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1.0 INTRODUCTION

1.1 Purpose of McNabney Marsh Vegetation Mapping Project

The purpose of the McNabney Marsh vegetation mapping project is to classify and map the dominant vegetation types of the approximately 130-acre marsh Study Area over time. The targeted vegetation types for monitoring and mapping are Cattail (*Typha ssp*), Pickleweed (*Salicornia virginica*) and Perennial Pepperweed (*Lepidium latifolium*). Vegetation was mapped using aerial imagery and computerized spectral analysis, as was done first in 2005, then 2007. The results of this study are compared with results from 2007 (Tuxen-Bettman 2008). Advantages and limitations of spectral-analysis are described with regard to site-specific scale and management considerations.

1.2 Location of Study Area

McNabney Marsh is located east of the town of Martinez in Contra Costa County, California (Vine Hill quadrangle; T2N, R2W; part of the historic Martinez Land Grant). The northern portion of the property is defined by Waterfront Road and a portion by Waterbird Road. The north-western boundary is defined by Interstate 680 and the southwestern by Service Road, a restricted access road for the Mt View Sanitary Treatment Plant. The southern boundary is Arthur Rd. The eastern fenced boundary abuts East Bay Regional Parkland. The property boundary and local landmarks are shown in **Figure 1.**

1.3 Overview of McNabney Marsh Vegetation Mapping Project

McNabney Marsh (named in honor of a former Mt Diablo Audubon Society leader) is co-owned by East Bay Regional Park District (EBRPD) and the Mountain View Sanitary District (MVSD). McNabney Marsh is also part of the 198-acre EBRPD Waterbird Regional Preserve. It is co-managed by MVSD, EBRPD, Contra Costa County Mosquito and Vector Control District and California Department of Fish and Game. The Peyton Slough Advisory Committee reviews management actions and provides recommendations for future management.

McNabney Marsh is a “semi-natural” system, receiving approximately two million gallons per day of treated effluent from the MVSD treatment plant. This water enters via Peyton Slough from the constructed Moorhen Marsh, located west of Interstate 680. From McNabney Marsh, water re-enters Peyton Slough, then flows north into the Carquinez Straits.

McNabney Marsh has been the focus of considerable attention following a major oil spill from an adjacent refinery in 1988. Since, the marsh has undergone extensive rehabilitation and restoration to facilitate the return of important natural wetland and scenic resources. In addition, the area of Payton Slough to the north of McNabney Marsh was also recently altered by heavy metal remediation activities. A new slough alignment was established, heavy metal-contaminated sediments were removed where possible and remaining contaminants contained by filling in an old slough channel. Flood-gates were also installed between McNabney Marsh and Payton Slough to the north; these first operated for water-flow management in 2009.

The purpose of the 2005, 2007 and 2011 monitoring efforts is to detect changes in extent and composition of marsh vegetation in this dynamic wetland system. In addition, more-recent concerns about extent and spread of invasive Perennial Pepperweed brings attention to condition of associated upland vegetation.

2.0 METHODS

2.1 Aerial Imagery Acquisition and Preparation for Mapping

The 2007 imagery was captured in late-fall; though the previous investigator mentioned difficulty in discerning spectral differences between fall-senescent Cattail and grassland species, and suggested that imagery captured earlier in the year closer to peak productivity might mediate this, and yield better resolution of Pickleweed. In addition, Mountain View Sanitation District desired to maximize likelihood of recording Perennial Pepperweed, which peaks earlier in the summer. Our aerial photography was acquired on June 20th, 2011 by Radman Aerial Surveys of Sacramento, CA. Two different photos were exposed; one using color infrared (IR) film, the other using regular color positive film. Photos were taken with 9"x9" film using a focal length of 6 inches. Photos were processed by an independent company, and then scanned by Radman at 1,200 dots per inch and delivered to us on a DVD. Pixel resolution of the raw images was approximately 6 inches.

2.2 Image Rectification

Both the IR and color images were rectified (mathematically adjusted to ground control points) for this project. Since a major objective of this project is to compare up-to-date mapping with a previous effort from 2007, and because the 2007 effort collected many high-precision GPS ground control points, we used imagery from the 2007 vegetation mapping project as our primary control for rectification of the 2011 aerial photos. Additionally, the field-botany crew for this project collected 6 new sub-meter accuracy GPS points at features readily viewable on the imagery, including light poles, a gate, fence corners, a bridge over the pipeline at the north end of the marsh, and an interpretive sign at a parking area (see **Figure 2**).

We used ESRI ArcView GIS v10 to rectify both true color and IR 2011 images, applying a second-order polynomial transformation. For the IR image we used 11 control points evenly distributed around the photos. Calculated RMS error (variance between selected control points) was 1.167 pixels - or 7 inches. The 2011 color image was rectified to the 2007 IR imagery and to the same GPS control. The color photo photogrammetry used 10 control points and achieved an RMS error of 1.2 pixels - about 7.2 inches. The projection chosen for image georectification was Universal Transverse Mercator (UTM), Zone 10, with North American Datum 1983 (NAD83).

2.3 Classification and Mapping of Vegetation

2.3.1 Field Data Collection

John Dittes and Josephine Guardino of *Dittes and Guardino Consulting* conducted field surveys on the McNabney Marsh site on July 2, 3 and 4th, 2011. The objective of these surveys was to collect data for characterization of vegetation, for spectral training of the computer program, and for accuracy assessment of the final vegetation mapping effort.

A total of 255 vegetation sampling points were recorded in the field (see **Figure 3**). These were not randomly located; rather they were chosen to represent the spectrum of vegetation types present. Homogonous stands of target vegetation, as well as mixes of varying proportions and patch sizes were subjectively chosen to aid in supervised classification and assessment of detection-sensitivity of spectral analysis.

At each sampling point the absolute percent cover of each species, of bare ground and thatch was visually estimated within a plot measuring one-meter in radius. Photographs of vegetation were also taken at each sample point. The camera was held at chest level and pointed straight down to document the vegetation/substrate in the sample plot. In addition, a number of oblique surface-level photographs were taken at select sites to document the physical condition, ecological setting and spectral characteristics of various vegetation types. All surface level photos were taken with a Cannon Power Shot SD850 IS zoom digital camera (8mp) with an AF Zoom 5.8-23.2mm, 1:2.8-5.5 lens. Photographs were taken with the Super Fine setting.

GPS points were recorded at sub-meter accuracy with a Trimble Geo XT Global Positioning System (GPS) surveying unit. All data and surface-level photo numbers were entered into an Excel spreadsheet and linked to the GIS data set.

In addition to plot-based sample points, numerous representative examples of each vegetation type were mapped by hand in the field, directly onto enlarged color and infra-red aerial photographs. Along with the plot-based data, these reference areas were also used in spectral-training of the computer program.

2.3.2 Vegetation Classification Using Plot-Based Data

Vegetation was classified from field data for 2011 mapping, based on categories developed for the two previous mapping efforts (Karin Tuxen-Bettman 2005, 2007). Modifications were made to these previous classes to reflect variability observed in the field during the July 2011 field work. Additional vegetation types were included in 2011 to account for types with similar spectral signatures on the June 2011 aerial photos, and for a few vegetation types that are of potential management interest. Each of the 42 plant species identified within plots was subsequently assigned to one of 12 vegetation cover classes, based on microhabitat (topography/moisture) and associated plant species. Table-

1 summarizes vegetation classes used for the 2011 mapping effort, and provides a comparison of these with classes used in 2007.

Table 1. *Comparison of vegetation classification categories from 2007 and 2011 mapping efforts; as in 2007, the "Grass Community" includes the vast majority of non-target species*

Class (2011)	Plant Community (2011)	Class (2007)	Plant Community (2007)
1	Common Reed (*Phragmites australis*)	n/a	Not mapped in 2007; was included in "2-Cattail" and "6-Common Rush"
2	Saltgrass (*Distichlis spicata*)	4	Saltgrass
3	Spearscale/Inundated Mud Flat (*Atriplex triangularis*)	3	Spearscale
4	Algae/Duckweed (*Lemna* sp.)	n/a	Not mapped in 2007; was included in "9-Water"
5	Black Mustard (*Brassica nigra*)	n/a	Not mapped in 2007; was included in "5-Grass Community"
6	Creeping Rye (*Leymus triticoides*)	n/a	Not mapped in 2007; was included in "5-Grass Community"
7*	Grass Community (Miscellaneous)	5	Grass Community (Miscellaneous)
8	Cattail (*Typha* spp.)	2	Cattail
9	Bulrush (*Scirpus acutus*)	6	Common Rush
10	Perennial Pepperweed (*Lepidium latifolium*)	7	Perennial Pepperweed
11	Mudflat (Non-vegetated)	8, 9	Bare, non-vegetated
12	Common Pickleweed (*Salicornia virginica*)	1	Common Pickleweed
Non-vegetated	Non-vegetated (Open Water, Roads, Misc.)	8,9	Bare, Water (Non-vegetated)

2.3.3 Supervised Classification of Aerial Imagery

The 2007 vegetation mapping efforts used a computer program to segment aerial imagery into homogenous patches of similar pixel values. These patches were assigned to vegetation classes based on 40 'training sites' that were subjectively chosen to represent dominant, observed cover types. Our methodology differed from 2007; the 2011 imagery had sufficient spectral contrast/resolution, and we were familiar enough with the vegetation, to allow hand-mapping of representative vegetation polygons on enlarged aerials in the field. These polygons were used to digitally-delineate groups of pixels representative of specific vegetation types (see **Table-2**). We ran approximately 45 iterations of a maximum likelihood classification by which the computer searched the aerial imagery for pixels matching the spectral signature of our training polygons. For each run, we also compared the outputs of the computer model with classes assigned to our 317 one-meter radius field plots. Spectral signature selection was fine-tuned and the model re-run until no longer able to improve accuracy of classification.

Table 2. *Training Class Categories and Pixels used for 2011 spectral training*

Training Class Category	**Number of Pixels Sampled**
Algae/Duckweed (*Lemna* sp.)	2511
Black Mustard (*Brassica nigra*)	740
Broad-leaved Peppergrass (*Lepidium latifolium*)	549
Cattail (*Typha angustifolia, T. latifolia*)	7427
Common Reed (*Phragmites australis*)	5534
Creeping Rye Grass (*Leymus triticoides*)	215
Hardstem Bulrush/Tule (*Scirpus acutus*)	109
Mudflat/Barren	1808
Non-vegetated (Open Water, Roads, Misc.)	4159
Saltgrass (*Distichlis spicata*)	2044
Spearscale (*Atriplex triangularis*)/Inundated Mud Flat	9953
"Grass Community"	8220
Pickleweed (*Salicornia Virginica*)	6336

We did not use the Normalized Difference Vegetation Index (NDVI) to map non-vegetated areas as was done in 2007. Instead, we compared an NDVI map to our aerial image and determined that we could achieve higher contrast and clarity for selecting non-vegetated areas by performing a histogram stretch on the IR photo. The stretched image was used to map pavement, standing water, and bare ground, and then these areas were masked out of the imagery that was used for the remaining analysis.

Image classification was performed using ESRI ArcGIS v10, with the Spatial Analyst Extension. We used the 'Maximum Likelihood Classification' module, with a 'Reject Fraction of 0.0, and a-priory rating of 'EQUAL'. The table below shows the classes that were used for spectral-training polygons, and the number of pixels in each training category. Note that there are more classes used for training than what were included in final mapping classes, owing to further aggregation of sub-types (e.g., cattail-1 and cattail-2 are lumped into final cattail category). Due to problems with shadows in fine detail of the 6 inch imagery, we down-sampled the imagery to represent one square-foot on the ground.

After each pixel was assigned vegetation class values on the aerial photograph, we needed to simplify the mapping, as it had a "salt and pepper" appearance. As mentioned in the 2007 report, this is a common problem when using high-resolution imagery. The "Majority Filter" in ArcGIS Spatial Analyst was applied to simplify the mapped edges. This filter assesses the relationship of each pixel with its neighbors, and assigns single pixels the majority value of the eight closest neighbors; it is an effective way to 'despeckle' a continuous grid of data values without compromising the integrity of the overall image. This is analogous to a “Dust and Scratches” filter in a photo editing program.

2.3.4 Manual Changes to the Automated Vegetation Classification

Our earlier-timed, June aerial imagery allowed for better-separation of cattail thatch from upland grassland than the October 2007 aerial image, as suggested by the previous investigator. It was also well-timed for capturing Perennial Pepperweed (see Discussion). This earlier timing though, complicated separation of Common Pickleweed from its surrounding associates (see Results and Discussion). Despite numerous iterations of model run and refinement, it was impossible to automate the extraction of *Salicornia* from surrounding vegetation with similar spectral characteristics. Consequently, we used our field-plot data, surface-level photos, and observed distribution patterns/habitat association, e.g., near mean high-water mark and below upland grassland/herbland, to manually map Common Pickleweed-dominated vegetation onto the color photograph, using the infrared image as reference. John Dittes (Senior Botanist) manually digitized 709 unique polygons containing *Salicornia* using ESRI ArcMap software. It is important to note that there is likely more Pickleweed present than was digitized, as only what was discernable on the aerial, and/or what was visited on the ground was mapped (see Discussion and Recommendations).

2.3.5 Accuracy assessment

Our mapping accuracy assessment was based on species cover data collected from the 317 vegetation plots in 2011. For each plot, the cover value of the dominant species was used to assign the plot to one of the 12 vegetation classes (see **Table 1**). Cover values of target vegetation in class-assigned plots were used to compare with computer-generated mapping results. As in the 2007 survey, Saltgrass and upland/grass classes were combined for the accuracy assessment. Also, we removed *Frankenia salina* from the assessment, as our field survey indicated that this species overlaps with too many of the other classes, including Common Pickleweed.

Our accuracy assessment methodology is similar to the 2007 effort. As before, "Omission Error” (or user’s accuracy) and “Commission Error” (or producer’s accuracy) are depicted for each class. “Omission Error” is the probability that a sample from the map actually matches the reference data class. “Commission Error” is the probability that a reference data-class will be correctly mapped (Karin Tuxen-Bettman 2007).

3.0 RESULTS

3.1 Vegetation Map

A vegetation map showing the 2011-mapped classes, including the three target types, is depicted in **Figure 4**; mapped acreages of each class are summarized in **Table 3**. As indicated, a total of 12.72 acres of Cattail Marsh, 2.12 acres of Common Pickleweed and 2.05 acres of Perennial Pepperweed were mapped, along with the other non-target types (see **Section 3.3** for Accuracy Assessment).

Table 3. *Mapped acreages of vegetation classes at McNabney Marsh in 2011; three target classes are in bold-face type*

Vegetation Class	**2005 (acres)**	**2007 (acres)**	**2011 (acres)**
Common Reed (*Phragmites australis*)	--	--	3.636718
Saltgrass (*Distichlis spicata*)	0.36	21.34	3.36116
Spearscale/Inundated Mud Flat (*Atriplex triangularis*)	53.11	10.54	22.48586
Algae/Duckweed (*Lemna* sp.)	--	--	3.268103
Black Mustard (*Brassica nigra*)	--	--	0.161772
Creeping Rye (*Leymus triticoides*)	--	--	0.316493
Grass Community (Miscellaneous)	25.95	25.55	27.39934
Cattail (*Typha* spp.)	**16.77**	**12.63**	**12.71892**
Bulrush (*Scirpus acutus*)	2.95	2.63	2.00973
Perennial Pepperweed (*Lepidium latifolium*)	**0.88**	**--**	**2.045433**
Mudflat (Non-vegetated)	33.4	14.30	1.354993
Common Pickleweed (*Salicornia virginica*)	**7.29**	**6.54**	**2.122295**
Non-vegetated (Open Water, Roads, Misc.)	0.85	48.02	60.61437
Total Acres	**141.56**	**141.55**	**141.4952**

3.2 Change in Target Vegetation Since 2007

Changes in vegetation between 2005, 2007 and 2011 are summarized in **Table 3**. These summary statistics indicate a net ret increase of 0.09 acres of cattail and a reduction of 4.42 acres of Common Pickleweed since the last (2007) mapping effort. The third target vegetation type, Perennial Pepperweed, was not mapped in 2007. From 2005 to 2011 though, Pepperweed acreage increased from 0.875 to 2.05 acres. A digital comparison of 2011 vegetation maps and GIS layers from the 2007 effort further illustrate change in two of three target vegetation types (see **Table 4).** Perennial Pepperweed was not mapped or quantified in 2007; instead, results from 2011 are compared to those from 2005, indicating an increase of 1.17 acres more than the 0.88 acres mapped in 2005.

Table 4*. Vegetation Change for Cattail and Pickleweed between 2007-2011as detected through digital subtraction; "Gain" is area mapped in 2011 but not 2007; loss is where It was mapped in 2007 but not 2011; area mapped in both efforts is also given*

Vegetation Change	**Acres**
Cattail Gain	8.45
Cattail Loss	8.35
Cattail Mapped in 2007 & 2011	4.26
Net Change in Cattail	**+0.09 acres**
Pickleweed Gain	1.02
Pickleweed Loss	5.43
Pickleweed Mapped in 2007 & 2011	1.10
Net Change in Pickleweed	**-4.41 acres**

Change in Common Pickleweed cover since 2007 is illustrated in **Figure 5,** Cattail change is shown in **Figure 6,** and change relative to both is illustrated in **Figure 7**. Distribution of Perennial Pepperweed in 2011 is illustrated in **Figure 8**.

3.3 Assessing Accuracy of Spectral Analysis

These 2011 results, and those from 2007 mapping efforts, need to be considered in light of estimated accuracy and precision afforded by methodology and aerial imagery. As indicated in the 2011 Accuracy Matrix (**Table 5**), we had varied success in computerized separation/extraction of vegetation classes, including target types. On comparing computer-model generated classes with ground-based plots, we found only 60.0% overall accuracy in the 2011 computer-generated map (n=255), as compared to 94.8% accuracy reported in 2007 (n=154). Among the three target vegetation classes in 2011, cattail was discerned with 78% accuracy (an improvement from 42% in 2007), Perennial Pepperweed with 38% accuracy (not measured in 2007), and Common Pickleweed with 65% accuracy (70% in 2007). It should be noted that these accuracy assessments are statistically-limited by small and unequal sample sizes. In our 2011 effort, Cattail only had 9 field-plots represented (12 plots in 2007), Perennial Pepperweed had 21 plots (0 in 2007), and Common Pickleweed had 66 plots (23 plots in 2007).

***Table 5**. Error Matrix for 2011 McNabney Marsh Spectral Analysis/Vegetation Map*

Count of PLOT_CLASS	**PLOT_CLASS**								
MAPPING	**1**	**3**	**7**	**8**	**9**	**10**	**11**	**12**	
1(Common Reed)	2		1						3
3 (Spearscale)		16	11		4	4	1	2	38
7 (Grassland)		25	78		2	7		21	133
8 (Cattail)			**2**	**7**	**3**	**1**			**13**
9 (Hardstem Bulrush/Tule)				1			1		2
10 (Perennial Pepperweed)		**1**	**6**			**8**			**15**
11 (Mudflat/Barren				1					1
12 (Common Pickleweed)		**6**				**1**		**43**	**50**
Grand Total	**2**	**48**	**98**	**9**	**9**	**21**	**2**	**66**	255
Omission Error	67%	42%	59%	**54%**	0%	**53%**	0%	**86%**	
Commission Error (Accuracy)	100%	33%	80%	**78%**	0%	**38%**	0%	**65%**	

Further indications of accuracy/precision are gained by visually comparing vegetation spectral-signatures on aerial base-photos with computer-generated polygons resulting from the 2011, and 2007 efforts. This is discussed in further detail below.

4.0 DISCUSSION

Cattail Marsh: Results of this 2011 mapping effort suggest negligible net change in cover of Cattail marsh since 2007. The mapping did show though, that spatial distribution of cattail did shift, with approximately 8.45 acres now growing at sites where it was not present in 2007 and about 8.35 acres absent this year where previously mapped in 2007. This spatial change could reflect a response to overall increased summer inundation elevations in the marsh since operation of tidal floodgates began in 2009. This change in overall water regime has likely affected other vegetation in the marsh, including the zone inhabited by Common Pickleweed, one of the other three target vegetation types.

Common Pickleweed: For multiple reasons, the 2011 aerial imagery was not particularly useful for separation of some vegetation types based on spectral signature extraction. Significantly, this proved to be the case with Common Pickleweed, one of the three target vegetation classes. The 2011 photo was flown earlier in the year (June 20) than was the 2007 image (October 23). Also, the spring and early summer of 2011 were unusually cool and wet. Lastly, the aerial photo was flown later in the afternoon in 2007 than it was for the 2011 year mapping effort. Apparently, these factors together with an overall earlier stage of vegetation development resulted in broad overlap of spectral signature between Common Pickleweed and surrounding associated vegetation.

As a result, where the 2007 investigator reported problems in separating out cattail thatch from surrounding dead/senescent grasses, we had problems separating out

Common Pickleweed from actively growing cattail and surrounding photosynthesizing vegetation. It appears that later in the year, Pickleweed is taller (more coarsely textured) and with its succulence, more clearly discernable from surrounding late season-senesced associates.

As mentioned in the methodology section, repeated running-refinement of the 2011 computer model resulted in obviously-inaccurate mapping of Pickleweed in surrounding areas, including both cattail stands and uplands. It was decided that manual delineation would provide best possible results for Pickleweed, given the circumstances. Although we collected more plot-based field data than the 2007 effort (255 versus 154 plots), we were never able to examine much of the vegetation in the western portion of the marsh, owing to tide gates being opened and functioning during our botany field-work. By the second and third day of field-work, water was over Waterfront Road, and the westernmost portion of the marsh completely inundated. As a result of this submersion/inundation, we did not have the opportunity to collect plot-data or visually ground-check Common Pickleweed signatures in the southwestern- and western-most portion of the marsh, where most of the difference between efforts was detected. The lead botanist (J. Dittes) feels that with more intensive ground-verification and additional hand delineation, more acreage of Common Picklweed could have been mapped in 2011.

Complicating interpretation further, on close examination of the 2007 Pickleweed map relative to the 2007 infra-red base imagery, it appears that Pickleweed could have been over-mapped by 2007 spectral analysis in some areas (J. Dittes Pers. Obs.).

In summary, we mapped approximately 4.41 fewer acres of Common Pickleweed than were mapped in 2007. But for mentioned reasons, these results are not conclusive, and not directly comparable to those from 2007. Further information regarding changes in Pickleweed cover might be gained from additional analysis of 2007 and 2011 aerial images and shape files, and more ground-based observations/verification.

Perennial Pepperweed: Mixed results were obtained from spectral analysis of Perennial Pepperweed, the third target vegetation type. We mapped Sensitivity in detection apparently depended on growth-stage, plant density, microhabitat and plant species association. Numerous smaller, more sparse, and non-flowering/fruiting colonies went undetected by the 2011 spectral analysis. Some of these colonies were confused with other upland broadleaf weeds, and with Saltgrass. Other colonies associated with wet edges of Cattail colonies went undetected as well.

5.0 CONSIDERATIONS/RECOMMENDATIONS

- ***Improve 2011 mapping of Common Pickleweed****:* To further evaluate actual change in extent of this target species since 2007, additional ground-verification and mapping is recommended. Targeted sites should include polygons mapped remotely during 2007 but not during 2011 and those areas not ground-verified during either year. Consider augmenting hand-mapping on aerial photo with sub-meter accuracy GPS-mapped boundaries and points. If done, it should be completed before the end of the 2011 growing season. Consideration might also be given to closer examination of 2007 spectrally-mapped Pickleweed to better assess accuracy/precision.

- ***More completely assess accuracy and precision of spectral-analyses mapping:*** Develop more robust measures of assessing accuracy and precision. This is an important consideration, as summarized by Tuxem et al. (2010). Closely examine results of the three spectral-mapping efforts conducted to-date; assess implications of potential past mapping errors. Consider balancing and increasing sample size of vegetation plots used for accuracy assessment/error matrix. Consider producing GPS-mapped vegetation boundaries in representative subset areas to compare to spectrally-produced map boundaries. Consider adding a post-map field verification task to the project.

- ***Explore ways to improve spectral analysis methodology:*** It would benefit future efforts to more-completely review 2007, 2005 and 2011 results, existing literature and query knowledgeable individuals regarding strengths, limitations and potential improvements to spectral analysis methodology, as applied to needs at MacNabney Marsh.

- ***Fully consider implications of project timing:*** As shown by difficulty in separating Common Pickleweed during the 2011 effort, timing of aerial photography is important for capturing target vegetation. The project was probably timed correctly for maximizing detection of Perennial Pepperweed and Cattail, but not so for Pickleweed. Timing should be determined each year depending on visual examination of desired target vegetation (it could vary somewhat year to year based on climate/moisture conditions of the year). Timing of the photo should also take into account tide-gate operation schedules. In general, the "wetter" the soil profile and vegetation, especially at higher-elevation positions, the more difficult it becomes to separate spectral signature of types.

- ***Include Common Reed (Phragmites australis) as a target vegetation type:*** This species was not previously mapped in McNabney Marsh in 2005 or 2007; instead it was mapped as part of the Common Rush (*Scirpus acutus*) class. Common Reed can spread rapidly in marsh systems, forming homogenous, rank stands. It is noted that some stands in California are of non-native genotypes that are highly invasive. Like Cattail, it can greatly affect structure and diversity of the marsh and should be tracked. Spectral analysis worked relatively well for Common Reed and Cattail.

- ***Further Incorporate Ground-Level Photography into monitoring protocol:*** In addition to species cover data, we took photographs of each of our 255 sub-meter GPS-mapped vegetation sample plots. These photos, along with a subset of oblique-views, can be repeated at any interval through time. These are point-specific data that are useful in addressing vegetation change and of aid in interpretation of future spectral-mapping results.

- ***Develop robust fixed-transect monitoring component for target vegetation types:*** Consider developing/implementing a statistically-robust, fixed-transect monitoring component for target vegetation types; in particular Common Picklweed and Perennial Pepperweed (neither of which appears satisfactorily delineated for management needs). A well-planned, balanced sampling design, with appropriate statistical test, can provide clear-cut indication of gains, loss, movement and vigor of target species/vegetation. These types of monitoring data cannot be used to quantify absolute area over the entire marsh, but if well-designed and statistically robust, these data, do provide irrefutable indication of trends that can be extrapolated to the larger system. These data would be invaluable in better interpreting results obtained from remote spectral analysis.

- ***Perennial Pepperweed Mapping Monitoring:*** With regard to assessing distribution and abundance of this invasive species, on-the ground monitoring efforts should address smaller "satellite" populations. While the 2011 spectral analysis did capture the majority of densely populated, flowering/fruiting Perennial Pepperweed areas, it also missed many smaller satellite populations, missed non-flowering patches, and confused spectral signature with some other upland types. With regard to invasive species management, smaller outlying "nascent" populations are of particular concern, as they are first indication of rate and direction of spread. Also, in severely infested areas, these smaller outlying populations are ones best dealt with first in eradication/control efforts. Consider augmenting mapping of this species with on-the ground data collection (GPS-mapping, fixed transects, photo plots, etc.).

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