A Procedure to Extrapolate Vegetation Cover Estimates Over Large Arid and Semi-arid Regions Using Multiple Spatial Resolution Imagery

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Abstract

Typically, land degradation on arid and semi-arid military training and testing lands in the desert Southwestern United States is associated with a decrease in total vegetative cover. Long-term field surveys have been established by the military to measure and monitor total vegetative cover over time. However, field methods are not cost effective due to the large area of training lands, nearly 3 million acres in the California deserts alone, that must be sampled. Measurements recorded at individual transects must still be spatially extrapolated to produce a complete census of the installation. Remote sensing has been used to spatially extrapolate such field measurements over larger areas, but in the past, imagery has lacked sufficient spatial resolution to accurately estimate total vegetative cover. In this study, nested, high resolution imagery was collected at different spatial resolutions for study sites at the Marine Corps Air Ground Combat Center in the south-central Mojave Desert of southern California. Vegetation cover estimates derived from these multiple resolution images were examined as a possible surrogate for sampling total vegetative cover in the field. Results indicate that a high correlation exists between field measurements of cover and estimates of cover derived from imagery. However, similar to field measurements, if the intent is to estimate total vegetative cover across large geographic areas, high resolution imagery is also costly in terms of collection, processing, and interpretation because a single image generally covers a small geographic area. Therefore, a protocol to scale detailed observations of total cover from high resolution imagery to lower resolution imagery that covers a larger geographic area was developed and tested. The results of this study indicate that a relatively high correlation exists between vegetation cover estimates derived from high resolution imagery and image brightness derived from a nested, lower resolution image. This protocol now allows military land managers to sample site-specific areas with high resolution imagery and extrapolate absolute estimates of vegetation cover across training and testing lands with more cost effective, lower resolution imagery that provides complete coverage of an installation.

Introduction and Background

A large number of Department of Defense (DOD) training and testing installations exist in arid and semi-arid environments of the desert Southwestern United States. The Marine Corps Air Ground Combat Center (MCAGCC) at Twentynine Palms, CA is located within the arid Mojave Desert, and therefore is highly susceptible to long-term disturbance caused by both natural and anthropogenic factors. The MCAGCC Natural Resources and Environmental Affairs (NREA) Division is responsible for the sustainability of natural resources in support of military readiness and the installation’s training mission. MCAGCC natural resource managers require information on land condition to make informed land management decisions related to sustaining the training mission while Supporting conservation and compliance efforts.

The U.S. Army Corps of Engineers (USACE) Engineering Research and Development Center (ERDC) is developing and designing the Land Management System (LMS) to...
improve capabilities and effectiveness in land and water resource management on DOD training and testing installations (Goran et al. 1999). LMS is an effort to design, develop, support, and apply an integrated capability for modeling and decision support technologies relevant to DOD management of lands, seas, and airspace. Integral to many of these capabilities are spatial technologies, including remote sensing and Geographic Information Systems (GIS). MCAGCC has been selected as a demonstration and field application test site for LMS, with an emphasis on wind erosion modeling/control and land based carrying capacity. Critical to both of these efforts is a need to develop methods to characterize and monitor vegetation amount, condition, and composition in a cost-effective manner.

Many DOD installations, including MCAGCC, have implemented the Land Condition Trend Analysis (LCTA) program, which is part of the Integrated Training Area Management (ITAM) plan for the U.S. Army, in order to provide a standardized method of inventory and monitoring of vegetation and wildlife (Tazik et al. 1992). Permanent plots are established and visited annually to conduct a detailed census of vegetation and wildlife. However, field surveys are expensive, and therefore a complete survey of large installations is cost prohibitive and a detailed vegetation map is often lacking. Long term trends in vegetation condition can be monitored by LCTA field surveys, but it is not feasible to assess vegetation condition at any one time over a large area based solely on field surveys. To make such an assessment, information collected at LCTA field survey point locations must be spatially extrapolated to those areas that are not sampled. However, field surveys, when supplemented with remotely sensed imagery, do provide the necessary information to characterize and monitor changes in vegetation condition at different scales and levels of detail and to extrapolate this information over larger geographic areas (Frank 1984; Musick 1986; Robinove et al. 1981; Senseman et al. 1996; Tueller 1995; Tweddale et al. 2000; and Tweddale et al. 2001).

The objective of this research has been to assess the accuracy of vegetation cover estimates derived from nested, multiple spatial resolution imagery, acquired from both fixed wing aircraft and satellite, compiled for three study sites at or near MCAGCC. A method to scale up vegetation cover estimates to larger geographic extents was developed and tested for accuracy.

**Materials and Methods**

**Ecological Description of Study Sites**

Three study sites were used in this research. These sites were selected to represent dominant plant communities that commonly occur in disturbed areas throughout this arid region. This area is part of the Great Basin Section of the Basin and Range physiographic province. The topography of the area has an elevation of 700 to 4,100 feet above sea level. Principal landforms consist of mountain ranges, hills, alluvial fans, ephemeral streams, playas, and lava flows.

Soils are generally gravelly fine sand. The vegetation is sparse and is comprised mainly of small shrubs and non-native grasses found in creosote bush scrub communities. Two of the study sites were located on the Marine Corp Air Ground Combat Center (MCAGCC) at Twentynine Palms, California. The third study site was located at a desert wash on Bureau of Land Management land, approximately twenty miles to the southeast, where disturbance was caused by occasional recreational off-road vehicle use.

Wood Canyon, an evergreen subdesert shrubland, is a highly disturbed desert wash that serves as a primary east to west travel corridor for military vehicles on MCAGCC (Figure 1a). Wood Canyon is unique because relatively small shrubs are absent, as a result of vehicle movements; yet larger shrubs, such as *Chilopsis linearis* and *Psorothamnus spinosus* dominate the landscape. Continuous disturbance allows this site to remain relatively stable, with low vegetation cover and diversity, and widely scattered shrubs that have a large range in the size of individual shrubs (Figure 1b). *C. linearis* is the largest of the shrubs, with heights ranging from four to twenty feet tall. Branches are slender with very long and simple leaves (Dole and Rose 1996).

Sand Hill (Figure 1c), a deciduous subdesert shrubland, is a relatively flat region dominated by *Larrea tridentata* and *Ambrosia dumosa*, but interspersed with *Schismus barbatus*, an exotic grass associated with disturbance. *L. tridentata* is ubiquitous throughout the Mojave Desert and can be found in almost all dominant vegetation communities. It is one of the most abundant and oldest shrubs of the desert, and grows to an average of four to six feet tall (Dole and Rose 1996). The canopy is very open which allows the underlying soils to be visible from above. *A. Dumosa* is found on mesas and plains along side *L. tridentata*. This shrub is compact and dense with an average height of two feet. Relatively few other species are apparent at Sand Hill. This site is divided by an unpaved gravel road; to the north the area is used by military vehicles during training exercises, while to the south off-road traffic has been prohibited since the mid-1980’s to protect installation water supplies and desert tortoise habitat. Shrubs in both areas are compact, dense, and relatively small in comparison to other populations in the Mojave.

Gold Crown Wash (Figure 1d), an evergreen subdesert shrubland, consists of two co-dominant species, *L. tridentata* and *P. spinosus*, with other shrubs occurring less frequently, particularly *Atriplex polycarpa* and *A. dumosa*. The site is the long and broad desert wash where there is evidence of localized off-road vehicle use. *P. spinosus* range in height from six to thirty feet. They are found in desert washes due to their high water requirements. This site offers a contrast to the other two study sites, both in terms of landuse and associated impacts (military versus recreational use) and the resulting diversity and variation in size of the plants.

**Image Acquisition**

A color infrared digital camera (Kodak DCS 420), and a Computerized Airborne Multicamera Imaging System
(CAMIS) were mounted on a fixed wing aircraft and flown over study sites May 20, 1999. The aircraft was flown at altitudes varying from 1,420 to 12,000 feet to collect multiple resolution imagery where the footprint of higher resolution images were nested or contained within the footprint of larger spatial resolution images (Table 1). In addition, an IKONOS 1m panchromatic and 4m multispectral satellite image from March 25, 2000, as well as a 28m Landsat TM-7 multispectral satellite image from August 12, 1999, were acquired for each of the study sites.

The Kodak and CAMIS images were radiometrically corrected using sensor models developed at the U.S. Army Corps of Engineers - Engineer Research and Development Center - Topographic Engineering Center (ERDC-TEC), Ft. Belvoir, Virginia to correct for lens anomalies and distortions. Radiometric calibration allowed for in-sensor comparisons of images at different spatial resolutions.

**Field Transects**

In order to assess the accuracy of vegetation cover estimates derived from high resolution systems, *in situ* cover estimates were measured at random locations within the three plant communities. Fixed radius transects were used to measure the area of each shrub within a 2.5 meter radius circle. The coordinates of the center point of the transect were collected with a differential GPS. A five meter buffer was created around this center point with a geographic information system so that an area to area comparison of cover measured in the field with cover estimates extracted from the classification of the digital imagery could be achieved. This comparison was accomplished by linear regression of field measurements of cover and image cover percentages for a total of ninety transects. Data recorded at these transects were also used for an area to area comparison of vegetative cover measured in the field with albedo extracted from digital imagery, again using linear regression of field measurements of percent cover and albedo. Field measurements of percent cover were also used to validate the final estimated cover map resulting from the scaling analysis.

**Scaling Analysis**

Scaling analysis utilized a spatially nested and co-registered pair of images of different spatial resolutions or pixel sizes that were subsetted to the same geographic extent or footprint. The higher resolution image (smaller pixel size) was classified using an unsupervised, maximum likelihood classification and post-classification sorting, resulting in map of vegetative cover and bare ground. The first principal component (brightness or “albedo”) was calculated from the lower resolution imagery (larger pixel size). A new cover map was created at the same resolution as the lower resolution image by aggregating from the cover classification of the underlying, nested high resolution imagery. For example, if scaling between 1.0m CAMIS imagery and 4.0m IKONOS imagery, a new cover map based on information from the 1.0m CAMIS imagery was created at 4.0m resolution. Each 4.0m pixel was assigned a cover value derived from the sixteen 1.0m CAMIS pixels underlying the 4.0m pixel. If 8 of 16 pixels in the underlying 1.0m image were classified as vegetation cover, and 8 were classified as bare ground, then the 4.0m pixel was assigned a

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**Table 1** Image collection systems used on fixed wing aircraft and satellite platforms to collect nested, multiple resolution images.

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Altitude</th>
<th>Spatial Resolution</th>
<th>Wavebands</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kodak DCS 420</td>
<td>1,420 ft</td>
<td>0.2m</td>
<td>green, red, NIR</td>
</tr>
<tr>
<td>CAMIS</td>
<td>3,200 ft</td>
<td>0.5m</td>
<td>blue, green, red, NIR</td>
</tr>
<tr>
<td></td>
<td>6,300 ft</td>
<td>1.0m</td>
<td></td>
</tr>
<tr>
<td></td>
<td>12,000 ft</td>
<td>2.0m</td>
<td></td>
</tr>
<tr>
<td>IKONOS</td>
<td>1.0m/4.0m</td>
<td></td>
<td>blue, green, red, NIR</td>
</tr>
<tr>
<td>Landsat 7 TM+</td>
<td>28.0m</td>
<td></td>
<td>blue, green, red, NIR, SWIR</td>
</tr>
</tbody>
</table>

**Figure 1** (A) 1.0m Computerized Airborne Multicamera Imaging System (CAMIS) image of Wood Canyon displayed in 3-D, Field photos of (B) Wood Canyon, (C) Sand Hill, and (D) Gold Crown Wash.
vegetative cover value of 50% (Figure 2). To facilitate aggregation, the smaller pixel size had to be an even multiple of the larger pixel size. Cover estimates derived from the higher resolution classification and aggregated to match the lower resolution image were compared to the first principal component (albedo) of the lower resolution imagery using simple linear regression. Aggregation from the lower to higher pixel resolution when producing the cover map facilitated a paired comparison of all pixels from both images at the same lower resolution pixel size using regression analysis. The regression equation describing the relationship between these variables, cover and brightness or albedo, was entered into a map calculator in a Geographic Information System (GIS). Using the entire geographic extent or footprint of the lower resolution as the input, independent variable, a map calculator was used to produce an estimated cover map for the entire geographic extent of the lower resolution image.

Results

Comparison of Image Cover Estimates to Field Cover Measurements

Estimates of cover derived from classifications of imagery of nested spatial resolutions were compared with field measurements of cover to validate the accuracy of the cover images using simple linear regression (Table 2.) High correlation coefficients (0.7 to 0.9) between field
measurements of percent cover and estimated percent cover from imagery of nested spatial resolutions indicates that accurate cover estimates can be extracted from classifications of high resolution airborne and spaceborne imagery.

**Comparison of Image Albedo to Field Cover Measurements**

In order to validate that albedo can be used as a surrogate measure for predicting total vegetative cover, albedo from the nested spatial resolution imagery were related to field measurements of cover using linear regression (Table 3). In this case, comparisons between field measurements of cover and image albedo were only made with the 0.5m, 1.0m, and 2.0m CAMIS imagery. All correlation coefficients were greater than 0.69, with the exception of the 2.0m CAMIS image at Wood Canyon. CAMIS 2.0m imagery was not available for the Sand Hill site. The high correlation coefficients indicated that albedo may be used to directly estimate percent cover, thereby eliminating the need to perform cover classifications of the imagery.

**Scaling Analysis**

Although scaling analysis has been completed at all 3 study sites, statistics and resulting extrapolated cover maps are only presented for the Wood Canyon study site. Statistical relationships between vegetation cover from the high resolution samples and image albedo (1st Principal Component) derived from the lower resolution imagery were identified between each possible combination of large scale (high spatial resolution) and small scale (low spatial resolution) imagery. A correlation matrix that summarizes the correlations between each of the possible combinations of resolutions is presented in Table 4 for the Wood Canyon study site at MCAGCC.

The 0.5m CAMIS imagery provided the best results for sampling cover and then scaling up to progressively coarser resolution imagery, with correlation coefficients of 0.79 with 1.0m CAMIS imagery and 0.68 with 2.0m CAMIS imagery. Using the example of scaling from 0.5m CAMIS imagery to 2.0m CAMIS imagery, the relationship between cover estimates derived from the 0.5m CAMIS image and the first principal component (image brightness) of the 2.0m CAMIS image was:

Extrapolated Cover Estimate = 222.0 - 0.833 (CAMIS 2.0m 1st principal component) (Eq. 1)

This relationship was entered into a map calculator to produce a map of estimated cover for the entire geographic extent or footprint of the CAMIS 2.0m image (Figure 3). The input was the 1st principal component image of the entire CAMIS 2.0m image, and not just the area that was subsetted to match the 0.5m CAMIS image. Estimating cover for the entire area of the 2.0m CAMIS image footprint (approximately 1.8km²) allows one to spatially extrapolate or “scale up” cover estimates to a much larger area than the footprint of the underlying 0.5m CAMIS image (approximately 0.01km²). The footprint of the 0.5m CAMIS image is

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**Table 2** Correlation coefficients (R²) between field measurements of percent cover and cover estimated from image classifications of varying spatial resolution.

<table>
<thead>
<tr>
<th></th>
<th>0.25m CAMIS</th>
<th>0.5m CAMIS</th>
<th>1.0m CAMIS</th>
<th>1.0/4.0m merge</th>
<th>2.0m CAMIS</th>
<th>4m IKONOS.</th>
</tr>
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<tbody>
<tr>
<td>Wood Canyon</td>
<td>0.93</td>
<td>0.89</td>
<td>0.81</td>
<td>0.53</td>
<td>0.74</td>
<td>0.75</td>
</tr>
<tr>
<td>Sand Hill</td>
<td>0.73</td>
<td>0.51</td>
<td>0.75</td>
<td>0.82</td>
<td>0.35</td>
<td>NA</td>
</tr>
<tr>
<td>Gold Crown</td>
<td>0.88</td>
<td>0.85</td>
<td>0.83</td>
<td>0.77</td>
<td>0.71</td>
<td>0.13</td>
</tr>
</tbody>
</table>

**Table 3** Correlation coefficients (R²) between field measurements of percent cover and albedo and texture calculated from images of varying spatial resolution.

<table>
<thead>
<tr>
<th></th>
<th>0.5m CAMIS</th>
<th>1.0m CAMIS</th>
<th>2.0m CAMIS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood Canyon</td>
<td>0.94</td>
<td>0.92</td>
<td>0.05</td>
</tr>
<tr>
<td>Sand Hill</td>
<td>0.69</td>
<td>0.69</td>
<td>NA</td>
</tr>
<tr>
<td>Gold Crown</td>
<td>0.91</td>
<td>0.74</td>
<td>0.70</td>
</tr>
</tbody>
</table>

**Table 4** Correlation coefficients (R²) between estimated cover from higher resolution (larger scale) imagery and a brightness index (1st principal component) from coarser resolution (smaller scale) imagery at the Wood Canyon study site, MCAGCC.

<table>
<thead>
<tr>
<th>Resolution</th>
<th>0.25m</th>
<th>0.5m</th>
<th>1.0m</th>
<th>1.0m IKONOS pan</th>
<th>2.0m</th>
<th>4.0m</th>
<th>28.0m</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.25m</td>
<td>1</td>
<td>0.5</td>
<td>0.46</td>
<td>0.25</td>
<td>0.72</td>
<td>0.15</td>
<td>0.00</td>
</tr>
<tr>
<td>0.5m</td>
<td>1</td>
<td>0.79</td>
<td>0.54</td>
<td>0.68</td>
<td>0.27</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>1.0m</td>
<td>1.00</td>
<td>0.53</td>
<td>0.59</td>
<td>0.31</td>
<td>0.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.0m IKONOS pan</td>
<td>1.00</td>
<td></td>
<td>0.05</td>
<td>0.39</td>
<td>0.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.0m</td>
<td>1.00</td>
<td></td>
<td>0.27</td>
<td>0.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.0m</td>
<td></td>
<td></td>
<td>1.00</td>
<td>0.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>28.0m</td>
<td></td>
<td></td>
<td></td>
<td>1.00</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>
shown as a rectangle superimposed on the image of estimated cover for the 2.0m CAMIS image in Figure 3.

Validation of Extrapolated Cover Estimates

Vegetative cover estimates derived from the scaling analysis produced cover estimates for the entire geographic extent of the small scale (coarse resolution), larger footprint image using Equation 1. These extrapolated vegetative cover estimates were validated by comparing them to field measurements of cover collected for fixed radius transects described above. For the Wood Canyon study site, this comparison was achieved by linear regression of extrapolated cover estimate derived from scaling analysis and in-situ measurements of total cover for 25 fixed radius transects. A high correlation ($R^2 = .76$) between extrapolated cover estimates and in situ measurements of total cover was found for the Wood Canyon study site, thus validating the accuracy of cover estimates derived from the scaling procedure. The relationship between extrapolated cover estimates and field validation measurements was:

$$\text{Field Measure of Cover} = -2.58 + 1.38 \times \text{(Extrapolated Cover Estimate)} \quad (\text{Eq. 2})$$

Conclusions

Airborne video imagery and emerging satellite imagery now provide adequate spatial resolution to characterize and monitor sparse desert vegetation. However, because of the relatively small geographic coverage of this type of imagery, it is still cost-prohibitive to acquire a complete coverage of a DOD training and testing installation, especially if the intent is to develop a monitoring protocol which would require temporal coverage. Therefore, a method has been developed that utilizes high resolution imagery to sample the landscape and provide detailed estimates of total vegetative cover. Cover estimates from these samples are validated with field measurements and then scaled up to larger geographic regions by relating them to albedo of smaller scale imagery with a larger geographic coverage. Scaling up cover measurements from large scale to small scale imagery allows for extrapolation of cover estimates over much larger geographic regions, thereby reducing the overall cost of characterization and monitoring of vegetation cover on DOD training and testing installations.

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