Bird populations and remote sensing

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Abstract: Bird populations are highly dependent on grassland structure, diversity and quality which, in turn, are disturbance dependent (e.g. grazing and fire). The reflectance differences in vegetation can be detected by satellite signals that are further analyzed through vegetation indices. Our purpose was to investigate the feasibility of applying remote sensing techniques to predict the breeding bird population in the northern mixed grasslands. Birding surveys were conducted in the summer of 2003 in Grasslands National Park (GNP), Saskatchewan, Canada. One Landsat Thematic Mapper (TM) image was acquired in the same year. Selected vegetation indices were calculated to investigate the relationships between spectral reflectance and the populations of four bird species. Results indicated that remotely sensed data could predict bird density with moderate accuracy: 53%, 51%, 43%, and 44% for Sprague's Pipit, Baird's Sparrow, Horned Lark, and Chestnut-collared Longspur, respectively. The ATSAVI spectral vegetation index showed the best results, followed by TVI and Wetness.

Introduction

Critical grassland habitat for species at risk (SAR) in the Canadian prairies is shrinking dramatically due to direct and indirect human influence. This has resulted in chronic population declines of species already at risk, such as Sprague's pipit, Baird's sparrow, and sage grouse. Loss, degradation and fragmentation of critical habitat due to human activities have impeded species recovery. While the characteristics of critical habitat for some SAR (e.g., sage grouse) are reasonably well understood (silver sagebrush, forbs in vegetation community), until recently it has been difficult, if not impossible, to measure these factors at a landscape scale. Remote sensing, with its advantages of large areal coverage and multiple spatial, spectral, and temporal resolutions, has been applied to predict avian populations

by linking remote sensing and habitat biophysical characterisitcs. Avery and Haines-Young (1990), for example, used satellite imagery to estimate the population of the dunlin *Calidris alpina* for the Flow Country of northern Scotland. The authors demonstrated that remotely sensed satellite imagery could be used to make accurate predictions of the dunlin population, and thereby assess the impact of forestry on this wading bird. The near-infrared band 7 of Landsat MSS, in addition to its sensitivity to green vegetation, is also sensitive to soil wetness. The habitat favored by dunlin is wet moorland interspersed with small pools, so that dunlin populations are significantly negatively correlated with a soil wetness index derived from the MSS band 7 reflectance values.

Palmeirim (1988) similarly mapped the habitat of several avian species using satellite imagery. The author combined the habitat classification derived from Landsat TM imagery and bird survey data to obtain habitat suitability estimates and produce maps reflecting the habitat needs of each individual species. One scene of TM imagery was used to produce a land cover map of a study area located in NE Kansas, USA, and then spatial algorithms were used to reclassify the land cover map to habitat classes for breeding birds. Bird surveys were conducted to obtain the composition and abundance of the required bird fauna at a number of points representative of all the major habitats present in the study area. Both the habitat map and bird survey results were input to a GIS to generate distribution, suitability and density maps, and to make crude estimates of population size. Other avian studies using remote sensing include predicting avian population, such as for ring-necked pheasant in Kansas (Houts et al. 2002), duck population and duck habitat (Cowardin et al. 1995), and linking landscape heterogeneity and bird population ecology with microwave remote sensing (Imhoff et al. 1997). Significant efforts have been made to map habitat, including relating bird abundance to forest stand structure (DeGraaf et al. 1998), modelling sage grouse winter habitat (Homer et al. 1993), modelling landscape-scale habitat use using GIS and remote sensing (Osborne et al. 2001), and evaluating breeding habitat for an African weaver-bird (Wallin et al. 1992). Previous studies have therefore demonstrated the effectiveness of using remote sensing to predict bird populations. However, there is limited study of the feasibility of remote sensing techniques to estimate the populations of any avian species in the mixed prairie ecosystem. Thus the primary objective of this research is to find the most suitable spectral vegetation indices for bird population estimation and to use these indices to develop bird population predictive models in a mixed prairie ecosystem.

Study Area

Our study area is located in Grasslands National Park (GNP), which has a geographical extent of 49.21N, 107.57W - 49.16N, 107.50W. GNP is located in southern Saskatchewan along the international border of Canada and the United States. The park is approximately 960 km^2 in total area over two discontinuous blocks, west and east. The first land was acquired for the park in 1984; therefore, some areas of the park have been under protection from livestock grazing for over 20 years. The park area consists of upland and valley grasslands. The GNP area has a mean annual temperature of 3.4^{0}C (Environment Canada 2003) and total annual precipitation of 325 mm where about half of the precipitation occurs as rain during the growing season of June to August. The dominant plant community in the uplands of the mixed prairie ecosystem is Needle-and-thread—Blue grama (*Stipa-Bouteloua*), which covers nearly two thirds of the park's area. The dominant species in this community includes needle-and-thread grass (*Stipa comata Trin. & Rupr.*), blue grama (*Bouteloua gracilis (HBK) Lang. ex Steud*.) and western wheatgrass (*Agropyron smithii Rydb.*). Spikemoss (*Selaginella Beauv.*) and June grass (*Koeleria macrantha (Ledeb) J.A. Schultes f.*) are present as well (Fargey et al. 2000).

The need to preserve habitat for the species at risk endemic on the Great Plains has stimulated much research of the ecosystem scale including land use, and landform habitat estimation and monitoring. The current understanding of relationships among ecological integrity, wildlife habitat, and disturbance is that some level of grazing and fire disturbance is an integral biological process of the mixed prairie ecosystem. Remote sensing appears to be the best tool to help restore the ecological integrity of grassland landscapes through advancing the knowledge of relationships between SAR habitats and disturbances caused by grazing and burning, as well as by developing a measuring and monitoring tool that can be used for SAR recovery strategy development.

The Canadian prairies are the northern range of the four species investigated in this study, Sprague's Pipit (*Anthus spragueii)* (SPPI), Baird's Sparrow (*Ammodramus bairdii*) (BASP), Horned Lark (*Eremophila alpestris)* (HOLA), Chestnut-collared Longspur (*Calcarius ornatus)* (CCLO) (Figure 1). The park area is located within the core habitat regions of these species.

Sprague's Pipit (*Anthus spragueii*)
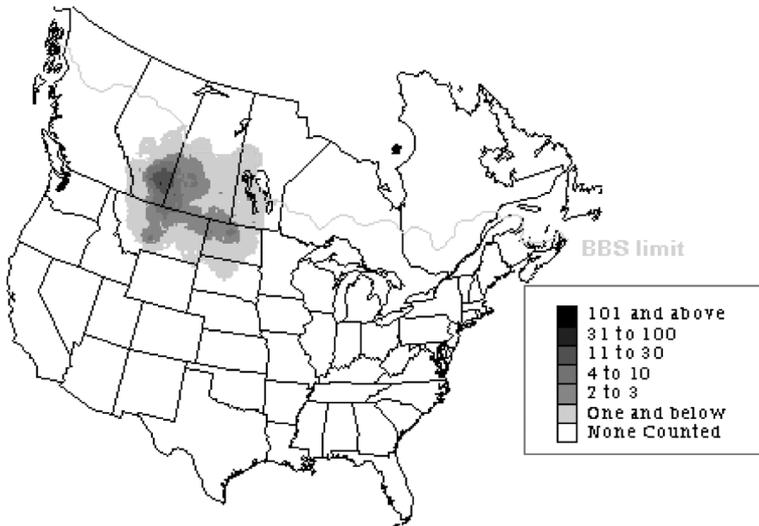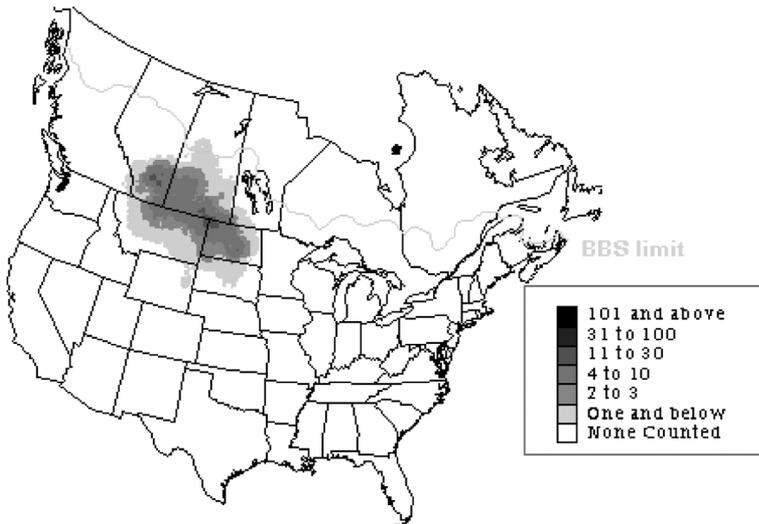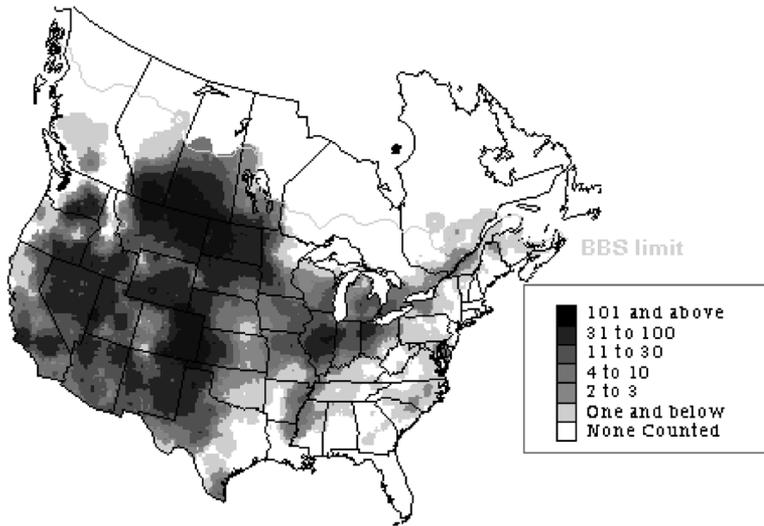

Baird's Sparrow (*Ammodramus bairdii*)

Figure 1: *Spatial distribution of the four bird species in North America. (Data sources: http://www.mbr-pwrc.usgs.gov/id/framlst/i5380id.html).*

Horned Lark (*Eremophila alpestris*)

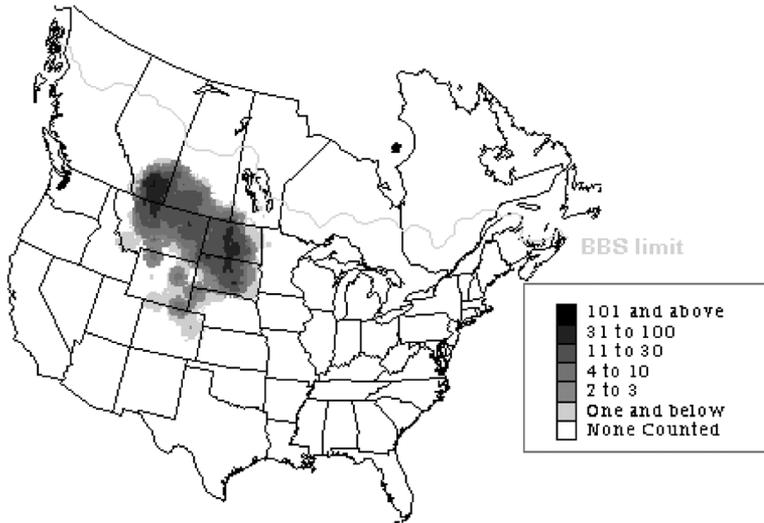# Chestnut-collared Longspur (*Calcarius ornatus*)

Figure 1: *(continued)*

Methods

Field data collection:

Field work was conducted in the summer of 2003 using a stratified random sampling method. Ten sites were selected from upland grasslands in the western block of GNP, as upland represents the mixed grass ecosystem. Five 100 x 100m plots were established in each site, and each plot was composed of two 100m transects placed perpendicular to each other with a north-west orientation. Point-count surveys targeting Sprague's Pipits, Baird's Sparrow, Horned Lark and Chestnut-collared Longspur, were conducted on the field sites during the growing season. Point counts were made at a 100m radius with a distance between closest survey points of at least 200m. At each point, the number of each species observed (aurally and/or visually) was recorded within a 5min interval, excluding flyovers. The survey methodology follows recommendations in the Canadian Land Bird Monitoring Strategy (Downes et al. 2000) and established protocols for GNP by Sutter (1997). This method permits quantitative sampling of breeding bird densities to be linked with habitat variables using song and visual recognition. Survey data were analyzed to species richness (no. species per hectare). Species diversity was calculated using Simpson's reciprocal index (Equation 1) (Feinsinger 2001).

$$[1] \quad D = \frac{1}{\sum_{i=1}^{S} p_i^2}$$

Where S is the total number of species and *P* is the proportion of species *i*.

Satellite image acquisition and pre-processing:

One satellite image acquired on August 10, 2003 was used in this project. The image was pre-processed for atmospheric, geometric, and radiometric corrections. The digital numbers (DN) were converted to 'at surface' reflectance using the method described by Markham and Barker (1986). The pre-processed image was then transformed to selected vegetation indices and all layers stacked together. The vegetation indices (VIs) selected for this study include Adjusted Transformed Soil-adjusted Vegetation Index (ATSAVI), Modified Soil Adjusted Vegetation Index (MSAVI), Perpendicular Vegetation Index (PVI), Triangular Vegetation Index

(TVI), Normalized Difference Vegetation Index (NDVI), and the Brightness (BI), Greenness (GI), and Wetness (WI) indices from the Tassel Cap transformation. NDVI, BI, GI, and WI have been broadly used in vegetation studies, and ATSAVI, MSAVI, PVI, and TVI were selected because they showed promising results for semi-arid environments. Equations for these vegetation indices are listed in Table 1.

Statistical analyses:

The geographic locations of the 50 plots (five plots for each site with 10 sites) were overlain onto the TM image with all vegetation index layers using a GIS overlay procedure. At each location, the mean value of a square of 3 x 3 pixels (90m x 90m area) were extracted for each layer, which approximately matched the area for the birding survey. Both birding survey and spectral plot data were averaged to site level for further statistical analyses. The Pearson's correlation coefficient analysis was performed to test the relationships between bird populations and spectral vegetation indices. Based on the results from the correlation analysis, a linear regression analysis was run with each species population with the spectral variable that showed the highest correlation coefficient for the same species. The regression models were tested using a Jack-Knife cross validation approach. This approach was implemented by withholding the spectral data for one site and building the functions using the data from the remaining sites. The process of removing one site from the dataset was repeated until all sites had been withheld.

Results and Discussion

Birding survey species richness:

Comparing the four principal surveyed species, Sprague's Pipit has the highest number of individuals followed by Baird's Sparrow, and Chestnut-collared Longspur, with the Horned Lark the lowest. While overall diversity was low (4.2) compared to diversity in other habitat types (James and Rathbun 1981). Relative to the average number of individuals recorded at each site (7.1/hectare), this diversity value reflects reasonable spatial overlap among species (Figure 2).

Relationships between species density and vegetation indices:

Pearson's correlation coefficient showed that particular spectral vegetation indices could provide moderately accurate estimation of bird density (Table 2). ATSAVI, TVI, PVI, Brightness, Greenness, and Wetness were well correlated with bird population density. This suggests that

Table 1: *Equations for the vegetation indices used in this study.*

| Vegetation Index	Equation	Reference
Adjusted Transformed Soil-adjusted Vegetation Index (ATSAVI)	$\dfrac{a(TM4 - aTM3 - b)}{aTM4 + aTM3 - ab + X(1+a^2)}$, X=0.08	Baret *et al.* 1992
Modified Soil Adjusted Vegetation Index (MSAVI)	$\dfrac{1}{2}\left[(2TM4+1) - \sqrt{(2TM4+1)^2 - 8(TM4 - TM3)}\right]$	Qi *et al.* 1994
Perpendicular vegetation index (PVI)	$\dfrac{TM4 - TM3 - b}{\sqrt{1+a^2}}$	Richardson and Wiegand 1977
Triangular vegetation index (TVI)	$60(TM4 - TM2) - 100(TM3 - TM2)$	Broge and Leblanc, 2000
Normalized difference vegetation index (NDVI)	$\dfrac{TM4 - TM3}{TM4 + TM3}$	Rouse *et al.* 1974
Brightness vegetation index (BI)	$.1544TM1+.2552TM2+.3592TM3+.5494TM4+.549TM5+.4228TM7$	Kauth and Thomas 1976
Greenness vegetation index (GI)	$-.1009TM1-.1255TM2-.2866TM3+.8226TM4-.2458TM5-.3936TM7$	Kauth and Thomas 1976
Wetness vegetation index (WI)	$.3191TM1+.5061TM2+.5534TM3+.0301TM4-.5167TM5-0.2604TM7$	Kauth and Thomas 1976
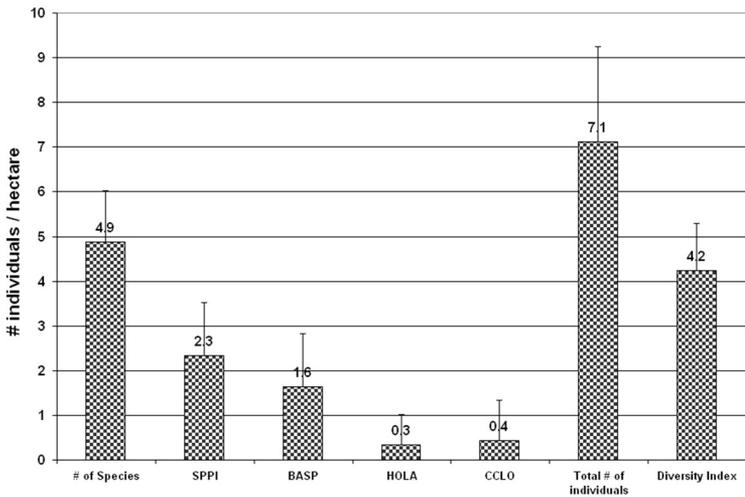
Figure 2: *Species richness of the surveyed birds in the study area with standard errors showing the variation among sites. (SPPI, BASP, HOLA, and CCLO are Sprague's Pipit, Baird's Sparrow, Horned Lark, and Chestnut-collared Longspur respectively)*

different bird species require different vegetation structures that are detected as different vegetation indices. The better results from ATSAVI, TVI and PVI are likely because they are developed for semi-arid regions and are thus more suited to low biomass vegetation land cover. The three indices from the Tasseled Cap transformation performed well because they are based on the principal component analysis, which represents the maximum variation from the canopy. NDVI, popularly used in other studies, did not perform well in the analyses, which is also consistent with another study in the same ecosystem (Guo et al., this issue). NDVI is not suited for detecting the vegetation canopy in the northern mixed grasslands due to influence from senescent materials.

Species density prediction model development:
    Bird population density prediction models were developed based on the spectral vegetation indices derived above. Results showed that 43% to 53% variation in species density could be explained by a single vegetation index (Figure 3) when linear relationships were tested. ATSAVI is the best spectral vegetation index to predict densities of Sprague's Pipit and Horned Lark. The TVI and Wetness yielded the best results for Baird's Sparrow and Chestnut-collared Longspur respectively. Theoretically, there is an

Table 2: Pearson's correlation coefficients between spectral vegetation indices and species population density. Bold numbers indicate significant results at p=0.05.

VIs	Statistic	SPPI	BASP	HOLA	CCLO
ATSAVI	r	**-.730**	-0.089	0.064	**.662**
	P.	**0.017**	0.808	0.861	**0.037**
MSAVI	r	-0.218	**-.698**	-0.5	0.413
	P.	0.546	**0.025**	0.144	0.235
PVI	r	**.698**	-0.023	-0.15	-0.6
	P.	**0.025**	0.95	0.686	0.066
TVI	r	-0.137	**-.714**	-0.51	0.323
	P.	0.706	**0.02**	0.129	0.363
Brightness	r	-0.606	0.04	0.294	**.641**
	P.	0.063	0.914	0.41	**0.046**
Greenness	r	-0.204	**-.658**	-0.53	0.38
	P.	0.571	**0.039**	0.119	0.279
Wetness	r	-0.184	-0.394	**-.656**	-0.13
	P.	0.611	0.26	**0.039**	0.723
NDVI	r	0.198	-0.595	-0.49	0.002
	P.	0.583	0.069	0.155	0.996

optimal vegetation structure range for each species of breeding birds in the grasslands, and species-specific densities will decrease in vegetation communities where the structure is outside of this optimum range (Sutter et al. 2000). While there is clearly spatial overlap among species, as indicated by our diversity measure, optimal habitat utilization varied among species sufficiently to be detected by remotely sensed vegetation indices. We observed this trend for Sprague's Pipit and Horned Lark (less abundant in high density vegetation regions), and Baird's Sparrow and Chestnut-collared Longspur (more abundant with less vegetation cover). Unfortunately, the number of samples in our current study is not large enough to build a non-linear model.

Conclusion

Our study indicated that remotely sensed data could provide moderate accuracy of bird density prediction for individual species, but that no single vegetation index is suitable for all types of breeding birds in the northern mixed grass prairies. This is because each bird species appears to be selecting slightly different habitats. The variation of bird population can be explained by a single spectral vegetation index with accuracy of 53% for Sprague's Pipit, the highest. The accuracy measurements are 51%, 43%, and 44% for Baird's Sparrow, Horned Lark, and Chestnut-collared
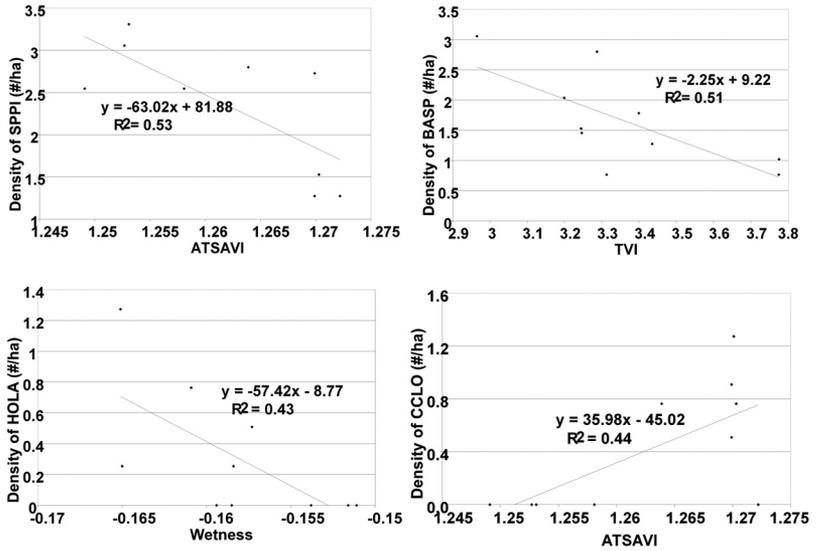
Figure 3: *The bird population prediction models for the four bird species within the study area.*

Longspur, respectively. Among spectral vegetation indices, ATSAVI was the best and followed by TVI and Wetness. This study showed the potential to use remote sensing techniques for species at risk recovery plan development. However, there are several limitations in this study. First, data used for analyses were from one year only. Even though birding data were available for 2004, the satellite imagery was not available and as a result we were unable to test our results. With additional satellite imagery in 2005, further investigation can be conducted in the near future. A second limitation was that the relationships were built on birding population and spectral vegetation indices directly. To understanding how remote sensing data can be used to predict bird populations, it is essential to understand the relationships between birding habitat and birding population, as well as between grassland biophysical and spectral characteristics.

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