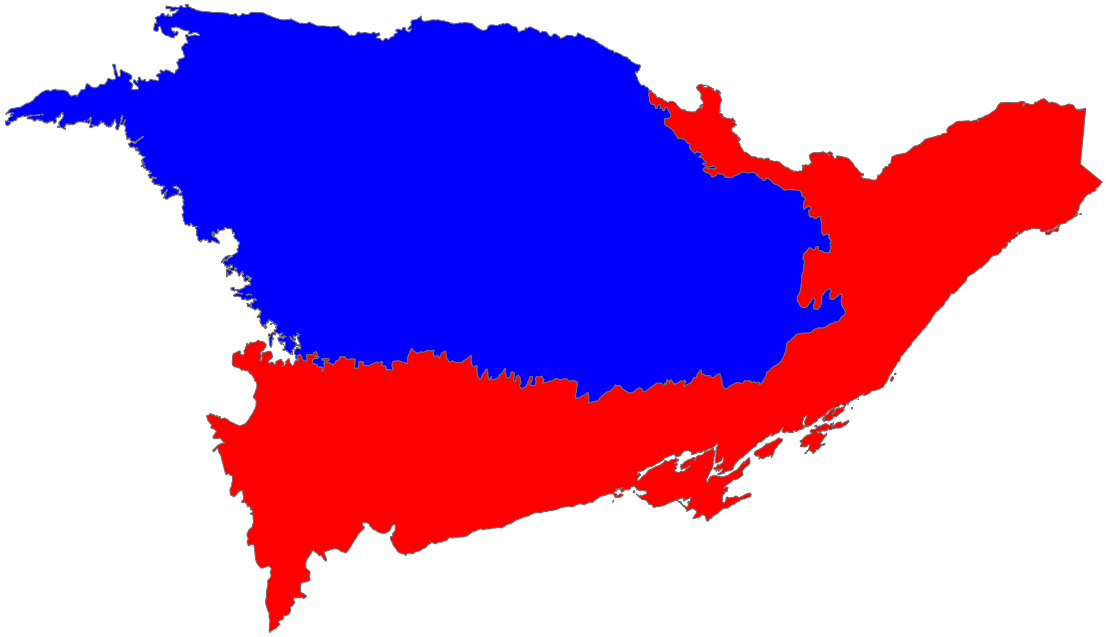
Boundary Detection in the Land Between



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Introduction

Ecotones in a landscape represent areas of change between two community structures. This change may be abrupt or gradual, and may occur on several or a single scale. In all cases, it represents an area of importance for multiple processes in several contexts (Fagan et. al, 2003). Historically, such boundaries have often been overlooked for conservation planning. However, ecotones tend to act as evolutionary hot spots, acting as regions of high diversity and high environmental heterogeneity (Smith et al., 1997). An example of such a region runs along a thin, relatively undeveloped transect between Kingston and Parry Sound, Ontario called 'The Land Between'.

The Land Between encompasses several key boundaries of importance in Ontario. On a geographic scale, the granite barrens characteristic of the Canadian shield reach their southernmost range, giving way to the limestone bedrock characteristic of southern Ontario (Hills, 1959). This change in bedrock is accompanied by two other changes in landscape characteristics: a decrease in altitude and a change in the predominant land cover from forested areas and small water bodies in the north to mixed-wood plains modified into agriculture and developed land in the south (Hills, 1959). The Land Between represents a thin strip of unique habitat that runs between the two major ecozones and contains its own unique habitat and landscape characteristics in the form of a complex mosaic of a multitude of differing land types (The Couchicing Conservancy, 2005). Though previously considered merely as an ecotone in itself, the Land Between is now seen as a separate landscape altogether, and not merely an amalgamation of the forest to the north and the plains to the south.

The continued expansion of urban sprawl and an increased interest in development in the Land Between has created a renewed interest in determining the extent of the Land Between, as knowledge of its spatial location would present a more developed case for the development of a land use strategy and policy in association the region (Chapman and Purnam, 1984). I intend to examine several land cover characteristics, elevation, and one anthropomorphic (road density) characteristic of the rapid change in Landscape structure in the Land Between.

An understanding of the underlying physiography would provide valued information not only on the physical boundaries, but also on possible biological boundaries such as species limits (Brown et al., 1996). Similarly, understanding of further possible development by means of road density in the Land Between would help to identify regions under risk from future development and how such a change may interact with possible species at risk in the area.

Data and Methods

Land Cover and Elevation

Land cover was derived from the Ontario Land Cover Database at a 25m grid across the study area (Fig. 1). An area of 81,276 km² was selected in order to encompass both the possible boundary of the land between, as well as sufficient area around it in order to differentiate areas of change from areas of stationarity. Land cover was broken down into 28 possible different classes, with 22 of those classes found in the area of interest. The map was sampled by means of a 5km grid excluding the Great Lakes and Lake Simcoe, as their large areas would severely affect the ability to detect changes in water density across the landscape. Approximately 70,000km² of the land cover area was

sampled around the Land Between in order to avoid extraneous data to the north as well as a second ecotone in southern Ontario (Fig. 1; Hills, 1959). In order to reduce grid squares that poorly represent land cover, only grid cells with at least 5% of the landscape found within were included. Elevation was similarly analyzed, with mean elevation measured for each grid cell used based on a 30m digital elevation model (DEM).

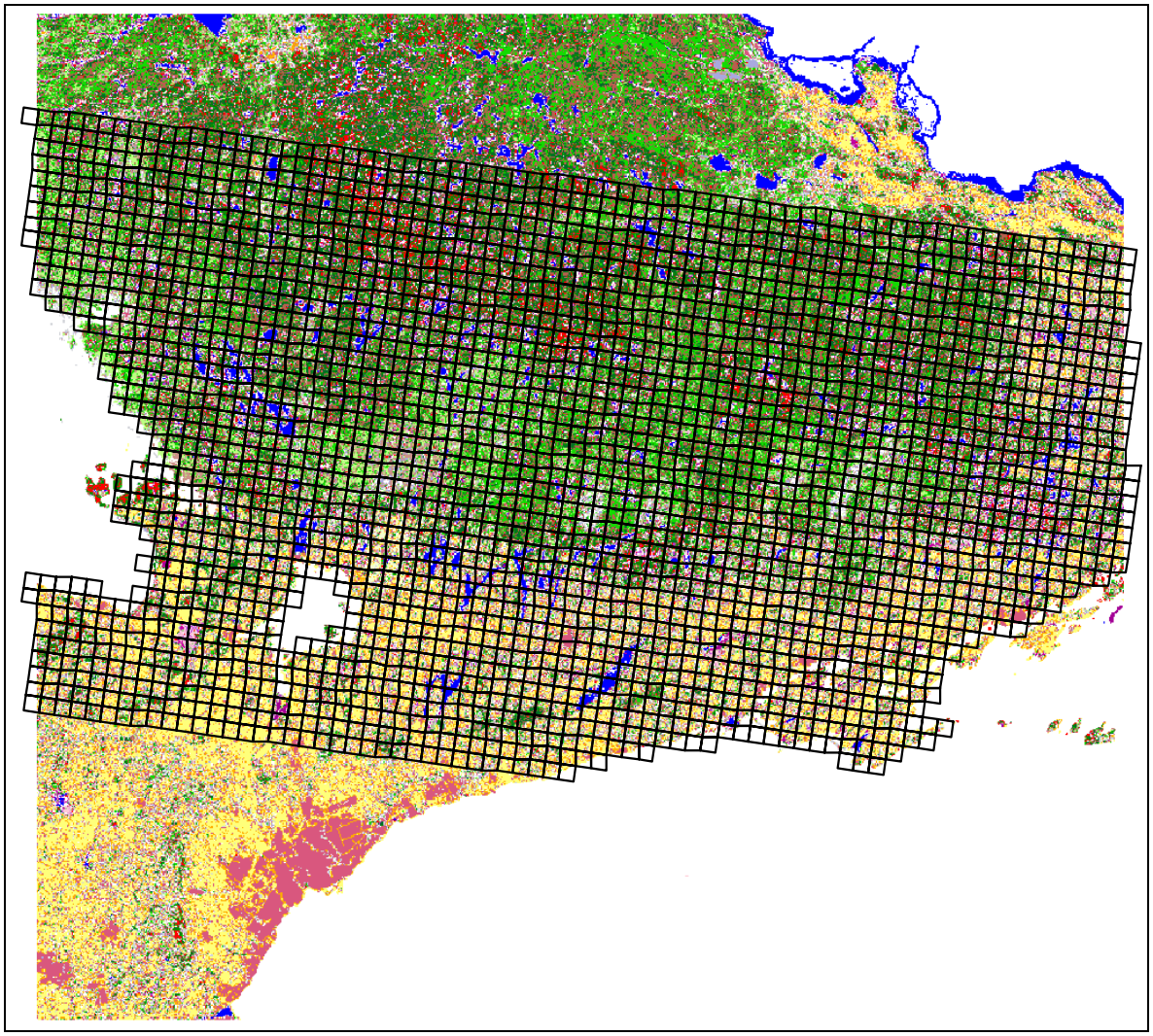

Figure 1. Land Cover Map Encompassing the Land Between.

Road Data

Road density was determined using the Line Density function in ArcMap Spatial Analyst. I characterized the resulting grid using the previously created sampling grid by using Hawth's Tools in order to determine mean road density. I used mean density for each cell with no weighting for different road types.

Boundary Detection

For land cover, we examined multiple factors: Water content, mean grid cell elevation, and mean road density were then transferred to BoundarySeer. Boundary detection for each map was conducted by means of lattice wombling (See Fortin, 1994). This method involves determining the difference between four adjacent cells and selecting for boundaries with the largest differences between them. A raster is created based on the centroids of the points of difference, which higher values denoting greater change between cells. For this study, I looked at the top 30% of boundary differences for all three maps examined.

Lattice wombling uses regularly spaced two dimensional data, such as a grid (Fortin, 1994). Because we are most interested in detecting where high degrees of differentiation lie within each possible landscape characteristic, I am less concerned with overall regional change, and more concerned with detecting high degrees of change over a small area which would be indicative of the Land Between. Such a change may take on several possible forms: a transition from one homogeneous region to another, a change from a homogeneous region to a more variable region, and finally a change between two variable regions.

Concurrent to wombling, fuzzy classification was used in an attempt to parse each land cover type into separate sub-classes. I separated each layer into three classes**.** Each cell is classified based on wombling results as well as raw data values, and a probability of assignment to each class is given to each cell, resulting in an RGB composite map showing the clustering of classes. Although class numbers are chosen arbitrarily, I chose blue to attempt to represent the area of highest transition which would signify the Land Between.

Determining significant spatial arrangement was done by means of a sub-boundary and boundary analysis examining various aspects of the spatial arrangement of the boundaries using randomization for comparison. I used 5000 Monte Carlo simulations for sub-boundary comparisons for each map and an additional 5000 simulations for boundary comparisons between maps. Between map comparisons were run similarly, using randomization of each map of interest in each combination (water and road, road and elevation, water and elevation), boundaries were examined for mean distance between boundaries and their overlap.

I compared water and wetlands and their concurrent combination layer separately in order to avoid comparing a class against itself during boundary analysis. Additionally, separating the two analyses allows us to see if the two layers have a greater joined effect in delineating The Land Between than a single layer of the two.

Results

Sub-Boundary Analysis

Boundaries tended to be both highly internally organized. Fuzzy Classification maps can be found in figure 2, and wombling boundaries can be found in figure 3. Sub-boundary statistics for every factor is found in table 1. In each case, boundaries appear to be significantly spatially clustered, with groups of sub-boundary clusters found together more commonly than would be expected at random. Additionally, sub-boundaries tended to have significantly longer mean and maximum lengths and had wider mean and maximum diameters. The Diameter/Length ratio, a proxy for branchiness, was

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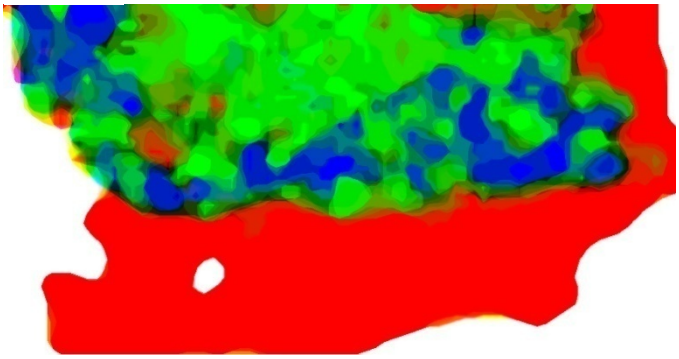

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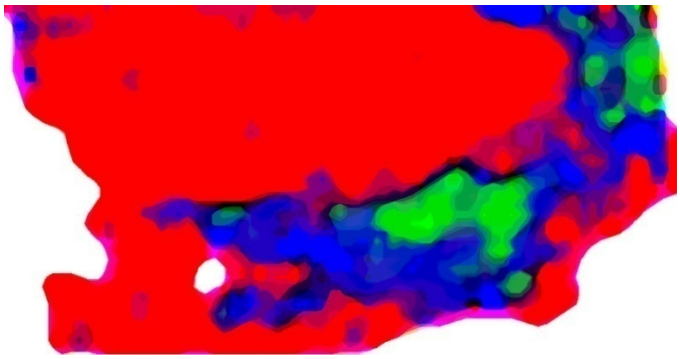

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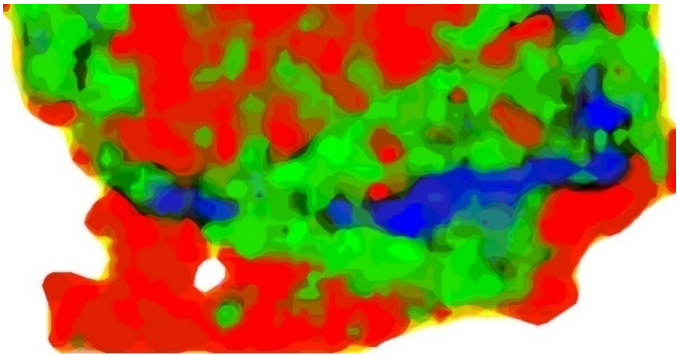

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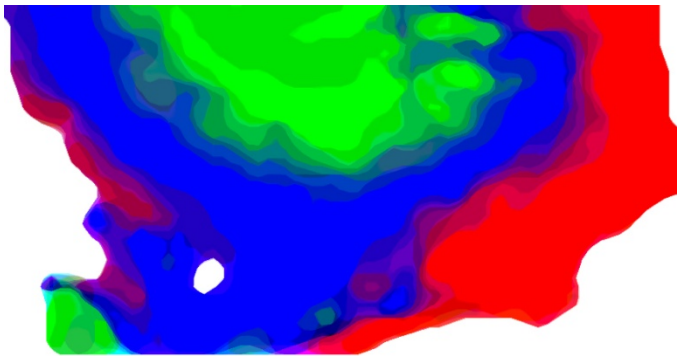

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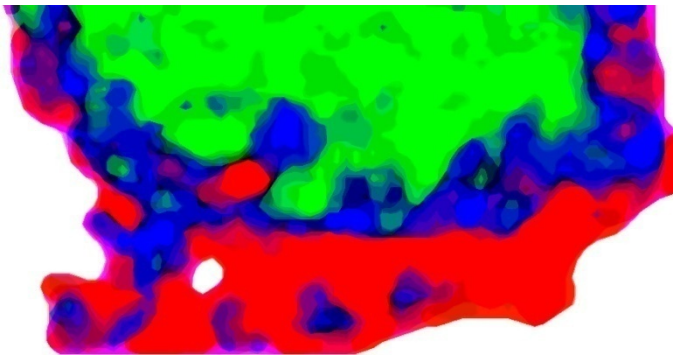

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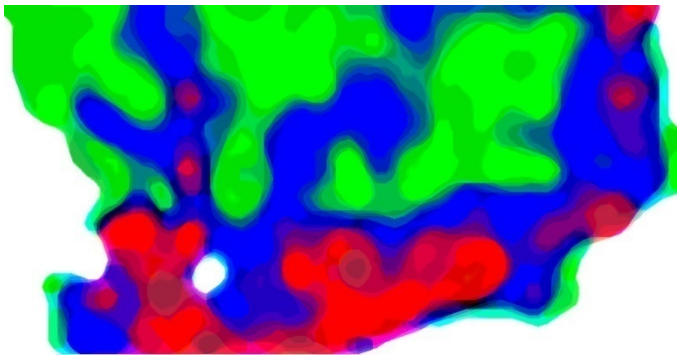

Figure 2. Fuzzy classes for A) water bodies, B) Wetlands, C) Wetlands and Water bodies, D) Elevation, E) Forest cover, and F) Road Density

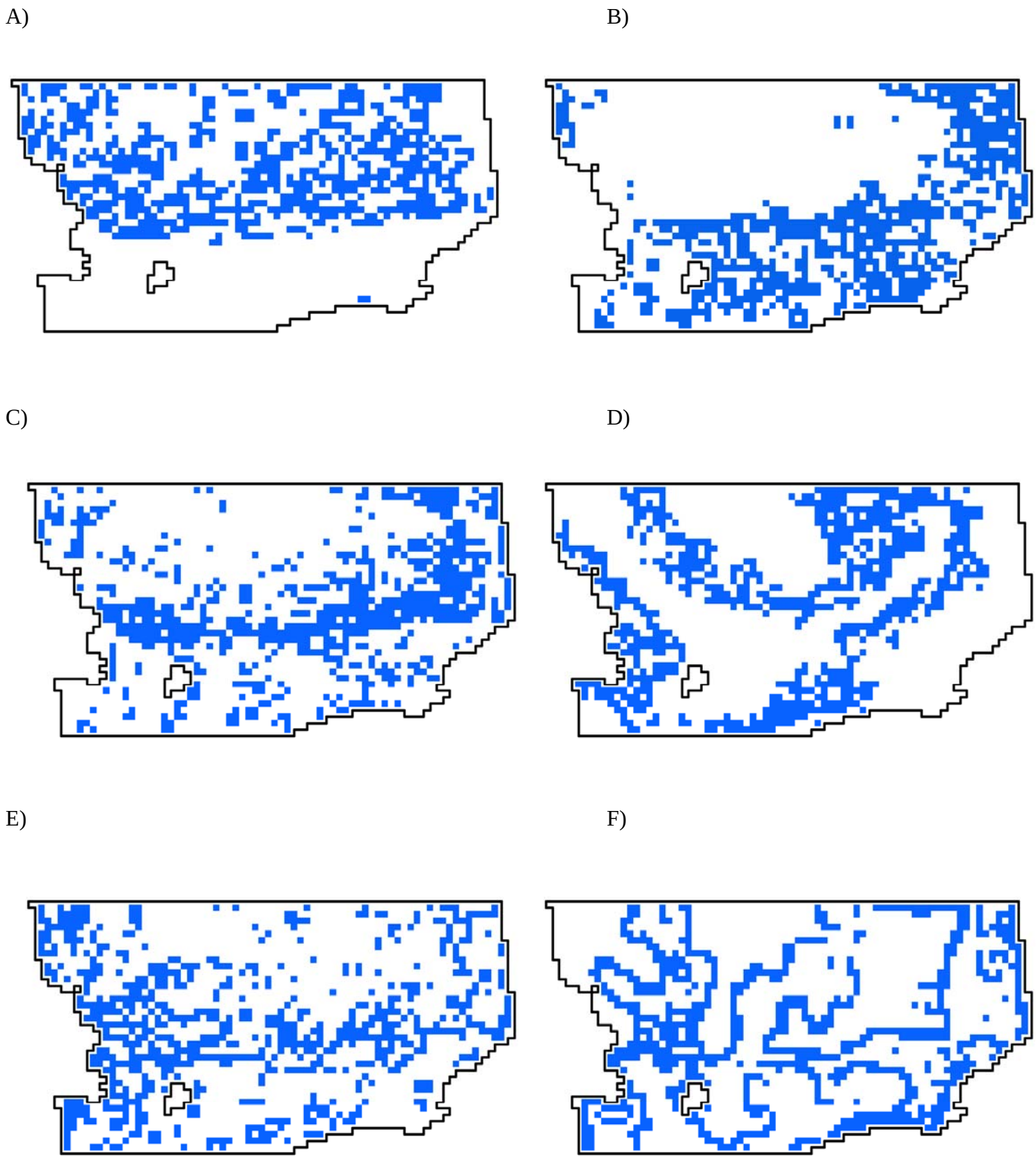

Figure 3. Boundary Points for A) water bodies, B) Wetlands, C) Wetlands and Water bodies, D) Elevation, E) Forest cover, and F) Road Density

significantly higher for all cases except elevation ($Z = -0.87$, $p > 0.05$) and all wet land cover types, which was significantly higher ($Z = 4.893$, $p < 0.001$).

Changes in elevation coincide with increased elevation within the Algonquin region in the north with The Land Between lying in a relatively even region of the landscape. The Land Between region appears to fall south of the Algonquin Dome group (green), and crosses the boundary between the other two groups. Elevation boundary points were found mainly in two locations: across boundaries, as well as a high proportion spread within the Algonquin Dome.

Forest classes appear to extend outwards in concentric half-circles. One class (green) appears to mimic the boundaries present in the Algonquin Dome. A second class (red) predominates the majority of the southern region as well as the edges of the map. The third class (blue) lies between the two classes, with the western edge of the class extending further into the middle of the green region. A few sparse areas in the south-east also contain a proportion of this class. Forest boundary points appear to mostly lie along the blue region of the map, with some singletons spread throughout the extent of the map.

Table 1. Sub-boundary Statistics for all boundaries

Layer	Sub-Boundaries	Singletones	Max Length	Mean Length	Max Diameter	Mean Diameter	Diameter / Length
Water	51*	20*	205*	13.51*	57*	6.216*	0.884*
Wetland	54*	21*	380*	12.759*	102*	5.519*	0.934*
Elevation	85*	49*	196*	8.106*	50*	3.918*	0.939
Road Density	43*	13*	234*	16.023*	71*	7.605*	0.867*
Forest	123*	53*	172*	5.602*	52*	3.585*	0.932*
All Wet	126*	58	258*	5.468*	67*	3.111	0.953+

* - Significant ($p < 0.05$) boundary cohesiveness. + - Significant ($p < 0.05$) boundary fragmentation

Water showed strong boundary delineation. However, the high variability in water density in the northern region of the study area results in a large amount of water boundary points falsely determining boundaries where there are simply a large amount of small water bodies spread throughout the region. The southern portion of the map was strongly delineated in terms of grouping, with the red group dominating the southern portion of the map. The green and blue classes appear somewhat interspersed, yet on the whole it appears that the blue class does delineate a region around the green class, and the blue class does appear to be found mainly within the hypothetical region encompassed by the Land Between. Boundary points for water are found mainly in the north and mainly between the blue and green classes. A drop-off in boundary points occurs in the red class as the southern portion of the map appears to be relatively homogeneous in water body count.

In contrast, wetlands appear to predominate on the eastern and central portions of the map. The red class, indicative of lower wetland count, lies mainly in the north and southwest. Wetland boundary points encompassed the southern and eastern portion of the map. The northern and western portion of the map appears relatively homogeneous, with little change in wetland density.

The combination of water and wetlands created a nested set of groups forming an arc from the northern edges of the map to the middle of the map. The red group contains

areas with smaller number of wetlands and water bodies, whereas the blue contains the highest. The Green group appears to act as an intermediary, buffering the land between the red and blue groups.

Boundary points are mainly clustered around the middle and north-eastern section of the region, with other points being found spread evenly across the southern and north-western portions of the map.

Road classes appear to be divided into three main sections: highly populated areas (red), main highways outside of cities (blue), and relatively non-developed land (green). Blue groups tent to be clustered around highways 11, 401, with some development around highway 35. Boundary points appear to create edges between different regions of the map, with a few singletons found spread throughout the map.

Boundary Overlap Analysis

Boundary overlap was used to determine congruence between boundary points. Two main overlap metrics were used: distance between boundary points (unidirectional for each pair as well as a pair-wise comparison, resulting in three distance metrics for each pair), as well as the number of sub-boundary points overlapping. Overall, distance metrics tended to show some degree of avoidance, whereas the number of sub-boundaries fluctuated between avoidance and congruence (Table 2).

Water and wetland areas separately showed high degrees of avoidance. In unison they tended to overlap well with most other boundaries. In particular, the combination of water and wetlands showed the highest degree of congruence of any combination with forest cover, with two metrics showing congruence and two showing non-significance (Table 2). With the exception of elevation, all other layers showed similar decreases in avoidance when water and wetland bodies we combined into one map.

Table 2. Overlap Analysis

Observed	O_g	O_h	O_{gh}	O_s
Water and Elevation	19833.2*	8102.678*	13967.939*	160*
Water and Wetland	7969*	14249*	6109*	174*
Water and Forest	13476.028*	4371.472	8923.75*	254$^+$
Water and Road	8858.4*	19365.526*	13977.003*	179
Wetland and Elevation	9386.602*	18037.994*	13715.298*	144$^+$
Wetland and Forest	9659.184*	4606.911	7133.047	241
Wetland and Road	5949.312*	8698.042	7323.677*	239$^+$
Elevation and Road	9712.04*	7941.037*	8826.539*	191
Forest and Elevation	7732.442*	5879.579*	6806.1*	196
Forest and Road	5810.532*	4299.938	5055.235*	263$^+$
all wet and elevation	8879.587*	8907.495*	8893.541*	124*
all wet and road	6002.876*	4928.101	5465.489*	251$^+$
all wet and forest	3708.379$^+$	4760.315	4234.346	293$^+$

* - Significant ($p < 0.05$) boundary avoidance. + - Significant ($p < 0.05$) boundary congruity

Discussion

The delineation of any boundary requires that a significant portion of land on either side of said boundary be included so as to determine the exact extent of where a possible boundary may end. However, care must be taken in order to ensure that additional boundaries outside the area of interest are not detected. In the case of the Land Between, while the closest major northern boundary of interest would be the Hill's boundary between the Lake Temagami Region (4E) and the Georgian Bay Region (5E) that acts as the northen boundary to the Land Between (Crsins, 2000). However, an ecoregion shift occurs between the Lace Simcoe Region (6E) and Lake Erie – Lake Ontario region (7E) much closer to the Land between. This boundary was detected by means of the change in elevation seen in the south-western region of the map. Hills' (1959) delineation of the boundary was based more on climatic and topographic variables explaining why the boundary was not detected by use of water body density.

Boundary delineation of elevation appeared to capture two main features: the ecoregion shift in the south, as well as the Algonquin Dome to the north. The Land Between appears to be captured as part of a relatively homogeneous region resting between the two. However, the region of homogeneity extends much further south, into the mixedwood plains region of Ontario.

Boundary detection relies on a shift from one region of relative homogeneity to another (Fortin et. al., 2000). While there is some degree of variability inherent in any landscape, the detection of a true difference of means as signified by a real boundary means that the degree of homogeneity within a patch should be less than at its border. In the Land Between, the increase in elevation found around the Algonquin region of the map shows a much greater degree of spatial variability than actually found in the Land Between.

Water body density appears to follow the curvature around the Algonquin Dome. While this does make it useful in determining boundaries along the mid-section of The Land Between, delineating a separation between the Frontenac Axis and The Land Between is not possible without the use of other abiotic factors. The presence of large lakes around the north-western portion of The Land Between reduces the amount of area available to smaller bodies more commonly found in the area,

Another land cover type of particular interest is determining the area of the Land Between is alvars. Found predominantly in southern Ontario and focused mainly in the Land Between, alvars represent sites of high biodiversity and rare species composition (Catling and Brownell, 1995). As strong foci of current conservation practices already (Lundholm and Larson, 2003), an understanding of how alvars fall into the Land Between can further aid in determining additional possible conservation measures to help maintain diversity in the land between. While a large percentage of Canadian alvars are present in The Land Between, their spatial location makes it difficult to use in boundary detection, as clustering of alvars results in a lack of usable detecability in the middle of The Land Between.

Road density finds its points of greatest variability within cities and along major corridors. Major cities and were generally represented as one group, while large highway corridors, such as highway 11 and the 401 tended to be represented by a second group. Sparsely covered land was well differentiated from heavy road work. Although there are

two main heavily traveled corridors represented in the study area, overall it appears that there is a fairly definitive boundary to heavy road building. From just south of Orillia to north-west of Kingston, boundary points tend to align well together, giving an idea of exactly where road building has encountered difficulty due to the terrain seen in The Land Between.

Forests tend to follow a similar curvature around the Algonquin dome to water. The congruence of forests to both water body and road boundaries suggests that forest boundary points do tend to well represent The Land Between's boundary for the most part. However, the same boundary differentiation difficulty that was found with water along the Frontenac Axis still appears to be quite valid for forest. Further boundary analysis would need to be performed in order to properly ascertain where a boundary might be found between these two geographical areas.

Most boundaries show avoidance with each other when distance measures were used in contrast to point overlap measures. Elevation tended to show the largest degree of boundary avoidance, whereas forest cover showed the highest congruence. In contrast to changes in elevation, an examination of the underlying bedrock might provide a better detailed delineation of The Land Between in relation to other abiotic variables.

Determining boundaries of interest in abiotic conditions provides a baseline for looking at changes in biological diversity (Rowe and Sheard, 1980). The combination of these two differing separate sets of boundaries allows us to more effectively delineate ecotones and areas of interest. In The Land Between, determining the exact location of the boundary of the land between depends on numerous factors, and as many as possible should be used in determining the edges of this complex mosaic.

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