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Vegetation Index Validation: Testing the efficiency of indices and tasseled cap transforms in identifying surface cover trends

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Abstract

Applicability of vegetative indices and tasseled cap transformations in ecological trend analysis is validated against numerous surveyed sample sites. Red-shift stretch and downward translation demonstrated close agreement with predicted vegetation increases while red-shift compression and upward translation was not as effective a predictor of vegetative declines. Vegetation indices and tasseled cap brightness and greenness transforms performed remarkably well in predicting vegetation trends. Moreover, a poor performance of the tasseled cap wetness index in predicting vegetation trends is revealed. In general, the vegetation indices are more accurate with an average 88% agreement with actual field data. Excluding the tasseled cap wetness index, the other two tasseled cap measures for brightness and greenness demonstrated they can reasonably be relied upon as vegetative trend indicators with an average 80% agreement between them and actual field survey plots. The 36% agreement provided by the tasseled cap wetness index is in need of further examination.

Keywords: Tasseled cap transformations; time series trend analysis; vegetation indices

1. Introduction

VEGETATION indices and tasseled cap transformations are routinely employed to identify vegetative surface cover from satellite imagery. Vegetation has characteristic spectral responses such as low red reflectance due to chlorophyll absorption and high near infrared (NIR) reflectance due to the reflectance from the internal structures of the canopy [1]. Remote sensing using multispectral imagers such as the Landsat instruments provide a wealth of data that can be used to monitor for changes in the environment.

Vegetation indices are useful tools to analyze for the increase or decline in vegetative surface cover. However, these indices are based primarily on the ratio between the red and NIR bands. Spectral response over time can demonstrate one of four possible trends: 1) Red-shift stretch in which the red response declines while the NIR increases. This response is consistent with increased vegetative surface cover resulting from higher red absorption from increased chlorophyll content and increased NIR reflectance due to higher reflectance from the internal structures of the increased vegetation cover. 2) Red-shift compression in which the red response increases while the NIR decreases. This response is consistent with decreased vegetative surface cover resulting from lower red absorption from decreased chlorophyll content and decreased NIR reflectance due to lower reflectance from the internal structures of the decreased vegetation cover. 3) Red-shift upward translation in which both the red and NIR response increase. We hypothesize that this complex response is due to both overall declining vegetative cover consistent with lower red absorption along with a change in composition of the vegetative surface cover with the new dominant species showing higher structural complexity that the original species. 4) Red-shift downward translation in which both the red and NIR response decline. We hypothesize that this complex response is due to both overall increasing vegetative cover consistent with greater red absorption along with a change in composition of the vegetative surface cover with the new dominant species showing lower structural complexity that the original species.

Since vegetation indices are essentially a measure of the red-shift, trends in vegetation indices are expected to correlate to trends in the spectral response. For the tasseled cap transformations, spectral trends which increase surface brightness are consistent with declining vegetative surface cover as vegetation tends to demonstrate lower reflectance than barren surface. Tasseled cap greenness responds to trends in the visible bands with lower visible reflectance resulting in a higher greenness index. Tasseled cap wetness measures the amount of water absorption in the scene. This correlates to the presence or absence of vegetative cover as vegetation tends to contain more water than barren surface.

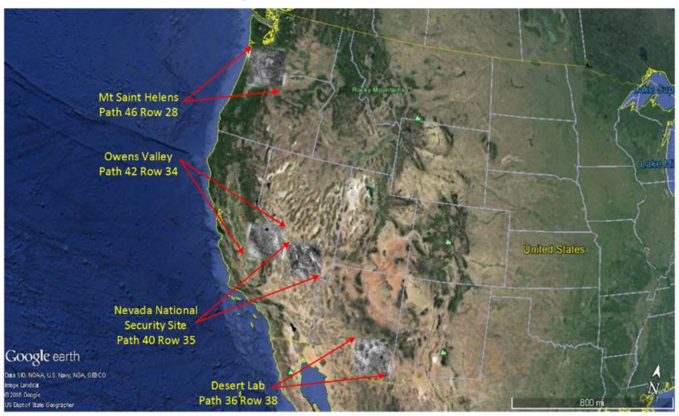
2. Problem identification and basic principle

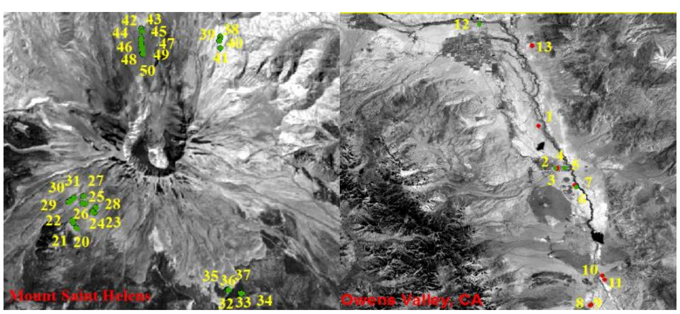
In this study, we measure the predictive efficiency of trends in six commonly used metrics of vegetative surface cover including three vegetation indices and three tasseled cap transforms. Trends in vegetative surface cover from fifty long-term survey plots are compared against trends in the vegetation indices and tasseled cap transformations derived from the USGS Climate Data Record database of Landsat surface reflectance data from those same plots.

A. Study Area Description

Figure one shows the location of the fifty survey plots used in this study. The location of each of the sites is provided in table one.

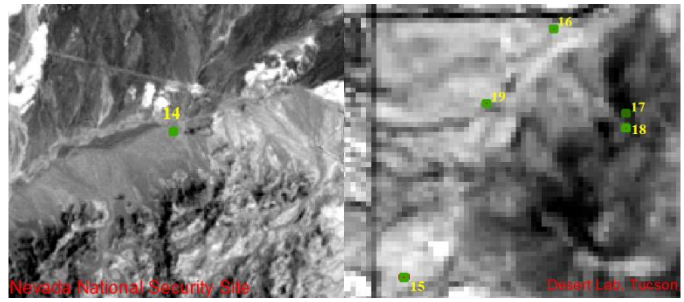
Study Site Locations





a. Mt Saint Helens, WA.

b. Owens Valley, CA.



c. Nevada National Security Site, NV.

d. Arizona State University, AZ.

Fig. 1 Location of the long-term vegetation survey plots

B. Data

The Landsat imagery used in this analysis includes a late spring/early summer cloud free image over each survey plot for each year in which survey data is available. Imagery covering the Mt Saint Helens area is from Path 46/Row 28, for the Owens Valles sites imagery is from Path 42/Row 34, for the NNSS site imagery is from Path 40/Row 35, and for the Desert Lab sites imagery is from Path 36/Row 38. The surface reflectance data product for each of these imagers was obtained from the EarthExplorer web site operated by the United States Geological Survey (http://earthexplorer.usgs.gov/). The data files are located in the Landsat Climate Data Record folder with the titles "Landsat Surface Reflectance - L4-5 TM".

TABLE I
SAMPLE SITE LOCATIONS

Site ID	Lat (N)	Long (W)	Site ID	Lat (N)	Long (W)
1	118.309	37.242	26	122.221	46.181
2	118.284	37.172	27	122.221	46.184
3	118.282	37.172	28	122.215	46.180
4	118.281	37.172	29	122.227	46.182
5	118.271	37.173	30	122.226	46.182
6	118.253	37.141	31	122.225	46.183
7	118.256	37.144	32	122.152	46.153
8	118.232	36.948	33	122.151	46.153
9	118.231	36.950	34	122.151	46.153
10	118.214	36.997	35	122.158	46.154
11	118.210	36.990	36	122.158	46.154
12	118.396	37.408	37	122.157	46.154
13	118.318	37.373	38	122.160	46.233
14	116.189	36.690	39	122.160	46.232
15	111.018	32.210	40	122.160	46.231
16	111.009	32.224	41	122.160	46.229
17	111.004	32.219	42	122.194	46.236
18	111.004	32.219	43	122.194	46.235
19	111.013	32.220	44	122.194	46.232
20	122.224	46.174	45	122.194	46.231
21	122.225	46.175	46	122.194	46.231
22	122.225	46.176	47	122.194	46.230
23	122.216	46.178	48	122.194	46.229
24	122.217	46.179	49	122.194	46.228

25	122.220	46.181	50	122.194	46.228

Validation of the performance of vegetation indices and tasseled cap transformations is accomplished by performing trend analysis of the Landsat imagery over sites of measured vegetation surface cover and composition. Fifty sites including thirty-one from Mt Saint Helens in Washington, thirteen from California's Owens Valley, one from the Nevada National Security Site, and five from the Desert Laboratory in Tucson Arizona were used for this analysis.

Field survey data from the Mt Saint Helens plots were obtained from the Ecological Archives website at http://esapubs.org/archive/ecol/E091/152/, [2]. Data for the Owens Valley plots were obtained upon request from the Inyo County Water department website at https://knb.ecoinformatics.org/#view/doi:10.5063/F1B56GNV . The Nevada National Security Site plot data was derived from two published studies in 1994 and 2003, [3], [4]. The Desert Lab survey site data were obtained from the Ecological Archives website at http://esapubs.org/archive/ecol/E094/083/, [5].

3. Methodology

A. Research Approach

Trends in surface composition and surface cover are compared against trends in vegetation indices and tasseled cap transformations. Accuracy of vegetation indices and tasseled cap transformations is determined by comparing trends in those metrics against actual long-term surveyed vegetation plots.

B. Research Methods

The research methodology consists of surface reflectance data collection; field survey data collection; and statistical analysis. USGS surface reflectance data is generated from a software package known as the Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS). The surface reflectance data is computed by applying an atmospheric correction to the raw Landsat imagery [6]. This atmospheric correction uses the Second Simulation of a Satellite Signal in the Solar Spectrum (6S) radiative transfer model to account for various atmospheric column constituents including water vapor, ozone, and aerosol optical thickness [7]. The USGS CDR data set provides us with observed surface reflectance values for each of the six reflectance bands for all survey sites in each year of the study.

The non-parametric Mann-Kendall (MK) trend test is used to establish the presence of trends in the spectral responses, vegetation indices, and tasseled cap transformations. This analysis essentially determines if a set of values (y) are increasing or decreasing over time. Mann-Kendall analysis looks at the sums of the signs of the differences between successive data points and calculates a score or "S" statistic with the following properties: for $S < 0$ (values are decreasing over time); for $S > 0$ (values are increasing over time). The magnitude of the S-statistic is a measure of the strength of the trend. These calculations are carried out in Excel using the XLSTAT add-in statistical application. This program generates the S statistic as well as the probability (p) value which is used to quantify the statistical significance of the trend. A more in-depth discussion of the MK trend analysis is available in [8].

4. Results and discussions

A. Validation of Vegetation Indices in Trend Studies

Vegetation indices have long been used to establish the presence of vegetative surface cover and to track how vegetative surface cover changes over time. In order to determine the accuracy of vegetation indices and tasseled cap transformations in ecological trend studies, we compare how those indices and transforms compare with actual field plot data. We consider both ratio indices which analyze the large difference in the red and NIR bands characteristic of vegetation and weighted ratios which focus on physical parameters such as surface brightness, greenness and wetness.

In this analysis we look at the following indices:

Normalized Difference Vegetation Index (*NDVI*), defined as

$$NDVI = \frac{\rho_{NIR} - \rho_{RED}}{\rho_{NIR} + \rho_{RED}}, \quad (1)$$

[9], where ρ_{NIR} is the reflectance in band 4 and ρ_{RED} is the reflectance in band 3; Soil Adjusted Vegetation Index (*SAVI*), defined as

$$SAVI = (1 + L)\,\frac{\rho_{NIR} - \rho_{RED}}{\rho_{NIR} + \rho_{RED} + L}, \quad (2)$$

where L is a soil correction factor set at 0.5 [10]; Modified Soil Adjusted Vegetation Index ($MSAVI_2$), defined as

$$MSAVI_2 = \frac{2\rho_{NIR} + 1 - \sqrt{(2\rho_{NIR} + 1)^2 - 8(\rho_{NIR} - \rho_{RED})}}{2}, \quad (3)$$

[11]; and Tasseled Cap transformations for Brightness (TC_B), Greenness (TC_G), and Wetness (TC_W) which are defined as

$$TC_B = 0.2043\rho1 + 0.4185\rho2 + 0.5524\rho3 + 0.5741\rho4 + 0.3124\rho5 + 0.2303\rho7, \quad (4)$$

$$TC_G = -0.1603\rho1 - 0.2819\rho2 - 0.4934\rho3 + 0.7940\rho4 - 0.0002\rho5 - 0.1446\rho7, \quad (5)$$

$$TC_W = 0.0315\rho1 + 0.2021\rho2 + 0.3102\rho3 + 0.1594\rho4 - 0.6806\rho5 - 0.6109\rho7, \quad (6)$$

where $\rho1\ldots7$ is the reflectance in band 1 through band 7 respectively [12].

Actual field plot data was collected from 50 long term study plots throughout the Western United States including 31 sites located on Mt Saint Helens in Washington, 13 plots in California's Owens Valley, 1 plot at the Nevada National Security Site in Nevada, and 5 plots at the Desert Lab in Tucson, Arizona. The time span of the permanent monitoring plots ranged from 12 to 28 years. At each plot, total vegetative cover and composition data were obtained.

A listing of the 50 plots, the change in percent vegetation cover and the spectral response and vegetative indices trends over those time periods is available on Google Docs at Plot Trends for validation of vegetation indices. Descriptions of how each plot changed over the time period of the study and how well the vegetation indices and tasseled cap transformations correlate to the actual field data is provided in another Google Docs file at Comparison of field data with vegetative indices.

TABLE II
CORRELATION OF INDICES TO SPECTRAL RESPONSE THEORY

Theory	NDVI	SAVI	MS_2	TC_B	TC_G	TC_W
ALL – 50 Sites	84	84	80	80	84	44
Red-Shift Stretch – 25 Sites	100	100	96	64	100	32
Red-Shift Compression – 3 Sites	67	100	67	67	100	100
Red-Shift Upward Translation – 7 Sites	29	14	14	100	14	100
Red-Shift Downward Translation – 15 Sites	87	87	87	100	87	27

Percentage of times the index match the re-shift theory of vegetation trend

Table two shows the level of agreement between the vegetative indices and tasseled cap transformations with the red-shift theory prediction for vegetation. For example, for the twenty five sites demonstrating red-shift stretch, trends in NDVI were positive in all twenty five cases (100% agreement with theory). For those same sites, tasseled cap wetness trends were consistent with increased vegetative cover at only eight of the sites (32% agreement with theory). Overall, the vegetation indices and the tasseled cap brightness and greenness show close correlation with the predicted vegetation trends based solely on the trends in spectral response for those sites. Trends in the tasseled cap wetness index ran counter to the predicted response more than half the time.

Table three shows the level of agreement between each red-shift theory and actual field data. Of the 50 plots analyzed, 25 demonstrated negative red trends with increasing NIR trends (Red-Shift stretch) consistent with increased vegetative surface cover. Actual transect data showed vegetative ground cover increasing in 24 of those 25 plots demonstrating Red-Shift Stretch (96% agreement with theory). Three of the plots demonstrated positive trends in the red response with declining NIR trends (Red-Shift compression) consistent with decreased vegetative surface cover. Two of the three plots did in fact show declines in surface cover (67% agreement with theory). Seven of the plots demonstrated increasing red trends with increasing NIR trends (Red-Shift upward translation). Four of these sites (57% agreement with theory) witnessed decreased vegetative surface cover while three demonstrated increases in surface cover. Fifteen plots demonstrated decreasing red trends with decreasing NIR trends (Red-Shift downward translation). Of these sites, 14 witnessed increased vegetative surface cover (93% agreement with theory) while 1 site experienced a decline in vegetative surface cover.

TABLE III
ACCURACY OF RED-SHIFT THEORY VS FIELD DATA

Spectral Response Trends	Accuracy of Red-Shift Theory
All Data – 50 Sites	88
Red-Shift Stretch – 25 Sites (Increasing Vegetation)	96
Red-Shift Compression – 3 Sites (Decreasing Vegetation)	67
Red-Shift Upward Translation – 7 Sites (Decreasing Vegetation w/comp change)	57
Red-Shift Downward Translation – 15 Sites (Increasing Vegetation w/comp change)	93

Table Four details the performance of each of the vegetative indices and tasseled cap transformations versus the actual field data. Overall, the vegetative indices performed better than the tasseled cap transformation, with the $MSAVI_2$ index recording the highest level of agreement (90%) with the actual measurements of vegetative surface cover. The tasseled cap wetness index demonstrated the least correlation (36%) with field data. This finding suggests caution in using tasseled cap wetness as a measure of vegetative surface cover change, especially in regions where vegetative cover is increasing.

TABLE IV
ACCURACY OF VEGETATIVE INDICES AND TASSELED CAP TRANSFORMATIONS VS FIELD DATA

Spectral Response Trends	NDVI	SAVI	MS_2	TC_B	TC_G	TC_W	AVG
All Data – 50 Sites	88	86	90	76	84	36	77
Red-Shift Stretch – 25 Sites	96	96	100	68	96	28	81
Red-Shift Compression – 3 Sites	100	67	67	100	67	67	78
Red-Shift Upward Translation – 7 Sites	57	71	57	57	57	57	60
Red-Shift Downward Translation – 15 Sites	93	80	80	93	80	33	74

Percentage of times the index match the actual field data

Composition change is evident in almost all of the surveyed plots with either the predominant species changing over the time period of the study or a significant expansion in one of the species compared to the others present in the initial survey. For those plots demonstrating red-shift upward translation, five out of the seven sites showed significant changes in their species composition between the initial and final surveys. Likewise in the fifteen re-shift downward translation plots, thirteen of the fifteen plots witnessed significant composition change.

B. Confidence Levels

Multitemporal satellite imagery is impacted by several factors including changes in sensor response, sensor stability, atmospheric effects, and illumination effects [13]. Geometric pixel registration errors are generally less than ½ pixel [14]. Radiometric uncertainty for the TM data are approximately 5% [15]. The USGS surface reflectance data set has been assessed against MODIS surface reflectance data and found to be highly correlated with discrepancies between 2.2 to 3.5 percent [16].

5. Conclusions

This study examined trends in spectral response, vegetation indices and tasseled cap transformations against fifty sites with known long term composition data to test the accuracy of four possible red-shift response hypotheses. Use of vegetation indices for ecological trend studies is problematic given the gap in understanding their meaning when the red and NIR bands are trending in the same direction. To address this information gap, red-shift translation postulates were developed and tested using actual field plot survey data.

We found that red-shift stretch and red-shift downward translation trends corresponded to actual increases in vegetative cover in over 90% of the sites studied. Red-shift compression and red-shift upward translation trends were not as accurate with actual field data showing declines in only 67% and 57% of the time respectively. For the vegetative indices and tasseled cap transformations, overall agreement between the indices and actual field data was 77%. Red-shift stretch and red-shift compression demonstrated the highest level of agreement with actual field data at 81% and 78% respectively. Red-shift upward translation and red-shift downward translation trends matched actual field data only 60% and 74% of the time respectively. Overall, the vegetative indices performed better than the tasseled cap transforms, with the MSAVI2 index recording the highest level of agreement (90%) with the actual measurement of vegetative surface cover. The tasseled cap wetness index demonstrated the least correlation (36%) with field data. This finding suggests caution in using tasseled cap wetness as a measure of vegetative surface cover change, especially in regions where vegetative cover is increasing. The striking difference in the accuracy of tasseled cap wetness compared to the other measures needs more in-depth investigation

These findings suggest that a simple explanation of composition change at sites demonstrating red-shift translation is not really telling us what is taking place. Likewise, the results of this study show that simple red-shift stretch and red-shift compression are not basic indicators of increase and decrease in vegetative cover, but may in fact also be the result of compositional change. Spectral response trends are influenced by several factors including changes in the amount of vegetation present and also the type. Since litter and barren surface also contribute significantly to the spectral response, changes in the percent cover of those surface components also must be considered.

Spectral responses measured by the Landsat program provide a unique resource for the ecological community to examine how sensitive areas have adapted to new environmental parameters. Vegetative indices and tasseled cap transformations allow us to elicit detailed information on changes taking place at the local assemblage level.

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The 1st International Conference on Energy, Environment and Economics (ICEEE 2016) was held at Heriot-Watt University, Edinburgh, EH14 4AS, UK, 16-18 August 2016. ICEEE2016 focused on energy, environment and economics of energy systems and their applications. More than fifty eight delegates from 31 countries with diverse expertise ranging from energy economics, solar thermal, water engineering, automotive, energy, economics and policy, sustainable development, bio fuels, Nano technologies, climate change, life cycle analysis etc. made conference true to its name and completely international. During conference total 51 oral presentations and six posters were shared between delegates. The presentations showed the depth and breadth of research across different research areas ranging from diverse background. ICEEE2016 aimed:

- To identify and share experiences, challenges and technical expertise on how to tackle growing energy use and greenhouse gas emissions and how to promote sustainability and economical, cost effective energy efficiency measures.

In total 11 technical sessions and two invited talks both from academia and industry provided insight into the recent development on the proposed theme of the conference. Preparation, organisation and delivery of the conference started from July 2015 and further co-ordinated by vibrant team of Conference Centre, Heriot Watt University. Conference organisers would like to acknowledge support from the sponsors particularly World Scientific Publication ltd and its team members for the delivery of the conference. Organisers are also thankful to all reviewers who contributed during peer review process and their contributions are well appreciated. At the end and during vote of thanks following awards have been announced and we would like to congratulate all well deserving delegates.

- Best Paper –Academia: Amela Ajanovic, EEG, TU Vienna, Austria
- Best Paper – Student : Christian Jenne,University of Duisburg-Essen, Germany
- Best Poster – Student: Yoann Guinard, University of New South Wales, Sydney, Australia
- Best Poster – Academia: E. Salleh, Universiti Kebangsaan Malaysia, Malaysia
- Active Participation Award - Yoann Guinard, University of New South Wales, Sydney, Australia

At the end we would like to extend our gratitude to all of you for your participation and hopefully welcome you again during ICEEE2017.

Editors:

Dr. Singh is Senior Scientist at Indian Agricultural Research Institute, New Delhi, India. Her area of expertise are bio energy and bio fuels, environmental engineering, carbon accounting and renewable energy integration for rural development.

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