistently mapping from year to year, these species are also the mix of species usually found in ”high marsh. In those locations where there is inconsistency in the assignment of specific high marsh species from year to year, the habitat model output is still clearly distinguishes high marsh.. Gumplant was identified early as a specific problem in overmapping, likely due to its relative low cover and numerous plant associations. Gumplant (mixed dominantly with Pickleweed) is included as an important habitat in the final model results.

Error Matrix for Levees (2009-2011)

For the purposes of calculating the error matrix for levees, we aggregated all vegetated habitat types into one “vegetated” category. We also aggregated all abiotic habitat types into one “unvegetated” category.

Table 14: Error Matrix For Levees (2009-2011)

		Mapped (Classified) Data			
Reference (Ground -Truthed) Data		Vegetated	Unvegetated	TOTAL VISITED	PRODUCER’S ACCURACY (%)
	Vegetated	47		47	100.0
	Unvegetated	2	8	10	80.0
	TOTAL MAPPED	49	8	Overall Accuracy 96.5%	
	USER”S ACCURACY (%)	95.9	100.0		

4. Methods

4.1 Methods Overview

Our mapping methodology (and final products) consist primarily of the following three elements: (1) development and description of a set of ecologically relevant habitat types; (2) remote sensing of these habitat types using a “spectral model” for the supervised classification of Ikonos imagery; and (3) GPS based ground truthing (with standardized protocols and procedures).

Our methods involved an iterative process of model improvement. First, we developed an initial list of habitat types based on preliminary ground truthing (rapid assessment) and extensive literature review. Second, we focused on satellite image acquisition and preprocessing of imagery. Third, once the satellite image was acquired and preprocessed, we developed an initial spectral model of habitat types and ran a supervised classification of imagery using this model (both in Erdas Imagine). Fourth, we would review model output both in GIS and in the field in order calibrate model results. Fifth, our model review would lead to improvements to the spectral model and changes to habitat type(s) and a rerunning of the supervised classification resulting in new and improved model output. Sixth, we would perform a review of this new model output (as in Step #4) and repeat Steps #5 and #6 until the model output was well calibrated, resulting in our final habitat model. Our last step was a field based validation of the final model output resulting in the final habitat datasets included in the report. Figure 12 illustrates the overall methodological process (and flow) used to develop the final habitat datasets. Each of these steps is described in more detail below.

4.2 Satellite Image Acquisition and Preprocessing

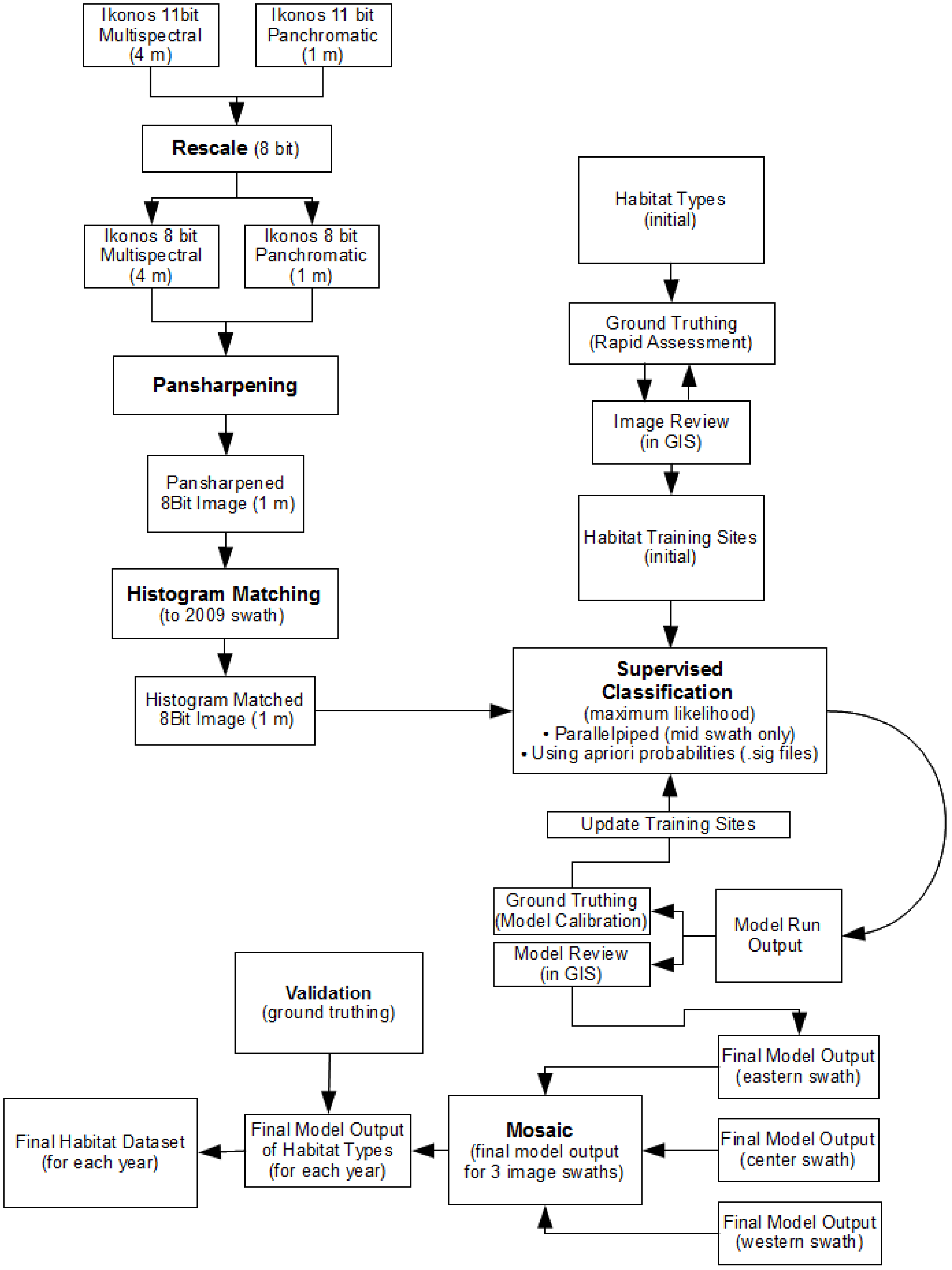
Satellite Image Acquisition

Habitat types were classified from Ikonos multispectral imagery for all three years (2009, 2010 and 2011). In all three years we obtained a cloud free image. The Ikonos imagery obtained for mapping has a spectral resolution of 1 panchromatic band (526-929 nm) and 4 multispectral bands: blue (445 – 516 nm), green (506-595 nm); red (632-698 nm); and near-infrared (757-853 nm). The imagery has a spatial resolution of 0.9 meter pansharpened (4 meter multispectral and .9 meter panchromatic). The near infrared band and “red edge” played a crucial role in differentiating different vegetation types and is essential for the supervised image classification of vegetation. The Ikonos imagery comes in 11 km swaths; and as a result, the study area was captured in three “snapshots” as the satellite passed overhead. This is made possible because of the bi-directional nature of the satellite sensor (there is always a trade off between spatial resolution and swath width). The acquisition parameters are explained in more detail in Appendix 7.3.

Image Acquisition Dates

The satellite was acquired in June or July of each year on a day closest to Mean Lower Low Water (MLLW). The acquisition was timed during a period of overall maximum vegetative growth within the study area and with full exposure of marshes and mud flats. In the end, we acquired imagery around noon on the following three days: June 23rd, 2009; July 4th, 2010; and July 7th, 2011.

Figure 12: Process/Flow Diagram of Methodology



Tidal Considerations

The goal for the timing of satellite image acquisition was to capture the study area at Mean Lower Low Water (MLLW). This ensures as much surface water had drained from the marshes as possible so as to reduce its contribution to reflectance as well as expose as much of the mudflat as possible. The Ikonos satellite passes over the study area around noon to minimize shadows and glint from the sun. Unfortunately, there are very few (if any) days when MLLW occurs near noon during the peak of marsh vegetation's growth (June/July). Our optimal acquisition days were when the lower-low tide occurs 1-hour before noon and the predicted tidal depth is less than 1 foot above (or below) the station's MLLW datum. We optimally want one hour after lower-low tide because there is a delay in the tidal cycle from North to South "up-estuary", which is roughly ½-hour between the San Mateo Bridge and Alviso. As a result, during the hour following an ebb tide the tidal depths across the study area will be more equivalent because northern areas will be in slack tide (i.e. not changing) for at least an hour while the southern portion reaches low slack tide. However, since days at which the Ikonos satellite will overpass do not always match with these optimal dates, we had to loosen our criteria to 1 hour before or after lower-low tide and a predicted tidal depth of less then 1 meter. Even though our criterion was necessarily relaxed, tidal availability between images limited the efficacy of using Ikonos imagery to capture overall changes to mudflat extent over time. Instead, we focused on maximizing the drainage of water from within the vegetation and its distance from the edge of the marsh, both of which should minimize water reflectance on vegetation spectral values.

Tidal predictions were downloaded from NOAA for the Redwood City, CA tidal station (see Table 15), and then sorted in a spreadsheet to allow for selection of dates when the tide at noon is at MLLW or rising to a maximum of 1m above MLLW. These dates were compared to dates within June and July when the satellite was passing overhead the study area, and the best three days that matched were requested for satellite capture (we paid a "tasking fee" to obtain the best of three possible days)

However, with only one capture each year, it is difficult or impossible to control for all the variability in the tide across the study area. Even the tide level of the bay can be offset from tidal conditions in some of the pre-Phase I restored ponds (e.g. SF2, Cooley Landing, etc.). As a result, there are differences in the amount of water and mud at a given location from year to year.

Table 15. NOAA Redwood City Harbor Station's Tidal Datums

datum	code	meters	Meters above NAVD88
HIGHEST OBSERVED WATER LEVEL	12/3/1983	3.293	2.98
MEAN HIGHER HIGH WATER	MHHW	2.501	2.19
MEAN HIGH WATER	MHW	2.308	1.99
MEAN SEA LEVEL	MSL	1.342	1.03
MEAN TIDE LEVEL	MTL	1.337	1.02
MEAN LOW WATER	MLW	0.366	0.05
MEAN LOWER LOW WATER	**MLLW**	**0**	**-0.32**
LOWEST OBSERVED WATER LEVEL	1/11/2009	-0.844	-1.16

Note: mature marsh surfaces predominantly w/in 0.1m of MHHW (Atwater et al 1979)

Image Deliverables and Review

The imagery for all three years was delivered as two separate products. The first product and most crucial product was the “raw” imagery (11bit) delivered in three swaths (west, center, and east). These individual image swaths were the imagery that was used to develop the habitat model and final habitat datasets. The second product, was a single mosaiced image that had been Digitally Range Adjusted (DRA) to balance the varying color values across the image. This second product was used in model review and other steps performed in GIS. Both products were Orthorectified and geometrically corrected by the satellite provider (GeoEye). Neither of these two products were radiometrically or atmospherically corrected by GeoEye.

The 2011 imagery was captured very close to MLLW and as result mud flats seemed fully (or near fully) exposed , especially when compared to 2009. In addition, vegetation was captured during a time of overall peak growth and flowering (as observed in near-IR reflectance) , again significantly more then in 2009 (but closer to 2010). However, it appeared that some restored marshes (e.g. Bair) contained more water (confirmed by field observations around the time of acquisition) then would have been expected during a time of MLLW, and might suggest some offset between MLLW as measures by the Redwood City tidal gauge and the draining of these restored ponds. The 2010 imagery was captured close to MLLW and the mudflats were almost, but not entirely, exposed. Vegetation appeared near peak growth during this time period although there was some variability across the study area. In 2009, the imagery was acquired during mean tide, so mud flats were not fully exposed. Also the 2009 imagery had a relatively lower reflectance (or Digital Number) in the near-IR band and slightly higher reflectance in the green band as compared to 2010 or 2011. As a result, vegetation in the 2009 imagery was potentially more senescent then in 2010 and 2011.

Image Preprocessing

The steps outlined for preprocessing were required to prepare the imagery for image classification into habitat types. All preprocessing and image classification was done in Erdas Imagine 9.3. The parameters and steps described below were developed with the goal of producing the most consistent and accurate model results between image swaths and between years.

1. Rescale

Image swaths that were normalized using histogram matching (HM) were rescaled to 8bit from 11bit in Erdas Imagine. Although HM was also attempted directly on the 11bit imagery, the model output was inconsistent and often very inaccurate between swaths and years. Once the imagery was rescaled to 8bit, model output using HM produced significant improvements in accuracy and consistency. (Note: We utilized the 11bit imagery in our atmospheric correction although these normalized images were not ultimately used for the final habitat datasets discussed in this report).

2. Pansharpening

Pansharpening is an image processing technique that "fuses" a combination of multispectral and panchromatic data acquired at two different spatial resolutions (4m and .9 m for Ikonos) into one multispectral image at the higher resolution (in this case .9 m). Although pansharpened imagery can modify original spectral values, comparison of the classification of the 4 meter imagery with the .9 meter pansharpened imagery produced significant improvements to model results. Images were pansharpened in Erdas Imagine using the High Pass Filter (HPF). This pansharpening technique is designed to maintain spectral integrity of the pansharpened output, which was important for maintaining consistent spectral classification of habitat types. The defaults were utilized with the exception of the weighting factor which was set to be at the lowest value (35) to maintain the "sharpest" image possible and to reduce the generalization of spectral values from the source images.

3. Masking

Once the 8bit swaths were pansharpened, we used a "mask" to produce an image that only contained the habitat locations being mapped within the project boundary. Masking the imagery assists in a number of ways: image normalization between years; focusing image classification on only those types of land cover (the mudflats, marshes and sloughs of the baylands) that the spectral model is classifying; and qualitative model review (simply by reducing the area being classified). We created a number of "masking" layers for use in image processing and classification. The three versions of our image mask are described in more detail below.

(a) Study Area Boundary

We edited the original SBSPRP boundary using the Ikonos imagery from 2009 as well as with input provided by Cheryl Strong at Don Edwards National Wildlife refuge in order to improve spatial inaccuracies in the original boundary file and to better conform to actual marsh and pond boundaries. This boundary was given to the satellite image provider to identify the image acquisition area.

(b) Inclusion/Exclusion Mask

This layer differentiates the area within the study area boundary into two areas - habitats being mapped (inclusion) and areas outside of these habitats (exclusion). Areas of "inclusion" included: mud flats, marshes, levees and uplands that are being mapped as part of the project; We utilized the inclusion/exclusion mask to generate imagery that included only the area within the project boundary actually being mapped. Areas within the study area boundary that were either "developed" or were not being mapped (e.g. open bay or flooded ponds) were masked out for the analysis and in the final model results. This mask was used at this stage in image preprocessing.

(c) Stratification Mask(s)

The inclusion/exclusion mask was stratified into broad habitat categories for analyzing model output. These categories include: water, mudflats, tidal marshes, non-tidal marshes, levees, uplands, vegetated areas and developed land cover. divide into the following categories: salt marsh, brackish marsh, fresh marsh, and managed marsh. The second, which is slightly more detailed (salt marsh, brackish marsh, freshwater marsh, upland, levee, an mud flat) The "tidal" habitat category was further divided into salt, brackish and freshwater marshes for use in stratifying the ground truthed validation samples. Sources of for stratifying the inclusion/exclusion mask, include: Baylands Habitat Goals Report (SFEI

2008); SBSPRP Existing Conditions Report (2004); vegetation datasets available for Guadalupe Slough (HT Harvey 2008); and, ultimately, our own edits based on manual interpretation of the 2009 Ikonos satellite imagery.

4. Normalization

(a) Histogram Matching
We applied a simple Histogram Matching (HM) routine to each image swath from 2010 and 2011 (6 total) using the corresponding image swath from 2009 as our base year. This is an image based correction method in which we use a “base year”and match the histograms of subsequent years to the base year in an effort to normalize the spectral variability of images over time. This simple method proved to be the most effective way of normalizing the imagery so the model could be applied effectively across all years. A distinct advantage of this method is both it is simple and easy to reproduce (even outside of the remote sensing software).

A large number of normalizations methods were attempted to normalize the imagery to actual spectral reflectance values and to account for atmospheric effects (see Atmospheric Correction below). Ideally, we would have converted the Digital Numbers (DN) in the raw imagery to spectral reflectance values for the different habitats types. However, since we utilized a simple HM method, the spectral values in the signature files used in the supervised classifications contain only Digital Numbers (8 bit) and therefore only only truly applicable for use within the study area.

(b) Atmospheric Correction

Significant effort was made to normalize the imagery across years and swaths through image based atmospheric corrections methods. These correction methods convert the raw Digital Numbers (DN) in the imagery to the percent of actual reflectance across each spectral band. The 11 bit imagery was successfully converted to at sensor radiance and then top of atmosphere reflectance (Taylor 2006) Although this method has shown to demonstrate reasonably good results for normalizing imagery over time and geography, it does not account for atmospheric effects, such as spectral absorption or scattering in the atmosphere. As a result, an additional process, known as the Empirical Line Method (ELM), was attempted to account for these atmospheric effects. The ELM method requires ground based reflectance of both a “light” and “dark” object using a field based hand spectrometer, which we obtained with the help of Liane Guild at NASA Ames. Unfortunately, we only acquired these ground based values for one swath and one year (2010). Although results showed improvements for some habitats, locations and years, the overall model output across years was not as consistent enough when compared to the simple Histogram Matching routine.

4.3 Habitat Types

One of the first, and key, steps in our mapping process was to create a list of recognized habitat types to be classified. These included biotic and abiotic habitat types in the the tidal marsh ecosystem at the species association and alliance scale that were also informative at the broader community scale (e.g. low, “mid” and high marsh). Our initial list of habitats were obtained from a series of pertinent species alliances and associations derived from the Manual of California Vegetation. We then combined this list derived from the MCV with a list of species identified during the City of San Jose's large-scale mapping effort in Guadalupe Slough in South San Francisco Bay. The work conducted by the City of San Jose contained an extensive list of common species field verified over the last two decades. We supplemented the resulting combined list with information regarding relevant species alliances and associations from the California Natural Diversity Database (CNDDB), the Bay Goals Species & Community Profiles (reference), and other published literature. Aside from the Bay Goals report, these lists are statewide floras, and as such they do not necessarily contain the local floristic detail required by this project. We supplemented these lists with expert knowledge and ground truthing by our lead biologist (David Thomson), whose knowledge of these habitats stems from over a decade of work.

The list of habitats being classified in the model was further refined over the first two years of the project and finalized in year three. The majority of changes were related to the inclusion of and edits to vegetation associations (and types) based on review of model output, as well as the exclusion of upland habitat types (e.g. Coyote Brush) because the latter often interfered with the spectral signals of other tidal marsh habitats. Changes to habitat types classified were made based on a number of factors. These include the effectiveness of a given habitat class during a model run, the spectral similarity (or difference) between a given habitat and another, the image characteristics of certain vegetation associations or habitats, and ultimately the importance to overall project goals.

4.4 Field Data Collection

4.4.1 Overview of Methods

Ground truthing served a number of functions: evaluating the range of species alliances/associations found throughout the study and generating training sites for our initial habitat types(preliminary); assisting with the evaluation and improvement of model results (calibration); and assessing the accuracy of final model results (validation). In all cases, ground-truthing was carried out in the field using a sub-meter GPS (Trimble Yuma with ProXT or a Trimble Recon with Geo-XH receiver). Ground truthing was conducted usually between May and November, with the majority occurring between June, July and August. The majority of ground truthing each year did not begin until July 15th so as to minimize the impact of field visits on sensitive species.

Our field methods were all based on the California Native Plant Society's Rapid Assessment methodology (CNPS 2005). This method is designed to catalog stands of vegetation based on the dominant/sub-dominant/co-dominant species quickly so that large areas can be efficiently mapped. Other species present are noted based on their contribution to plant coverage as well as any other significant biotic or abiotic entities that could contribute to reflected spectra. Based on the function of the field data collected (preliminary habitat characterization, model calibration, or model validation), we used different standardized ground truthing protocols and post-collection methods (see Table 16). Preliminary ground truthing reflected our our most intensive data collection at a given site, and was taken directly from the Rapid Assessment method. Ground truthing data collected for model calibration and validation were (primarily) collected within a radius (10-20 meters) of our field biologist and information on species associations and habitat conditions were generally less comprehensive. The total quantity of all ground truthed collected by year is show in Table 17.

Table 16: Ground Truthing Types and Purposes

GROUND TRUTHING TYPE	**PURPOSE**	**OVERVIEW OF COLLECTION PROTOCOL**
Preliminary (Rapid Assessment)	Field assess“stands” of plant alliances/ associations. Collect habitat samples for model training sites.	Standardized collection protocol using a Trimble Pathfinder Office data dictionary (based on CNPS *Rapid Assessment)*
Calibration	Focused field data collection to calibrate the model	
Validation	Statistically quantify the model’s accuracy	

Vegetation and abiotic habitat cover was collected using sub-meter GPS and a standardized digital field data collection form (see Appendix 7.2) stored as a “data dictionary” in the Terrasync software on the Yuma. The spatial location of each validation location was usually collected as a point feature. The percent cover (class), as well as size, pattern (clumped, ordered or random), shape (linear, round, irregular), height (class) and phenology, of each species present were estimated to the nearest cover class and recorded in the survey form developed specifically to support data collection for each type of ground truthing. In addition, a series of abiotic conditions were recorded, including mud, biofilm, water, bare earth, and algae, to the nearest cover class. Digital photographs were taken facing north, south, east and west at each location to assist with model review.

Table 17: Total Quantity of Ground Truthing Data collected by year and by type.

Ground-Truth Data Type	Year 1	Year 2	Year 3	*Totals*
Rapid Assessment	81	62	0	*143*
Calibration	183	309	158	*650*
Validation	0	69	211	*280*
Totals	*264*	*440*	*369*	**1073**

4.4.2 Types of Ground Truthing

1. Ground Truthing (preliminary)

The initial compiled list of common alliances (dominant) and associations (dominant, co-dominants, and/or sub-dominants) was modified based on preliminary fieldwork conducted throughout the study area. This “preliminary ground truthing” was mainly conducted in year one, and to a lesser degree year two, with very preliminary ground truthing conducted in year three. Data collection techniques conducted during this preliminary phase, were the most data intensive, and were designed to fully characterize the floristic diversity and structure of a unique and consistent “stand” of vegetation and were focused on providing the project additional field based information regarding the spatial and taxonomic variability of species alliances and associations throughout the study area. The larger list of species compiled during this process, but were not necessary all classified in the final model, was utilized in our digital survey forms during ground truthing.

Our fieldwork, which also included ground truthing focused on model calibration and validation, was in an iterative process, ensuring all significant stands of vegetation could be captured by the model. If ground truthing began to reveal that a significant alliance or association was missing from out habitat list we would add it. Alternatively, if an association was not found to be significant we would remove it from our list. Our draft list of habitat types (at both the alliance and association scale) was presented to Refuge biologists for feedback on what they perceived as critical, important, or potentially useful to ongoing management so the work was prioritized appropriately. Detailed descriptions of our habitat types can be found in Section II. The final list of habitats types that were classified in the model can be found in Tables 1 and 2.

This phase of ground truthing was also focused on acquiring initial training sites for the spectral classification. Rapid Assessment data were acquired from representative “stands” of habitat classes throughout the study area. As the first characterization data for each cover type this step required the most time in the field, to ensure the GIS team had as much information on the unique characteristics of a “stand” of a given habitat type. A key concept of any vegetation mapping method is that of a “stand”, or distinct association of species. In our case similar stands should reflect similar enough spectra such that a supervised classification of the data will adequately map habitats of interest in the study area. A vegetation “stand” is based on the perception of dominance, and is similar to the concept of a plant community. If dominance relationships change this may be considered a different stand. A problem with visualizing plant communities, which also creates a problem with their spectral classification, is where the community is very mixed (no clear dominance). This makes it difficult to delineate a stand in the field and its spectra make it a challenge to distinctly classified.

Another important concept is that of phytokinetic cover, which differs from living plant cover by accounting only for photosynthetic parts of plants. We are utilizing a range of spectral bands, including near-infrared wavelengths, which chlorophyll reflects very well, so phytokinetic cover is more appropriate than total cover by plants. This had a significant effect on the mapped cover values, even the same species as conditions changed and phenotypic plasticity varied the amount of “leaf area”

2. Ground Truthing (calibration)

After we had developed our initial training sites and habitat model and run a supervised classification of the imagery, we sent our field biologist out in the field to calibrate model output. Issues with specific locations or habitat types were identified during our model review in GIS. Members of the project team would identify an area where the model was under performing or questionable, and send out the field staff to acquire data in those locations to calibrate the model. Ocular estimates of plant cover were usually made within a set radius (~20 meters) or by generating a polygon by walking around a distinct vegetation “patch” (not necessarily a complete “stand').

3. Ground Truthing (validation)

Each year, we generated a stratified random sample, using the habitat categories from our stratification mask, for statistically testing model accuracy. These data cannot were not utilized for rapid assessment or model calibration. Our field biologist navigated to each validation location using the sub-meter GPS and then made ocular estimates of plant and other ground cover within a 20-meter radius of the GPS point location. Details on the process and methods we utilized for validation sampling in the "Validation" section of the report.

Owing to limitations of time and resources, we prioritized our validation sampling to focus on priorities for the restoration and long-term management. Validation was focused on tidal marshes, including fringe marshes and restored ponds open to tidal action. The second priority was given to managed and "muted" marshes (marshes with little or no tidal action). The third priority was given to levees, since we were tasked only to identify the presence (or absence) of vegetation on levees. Upland was given the lowest priority; and as a result, very few validation samples exist for these locations.

4.4.3 Post-Processing

Ground truthing data were post-processed to improve spatial accuracy, add new columns to summarize the habitats present at each ground truthed location, and to support data management. Ground truth validation point locations were downloaded from the handheld GPS unit in Pathfinder Office (as .ssf files), and differentially corrected using local base stations to improve spatial accuracy. The resulting corrected ground truthed data (stored as .cor files) were exported as feature classes to a file geodatabase in ArcGIS. Project team members would then add a series of new columns to the ground truthed dataset's attribute table (see Table 18) and populate them in GIS for each ground truthed location.

Table 18: Columns Added to Ground-Truthing Feature Classes in post-processing

Field	**Description**
"UniqueID"	A unique identifying name for each point.
"photos"	Hyperlink to directory location of digital photos.
"Habitat"	Habitat Category (ie. salt marsh, brackish marsh, levee, etc).
"MarshLevel"	High, "mid" or low elevation (salt) marsh.
"Mrsh_Hab_Cls"	List of dominant (or co-dominant) habitat types within sample
"Mrsh_Hab_ClsO"	List of sub-dominant class(es) habitat types within sample

To populate the "Mrsh_Hab_Cls" and "Mrsh_Hab_ClsO" columns,which were used in conjunction with the final model results to generate the error matrices,, the following rule set was applied:

- Species or abiotic habitat(s) with the highest percent cover were listed as dominant within the validation area. If multiple species or abiotic habitats shared the highest cover rating, all are listed as dominant.

- Habitat types were assigned as "sub-dominant" if they were at least one cover class below another (dominant) habitat type

- Only species or abiotic habitat(s) with >15% cover are listed as sub-dominant.

- Habitat types comprised of species associations were designated if species were recorded in the field as having both an “ordered ”pattern (e.g. Pickleweed/- Pepperweed would be assigned if both Pickleweed and Pepperweed have greater 15% cover and both have an “ordered” pattern). If either species had a “clumped” pattern both classes were listed at the alliance level.

4.5 Habitat Model

4.5.1 Training Sites

Our preliminary ground truthing was used to generate a series of “training sites” which formed the basis of our spectral habitat model used to classify the satellite imagery. For each “habitat” type, we identified preliminary ground truthing points with the highest percent cover (or mix of high percent of covers) and with the most recognizable spectral and spatial signature. Each habitat type was assigned one or more training sites, based on our review of the variability of the given habitat both in the field and on the satellite image (in false-color), the geographic distribution across the study area, and the variability of observed plant associations identified for a given habitat.

The initial set of training sites were digitized with based on preliminary ground truthing points, existing vegetation datasets in South San Francisco bay, and other secondary data sources (e.g. LIDAR and oblique imagery available online from Bing Maps). These sites, which are examples of areas and their related spectral signatures for each type of vegetation or vegetation association, are used to “supervise” the classification of the satellite imagery into habitat types or other abiotic features like sediment and water. The size of each training sites also varied, depending on the relative spatial footprint of a given habitat, spectral separability, and phenological variability of a given habitat across the study area. Polygons used for training the satellite image were digitized between 1:800 and 1:2400 scale and the median size for all 50 training sites was 320 square meters. Once a set of training sites was finalized, they were converted to “Areas of Interest” in Erdas Imagine” which were subsequently used to generate the spectral signature files (.sig) used in the supervised classification of the imagery. These “spectral signature files” are the foundation for the habitat model discussed throughout this report.

Each of the 24 habitat types were assigned training site(s). As we performed our review of model output (see below) throughout the three year project period, we would modify or add training sites to help improve model results. The majority of training sites were derived from the spectra of the original 2009 imagery. However, a handful of training sites were also added from 2010. For certain habitats (e.g. Pickleweed) we utilized a number of training sites to represent the various phrenological and growth patterns for a given habitat across the image(s) and years. The final habitat model(s) contain a total of 50 unique training sites (and related total spectral signatures) representing the 24 (19 biotic and 5 abiotic) amount of habitats mapped.

Our goal was to develop a habitat model that would perform within accuracy standards for all years – delivering a consistent model response between years (and between image swaths for a given year) was the focus of model development. As a result, certain models (or even normalizations) produced results with higher levels of accuracy (for a given year or given image swath) then seen in the final model. However, model output using these model iterations did not produce as consistent output over the 3 years of the study.

Since the study area was comprised of three source images for each year, representing three snapshots (or image “swaths”) from the satellite as it passed overhead, the best model response was obtained by customizing the model for each of the these three image snapshots. As a result, there are three models total – one for each image swath – and each model is run on all three years of imagery. The vast majority of the training sites are identical across all three models, with approximately 15% of the training sites being unique to each model. In some cases, the number of training sites for a particular habitat were reduced (e.g. Alkali Bulrush in the “mid” image swath including Ravenswood and Edens landing) because they were both unnecessary and were causing significant habitat mis-assignments. These three spectral signature models represent the foundation for the automated classification of the imagery into distinct habitat classes.

4.5.2 Supervised Classification

Once the images had been been preprocessed and a set of training sites had been generated we utilized the resulting spectral habitat model (.sig files) to run a supervised classification of the imagery in Erdas Imagine. The supervised classification(s) were comprised of three components (in addition to the spectral signature file itself): (a) a parametric rule (maximum likelihood); (b) non-parametric rule (parallelpiped); and (c) a priori probabilities .

Maximum likelihood (a class probability density function extracted from the signature files for each class) calculates the probability that a given pixel belongs to a specific class . Each pixel is assigned to the class that has the highest probability (i.e. the maximum likelihood). These spectral signatures are used to “train” the parametric classifier (in this case maximum likelihood). The eastern swath was classified using the maximum likelihood parametric rule.

Both the western and center image swaths (for all years) were classified with a non parametric rule (parallelpiped). The parallepiped classifier, also called a “box classifier”, assigns pixels based on how they fit into a rectangular area defined by the highest and lowest image values in each band. Non parametric rules do not use an statistics in classifying the pixels and are used only *after* the parametric rule has been applied (n a multilevel approach). For pixels that overlapped (were in more then one “box”) run classifed (not in any “box”), the parametric rule was then applied. When the model was run with this multilevel non-parametric/parametric rule(s) for the western and middle image swaths, habitats types were mapped more consistently and accurately.

The use of the maximum likelihood classifier, which is based on probability theory, allows for the application of a priori probabilities (in the form of statistical weights) to each training signature. Although the vast majority of habitat signatures were given the same weights, probabilities were modified for certain habitats based on the level of over or under mapping of a given habitat (Type I or Type II errors) Calibration between field based observation so relative cover for each habitat type was greatly improved when we applied these apriori probabilities. The probabilities for each of a given habitat's training sites are stored directly in the signature files.

4.6 Review of Model Output and Ground Truthing (calibration)

The study area was divided into a set of quarter and one kilometer square grid cells to facilitate a systematic review of the supervised vegetation classification for a sample of selected grids. Model review, and the consequent identification of new or improved training sites for a given habitat type, was conducted in ArcGIS. Team members identified all the habitat types within the selected grid cells and qualitatively measured the accuracy of the habitat assignment according to a standard set of review parameters. The reviewers based their assessments of model output on a number of resource. These include: ground truthing data produced for the project, the satellite imagery itself (visualized in “false-color); vegetation data available from the SBSP Existing Conditions Report (2004); vegetation datasets available for Guadalupe Slough (HT Harvey 2008) ; and oblique imagery available online from Bing maps. The primary analysis focused on how each habitat classification within the grid cell was assessed to be over, on, or under classified. If the given habitat type was over or under classified, the reviewer estimated the percentage of error within a set number of classes. Team members also rated their confidence of the accuracy of the habitat assignment on a scale of low, medium, and high. The results of our review were recorded directly onto a spreadsheet for ease of analysis and to assist in quickly summarizing the results of the review. Team members recorded their observations about each habitat type within the grid cell in the spreadsheet and prepared a general summary of the general trends of supervised vegetation classification assignment review. This review was performed for each iteration of the supervised vegetation classification.

Since the habitat model consists of a series of training site(s) for each habitat class (that are used to represent the “spectral signature” for each habitat being mapped), the primary mechanism for implementing these changes was either to alter existing training sites or to intrude new and/or multiple training sites for each habitat. A significant amount of project time was spent in the process of model review and model refinement. In the end, dozens of models were developed with various numbers of and types of habitats.

Necessary improvements to the model were identified from our model review and as we obtained more ground truthing data allowing us to calibrate model output with actual vegetation distributions. Additional ground truthing was conducted at this stage to “calibrate” field based observations with model output as the model reviewer identified problematic or questionable habitat assignments. As a result we better understood the spectral differences (or similarity) of a particular habitat. For example, although mapping the extent and distribution of Iceplant (both Carpobrotus sp. and Mesembryanthemum nodiflorum) would be useful to the restoration effort (in in effort to understand its impact on marsh vegetation dynamics), it's spectral similarity to Pickleweed resulted in significant Type I errors (false positive) where Iceplant was erroneously displacing large amounts of Pickleweed . As a result, we excluded this species from our model during Year Two, resulting in increased accuracy of other priority habitats (notably Pickleweed).

Improvements to the habitat model were made iteratively, as we performed our qualitative review of model output and as we ground truthed additional areas and habitats. Changes to the model resulted in the increased accuracy of individual habitats and improvements to the “mix” of various vegetation associations being mapped. These improvements resulted from introducing training sites that better captured the habitat and phenological variability in the study area and were spectrally 'distinct' enough to be mapped as distinct habitats.

4.7 Final Habitat Model and Supervised Classification

Once the output of a given model was well calibrated with our GIS based review of model output and field observations, we finalized a given model for each year. Most variations in the model were made n year one and year two, with some smaller changes being made in year three. The final habitat models (.sig file for each image swath) were used in our final supervised classification and applied to all years.

Mosaicing

The final step before model validation was to mosaic the three final model outputs (west, center, and east) for each year into a single raster image of habitat types. Since there is overlap of approximately 1/2 mile between the images, we determined the best order for mosaicing, through qualitative evaluation of the overlapping area. All three years were consequently mosaiced (in ArcGIS) into one file in the following order of priority for pixel assignments: center (first) - which is closest to nadir, east (second), west (third). The only exception to this rule was at pond A6 and its surrounding marshes. At this location we included the model output from the eastern image since habitat classification in A6 was more consistent and accurate in this swath.

Manual Edits

Gross errors, including vegetation in open bay as well as in slough channels, were manually edited in Erdas Imagine 9.3 (using the Raster Tools available in the Viewer). The accuracy assessments for all three years were run on the original model output, but regardless, the manual cleaning would have had no impact on the outcome of the accuracy assessment.

4.8 Model Validation

Validation Overview

After we finalized model outputs for all three years of imagery, we quantified the accuracy of our classification results. Using our validation dataset for each year (described in more detail below), we assessed the accuracy of image classification for habitat types at both the alliance and association level. The error matrices were populated using the dominant habitat types (both at the alliance and association level) found within the area of the validation sample. We used the results to generate overall classification accuracy, individual class (habitat type) accuracies, and Kappa statistics for each year (see Section II: Results).

Validation Datasets (2009-2011)

In Year Three the vast majority of ground truthed data was collected for model validation. In Year One and Year Two we allocated the bulk of ground truthing time to collect Rapid Assessment and Calibration data, which was necessary to develop the model. In order to validate the model across all 3 years of imagery, we supplemented the validation data set using other ground truthing data types (see Figure 13).

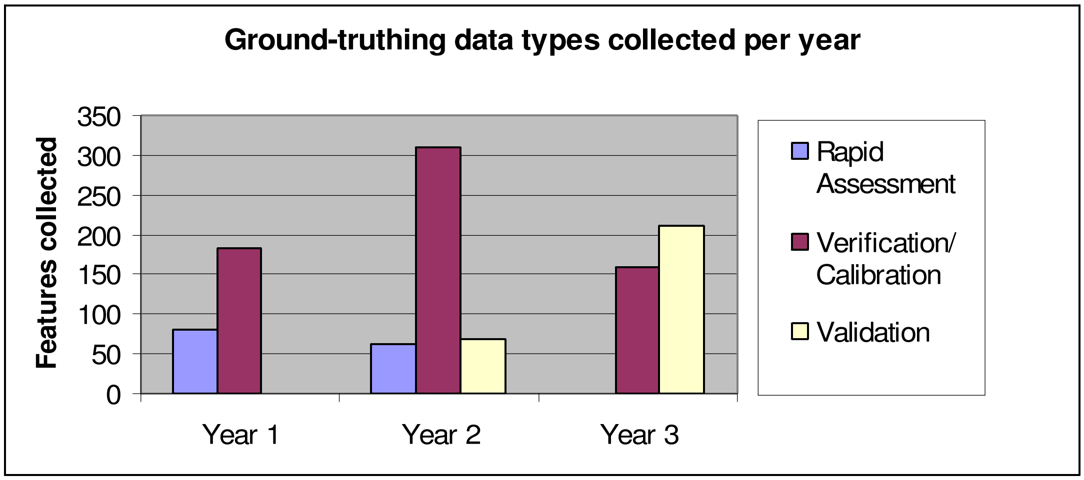


Figure 13: The relative proportion of ground truthing data collected over three year project period.

To identify data initially collected for other purposes to supplement our validation sample for each year, we screened data collected as rapid assessments or for calibration using the following criteria:

- not used for training site generation;
- included habitats mapped in the final version of the model;
- had high spatial and attribute accuracy; and
- could be digitized to create a polygon with an area of $50m^2$ or greater.

Using these supplemental data, the number of final validation samples (*n)* for each year are as follows:

Year 1 (2009):	188
Year 2 (2010):	202
Year 3 (2011):	230

Stratified Random Sampling (2010 & 2011)

To quantify the model's accuracy, we generated a stratified random sample of locations across the study area (using the Create Random Point tool in ArcGIS). We utilized our stratification mask, developed earlier in the project cycle, to stratify our sampling by the relative area of each broad habitat category. Because the acreage between salt, fresh and brackish marshes differs greatly across the study area , generating samples stratified across these broad habitats increased the likelihood that habitat types would be sampled based on their relative dominance throughout the study area (Table 19). Habitat categories used in the stratification, included: salt, brackish and fresh marshes (tidal); marshes with restricted tidal regimes (non-tidal), and levees. Validations datasets were supplemented for all years with other ground truthing datasets available for that year (see above). The sampling methodology used for validation is most pertinent to 2011 (and to a lesser degree 2010), which was the only year in which the majority of ground truthing was generated using this methodology.

We focused our ground truthing for validation in tidal marshes, and as a result, the majority of the validation sampling occurred in these locations. In 2011, we generated a stratified random sample of 200 locations across salt, brackish and freshwater marshes. Although we generated a stratified random sample of 100 points within "non-tidal" marshes in 2011, we were only able to sample 10% of these locations. As a result, we aggregated our sampling within these non-tidal marshes across all years (see Appendix 7.4). In 2010, we generated a stratified random sample of 200 locations across salt, brackish and freshwater marshes but only ground truthed 68 of these locations. Validation points were then exported onto a hand held GPS and used to navigate to validation locations. Ground truthing data that was collected from a stratified random sample included ocular estimates within a 20 meter radius of the field biologist.

Table 19: Habitat Categories (with acreage)

Tidal Marsh Habitats and Mudflats (focus of validation)	Acres	Other Habitats in Study Area	Acres
Salt Marsh	9,954	Non-Tidal Marshes*	3,952
Brackish Marsh	958	Levee	1,273
Fresh Marsh	195	Upland	1,619
		Water	3,054
Mudflats	10,148	Unvegetated	303
		Developed	34

[1] The area(s) in this table do not necessarily represent the exact acreage of each broad habitat category since they were derived from our stratification mask which was created at generally coarser scales then use in the analysis. Actual areas encompassing these categories (salt, brackish, and freshwater) can be generated from the final habitat datasets.

* Non-Tidal marshes included diked, managed or muted marshes.

Validation Sample Size (2011)

The total number of validation points (200) was determined by estimating the time and cost required to ground truth locations relative to the project budget but still created an adequate sample size for he study area. In order to achieve at least a minimum sample size for each habitat type, the number of validation points generated for salt, brackish and fresh habitat classes was based on a number of factors. These included: (a) the number of habitat types for each habitat category; (b) a minimum *n* of 5 for each habitat type; and (c) the relative area of each habitat category across the study area (see Table 20).

Table 20: Validation Sample Size for Salt, Brackish and Freshwater Habitats (2011)

	(a) # of modeled habitat types per marsh category	Multiplied by (b) the target sample size (n = 5) per habitat class	Summed with (c) points remaining in "validation budget" (110) proportionally divided by the relative acreage of each marsh habitat	(equals) # of validation points per habitat category
Salt	10	x 5 = 50	+ 99	= 149
Brackish	5	x 5 = 25	+ 9	= 34
Fresh	3	x 5 = 15	+ 2	= 17
Total		90	+ 110	= 200

In 2011, 211 features were collected specifically for model validation (including 8 for Non-Tidal and 3 for Uplands). While these validation locations had been randomly generated to proportionally sample fresh, brackish and salt marsh habitats, we reviewed the number of validation points collected in 2011 to verify habitat classes received a minimum of 5 validation points per mapped habitat class. Based on this review, we identified under-represented habitat classes in the data set and supplemented and additional 19 points originally collected for verification purposes for a total of 230 validation points .

Generating Error Matrices and Kappa Statistics

To assess the accuracy of the final model for each year, the habitat types classified by the model were compared to the field verified dominant habitat types in all final validation locations. The habitat types assigned in the " Mrsh_Hab_Cls" (dominant) column during post-processing of the ground truthing datasets were used for comparison to model output. Due to the small sample size for Pickleweed /-Gumplant, we supplemented the sample for this specific habitat type with data from the "Mrsh_Hab_ClsO" (sub-dominant) column. Model output (of habitat types) for each year's set of final validation polygons were generated using the Tabulate Area tool in ArcGIS). The resulting tables contained total pixel counts of habitat types mapped by the model within ground truthed locations.

The error matrix was manually populated by determining the success (or failure) of the habitat types in the model output (within the validation radius) to match the habitat types determined in the field. We ranked habitat types from the model by dominance (as % of total area) and compared it to the habitat types assigned from field observations.

Results were recorded in an error matrix for each year of the model. In addition, scores and error matrices were generated from validation locations which fell in non-tidal wetland habitats (e.g. diked, managed, and muted marshes) and these results were pooled across all three years of the model to generate a sufficient sample size. Finally, scores and a separate error matrix were generated from validation data collected on levees(aggregated for all three years) to test the ability of the model to detect vegetation versus unvegetated levee habitats. We also generated error matrices at the broader habitat alliance level.

Table 21 outlines the statistics generated from the error matrices at the alliance and association level.

Table 21: Accuracy Statistics in Error Matrices (Garfield et al 2009)

STATISTIC	DESCRIPTION	COMPUTATION
User's Accuracy	Percentage of model-derived samples that are correctly mapped	Major diagonal value divided by the column total
Producer's Accuracy	Percentage of field-derived samples that are correct mapped	Major diagonal value divided by the row total
Overall Accuracy (Observed Agreement)	Percentage of correctly mapped samples	The sum of the major diagonal elements of the error matrix divided by the total number of samples
Chance Agreement	Percentage of chance agreements between model-derived and field-derived classifications	Sum of the products of corresponding User's Accuracy Producer's Accuracy values
Kappa	Measure of difference between observed agreement and chance agreement	(Observed Agreement - Chance Agreement) / (1 - Chance Agreement)

5. Final Recommendations

As a result of our three year mapping project, we have developed a series of recommendations for the using the datasets produced from the project as well as for updates in the future. These, recommendations are as follows:

1. Time Period of Update

3-5 years depending on scale and frequency of needs (and funds)

2. Satellite Image Acquisition (future)

Updates can be made in the future using Ikonos imagery which works accurately at both the vegetation *Alliance* level and provides critical, although less accurate, data regarding vegetation *Associations.* However, the Ikonos imagery is at the end of it's planned life cycle, and as a result we recommend acquiring higher spatial resolution imagery in the future (< 1 meter), such as is already available from the GeoEye1 satellite. The 5 multispectral bands for GeoEye1 are very similar to Ikonos [blue (450-510 nm); green (510-580 nm); red (655-690 nm); near IR: (780-920 nm); panchromatic: (450-510 nm)]. Although there has been little work utilizing one model for both imagery types, the similarity between the sensors suggests that the spectral model could be applied to GeoEye1 imagery.

In an attempt to overcome inconsistencies between years (and between swaths), we also recommend investigating the purchase of acquiring at least three images per year and generating an average between them to represent that year. If financial resources are a concern, a first attempt at this process should utilize archived imagery (from Ikonos or Geoeye2) if available, since there is a significantly reduced cost for this imagery as opposed to a new acquisition (although purchasing archived imagery does not necessarily account for timing the satellite acquisition with optimal tides).

For certain specific sites of interest (specifically locations of high marsh or ecological transitions), we also recommend exploring the use of Hyperspectral imagery with similar spatial resolution (~1 meter). Since the swath width of these sensors will be significantly smaller then the Ikonos, this type of imagery analysis (at high spatial and spectral scales) can usually only be applied to small areas.

3. Use of Habitat Datasets (2009-2011)

Since the model worked within acceptable accuracy limits for habitats at the Alliance level, it can reliably used to track changes at these scales into the future. Due to limitation of accuracy of certain habitat types representing vegetation associations, we recommend the following: (a) vegetation associations that mapped with acceptable levels of accuracy (>= 75%) for a given year, or *in specific* locations, be considered a baseline for change analyses to be conducted in future years; and/or (b) vegetation associations be both lumped into low “mid” and high marsh categories for the purpose of change analyses. In addition, the SBSPRP can choose to use the highest accuracy year (e.g. 2011) or an average between years to create a potentially higher accuracy baseline dataset for tracking changes into the future.

4. Change Analysis

In order to best characterize both *where* and *when* changes might be occurring throughout the study area, we recommend performing change analyses using the habitat datasets produced from the study (as well as with similar habitats produced in the future). The focus of these change analyses would be on the shift from one habitat type to another (e.g. Alkali Bulrush to Pepperweed) or between abiotic (e.g. mud) to biotic (e.g. Pickleweed). In specific locations, such as where there is significant high marsh, change analyses can be calculated for broader habitat categories (e.g. low, “mid” and high marsh).

5. Create New Habitat Category Boundaries

The habitat datasets provide invaluable information regarding not only the distributions and extent of habitat types, but also large habitat categories. We therefore recommend that the habitats classes be “lumped” into the following broader habitat categories: salt, brackish marsh, and freshwater marshes (within tidal and mudflat areas).

6. Mapping Mudflats

A potential solution for overcoming issues related to mapping changes to mud flats and the timing of tides wold be to acquire a range (3 or more) of archived imagery for the time period (for Ikonos, geoeye2, or other high resolution satellite imagery where available) and average the extent and distribution of mud flats from these images. Imagery can be acquired from times throughout the year to identify images taken closest to MLLW. In addition, archived imagery is significantly less expensive.

These multispectral imagery might also provide a useful mechanism for mapping the extent of biofilm occurring on mudflats. Owing to the large importance that biofilm might have on feeding behaviors of avifauna, we also recommend using hyperspectral imagery with high spatial resolution (< 5 meters) to better understand the types of and potential varying spectral properties of biofilm.

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7. Appendices

7.1 APPENDIX: Products

1. Final Report
   - habitat types
   - results
   - methods
   - map book
   - power point presentation
2. Habitats Datasets (09-11) – as raster images
3. Habitat Model
   - signature files (.sig files) w/ apriori probabilities
4. Ikonos Imagery (2009,2010,2011)
   - Digital Range Adjusted (DRA) raster mosaics
   - Raw Ikonos Imagery (11 bit)
   - Normalized Imagery (histogram matched and atmospheric correction)
5. Trimble Data Dictionaries (.ddf) for ground truthing
6. Maps (ArcGIS MXDs)
7. GIS Database
   - ground truthing data (2009-2011)
   - training sites
   - study area boundary
   - habitat mask (inclusion/exlcusion)
   - habitat mask stratification (by habitat category)
   - Tables and Features Classes used for Mosaicing
   - Model Review Grid(s) feature class
   - ArcGIS layer files (.lyr) for habitat rasters
   - field spectra
8. Digital Field Photos

7.2 APPENDIX: Field Survey Form (Rapid Assessment)

Field Survey Form

(Rapid Assessment)

Location/Environment

- Polygon/Stand #
- Date/Time
- Surveyor(s)
- Is GPS within Stand?
    - Yes
    - No
- If No, Distance?
- If No, Bearing?
- Tide in Field
    - Low
    - Med
    - High
    - Flood
- Tide Verification
- Field Photos

All Features

- Size of Stand
    - < 1/4 acre
    - 1/4 -1/2 acre
    - 1/2 - 1 acre
    - 1 - 5 acres
    - 5 acres
- Algae
    - < 1 %
    - 1-5%
    - 5-15%
    - 15-25%
    - 25-50%
    - 50-75%
    - >75%
- Biofilm
    - Same cover classes as algae
- Litter/Wrack
    - Same cover classes as algae
- Bare/Fine (Dry)
    - Same cover classes as algae
- Mud (Wet)
    - Same cover classes as algae
- Lg Rock
    - Same cover classes as algae
- Water
    - Same cover classes as algae
- Aspect
    - N
    - NE
    - E
    - SE
    - S
    - SW
    - W
    - NW
- Slope
- Total Phyto Cover
    - Same cover classes as algae
- Hist, Age, Comments

Common Veg Features

- Common Species
    - Dis spicata
    - Fra salina
    - Gri stricta
    - Jau carnosa
    - Lep latifolium
    - Mes nodiflorum
    - Sal europaea
    - Sal spp.
    - Sal virginica
    - Sci robust/maritim
    - Sci spp.
    - Spa spp.
    - Typ angustifolia
    - Typ latifolia
- % Cover
    - Same cover classes as algae
- Pattern
    - Clumped/Patchy
    - Ordered/Regular
    - Random
- Shape
    - Linear
    - Round
    - Irregular
- Height Class
    - <6"
    - 6"-1'
    - 1' - 2'
    - 2' - 3'
    - 3' - 4'
    - 4' - 6'
    - 6'
- Phenology
    - Leafing
    - Flowering
    - Sinescence
    - Dead/Defoliated

Uncomon Veg Features

- Uncommon Species
    - Atr triangularis
    - Bac pilularis
    - Bro diandrus
    - Car edulis
    - Con maculatum
    - Foe vulgare
    - Rap sativus
    - Sal soda
    - Tet tetragonioides
    - Cus salina (Dodder)
- % Cover
    - Same cover classes as algae
- Pattern
    - Same as common veg features
- Shape
    - Same as common veg features
- Height Class
    - Same as common veg features
- Phenology
    - Same as common veg features

Rare Veg Features

- Rare Species
    - Ach millefolium
    - Amb psilostachya
    - Atr semibaccata
    - Bas hyssopifolia
    - Bet vulgaris
    - Che chenopodioides
    - Cot coronopifolia
    - Cre truxillensis
    - Ele macrostachya
    - Ele parvula
    - Epi brachycarpum
    - Epi ciliatum
    - Iva axillaris
    - Jun balticus
    - Jun bufonius
    - Jun mexicanus
    - Lim californicum
    - Lot corniculatus
    - Pol monspeliensis
    - Ros californica
    - Rub ursinus
    - Rum crispus
    - Sal subterminalis

- % Cover
    - Same cover classes as algae
- Pattern
    - Same as common veg features
- Shape
    - Same as common veg features
- Height Class
    - Same as common veg features
- Phenology
    - Same as common veg features
- Other Species
    - Same as rare species
- % Cover
    - Same cover classes as algae
- Pattern
    - Same as common veg features
- Shape
    - Same as common veg features
- Height Class
    - Same as common veg features
- Phenology
    - Same as common veg features

Interp of Stand

- Alliance/Association (field assessed)
- Other Alliance/Assoc
- Confidence
    - low
    - medium
    - high
- Adjacent Alliances
- Comments
- Site Impacts

7.3 APPENDIX: Satellite Acquisition Parameters

- Satellite Image Provider: GeoEye Corporation

- Ikonos multispectral 4-band (11 bit) (comes in 3 swaths: west, center, east)
  The at-nadir resolution of the Ikonos imagery is .82 meter multispectral and 3.2 meter panchromatic. GeoEye produced imagery for the project with 0.9 meter panchromatic and 4 meter multispectral spatial resolution and we utilized these slightly higher resolution products for the project – this can be requested when ordering the standard resolution product resolution:
    - multispectral (4 meter)
    - panchromatic (1 meter)

- Ikonos pan-sharpened Digital Range Adjustment (DRA) mosaic
    - DRA should focus on balancing colors in baylands and not water in the open bay
    - used for model review and manual interpretation of imagery

- Coordinate System
    - UTM, Zone 10 North, NAD83

- Image Acquisition Boundary
    - use "Ikonos_image_boundary" feature class in GIS database

- Orthorectified Professional (10 meter CE90 accuracy / 1:12,000 NMAS map accurcy)
  Due to the very small relief within the study area the "Pro" orthorectification product from Geoeye usually produces a product with 2-5 meter accuracy. When purchasing imagery in the future please specify this level of accuracy needs (2 -5 meter).

- Time of Overpass: ~100 seconds

- Tasking Fee ($3000 at time of study)
  Owing to the tide restrictions and relatively few days in June or July that meet tidal requirements, we suggest that future purchases pay the tasking fee, which will give three potential satellite passes to obtain an adequate image.

7.4 APPENDIX: Non-Tidal / Levee Acreage Tables and Non-Tidal Error Matrices

Acreage by Habitat Type in Non-Tidal Marshes(diked, managed or muted marshes)

Habitat Type	**2009 (acres)**	**2010 (acres)**	**2011 (acres)**	**Net Change as % (09-11)**
Algae (alliance)	**2.7**	**15**	**5.3**	**91.6**
Alkali Bulrush	3.4	3.6	2.2	-36.5
Alkali Bulrush /- Pepperweed	18.5	23.9	21.5	16.1
Alkali Bulrush /- Pickleweed	33.5	14.7	6.5	-80.7
Alkali Bulrush /- Spearscale	1.3	3.8	5.7	325
Alkali Bulrush (alliance)	**53.3**	**42.5**	**33.7**	**-36.9**
Alkali Grasses (alliance)	**250.4**	**432**	**472.4**	**88.7**
Alkali Heath (alliance)	**116.6**	**91.1**	**155.2**	**33.1**
Bare Earth	600	548	358	-40.3
Bare Earth / Wrack (alliance)	**947**	**894**	**604**	**-36**
Mud with Biofilm	30	41.2	24.9	-16.9
Mud (alliance)	**983**	**976**	**783**	**-20.4**
Freshwater Bulrush	20.2	4.7	12.2	-39.4
Freshwater Bulrush /- Cattail	20.2	2.4	14.1	-30.4
Freshwater Bulrush (alliance)	**40.4**	**7.1**	**26.3**	**-34.9**
Cattail (alliance)	**19**	**1.3**	**77.2**	**306**
Cordgrass	17.8	26.9	136.6	666.5
Cordgrass /- Pickleweed	17.8	55.7	42.5	138
Cordgrass (alliance)	**35.6**	**82.6**	**179**	**402**
Mud	66.3	85	43.5	-34.5
Mustard (alliance)	**111**	**117.7**	**117.3**	**5.4**
Pepperweed	382	218	315	-17.6
Pepperweed /- Alkali Bulrush	8.7	10.2	12	39
Pepperweed (alliance)	**390**	**228**	**327**	**-16.3**
Pickleweed	698	591	503	-27.9
Pickleweed /- Gumplant	27	73.6	125.9	366
Pickleweed /- Jaumea	46.3	74	37.5	-19
Pickleweed (alliance)	**771**	**739**	**667**	**-13.5**
Saltgrass (alliance)	**114**	**84**	**14**	**-87.7**
Water (alliance)	**214**	**227**	**271**	**26.9**
Wrack	347	346	246	-29
Total Associations	*3164*	*3078*	*2748*	*-6.9*
Total Alliances	*3163*	*3089*	*3018*	*-4.6*

Acreage by Habitat Type on Levee (top)

Habitat Type	**2009 (acres)**	**2010 (acres)**	**2011 (acres)**	**Net Change (09-11) (percent)**
Algae (alliance)	**26.5**	**18.5**	**11**	**-58.4**
Alkali Bulrush	0.8	1.7	1.1	38.4
Alkali Bulrush /- Pepperweed	2	2.9	6.6	222.5
Alkali Bulrush /- Pickleweed	1.9	0.8	1.5	-19.5
Alkali Bulrush /- Spearscale	0.5	1.8	1.3	146
Alkali Bulrush (alliance)	**4.5**	**5.5**	**9.4**	**110.2**
Alkali Grasses (alliance)	**94.6**	**86.7**	**84.4**	**-10.7**
Alkali Heath (alliance)	**32.9**	**34.1**	**47.9**	**-44.5**
Bare Earth	337.8	275	178.5	-47.5
Bare Earth / Wrack (alliance)	**488.6**	**370.3**	**271.4**	**-44.5**
Mud with Biofilm	62.7	74.2	49.9	-20.5
Mud (alliance)	**502**	**390**	**309**	**-38.5**
Freshwater Bulrush	1.5	0.6	1.6	12.7
Freshwater Bulrush /- Cattail	0.9	0.1	1.3	49.1
Freshwater Bulrush (alliance)	**2.3**	**0.7**	**2.9**	**26.2**
Cattail (alliance)	**0.5**	**0.3**	**2.5**	**443**
Cordgrass	3.7	11.2	23.6	544
Cordgrass /- Pickleweed	10.5	8.5	14.2	35
Cordgrass (alliance)	**14.2**	**19.7**	**37.8**	**166.4**
Mud	50.1	15.6	26.9	-46.2
Mustard (alliance)	**33.1**	**21.3**	**29.1**	**-12.3**
Pepperweed	59.7	62.7	71.8	20.2
Pepperweed /- Alkali Bulrush	1.1	1.4	2	78.6
Pepperweed (alliance)	**60.8**	**64.1**	**73.8**	**21.3**
Pickleweed	202.2	169	151.8	-24.9
Pickleweed /- Gumplant	5.3	9.7	13	143.5
Pickleweed /- Jaumea	7.4	10.1	11.2	51.1
Pickleweed (alliance)	**215**	**188.8**	**175.9**	**-18.1**
Saltgrass (alliance)	**40.3**	**20.1**	**6.5**	**-83.9**
Water (alliance)	**50**	**34.9**	**97.2**	**94.3**
Wrack	150.8	95.3	92.9	-38.4
Total Associations	*1150*	*938*	*916*	*-20.3*
Total Alliances	*1176*	*954*	*926*	*-21*

Alliance level Error Matrix for Non-Tidal Marshes (diked, managed, or muted): 2009-2011 (all years)

		Mapped Data															
		Algae	Alkali Bulrush	Alkali Grasses	Alkali Heath	Bare Earth/ Wrack	Cattail	Cordgrass	Freshwater Bulrush	Mud	Mustard	Pepperweed	Pickleweed	Saltgrass	Water	TOTAL VISITED	PRODUCER'S ACCURACY
Reference (Ground-Truthed) Data	Algae															0	NA
	Alkali Bulrush												2			2	0.0
	Alkali Grasses			1				1				1				3	33.3
	Alkali Heath				2											2	100.0
	Bare Earth/ Wrack			4		5										11	45.5
	Cattail			1												1	0.0
	Cordgrass															0	NA
	Bulrush															0	NA
	Mud					2		1		1		2	3		1	10	10.0
	Mustard			1							1					2	50.0
	Pepperweed															0	NA
	Pickleweed				1			1				2	23			27	85.2
	Saltgrass															0	NA
	Water			1								1	3			5	0.0
	Wrack															0	NA
	TOTAL MAPPED			8	3	7		3		1	1	6	31		1	Overall Accuracy 52.4%	
	USER"S ACCURACY	NA	NA	12.5	66.7	71.4	NA	0.0	NA	100.0	100.0	0.0	74.2	NA	0.0		

Association level Error Matrix for Non-Tidal Marshes (diked, managed, or muted): 2009-2011 (all years)

		Mapped Data																										
		Algae	Alkali Bulrush	Alkali Bulrush /- Pepperweed	Alkali Bulrush /- Pickleweed	Alkali Bulrush /- Spearscale	Alkali Grasses	Alkali Heath	Bare Earth	Cattail	Cordgrass	Cordgrass /- Pickleweed	Freshwater Bulrush	Freshwater Bulrush /- Cattail	Mud	Mud w/ Biofilm	Mustard	Pepperweed	Pepperweed /- Alkali Bulrush	Pickleweed (annual)	Pickleweed (perennial)	Pickleweed /- Gumplant	Pickleweed /- Jaumea (w/ Saltgrass)	Saltgrass	Water	Wrack	TOTAL VISITED	PRODUCER'S ACCURACY (%)
Reference (ground-Truthed) Data	Algae																										0	NA
	Alkali Bulrush																				1						1	0.0
	Alkali Bulrush /- Pepperweed																										0	NA
	Alkali Bulrush /- Pickleweed																				1						1	0.0
	Alkali Bulrush /- Spearscale																										0	NA
	Alkali Grasses						1					1						1									3	33.3
	Alkali Heath							2																			2	100.0
	Bare Earth						4		5																	2	11	45.5
	Cattail						1																				1	0.0
	Cordgrass																										0	NA
	Cordgrass /- Pickleweed																										0	NA
	Freshwater Bulrush																										0	NA
	Freshwater Bulrush /- Cattail																										0	NA
	Mud								2			1			1						1				1		6	0.0
	Mud w/ Biofilm																	2			2						4	0.0
	Mustard						1										1										2	0.0
	Pepperweed																										0	NA
	Pepperweed /- Alkali Bulrush																										0	NA
	Pickleweed (annual)																										0	NA
	Pickleweed (perennial)																	2			22						24	91.7
	Pickleweed /- Gumplant																										0	NA
	Pickleweed /- Jaumea (w/ Saltgrass)							1			1											1					3	0.0
	Saltgrass																										0	NA
	Water						1											1			3						5	0.0
	Wrack																										0	NA
	TOTAL MAPPED	0	0	0	0	0	8	3	7	0	1	2	0	0	1	0	1	6	0	0	30	1	0	0	1	2	Overall Accuracy 50.8%	
	USER"S ACCURACY (%)	NA	NA	NA	NA	NA	12.5	66.7	71.4	NA	0.0	0.0	NA	NA	100.0	NA	100.0	0.0	NA	NA	73.3	0.0	NA	NA	0.0	0.0		

7.5 APPENDIX: Map Book

(available as separate document)