Pickleweed Vigor in a Californian Salt Marsh: A Remote Sensing Approach

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Abstract

Only about 10% of California's historical coastal wetland prior to 1850 exists today. Since wetlands provide valuable ecological and societal services, measures have been implemented to protect and restore these ecosystems in recent years. However, there is still a large need for information on these ecosystems to better inform management and policy in the face of a changing environment. This study attempts to fill some of this knowledge gap by examining drought impact on pickleweed (*Salicornia virginica*) health in the Californian coastal wetland located at Salinas River National Wildlife Refuge and how it can be assessed using fine resolution remote sensing data. Since pickleweed is a succulent, it was expected that the drought would have minimal effect on the observed health with the majority of the stress being observed at the height of the drought (2016). Therefore, the objective of the study was to determine which parts of the wetland, if any, came under stress during the most recent Californian drought (2011-2016) and if fine resolution remote sensing would be a viable tool for this type of research. RapidEye imagery from August or September 2014, 2015, 2016, 2017, and 2018 was used to conduct the study using QGIS for analysis. Images were classified using supervised classification into four categories (Water, Healthy, Stressed, and Bare Soil) and area was calculated for each year. Healthy areas had a large fluctuation through the five years assessed. However, data shows that there is a positive correlation between healthy plants and wet years. Therefore, the data suggest that drought did have an adverse impact on the salt marshes and that fine resolution remotely sensed data is viable for thisresearch.

Keywords: *Remote Sensing, Pickleweed, Wetlands, Drought, Geospatial Applications*

Introduction

Wetlands serve important ecological and societal functions in terms of biodiversity and ecosystem services. Drought is a weather event that can have major impacts on biodiversity primarily by creating a lack of water for plants, a condition that decreases the abundance of plants in an area. As there are more frequent and severe weather disturbances such as drought, wetland mapping and assessment will be of growing importance to conserve the biodiversity of and ecosystem services provided by wetland vegetation. In fact, only about 10% of California's historical coastal wetland prior to 1850 exists today (California Department of Fish and Wildlife, 2001). Recent studies observe that wetland management has a multi-scalar need for information, but the information available is either not complete, inconsistent, or not easily accessible (L.-M. Rebelo et al., 2009). One way to obtain this data is through remote sensing. Remote sensing includes using passive or active sensors to collect spatial data with little to no intrusion. Many forms of remotely sensed data exist, from Radar and Sonar to Light Detection and Ranging (LiDAR), Satellite Imagery, and Aerial Imagery. Satellite data is composed of images of reflected visible and infrared portions of the electromagnetic spectrum. Various calculations can be derived from these images to assess myriad conditions in a landscape. For example, remote sensing and geospatial technologies were used to assess spatiotemporal changes in plant vigor during the most recent California drought (2011-2016) in a pickleweed (*Salicornia virginica)* dominated wetland at Salinas River National Wildlife Refuge (SRNWR). In some regions of the state, such as San Pablo Bay, this shrubby, perennial succulent provides habitat for endangered species; thus, this population of pickleweed is an important proxy for analyzing the effects of drought on pickleweed dominated wetlands throughout various regions of the state that harbor endangered species. While pickleweed health and environmental response may be factors in this analysis, this is an observational study focused on analyzing drought impacts on *S. virginica* and our ability to use fine resolution remote sensing methods to collect that data to be used for future wetland assessment and management planning.

There have been several case studies related to collecting information on wetlands with geographic information systems (GIS) and remote sensing. One important case study combined Landsat TM (satellite imagery) data and ground truthing (accuracy assessment) to create a thematic map of Muthurajawela Marsh in Sri Lanka. A similar approach was applied to collect data on a wide variety of wetlands across the world, allowing for more precise monitoring and change prediction in wetlands (Rebelo et al., 2009).

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Regarding *Salicornia virginica* monitoring with remote sensing, one study determined that dominant species along the Petaluma River have different canopy structures and, therefore, have different spectral signatures. It is discussed that vegetation indices (calculations using light reflectance of vegetation's surface to determine health) are crucial to this type of analysis and that the normalized difference vegetation index (NDVI) that was calculated provided accurate estimates of vegetation health in the ecosystems studied. Landsat TM (thematic mapper) bands 1, 2, 3, and 4 were used to calculate the vegetation indices for the study. This approach can be used to analyze canopy/plant condition using a spectral signature of water absorption. As such, they concluded that the use of multispectral analysis is promising for future research and monitoring (Zhang et al., 1997).

Methods

Site Selection

Pickleweed is found throughout the state and houses endangered species such as the salt marsh harvest mouse (*Reithrodontomys raviventris*). Gaining a better understanding of how this plant reacts to changing environmental conditions may inform further conservation efforts in many parts of the state. With multiple prior studies focusing on the San Pablo Bay area, Salinas River National Wildlife Refuge was selected to broaden the scope of current literature. This selection was made because of the similarity in plant composition and close geographic location to San Pablo Bay (Fig. 1).

Fig. 1: SRNWR Location
(U.S. Fish and Wildlife Service)

Analysis

High resolution (≤ 30m pixel size) datasets are important to ensure that the desired area of interest is correctly identified. High resolution images allow data to be assessed at smaller spatial scales and produce a more accurate representation of the ground conditions. Normalized difference vegetation index (NDVI) is a method that uses the red and infrared portions of the electromagnetic spectrum to measure plant stress. NDVI is comparison between reflected infrared light and red light from an object's surface to determine if it is healthy vegetation (Fig. 2).

$$NDVI = \frac{(NIR - Red)}{(NIR + Red)}$$

Fig. 2: Normalized Difference Vegetation Index (GIS Geography)

Therefore, the sensor used for this study to be able to collect at least 4 bands (Red, Blue, Green, and Near Infrared). RapidEye imagery is available starting October 2013 through Planet Labs' Open California Initiative. The need for inexpensive imagery that has high resolution and the necessary bands led to the use of RapidEye imagery, which has 5m resolution and collects the necessary bands making it an appropriate sensor for this study (Planet Team). The 5m resolution size means that each pixel side measures 5 meters on the ground, thus the image covers 25 square meters.

This study relies on the comparison of drought years to wet years within the context of the appropriate water year. Water years, a set time that encompasses the entire rainy season, are calculated from October 1st through September 30th the following year. Since the full impacts of the drought would most likely correspond to the amount of precipitation received during a water year, efforts were focused on conditions in August and September. To get accurate measurements of the stress conditions at SRNWR, efforts were focused on conditions during August or September beginning in 2014. RapidEye imagery for each of the five years was downloaded for August or September 2014, 2015, 2016, 2017, 2018 (Planet Team). These images capture conditions between drought, wet, and average water year conditions.

Using Quantum GIS (QGIS), subsets, or smaller sections of an image, of the study site were extracted from the original images to ensure the analysis performed was, indeed, on pickleweed dominated sections of the wetland (QGIS Development Team, 2017). This was accomplished by using a plant community map provided by the Refuge Manager (Fig. 3). Using a minimum distance algorithm, which assigns pixel values based upon proximity of other similar pixels, a supervised classification was performed that classified each pixel into one of four macroclasses; Water, Healthy, Stressed, and Bare Soil. Training data are areas of the image where the software is told what to classify pixels of a certain value as. The training data for the classification was created using a self-calculated NDVI as a reference to identify healthy and stressed areas with NDVI values above .35 were added to the Healthy macroclass and those with values at or below .349 were added to the Stressed macroclass. False color infrared images were used to identify other land cover categories (ex: water and bare soil) via visual interpretation. Once the images were classified, area was calculated per class for comparison between the five years studied. The data were compiled and compared using bar graphs and scatter plots.

Fig. 3: Plant Community Map
(U.S. Fish and Wildlife Service)

Ground Truthing

To test the results of the remote sensing study, it was necessary to ground truth. Ground truthing is the process of collecting field data to compare with remote sensing data to verify model results. Working under special use permit #2018-03, fieldwork was conducted at SRNWR to collect data to test against the model created from remotely sensed data (U.S. Fish and Wildlife Service, 2018). Using ArcGIS, a random point layer was created within the boundaries permissible by the permit (Environmental Systems Research Institute). The point layer was loaded into a Trimble Geo7x and two Garmin handheld GPS units used for navigation in the field (Trimble Inc, 2013; Garmin Ltd., 2007). In the field, plant surface temperature, landcover, and plant color were recorded at each individual point. Infrared thermometers were used to take an average surface temperature of the plants at each point. Air temperature was collected at a later date from a local weather station ("Monterey, CA | Weather Underground"). Land cover types were described using the same terminology of the image classification (Health, Stressed, etc). Plant stress is typically measured from field data through the algorithm for the Water Stress Index (WSI) (Fig.4):

$$WSI = \frac{[(T_f - T_a) - (T_f - T_a)_l]}{[(T_f - T_a)_u - (T_f - T_a)_l]}$$

Fig. 4: Water Stress Index (Hatfield, 1990)

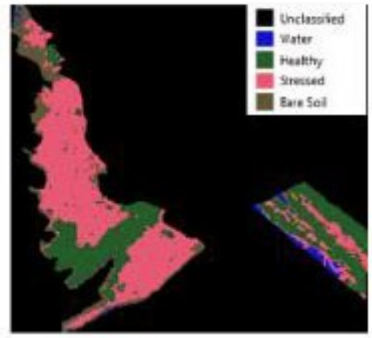

Fig. 5: 2014 Classification (Dry)

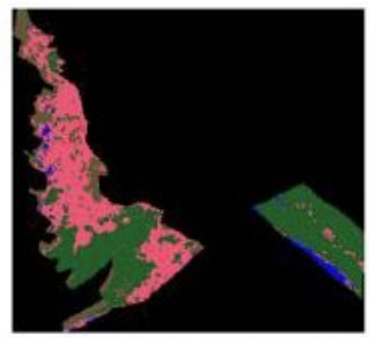

Fig. 6: 2015 Classification (Dry)

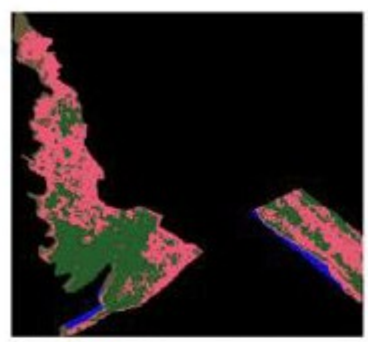

Fig. 7: 2016 Classification (Dry)

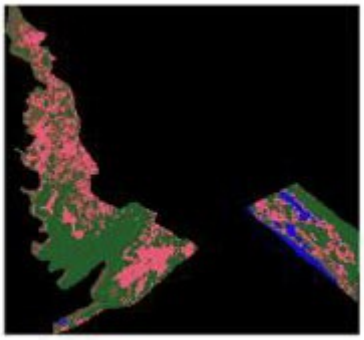

Fig. 8: 2017 Classification (Wet)

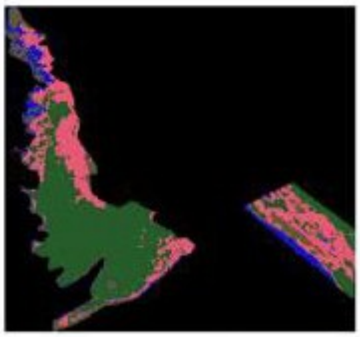

Fig. 9: 2018 Classification (Wet)

Here Tf – Ta represents the difference between foliage and air temperature, (Tf – Ta)u represents the upper baseline, and (Tf – Ta)l represents the lower baseline (Hatfield, 1990). In contrast with NDVI, a high WSI value indicates stress while lower values indicate healthy vegetation. WSI was calculated from the values using ArcGIS, with values ranging between 0.0 – 1.0. Data points with WSI values above .65 were classified as stressed. These data were added to the random point layer overlaid on the extent of the study area. These data were compared to that of the supervised classification for 2018 to ensure accuracy of the model.

Results

Remote Sensing Data

For SRNWR, the five classified subsets (Figs. 5, 6, 7, 8, 9) show a visual difference between years in the amount of healthy and stressed vegetation. Water was the one class with the least amount of presence in all years and healthy vegetation had the largest area in 2018 at 199,625 m2. The area of healthy vegetation fluctuates throughout all five years but increases starting in 2017. In earlier years, stressed vegetation was more prominent across the landscape. Starting in 2017, the fluctuation in the amount of stressed vegetation present is less dramatic (Table 1 and Figs. 10 and 11). Similarly, healthy and stressed vegetation

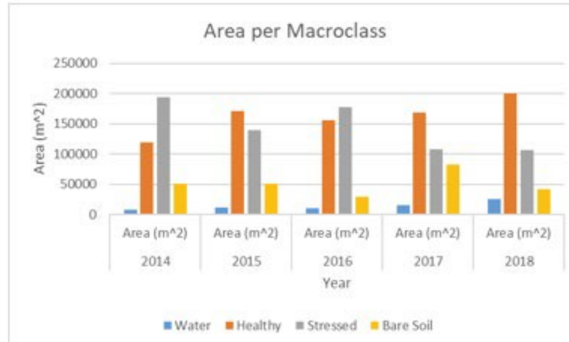

Fig. 10: Area per Macroclass

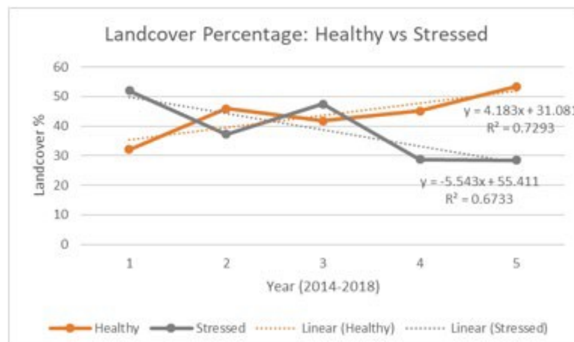

Fig. 11: Landcover Percentage Comparison

follow this same pattern in the three years for which landcover (%) was compared to historical average rainfall (% Average Precip) (Table 1 and Figs. 12 and 13). Weather data is incomplete for two of the five years (2015 and 2018). These data were excluded from the comparison (State of California).

Table 1: Area and % coverage for each year

Salinas River	2014			2015			2016			2017			2018		
MacroClass	Area (m^2)	%	% of Avg Precip	Area (m^2)	%	% of Avg Precip	Area (m^2)	%	% of Avg Precip	Area (m^2)	%	% of Avg Precip	Area (m^2)	%	% of Avg Precip
Water	8600	2.29	62%	11475	3.07	NULL	10575	2.83	136%	15450	4.13	152%	26225	7.01	NULL
Healthy	119775	32.01	62%	171800	45.91	NULL	156475	41.81	136%	168700	45.08	152%	199625	53.34	NULL
Stressed	194450	51.96	62%	139475	37.27	NULL	177425	47.41	136%	107700	28.78	152%	106600	28.49	NULL
Bare Soil	51400	13.73	62%	51475	13.76	NULL	29750	9.95	136%	82375	22.01	152%	41775	11.16	NULL

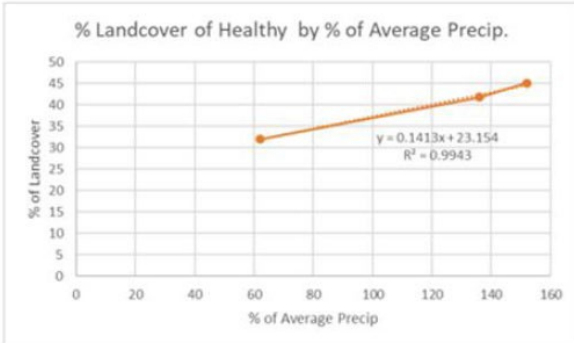

Fig 12: % Healthy landcover in terms of precip.

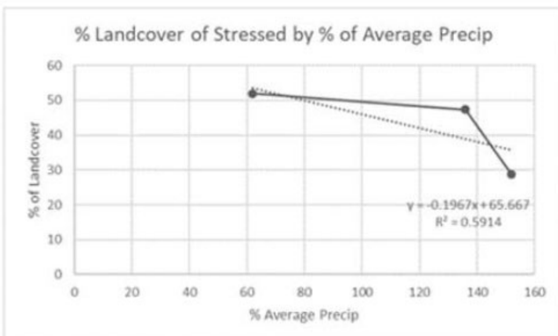

Fig. 13: % Stressed landcover in terms of precip.

Ground Truthing Data

The ground truthing data mostly corresponds to the remote sensing data. Foliage was as much as 12.6˚F higher than air temperature, and 10.9˚F cooler than air temperature. Using these values, the calculated WSI values varied between values of 0.0 and 1.0. After classification of the points as described in the methods, five of the forty points did not match up with the classification, including three points that indicate stressed vegetation and two points that indicate healthy vegetation where the opposite result is represented in the remotely sensed data (Fig. 14).

Discussion

Remote Sensing Data

Both the area of healthy and stressed vegetation varied greatly between the five years. Stressed vegetation decreased after 2017 (Figs. 10 and 11), suggesting that the drought stressed the pickleweed, especially in 2014 and 2016. During the wet 2017, adramatic downward trend in the total area of stressed vegetation is observed, as the amount of healthy vegetation starts to recover (Fig. 11). The results suggest that the ecosystem is sensitive to weather patterns and is adversely affected by drought (Fig 12 and 13). Stressed vegetation fluctuated less as healthy vegetation began to recover, however, which indicates that there are potentially further stress factors present in the salt marshes that were not assessed (such as lack of nutrients and wind stress).20614

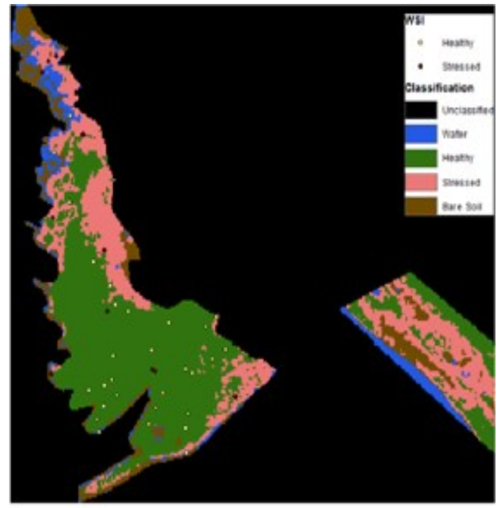

Fig. 14: Field Data and 2018 Classification

Ground Truthing Data

Out of the 40 points collected and assessed, 35 agreed with the remote sensing data. These results support the remote sensing model's findings for 2018 and suggest that the model was accurate in describing on the ground conditions in SRNWR. Since each data point only reflects the measurements from a single plant, and each remote sensing pixel is the mean value for 25m2 on the ground, there is a chance that this disagreement comes from the discrepancies between the sampling size of the two datasets.

Conclusion

Limitations of this study come from the quality of the data, specifically availability of precipitation data, and the total area of plants sampled at each survey point. Future studies should look at the ecosystem with higher temporal turnover, over entire seasons, and with larger sample plots to gather more spatiotemporal information. Additionally, weather data should be collected from an onsite weather station to increase the amount of precipitation data available for analysis. The addition of more information may tease out additional subtleties in the changes in the stress found within the wetland and to further improve future models and analysis.

Conservation requires planning for current and future environmental conditions. The results from this study help inform how drought impacts California's coastal salt marshes. Additionally, since data were able to be collected and statistically analyzed, fine resolution remotely sensed data can be deemed a viable tool for salt marsh studies. Having a greater understanding of how ecosystems respond to environmental changes helps inform further conservation efforts. Therefore, this study and similar others help inform the decision-making process and future conservation planning efforts.

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