Habitat Evolution Mapping Project

Decadal Update

(2019 & 2021)

Preliminary Results (2019)

May 21st, 2021

Habitat Evolution Mapping Project

Decadal Update (2019 & 2021)

Preliminary Results (2019)

South Bay Salt Pond Restoration Project

Submitted by

Brian Fulfrost and Associates

7011 SE Thorburn St

Portland, OR 97215

bfaconsult@gmail.com

Prepared by

Brian Fulfrost, Geospatial Scientist (PI)

with the assistance of

David Thomson, Lead Biologist

Matt Hinshaw, Field Biologist

Table of Contents

Executive Summary

This report outlines the *preliminary* results of the 2019 update to the original Habitat Evolution Mapping Project (HEMP). HEMP mapped the marshes and mudflats south of the San Mateo bridge yearly between 2009 and 2011. This update to that project (which we refer to as "HEMP2"), is a two-year project designed to understand the current status of these habitats, and to map and quantify the changes over the last decade. Originally planned for 2019 and 2020, the second year of HEMP2, was moved to 2021 and is now underway. The goal of the update is to better inform the South Bay Salt Pond Restoration Project (SBSP), it is partners and stakeholders, about the status of marsh and mudflat habitats within the study area and to assess changes to these habitats since the first study a decade ago.

The preliminary datasets produced from the HEMP2 study, and presented in this report, provide the SBSP Project Management Team (PMT) important resources for quantifying and visualizing the current distribution and extent of tidally influenced salt, brackish and freshwater marshes, as well as tidal mudflats, within the study area (See Figure 1). In combination with the results from the first phase of HEMP (Fulfrost, B., Thomson, D., 2012), they also allow the PMT and its' partners and stakeholders to better understand how tidal marshes have evolved over the last decade (2009-2019). We cannot assess changes to mudflats for this same period since we were unable to use the mudflat data from the previous report as a good baseline. However, we do now have mudflat distribution and extent from 2016 (Fulfrost, B., 2017), and we applied these same methods to the 2019 imagery.

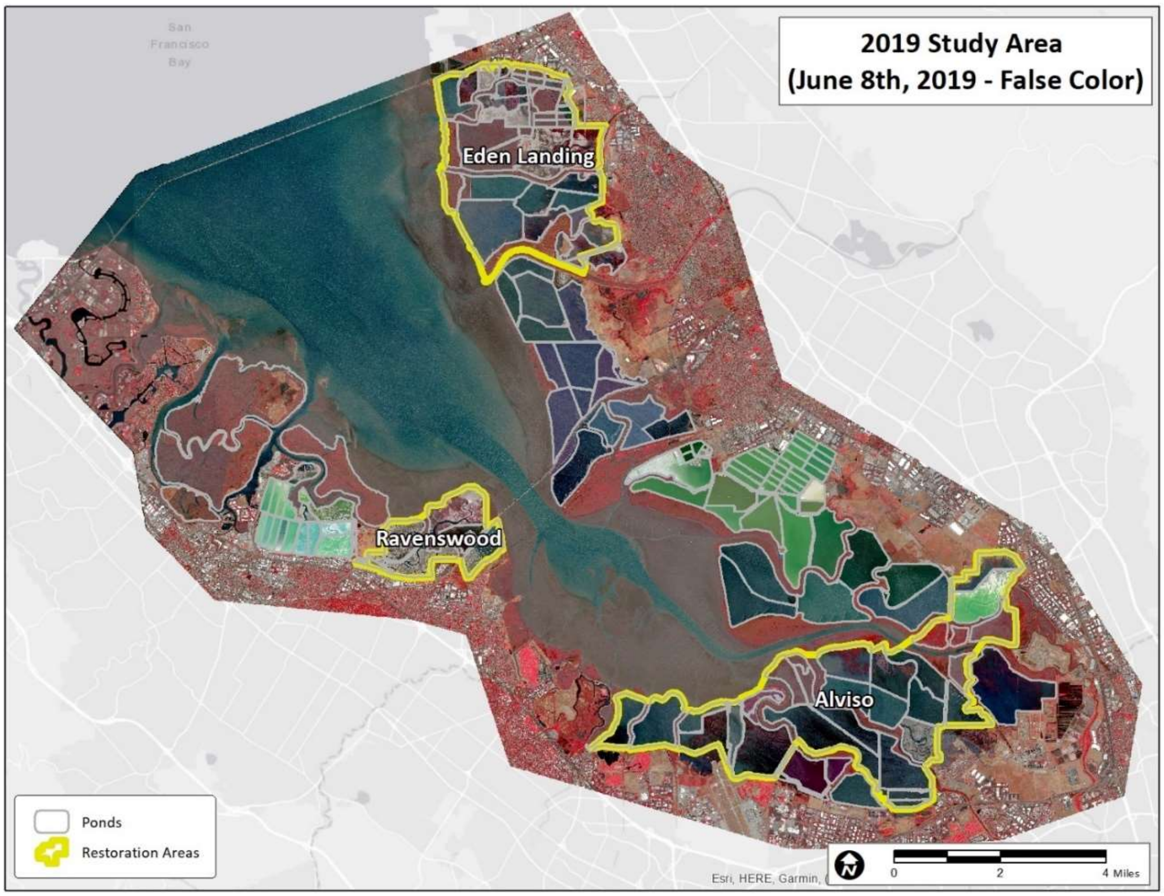
Overall, vegetation communities within tidal marshes have remained relatively stable, especially within fringe marshes along sloughs and marshes that already are well established. Based on our preliminary acreage tables for the entire study area (see Figure 3), there has been a small increase in the acreage of low salt marsh and a subsequent small decrease in the "mid" marsh plain. At the same time there also appears to be an overall increase in brackish marsh, especially in the Alviso area (and adjacent marshes). These overall trends could be variability across years, differences in the application of methods, or even some stochastic combination of factors.

Within the restored ponds, the trends and changes are much easier to understand (and quantify). Within several restored ponds there has been a significant increase in floral colonization (e.g. E9/E8A, A21, A20, North Creek marsh), but not as much in others (A6 & A17). The ponds with less floral colonization have changed into large mudflats, where biofilm also predominates. In some locations, such as the Alviso restoration unit, there also appears to be an in increase in brackish marsh since 2009-211. It is unclear whether this is interannual variability or a potential general shift in salinity.

Overall, the tidal mudflats directly facing the bay (i.e. *not* within ponds or sloughs) south of the San Mateo appear to be relatively unchanged from 2016. The contour of MLLW provided by the USGS from 2005 (Jaffee, B. & Foxgrover, A., 2006), also shows a general spatial correspondence with the current extent. Although tidal mudflats directly exposed to the bay remain relatively unchanged since 2016 (and even 2015), there are some locations with evidence of accretion and/or erosion. Although it is to be expected, there is also a decrease of mudflats *within* restored ponds with floral colonization.

The acreage of Pepperweed appears to be significantly reduced from 2009-2011 (see Table 3). Some of this decrease in Pepperweed is probably being mapped as Alkali Bulrush, where it co dominant or sub dominant, or within the Ruderal habitat classification. Part of the decrease could also potentially be a result of phenological differences (e.g. dead Pepperweed) at the time of satellite flyover. However, we also noticed a higher prevalence of Spearscale in our field surveys, especially in Aviso and surrounding marshes. Interannual differences in Spearscale within the study area have been noted elsewhere (John Bourgeoise, personal communication). It is very likely that a proportion of the increase in Alkali bulrush and Ruderal habitat acreages include some Pepperweed. At the same time, the increase in Spearscale and Alkali Bulrush, could also indicate that these vegetation alliances are competing with Pepperweed at these locations, and not allowing it to completely dominate. Some locations, like the levee and adjacent on the east side of A17, that show a significant reduction in Pepperweed from the previous study, could also be partially a result of restoration efforts. In the end, Pepperweed's distribution continues to be persistent and pervasive throughout out the study area but appears to have decreased in density and extent.

Figure 1: Habitat Evolution Mapping Project - Study Area



All results here are *preliminary* and therefore the habitat acreages, maps and conclusions presented here should also be considered preliminary. HEMP2 is a two-year project. We have used our first year (2019) to re-apply the methods from HEMP1 (and our 2016 mudflat study) to newer and higher resolution satellite imagery (Worldview-2). In this process, we have refined out habitat classifications, enhanced some of our methods (e.g. mudflats), and brought into clearer focus some of the issues with the original HEMP datasets. In year two, we will not only provide updated habitat data (for 2021), but also improve upon our confidence in our model methods and results. We will then apply what we have learned to make changes to our habitat model, and in turn refine both our 2019 and 2021 results. We will also make edits and cleanup obvious issues (e.g. bottom reflectance of water in ponds showing up as vegetation) in the original HEMP datasets (already underway). In turn, this will allow us to have more confidence in our change analysis between the two time periods (2009-11 & 2019/21). Our final report (due in the Spring/Summer of 2022) will contain the final habitat datasets for 2019 and 2021, including an updated (and final) change analysis with the original HEMP study (09-11) identifying acreage, percent, and locations of change. In the interim, we have included extensive change graphics (see Results section). The final report will also include more background materials and additional technical details on our methods not included in this interim report.

Section 1. Habitat Types

We mapped 19 unique habitat types (see Table 1), 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 12 tidal marsh habitat classes include: 7 salt marsh, 3 brackish, and 2 freshwater vegetation specific habitat types. Descriptions for each habitat types are included in Appendix 1.

Within the context of this report, "habitats" refer to the mapped classes of vegetation alliances (or associations), tidal mudflats, and other abiotic classifications (e.g. bare earth). Our vegetation classifications are based on rules of dominance, co-dominance, and sub-dominance, that follow the same set of guidelines found in the Manual of California Vegetation (Sawyer, J.O., T. Keeler-Wolf, and J. M. Evens. 2009). Although these vegetation classifications are useful unto themselves, they are also primarily used as proxies for estuarine habitats. These habitats include salt marsh (low, "mid" high, and high), brackish marsh, freshwater marsh, and tidal mudflats. We continue to use common names for these habitats as they are the most inclusive and the most easily understood and avoid any issues differentiating localized differences in species (e.g. *Schoenoplectus californicus* vs *Schoenoplectus acutus*) as well as any difference between endemic or invasive hybrids (e.g. *Spartina foliosa* vs *Spartina alterniflora*).

There is a single classification for Pickleweed (this can include *Sarcocornia pacifica* or *Salicornia Europaea*). We did not map *Sarcocornia pacifica* separately from *Salicornia europaea* separately from each other since we had difficulty distinguishing these sperate species in HEMP1. However, in our Cordgrass /- Pickleweed classification, which represent low (to mid marsh transition), it is more likely that the Pickleweed contains at least some *Salicornia europaea*. At the same time, our Pickleweed classification is more likely to contain *Sarcocornia pacifica* (see Appendix 1). The spectral similarity of Gumplant with other habitats (e.g. Alkali Bulrush), as well as its distribution pattern (often along channels), combine to make it difficult to differentiate it from surrounding vegetation. It is for this reason we map "Gumplant" as an association of Pickleweed. Along with Gumplant, Alkali Heath (Frankenia salina) is often an important indicator of high marsh.

Table 1: Habitat Classifications

Habitat Type		Alliance	Mapped Habitats (19) [Alliance /- Association]
Salt Marsh (9)	Salt Marsh – low (MTL-MHW)	Cordgrass	**Cordgrass**
			Cordgrass /- Pickleweed
	Salt Marsh – "mid" (MHW-MHHW)	Pickleweed	**Pickleweed**
			Saltgrass
			Pickleweed /- Jaumea
	Salt Marsh – high (MHHW)	Alkali Heath	**Alkali Heath**
		Pickleweed /- Gumplant	**Pickleweed /- Gumplant**
Brackish Marsh (3)		Alkali Bulrush	**Alkali Bulrush**
		Spearscale	**Spearscale**
		*Pepperweed**	***Pepperweed****
Freshwater Marsh (2)		Freshwater Bulrush	**Freshwater Bulrush**
		Cattails	**Cattails**
Upland (2)		Alkali Grasses	**Alkali Grasses**
		Ruderal	**Ruderal**
Non-Vegetated (3)		Mudflat	**Mudflat**
			Mudflat with Biofilm
		Wrack	**Wrack**
		Bare Earth	**Bare Earth**
		Water	**Water**

**Pepperweed was not included in the 'Brackish Marsh' habitat category when acreages were calculated.*

We used the same habitat classifications mapped in the first phase of the project (2009-2011), with some exceptions. In 2019, we mapped *mostly* at the vegetation alliance level. One conclusion from the first HEMP study (09-11), was that we achieved our best results at the vegetation alliance level. Although we collected detailed ground truthing data down to individual plant species (and even assigned these locations vegetation associations), we mapped habitats mostly at the alliance level since the accuracy of many habitat associations (e.g. Alkali Bulrush /- Pickleweed) between 2009 and 2011 were below acceptable levels. This is not true for all habitats. Habitat associations (e.g. Pickleweed /-Gumplant) that were essential for differentiating low, "mid", and high salt marsh were included in both studies. Although the accuracy of some of these associations is lower than is desirable (see Accuracy Assessment below), we do believe that we can increase this accuracy (both in 2019 and 2021) in our second year of mapping. For detailed descriptions of each habitat classification see Appendix 1.

Section 2. Results

Included below are acreages values and maps for the South Bay Salt Pond Restoration Project (SBSPRP) management areas as well as for the entire study area. We have summarized acreages by mapped habitat classification (see Table 2 and Figure 2) as well as by both broad habitat categories (see Table 3). Our preliminary results demonstrate that the overall accuracy of all mapped habitats is very high at the vegetation alliance level (82%) and still very good at the vegetation association level (73%). Although we did not distinguish between muted/managed marshes and tidal marshes (including fringe marshes and restored ponds) in our mapping or accuracy assessment, the wider range of salinity and mix of (often ruderal) vegetation in the muted or managed marshes likely do not map as well since our habitat model focused on vegetation at locations fully exposed to tidal action.

The results are summarized in a variety of ways to assist in interpretation. Results are presented both taxonomically by mapped habitat category (see Table 2 and Figure 2) as well as grouped into broader estuarine habitat categories (e.g. salt marsh, brackish marsh, and freshwater marsh). The 'salt marsh' category has also been further sub divided into low, "mid" marsh, and high marsh (see Table 1).
In addition to the 2019 acreage values for habitats, we have also provided acreage values from 2009-2011 for comparison (see Table 3 and Figure 3). When we started to compile the values from the baseline study (09-11), we identified some issues with these datasets, largely in 2011. For example, although we were successful a differentiating Alkali Heath (Frankenia salina), we believe it was heavily over mapped in 2011. As a result, we have not included acres of change by habitat or location and the acreage values shown in the tables below are *preliminary*. In our second year (2021) of the update to the original HEMP study, we will review and fix any obvious misclassifications in the original datasets and provide tables and maps that highlight the quantity and location of change.

In addition to summarizing the results for the entire study area we have also included acreage values by SBSP restoration unit for 2019 (see Table 4) and between 2019 and 2009-11 for each unit separately (see Figures 4-6). These acreage values mostly exclude ponds with water or undergoing enhancement. We have also included a brief discussion below of the results for restored ponds (e.g. Island Ponds, A6, E9/E8A), and select marshes (e.g. Faber/Laumeister).

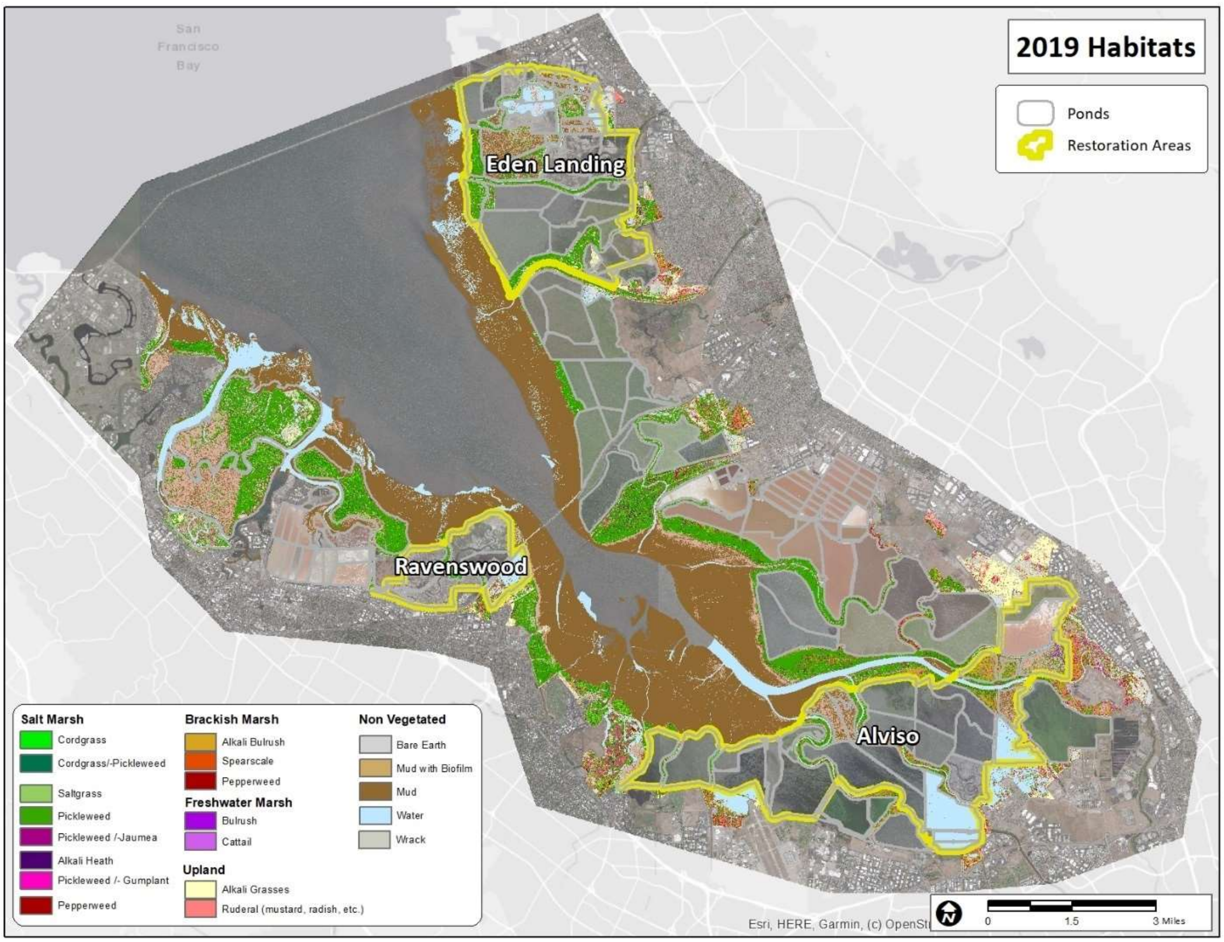
Mapped Habitat	**Acres (2019)**
Alkali Bulrush	1,039
Alkali Grasses	857
Alkali Heath	67
Bare Earth	1,613
Freshwater Bulrush	79
Cattails	218
Cordgrass	593
Cordgrass/-Pickleweed	522
Mudflat	17,081 * include biofilm
Mudflat with Biofilm	2,643
Pepperweed	322
Pickleweed	6,600
Pickleweed /- Gumplant	555
Pickleweed /- Jaumea	250
Ruderal	596
Saltgrass	91
Spearscale	232
Water	8,490
Wrack	966

Table 2: 2019 Preliminary Acreages by Mapped Habitat Classification

2.1 *Results – Study Area*

Overall, vegetation communities within tidal marshes have remained relatively stable, especially within fringe marshes along sloughs and marshes that already are well established. Based on our preliminary acreage results (see Table 3 and Figure 3) there is some evidence that here has been an increase in low salt marsh and an overall decrease in the "mid" marsh plain, although this could at least partially be a result of our methods. In some locations, such as the Alviso restoration unit, there also appears to be an in overall increase in the extent and distribution of brackish marsh. However, it is unclear whether this is interannual variability or a larger trend of shift in salinity. Within several restored ponds there has been a significant increase in floral colonization (e.g. E9/E8A, A21, A20, North Creek marsh), but not as much in others (A6 & A17). The ponds with less floral colonization have changed into large mudflats, where biofilm also predominates.

Figure 2: 2019 Preliminary Results



Pepperweed

The acreage of Pepperweed appears to be significantly reduced from 2009-2011 (see Table 3) Some of this decrease in Pepperweed is probably being mapped as Alkali Bulrush, where it co dominant or sub dominant, or within the Ruderal habitat classification. Part of the decrease could also potentially be a result of phenological differences (e.g. dead Pepperweed) at the time of satellite flyover. However, we also noticed a higher prevalence of Spearscale in our field surveys, especially in Aviso and surrounding marshes. Interannual differences in Spearscale within the study area have been noted elsewhere (John Bourgeoise, personal communication). It is highly likely that a proportion of the increase in Alkali bulrush and Ruderal habitat acreages include some Pepperweed. At the same time, the increase in Spearscale and Alkali Bulrush, could also indicate that these vegetation alliances are competing with Pepperweed at these locations, and not allowing it to completely dominate. Some locations, like the levee and adjacent on the east side of A17, that show a significant reduction in Pepperweed from the previous study, could also be partially a result of restoration efforts. In the end, Pepperweed's distribution continues to be persistent in extent and distribution but to have greatly decreased in density and volume.

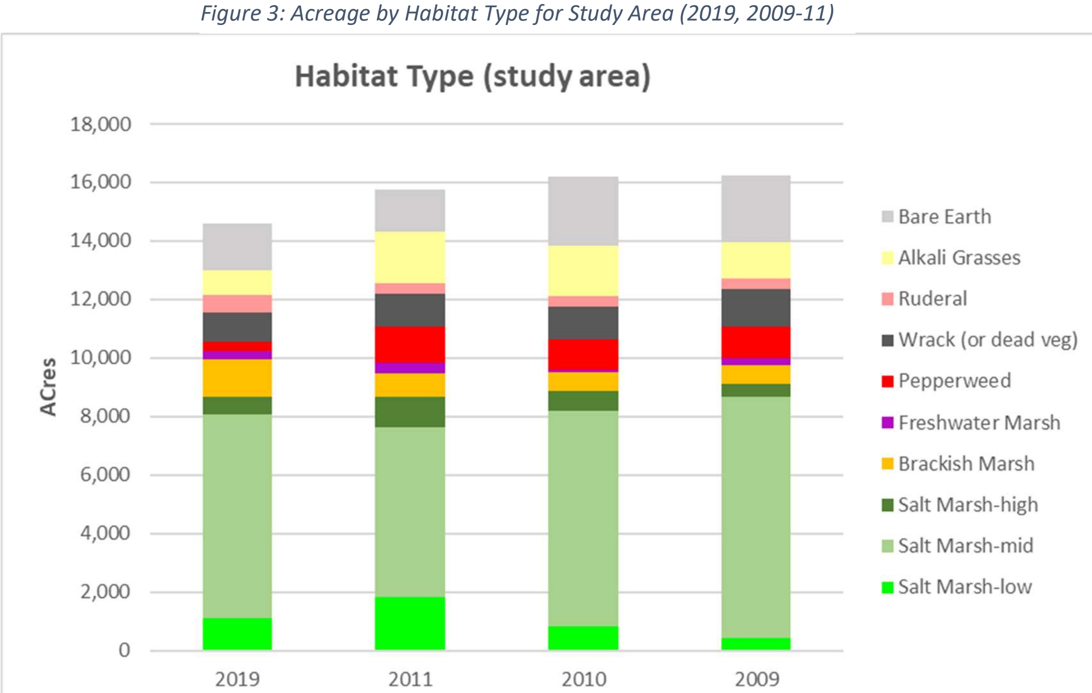
2.2 Results - Acreage by Study Area

Table 3: Acreage by Habitat Type for Study Area (2019, 2009-11)

Year	Salt Marsh (low)	Salt Marsh (mid)	Salt Marsh (high)	Brackish Marsh	Freshwater Marsh	Pepper weed	Wrack	Ruderal	Alkali Grasses	Bare Earth
2019	1,116	6943	624	1,272	298	322	966	596	857	1,613
2011*	1,814	5,811	1,040	790	368	1,269	1,114	356	1,771	1,405
2010	818	7,377	697	610	86	1,051	1,130	333	1,719	2,370
2009	446	8,234	451	640	205	1,113	1,252	360	1,257	2,264

*Some acreages from 2011 (and to a lesser degree 2009-10) are being revised to account for issues identified while producing this report.

Figure 3: Acreage by Habitat Type for Study Area (2019, 2009-11)



2.3 *Results - Acreages by SBSP Restoration Unit*

In Alviso (see Figure 4), mid salt marsh (comprised mostly of Pickleweed, Jaumea and Saltgrass), appears to have grown since 2010 and 2011, although it is similar to acreages recorded in 2009. High salt marsh appears to have grown and Cordgrass remains relatively similar to previous years. Brackish marsh (comprised mostly of Alkali Bulrush and Spearscale) also seems to have grown since 2009 and 2010. There has also been a slight increase in Freshwater marsh. Pepperweed appears to be reduced from previous years, although some of this “missing” Pepperweed this could be mapping as Ruderal or Alkali Bulrush.

Figure 4: Acreage by Habitat Type for Alviso (2019, 2009-11)

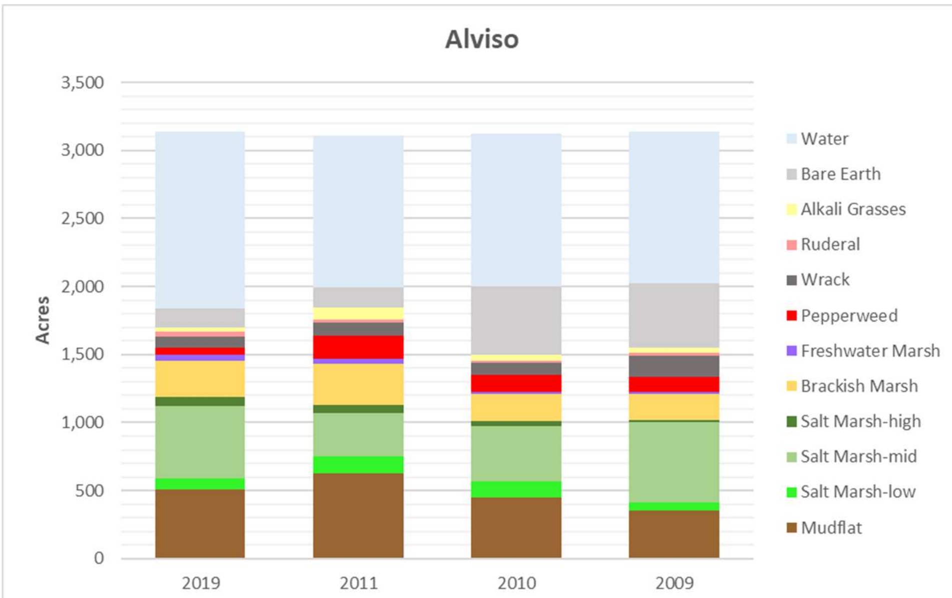


Figure 5: Acreage by Habitat Type for Ravenswood (2019, 2009-11)

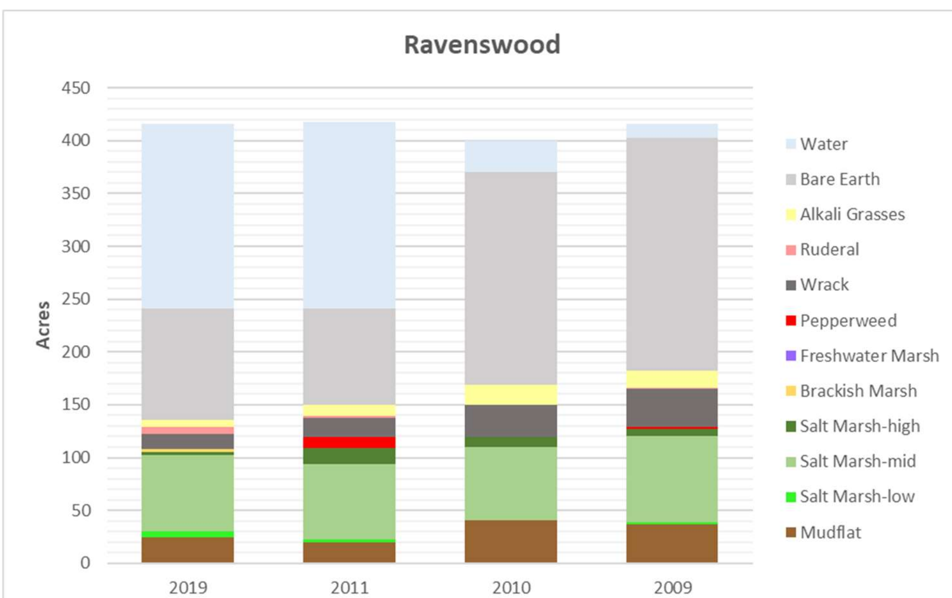
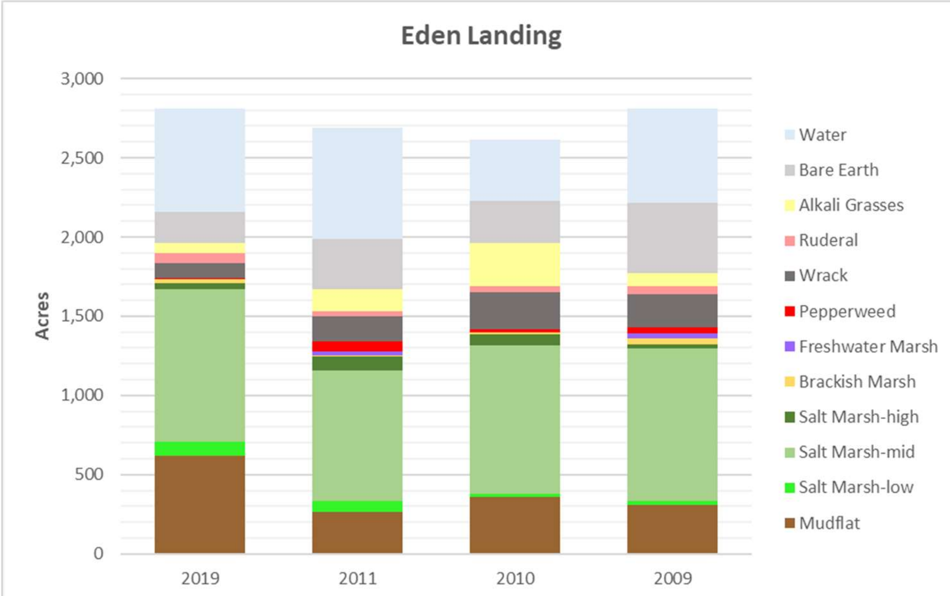


Figure 6: Acreage by Habitat Type for Eden Landing (2019, 2009-11)



In Eden Landing, where there has been restoration of ponds E9 and E8A since HEMP1, we see a significant increase in mudflats, and a corresponding increase in low salt marsh (Cordgrass) and mid salt marsh (Pickleweed). This also reflects increases in mudflats, pickleweed and cordgrass at North Creek Marsh. There also appears to be both a small increase in Brackish marsh (i.e. Alkali Bulrush) as well as Ruderal vegetation, mostly in the east side of Alameda Creek and Old Alameda Flood Control Channel.

Table 4: Acreages for Mapped Habitats by Restoration Unit (2019)

Mapped Habitat	Alviso (2019)	Ravenswood (2019)	Eden Landing (2019)
Alkali Bulrush	234.3	2.8	28.4
Alkali Grasses	33.0	6.9	63.5
Alkali Heath	1.5	0.8	5.9
Bare Earth	140.5	106.0	195.5
Bulrush	21.1	0.0	0.0
Cattails	24.0	0.0	0.3
Cordgrass	55.0	2.6	36.6
Cordgrass /- Pickleweed	27.1	2.8	46.3
Mudflat	97.5	14.4	203.8
Mudflat with Biofilm	409.1	9.9	418.4
Pepperweed	47.0	0.6	5.7
Pickleweed	520.8	70.9	947.9
Pickleweed /- Gumplant	66.5	1.9	29.6
Pickleweed /- Jaumea	8.6	1.4	12.3
Ruderal	35.0	6.0	61.9
Saltgrass	2.6	0.3	6.6
Spearscale	31.4	0.0	0.3
Water	1,299.7	174.2	657.1
Wrack	83.6	14.0	92.8

Notes for Interpreting Tables (and related Figures)

- At least part of the differences in acres from year to year could result from a number of things that are not inherently changes to the distribution, extent, or total acreage of habitats. This includes possible phenological differences (and their impact on plant distribution), differences in amount and patterning of dead vegetation, as well as difference in tide level (causing variable amount of water and/or mud within marshes and ponds).

- The total acreages for the HEMP1 data vary slightly from year to year. The polygon 'mask' used to calculate habitat acreages in the HEMP1 data (2009-2011) varied from year to year (up to ~300 acres). In 2011, the 'mask' used to generate the final data cut off a few sloughs, lowering the overall total. The mask used for the 2009 and 2010 datasets were similar although not identical and did not exclude any significant habitat. These two years (2009& 2010) also include a small amount of buffer around the study area, which could include the larger values for bare earth. For 2019, we used the largest 'mask' of the three (from 2009) and applied it to the 2019 imagery for comparison purposes.

- We did not include water or mudflats in when comparing our acreage totals for the entire study area since the mudflats and related water levels in 2009-2011 were taken at various tidal levels. This also accounts for the differences in total acreages for each year (see Table 3 and Figure 3). Differences in acreages of water (and to a lesser degree mudflats) for the SBSP restoration units over time (see Figures 4-6) are at least partially due to these differences in tidal levels at the time of satellite overpass.

2.4 *Results – Mudflats*

There were approximately **17,142 acres of mudflats** within the study area in 2019 at the time the image was taken (June 8th) at slightly below MLLW. Overall, the tidal mudflats directly facing the bay (i.e. *not* within ponds or sloughs) south of the San Mateo appear to be relatively unchanged from 2016. The contour of MLLW provided by the USGS from 2005 (Jaffee, B. & Foxgrover, A., 2006), also shows a general spatial correspondence with the current extent, although there is a possible sign of erosion since 2015, in the central part of the bay, south of the Dumbarton bridge (see Figure 7). Although we reported 18,435 acres of mudflat within the same area in our 2016 study (Fulfrost 2017), most of this difference is within restored ponds or within wetlands (see Table 5). *This difference does not seem to be a result of any significant erosion on mudflats directly exposed to the bay (see Figure 7 and Figure 8)*. After an intensive qualitative review of both datasets, we believe the differences in acreages between these years are a result of a number of factors, including: (a) slight differences in how we extracted mudflats from our unsupervised classification and NDWI (see Methods – Mudflat Model), whichresulted in a slightly larger mudflat edge in 2016; (b) small differences in tidal height between the years; (c) possible interannual variability; (d) floral colonization of mudflats in many locations including Coyote Creek (above A6), on the south side of Ogilvie Island, and in Calavares marsh; (e) and actual decrease of mudflats *within* restored ponds where floral colonization has increased, notably in the Island Ponds, E9/E8A, and Baumberg. There was also a significant decrease in mudflats at pond SF2 (between 2016 and 2019). This difference is likely due to the managed tide gate at that pond. Decrease in mudflats in restored ponds is also to be expected where floral colonization is targeted.

Although tidal mudflats directly exposed to the bay remain relatively unchanged since 2016 (and even 2015), there are some locations with evidence of accretion and/or erosion. On the western side of Alviso slough, the pickleweed marsh has grown approximately 6 meters since 2011 in some locations, with a subsequent decrease in the narrow mudflat that is contiguous to the fringe marsh. At the mudflat at the mouth of Mowry slough, there appears to be up to 60 meters of erosion since 2016, however it is very localized (i.e. *not* a large area). Within the mudflats at the "center" of the bay south of Dumbarton bridge there are also minor locations of both erosion and accretion. On the southern side of A6, just west of the breach, there appears to be a small portion of mudflat eroding as compared to 2016, creating a 'broad' notch. On the west side of Ogilvie island, a very small "notch" of erosion has appeared since 2011, despite mudflats accreting between the island and the marsh on it is the south side. Some or all of these locations could also be interannual or even seasonal variability. Our 2021 image should give us a better understanding of bi-annual changes (2019 -2021) and over the five-year period (2016-2021).

Table 5: Preliminary Mudflat Acreage (2019 and 2016)

Mud Flat Type	Acres of Mudflats (June 8, 2019)	Acres of Mudflats (April 13, 2016)
Bay/Slough	**13,800**	14,413
Pond/Wetland	**3,342**	4,022
Total	**17,142**	18,435

In the first HEMP study, we did not obtain satellite imagery at MLLW. As a result, we cannot use the acreages and maps of mudflat extent to analyze change to mudflats in 2019. However, in 2016 we obtained an image close to MLLW with the Worldview-3 satellite sensor (nearly identical spectrally to the 8 bands in Worldview-2 used in 2019). The timing of the image with MLLW, in combinations with the increased spectral resolution of these sensors, allowed us to develop techniques to map mudflats, even under shallow water. We used these techniques to successfully map mudflats in 2019. These techniques are focused on mapping the extent and distribution of mudflats and not in identifying biofilm on the mudflats, we continue to use the same methods used in 2009-2011 (pixel based supervised classification) for mapping the vegetative habitats (including mudflat with biofilm).

Mudflat with Biofilm

Preliminary results from 2019 indicate that biofilm is predominate within restored ponds, as well as on large mudflats found within sloughs. This is true in A20, A19, A6, Bair Island and to some degree at E9, E8A, and the Baumberg tract. Even at those locations of mudflat classified as not having biofilm, it is possible that these mudflats have a lower density or different species of biofilm that are harder to distinguish in our classifications. Mudflats that are closer to the edge of the marsh have also had more time for the tide to recede and therefore for microphytobenthos and diatoms to emerge. Although we only had one ground truthing location that was correctly classified as Mudflat with Biofilm, we believe our field team's ability to assess mudflat with biofilm in situ, especially at offset distances, is not as great as the ability to identify bioflm from the false color imagery itself.

Figure 7: 2019 Mudflats (preliminary)

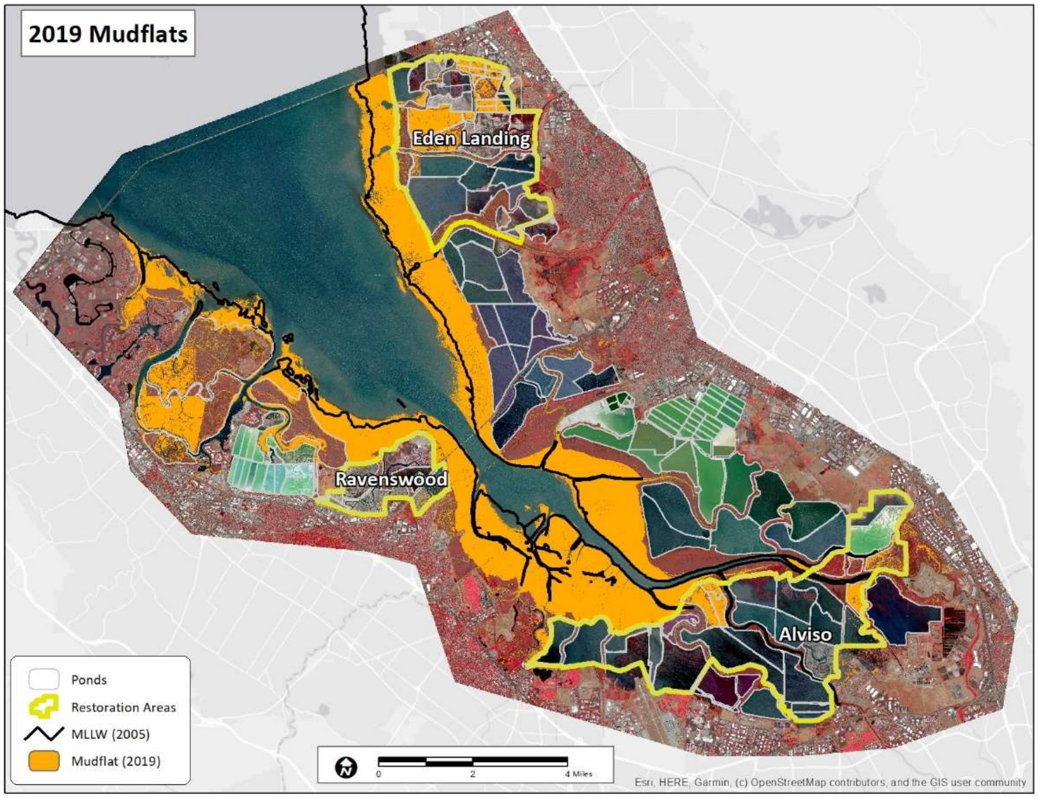
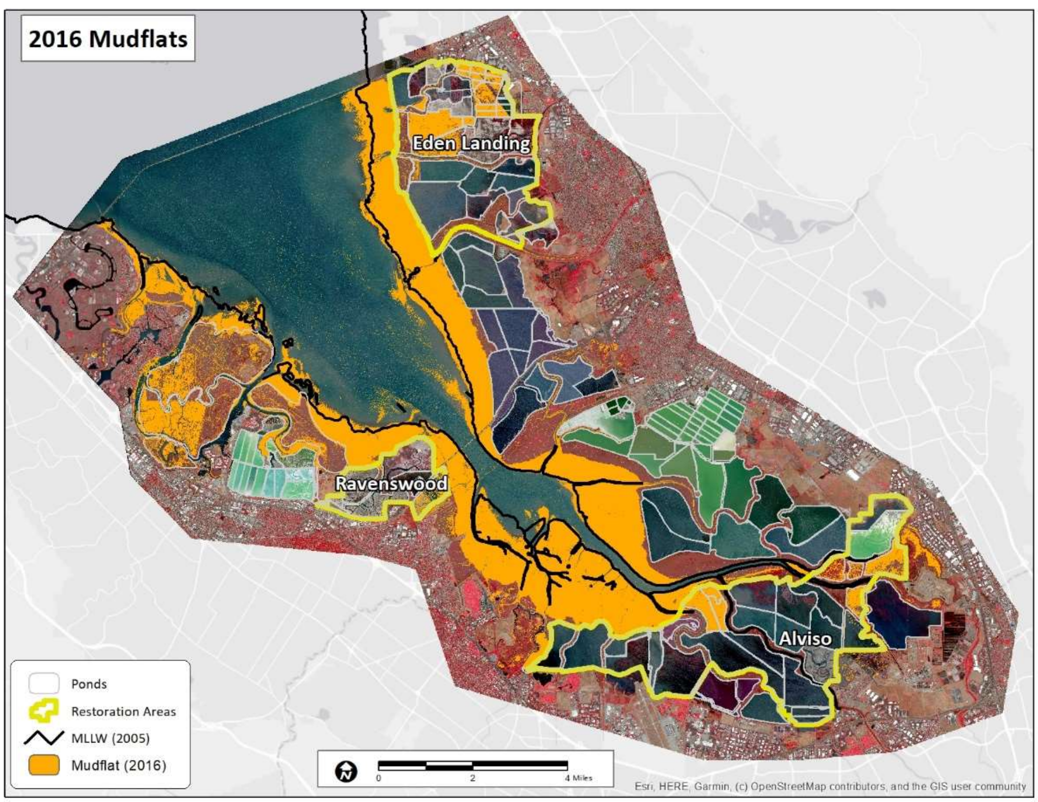


Figure 8: 2016 Mudflats



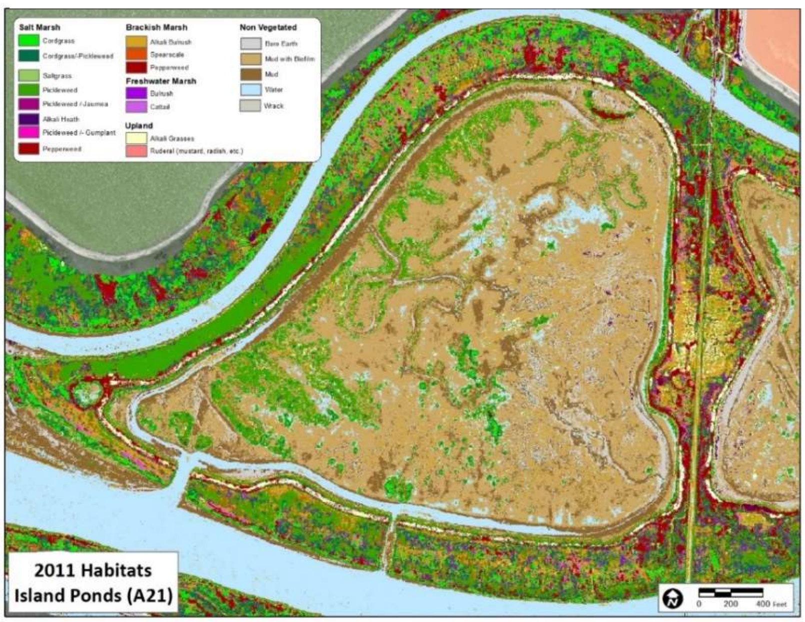
2.5 *Results – Restored Ponds*

Island Ponds (A21, A20, A19)

The most significant change within restored ponds (apart from E8A) appears to be in A21, a pond opened to tidal action before the first HEMP study (09-11). By 2011, pickleweed and cordgrass had begun to colonize channels within the mudflats found within the pond. By 2019, A21 has become mostly a brackish marsh, dominated by Alkali Bulrush. Pickleweed and spartina have also successfully colonized some locations, especially around the southern (and southwestern) edge of the old “burrow” ditch, where mudflats also seem persistent. In A20, a similar pattern has emerged, although Alkali Bulrush is not as distributed throughout the pond or as dense compared to A21, and mudflats (and mostly mudflats with biofilm) take up a significantly larger proportion of the pond.

Figure 9: Pond A21 (2019)

Figure 10: Pond A21 (2011)



However, in A19, the pond is still dominantly mudflat or mudflat with biofilm, with some notable exceptions. Throughout the pond there are small patches of Pickleweed and Cordgrass forming along channels emanating from the burrow ditch. There are also some patches of Alkali Bulrush. However, the largest contiguous stand of vegetation in A19 is Freshwater Bulrush in the northeastern portion of the pond (shown in the image to the right in purple). It is likely the water and/or soil salinity of these ponds decreases as you move east along Coyote Creek, and the vegetation within the pond seems to reflect this change.

Figure 12: Pond A19 (2019)

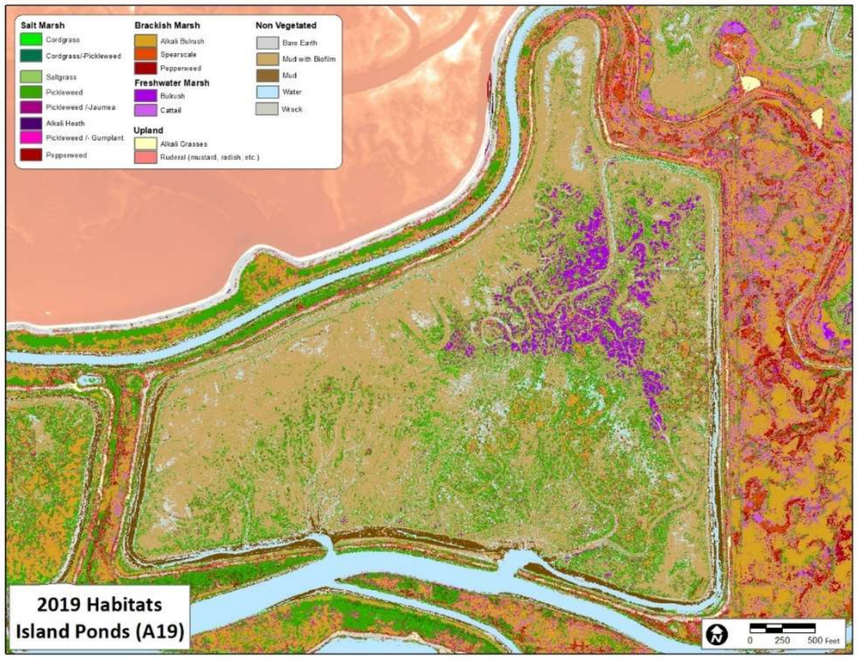


Figure 11: Pond A19 (2011)

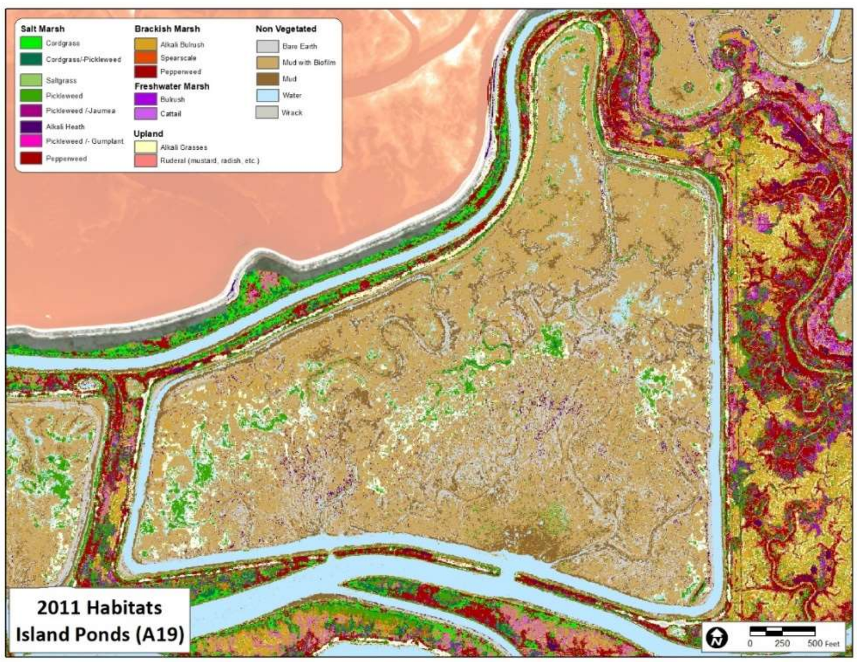
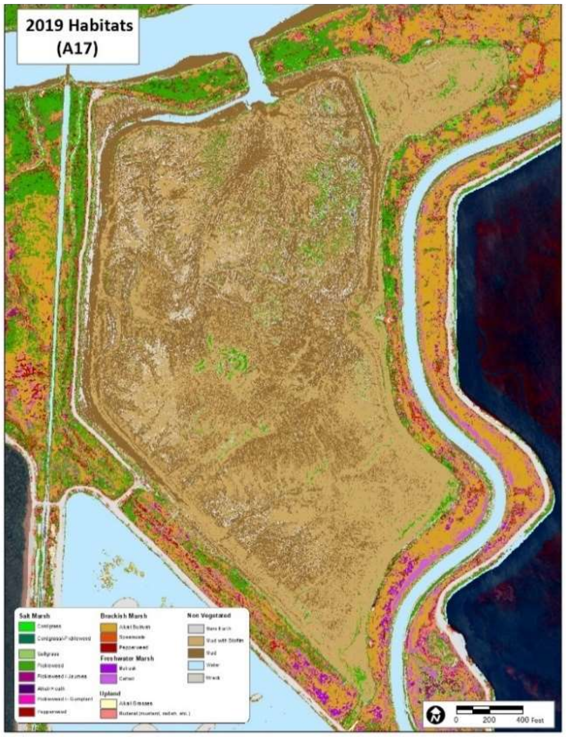


Figure 13: Pond A17 (2019)



A17

Since 2012, when pond A17 was breached, the pond has become mostly a giant mudflat, largely dominated by biofilm. There appears to be some minor floral colonization apparent within the pond (see Figure 13). There are small patches of Pickleweed and Cordgrass, but they have not developed consistently along the channels nor developed into larger mats.

A6 ("Ducks Head")

The levees around A6 were breached in 2011, before our satellite flyover, so the habitats map for that years shows the pond soon after the breach. At that time, mudflats were already starting to form within the pond although it was too soon to see any significant floral colonization (apart from the remnant levee in the center of the pond). In 2019, there appears to be some floral colonization of pickleweed along channels that have formed on the mudflats within the pond. There are also some large patches of Cordgrass as well as "spottier" clumps of Cordgrass. However, the

Figure 15: Pond A6 (2019)

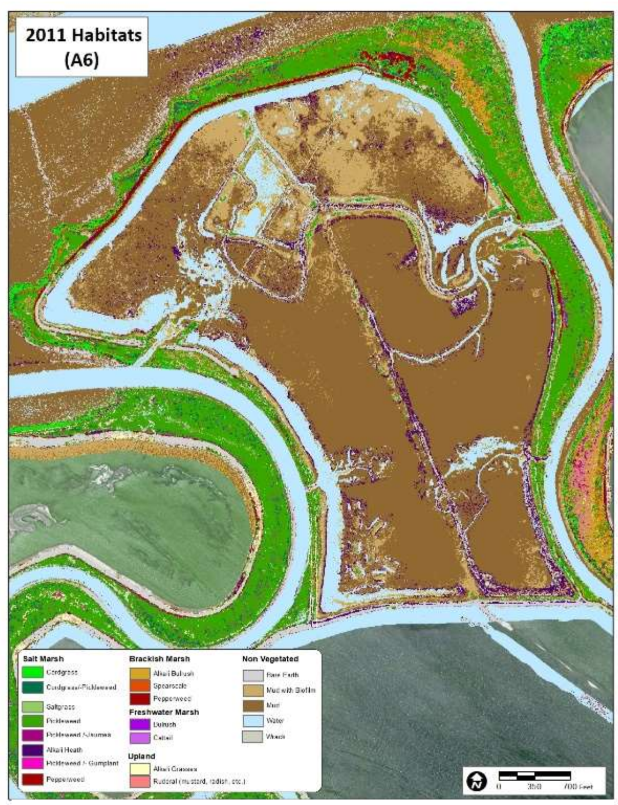


Figure 14: Pond A6 (2011)

pond still appears to be dominantly mudflat with biofilm. The among of floral colonization seen within the Island Ponds does not appear to have been repeated in A6.

Since 2011, the fringe marsh on the north side of A6 has expanded northward from approximately 8 meters on the west side of the top of the duck's head (but before the "bill") to 30 meters or more on the east side at the mouth of Alviso slough (see Figure 16 and 17). The colonized mudflat is now mostly low marsh with Cordgrass, a small amount of Pickleweed (likely annual) and some Alkali Bulrush. The Pickleweed marsh on the west side of Alviso slough has also grown approximately 6 meters, at least in some locations. It is also possible that the mudflat above A6 has accreted; however, our 2011 image was not taken at MLLW so we cannot say definitively. The mudflat at this location has remained nearly identical to that from 2016.

Figure 16: Above A6 (2019v

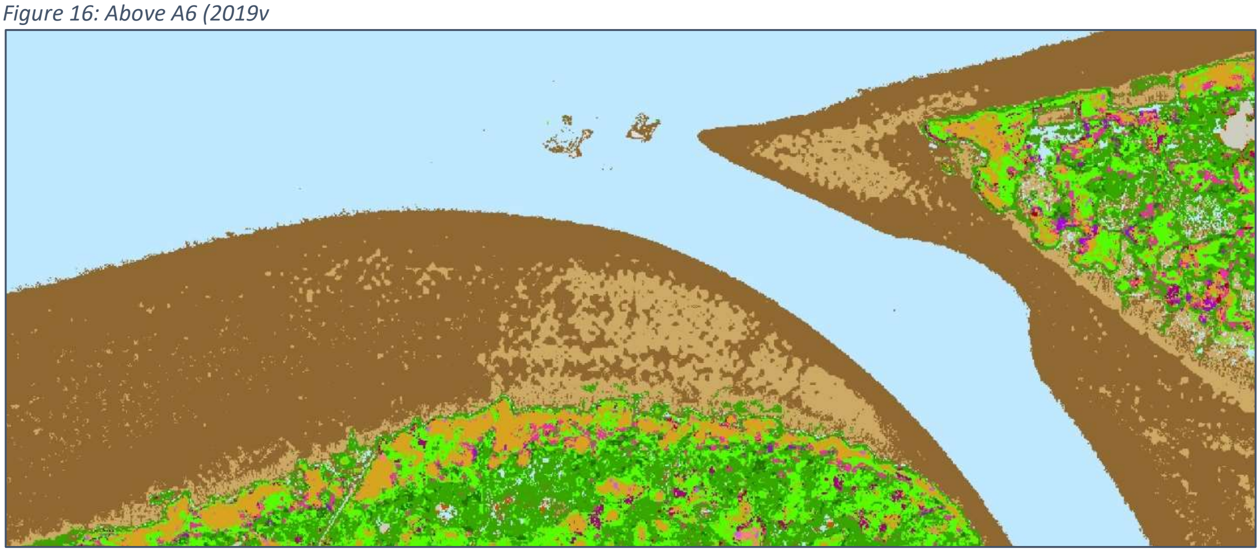
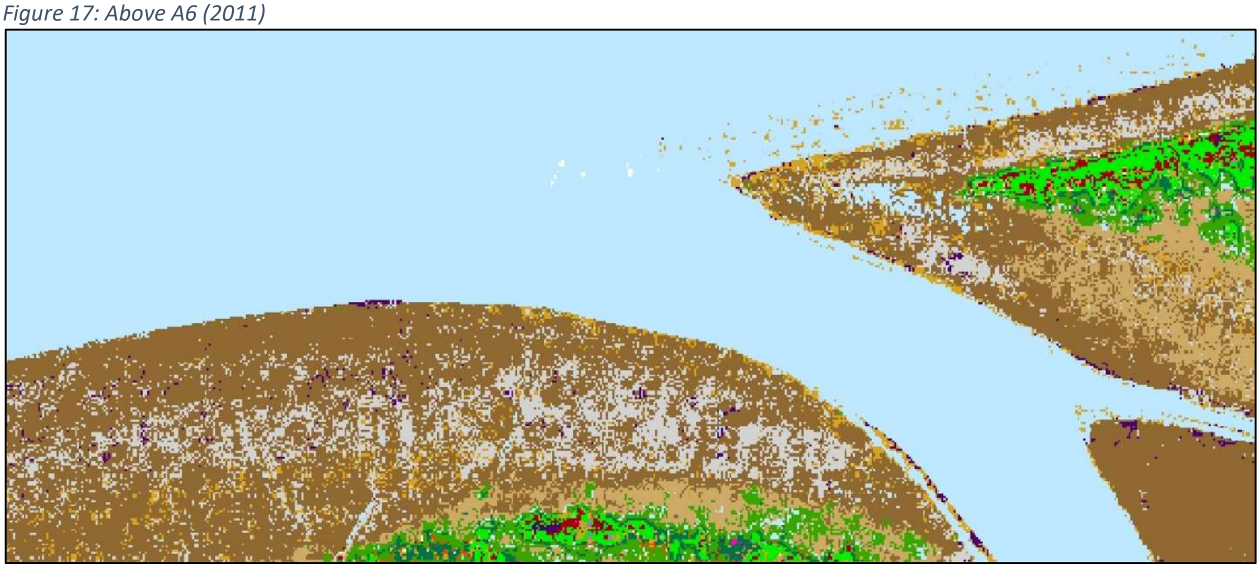


Figure 17: Above A6 (2011)



E9/E8A

Figure 18: E9/E8A (2019)

At the time of the first HEMP study, E9 and E8A had still not been opened to tidal action (although work had begun). In 2019, there has been significant floral colonization, dominantly Pickleweed, within E8A, where there are dense 'mats' of Pickleweed with patches of Spartina, emanating out from the channels. In some places these appear to be dense enough to 'fill-in' large sections of mudflat between channels. Pickleweed (and some Spartina) also appears to be actively colonizing the mudflats in E9, although it is significantly less dense when compared to E8A. Pickleweed is generally more dispersed in E9 although it appears to potentially be forming into denser mats, especially in the south-central part of the pond.

Mt Eden Creek Marsh and North Creek Marsh

Pickleweed has colonized into dense thick mats within the central Baumberg tract (i.e. North Creek Marsh). There are also significant patches of Cordgrass, both dispersed and in denser stands, often adjacent to pickleweed. However, the southern area of North Creek Marsh, as well as most of Mt Eden Creek Marsh, are still dominantly mudflats, with some significant dispersed patches of pickleweed, mostly found forming channels within the mudflat.

Figure 19: Baumberg (2019)

Figure 20: Baumberg (2011)

2.6 *Results – Selected Marshes*

Bair Island

Figure 22: Bair Island (2019)

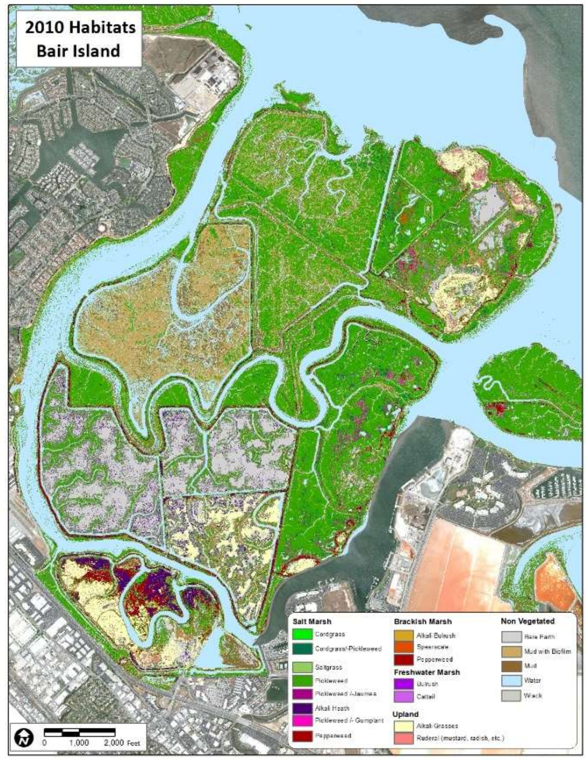


Figure 21: Bair Island (2010)

Much like 2011, the western side of Middle Bair is still a giant mudflat but some Pickleweed and Cordgrass colonizing mostly along channels on the western and south-central sides of the island. Biofilm appears to be distributed throughout. In Outer Bair, the southwestern part of the Island, just above Corkscrew slough is still mostly a mudflat, although Pickleweed and Spartina have colonized along the channel formed and emanating out of the levee breach. On the surface, the rest of middle and outer Bair both appear to be very similar to 2011, with some possible exceptions. In the marsh on the eastern side of middle Bair, the map shows less Pepperweed. However, significant patches of other ruderal vegetation were identified in the field and mapped in a portion of these locations (including at least one large patch of Sea Lavender). Inner Bair had begun to be breached in 2011 and by 2019 most of the island is a mudflat, once again dominated by biofilm, with Pickleweed in some locations including the mounds in the central part of the island. Pickleweed can also be found in denser mats and colonizing along with Cordgrass in channels on the eastern most side of Inner Bair. Adjacent to these channels are also a number of large stands of Gumplant.

Faber-Laumeister

The Faber-Laumeister marsh continue to contain significant patches of high marsh species like Gumplant and Alkali Heath throughout the marsh plain and along channels. In the southern tract, there appears to be a significant amount of Alkali Bulrush, which did not appear in any significant stands on the 2009-11 maps at this location. This presence of Alkali Bulrush here in dense thick stands proves some further evidence for a potential increase in brackish marsh and small decrease in salt marsh in and around the

Alviso restoration area. However, it is unclear whether this potential shift is a general trend or alternatively could be normal interannual variability that has been noted elsewhere (John Bourgeoise, personal communication).

Figure 24: Faber/Laumeister (2019)

Figure 23: Faber/Laumeister (2011)

Calavares Marsh

The mudflat on south side of *Calavares* marsh continues to be colonized by Cordgrass and to a lesser extent Pickleweed (probably *Salicornia europaea*) at its forward (and likely lowest) point, extending up to 40 meters or more from the edge of low marsh in 2011. This marsh also has a significant patch of *Alkali Bulrush* in the center, indicating a range of salinities.

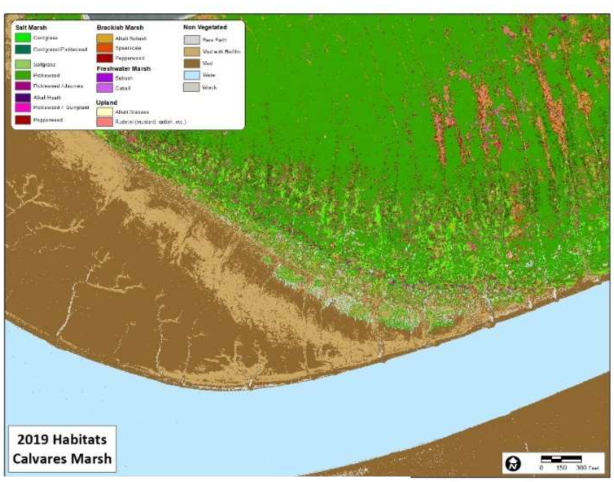


Figure 26: Calavares Marsh (2019)

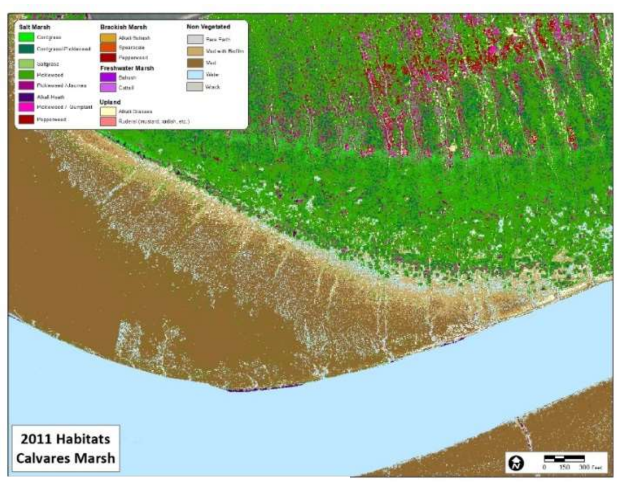


Figure 25: Calavares Marsh (2011)

2.7 Accuracy Assessment

Results of the accuracy assessment indicate that the overall accuracy of the final habitat datasets more than met our accuracy goal (of at least 70%) both at the dominant habitat alliance (82%) and association level (73%). Since we have significantly reduced the mapped vegetation associations, mostly sub-dominant associations of alkali bulrush, it is not surprising to see this increase in overall accuracy at the *association* level (accuracy for tidal marshes at this level was 61% in 2011, 66.8% in 2010; and 56% in 2009). However, some specific, habitat types did not map as well, notably Gumplant (67%) and Cordgrass (64%). Based on our error matrices (see below), it appears that Cordgrass is being mapped as Pickleweed about one third of the time. However, it is important to note that at 100% of the locations that were classified as Cordgrass in our error matrix, our field surveys identified these locations also as Cordgrass (this is the "Users Accuracy" column for Cordgrass (see Table 6). In our second year of mapping (2021), it is probable that we can improve this accuracy (in both 2019 and 2021) by refining our training sites (already underway). Certain habitats at the Alliance level also exceeded the accuracy of the overall model. These included Pickleweed (96%) and Alkali Bulrush (88%).

There are certain habitats, notably Spearscale, with only one ground truthing location where Spearscale was dominant. This is also true for Alkali Heath, which did not have any ground truthing locations where it was the dominant vegetative cover. However, for both of these habitats there were many surveys where these habitats were sub-dominant (and for Spearscale a few were co-dominant). For Alkali Heath, this usually meant less than or equal to 25% cover (and often less than 15%). At a vast majority of these locations, where either Spearscale or Alkali Heath were noted in our field surveys (but not dominant), they were also present in the classified result, indicating good model performance although not reaching a threshold for statistical validation. In 2021, we will consider using existing surveys where Spearscale or Alkali Heath were co- or sub-dominant, to supplement our validation dataset.

We have included below (see Table 6 and 7) the error matrices used for quantifying the statistical accuracies of our habitat classifications. The tables include accuracy assessments for habitats at both the habitat alliance and habitat association level. The association error matrix includes all the habitat classification using in our model, shown in all the maps, and in our preliminary datasets. As in the first mapping report (09-11), we found the best accuracy for our habitat classifications in 2019 at the Alliance level. Our improved overall accuracy is partially a result of not mapping many of the inaccurate vegetation associations (e.g. Alkali Bulrush /- Pickleweed) used during the first HEMP study. As a result there is a lot less difference between our Alliance (15 classes) and Association (19 classes) level error matrices. Significantly, we did not map any vegetation associations with Alkali Bulrush, since previous work indicated the low level of accuracy associated with mapping these associations. Although we mapped Spearscale (*Atriplex spp.*) only as an association with Alkali Bulrush in previous years, it appeared to have significantly wider distribution in 2019 than previous years and as a result it has been given its own habitat category. However, for some vegetation communities, including Pickleweed /-Gumplant, Pickleweed /- Jaumea, and Cordgrass /- Pickleweed, we continued to map these habitats at the association level because these were essential for differentiating low, "mid" high, and high salt marsh (see Table 1).

Table 6: Error Matrix (2019) - Alliance Level (15)

		Mapped (Classified) Data															
		Alkali Bulrush	Alkali Grasses	Alkali Heath	Bare Earth/Wrack	Cattail	Cordgrass	Freshwater Bulrush	Mud	Pepperweed	Pickleweed	Pickleweed /-Gumplant	Ruderal	Saltgrass	Spearscale	Water	TOTAL VISITED	PRODUCER' S ACCURACY (%)
Reference (Ground Truthed) Data	Alkali Bulrush	28									2	2					*32*	**88%**
	Alkali Grasses		1														*1*	**100%**
	Alkali Heath																-	***NA***
	Bare Earth/Wrack				4											1	*5*	**80%**
	Cattail	3				10											*13*	**77%**
	Cordgrass						14				8						*22*	**64%**
	Freshwater Bulrush	2				1		5									*8*	**63%**
	Mud								9								**9**	**100%**
	Pepperweed	2								11	1	1			1		**16**	**69%**
	Pickleweed	1									54	1					**56**	**96%**
	Pickleweed /-Gumplant										3	6					**9**	**67%**
	Ruderal										1		1				**2**	**50%**
	Saltgrass										1			3			**4**	**75%**
	Spearscale	1															*1*	**0%**
	Water	1														1	*2*	**50%**
	TOTAL MAPPED	*38*	*1*	-	*4*	*11*	*14*	*5*	*9*	*11*	*70*	*10*	*1*	*3*	*1*	*2*	**OVERALL ACCURACY**	
	USER"S ACCURACY (%)	**74%**	**100%**	***NA***	**100%**	**91%**	**100%**	**100%**	**100%**	**100%**	**77%**	**60%**	**100%**	**100%**	**0%**	**50%**	**82%**	

Observed Accuracy 0.82

Chance Accuracy 0.19

Kappa **0.78**

Table 7: Error Matrix (2019) - Association Level (19 Mapped Habitat Classifications)

		Mapped (Classified) Data																			
Reference (Ground Truthed) Data		Alkali Bulrush	Alkali Heath	Alkali Grasses	Bare Earth/Wrack	Cattail	Cordgrass	Cordgrass /- Pickleweed	Freshwater Bulrush	Freshwater Bulrush /- Cattails	Mud	Mud with Biofilm	Pepperweed	Pickleweed	Pickleweed /- Jaumea	Pickleweed /- Gumplant	Ruderal	Saltgrass	Spearscale	Water	TOTAL VISITED	PRODUCER' S ACCURACY (%)
	Alkali Bulrush	28												1	1	2					32	88%
	Alkali Heath																				-	NA
	Alkali Grasses			1																	1	100%
	Bare Earth/Wrack				4															1	5	80%
	Cattail	3				10															13	77%
	Cordgrass						4	6						1							11	36%
	Cordgrass /- Pickleweed							4						7							11	36%
	Freshwater Bulrush	2							2	3											7	29%
	Freshwater Bulrush /- Cattails					1															1	0%
	Mud										2	8									10	25%
	Mud with Biofilm											1									1	100%
	Pepperweed	2											11	1		1			1		16	69%
	Pickleweed	1												51		1					53	96%
	Pickleweed /- Jaumea													1	2						3	67%
	Pickleweed /- Gumplant													3		6					9	67%
	Ruderal													1			1				2	50%
	Saltgrass													1				3			4	75%
	Spearscale	1				1															1	0%
	Water	1																		1	2	50%
	TOTAL MAPPED	38	-	1	4	11	4	10	2	3	2	7	11	67	3	10	1	3	1	2	**OVERALL ACCURACY**	
	USER"S ACCURACY (%)	74%	NA	100%	100%	91%	100%	40%	100%	0%	100%	14%	100%	76%	67%	60%	100%	100%	0%	50%	**73%**	

Observed Accuracy	0.73
Chance Accuracy	0.17
Kappa	**0.68**

Section 3. Methods

All habitats and mudflats were derived using semi-automated classification of high-resolution satellite imagery. On June 8th, 2019, we obtained a multispectral satellite image from the Worldview-2 sensor captured just below Mean Lower Low Water (MLLW), providing full exposure of tidal mudflats, and limiting water within marshes. For mapping habitats, we repeated the methods used between 2009 and 2011 because they achieved accurate results, are easily replicable, and widely used. For mudflats we used methods developed in our 2016 pilot study (Fulfrost, B., 2017) using imagery from the Worldview-3 sensor. Both our methods for mapping vegetative (and non-vegetative) habitats and our separate process for mudflats, which rely on identifying and distinguishing habitats based on their unique spectral responses, are optimized when using multispectral imagery like that found in the Worldview-2 (or Worldview-3) sensor.

We began with the development and description of a set of ecologically relevant habitat types, which was completed in 2009-2011 (see Table 1 and Appendix 1). Our methodology for mapping the vegetative (and related abiotic) habitat types then consisted largely of six steps. First, we focused on the identifying days and timing of satellite image acquisition at Mean Lower Low Water (MLLW), QA/QC of delivered imagery, and preprocessing to prepare the imagery for analysis. Second, we conducted GPS based ground truthing for validation and later calibration of the model as well as for building our initial training sites (see 'Habitat Model' below). Third, we developed an initial spectral model of habitat types and ran a supervised classification of imagery using this model. Fourth, we would review model output both in GIS and in the field in order to calibrate model results. Fifth, our model review would lead to improvements to the spectral model and changes to our training sites, rerunning of the supervised classifications, resulting in new and improved model output. Sixth, we would repeat Steps #4 and #5 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 summarized in thi report.

3.1 Satellite Acquisition and Pre-Processing

Satellite Acquisition

In order to capture both the full extent of vegetation with tidal marsh as well as the full extent of tidal mudflats, our first requirements is to obtain imagery closest to Mean Lower Low Water (MLLW). The only satellite imagery that meets both our spatial (~ 1 meter) and spectral requirements (4 band or better) are those satellite available from MAXAR (formerly Digital Globe). These satellites pass over approximately at noon to minimize sun going while closest to 'nadir' (i.e. directly above the area of interest). As in previous years, we used the National Oceanographic and Atmospheric Associations (NOAA) tide prediction from their Redwood City tide gauge (ID 9414523) obtained online (see https://tidesandcurrents.noaa.gov/tide_predictions.html) to identify days between May and August where MLLW was closest to noon. This time period (May – August) is the best for mapping overall maximum vegetation growth. We identified six days within this period that met our tidal requirements. On June 8th, 2019, an image from the Worldview-2 satellite entirely free of cloud cover was acquired that was slightly under MLLW (see Table 8).

Wrodlview-2 is an 8-band multispectral sensor, that includes a 'coastal' blue band that is very useful for mapping shallow water mudflats. It also provides additional bands (yellow, red edge, 2 near infrared) that aid in vegetation discrimination. The combination of these additional bands, as well as mapping at MLLW between May and August, allow us to best discriminate the different species of concern and to map tidal mudflats at their maximum extent.

Table 8: Tide Values for June 8th, 2019

	Tide Values (relative to MLLW)	
Day and Time of Acquisition	Predicted (Redwood City)	Actual (Redwood City)
June 8th, 2019 @ 12:04pm	-0.53	-0.18

We received the imagery approximately two weeks after satellite flyover. We performed a thorough QA on the imagery, which came in three "snapshots", although the vast majority (> 96%) of the study area was contained in two of these snapshots. The Worldview-2 is bi-directional satellite that can rotate during acquisition to cover an area larger than its normal swath width. During this review process, we evaluated the images (all 8 bands) for any erroneous values (like negative values), image distortion, or significant geometric issues. In the pansharpening process, we noticed an issue regarding the alignment of the panchromatic and multispectral image for one of the snapshots. Although it took us some time to diagnose, the georeferencing file for one of the images contained the incorrect registration coordinates.

Atmospheric Correction

In order to remove impacts of the atmosphere on the reflected values of the features of concern (i.e. the marshes and mudflats) that are recorded at the satellite, the satellite provider (MAXAR) performed an atmospheric correction and delivered the final imagery (June 8th, 2019) as 11-bit ground reflectance values. We also received uncorrected imagery from MAXAR in case there we an issue with the correction or we wanted to compare other atmospheric correction methods. However, after comparing the two sets of images, the atmospheric correction performed by MAXAR met all our expectations, reducing sun glint, haze, and other atmospheric effects.

Pansharpening and Orthorectification

The imagery is delivered by the satellite provider as two separate sets of files: one panchromatic at half meter resolution; and one multispectral image at 1.8-meter resolution. We fused these images together in Erdas Imagine 2020 (using the HCS method designed specifically for Worldview-2) to produce a multispectral image of the study area at half meter resolution which we used to build our habitat model.

Although we received geocorrected imagery (which gave the delivered imagery a >= 10 meter spatial accuracy), we improved upon this and reduced any underlying terrain distortion by orthorectifying each of the 3 pansharpened snapshots (in Erdas Imagine 2020). We orthorectified all three snapshots using local ground control points obtained from high resolution aerial photography available as streaming web services from Alameda, Santa Clara, and San Mateo counties. For terrain correction, wea used a 2-meter Digital Elevation Model (DEM) downloaded from the USGS (Buffington, K.J., and Thorne, K.M., 2019). Although we did not test the final accuracy of the resulting orthorectification, we performed an additional QA/QC on the results comparing it to our source of higher accuracy (the high-resolution aerial imagery). We focused our improvements on the baylands and not the adjacent urban areas. Using a series of spot tests throughout the baylands for each image 'snapshot', we approximate the spatial accuracy of the final images (and model results) to be 1-2 meters (or less).

3.2 Habitat Model

Step 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 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 phenological variability of a given habitat both in the field and on the satellite image, the geographic distribution across the study area, and the variability of observed plant associations identified for a given habitat. 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. Once a set of training sites was finalized, they were converted to "Areas of Interest" in Erdas Imagine (Erdas Imagine 2020, Ver 16) which were subsequently used to generate the spectral signature files (.sig) used in the supervised classification of the imagery (see Step 2). These "spectral signature files" are the foundation for the habitat model discussed throughout this report. To optimize the performance of the habitat classifier our classifications focus on training sites found within tidal marsh and restored ponds open to tidal action.

Step 2: Supervised Classification

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 (not used).

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 parallelepiped 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. Nonparametric rules do not use statistics in classifying the pixels and are used only after the parametric rule has been applied (in a multilevel approach) and there is no one signature more likely to be correct.

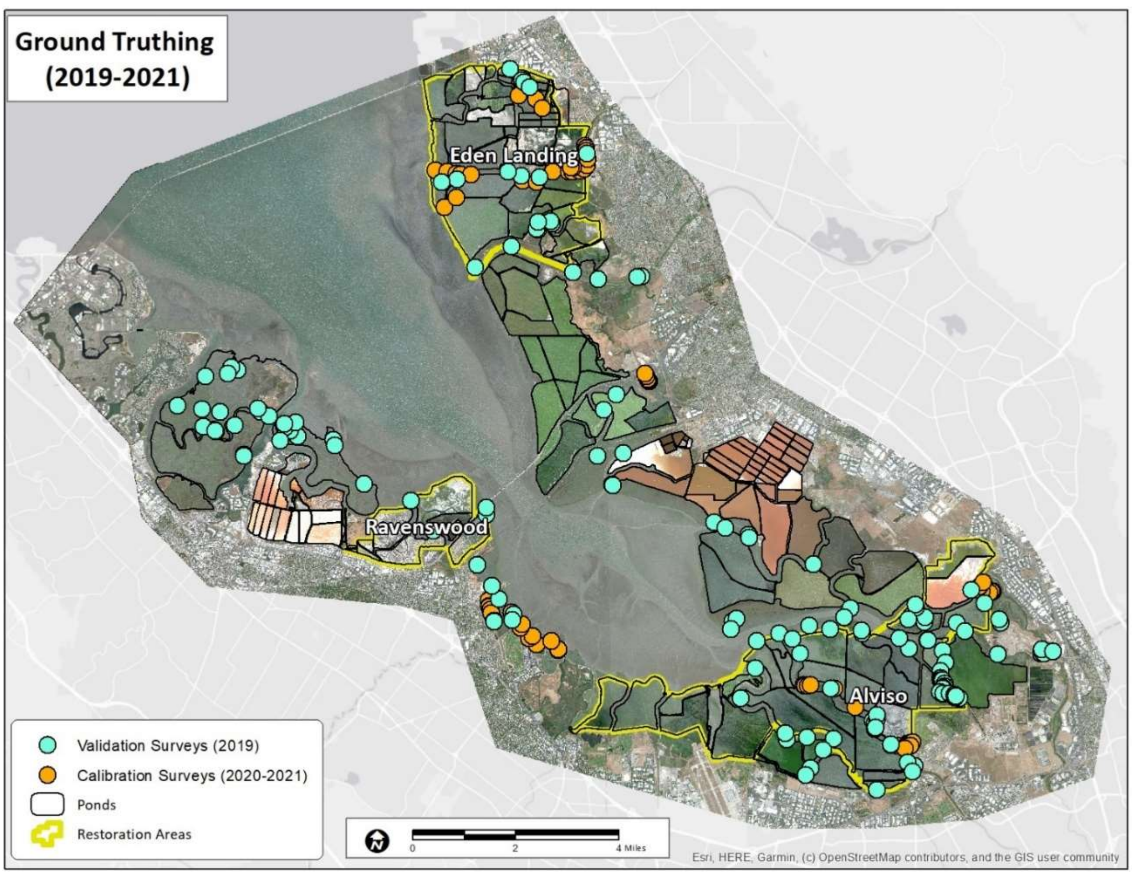
Step 3: Review of Model Output and Ground Truthing (calibration)

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 introduce 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.

3.3 Ground Truthing

We conducted approximately 295 in situ surveys (see Figure 27) of vegetative and non-vegetated habitats within the study area between 2019 and 2021. This ground truthing served several functions, including calibrating the edge (and presence of biofilm) of mudflat during satellite flyover (or similar tidal days); generating training sites for our habitat types; assisting with the evaluation and improvement of model results (calibration); and assessing the accuracy of final model results (validation). We conducted ocular surveys of vegetation and abiotic habitats using the Rapid Assessment/Releve methods promulgated by the California Native Plant Society (CNPS, 2019) and used in the Manual of California Vegetation. The 'standard' survey we use for validation is to navigate to a survey point with a sub meter mapping grade GPS (Trimble ProXT or GeoXT) and record the dominant, co-dominant and subdominant vegetation species (or abiotic habitat) within a 20-meter radius. In addition to species, our survey forms include a significant amount of other information (e.g. percent

Figure 27: Ground Truthing (2019-2021)



cover, pattern, and shape) to aid in interpretation, including assigning each survey points a habitat category (e.g. “Pickleweed /- Gumplant”).

Validation

We created a stratified random sample of 200 survey points to be used for our statistic validation of our final model classification. Points were stratified by the relative area of salt, brackish and freshwater marshes (see Table 9). We used a modified version of SFEI’s Eco Atlas, developed for the previous habitat mapping project (09-11), for our habitat stratification. Although we met our desired sample for brackish and freshwater marshes, we did not get to all the salt marsh survey locations. This was least at partially due to COVID restrictions in 2020 when we had hoped to supplement any missing surveys for 2019. Since we are only allowed into the marsh starting mid-July, a proportion of our validation points are from levees, boardwalks, or boat.

Table 9: Proportion of Validation Points by Habitat Type

Habitat Type	# of surveys completed	# of surveys in sample
Salt Marsh	**91**	*149*
Brackish Marsh	**49**	*34*
Freshwater Marsh	**21**	*17*
Upland	**3**	-
Non-Vegetated	**16**	-
Total	**180**	*200*

Our habitat model focuses on tidal marshes to ensure highest accuracy, and subsequently our validation surveys also focused on these locations, including fringe marshes and restored ponds. We continue to see that in muted marshes, which often have a more complex mix of vegetation and salinity, as well as more ruderal intrusion, the model results are not as consistent or as accurate. To optimize the performance of the habitat classifier our classifications focus on training sites found within tidal marsh and restored ponds open to tidal action.

We created standard error matrices for habitats at both the Alliance and Association level. These matrices (see Table 6 and 7) allow us to evaluate the statistical accuracy of the classified results by comparing habitats obtained from our ground truthing with habitats classified by our model. Matrices calculate a number of values that can be used to assess the accuracy of the model (see Appendix 2), including the *Kappa* statistic. In evaluating our model results, we focus on overall accuracy, which tells us how well the classified results matched our ground truthing for all habitats; “producers” accuracy for each habitat, which tells us how well our classified results matched our ground truthing for a particular habitat; “user's” accuracy, which essentially tells us how often the class on the map will actually be present on the ground, and the *Kappa* statistic. Kappa essentially evaluates how well the classification performed as compared to just randomly assigning values, i.e. did the classification do better than random. Values close to 1 indicate that the classification is significantly better than random.

Calibration
In addition to our field surveys used for model validation, we visited approximately 115 additional locations throughout the study area in 2020 and 2021 (including the Palo Alto baylands, Faber/Laumeister, Alviso slough, Coyote Creek lagoon, Baumberg, Old Alameda Flood Control Channel, levees around E9/E8A, and La Riviere marsh) to 'calibrate' how well out model was doing as part of an iterative process of improving the model. These locations were also surveyed using a mapping grade sub meter GPS (Trimble GeoXT or Trimble Yuma) but not all locations included surveys of a 20-meter radius. At some locations, only basic species and habitats information was acquired, by walking the length of features as lines or locating small patches of specific vegetation as points or polygons. Some of these locations were also used as training sites for our supervised classification. Since most of our ground truthing was curtailed in 2020, we obtained most of these surveys in 2021. All of our calibration occurred before we formally allowed into the marsh based on our Special Use Permit (SUP) from the USWFS. As a result, all of calibration was taken from a levee, boardwalk or by boat.

3.4 Mudflat Model

In 2016 (Fulfrost 2017), we developed techniques designed to map the extent and distribution of tidal mudflats under various tidal conditions. We applied these same methods to the 2019 imagery.

Step #1: Ground Truthing
To provide in situ measures of mudflat edge to calibrate with the edge of mudflat from our model, we visited 5 locations (including the mouth of Coyote Creek, the mudflat at the mouth of Newark slough, and the mudflats within A19) with a sub meter mapping grade GPS (Trimble ProXT or GeoXT) and walked the 'water line' at the approximate time of satellite overpass (on June 8th, 2019) as well as on similar tidal days. The ground truthing was primarily used to qualitatively assess (i.e. calibrate) the model's ability to capture the presence of mudflat, the presence of biofilm on mudflat (used in the habitat model) and verifying the "edge" (or full extent) of mudflat. The ground truthing surveys also allowed us to better evaluate how good different image processing techniques were at identifying and/or differentiating various "types" of mudflats based on the presence of biofilm, % water coverage, water depth, % exposure, and water "sheen" (as a proxy for soil moisture).

A variety of factors at time of image acquisition can influence the precision of our image analysis techniques to map the full extent of mudflat and specifically map the "edge" of mudflat, defined for this study as MLLW. These factors include (but are not limited to): tide level, wind waves, water turbidity, barometric pressure, mud flat slope, and water depth. We used a combination of spectral image processing techniques to derive and calibrate our final mudflat extent and distribution (Steps #2-4).

Step #2: Unsupervised Classification
We ran our unsupervised classification with 30 (and 50 for comparison) classes using a variety of band combinations (including all bands) of the 8 bands available on Worldview-2. In the end we used the 3 band "mud flat composite" (near infrared, yellow and coastal blue bands). The unsupervised classification (ISO cluster) delineated mud flats cleanly from adjacent marshes and other land cover features. Although the focus of our work was on mudflat extent, the unsupervised classification also appears to do a good job at differentiating a variety of mudflat "types" that likely relate to geomorphology, moisture or ponding water, and the presence of biofilm. We selected the classes most

associated with mudflats by comparing the results to imagery itself, the NDWI (see Step #3), and the zero-contour derived from the MSAVI2 band index (used as a proxy for the MLLW).

Step #3: Normalized Difference Water Index (NDWI)

The Normalized Difference Water Index (NDWI), which is a ratio of the Green to Near Infrared bands, has shown to be very good at differentiating the land/water interface (Baiocchi, V., et al, 2012; Ji, L., Zhang, L., & Wylie, B., 2009; Ho, L. T. K., Umitsu, M., & Yamaguchi, Y., 2010; McFeeters, S. K., 1996).

$$\text{NDWI} = \frac{(Xgreen - Xnir)}{(Xgreen + Xnir)}$$

Index values between -1 to 0 depict land while values between 0 and 1 depict water. The NDWI demonstrated the best ability to identify the possible presence of “shallow water” mudflat from exposed mudflat, especially in areas with very shallow slopes (e.g. Eden Landing). We utilized thresholds based on previous research that explored the use of NDWI (and MNDWI) to delineate open water and coastal water features (Ji, L., et al, 2009). We used the index (index values are in parenthesis) to differentiate four types of features:

- “land” (< -0.3) - which directly adjacent to mudflats was marsh.
- “mudflat“(-0.3 to 0) - which seemed to delineate exposed mudflat.
- “shallow water” (0 to 0.3) - which might indicate possible shallow water mudflat.
- “water” (> 0.3) - which indicates deeper water

Step #4: Modified Soil Adjust Vegetation Index (MSAVI2)

$$MSAVI2 = \frac{\left(2*NIR+1-\sqrt{(2*NIR+1)^2-8*(NIR-RED)}\right)}{2}$$

The Modified Soil and Vegetation Index (we used the second revision or “MSAVI2”) adds an additional measure for us to calibrate the edge of mudflat under shallow water. In our pilot study (Fulfrost 2017), we found that the MSAVI2 zero contour corresponded very well with the MLLW line (as long as the image was captured close to MLLW). We used the results of MSAVI2, and specifically the zero contour, to assist in determining what classes from the unsupervised classification best represented the edge of the mudflat. MSAVI2 is well suited to mapping mudflat since it can be applied to areas of high soil surface exposure like mudflats to identify a change from “soil” (or mudflat) to “no soil” (or water) even in shallow environments.

Step #5: Final Mudflats

We calculated the final mudflat extent and distribution using a combination of our unsupervised classification and NDWI. After the results of both of these techniques had both been evaluated and calibrated to the MSAVI2 (or MLLW) line, they were combined so to maximize the usefulness of each approach. Locations were considered to be "mudflat" if they met either one of the following two criteria:

1. identified as "mudflat" in *both* the (a) unsupervised classification *and* (b) the NDWI; or
2. identified as both (a) "shallow water" in the NDWI *and* identified as (b) "mudflats" in the unsupervised classification.

After reviewing locations that were identified from the NDWI as "shallow water", it was not clear that all of these areas were actually shallow water *mudflats*. As a result, we only included areas of "shallow water" that were *also* identified as mudflats by the unsupervised classification. We used a mask that was derived from SFEI's Bay Area Aquatic Resource Inventory (BAARI) to calculate acreages of mudflats that were directly exposed to the bay ("bay/sloughs") and those within wetlands or restored ponds ("pond/wetland").

Limitations and Uncertainty

The methods serve as a cost-effective means for mapping and tracking to changes to mudflats, with some limitations. Although we have developed a relatively robust mechanism to map mudflat extent and distribution, we have not yet quantified the degree of spatial or temporal variability corresponding to the mapped presence of mud flats at a given location or quantified the degree of uncertainty in our modeling approach. Quantifying the range of "normal" variability of seasonal and interannual variability of mudflat extent (and "type") would improve our understanding of changes to those mudflats. Mean Lower Low Water (MLLW) serves as a convenient and documented method for delineating the edge of mudflats (Jaffee, B. & Foxgrover, A., 2006). However, using MLLW can introduce mitigating factors when calculating changes to mudflats due to possible spatial and temporal variability that are inherent in tidal datums and uncertainties in various method used to map the MLLW line (Jaffee, B. & Foxgrover, A., 2006). The largest uncertainties appear to occur in areas of very gradual slopes with very shallow water, where there is not as distinct boundary (e.g. Eden Landing). Consensus should be obtained whether extremely shallow water mudflats are intertidal or subtidal (or perhaps somewhere shifting between the two).

Section 4. Conclusions and Next Steps

Although our results for 2019 are preliminary, the picture of change(s) south of the Dumbarton bridge has some clear trends. Mudflats fully exposed to tidal action remain relatively unchanged since 2016, although this does not preclude localized areas of mudflat accretion or erosion. At the same time, the acreage of mudflats within restored ponds has decreased since 2016. This decrease is to be expected within ponds where there has been significant floral colonization. Overall, differences in the extent and distribution of mudflats could at least partially be due to interannual differences not necessarily representing long term trends (of accretion or erosion).

Since 2011, there appears to be an overall growth of Alkali Bulrush, especially in and around Alviso. On a number of fringe marshes (not within restored ponds), including Calavares marsh and above pond A6, there has been growth of low marsh (up to 40 meters in some locations) onto the adjacent mudflats. In Alviso slough, the Pickleweed marsh has grown up to eight meters onto the narrow mudflat that is adjacent the fringe marsh within the slough. At Ogilvie Island, Pickleweed along with Cordgrass, has completely colonized the eastern portion of Ogilvie since 2009, and Alkali Bulrush has also grown and has begun to compete with the salt marsh on the south western part of the island.

Within the restored ponds, there has been significant floral colonization in A21 and A20 (mostly Alkali Bulrush with Pickleweed and Cordgrass), North Creek marsh (Pickleweed and Cordgrass), as well as E8A (Pickleweed and Cordgrass), and to a lesser degree E9. In other restored ponds, notably A6, A17, and Mt Eden Creek marsh, mudflats have developed, with some floral colonization of Pickleweed and Cordgrass. Interestingly, biofilm is dominant and evenly distributed on mudflats that have developed within the restored ponds.

Overall, the preliminary results show some identifiable trends over the entire study area. However, as we “zoom in” to the restoration unit (Alviso, Eden Landing, and Ravenswood) and to specific restored ponds and marshes, the trends are even more clear, and our confidence in these trends is also greater. At the broader geographic scale, there is more tidal, faunal/phenological, and even image processing variability. At the finer geographic scales, there is significantly less environmental variability, and it is easier to control for data processing issues that might influence how results are presented.

As we finalize this report, we have already begun working on “Year Two” (2021). Once we have competed mapping the study area for our second year, we will use that knowledge to make any necessary modifications to our first year (2019) results. We will also clean up any outstanding issues with the 2009-2011 datasets. The final datasets from all years will be used to calculate acreages and locations of change (by habitat) between HEMP 2.0 (2019, 2021) and HEMP 1.0 (2009-11). We will also use the data from the Invasive Spartina Project (ISP) to try to differentiate native and invasive cordgrass. Our final report, with all datasets and imagery from 2019 and 2021, will be completed in the summer of 2022.

REFERENCES

Baiocchi, V., Brigante, R., Dominici, D., & Radicioni, F. (2012). Coastline detection using high resolution multispectral satellite images. In *Proc. FIG Working Week* (pp. 263-276).

Buffington, K.J., and Thorne, K.M. (2019). *LEAN-corrected San Francisco Bay digital elevation model, 2018*: U.S. Geological Survey data release, https://doi.org/10.5066/P97J9GU8.

California Native Plant Society (CNPS). (2019). "*CDFW-CNPS Protocol for the Combined Vegetation Rapid Assessment and Relevé Field Form".* https://www.cnps.org/plant-science/field-protocols-guidelines

Congalton, Russel G. (1991). *"A Review of Assessing the Accuracy of Classifications of Remotely Sensed Data".* Remote Sensing of Environment. 37:35-46

Fulfrost, B., Thompson, D., Archbald, G., Loy, C., & Fourt, W. (2012). "*Habitat Evolution Mapping Project Final Report"*. South Bay Salt Pond Restoration Project. Brian Fulfrost and Associates. Oakland, California, USA.

Fulfrost, B. (2017). "*Incorporating the Coastal Blue Band into a Remote Sensing Toolkit for Mapping Intertidal Mudflats in South SF Bay: A White Paper"*. San Francisco Bay Joint Venture. Brian Fulfrost and Associates. Oakland, California, USA. https://bfa.egnyte.com/dl/Um8tmbhuzl/

Garfield N, Madden K, Haag S, Shull S, Upchurch S, and N. Herold. (2009). "*Mapping Land Use and Habitat Change in the NERRS: Standard Operating Procedures"*. A document produced by the Habitat and Mapping Change Technical Committee for the National Estuarine Research Reserve System. Estuarine Reserves Division, Office of Ocean, and Coastal Resource Management, National Oceanic and Atmospheric Administration, US Department of Commerce, Silver Spring, MD.

Ho, L. T. K., Umitsu, M., & Yamaguchi, Y. (2010). Flood hazard mapping by satellite images and SRTM DEM in the Vu Gia–Thu Bon alluvial plain, Central Vietnam. *International archives of the photogrammetry, remote sensing and spatial information science*, *38*(Part 8), 275-280.

Jaffe, B., & Foxgrover, A. (2006). *A history of intertidal flat area in South San Francisco Bay, California: 1858 to 2005* (No. 2006-1262). US Geological Survey.

Ji, L., Zhang, L., & Wylie, B. (2009). Analysis of dynamic thresholds for the normalized difference water index. *Photogrammetric Engineering & Remote Sensing*, *75*(11), 1307-1317.

Kuwae, T., Beninger, P. G., Decottignies, P., Mathot, K. J., Lund, D. R., & Elner, R. W. (2008). Biofilm grazing in a higher vertebrate: the western sandpiper, Calidris mauri. *Ecology*, *89*(3), 599-606.

McFeeters, S. K. (1996). The use of the Normalized Difference Water Index (NDWI) in the delineation of open water features. *International journal of remote sensing*, *17*(7), 1425-1432.

Sawyer, J.O., T. Keeler-Wolf, and J. M. Evens. (2009). "*A Manual of California Vegetation, Second Edition"*. California Native Plant Society (CNPS), Sacramento, CA. 1300 pp.

APPENDIX 1: Habitat Type Descriptions

Cordgrass (Spartina sp.) Herbaceous Alliance

California Cordgrass marsh (low marsh / MTL - MHW)

Spartina foliosa is dominant in the herbaceous layer with, Salicornia europaea, Bolboschoenus maritimus Schoenoplectus californicus & 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.

Membership Rules

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

Remarks

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.

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 (Sarcocornia pacifica *or* Salicornia europaea) Herbaceous alliance

Pickleweed mats (below MHW to above MHHW)
Annual pickleweed marsh (low marsh habitat/ MTL - MHW)

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 up to 1.5m; canopy is intermittent to continuous. 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 marshes, alkaline flats. The USFWS Wetland Inventory (1996 national list) recognizes Salicornia virginica and Salicornia europaea as OBL plants.

Elevation: 0.15-2.5m (perennial); 0.5 -1m (annual)

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

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, Frankenia Salina, 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. 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. Some evidence that this association occupies lower high marsh elevations.

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

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 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 GRST are FRSA, DISP, SAPA, LICA, TRMA, and ARSU (if present).

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., Agrostis avenacea, Cressa truxillensis, Distichlis spicata, Hordeum murinum, Lasthenia spp., Lepidium spp., Limonium californicum, Monathochloe littoralis, 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 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 DISP, GRST, SAPA, ARSU, LICA, TRMA, and upland transition species.

Saltgrass (Distichlis Spicata) Herbaceous Alliance

Saltgrass flats (high marsh/upland transitions)

Distichlis spicata is dominant or co-dominant in the herbaceous layer with Agrostis viridis, Ambrosia chamissonis, Anemopsis californica, Atriplex prostrata, Batis maritima, Bromus diandrus, Cotula coronpifolia, Eleocharis palustris, Frankenia salina, Hordeum brachyantherum, H. murinum, Jaumea carnosa, Juncus arcticus, J. cooperi, Leipdium latifolium, Leymus triticoides, Limonium californicum, Muhlenbergia asperifolia, Parapholis strigosa, Pascopyrum smithii, Poa secunda, Puccinellia nuttalliana, Sarcocornia pacifica, Sporobolus airoides, and Triglochin maritima. Emergent shrubs, such as Allenrolfea occidentalis, Atriplex spp., Ericameria albida, Ericameria nauseosa, Sarcobatus vermiculatus, 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 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 FRSA, GRST, SAPA, LICA, TRMA, and upland ecotone species.

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

Bolboschoenus maritimus was mapped as "Alkali Bulrush", to avoid differentiating between it and B. robustus. Usually mapped with ATTR, LELA, SAPA, FRSA, CORD, and TULE.

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

Cattail (Tyhpus angustifolia | latifolia) Herbaceous Alliance

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 wastewater, although there was a small amount of TYLA at the head of Newark Slough.

Spearscale (Atriplex triangluaris) Herbaceous Alliance

Atriplex triangluaris (now considered non-native) can form large stands where it can dominate especially the high marsh-upland transition. However, Atriplex triangular is often associated with Bolboschoenus maritimus and/or Lepidium Latifolium where is can be co dominant or sub dominant.

Habitats: Tidal brackish marshes. The USFWS Wetland Inventory (1996 national list) recognizes Atriplex triangluaris as an OBL plant.

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). 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.

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 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 "Ruderal" below for list).and locations mapped as Ruderal might also include Pepperweed.

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

Historic Tidal Marsh / Upland Transitional Habitat

In some areas the upland transition was 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 from 09-11).

Ruderal (*various*) Herbaceous Alliance
Peripheral halophytic disturbance community

This is a mostly invasive herbaceous habitats class that is essentially disturbance communities dominated by exotic species. We combined the following mapping classifications into a single 'Ruderal' category: Mustard (Brassica negra), Radish (Raphanus raphanistrum), Common Reed (Phragmites australis), Iceplant (Carpobrotus edulis), and Sea Lavender (Limonium ramosissimum). Abundant annual on levees, paths, disturbed soils above tide line. Although not directly mapped, this herbaceous allaince can also include 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 a series of ruderal, mostly invasive halophytic tolerant upland species, common to levee flanks, tops, and uplands, and combined these into one classification (ie. Ruderal). These plant communities are often referred to as "peripherial halophytes". In the first phase of the HEMP project, this habitats class was *mostly* mapping Mustard (Brassica spp) and therefore was called *Mustard*, although it likely included other peripheral halophytes.

Abiotic Habitat Types

Mudflats were mapped as "*Mud*" and 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).

Mudflats with Biofilm have been noted as an important characteristic of some mudflat, comprised of microphytic communities on the surface of mudflats, and have been shown as an important food resource for foraging birds (Kuwae, T., Beninger, P. G., 2008). For these reasons, it was included as a distinct habitat type in the 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). Dead or dried out vegetation can also map as wrack.

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.

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.

APPENDIX 2: Accuracy Statistics included in Error Matrices.

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)

(Adapted from Garfield et al 2009)