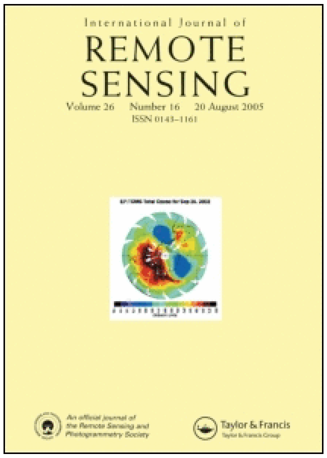

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Spectral and biophysical relationships of montane sagebrush communities in multi-temporal SPOT XS data

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Abstract. Correlation and multiple regression analysis was used to examine the relationships between spectral and biotic factors within the sagebrush communities of Grand Teton National Park, Wyoming. Field-sampled data on biophysical factors were regressed against June 1996 and September 1996 SPOT multi-spectral reflectance data for fifty-one plots. Highest r^2 values were generated for regression models using June reflectance data alone for predicting biophysical factors. Predictability of bitterbrush cover was improved using September reflectance data alone. Models predicting biophysical characteristics of sagebrush communities generally were not improved by using a combined June–September data set. Regression models for big sagebrush height, low sagebrush cover, and rock/soil cover were improved slightly using the combined two-date data set. Selection of remotely sensed data for biophysical studies of vegetation communities should be driven by the ecological and phenological characteristics of the vegetation community to be studied.

1. Introduction

Sagebrush (*Artemisia spp.*) shrublands are a dominant feature of the landscape in the intermountain USA, covering over 44 million ha (West 1983). Kuchler (1964) classified the western sagebrush shrublands occurring above 41° N latitude into the *sagebrush steppe* potential natural vegetation community. The sagebrush community provides cover and forage for numerous wildlife species, including pronghorn, deer, elk, bison, and numerous small non-game birds such as sage grouse (Knight 1994). Within Grand Teton National Park, Wyoming, there is considerable interest by resource managers in mapping sagebrush vegetation communities for improved wildlife management, fire potential mapping and behaviour prediction, and protection of endemic plant and animal species. Analysis of remotely sensed data offers

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the potential to move beyond simple nominal-scale vegetation mapping toward community-level predictive modelling of biophysical factors such as vegetation height and cover.

Several diverse approaches have been taken in using remote sensing for mapping and modelling shrublands, including classification (McGraw and Tueller 1983, Ustin *et al.* 1986, Reiners *et al*. 1989), spectral mixture modelling (Ustin *et al*. 1986), time-series analysis (Kremer and Running 1993), and correlation and regression analysis (Senseman *et al*. 1996, Everitt *et al*. 1996). Research has also been directed toward examining relationships between phenologically-related changes in shrubland vegetation condition and spectral response, with the intent of deriving better spectrally-based estimates of rangeland biophysical parameters (Senseman *et al*. 1996, Everitt *et al*. 1996). Seasonal changes in spectral reflectance at local scales are a function both of the species composition and the environmental conditions of a site (Everitt and Escobar 1996). Phenological characteristics of different life forms (grasses, forbs, and shrubs) modify the spectral-temporal response patterns of a site as a function of the relative dominance and abundance of each life form within a community. Grasses and forbs progress at a more rapid phenological rate than shrubs, initiating greenup and senescence earlier in the season in this region (Blaisdell 1958).

In addition to controlling species composition, soil properties significantly affect the condition of vegetation on a site. Coarse, rapidly draining soils provide less water holding capacity during periods of low rainfall, and vegetation occurring on these sites may undergo moisture stress sooner than vegetation on more finely textured soils. Big sagebrush (*Artemisia tridentata*), for example, produces both ephemeral and overwintering leaves. Ephemeral leaves are produced in the spring and are lost in late summer and fall as water stress develops (Knight 1994). This seasonal leaf loss results in a decrease in plant leaf area index (LAI), with the effect of decreased absorption in visible wavelengths and decreased reflectance in the near-IR. Phenologically-associated changes in vegetation condition, therefore, may facilitate prediction of biophysical attributes of vegetation communities from satellite remotely sensed data (Everitt and Escobar 1996). The objectives of this paper were to examine relationships between sagebrush biophysical factors and spectral response during two periods of the growing season in Grand Teton National Park (GTNP), and to develop regression models for predicting sagebrush community biophysical factors from single- and multi-date SPOT multi-spectral data.

2. Study area

Sabinske and Knight (1978) identified four distinct sagebrush communities within Grand Teton National Park: low sagebrush (*Artemisia arbuscula*), mountain big sagebrush (*Artemisia tridentata ssp. vaseyana*), mixed low sagebrush/big sagebrush, and bitterbrush (*Purshia tridentata*)/big sagebrush (figure 1). Bitterbrush is an evergreen species that retains its leaves in the fall and is still photosynthetically active while grasses, forbs, and sagebrush have senesced or experienced loss of ephemeral leaves by late summer or early fall. Soil texture was suggested as the primary control over distribution and species composition of the four communities within the outwash plains of Jackson Hole (Sabinske and Knight 1978). The four vegetation communities show distinct geographical occurrences within Grand Teton: bitterbrush-dominated stands occur in the south-east near Blacktail Butte; pure stands of big sagebrush occur on the east bank of the Snake River in the Antelope Flats region north of Blacktail Butte; and the low sagebrush and mixed big/low sagebrush communities

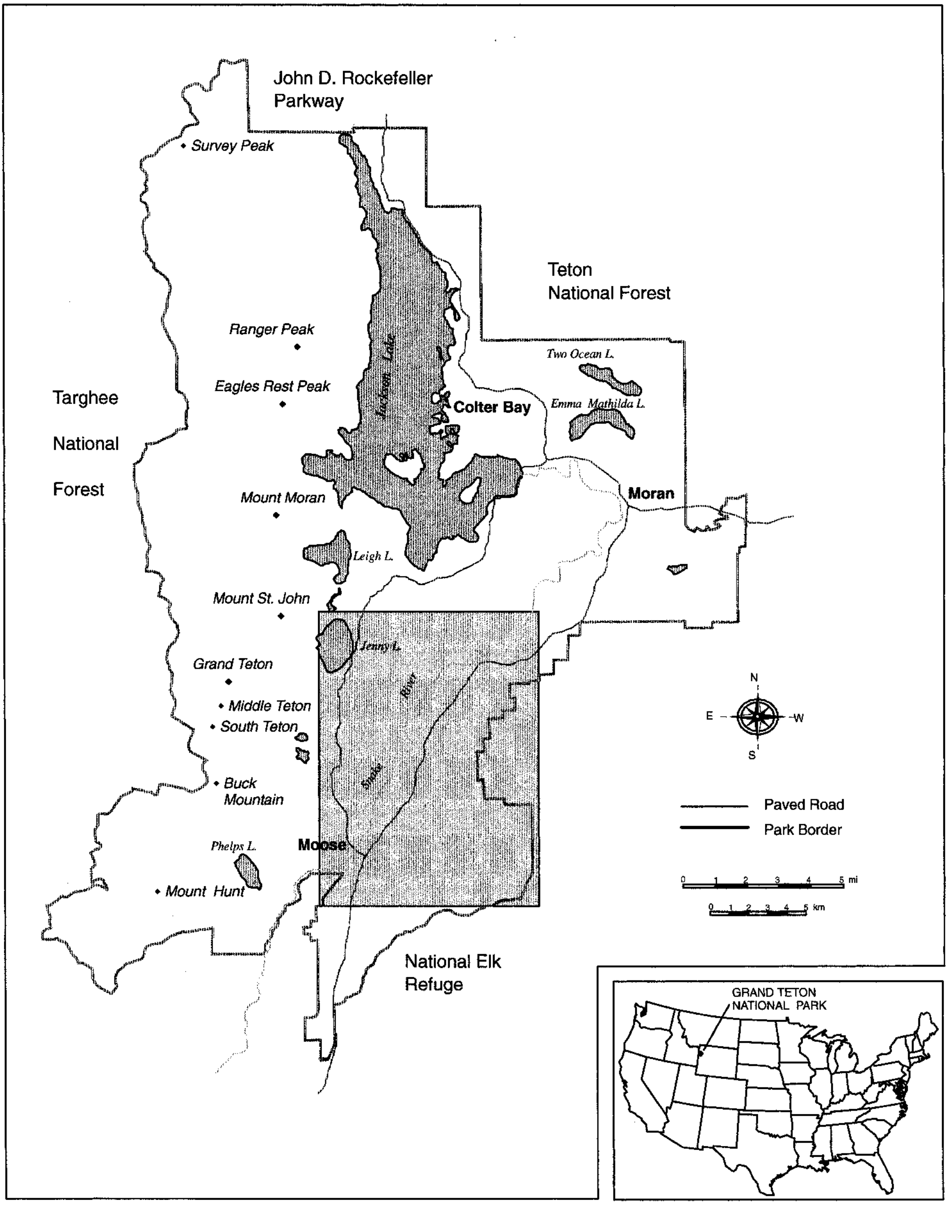

Figure 1. The study area in south Grand Teton National Park, Wyoming, USA.

occur on the west side of the Snake River, with the low sagebrush stands adjacent to the base of the Teton Range (Sabinske 1972). Major graminoids and forbs found in association with the sagebrush include Idaho fescue (*Festuca idahoensis*), bluegrass (*Poa spp.*), sulphur buckwheat (*Erigeron umbellatum*), yarrow (*Achillea millefolium*), dandelion (*Taraxacum spp.*), arrowleaf balsamroot (*Balsamorrhiza sagittata*), pussytoes (*Antennaria microphylla*), silvery lupine (*Lupinus argenteus*), and prairie-smoke (*Geum trifolium*). Collectively, the sagebrush communities provide a significant source of forage for deer, elk, pronghorn antelope, and bison, particularly in winter.

Bitterbrush is particularly valuable as a browse species, with deep roots that allow it to survive sustained moisture deficits, and retaining higher levels of nutrients than other browse species during winter months.

3. Methods

3.1. *Field data collection*

Field plots were distributed across the sagebrush flats of Grand Teton National Park, ensuring whenever possible that at least one sample plot was randomly located within each section of a township, and that the four communities defined by Sabinske and Knight (1978) were adequately represented among the sampled sites. A line-intercept technique was used to measure shrub cover and height by species. For each sample plot, a 50 m transect was defined using a tape measure in a random direction from an arbitrary starting point. To minimize potential effects of clumping or lineation on sampling of shrub vegetation, a 90° change in direction was made at the 25 m point. The transect was then extended for an additional 25 m, for a total transect length of 50 m. Shrub cover by species was measured within each 1-m increment along the tape by counting the amount of shrub canopy intercepted by the tape measure. Intercept values were averaged to derive total cover by shrub species for the plot. Height of each shrub intercepted by the tape was measured in centimetres, and values averaged to derive mean shrub height by species for the plot. Visual estimates of cover by forbs and graminoids were recorded using the Daubenmire technique (Daubenmire 1959) within twenty $0.5\,m \times 0.5\,m$ quadrats established at 2.5 m intervals along the 50 m transect. Ground cover not occupied by plants was classified into litter, persistent litter (sticks larger than 1 cm diameter), and rock/soil. Site locations were recorded using a global positioning system. Fifty-one plots distributed throughout the Grand Teton sagebrush flats were sampled during late June and early July 1996.

3.2. *Satellite data*

SPOT multi-spectral satellite data for 17 June, 1996 and 3 September, 1996 were used for this study. We have observed that peak vegetation greenness in Grand Teton National Park typically occurs in mid to late June, and by late-August to early-September most non-forest vegetation communities have essentially ceased photosynthetic activity for the growing season. The June data was acquired coincident with field sampling of the sagebrush communities. The SPOT multi-spectral scanner acquires data in three bands (green, 0.50–0.59 μm; red, 0.61–0.68 μm) and near-infrared, 0.79–0.89 μm), with a spatial resolution of 20 m. Each data set was georeferenced to a Universal Transverse Mercator (UTM) coordinate system, using control points and a nearest-neighbour resampling algorithm. Data were converted to reflectance values to reduce the effects of seasonally-dependent illumination and sun angle on spectral response of vegetation. A normalized difference vegetation index (NDVI) was computed for each image [$NDVI = (NIR - RED)/(NIR + RED)$] . Values for a 3 pixel × 3 pixel block centred on each field sampled site were extracted from each image and averaged to derive mean per-band spectral reflectance values for each site.

3.3. *Analysis methods*

An agglomerative hierarchical iterative clustering algorithm was used to assign each of the fifty-one field sites to one of the four Sabinske and Knight (1978) community types. The algorithm iteratively computes the Euclidean distance between a sample and a specified number of cluster centroids in *n*-space. Cluster centroids are recomputed at the conclusion of each iteration until a specified threshold is attained. Variables used in the cluster analysis were height and shrub cover by big sagebrush, low sagebrush, and bitterbrush, and cover by five general understory classes (forbs, graminoids, litter, persistent litter, and rock/soil).

Correlations between environmental data and spectral data for all sites were calculated using significance levels of $\alpha = 0.01$ and 0.05. Despite the seasonal differences in the June field data and the September satellite imagery, many variables (big sagebrush height and cover, bitterbrush height and cover, low sagebrush height and cover, litter cover, persistent litter cover, and rock/soil cover), exhibit little change during a single growing season. Stepwise multiple regression analysis was selected to answer several questions relating to the relationships between sagebrush community structure and spectral response, such as, to what degree of confidence are biophysical factors of the sagebrush communities predictable from spectral data, and whether the use of multidate data (summer and fall) increases the predictability of structural factors? Three sets of regression runs were performed using the June SPOT data, the September SPOT data, and a combined June/September SPOT data set. Regression analysis results were tested for significance at $\alpha = 0.05$.

4. Results and discussion

4.1. *Biophysical characteristics*

Maximum mean shrub heights are found in the bitterbrush community (table 1). Mean values for big sagebrush and bitterbrush within this community type were 55 cm and 43 cm, respectively, although big sagebrush heights of over 100 cm were found on both pure big sagebrush and bitterbrush sites. Highest total mean cover by shrub species (30% cover) occurred on bitterbrush sites as well. Morphologically, bitterbrush forms dense, widespread canopies with diameters up to 2–3 m, often closely intermixed with and beneath more open canopies of big sagebrush. High cover of big sagebrush typically co-occurred with high cover of bitterbrush. Maximum cover recorded for bitterbrush on a single plot was 36%, and 18% big sagebrush on the same site. In pure stands of each type, values of cover for big and low sagebrush ranged between 15–20% and 12–28%, respectively. On sites where the two species occurred together (mixed big/low sagebrush), the range of cover was greater (3–19% for big sagebrush, 2–18% for low sagebrush), but the mean cover for a single species was lower.

Although shrub cover was relatively low for the four sagebrush communities, total mean cover by graminoids and forbs exceeded the mean shrub cover in each community. Mean graminoid cover ranged from 8% in the low sagebrush community sites to 17% in the bitterbrush community. Mean forb cover exhibited a lower range across the four communities, ranging from 13.6% to 15.9% (table 1). Graminoids and forbs, therefore, comprise a major component of the photosynthetically active vegetation within a sagebrush stand. Large amounts of dead sagebrush (recorded as persistent litter) are a characteristic of older pure big sagebrush stands. High cover of persistent litter (8.4%) was recorded within big sagebrush plots, two to three times the mean values recorded within bitterbrush or mixed big/low sagebrush sites. Cover by rock and soil was substantially higher (approximately two times higher) in low sagebrush and mixed big/low sagebrush communities compared to the pure big sagebrush and bitterbrush communities (table 1).

Table 1. Mean values for vegetation parameters by sagebrush community type (SD = standard deviation).

	Low sagebrush ($n=5$)		Bitterbrush/ big sagebrush ($n=13$)		Big sagebrush ($n=15$)		Mixed big/ low sagebrush ($n=18$)	
Sagebrush community	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Big sagebrush height (cm)	0.0	0.0	55.1	11.7	50.8	8.6	41.8	6.8
Low sagebrush height (cm)	18.4	1.9	0.0	0.0	0.0	0.0	12.5	7.3
Bitterbrush height (cm)	0.0	0.0	43.9	5.4	0.0	0.0	0.0	0.0
Big sagebrush cover (%)	0.0	0.0	13.0	5.2	16.0	4.5	10.0	5.5
Low sagebrush cover (%)	19.0	6.3	0.0	0.0	0.0	0.0	6.0	5.9
Bitterbrush cover (%)	0.0	0.0	17.0	11.0	0.0	0.0	0.0	0.0
Total shrub cover (%)	19.0	6.3	30.0	10.5	16.0	4.5	16.0	6.0
Graminoid cover (%)	8.3	3.8	17.6	8.4	12.1	3.6	11.1	4.8
Forb cover (%)	15.9	3.4	13.9	5.8	15.6	5.2	13.6	5.9
Litter cover (%)	6.2	1.4	8.8	4.1	9.4	5.5	4.5	3.5
Persistent litter cover (%)	0.4	0.7	3.5	2.4	8.4	4.5	2.2	1.7
Rock/soil cover (%)	29.6	11.7	12.4	10.7	13.1	6.5	33.2	10.2

Height and cover were strongly positively correlated within each shrub species (e.g. bitterbrush) for all three shrubland species, indicating that cover increased with height of the plant for all three communities (table 2). Correlations for height and cover between shrub classes, however, indicated that low sagebrush cover and height were consistently negatively correlated with bitterbrush and big sagebrush height and cover. Low sagebrush is generally not found in bitterbrush stands, and in mixed stands where big and low sagebrush co-occur, low sagebrush is increasingly dominated by big sagebrush in progression from sites with coarse soils to finer soil texture (Sabinske and Knight 1978).

In comparison, bitterbrush height and big sagebrush height was moderately positively correlated ($r=0.39$), while bitterbrush cover and big sagebrush cover were uncorrelated, suggesting less competition between the two shrub species. Cover by rock and soil was negatively correlated with height and cover of both big sagebrush and bitterbrush, but positively correlated with low sagebrush cover and height (table 2). Correlations for graminoid cover however, exhibited a pattern opposite those for rock/soil correlations. Graminoid cover was positively correlated with height and cover of bitterbrush and big sagebrush height, and negatively correlated with low sagebrush height and cover (table 2). Forb cover was not significantly correlated with any other biophysical factor.

4.2. *Spectral characteristics*

Correlations between SPOT green and red bands were high for both dates of data (June: $r=0.93$; September: $r=0.98$) (table 3). Correlations between visible bands and the near-IR bands were significant but low for both dates. The effect of seasonality on the band-pair correlations is evident in the higher correlations between visible bands and the near-IR band in September (green:NIR: $r=0.54$; red:NIR: $r=0.52$) compared to June (green:NIR: $r=0.45$; red:NIR: $r=0.28$). By fall, most vegetation has senesced, decreasing the contrast between red absorption and near-IR reflectance and increasing the correlation coefficient (table 3). June near-IR reflectance was uncorrelated with September green and red reflectance. All other multidate correlations (June to September) were significant and positive (table 3).

4.3. *Biophysical-spectral relationships*

4.3.1. *Correlation analysis*

The three shrub species (big sagebrush, low sagebrush, and bitterbrush) show striking seasonally-related differences in spectral-biotic correlations. Correlations between SPOT visible band reflectance and big sagebrush height and cover were higher for June than September, while the highest correlations between visible reflectance and bitterbrush height and cover were observed for the September data (table 4). Spectral-biotic correlations for green and red reflectance and low sagebrush cover and height exhibited a pattern similar to big sagebrush, with higher correlations in summer than fall. With the exception of bitterbrush height, bitterbrush cover, and graminoid cover, spectral-biotic correlations in both dates were not improved by transformation of the SPOT data to NDVI (table 4). Forb cover was not significantly correlated with any spectral bands or band transformation in either the June or September data. Rock/soil cover was strongly positively correlated with the visible bands and negatively correlated with the NDVI in both dates, and exhibit little difference attributable to seasonality. No significant correlations existed between

Table 2. Correlations between biotic variables.

	Big sagebrush height	Low sagebrush height	Bitterbrush height	Big sagebrush cover	Low sagebrush cover	Bitterbrush cover	Forb cover	Graminoid cover	Rock/soil cover	Rock/soil cover
Big sagebrush height	1.000									
Low sagebrush height	−0.611**	1.000								
Bitterbrush height	0.395**	−0.437**	1.000							
Big sagebrush cover	0.769**	−0.596**	0.192	1.000						
Low sagebrush cover	−0.767**	0.704**	−0.343*	−0.711**	1.000					
Bitterbrush cover	0.290*	−0.358**	0.814**	0.046	−0.280*	1.000				
Forb cover	−0.003	−0.003	−0.092	−0.086	0.113	−0.234	−0.223	1.000		
Graminoid cover	0.384**	−0.345*	0.421**	0.253	−0.323*	0.451**	−0.158	1.000		
Rock/soil cover	−0.435**	0.512**								

**Correlation is significant at the 0.01 level (2-tailed).
*Correlation is significant at the 0.05 level (2-tailed).

Table 3. Correlations between band pairs for June 1996 and September 1996 XS data.

	June 1996			September 1996		
	Band 1	Band 2	Band 3	Band 1	Band 2	Band 3
June B1	1.00	0.93**	0.45**	0.62**	0.53**	0.46**
June B2		1.00	0.28*	0.75**	0.70**	0.40**
June B3			1.00	0.20	0.15	0.68**
September B1				1.00	0.98**	0.54**
September B2					1.00	0.52**
September B3						1.00

**Correlation is significant at the 0.01 level (2-tailed).
*Correlation is significant at the 0.05 level (2-tailed).

Table 4. Correlations between biophysical factors and SPOT XS reflectance data ($n=51$).

	Band 1	Band 2	Band 3	NDVI
June 1996				
Big sagebrush height	−0.57**	−0.62**	−0.23	0.50**
Low sagebrush height	0.50**	0.63**	0.15	−0.55**
Bitterbrush height	−0.22	−0.43**	0.26	0.58**
Big sagebrush cover	−0.46**	−0.51**	−0.22	0.40**
Low sagebrush cover	0.43**	0.52**	0.11	−0.47
Bitterbrush cover	−0.15	−0.35*	0.17	0.45**
Forb cover	0.04	0.03	0.07	0.01
Graminoid cover	−0.33*	−0.46*	0.07	0.51**
Rock/soil cover	0.72**	0.81**	0.26	−0.69**
September 1996				
Big sagebrush height	−0.32	−0.28*	−0.02	0.29*
Low sagebrush height	0.44**	0.42**	0.15	−0.37**
Bitterbrush height	−0.41**	−0.46**	0.12	0.60**
Big sagebrush cover	−0.27	−0.24	−0.07	0.21
Low sagebrush cover	0.23	0.17	−0.09	−0.23
Bitterbrush cover	−0.41**	−0.47**	0.12	0.62**
Forb cover	0.00	0.03	−0.09	−0.07
Graminoid cover	−0.35*	−0.38**	−0.00	0.43**
Rock/soil cover	0.75**	0.72**	0.38**	−0.58**

**Correlation is significant at the 0.01 level (2-tailed).
*Correlation is significant at the 0.05 level (2-tailed).

June near-IR reflectance and biotic factors, and September near-IR reflectance was correlated only with rock/soil cover (table 4).

4.3.2. *Regression analysis*

Three analyses were performed using the environmental data as dependent variables. The first analysis used only the June SPOT bands as predictors, the second analysis used the September data only, and the third analysis used a combined June–September six-band data set. Table 5 shows the multiple regression models and associated statistics for the environmental models. In general, single biophysical factors of the sagebrush communities were not well predicted by either single-date or the combined two-date satellite multi-spectral reflectance data set.

Table 5. Regression models predicting sagebrush biophysical factors using single and multi-date SPOT multi-spectral data.

Biophysical factor	Regression model	Model R^2
June 1996 data		
Big sagebrush height	$-2.59\ June_{RED}+145.35$	0.38
Low sagebrush height	$1.24\ June_{RED}-42.50$	0.40
Bitterbrush height	$-7.70\ June_{RED}+10.20\ June_{GREEN}-103.45$	0.43
Big sagebrush cover	$-0.008\ June_{RED}+0.43$	0.26
Low sagebrush cover	$-0.008\ June_{RED}-0.29$	0.27
Bitterbrush cover	$-0.034\ June_{RED}+0.047\ June_{NIR}-0.54$	0.35
Forb cover	*No model generated*	—
Graminoid cover	$-1.65\ June_{RED}+1.72\ June_{GREEN}+7.12$	0.28
Rock/soil cover	$2.62\ June_{RED}-81.11$	0.66
September 1996 data		
Big sagebrush height	$-1.86\ Sept_{GREEN}+120.96$	0.10
Low sagebrush height	$1.21\ Sept_{GREEN}-44.11$	0.19
Bitterbrush height	$-3.08\ Sept_{RED}+2.46\ Sept_{NIR}-35.13$	0.40
Big sagebrush cover	$-0.006\ Sept_{GREEN}+0.36$	0.07
Low sagebrush cover	*No model generated*	—
Bitterbrush cover	$-0.038\ Sept_{RED}+0.01\ Sept_{NIR}-0.036\ Sept_{GREEN}+0.60$	0.46
Forb cover	*No model generated*	—
Graminoid cover	$0.52\ Sept_{RED}+35.78$	0.15
Rock/soil cover	$3.39\ Sept_{GREEN}-118.84$	0.57
Combined June/September 1966 data		
Big sagebrush height	$2.43\ Sept_{NIR}-3.05\ June_{RED}-1.49\ June_{NIR}+112.25$	0.54
Low sagebrush height	$1.24\ June_{RED}-42.50$	0.40
Bitterbrush height	$-7.70\ June_{RED}+10.20\ June_{GREEN}-103.45$	0.43
Big sagebrush cover	$-0.008\ June_{RED}+0.43$	0.26
Low sagebrush cover	$0.01\ June_{RED}+0.004\ June_{NIR}-0.009\ Sept_{NIR}-0.04$	0.44
Bitterbrush cover	$-0.038\ Sept_{RED}+0.01\ Sept_{NIR}-0.036\ Sept_{GREEN}+0.60$	0.46
Forb cover	*No model generated*	—
Graminoid cover	$-1.65\ June_{RED}+1.72\ June_{GREEN}+7.12$	0.28
Rock/soil cover	$1.85\ June_{RED}+1.46\ Sept_{GREEN}-110.96$	0.71

June red reflectance entered into all regression models predicting biophysical characteristics from the June single-date reflectance data. Height was predicted better than cover for all three vegetation types (big sagebrush, low sagebrush, and bitterbrush) (table 5). Highest r^2 values were produced for rock/soil ($r^2=0.66$). Models generated using the September reflectance data showed no improvement in predictability over June reflectance models, with the exception of bitterbrush cover (September: $r^2=0.46$; June: $r^2=0.35$) (table 5). Models for bitterbrush height and cover were the only predictive equations incorporating multiple bands of satellite data as predictors. No statistically significant model was generated for low sagebrush cover or forb cover using the September reflectance data.

Models predicting biophysical characteristics of sagebrush communities generally were not improved by using a combined two-date set of satellite data. The predictability of big sagebrush height ($r^2=0.54$) and low sagebrush cover ($r^2=0.44$) were increased over single-date models using June red and near-IR reflectance and September near-IR reflectance. The predictability of rock/soil cover was improved slightly by use of multidate data, from $r^2=0.66$ using June red reflectance alone to $r^2=0.71$ by including September green reflectance in the equation. No statistically significant model was generated for forb cover using either single-date reflectance or the combined June–September reflectance data.

Statistical relationships between the biophysical and spectral data are consistent with field observations of sagebrush communities in Grand Teton National Park. In the June and September single-date regression models, and the combined June–September models, SPOT red reflectance entered with a negative coefficient in models predicting big sagebrush height and cover, bitterbrush height and cover, and graminoid cover, but with a positive coefficient in models predicting low sagebrush height and rock/soil cover. Red reflectance on both dates is a function of the total vegetation cover of a site. Big sagebrush and bitterbrush sites, with greater water availability, support greater amounts of total vegetation in the form of shrubs and graminoids. Intercanopy gaps between individual big sagebrush plants are dominated by grasses or bitterbrush, reinforcing the vegetation spectral response for a site. Low sagebrush sites, in contrast, with coarser soils and less water availability, generally have less shrub cover and intercanopy gaps are dominated by exposed soil and rock, rather than grasses. Shrub height, as much as shrub cover, drives spectral response in the visible wavelengths within the sagebrush communities, as taller shrubs cast more shadow on adjacent shrubs and understory vegetation. Brightness is the strongest component of spectral response in vegetation canopies (Kauth and Thomas 1976, Crist and Cicone 1984), and taller shrubs, by casting larger shadows, decrease the overall spectral response. Low sagebrush and mixed big/low sagebrush sites cast progressively less shadow as big sagebrush becomes less dominant and cover by rock and soil increases. This is further borne out by the inverse relationships between height and cover for big sagebrush and low sagebrush, and the positive relationship between rock/soil cover and low sagebrush height and cover (table 2).

Maximum seasonal greenness for the sagebrush communities occurs in mid-to-late June in Grand Teton National Park, providing maximum contrast overall between vegetation-dominated (big sagebrush and bitterbrush communities) and soil-dominated (low sagebrush and mixed big/low sagebrush) areas. The improved predictability of bitterbrush cover and height in fall versus summer data is a result of differing effects of phenology on the diverse vegetation communities within the park. In the June data, the spectral contribution from bitterbrush is subsumed in the overall strong vegetation spectral response from shrubs, grasses, and forbs. Bitterbrush is still photosynthetically active during September, while grasses, forbs, and sagebrush have senesced and essentially ceased all photosynthetic activity. Maximum spectral contrast between bitterbrush and other vegetation therefore occurs during late summer and fall.

5. Conclusions

Results indicate that several sagebrush community biophysical factors are predictable from remotely sensed data, although the strength of the predictive models is not high. R^2 values for models using data acquired at peak summer greenness (June) were generally higher than r^2 values for models using end of growing season (September data). As most models were not improved by using two combined dates of data, the use of multiple dates of data may not provide a substantial enough increase in model predictive power to justify using more than a single date for many applications. Selection of remotely sensed data for biophysical studies of vegetation communities should be driven by the ecological and phenological characteristics of the vegetation community to be studied.

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