Quantifying Aerial Photo Polygon Complexity on a Subalpine Landscape of Wells Gray Park, British Columbia

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ABSTRACT

This study examines patterns of landscape diversity in a 20,000-ha montane-subalpine forest in southern Wells Gray Provincial Park, B.C. Landscape pattern was assessed by sampling aerial photos to quantify the extent of variation in topographic features and polygon (ecosystem unit) distribution patterns. Sixty-eight circular plots, representing pixel sizes of 450 m and 750 m diameter, were used to assess landscape properties, including terrain features and the types and arrangements of polygons. Vegetation data for the polygons were extrapolated from 170 ground plots sampled throughout the study area. Relationships between various complexity indices derived from the polygon patterns and physical terrain features were examined using Principal Components Analysis and Pearson correlations. Vegetation variation within polygons (beta-diversity), as defined by the first axis of Detrended Correspondence Analysis, was also examined for 5 main polygon types in relation to major abiotic factors and forest structural attributes. The results suggest that polygon complexity is weakly related to the interaction of elevation, slope, and aspect. The influence of natural disturbance from windthrow, fire, rock slides, and avalanches on polygon complexity may depend on the extent of disturbances and the conditions prior to the disturbance. Total length of polygon boundaries was the most influential variable on the polygon complexity and diversity indices tested. Overall beta-diversity within a polygon type was related to stages of vegetation development, hence, disturbance history. Beta-diversity of vegetation in the same stage of development was strongly influenced by physical environment, (e.g., elevation, slope, and aspect).

Key words: aerial photography, landscape diversity, subalpine.

Subalpine landscapes exhibit wide variety in physical terrain features and vegetation patterns. Recent advances in landscape ecology offer new approaches for quantifying pattern complexity from maps and remote imagery (Forman and Godron 1986, Krummel et al. 1987, Forman and Godron 1988, Turner and Ruscher 1988, Ritters et al. 1995, Metzger and Muller 1996, Rescia et al. 1997). In particular, a number of landscape complexity indices have been developed for describing relationships among spatial structures (e.g., forest/nonforest patches) and making inferences about how those relationships change through time (Krummel et al. 1987, 1988; Turner 1990; Sachs et al. 1998). Owing to the inherent variability of landscape systems, some indices have proved unsuccessful in demonstrating useful relationships (Hulshoff 1995, Garrabou et al. 1998). Other comparative studies have searched for factors in common among different indices (Ritters et al. 1995, Cain et al. 1997). Despite the availability of quantitative methods for description and forecasting at the landscape scale, knowledge of this type for most areas in British Columbia is lacking.

A subalpine landscape may be thought of as a complex mosaic of vegetation structural types dispersed over a highly variable physical terrain. The resulting patterns are commonly shown as polygons (i.e., ecosystem units) on forest cover maps. At the landscape scale, ecological questions may relate to the types, sizes, and distributions of polygons in relation to landform and disturbance. Alternatively, questions may be asked relating to the structure and dynamics of vegetation within polygons. The 2 approaches are complimentary, as each may identify processes affecting the other. For example, a set of adjacent polygons may be maintained by disturbances such as fire, rock slides, and avalanches. While many previous studies on subalpine vegetation have been reported, the use of polygons to organize and extrapolate information to the landscape scale has not been attempted in this ecosystem.

The objective of this study is to quantitatively describe the complexity of a subalpine landscape by: 1) examining relationships among polygon patterns (e.g., types, sizes, boundaries) and various environmental factors, including topography, soils, and disturbance; and 2) examining the

Table 1. Polygon attributes measured or calculated for the aerial photo plots. Range of values shown pertain to the larger (750 m diameter) plot size used.

General description and calculation	Range in large plots
Number of polygon types (NPT)	4–18
Total number of polygons (NOP)	4–27
Number of boundary types	3–28
Total number of boundaries (TNB)	3–40
Total length of boundaries (mm on aerial photo)	116–518
Percentage of plot area occupied by largest polygon	11.7–70
Shannon diversity index	0.86–2.61
Shannon evenness index	0.53–0.97
Simpson diversity index	1.92–12.56
Simpson evenness index	0.28–0.92
Polygon dominance index {$DI = Ln[NPT] + \Sigma[P_k Ln(P_k)]$, where P_k denotes proportion of polygon type k}	0.05–0.79
Shape index {$LSI = (0.25\Sigma L_{ik})/A^{1/2}$, where L_{ik} denotes total length of edge between polygon type i and k}	0.65–2.92
Average perimeter:area ratio	0.06–0.26
Area complexity index {ACS = H(a) x H(c), where H(a) denotes Shannon diversity of area types, and $H(c) = H(a)/Log_2(NOP)$}	2.20–28.08
Boundary complexity index {BCS = H(b) x H(c), where H(b) denotes Shannon diversity of boundary types, and $H(c) = H(b)/Log_2(TNB)$}	1.43–55.15

extent to which vegetation variation within polygons can be accounted for by environmental conditions.

STUDY AREA

A 20,000-ha area in southern Wells Gray Provincial Park, B.C., was selected for study. The area consists of a broad, mountainous plateau with steep-sided valleys and moist, forested highlands at elevations of 1,300–2,100 m. The majority of the area has been classified as Engelmann Spruce–Subalpine Fir (ESSF) zone, with wc2 (wet cold) and vv (very wet and very cold) being the dominant subzones (Lloyd et al. 1990). Throughout the study area, the forests have experienced a variety of natural disturbances from lighting strikes, snow avalanches, windthrow, and rock slides (scree).

DATA COLLECTION AND ANALYSIS

Polygons and Physical Terrain Features

Following the guidelines in *Standards for Terrestrial Ecosystems Mapping* (RIC 1995), polygons were mapped onto 1:15,000, colour aerial photos of the study area. Polygons represent subjectively delineated areas that are relatively uniform in vegetation, topographic features, and soil conditions.

To characterize polygon patterns across the landscape, 2 sizes of concentric circular plots (3-cm and 5-cm diameter plots on the aerial photos, corresponding to approximately 450 and 750 m on the ground) were systematically sampled on the aerial photos. In total, 68 plots of each size, spaced at roughly 8-cm intervals between centres on the photos, were examined. The use of 2 plot sizes allowed for testing of the effects of "size of observation window" on the assessment of landscape complexity. Within the aerial photo plots a number of polygon attributes, such as total number of polygon types, and boundary types and lengths (Rescia et al. 1997), were visually determined and used to calculate various diversity/complexity indices (Table 1). Owing to the occurrence of logging in parts of the study area, 8 plots were removed, leaving a total of 60 plots for analysis.

Also recorded from the aerial photo plots were a number of physical terrain features and disturbance conditions (Table 2). The physical data were obtained from inspection of 1:20,000 and 1:10,000 topographic (TRIM) maps of the study area. The types and extents of disturbances for each plot were determined through a combination of aerial photo interpretation and referencing an extensive database of the study area (Bradfield et al. in prog.). An aspect index (AI) for each plot was calculated as an area-weighted value of aspect favourability (Beers et. al. 1966). AI varies from –1.0 to +1.0, with higher index values indicating higher potential incident radiation.

Correlations within and between the sets of polygon variables and the physical terrain/disturbance variables were examined in 2 ways: 1) by calculating Pearson correlation coefficients (or Spearman correlations, depending on the nature of the variables); and 2) by applying principal components analysis (PCA) to each set of variables, followed by calculating between-set correlations using the first PCA axis as a summary descriptor of each set.

Table 2. Physical terrain features and disturbance variables recorded in the aerial photo plots.

Highest elevation (m)
Lowest elevation (m)
Elevation at the central point (m)
Within-plot elevation range (m)
Aerial coverage (%) of 5 slope categories: slope >100%, 50–100%, 20–50%, 10–20% and <10%
Slope at the central point (%)
Number of slope categories recorded in the plot
Aerial coverage of largest slope category (%)
Aerial coverage (%) of 9 aspect categories: N, NE, E, SE, S, SW, W, NW and Undulating/flat.
Number of aspect types recorded in the plot
Aerial coverage of largest aspect category in the plot
Aspect category at the central point (1–9)
Estimated area (%) weakly influenced by fire
Estimated area (%) moderately influenced by fire
Estimated area (%) heavily influenced by fire
Presence of windthrow (binary)
Aerial coverage (%) of rock outcrop
Aerial coverage (%) of avalanche
Aerial coverage (%) of scree/rockslide
Aerial coverage (%) of standing water
Aspect index (area weighted by aspect types)

Within-polygon Variation in Relation to Environmental Factors

Variation within polygons was assessed using information from a database of 170 vegetation plots sampled in an extensive ground survey of the study area during 1995–97 (Bradfield et al. in prog.). For this purpose, 5 polygon types that occurred frequently in the study area and contained a sufficient number of ground vegetation plots for analysis were selected (Table 3). Using this approach, minimum estimates of plant species richness were determined for each polygon type and for the smaller aerial photo plots (450 m diam) based on the polygons they contained. Difficulties in matching some polygons with ground vegetation plots impeded using this approach with the larger plots (750 m diam) on the aerial photos. Consequently, it was possible to examine the relationship between total plant species richness and landscape complexity.

Vegetation variation within the 5 main polygon types, separately and combined, was measured as the number of standard deviation (s.d.) units (termed beta-diversity) on the first axis of a detrended correspondence analysis (DCA) (Økland 1986, Backéus 1993, Zhang 1998). Two questions were addressed in analyzing the vegetation-environment relationships within the polygon types: 1) To what extent do individual environmental variables account for the observed species variation that is associated with beta diversity?; and 2) How successful are groups of related environmental variables in explaining the species variation? To answer the above questions, environmental factors were selected in decreasing order of their ability to explain the variance in species composition according to a Monte Carlo permutation test performed by CANOCO (version 3.15; ter Braak 1987, 1990). Twelve abiotic environmental variables in 3 categories (disturbances, topography, soil/surface features) were available for correlating with the species variation. In addition to examining relationships with abiotic factors, we also tested the abilities of various forest structural attributes, such as stand density, basal area, and canopy height, as well as the polygon type classification, to explain variation in species composition.

RESULTS AND DISCUSSION

Polygon Complexity, Physical Features, and Natural Disturbances

The aerial photo plots spanned an elevation range of 1,310–2,426 m and encompassed considerable variation in polygon features (Table 1). The range of calculated values for the Simpson index (SI) and the area and boundary complexity indices (ACS and BCS) was generally large, indicating that those indices could be sensitive to the differences among the plots of this study. Several correlations were detected among individual factors within each separate group (i.e., among the physical features and among the polygon features); however, there were no significant relationships between the variables of the 2 groups.

The first PCA axis of the physical terrain data explained 23 and 19% of the total variance for the large and small plots, respectively. For both plot sizes, the first PCA axis represented a terrain gradient from high elevations with steep slopes and N–NE aspects, to lower elevations with gentle slopes and S–SW aspects. The correlations between the PCA axis of the terrain data and the polygon attributes were weak; however, a weak but significant correlation ($r < 0.4$, $P < 0.05$) was shown for total length of polygon boundaries and the indices calculated from the length of boundaries.

The first PCA axis of the polygon data explained 61 and 63% of the total variance for the large and small plots, respectively. The axis represented an overall summary of the relationships among the area complexity index and several dominance indices, such as H and SI. There was no significant correlation between the first PCA axis from the physical terrain data and that from the polygon data.

The only significant relationship detected between polygons and terrain features was that between total polygon boundary length and the first PCA axis of the terrain data. The length of polygon boundaries is a function of the number and shapes of polygon patches on the landscape. Such boundaries are key features at the landscape scale, and have been linked to ecological processes influencing biotic and abiotic conditions that affect overall biodiversity (Forman and Godron 1988, Wiens et al. 1985, Holland et al.1991,

Table 3. Characteristics of the 5 main polygon types in the study area. Polygon letter codes refer to dominant understory species (FA, *Menziesia*; FV, *Valeriana*; FR, *Rhododendron*). Polygon numerical codes refer to developmental stages (4, saplings; 5, young forest; 6, mature forest; 7, old forest). "Variance explained" refers to variation in species composition accounted for by groups of abiotic (A–C) and biotic (D, E) factors.

	Polygon type (structural stage)					
	All	FA (4,5,6,7)	FV (5,7)	FR (4,5)	FR (6)	FR (7)
ESSF site[a]	wc2/vv	wc2	wc2/vv	vv	vv	vv
Number of vegetation plots	92	14	17	15	23	23
Species richness	156	68	79	63	87	91
Beta-diversity (s.d. units)	4.81	4.34	3.88	4.03	3.75	3.10
	Variance explained (%)					
Disturbances (A)	10	50	21	31	28	26
Topography (B)	10	28	23	32	34	31
Soil and surface features (C)	10	42	31	30	34	32
Forward selection from A+B+C	19	46	40	55	44	19
Vegetation structure (D)	20	86	67	77	58	60
Polygon types (E)	18	28	19	10		

[a] Engelmann Spruce–Subalpine Fir (ESSF) biogeoclimatic subzones: wc2 = wet cold; vv = very wet, very cold.

Metzger and Muller 1996, Rescia et al. 1997). Furthermore, our results suggest that polygon boundary features are also associated with a complex gradient of physical terrain factors and natural disturbances.

We suggest that the effects of disturbance on patterns of polygon complexity depend on the pre-existing patterns (i.e., before the disturbance occurred) and on the extent (i.e., total area affected) of the disturbance. For example, in a heterogeneous system, a disturbance such as a large fire may decrease landscape complexity. In contrast, in a homogeneous system, medium- to small-scale disturbances may lead to an increase in complexity. No effects related to the 2 plot sizes used on the aerial photos were detected in this study.

Within-polygon Vegetation Variation in Relation to Physical Environment and Disturbance

Of the 60 aerial photo plots examined, only 24 contained polygons that could be directly related to vegetation plots. Using that information, the minimum estimates of total species richness ranged from 21 to 70 species in the smaller (450 m diam) aerial photo plots. There was no significant relationship between the estimated species richness and polygon complexity or physical terrain features, although species richness was found to vary greatly within polygon types.

The vegetation beta-diversity ranged from 3.1 to 4.3 (s.d. units) for the 5 major polygon types examined (Table 3). The old-growth forest polygon type (FR7) showed the lowest beta-diversity, with polygon types containing mixed development stages (FA, FR, FV) exhibiting higher values of beta-diversity. The variance in vegetation data explained by different groups of environmental variables is also given in Table 3. The variation within polygon types with a single development stage (FR6 and FR7) tended to be related to topographic, soil, and surface features. Disturbance showed stronger impacts on species variation in the mixed polygon types, suggesting a closer relationship between stage of vegetation development, hence, disturbance history and species composition. The total variance explained by forward selection of significant variables ranged from 19% (combined polygons) to 55% (FR45). The low variance explained for the FR7 type indicates that other, unmeasured variables may be influencing old-growth vegetation. The effects of complex biotic interactions among species (e.g., host-pathogen, plant-mycorrhizal) may increase with developmental stage of the forest so that landscape variables become less influential.

The variance explained by forest structural attributes was relatively low (<30% from forward selection; Table 3), suggesting that overall forest structure and species composition are not strongly linked in the study area. Compositional variation of vegetation in the same stage of development was most strongly influenced by physical factors such as elevation, slope, aspect, soil, and surface features. In general, vegetation in multiple stages of development will be defined by mixed polygon types in the process of aerial photo interpretation. Therefore, within-polygon diversity will be largely influenced by variability in topographic features, soil conditions, and small-scale disturbances.

SUMMARY

- Polygon features recognized on aerial photos are weakly correlated with physical terrain features.

- The total length of polygon boundaries is the main determinant of polygon complexity and is the key factor related to physical terrain features.
- The impact of natural disturbances on polygon complexity depends on the extent of disturbance and the landscape conditions prior to the disturbances.
- Beta-diversity is related to the stage of vegetation development and environmental conditions.

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