PROTOTYPE APPLICATION OF NASA MISSIONS TO IDENTIFY PATTERNS OF WETLAND VEGETATION DEVELOPMENT WITHIN THE SOUTH SAN FRANCISCO BAY SALT PONDS

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ABSTRACT

The South Bay Salt Pond Restoration Project is the largest tidal wetland restoration on the west coast of the United States. Monitoring vegetation development in these emergent habitats with remote sensing can provide restoration managers with an indication of ecological health and progress of development. Remotely sensed imagery was used to monitor vegetation development and to map vegetation patterns and biota changes historically, during, and after salt pond construction for ponds numbered A19, A20, and A21. Percent vegetative cover was mapped using the Normalized Difference Vegetation Index (NDVI) from MODIS, Tasseled Cap Greenness (TCG) and NDVI from Landsat TM, and the Ratio Vegetation Index (RVI) from ASTER. Field parameters included *in-situ* measurements and geographic locations for percent vegetative cover, and site specific species information. Field data were incorporated into GIS, and vegetation was analyzed using spatial statistics methods and a qualitative post-classification comparison technique. NDVI values obtained from the Landsat scenes indicated a net gain of 3.35 acres of vegetation cover from February 2006 (before pond breaching) to August 2009 for pond A21 and 1.33 acres and 3.14 acres for ponds A20 and A19, respectively. Increases in vegetation indicate the marsh has built up to a steady-state condition to provide appropriate habitat for endangered plant and animal species and also indicates the success of restoration practices.

KEYWORDS: wetlands, NDVI, Landsat TM, MODIS, vegetation change

INTRODUCTION

The highly productive wetlands of the San Francisco Bay estuary have decreased in areal extent by 90% since 1825 due to the development of evaporative salt ponds, of agricultural areas, and urban expansion (Foxgrover et al. 2004). This loss has contributed to the disappearance of important marshland vegetation species such as *Spartina foliosa* (cordgrass), *Typha latifolia* (cattails), and *Salicornia virginica* (common pickleweed) all of which historically have provided refuge for many endangered species such as the California clapper rail (*Rallus longirostris obsoletus*) and salt marsh harvest mouse (*Reithrodontomys raviventris raviventris*) (Atwater *et al.*, 1979; H.T. Harvey & Associates, 2008). Wetland ecosystems are also valuable for providing flood-protection, recreation, storm buffering, groundwater recharge/discharge, carbon sequestration, and biological diversity (Brander *et al.*, 2006). Recovery efforts are now underway to restore these sensitive ecosystems in the South San Francisco Bay, placing great importance on measures, such as remote sensing, to monitor and quantify habitat development during marshland recovery without disturbing these sensitive ecosystems.

The South Bay Salt Pond Restoration Project (the Project) is the largest tidal wetland restoration project on the west coast and is managed by the California State Coastal Conservancy (CSCC), California Department of Fish and Game (DFG) and U.S. Fish and Wildlife Service (FWS) (Trulio *et al.*, 2007). In March 2003, over 15,000 acres of former commercial salt ponds in the South San Francisco Bay (Figure 1) were purchased by DFG and FWS from Cargill Inc. to begin the restoration process. Over the next few decades, the goal of the Project is to restore these former salt ponds to a wetland landscape incorporating marshes, tidal flats, and sloughs, there by regaining some of the diversity originally present in the area, improving flood protection, and increasing wildlife-oriented public access (Trulio *et al.*, 2007). To achieve these goals The Project management team has decided on an adaptive management strategy, where each phase of restoration will be decided upon and implemented progressively as more data are acquired (Trulio *et al.*, 2007). Effective planning and identification of scientific needs is necessary for the success of each phase of the restoration. Monitoring and understanding patterns of vegetation development is a key component needed to inform short-term management decisions about the effectiveness of each phase of restoration in regards to the changing habitats uncertainty.

In March of 2006, the U.S. Fish and Wildlife Service (USFWS) Don Edwards National Wildlife Refuge and the Santa Clara Valley Water District took a first step in the restoration process and initiated tidal pond inundation to three Alviso salt ponds also known as the Island Ponds (Callaway *et al.*, 2010). The levees of the salt ponds A19, A20, and A21 (Figure 1) were breached allowing tides to commence the restoration process. Tidal waters were allowed to flow daily for the first time in over 100 years with the goal of allowing natural sedimentation processes to restore the tidal marsh habitat for successful vegetation reestablishment (Callaway *et al.*, 2010). The dominant plant species found on the levees of A19, A20, and A21 before breaching was pickleweed and cordgrass which were predicted to colonize the newly developing mudflats (H.T. Harvey & Associates, 2005). In a study in 2008, aircraft based color infrared imagery was used to determine that Ponds A19, A20, and A21 had established approximately 6.07, 2.93, and 4.29 acres of salt marsh vegetation, respectively, on the levees and in the pond by the end of 2008 (SCVWD and FWS 2009). Results from our study are compared with the results from H.T. Harvey & Associates, and are discussed below.

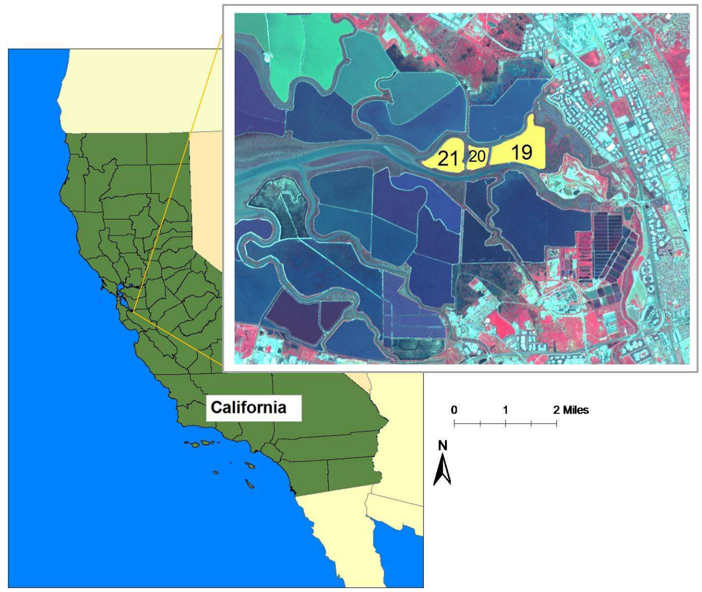

Figure 1. Study location of the Ponds A19, A20 and A21. The salt ponds are located at the southern end of the San Francisco Bay, California.

To address the needs of The Project during the current phase of restoration, we examined patterns of vegetation change (Figure 2) for A19, A20, and A21. Our goals in this project included 1) to broadly examine patterns of floral colonization within the island ponds and the fringing marsh after breaching of the levees, 2) assess the net gain or loss of biotic habitat, and 3) determine if this prototype project is feasible for restoration managers in years to come as a replacement to costly aircraft imagery. In order to assess patterns of floral colonization for the study area, remote sensing methods were used in conjunction with *in-situ* observations to map the current locations of vegetation for these ponds. Using the Tasseled Cap Greenness Index (TCGI) (Kauth and Thomas, 1976) and the Normalized Differenced Vegetation Index (NDVI) (Kriegler *et al.*, 1969, and Rouse *et al.*, 1973) from Landsat TM5 satellite images, the Red Vegetation Index (RVI) (Jordan, 1969) from Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) on NASA's Terra satellite, and the NDVI from Moderate Resolution Imaging Spectroradiometer (MODIS) (Kriegler *et al.*, 1969, and Rouse *et al.*, 1973) on NASA's Terra and Aqua satellites, a time-series of vegetation colonization was mapped for seasonal and annual changes between the years 2006–2010. To quantitatively determine the net gain or loss of biotic habitat, Geographic Information Systems (GIS) spatial statistics methods and qualitative post-classification comparison techniques presented in Tuxen et al. (2000) were used to determine areas of the pond that have gained/lost vegetation and locations of preferential vegetation development.

Figure 2. Before (left) with a thick gypsum crust and after (right) of Pond A21 now with sediment and vegetation (http://www.southbayrestoration.org).

METHODOLOGY

Three different satellite remote sensing indices including the RVI, the NDVI, and the TCGI were calculated using ERDAS Imagine 9.3 to map vegetation in ponds A19, A20 and A21. Vegetation changes over time were mapped using a series of satellite images taken between the years of 2006-2009. To calibrate the time-series of image reflectance values to vegetation cover, field work was conducted in the three ponds. Field work consisted of mapping the visible locations of existing vegetation on the mudflats and the surrounding tidal channel. A database of vegetation GPS locations and species information was created in ArcGIS 9.2 for correlation with the satellite imagery. GIS zonal statistics methods were then used to analyze RVI, NDVI, and TCGI change on these locations from 2006-2009.

Satellite Indices and Remote Sensing

Landsat TM5 revisits the same point on the globe every 16 days with an equatorial crossing time of 10-11 am (Landsat). Both Terra and Aqua revisit the same spot on the globe every day with equatorial crossing times of 10 - 11 am and 12:30 – 1:30 pm respectively (LP DAAC, Land Processes Distributive Active Archive Service). With these equatorial-crossing times, imagery was selected that took into consideration tide height along with clouds and sensor anomalies. Scenes were obtained which corresponded to tide heights of less than 4 ft above mean low at the nearest tide station (~3.5 km to the west and down stream of the study area) to allow for an un-inundated view of all vegetation within the ponds. Selected scenes had 0% cloud cover in the study area and surrounding bay region. Once these criteria were met there were seven Landsat scenes, twenty MODIS scenes, and three ASTER scenes available for analysis from February of 2006 to April of 2010. All Landsat TM 5 images were preprocessed to top-of-atmosphere reflectance using radiometric guidelines outlined in Chander et al. (2007). All MODIS images were corrected using the standard correction coefficient outlined by the LPDAAC. All ASTER images were also radiometrically and geometrically corrected for our study site.

The first index used was the RVI index shown in Equation 1, which is a ratio of near-infrared to red where NIR is near-infrared wavelengths (780–860nm) and Red is red wavelengths (630–690nm) (Jordan, 1969).

$$RVI = \frac{NIR}{\mathrm{Re}\,d} \qquad \text{Equation (1)}$$

The RVI index was applied to the ASTER 15-meter *AST_07 Surface Reflectance product* images from April 2006, September 2006, and October 2008 (https://wist.echo.nasa.gov/). ASTER is an on-demand product from the NASA Terra satellite meaning new images must be requested. The RVI ratio is based on the amount of vegetation within a pixel where larger NIR values increase this ratio because of the high correlation with the presence of healthy photosynthesizing plants (Lillesand and Kiefer, 2000). In this study, the RVI index was used to detect the presence and relative abundance of vegetation within the ponds at specific time markers during the restoration.

The second index used in this study was NDVI applied to both Landsat TM5 and MODIS images. The NDVI calculates the normalized ratio of the NIR to Red using Equation 2:

$$NDVI = \frac{NIR - \text{Re}\,d}{NIR + \text{Re}\,d} \qquad \text{Equation (2)}$$

The NDVI values range from -1 to 1 where water usually ranges from -0.8 to -0.3 and vegetation is greater than 0. MODIS *MOD09GQ and MYD09GQ surface reflectance products* for California from February 2006 to May 2010 were used in calculating NDVI (Equation 2). The MODIS products are provided as surface spectral reflectance and are geometrically corrected. The NDVI index was also applied to Landsat TM5 30-meter *L1T terrain corrected products* obtained from the USGS Global Visualization Viewer (http://glovis.usgs.gov/) ranging from June 2006 to April 2010. The L1T product has been geometrically and radiometrically processed in a digital number format. Additional radiometric correction was applied to all images obtained to provide additional accuracy in the scene-to-scene comparison for the change-detection and time-series analysis. Landsat TM5 L1T products are provided as at-sensor radiance, and additional processing following the methods of Chander et al. (2007) was used to convert the scenes to at-sensor reflectance. An ERDAS Imagine model was used for these processing steps.

Once reflectance was calculated for the Landsat imagery, the TCGI was calculated from the Landsat TM5 reflectance images to provide a secondary assessment of vegetation colonization throughout the ponds (Kauth and Thomas, 1976). The TCGI calculates the weighted sum of Landsat bands 1–5 and 7 and calculates the relative amount of greenness for a given pixel (Equation 3):

$$\begin{aligned} TCGI &= Band1(-0.2728) + Band2(-0.2174) + Band3(-0.5508) + \\ &Band4(0.7221) + Band5(0.0733) + Band7(-0.1648) \end{aligned} \qquad \text{Equation (3)}$$

The TCGI is one output from the Tasseled Cap principal component analysis. The Tasseled Cap (TC) method also provides Wetness and Brightness as additional principal components. The TC method uses all of the Landsat bands and is based on the analysis that the data when transformed into orthogonal axes to each other will provide a clear spectral delineation of greenness, wetness and brightness (Crist and Cicone, 1984).

Field Data Collection

The purpose of choosing ponds A19, A20 and A21 as our area of study reflects the necessity of monitoring emergent vegetation in ponds that have already undergone breaching. Data were collected in the field on May 2, 2010 and May 14, 2010, which corresponded as closely as possible to satellite overpasses and low tides. The interior of each pond was examined for existing vegetation from the levees, as the mud of the borrow ditches was too thick to cross. Ponds A19 and A20 showed almost no vegetation due to the seasonal effect where the annuals will not emerge until July/August and because A19, and A20 have developed marshes and mudflats at a slower rate than

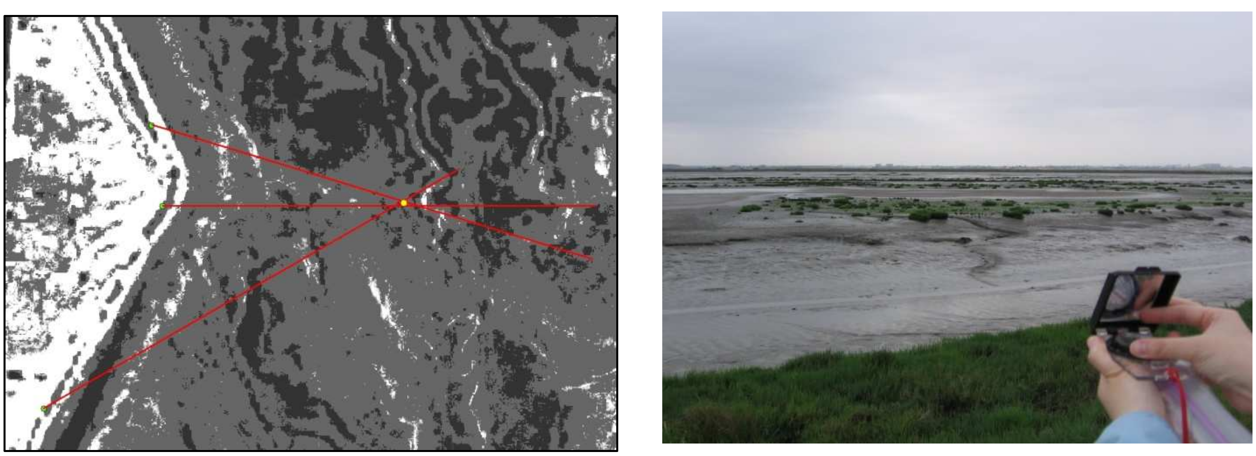

Figure 3. Triangulation method (left) used in ArcGIS for delineating edges of vegetation patches for Pond A21. A team member is shown (right) in the field using this method to locate patches of vegetation.

A21 (Callaway *et al*., 2010). Pond A21, however, has had significantly more vegetation development and provided a wide range of cover categories for collection. When vegetation was seen, a GPS coordinate was taken for our location on the levee, and a compass bearing was taken toward the center of the vegetation. This process, repeated at least 3 times per patch, was used to triangulate the geographic position of small vegetation clusters in the middle of the ponds (Figure 3). The triangulation image in Figure 3 (left) shows an elevation map for a portion of A20 and the image on the right shows a small vegetation patch on the mudflat. For larger patches, bearings were taken to denote the perimeter of the patches from various points along the levee. All vegetation was noted on a field map containing a recent GoogleEarth image. Additionally we recorded vegetation species data, the extent, size, and homogeneity of the vegetation cover.

GIS Analysis and Change Detection

The goal of the GIS portion of the analysis was to map existing vegetation using data gathered during fieldwork to calibrate the three remote sensing indices with the known areas of vegetation. This qualitative threshold method will allow for a comparison of areas of vegetation with previous years where field data do not exist to create a change-detection series and to quantify the amount of vegetation change since levee breaching. To do this, all of the field data were imported into a GIS database, and vegetation polygons were created using the triangulation measurements along with our field maps for each pond (Figure 3). Landsat TM5 NDVI images from April 10, 2010 were then used for calibrating NDVI values to categories of ground cover types (Table 1). Calibration was done by extracting NDVI pixel values for categories of known water, saturated mud, wet mud, salt, semi-dry mud, algae, low density vegetation (<30% cover), and high density vegetation (>30% cover) (Hardisky *et al*., 1984) by using the results from the field work. These vegetation cover classes reflect an arbitrary distinction between high and low density vegetation, and the 30% threshold was appropriate for this study because vegetation was either clustered in patches of many individual plants or found as an individual plant separated from clustered patches. Approximately 50-60 pixel values were extracted for each category and univariate statistics were run for each category (Table 1). Areas of overlap were accounted for by adjusting the thresholds and reanalyzing the image until an accurate representation for that category was obtained following the qualitative post-classification comparison techniques outlined by Tuxen et al. (2008). Once the calibration was created for the most recent image, the calibration was applied to all the Landsat TM5 images to obtain a time-series of vegetation, and calculated for percent vegetative cover. This same method was used for obtaining vegetation maps for ASTER RVI images, and MODIS NDVI images.

Table 1. NDVI thresholds used to classify all Landsat images from 2006-2010

NDVI Category	Mean NDVI	2 Standard Deviations	Low Threshold	High Threshold
Water	-0.277	± 0.102	-0.379	-0.175
Saturated Mud	-0.154	± 0.054	-0.208	-0.100
Wet Mud	-0.052	± 0.058	-0.110	0.006
Salt	0.006	± 0.004	0.002	0.010
Slightly Wet Mud	0.053	± 0.048	0.005	0.101
Algae	0.113	± 0.0016	0.111	0.114
Low Density Vegetation	0.223	± 0.104	0.119	0.327
High Density Vegetation	0.379	± 0.114	0.265	0.493

RESULTS AND DISCUSSION

Results of the remote sensing and GIS analysis demonstrate a general increase in total vegetation from time of levee breaching. The combination of remote sensing indices and sensor pixel sizes provided both detailed and homogenous views of the salt pond vegetation landscape. Percent vegetation cover was calculated for each year from the satellite indices demonstrating the effectiveness of using remote sensing for wetland monitoring.

Landsat

Results from the NDVI classification are shown in Figure 4. In this time-series, changes in NDVI distribution are shown from June 2006 to August 2009, and the general increase in vegetation cover is noticeable. The dark green patches are estimated to be densely vegetated areas (>30% cover) because of the linear relationship between NDVI and Leaf-Area Index. The dense patches have remained geographically consistent along the levees. The light-green areas comprise the low density vegetation class representing vegetation cover of approximately <30%. The low-density vegetation cover class is an important category because not all vegetation in this area occurs in closely spaced homogenous patches. The majority of the vegetation is sparse, with most of the distribution occurring in random non-heterogeneous clusters. In the field, this category was classified by the occurrence of one single plant surrounded by mud. The lightest green areas represent algae and bio-films giving an indication that algae/bio-films reflect somewhat in the NIR. Interestingly, mud was classified in both the positive and negative NDVI values. Intuitively, wet mud is classified close to the water category with a negative NDVI value because water reflects more in the visible spectrum than in the NIR; saturated/wet mud falls in this category. However the semi-dry mud category is assumed to be a well-drained mudflat, because an understanding of the geography of the area informs us that these areas are generally higher than the surrounding channels and this allows the water to drain for a longer period of time. Also, since algae are found in the general vicinity, this mud category may be influenced by the reflectance of scattered algae on the surface. The area of vegetation change in acres in Pond A21 is shown in Figure 5, and each year shows greater total vegetation cover than the previous year. In April of 2010, Pond A21 shows 13.12 acres of algae and 7.78 acres of low density vegetation. The low-density vegetation cover is estimated to have a density of approximately 1%, and this represents a total vegetation cover of 0.08%. Eight months prior to this in August 2009, Pond A21 had 28.02 acres of low-density vegetation and 10.23 acres of high-density vegetation representing total vegetation cover of 2.65%. Percent vegetation cover changes calculated with Landsat NDVI for all three ponds are shown in Table 2.

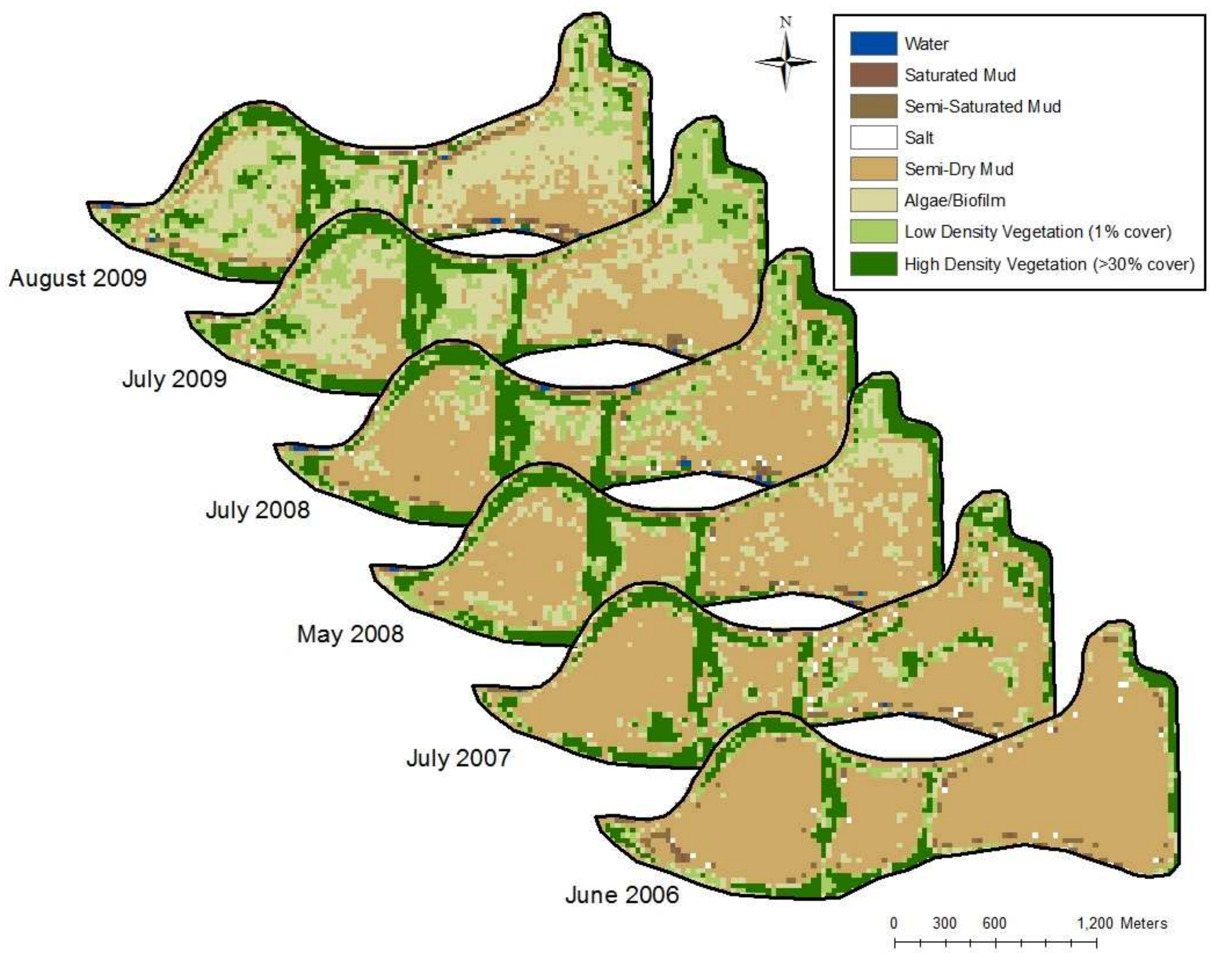

Figure 4. Time-series of vegetation changes for the Island Ponds from 2006–2009 using Landsat TM. A21 in located on the left, A20 in the middle, and A19 on the right.

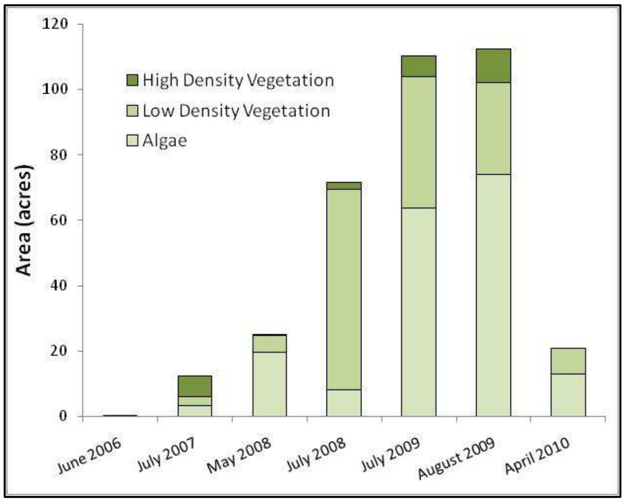

Figure 5. Changes in area (acres) of vegetation classes for Pond A21 calculated from Landsat NDVI.

Table 2. Percent Vegetation Cover derived from Landsat imagery.

	Vegetation coverage (acres)	Percent Vegetation Cover (%)
Pond A21		
April 2010	0.08	0.06
August 2009	3.35	2.65
July 2009	2.34	1.85
July 2008	1.21	0.96
May 2008	0.18	0.15
July 2007	1.96	1.55
June 2006	0.00	0.00
Pond A20		
April 2010	0.36	0.56
August 2009	1.33	2.07
July 2009	1.17	1.82
July 2008	3.03	4.72
May 2008	0.61	0.95
July 2007	0.76	1.18
June 2006	0.00	0.00
Pond A19		
April 2010	3.61	1.33
August 2009	3.14	1.16
July 2009	3.81	1.40
July 2008	5.31	1.96
May 2008	3.59	1.32
July 2007	8.62	3.18
June 2006	1.38	0.51

Landsat TCGI calculations generally agree with the NDVI when mapping locations of vegetation. However, the TCGI estimates lower percent vegetative cover when compared with the NDVI. A possible explanation for this is that the NDVI uses only two bands, NIR and Red, whereas the TCGI takes into account all Landsat TM bands and uses positive coefficients for the NIR and the Short-Wave Infrared (SWIR) bands and negative coefficients for all other bands. Bright soils such as the semi-dry mud category in the salt ponds reflect much higher in the SWIR region than vegetation. This effect plus the heterogeneous spatial distribution of small vegetation patches allows the mud to dominate and skew the overall TCGI value (Goward, 1985). This combination of bright soils and vegetation reflectance in the SWIR contributes to the final TCGI value for the pixel, which may underestimate actual vegetation cover. These results suggest that in wetland areas NDVI is better suited for classifying vegetation cover.

MODIS

NDVI values obtained from the MODIS scenes indicated a gain of 0.77 acres of vegetation cover from February 2006 to May 2010 for pond A21. A sediment accumulation study conducted by Callaway et al. (2009) confirmed vegetation recruitment in Pond A21 within the first three years of the levee breach. Small amounts of vegetation growth were observed in the first two years, while extensive patches of vegetation were seen in Pond A21 by year three following the levee breach (Callaway *et al.* 2009).

The sharp increase in vegetation cover in November of 2008 and 2009 indicates seasonal vegetation activity of the newly colonized plants in Pond A21 following the breach. The MODIS NDVI values from November 2008 and 2009 show high density vegetation cover particularly in the southeastern region of the pond that was not observed in November of previous years. This seasonal phenology suggests the area may be colonized by annual plants such as the *Salicornia europeae* (annual pickleweed). In a vegetation survey conducted by H.T. Harvey & Associates (2008), they observed vigorous and healthy pickleweed growth in 2008 in the south bay marsh region. Future fieldwork should be conducted during November to further investigate the southeast region of Pond A21 to verify this seasonal vegetation activity.

ASTER

The ASTER RVI analysis shows similar vegetation trends when compared with the Landsat NDVI maps. Although only two scenes were available from ASTER that corresponded with low tides, these two scenes provided a higher-resolution snapshot of how total vegetation has changed for the three Ponds from 2006–2008. ASTER defines the locations of vegetation patches and the tidal channels much more precisely than Landsat or MODIS. The

ASTER RVI analysis calculated a percent vegetation cover of 0.56% in October 2008 (Table 3). The closest comparison can be made with the Landsat scene from July 2008 (Table 2) which calculated 0.96% vegetation cover. Because of the lower spatial resolution of Landsat compared with ASTER, it is possible that Landsat slightly overestimates the total amount of vegetation.

Studies conducted in regions with high temporal and meteorological variations such as marshlands face many challenges that limit the number of available satellite scenes that are suited for analysis. Factors that influence the number of suitable scenes includes but is not limited to the diurnal variation of the tides, coastal fog, as well as satellite sensor anomalies such as banding and memory effects associated with cloud coverage and bright objects in the coastal region. For example, among the 77 Landsat TM scenes captured from January 2006 to April 2010, only 9 scenes were available with low tides, cloud free, and without sensor anomalies. MODIS on Aqua and Terra, however, offered a total of 523 scenes with 86 scenes suitable for analysis for these four years. MODIS products are often used for large scale studies of terrestrial vegetation since MODIS has a high temporal resolution but a coarse spatial resolution compared with ASTER and Landsat TM5. The consistent temporal advantage of MODIS allowed our study to capture the seasonal phenological activity of the vegetation in the salt ponds that was not observed by ASTER nor Landsat TM5 due to the temporal coverage.

When comparing the ability of all three satellite sensors to detect and map vegetation cover, each sensor has its strengths and has a different capability for estimating seasonal and annual vegetation trends. Table 3 shows the comparison of the three sensors with the four different indices and the estimation of percent vegetation cover at a specific period of time. The Landsat NDVI classification shows an increase in percent vegetative cover from 0% in 2006 to 2.65% in August 2009. Similarly, the Landsat TCGI calculated an increase in percent vegetative cover of 2.30%. The NDVI calculated with MODIS between 2006–2009 shows an increase in vegetative cover from 0% in 2006 to 0.852% in July 2009. The ASTER scene does show an increase in vegetation; however it cannot be compared with 2009 values from the other sensors because the only ASTER scene available was from 2008. Areas in the middle of the pond showed the most noticeable vegetation increases, however areas around the main channel which surrounds the middle mudflat generally showed large decreases in vegetation between these two years.

For Pond A21, a seasonal trend for spring and summer is observed from Landsat imagery; this trend is better observed with MODIS imagery. Generally, summer months (July-August) have higher vegetation coverage while spring months (April-May) have lower vegetation coverage. When compared with the amount of vegetation growth estimated by H.T. Harvey & Associates (2008) of 7.1 acres, these values compare well because H.T. Harvey & Associates estimated this value based on the vegetation growth for the levees as well as the mudflat. The values in Table 3 show vegetation growth only for the mudflat suggesting the levees experienced increased vegetation growth compared with the mudflat.

Table 3. Comparison of percent vegetation cover for Pond A21 using the four satellite indices.

	Vegetation coverage (acres)	Percent Vegetation Cover (%)
ASTER RVI October 2008	0.70	0.56
Landsat NDVI August 2009	3.35	2.65
Landsat TCGI August 2009	2.91	2.30
MODIS NDVI July 2009	1.11	0.88

CONCLUSION

Percent vegetation cover was mapped in this study using three different satellite sensors, and four different vegetation indices. The Landsat TM5 satellite and the ASTER and MODIS sensors on the NASA Terra and Aqua satellites provided images for numerous days for the years 2006–2010. The RVI index was applied to ASTER scenes, NDVI applied to both Landsat and MODIS scenes, and the TCGI applied to all Landsat scenes. All the sensors used were able to detect vegetation changes for the Ponds A19, A20, and A21with increases generally around 1-2% from the time of levee breaching in 2006. The Landsat NDVI index calculated the highest percent vegetation cover in August 2009 at 2.65%, whereas the TCGI estimated this value slightly lower at 2.30%. The MODSI NDVI calculated percent vegetation cover at 0.852% during July 2009. Even though the lower spatial resolution of MODIS obscures the delineation of the pond and vegetation edges, the temporal resolution of MODIS allowed us to find a seasonal trend in vegetation changes that was not as easily noticed with Landsat and ASTER. November of 2008 and 2009 showed large increases in the NDVI providing evidence that the vegetation in these ponds is annuals rather than perennials. It is recommended that MODIS be used for understanding seasonal changes for the salt ponds, and the Landsat and ASTER be used for mapping actual locations and extant of vegetation.

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