Evaluating the Use of Landsat 30m Enhanced Thematic Mapper to Monitor Vegetation Cover in Shrub-Steppe Environments

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Abstract

Many land-management agencies are caught between decreased budgets and increasing public interest. Furthermore, semi-arid landscapes are sensitive to management prescriptions and use, and require a significant amount of monitoring in order to assess vegetation productivity and health. The purpose of this study was to evaluate the use of Landsat Enhanced Thematic Mapper (ETM) Imagery to monitor seasonal vegetation cover in a shrub-steppe ecosystem. The study area, managed by The Utah School and Institutional Trust Lands Administration, consists of a shrub-steppe environment in south-central Utah. Biotic (tree, shrub, grass, and forbs) and abotic (slope, aspect, elevation, landform type, and slope shape) data were collected during the 2001 growing season and compared with three dates of Landsat ETM satellite imagery. The relationships between remotely sensed parameters, photosynthetically active ground cover and bare ground were significant. Stepwise linear regression for total vegetation cover identified the ETM bands 2, 4, and 5 with NDVI as the strongest predictor variables ($r^2 = 0.86, p < 0.01$). Combined predictor values for bare ground using ETM bands 3, 4, 5, and 7 with NDVI had a stronger relationship ($r^2 = 0.92, p < .01$). Correlations between percent vegetation cover estimates versus ETM individual reflective bands and NDVI showed little relationship between vegetation cover and the NIR (band 4) but a strong relationship with NDVI for this semi-arid landscape. Remote sensing information may be the key for public and private land mangers to make optimal economic and environmental decisions regarding use of state, public, and private rangelands.

Introduction

Remotely sensed imagery has been used to estimate vegetation cover and biomass for agriculture (Pinter *et al*., 2003), rainforests (Steininger, 2000), urban areas (Small, 2001), and rangeland (Todd *et al*., 1999). Research relative to the use of satellite-based remote sensing imagery to assess landscape level landcover in semi-arid rangelands is not new and work continues. Previous work has examined spectral characteristics of landcover (Zhu *et al*., 2003, Muldavin *et al*., 2001, West, 1999, Bork *et al*., 1998, Sohn and McCoy, 1997, Tueller, 1987, Frank, 1985, Frank, 1985a, Robinove *et al*., 1981), estimated biomass, cover, and carbon (Tolk *et al*., 2003, Wylie *et al*., 2003, Wylie *et al*., 1995, Anderson *et al*., 1993, and Wylie *et al*., 1991), developed and evaluated landscape change (Elmore *et al*., 2000, Pickup *et al*., 1993, Graetz, 1987, and Frank, 1984) and has provided the background necessary to begin the development of remote sensing based tools for monitoring of semi-arid landscapes. Work by Graetz (1987), West (2003, 2003a), West and Wu (2003), and Washington-Allen *et al*. (2003, 2003a) has also promoted and established the necessity and utility of using remote sensing based metrics as a tool for effective landscape level monitoring. This previous work, among others, has helped establish a baseline and rationale for land managers to acquire the expertise and technology necessary to monitor rangelands using satellite based remote sensing from a variety of platforms providing application to a wide span of spatial scales.

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The normalized difference vegetation index (NDVI) has established itself as the most common broadband index used to estimate vegetation parameters and is as accurate as most of the other broadband indices including the square of scaled NDVI, the soil adjusted vegetation index (SAVI) (Rundquist, 2002), the Tasseled Cap, greenness vegetation index (GVI), brightness index (BI) and the wetness index (WI) (Todd *et al*., 1999). Lu *et al*., (2003) showed linear and curvilinear relationships between field-measured leaf area index (LAI) and NDVI and used these relationships to help separate land cover components and infer LAI across Australia.

The documented strength of the NDVI to measure surface vegetation cover and LAI has provided the basis for the development of monitoring tools to assess land cover conditions at relatively high temporal resolution. While this study focuses on the use of the Landsat 7 Enhanced Thematic Mapper (ETM) sensor to assess the strength of the relationship of NDVI with ground based vegetation cover measurements, the ability to transfer this relationship to higher temporal resolution, but lower spatial resolution sensors like MODIS exists (Tian *et al*., 2002). Therefore, the potential to make this application operational to management agencies is strong given the current access to high quality, high temporal, but lower resolution imagery.

The Utah School and Institutional Trust Lands Administration (TLA) was established to manage approximately 3.5 million-acres of real estate trust lands that the U.S. Congress granted to the state of Utah for the support of schools and other beneficiary institutions (State of Utah School and Institutional Trust Lands Administration, 2002). Trust lands include both surface and mineral lands. Significant uses of surface lands include grazing by domestic livestock, habitat by wildlife, and recreation. Trust lands are leased to private landowners and grazing associations on a 15-year permit basis. The amount that the lessees pay is tied to forage production that determines the number of animal units they can graze during a given season. Vegetation production is directly related to past grazing use, long-term range condition, and climatic variations. Given the number of leases and the limited TLA staff available to monitor forage production, utilization, and range conditions, the information needed to make decisions regarding annual stocking rates is often limited. To ensure proper range conditions are maintained to sustain the grazing leases that generate income for state schools, a better system of monitoring forage availability and overall range condition is needed. Such a system would make it possible for TLA to optimize income while maintaining long-term range conditions on the lands TLA administers.

Presently, trained range technicians are employed to monitor vegetation utilization, production, and range conditions on lands grazed by domestic livestock. These technicians must establish permanent vegetation transects on areas to be monitored and return periodically throughout the growing season to sample these transects and assess forage availability and utilization. Given that this information is often available well after the grazing season, the ability of managers to balance long-term forage use with production may be compromised. While these methods meet the current standards for accuracy and precision, on larger areas they are labor intensive, expensive, and subject to sampling error.

In 1987, Graetz stated that satellite imagery has found little use in rangeland inventory and monitoring, and based on personal experience with management agencies, we concur that in the intervening years, there has been little adoption of these technologies for systematic monitoring of rangelands at an operational level. However, based on the aforementioned literature, remote sensing offers a viable and alternative method to objectively and systematically monitor rangeland condition and trend by estimating photosynthetically active vegetation throughout a growing season. The strength of the relationship between the NDVI and percent cover of active vegetation on the surface in semi-arid rangelands may make it possible to assess variations in rangeland productivity through the growing season.

The primary objective of this project was to evaluate the use of Landsat 7 ETM to monitor seasonal vegetation cover in a shrub-steppe ecosystem. Further, we look at how this or other remote sensing (RS) technologies can be used to assist public and private land managers to make better business and ecological decisions regarding the use of state, federal, and private rangelands.

Methods

Study Area

The study site is located in south-central Utah in portions of Garfield, Piute, and Wayne Counties and is known as the Parker Mountain Allotment (Figure 1). This allotment comprises 31,475 hectares, 80 percent of which consists of mountain sagebrush rangelands. Pinion/Juniper communities cover approximately 11 percent, and the remainder consists of deciduous and coniferous forests. Elevation ranges between 2,300-3,000 m ASL. Slopes are generally moderate with an average of 10 percent. Annual precipitation in the area averages 22.5 cm per year falling predominantly in the late summer, fall, and winter months (Figure 2). During the 2001 year, approximately 18.3 cm of precipitation was recorded. The area has traditionally been used as spring-summer grazing by both domestic cattle and sheep. There are local populations of antelope (*Antilocarpra americana*), mule deer (*Odocoileus himionus*), elk (*Cervis, elaphus canadensis*), sage grouse (*Centrocercus urophasianus*), and the Utah prairie dog (*Cynomys parvidens*).

Field Data Collection

Field data collection was performed during the months of June and July 2001. A total of 33 reference sites were selected based on the concept of “ecological stands,” or homogeneous areas with respect to (a) the existing dominant/diagnostic species of the uppermost or dominant stratum, and (b) abiotic characteristics (e.g. soils, climate, slope, aspect, etc.). Reference sites were larger than 120 x 120 meters, or 4 x 4 Landsat ETM pixels. All sample sites were

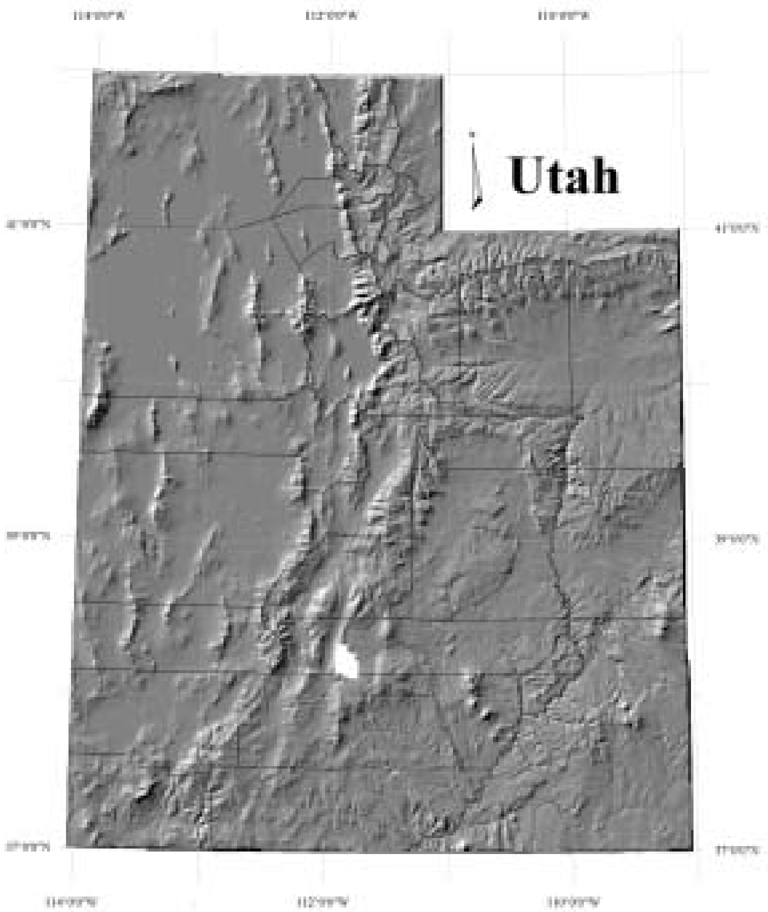

Figure 1 Geographic Location (area in white) of the Parker Mountain, Utah grazing allotment used for this study.

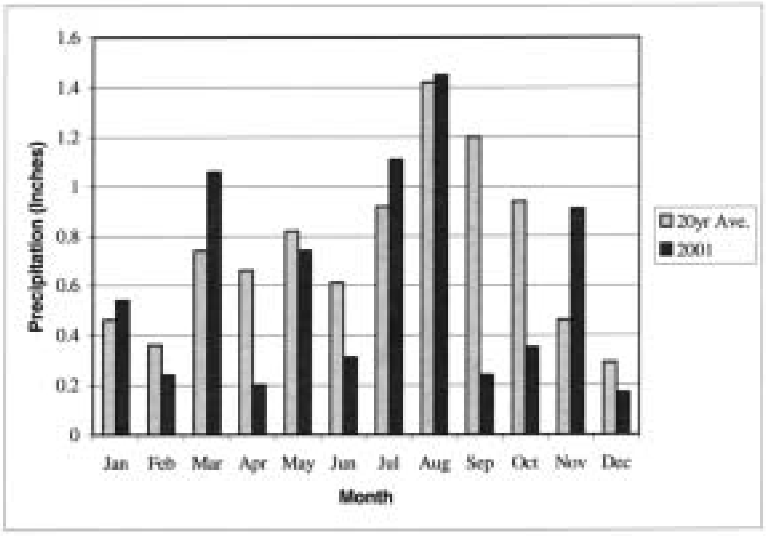

Figure 2 Historic and current (with imagery date) precipitation distribution for the study area.

located in the field with a Trimble(tm) GeoII GPS receiver. Field sites were located and recorded independently from remotely sensed imagery. That is, imagery was not used to locate field sites.

Field data consisted of ocular estimates of total, two-dimentional, percent cover of biotic and abiotic components. Vegetation cover was separated into four life forms (tree, shrub, grass, and forb) and estimates of percent cover for the top four prevalent species were recorded if present. Percent cover estimates were made to equal 100% when considering both biotic and abiotic components (e.g. bare soil, rock, etc.) Occular estimates were calibrated by comparison of estimates from two individuals.

Image Processing

Three Landsat 7 ETM images collected throughout the 2001-growing season were used for this study (Figure 3). These data sets included a May 31, 2001, a June 16, 2001, and a July 17, 2001 image to represent vegetation through one summer growing season. Images earlier and later in the growing season were not available due to cloud cover. The May 31 image was rectified to a 1m digital orthophotoquad to a root mean square (RMS) tolerance of 15m using a bilinear interpolation. The June and July mages were geometrically registered to the May image to a tolerance of no more than 15m RMS between images. All images were radiometrically and atmospherically normalized by converting to exoatmospheric reflectance and correcting for solar angle using the Cosine Theta atmospheric correction model described by Chavez (1996). Mean reflectance values from the six reflective spectral bands were calculated for all 33 field sites.

Results

Air temperatures in this high elevation, shrub-steppe environment varied significantly throughout the summer months. A general increase in temperature occurred from April through the end of July during the summer of 2001, but temperatures during this time cycled about every 10 days with a drop in temperature of approximately 10 degrees Celsius. Maximum and minimum temperatures were similar for each of the acquisition dates (Figure 4), but temperatures preceding image collection varied. The May 31, 2001 image had sustained temperatures 10 days before image collection, while the June 16, 2001 and July 19, 2001 images had lower temperatures during the equivalent time period. Moreover, the June 16 image had minimum nighttime temperatures below freezing within hours of image capture. Cumulative precipitation increased from 22.23 cm to 28.83 cm during the months of April through the end of July (Figure 5). Cumulative precipitation was 23.28 cm for the May 31, 2001 and June 16, 2001 image dates and increased to 27.18 cm for the July 19, 2001 image.

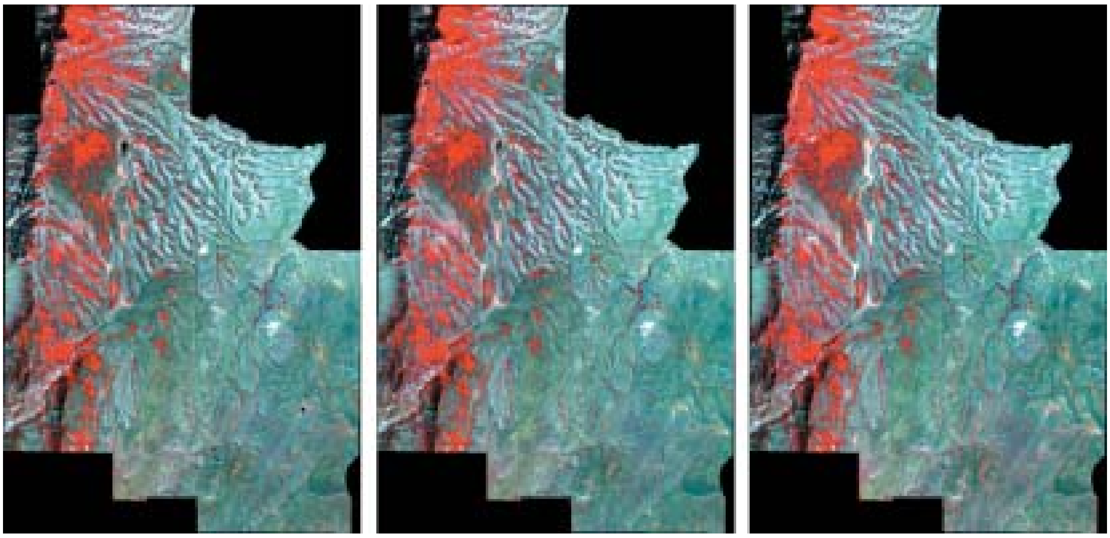

Figure 3 Time Series Landsat 7 ETM+ imagery from May, June, and July of 2001.

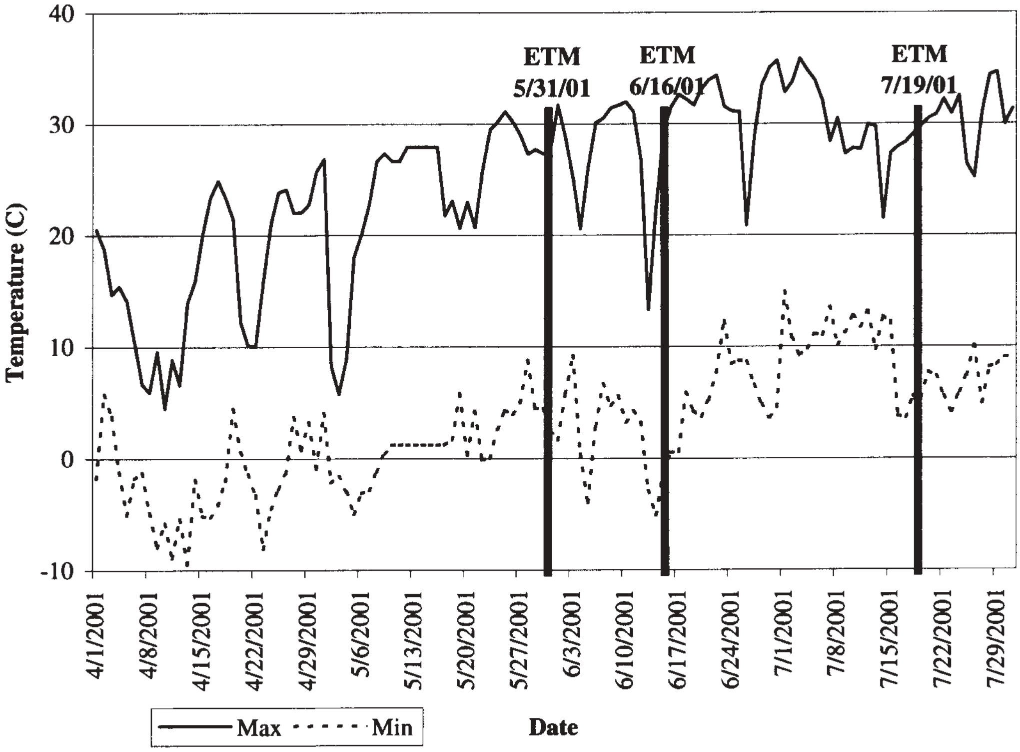

Figure 4 Maximum and Minimum Temperatures of the study area from April through July.

Of the 33 field sites sampled, 10 sites were associated with juniper communities, 11 were dominated by sagebrush and the remaining 12 were dispersed amongst a variety of shrub and grass communities. Field samples were matched to the most temporally close ETM image to evaluate the relationship between imagery and field data. Correlation between vegetation cover and ETM derived spectral values for individual bands and NDVI consistently showed the strongest relationship between total vegetation cover and NDVI (Table 1 and Figure 6). Total vegetation cover consisted of the sum two-dimentional cover estimate for all species recorded on a particular site and had the highest, directionally predictable, and significant ($p < 0.001$) relationship with all spectral bands with the exception of the NIR, which had little (but positive) relationship with total vegetation cover. When cover components (tree, shrub, forb, and grass) were considered separately, correlations with the NIR band were stronger and positive except for the tree component, which was negative. The inclusion of trees within total vegetation cover seems to negate the positive correlations with the other components when compared with NIR. Correlations between the red band and individual cover components are negative, as one would expect for photosynthetically active vegetation, but low except when all components are combined into the total vegetation cover category.

When field sites were separated into the two predominant cover classes (juniper and sagebrush), relationships between vegetation cover and spectral response were similar in that total vegetation cover and NDVI showed the highest correlation, but varied within the different vegetation components. Within the Juniper dominated landscapes, correlation between NDVI and the tree vegetation class was similar to the total vegetation cover correlation and significant ($p > 0.05$) (Table 2 and Figure 7). However, correlation between NDVI and Forbs, Grass, and the combination of Grass and Forbs (Herbaceous) decreased when compared with the combined field data (Table 1), most likely due to overshadowing of the understory by the Juniper trees or the paucity of understory cover in these sites.

Landscapes dominated with sagebrush showed relatively high and significant ($p < 0.05$) correlations between NDVI and Shrubs, Forbs, Grass, and Forbs/Grass combination (Herbaceous) (Table 3). Correlation between NDVI and total vegetation cover was again the strongest (Figure 8). For grasses, correlation with the NIR band was particularly weak within the sagebrush communities, but showed some strength in the red band.

Analysis using stepwise linear regression to estimate total vegetation cover and total bare ground from reflectance values of the 6 reflective bands and NDVI showed that spectral bands 2, 4, and 5 (Green, NIR, and MIR1) and NDVI were most significant in identifying total cover (Table 4) with a multiple r^2 of 0.86. Percent total vegetation cover for each image within the time series was estimated using the coefficients of this stepwise regression (Figure 9).

Table 1 Correlation coefficients (r) between ETM spectral response, NDVI and percent cover components for all cover types (n=33). The column labeled 'Herbaceous' is the sum of Grass and Forbs ($p < .01$).

	Tree	Shrub	Forbs	Grass	Herbaceous	Total Cover
Blue	-0.056	-0.194	-0.278	-0.298	-0.357	-0.765
Green	-0.064	-0.214	-0.236	-0.273	-0.322	-0.746
Red	-0.032	-0.217	-0.272	-0.307	-0.364	-0.775
NIR	-0.406	0.025	0.479	0.178	0.303	0.040
MIR1	-0.233	-0.108	-0.131	-0.173	-0.198	-0.631
MIR2	-0.094	-0.168	-0.250	-0.283	-0.335	-0.746
NDVI	-0.198	0.244	0.545	0.411	0.538	0.813

Table 2 Correlation coefficients (r) between ETM spectral response, NDVI and percent cover components for pinion / juniper dominated landscapes. n=10, $p < .05$.

	Tree	Shrub	Forbs	Grass	Herbaceous	Total Cover
Blue	-0609	0.635	0.444	-0.013	0.133	-0.626
Green	-0.554	0.587	0.491	-0.059	0.108	-0.573
Red	-0.577	0.554	0.629	-0.009	0.197	-0.569
NIR	-0.118	0.409	0.502	-0.167	0.016	-0.004
MIR1	-0.536	0.545	0.677	0.116	0.325	-0.427
MIR2	-0.547	0.551	0.663	0.063	0.273	-0.492
NDVI	-0.737	-0.507	-0.466	-0.162	-0.296	0.786

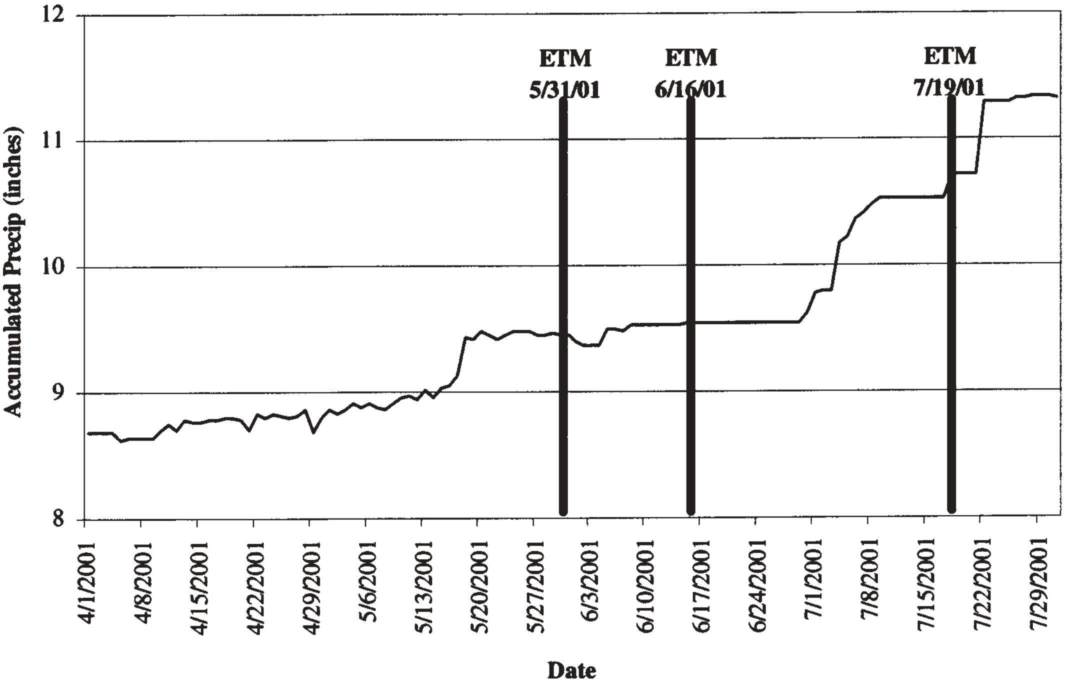

Figure 5 Cumulative precipitation on the study area from April through July. Imagery collection dates are indicated by solid vertical lines and the acquisition date.

For bare ground, a stepwise linear regression identified ETM bands 3, 4, 5, and 7 (red, NIR, MIR1, MIR2) with NDVI as the strongest combined predictors with a multiple r^2 of 0.92, though the strength of each predictor variable was somewhat less when compared with the individual variables when total vegetation cover was estimated (Table 5). Percent total bare ground was estimated for each of the three images for the entire study area using the coefficients derived from the stepwise regression (Figure 10).

Since percent bare ground (inclusive of all non-photosynthetic cover) is the reciprocal of percent total vegetation cover in our application (% bare ground = 100 - % vegetation cover), this reciprocal was compared to the modeled percent bare ground estimate to serve as a coarse, 1st order validation of the bare ground regression model. Table 6 shows the calculated differences between the total vegetation cover reciprocal and the modeled

Table 3 Correlation coefficients (r) between ETM spectral response, NDVI and percent cover components for Sagebrush dominated landscapes. n=11, $p < .05$.

	Tree	Shrub	Forbs	Grass	Herbaceous	Total Cover
Blue	-0.124	-0.725	-0.543	-0.523	-0.614	-0.870
Green	-0.136	-0.731	-0.516	-0.511	-0.593	-0.861
Red	-0.111	-0.722	-0.557	-0.531	-0.625	-0.875
NIR	-0.420	-0.558	0.278	0.040	0.150	-0.283
MIR1	-0.096	-0.736	-0.526	-0.438	-0.545	-0.826
MIR2	-0.071	-0.714	-0.604	-0.528	-0.644	-0.878
NDVI	-0.097	0.552	0.835	0.625	0.814	0.877

Table 4 Significance of predictor variables used to estimate total vegetation cover using stepwise regression with scaled reflectance and NDVI.

	t value	P (>|t|)
Green	-3.17	0.01
NIR	3.32	0.01
MIR$_1$	-2.19	0.06
NDVI	-2.64	0.03

Residual standard error: 13.75 on 9 degrees of freedom
Multiple R-Squared: 0.86
F-statistic: 14.21 on 4 and 9 degrees of freedom, p= 0.00063

Table 5 Significance of predictor variables used to estimate total bare ground using stepwise regression with scaled reflectance and NDVI.

	t value	Pr (>|t|)
Red	2.60	0.03
NIR	-1.54	0.16
MIR1	2.40	0.04
MIR2	-1.84	0.10
NDVI	2.03	0.07

Residual standard error: 11.89 on 8 degrees of freedom
Multiple R-Squared: 0.92
F-statistic: 18.4 on 5 and 8 degrees of freedom, the p= 0.00033

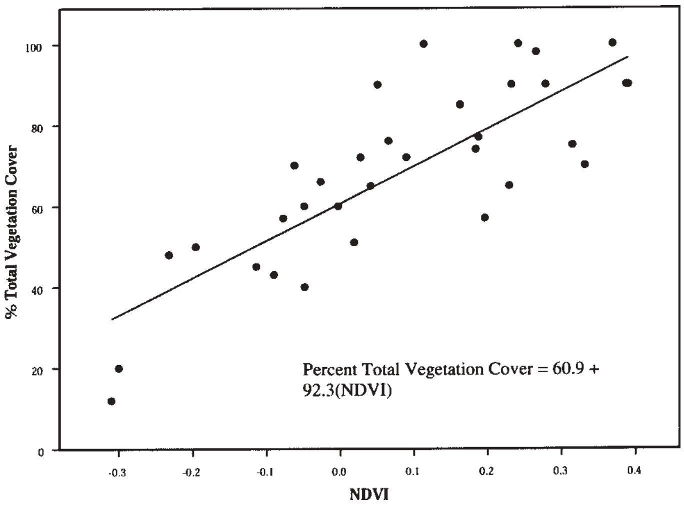

Figure 6 Relationship between NDVI and percent total vegetation cover for all cover types.

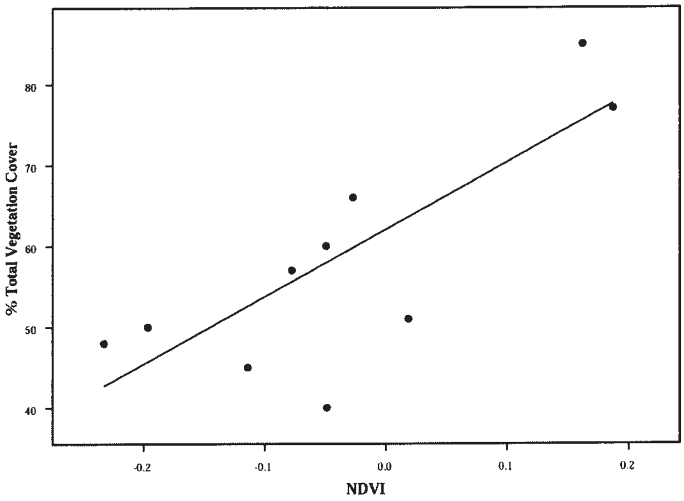

Figure 7 Relationship between NDVI and percent total vegetation cover pinion/juniper dominated landscapes.

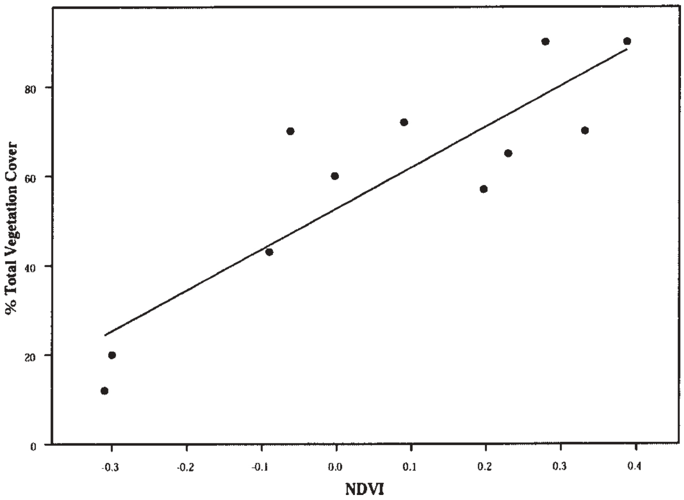

Figure 8 Relationship between NDVI and percent total vegetation cover for sagebrush dominated landscapes.

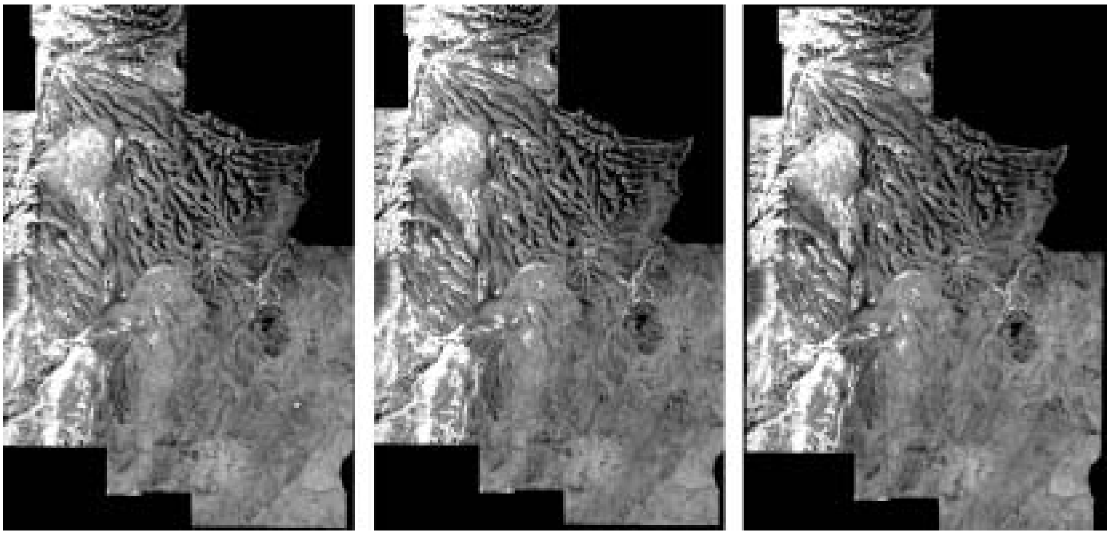

Figure 9 Modeled total vegetation images from a stepwise linear regression using ETM bands 2, 4, and 5 along with NDVI.

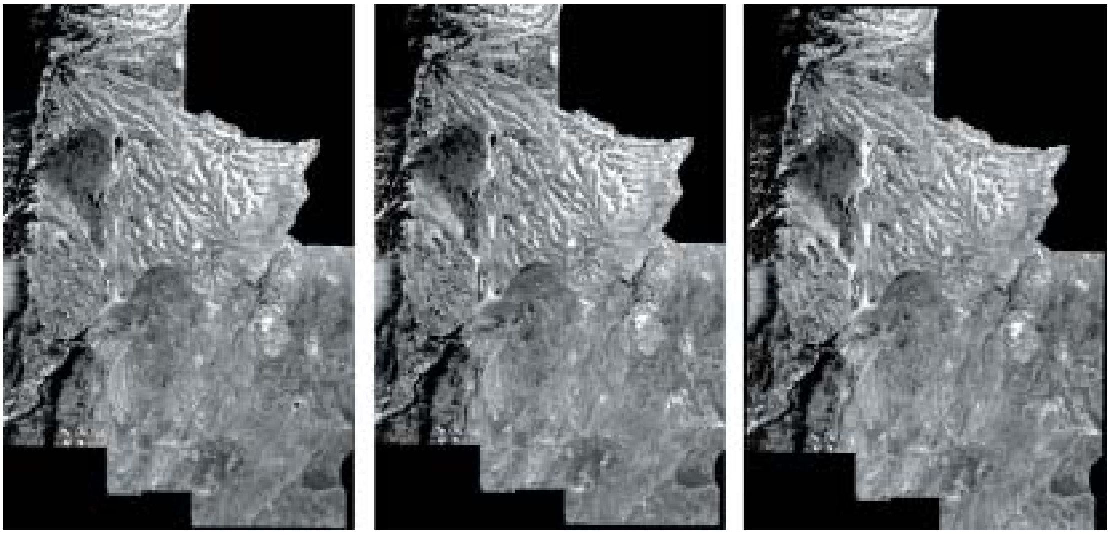

Figure 10 Modeled bare ground images from a stepwise linear regression using ETM bands 3, 4, 5, and 7 along with NDVI.

Table 6 Difference statistics between calculated percent bare ground and the reciprocal of the calculated percent total vegetation cover.

	Min	Max	Mean	SD
May	0	49	10.7	3.0
June	0	31	3.7	2.3
July	0	43	2.2	2.0

percent bare ground estimate. Mean differences between the two data layers are lowest for the July image (a mean difference of 2.2%) and largest for the May image (a mean difference of 10.73%). This may be due to the timing of data collection that took place in late June through mid July, thus better comparing ground cover conditions with the timing of image collection.

Discussion

We have demonstrated that on semi-arid rangelands, medium resolution (30m) remotely sensed imagery can be used to monitor vegetation cover within one growing season and by extension between growing seasons. The strength of the relationship varies depending on landscape stratification into defined community types.

The relationship between remotely sensed parameters and photosynthetically active ground cover were relatively strong for specific predictor variables. When only juniper-dominated landscapes were concerned, the somewhat erratic relationships between spectral variables and vegetation cover may be a function of the overstory and community characteristics of juniper. Areas that are dominated by juniper trees commonly have poor understories due to the strong competition for water by the tree canopy. Grasses and forbs that occur in these communities tend to grow relatively close to trees due to the increased quality of soil and partial shading (and thus conservation of water) by the overstory. Interspaces between juniper trees tend to be sparse due to poor soil quality from erosion and competition from near surface roots supplying water to trees.

Sagebrush communities are characterized by an overstory of sagebrush with grasses and forbs occupying the interspaces and sometimes under the canopy. Productive sagebrush stands consist of a relatively even distribution of these three life forms. Therefore, the relatively strong correlation between spectral variables and vegetation cover is indicative of this association of life forms and the lack of juniper trees to increase shading of understory species. The low correlation coefficient between grass and the NIR within the sagebrush stands may be a function of either the phenological stage of these plants or the presence of senesced vegetation from the previous growing season. While field personnel are trained to ignore senesced vegetation, it may have biased the visual estimation of percent cover. Additional work is required to explore these relationships further.

Where semi-arid rangelands are concerned, estimates of percent cover do not necessarily translate to the condition of the landscape where a high amount of cover is equivalent to “good” condition. In a number of cases within the Intermountain West of the United States, high amounts of photosynthetically active vegetation cover may very well mean a landscape of poor condition consisting of annual invasives with little or no native vegetation. It is important therefore that measurements of the cover of photosynthetically active vegetation through remote sensing be place in the context of the landscape, and not as a direct measure of condition.

Management of natural resources is a complex effort that is continually in need of new methods of quantification and monitoring. Remote sensing can provide managers with estimates of actively growing vegetation cover along with estimates of bare surfaces (devoid of vegetation). With the convergence and increased availability of Geographic Information Systems (GIS), Global Positioning Systems (GPS) and Remote Sensing (RS), managers can effectively inventory and monitor resources over large landscapes. The use of the NDVI and other remotely sensed parameters to monitor vegetation has been demonstrated at coarse resolutions covering large areas. However, the use of this and other spectral indices at finer resolutions also show promise where semi-arid rangelands are considered. These landscapes are sensitive to management prescriptions and thus require a significant amount of monitoring in order to evaluate productivity and defined health. The cost of effectively monitoring these large landscapes on the ground has been and is increasingly expensive. The use of remotely sensed imagery at coarse and finer scales can provide a cost effective means to monitor production thus reducing costs to managers in the field by making it possible for them to focus in areas that show a significant change through time.

Natural resource managers working in semi-arid, shrub-steppe or similar environments can look to remote sensing as a tool to help monitor and manage rangelands. However, access to suitable imagery and the expertise necessary to process these data still provide a challenge to most land management institutions today. We see this as a natural evolutionary process, where improved access to data and software coupled with appropriate training of existing and future managers will invariably lead to increased use of remote sensing tools. In the meantime, it is the responsibility of those with the expertise in these fields, be they at universities, state, federal, and or private agencies to make these technologies available to managers in a manner that is easily understood and assimilated into normal land management practices. Conversion of spectral information from remote sensing platforms into commonly understood bio-physical parameters such as percent cover is one way to accomplish this.

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