MANAGING LOGGERHEAD SHRIKE HABITAT USING REMOTE SENSING PRODUCTS

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ABSTRACT

The prairie population of the loggerhead shrike (*Lanius ludovicianus excubitorides)* is dependent upon two characteristics of a grassland landscape that require specific management to maintain: shrubs taller than 1.8 m tall for nesting and tall grass for foraging. The purpose of this study is to measure the landscape variables that are important to loggerhead shrike persistence at landscape spatial scales to help understand the impact of management decisions and seek alternative solutions if required. Results indicated that shrikes prefer to nest in scattered shrubs, particularly thick or thorny species. Reflectance based vegetation indices differed in their performance dependent upon the vegetation variables used. L-ATSAVI and ATSAVI are the best LAI estimators, while MSAVI2 is good to estimate the shrub cover. A logistic regression model, using loggerhead shrikes active or inactive nesting as the dependent variable and biophysical, topographical, and remotely sensed data extracted from both ground and space, as the predictors was developed. The predictive performance of the selected models was shown to be high, indicating a good fit of the model to the data. Further analysis showed that all the variables considered (Dead cover in tall shrub habitat and ATSAVI) had significant, independent contributions towards explaining the variation in the dependent variable. The selected model clearly delineated areas predicted as highly suitable loggerhead shrikes habitat.

INTRODUCTION

The prairie population of loggerhead shrike (*Lanius ludovicianus excubitorides)* is dependent upon two characteristics of the grassland landscape that require specific management to maintain; shrubs taller than 1.8 m tall for nesting and tall grass for foraging (Prescott and Collister 1993). In the final decades of the 20th century on into the 21st century, land use and ownership changes have resulted in increasing utilization by cattle in the grasslands (Willms et al. 1985, Dormaar et al. 1994, Willms et al. 2002) and reductions in shrub densities both in shelter belts (Bjorge and Prescott 1996) and in riparian zones. Both of these factors, combined with a lack of good population data where they persist (Bjorge and Prescott 1996) contribute to their threatened status. Recent surveys in Grasslands National Park of Canada (GNPC) suggest that the park supports a stable population of loggerhead shrikes; however, recent actions in the park that follow through on management plan promises (reintroduction of bison and fire) may affect this stability. The purpose of this study is to measure the landscape variables that are important to loggerhead shrike persistence at landscape spatial scales to help understand the impact of management decisions and seek alternative solutions if required.

Multiple factors, including landuse change, pesticide use, habitat fragmentation or direct human caused mortality may have all contributed to the drop in loggerhead shrike numbers. Nevertheless, studies conducted in the Canadian Great Plains have identified habitat availability during the breeding season as a limiting factor for this species (Prescott and Collister 1993, Telfer 1993). A survey conducted in 1995 in southern Alberta suggested that loggerhead shrike populations were higher than previously reported (Bjorge and Prescott 1996). More recent surveys (Didiuk, 2005) have helped in understanding the distribution of shrikes on the prairies, including in GNPC and greater park ecosystem. As well, a 10 year old assessment of habitat use in southern Alberta concluded that shrub cover and the presence of tall grass structure correlated with occupied loggerhead shrike territories (Prescott and Collister 1993). All of this suggests that we have an opportunity now to map the entire extant loggerhead shrike habitat in GNPC, to manage and to protect those holdings, as well as to develop methods to enhance loggerhead shrike habitat in areas where it has been degraded by exotic invasions or disturbances.

Shrub communities in GNPC occupy approximately 10% of current park holdings and are perhaps the most heavily modified ecosystem in the park. Topographically limited to the riparian zone around ephemeral creeks and rivers, shrub communities have been affected by human altered hydrology as well as invasion by aggressive exotic plant species such as smooth brome (*Bromus inermus*). These relatively recent and ongoing changes will have an impact on loggerhead shrikes, yet we know very little of the dynamics of these communities nor do we understand the effect of management activities on their structure or stability. A recent project has mapped the distribution of shrubs in GNPC (Penniket 2004); however, the classification resolution is relatively low; for instance it distinguishes two classes for shrub height, shorter or taller than 50 cm. While this study is an excellent basis upon which to plan our study, we feel that we can improve on its information content for shrikes by focusing on the aspects of the shrub community and adjacent grassland community that are of known importance.

Satellite imagery has been effectively used to measure habitats for loggerhead shrikes in eastern Canada (Jobin et al. 2005). We have learned from recent work using satellite imagery and aerial photography in GNPC that it is possible to assess the density and dispersion of shrubs and grasses in riparian and grassland communities of varying shrub density using remote sensing (Penniket 2004, Guo et al. 2005a). Leaf area index, an important measure of branch and leaf density is readily detected in high resolution satellite images, and correlates well to habitat requirements of shrikes that prefer dense shrubs for nesting habitat, but sparse shrubs for foraging habitat. A recent study in GNPC was successfully able to map sagebrush distribution and abundance and link these to soil parameters such as texture and hydrology (Penniket 2004). These studies suggest to us that by linking ground based reflectance and biophysical measures to remotely sensed imagery we can effectively characterize the patterns of key habitat variables at landscape spatial scales.

OBJECTIVES

The goal of this project is to develop a means of predicting loggerhead shrike habitat using remote sensing techniques. The specific objectives are to: 1) use information already available on the distribution and abundance of loggerhead shrikes in the GNPC greater park ecosystem to measure local characteristics that correlate with occupied habitats, 2) link these characteristics to reflectance properties from ground based and satellite remote sensing data that relate to habitat quality for loggerhead shrikes, 3) measure habitat availability in the GNPC greater park ecosystem, and 4) identify areas within the GNPC greater park ecosystem of high conservation value for future management and protection.

METHODS

Study Area

The study area is located in the GNPC and surrounding lands, in southwest Saskatchewan, Canada (N 49º12’, W 107º24’). The GNPC has an area of about 906.5 square kilometers and comprised of two discontinuous blocks – East and West. GNPC is the first national park in Canada to preserve a portion of the vast mixed-prairie grasslands and it plays a vital role in protecting the region's remaining ecological diversity. The area has a semi-arid continental climate with temperature ranges of -55 to +45^{0}C and annual precipitation is around 300-330 mm. The variation in climatic factors, topography, and landuse/landcover, make this area an ideal setting to understand the biophysical response behavior differences of shrub flora in the light of disturbance regimes. More importantly, many fauna endangered or threatened in the Canadian Prairies, are presently seen only in the park area.

Data Collection and Pre-processing

Field design: Field data collection was conducted in the summer of 2006 and 2007 in the West block of GNPC. We collected data from three different types of sites according to the nesting occurrence: active nesting, inactive nesting and control sites. Active nesting was defined as those currently maintained by a Loggerhead Shrike. Inactive nesting area was where a nest was previously recorded but was unoccupied in the most recent survey. Control sites were riparian reaches where a loggerhead nest was never observed. GPS points were selected in the shrub community adjacent to active, inactive or control shrike nest sitesWe measured 45 sites (16 active, 8 control, and 18 inactive).. From each point, a 100-m measuring tape was extended in each cardinal direction (North, South, East, West) - two transects.. At regular intervals we measured Daubenmire cover, biomass, robel pole vegetation cover, leaf area index, hyperspectral reflectance, low shrub encounter density and tall shrub patch density. The 50cm x 20 cm Daubenmire frame was placed with the narrow edge on transect at the 20, 40, 60, 80 and 100m mark. All variables collected from each site were averaged to represent the characteristic of the site.

Satellite image acquisition and pre-processing: Four SPOT images (SPOT 4 and 5) were purchased for the study area: 2.5m resolution panchromatic on July 27, 2006, 10m multispectral on July 27, 2006, and 20m multispectral on June 28, 2006 and August 16, 2007. They were processed for geometric and radiometric corrections using PCI Geomatica software. Vegetation indices were calculated to correlate with habitat characteristics.

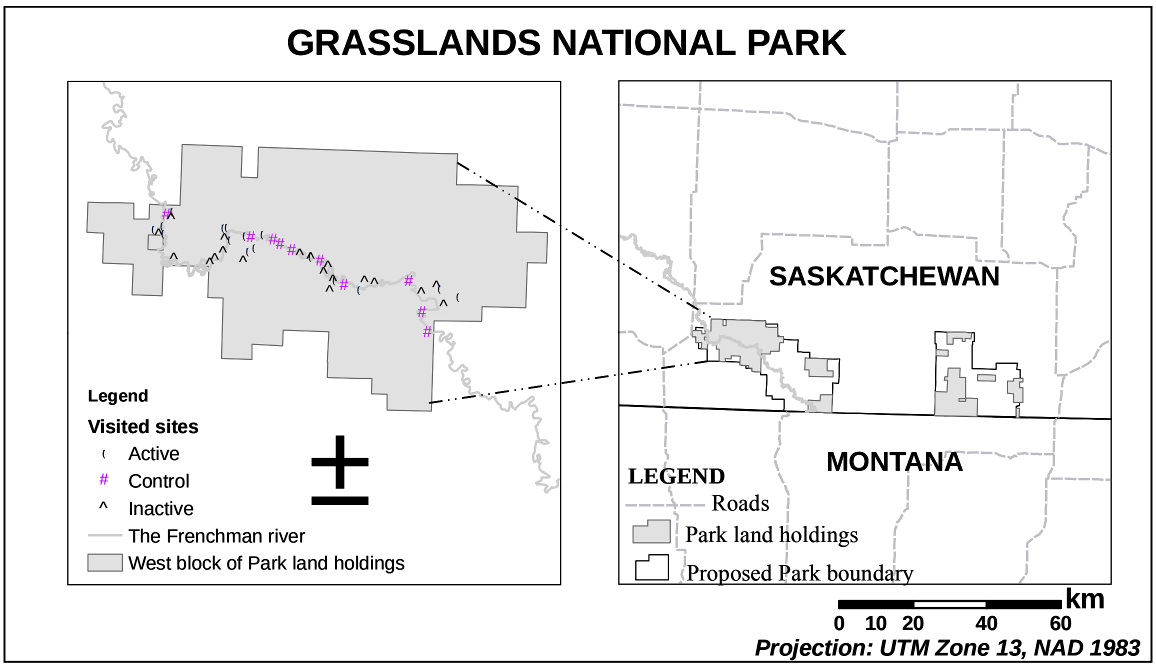

Figure 1. Study area (the west block of GNP) and field sites.

Data Analysis

Comparing habitat characteristics among sites. The biophysical and topographical variables collected from sites and transects were analyzed using the Analysis of Variance (ANOVA) to detect differences among three site types (active nesting, inactive nesting, and control) at a P-value of 0.10 level. Since the results of the ANOVA analysis can only detect whether or not a difference exists, the Scheffe post-hoc test was chosen for its relatively conservative ability to determine exactly which site types differed significantly from one another. The results could be used to identify some of the most relevant biophysical and topographical factors that significantly affect the habitat suitability. This information may be used as input variables in habitat modeling process and suggest future scenarios for the species-at-risk within or around the study area.

Linking the significant habitat characteristics to reflectance. To identify the best spectral indices or parameters to estimate significant habitat characteristics, ground biophysical measurements were correlated to spectral vegetation indices (Table 1) that are derived from both ground hyperspectral data and satellite imagery. ATSAVI has proven useful to estimate LAI in the mixed grass ecosystem (Guo et al., 2005b), and we improved the index further by incorporating litter component (L-ATSAVI, which is expressed as,

$$\frac{a(\rho_{800} - a\rho_{670} - b)}{a\rho_{800} + \rho_{670} - ab + X(1+a^2) + L \times (0.5 \times (\rho_{2000} + \rho_{2200}) - \rho_{2100})} \quad \text{(He et al, 2006)}$$

Regression analysis was used to identify the best predictors for estimating the different shrub communities from the remote sensing data. Linking field measured biophysical variables to satellite retrievals will help to scale our knowledge of the shrub habitats from the site level to the community level (and finally to the landscape/ecosystem level). This will help in furthering our understanding of the suitable habitat selection function by the dependent fauna.

Table 1. Biophysical VIs Investigated in this Study

VIs	Name	Equation	References
NDVI	Normalized Difference Vegetation Index	$\frac{\rho_{800} - \rho_{670}}{\rho_{800} + \rho_{670}}$	Rouse et al., 1974; Haboudane et al., 2004
SAVI	Soil Adjusted Vegetation Index	$(1+L)\frac{(\rho_{800} - \rho_{670})}{\rho_{800} + \rho_{670} + L}, L = 0.5$	Huete, 1988; Haboudane et al., 2004
TSAVI	Transformed Soil-Adjusted Vegetation Index	$\frac{a(\rho_{800} - a\rho_{670} - b)}{a\rho_{800} + \rho_{670} - ab}$	Baret et al., 1989
MSAVI2	Modified Soil Adjusted Vegetation Index	$\frac{1}{2}\left[2(\rho_{800}+1) - \sqrt{(2\rho_{800}+1)^2 - 8(\rho_{800} - \rho_{670})}\right]$	Qi, et al., 1994 ; Haboudane et al., 2004
ATSAVI	Adjusted Transformed Soil-Adjusted Vegetation Index	$\frac{a(\rho_{800} - a\rho_{670} - b)}{a\rho_{800} + \rho_{670} - ab + X(1+a^2)}$, X=0.08	Baret and Guyot, 1991
RDVI	Renormalized Difference Vegetation Index	$\frac{\rho_{800} - \rho_{670}}{\sqrt{\rho_{800} + \rho_{670}}}$	Reujean and Breon, 1995; Haboudane et al., 2004

Note: The coefficients *a* (gain) and *b* (offset) in the equations for TSAVI and ATSAVI are derived from the NIR vs. Red rock-soil baseline. In our study area, *a* is 1.22 and *b* is 0.03 (X. Guo, unpublished data). ρ, reflectance. When calculated VIs using satellite data, ρ_{800}, ρ_{670} in the equation were ρ_{NIR} and ρ_{Red}, respectively.

Using logistic regression to predict the suitable area for the loggerhead shrike habitat. A variety of analytical techniques have been used to investigate the relationship of wildlife habitat and environment. These include logistic regression, discriminant analysis, canonical correlation analysis, supervised non-parametric classifiers and neural networks. The most common analysis to define habitat suitability, where records show only the presence, is logistic regression. For this purpose, a General Linear Model was developed by using binary logistic regression design. This statistical analysis is especially helpful when presence has to be compared with absence (binary). At the same time, the outcomes show us the degree to which a factor is significant relative to nesting occurrence. Binary logistic regression has also been used to classify observations into one of two categories, and it may give fewer classification errors than discriminant analysis for some cases. Two types of environmental factors (biophysical and topographical) were the model predictors. Finally, a variety of statistical tests can be applied in order to assess how well the models describe the data. In this study, three tests (Pearson, Psuedo R^2, predicted correct percentage, and Hosmer-Lemenshow) were used. The Hosmer-Lemenshow test assesses the fit of the model by comparing the observed and expected frequencies. The estimated probabilities are grouped from lowest to highest, and then the Chi Square statistic is calculated to determine if the observed and expected frequencies are significantly different. When the Hosmer-Lemenshow test is significant, it means that the observed counts and those predicted by the model are not close and the model does not describe the data well, and *vice versa*. In order to obtain some vegetation classes that shrikes preferred and to predict the suitable area, we used a classified map that consists of shrub, shrub and grass mixed, dense grass, sparse grass, bareground, and water, represent the dominate types of land cover in GNP and surroundings (Guo et al., 2008).

RESULTS AND DISCUSSION

Habitat Characteristics

Overstory characteristics (Table 2 and Figure 2). From surveyed active sites, we found shrikes used tall shrubs, especially thorny buffaloberry (*Sheperdia argentea*) for nest locations. Therefore, the biophysical properties of tall shrubs were specifically checked in the study sites. Data analysis showed 88% of tall shrubs are thorny buffalo berry in active sites, 91% in inactive sites, and 77% in control sites. Mean height of tall shrubs in active sites was 2.66 m, 25% shorter than that in inactive sites and 20% shorter than that in control sites. Similarly, mean length and width of tall shrubs are also smaller than that in inactive and control sites. Shrubs in active sites are closer to the site centers in comparison with other two types of sites. The dead cover of shrubs is greater in active sites in comparison with inactive and control sites: 42% greater than that in inactive sites and 5% greater than that in control sites. However, these variables are not significantly different among three types of sites.

It is expected that we have more tall shrubs, especially thorny species, and smaller shrub size in active sites, because shrikes like scattered shrubs or trees, particularly thick or thorny species, serving as nesting substrates, impaling stations and hunting perches (Porter et al. 1975, Smith 1991, Collister 1994, Chabot et al. 1995, Collister and Henry 1995, Cuddy 1995, Woods 1995*a*, Yosef 1996). Some studies even indicated that thorny plants such as thorny buffaloberry most likely discourage mammalian predators. The higher dead cover canopy in active sites is also reasonable because studies of shrikes showed that shrikes use dead branches to perch on while hunting for prey. According to our analyses, dense shrubs and less dead canopy in inactive sites areas are the biophysical characteristics of abandoned sites and may contribute to site abandonment.

Table 2. Measured Overstory Characteristics and ANOVA Results between Habitat Categories

Measured variables		Mean			Sig.*		
		Active	**Inactive**	**Control**	**Active-Control**	**Active-Inactive**	**Control-Inactive**
Overstory characteristics	Thorny buffalo berry %	88	91	77	086	1	0.49
	Dead canopy cover %	34.4	20	32.7	1	0.08*	0.25
	Shrub distance to centre (m)	5.4	17	11.4	0.99	0.1	1
	Length (m)	6.5	7.8	7.1	1	1	1
	Width (m)	4	6.3	5.4	0.71	0.09*	1
	Length*Width (m^2)	29.6	57.4	45	1	0.42	1
	Height (m)	2.7	3.3	3.2	0.28	0.06*	1

* Small significance values (<0.1) indicate group differences

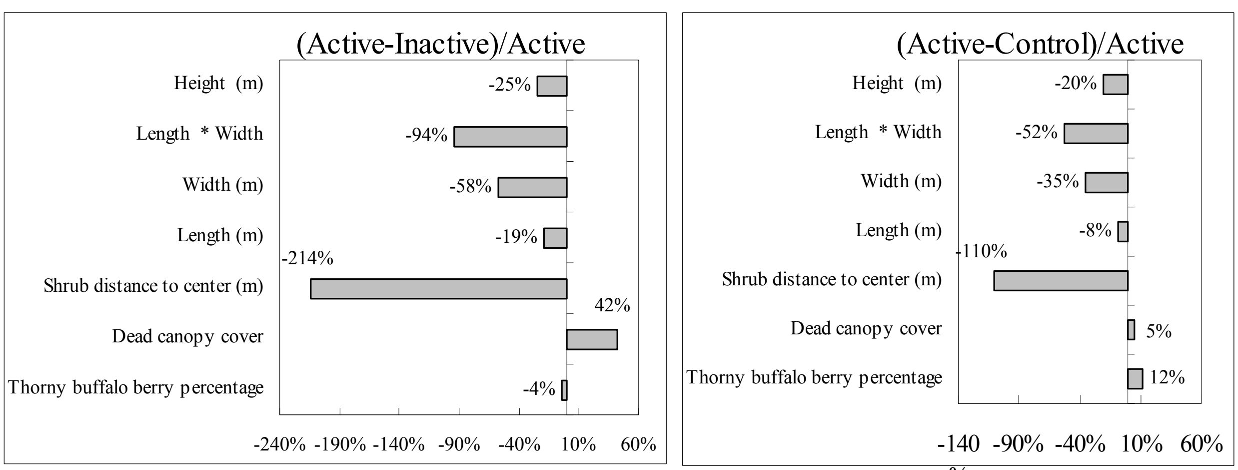

Figure 2. Relative differences of overstory characteristics between active and inactive or control sites.

Understory characteristics (Table 3 and Figure 3). In the understory, mean dead cover and litter cover in active sites are 7.51% and 67.06% respectively, much less than that in inactive and control sites. Mean shrub cover in active sites is 24.53%, 23% more than that in inactive sites, but 77% less than that in control sites. Grass height in active sites is 0.31m, significantly shorter than that in inactive and control sites. LAI in active sites is 1.67, 21% less than that in inactive sites and 71% less than that in control sites. As for biomass data, active sites have an average of 25.79 g litter, 9.75 g green material and 1.34 g forb. Litter and green biomass in active sites is less than that in inactive and control sites, while forb biomass in active sites is more than that in inactive and control sites. The shrub cover and LAI are significantly different between active and inactive sites.

These results suggest that shrikes in our study area prefer nest at the locations with less grass productivity (less green cover and less LAI), less dead materials, shorter grass, and more open spaces (fewer low shrubs and thus more open). Studies in other areas also reported the similar results to ours. For example, some studies found that shrikes prefer open habitat characterized by grasses and forbs of low stature (Stewart 1975, Rotenberry and Wiens 1980, Brooks and Temple 1990*a*, De Geus 1990, Poole 1992, Prescott and Collister 1993, Hellman 1994, Cuddy 1995, Yosef 1996, Pruitt 2000). Other studies found that abundance of loggerhead shrikes was positively correlated with percent shrub cover, percent bare ground, and average height of emergent forb/shrub; abundance was negatively correlated with percent grass cover (Rotenberry and Wiens 1980) and grass height (Collister 1994).

Table 3. Measured Understory Characteristics and ANOVA Results of Habitat Categories

	Measured variables	Mean			Sig.*		
		Active	**Inactive**	**Control**	**Active-Control**	**Active-Inactive**	**Control-Inactive**
Understory characteristics	Dead cover %	7.5	11	10.3	0.97	0.46	1
	Litter cover %	67.1	82.4	91.9	0.13	0.44	1
	Shrub cover %	24.5	18.8	43.4	0.02*	0.95	0.000*
	LAI	1.7	2	2.9	0.01*	0.09*	0.08*
	Grass height	0.3	0.4	0.6	0.018*		
	Biomass-Litter (g/m^2)	25.8	44.8	N/A	N/A		N/A
	Biomass-Green (g/m^2)	9.8	12.2	N/A	N/A		N/A
	Biomass-Forb (g/m^2)	1.3	0.6	N/A	N/A		N/A

* Small significance values (<0.1) indicate group differences

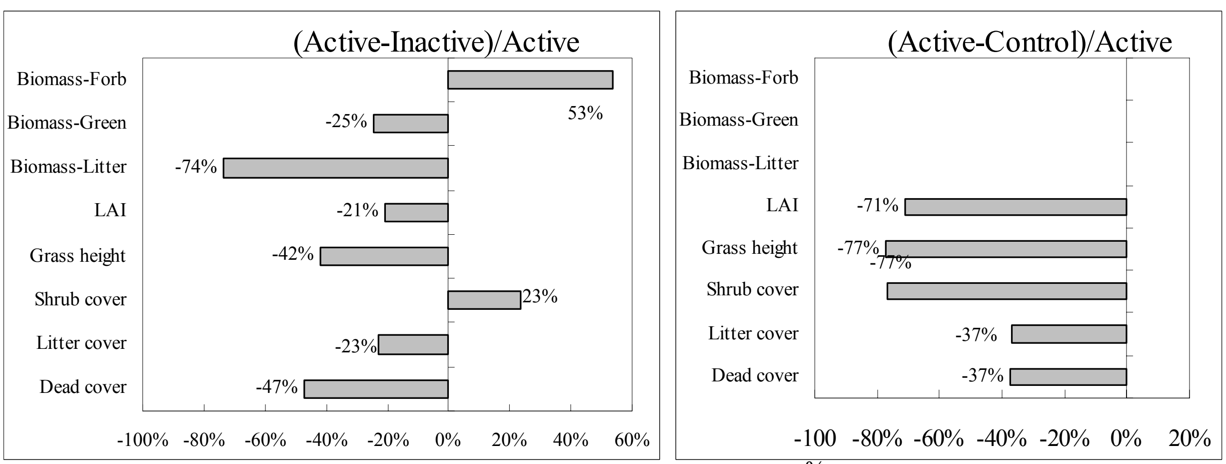

Figure 3. Relative differences of understory characteristics among sites.

Territory characteristics (Table 4 and Figure 4). Comparisons between inactive and control sites revealed that occupied territories are further away from roads: on average, active sites are 2227 m away from the road, inactive sites are 1779 m away from the road and control sites are 1315 m from the road. Using ATSAVI as green vegetation indicator, we found that there is less green vegetation around active sites in comparison with inactive and control sites. Closer to the sites, the differences in green vegetation cover between active and the other surveyed sites are even greater. The active sites are averagely 5% lower at 2000m to 14% lower at the sites than inactive sites and are 4% lower at 2000m to 45% lower at the sites than control sites. The difference for ATSAVI within sites and within 200 m are significantly different between active and control sites ($P < 0.1$, Table 5).

Lower ATSAVI values mean less green vegetation, most likely indicating that active sites surrounded by shorter grass and fewer shrubs, which could provide a greater amount of usable foraging area for shrikes in comparison with inactive and control sites. The most important aspect of active sites observed in this population is that active sites were located further from the road. Other studies also have found reduced success and high predation rates of roadside nests (Burton 1990, De Geus 1990). The reason for shrikes nesting away from road could be explained by the characteristics of roadside habitat --- making nests more vulnerable to predation (De Geus 1990). Linear habitat features such as roadsides, often act as travel lanes for predators (Crabtree et al. 1989).

Table 4. Measured Territory Characteristics and ANOVA Results of Measured Variables

Measured variables		**Mean**			**Sig.***		
		Active	Inactive	Control	Active-Control	Active-Inactive	Control-Inactive
Territory characteristics	Distance to road (m)	2227	1779	1315	0.3	1	1
	ATSAVI	0.3	0.34	0.46	0.000*	0.88	0.03*
	Mean ATSAVI within 200m	0.25	0.29	0.38	0.01*	0.84	0.06*
	Mean ATSAVI within 500m	0.21	0.24	0.27	0.09*	0.85	0.54
	Mean ATSAVI within 1000m	0.19	0.19	0.21	0.33	1	0.45
	Mean ATSAVI within 2000m	0.17	0.18	0.18	0.67	0.24	0

* Small significance values (<0.1) indicate group differences

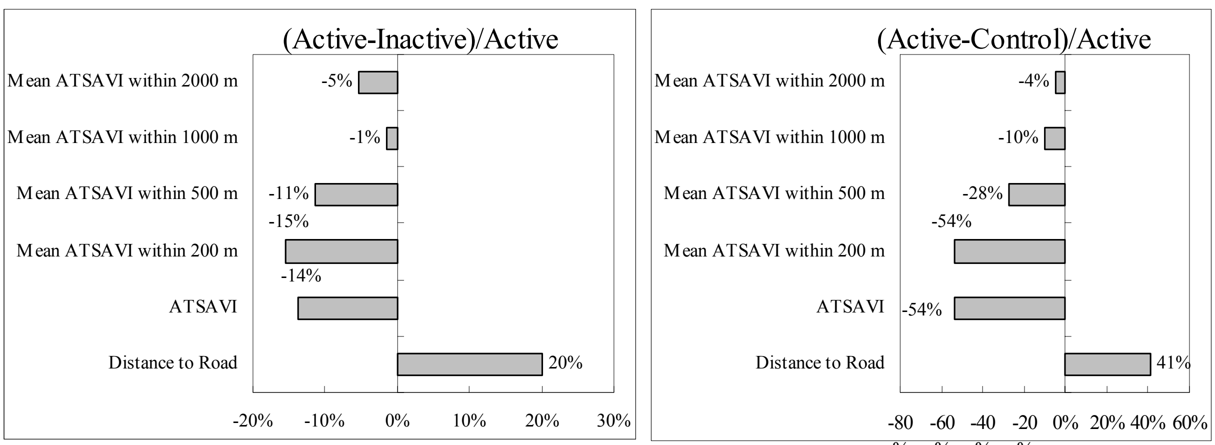

Figure 4. Relative differences of understory characteristics between active and inactive or control sites.

Suitable reflectance properties to identify habitat characteristics. All selected hyperspectral vegetation indices showed significant differences among three groups in which control sites always differed from the others (Table 5). To determine the VIs in estimating significant vegetation habitat characteristics, the correlation coefficients between VIs and these vegetation variables were computed (Table 5). All of the correlation coefficients were significant ($P<0.01$ or <0.05), which indicated the high correlations between vegetation variables and VIs. Among the VIs, L-ATSAVI was slightly better than other indices in estimating LAI, which is consistent with the previous study in the same study area (He et al., 2006). MSAVI2 showed the better performance in estimating shrub cover. ATSAVI is a better grass height indicator. Figure 5 further demonstrated that the relationships between hyperspectral VIs and vegetation properties were linear.

Table 5. ANOVA Results of Hyperspectral Vis among Habitat Categories and the Correlation Coefficients between these VIs and Significant Vegetation Characteristics

VIs	ANOVA Sig.	Post Hoc Tests (Group differences)	Correlation coefficients		
			LAI	Shrub cover	Grass height
Simple Ratio	0.023*	Active/Inactive-Control	-0.89**	-0.49*	-0.81**
NDVI	0.009**		0.91**	0.52**	0.81**
SAVI	0.009**		0.91**	0.64**	0.83**
TSAVI	0.016*		0.91**	0.52*	0.82**
ATSAVI	0.019*		0.93**	0.59**	0.83**
L-ATSAVI	0.021*		0.93**	0.59**	0.82**
MSAVI2	0.010*		0.91**	0.65**	0.82**
RDVI	0.024*		0.89**	0.49*	0.81**

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

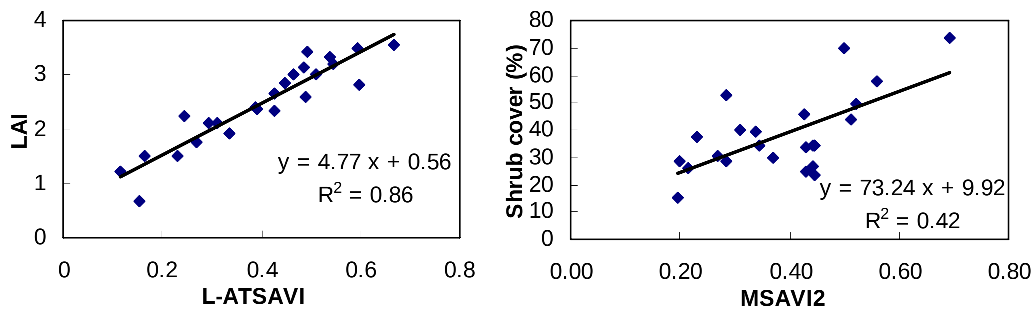

Figure 5. The relationships between hyperspectral VIs and significant vegetation characteristics.

Satellite data. We also calculated all selected vegetation indices using satellite data from the June SPOT 4 image and the July SPOT 5 image with selected biophysical variables (Table 6). ANOVA results also demonstrated that broadband VIs were significantly different among three sites, in which control sites also differed from the others. All of the correlation coefficients were significant (P<0.01 or <0.05). Compared June image with July image, we found that June image was better to identify total LAI and shrub cover, while the July image was effective at estimating grass height. The performance of VIs was also different between June and July images. Using June image data, ATSAVI was better than other indices in estimating LAI and grass height. However, using July image data, NDVI instead of ATSAVI was better in estimating LAI and grass height. No matter which image being used, MSAVI2 always showed the better performance in estimating shrub cover. Figure 6 also demonstrated that the relationships between braodband VIs and vegetation properties were linear.

Table 6. The Correlation Coefficients between Satellite VIs and Significant Vegetation Characteristics

		Simple Ratio	NDVI	SAVI	TSAVI	ATSAVI	MSAVI2	RDVI
SPOT4 (06.22)	**LAI**	-0.86**	0.86**	0.85**	0.86**	0.86**	0.84**	0.86**
	Shrub over	-0.43*	0.45*	0.54**	0.46*	0.50*	0.56**	0.43*
	Grass eight	-0.77**	0.80**	0.79**	0.80**	0.80**	0.80**	0.77**
SPOT5 (07.27)	**LAI**	-0.83**	0.83**	0.81**	0.82**	0.82**	0.80**	0.83**
	Shrub over	-0.44*	0.46*	0.51*	0.46*	0.49*	0.52**	0.45*
	Grass eight	-0.84**	0.85**	0.83**	0.85**	0.84**	0.83**	0.85**

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

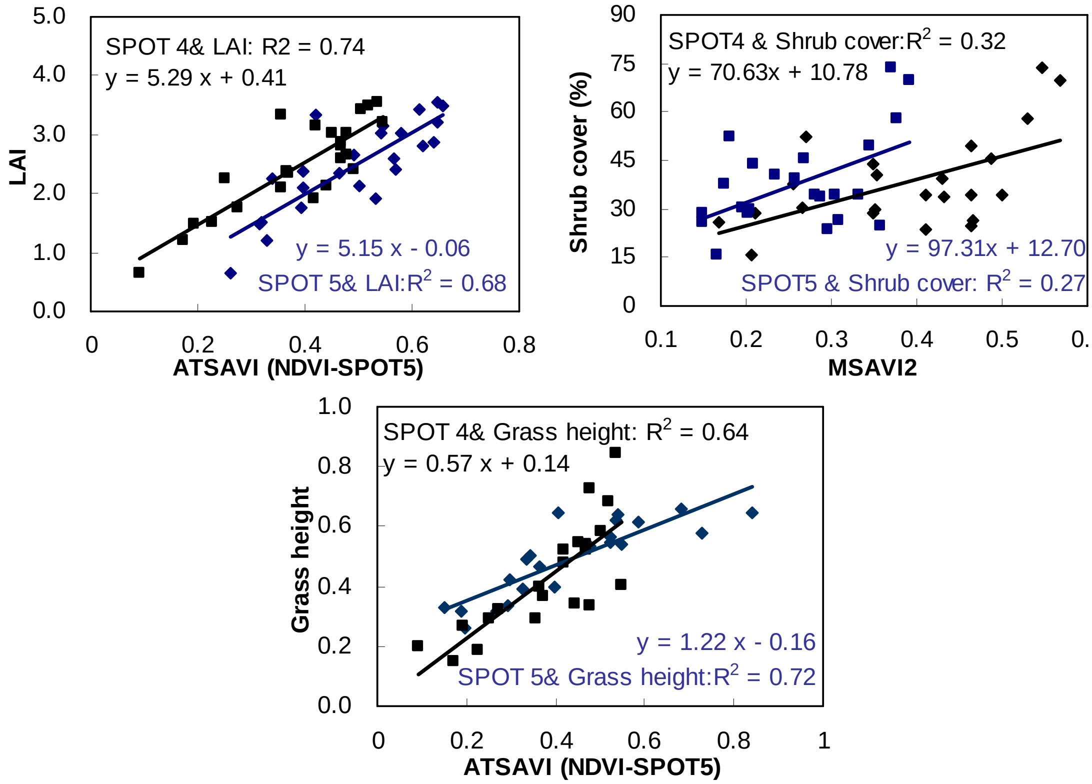

Figure 6. The linear relationship between broadband VIs and significant vegetation characteristics.

Logistic regression habitat modeling and mapping. The logistic regression coefficient, its standard error, and Wald test were shown in Table 7. If the Wald statistic is significant (i.e., less than 0.05) then the parameter is useful to the model. For example, we can see that dead shrub canopy cover, shrub patch width, shrub patch height in Table 8E, 8H, and 8I resulted in a small Wald statistic, therefore, and these two variables might be useful to build the regression models.

The log likelihood, Pseudo R^2 (Cox & Snell R^2 and Nagelkerke R^2), overall predicted correctly, and Hosmer & Lemeshow test were presented in table 7 to evaluate the models. R^2 is comparable to R^2 from ANOVA conducted on individual observations. The interpretation of the log likelihood and Pseudo R^2 is: the less log likelihood, the higher R^2, the more proportion of variation in the dependent variable accounted for by the independent variable or variables. In this case, 21% of variation in active or inactive of nesting was accounted for by an index of the dead shrub canopy cover. Comparing Table 8E and 8H we saw that the model with 'dead shrub canopy cover' accounted for 1% less of the variation in active and inactive than did the model with 'shrub patches width': the latter variable had a less log likelihood and, consequently, a greater Psuedo R^2. Hosmer & Lemeshow Test is a goodness-of-fit test of the null hypothesis that the model adequately fits the data. If the null is true, the statistic should have an approximately chi-square distribution with the displayed degrees of freedom. If the significance of the test is small (i.e., less than 0.05) then the model does not adequately fit the data. Table 8E showed a close chi-square distribution (7.71) with the displayed degrees of freedom (7) and the significance (0.36) was greater than 0.05, then the model should fit the data. The overall predicted correct helped to assess the performance of the models.

Having obtained the results in Table 7A-N, we conducted a multiple logistic regression analysis to determine how many different factors may be contributing to variation in the nesting presence. We therefore ran another model, with the stepwise method to select the suitable independent variables, shown in Table 7O. In this case, we saw that only two variables, ATSAVI and 'Shrub dead canopy cover', were selected to enter the model. The effect of each of the two variables was significant when controlling for the effect of the other. Note that the Pseudo R^2 for the 2-variable model was higher compared to the Pseudo R^2 for all other single variable models in Table 7 A-N. Thus, by including both ATSAVI and 'Shrub dead canopy cover' in the model, we are able to increase the Pseudo R^2. We also examined the goodness of fit of the model in Table 7O and the results showed no reason to reject the fit of the model, implying that the assumption made in logistic regression that residuals are binomially distributed was satisfied. The higher predicted correct in Table 7O (72%) showed the predicted probability of the model for nesting presence. Based on Table 7O, the logistic model for suitable habitat mapping should be:

$$Y=\frac{1}{1+e^{-U}},\ U = 0.73 + 0.013 \times Ds - 12.62 \times ATSAVI$$

where Ds is dead material in tall shrub canopy. From above equation we can see that dead material in tall shrub canopy positive contribute to the shrike nest selection, and ATSAVI is inversely related to the shrike nest selection.

Table 7. Logistic Regression Analysis of Active Sites/Inactive Sites in Relation to Habitat Features

Model evaluation							Model Summary				
-2 Log likelihood	Cox & Snell R^2	Nagelkerke R^2	predicted correct	Test Chi-square	df	Sig.	Cons.	Coef.	S.E	Wald	Sig.
A) Independent Variable: Distance to the road											
45.71	0.03	0.04	59%	9.72	8	0.29	-0.75	0.00	0.00	0.94	0.33
B) Independent Variable: SPOT4 ATSAVI											
45.72	0.03	0.04	59%	7.26	8	0.51	0.65	-2.77	2.89	0.92	0.34
C) Independent Variable: SPOT4 ATSAVI-200 m											
45.63	0.03	0.04	56%	2.49	8	0.96	0.63	-3.23	3.21	1.01	0.32
D) Independent Variable: Thorny buffalo berry percentage											
37.24	0.01	0.01	52%	2.67	2	0.26	0.56	-0.71	1.83	0.15	0.70
E) Independent Variable: Dead shrub canopy cover											
30.02	0.21	0.28	65%	7.71	7	0.36	0.07	0.07	0.03	4.67	0.03
F) Independent Variable: Shrub distance to center											
29.44	0.22	0.30	65%	4.82	7	0.68	1.13	-0.13	0.08	2.70	0.10
G) Independent Variable: Shrub patch length											
35.13	0.03	0.05	62%	12.95	7	0.07	0.84	-0.12	0.13	0.86	0.35
H) Independent Variable: Shrub patch width											
29.66	0.22	0.29	77%	2.87	7	0.90	2.67	-0.55	0.27	4.05	0.04
I) Independent Variable: Shrub patch height											
30.50	0.19	0.26	73%	4.86	7	0.68	4.73	-1.61	0.89	3.28	0.07
J) Independent Variable: Dead cover in understory											
35.92	0.09	0.12	50%	4.69	7	0.70	0.76	-0.11	0.07	2.06	0.15
K) Independent Variable: Little cover in understory											
36.91	0.06	0.08	57%	4.90	7	0.67	1.18	-0.02	0.01	1.64	0.20
L) Independent Variable: Forb cover in understory											
36.92	0.02	0.02	52%	4.10	7	0.77	0.34	-0.06	0.09	0.46	0.50
M) Independent Variable: Shrub cover in understory											
37.42	0.04	0.06	54%	7.68	7	0.36	-0.84	0.03	0.03	1.20	0.27
N) Independent Variable: LAI											
38.01	0.02	0.03	50%	10.93	7	0.14	0.53	-0.36	0.45	0.64	0.42
O) Best multiple logistic regression model: STEPWISE											
23.19	0.37	0.49	72%	5.05479258	6	0.54	0.73				
ATSAVI								-12.62	6.528	3.7392	0.053
Shrub Dead Canopy Cover								0.1273	0.057	5.0558	0.025

From above analysis, we found that shrikes need tall shrubs as nest support in the study area and shrikes prefer the area with dead material in tall shrub canopy. We extracted shrub and shrub-grass mixed layers from classification map (Guo et. al., 2008) to aid suitable habitat mapping. Specifically, since the established logistic model included two parameters (dead shrub cover and ATSAVI), we have to get these two variables for entire park area in order to run the model. The ATSAVI map for entire study area can be derived from satellite image. However, dead cover in tall shrub canopy is not easy to be obtained. Alternatively, we have extracted GIS layer for shrub and shrub-grass mixed classes, and the suitable habitat for shrike nesting should be within this GIS layer. Therefore, we use extracted shrub GIS layer to clip the ATSAVI map, then we use mean dead shrub cover (28.5%) and clipped ATSAVI map to run the established logistic model for suitable habitat mapping. The final suitable habitat map is showed in Figure 7. The proportion of the total study area that was predicted as suitable habitat for the loggerhead shrikes (using probability of occurrence at a $\geq 0{\cdot}5$ level) was 72%.

Figure 7. The suitable shrike habitat map for GNPC West Block.

CONCLUSIONS

The analysis results indicated that shrikes prefer to nest in scattered shrubs, particularly thick or thorny species, likely because the shrubs could serve as nesting substrates, impaling stations, and hunting perches, and discourage mammalian predators in our study area. The higher canopy dead cover in active sites is identified, suggesting that the dead branches might be used by shrikes for perches while hunting for prey. Based on understory data analysis, this study also found that shrikes prefer nesting at the locations with less grass productivity (less green cover and less LAI), less dead materials, shorter grass, and more open spaces (less low shrubs and thus more open).

Analysis of territory characteristics showed that ATSAVI is lower within and around active sites, suggesting shorter grass and fewer shrubs in those sites. The shorter grass could provide a greater amount of usable foraging area for the shrike. The most important aspect of active sites observed in this population is that active sites are located further from the road. The reason for shrike selecting nests away from road is perhaps because of characteristics of roadside habitat-- making nests more vulnerable to predation.

The hyperspectral vegetation indices and broadband indices were both significantly related to these most relevant factors. The performance of the vegetation indices are different considering the different vegetation variables. L-ATSAVI and ATSAVI are the better LAI estimators, while MSAVI2 is good to estimate the shrub cover.

The logistic regression model, using loggerhead shrikes active or inactive nesting as the dependent variable and biophysical, topographical, and remotely sensed data extracted from both ground and space, as the predictors were conducted. The predictive performance of the selected models was shown to be high, indicating a good fit of the model to the data. Further analysis showed that all the variables considered (Dead cover in tall shrub habitat and ATSAVI) had significant independent contributions towards explaining the variation in the dependent variable. The selected model clearly delineated areas predicted as highly suitable loggerhead shrikes habitat. Conservation of this species will depend on management actions that protect the critical habitats identified in the model.

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