Boundary Detection of *The Land Between*

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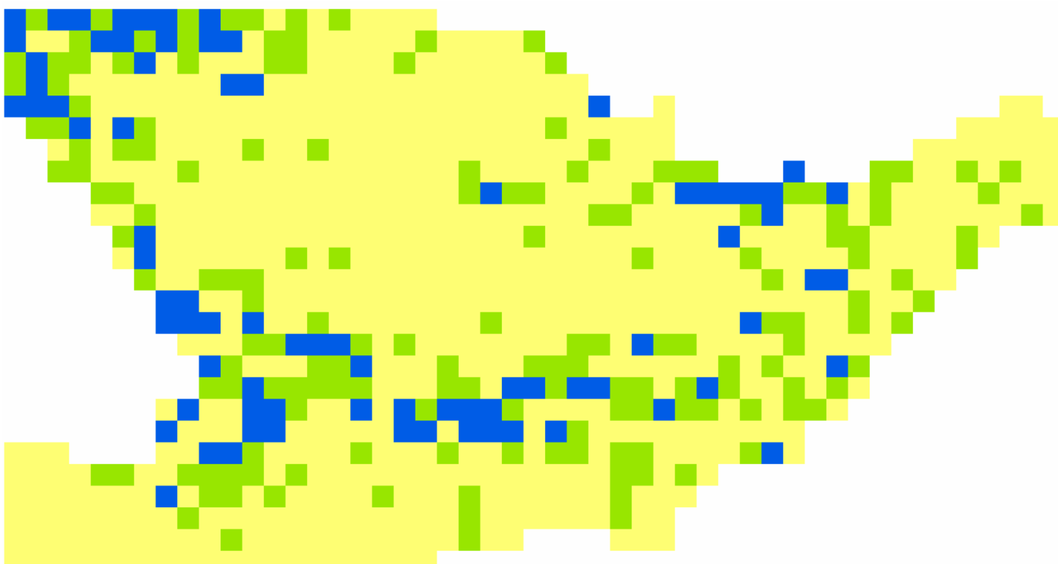

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Summary of the Analytical Steps and Findings

To determine the geographical limits of *The Land Between* several analyses were performed. First we sampled Ontario Land Cover data using a 5x5km sampling grid and performed a series of boundary detection methods (Figure 5; Lattice-Wombling edge detection algorithm, fuzzy boundary classification) and spatial boundary statistics to determine whether or not the boundary of different landscape features (forest, water bodies, wetlands, elevation and road density) overlapped spatially (Fortin and Dale, 2005). To determine the most appropriate scale to delineate *The Land Between*, we sampled Ontario Land Cover data using a 1x1 km grid and performed a series of boundary analyses using wavelets at multiple scales (2x2km, 4x4km, 8x8km and 16x16km). As expected, *The Land Between* showed boundaries at several scales; yet given that our goal is to determine the outer limits of *The Land Between*, the 8x8 km sampling grid resolution provided the best contour. Supported by this finding and the fact that the next step is to relate Ontario breeding bird species response to the unique environmental conditions of *The Land Between*, we sampled the Ontario Land Cover data using a 10x10 km grid and performed a new series of boundary analyses to determine the spatial coincidence between the environmental variables and the breeding birds that are found in *The Land Between* (data source is the Ontario Bird Atlas 2001-2005).

At this point this report does not include analyses with Ontario mammal data as this dataset is projected in NAD27 while all the other datasets are projected in NAD83; such analyses may be included in the scientific paper to be written next year.

Introduction

Ontario comprises several ecosystems (Figure 1), which are divided in ecoregions and districts (Figure 2) that reflect the underlying geomorphology (Handcock and Csillag, 2202). Some ecosystems are protected as federal or provincial parks (Figure 3, Table 1), as is the case for a fragile ecosystem in southern Ontario approximately stretching between Kingston and Parry Sound. Its unique geomorphology and landscape characteristics distinguish it from adjacent major ecozones (Canadian Shield and southern Ontario) and form a complex landscape mosaic. Ecotones in a landscape represent areas of change between two community structures (Figure 4). This change may be abrupt or gradual, and may occur at a single scale or at multiple scales (Figure 5; Gosz 1993). 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, as they are often regions of high diversity and high environmental heterogeneity (Smith et al., 1997). An example of such a region is a thin, relatively undeveloped transect between Kingston and Parry Sound, Ontario called 'The Land Between'. *The Land Between* can be considered an ecotonal zone both in terms of geomorphology but also species richness as several species reach either their southern or northern geographical range in *The Land Between*.

However, the question remains: Where is the boundary of this ecotone? While ecological boundaries have been acknowledged through the determination of ecoregions and districts at the provincial level as planning units (Figure 2), they do not reflect the spatial dynamics of vegetation and wildlife and do not relate to global changes due to climate warming and land use change (Handcock and Csillag, 2002). Hence it is important to determine *The Land Between*'s boundaries for conservation planning.

Table 1. Area Calculations of The Different Land Classes Found in Ontario Parks.

Classification	Area (ha)	Percentage of Total Area (%)	Number of Patches
Mudflats, marsh, swamp, fen, bog	2 519 800	2.51	2 801
Tundra heath	32 400	0.03	42
Deciduous	1 477 200	1.47	2 391
Coniferous	3 443 900	3.44	3 550
Cuts, burns	654 700	0.65	609
Mines	68 300	0.07	166
Settlement	5 000	0.01	28
Pasture, cropland	29 400	0.03	108
Alvar	900	0.00	4
Unclassified	2 500	0.00	7
Total	8 234 100	8.22	9 706

Material and Methods

<u>The Land Between</u>

The Land Between encompasses several key boundaries 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 an ecotone in itself, *The Land Between* is now seen as a separate landscape altogether, and not just 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 with the region (Chapman and Purnam, 1984). 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.

Land Cover, Elevation and Road Data

Land cover data for the study area was derived from the Ontario Land Cover Database (1991-1996), which classifies land cover from satellite remote sensing data at a 25x25m resolution. An area 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 greater uniformity. Land cover mapping was resampled first using a 5x5 km sampling grid excluding the Great Lakes and Lake Simcoe, as their large areas would severely affect the ability to detect boundary changes in water density across the landscape. Then it was sampled using the same 1x1 km grid used by Andrew Couturier (Bird Studies Canada) to be able to compare results between the two projects. Finally, as a result of preliminary analyses which showed that a 8x8km resolution provided the best contour for *The Land Between*, and to match the 10km resolution Breeding Bird data, the study area was sampled using a 10x10km grid.

In order to reduce grid squares that poorly represent land cover, only grid cells with at least (50%) of the landscape found within were included. Yet, please note that all the boundary detection algorithms are going to be affected by the edge of the study area and create false high rates of change known as the edge effect (Fortin and Dale, 2005).

The Ontario Land Cover database (Figure 1) is classified into 28 possible different classes, with 22 of those classes found in the area of interest. Ontario Parks (Figure 3) comprise different proportions of the classes as presented in Table 1. The first analyses using 5x5km (Figure 8a) and 1x1km (Figure 8b) sampling grids were based on a coarse reclassification of the 22 land cover classes (forest, water, wetland, alvar). Elevation was similarly analyzed, with mean elevation measured for each grid cell used based on a 30m digital elevation model (DEM). We 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.

For the final analysis based on the 10x10km, a finer reclassification of the land classes was used:

Open areas: cropland, pasture and cleared land
Water: water, swamps, fens and bogs
Coniferous forest: sparse and dense coniferous forest and coniferous plantations
Deciduous forest: sparse and dense deciduous forest
Mixed forest: mixed forest and old cuts & burns
Alvar: alvar
Urban areas: settlements and mine tailings
Road: road length

Road density was determined using the Line Density function in ArcMap Spatial Analyst. We characterized the resulting grid using the previously created sampling grid by using Hawth's Tools in order to determine mean road density for each cell with no weighting for different road types (i.e. same weight for highways and rural roads).

Ontario Breeding Bird Atlas

Using the Atlas of theBreeding Bird Atlas of Ontario 2001-2005 (Cadman et al., 2007), we selected 113 species that were found within the study area.

Boundary Detection Analyses

There are several boundary detection methods (Figure 6). As we are using quantitative data (amount of area of each land class per sampling cell), two edge detection methods were used: lattice-Wombling and wavelet (Fortin and Dale 2005).

(1) Analyses based on the 5x5km grid data

Boundary detection for each map was conducted by means of lattice-Wombling (Fortin, 1994). This algorithm determines the local difference between four adjacent cells and selects for boundaries with the largest differences between them (Figure 7). A raster is created based on the centroids of the points of difference, where higher values denote greater change between cells. For this study, we used the top 30% of rates of change as boundary locations.

Lattice-Wombling uses regularly spaced two dimensional data, such as a grid (Fortin, 1994). Because we are interested in detecting a transition from one homogeneous region to another and lattice-Wombling may be sensitive to local boundaries, we also used wavelet analysis to detect boundaries at multiple scales (as described in the next section).

Concurrent to the Lattice-Wombling, fuzzy classification was used in an attempt to parse each land cover type into separate regions. For this fuzzy classification, we used three classes**.**

Each cell is classified based on the rate of change computed using lattice-Wombling and a probability of assignment to each class is given to each cell, resulting in a tri-color composite map that shows the clustering of classes. Blue represents the area of highest transition and likely represents *The Land Between*.

Determining significant spatial arrangement in boundaries was accomplished by means of a sub-boundary and boundary analysis (Fortin and Dale, 2005) that examined various aspects of the spatial arrangement of the boundaries using a randomization procedure based on 5000 Monte Carlo simulations. Comparisons between maps (i.e., Mixed Forest boundaries and Urban boundaries) in terms of spatial boundary overlaps (mean minimum distance and direct spatial overlap) were also computed and their significance was assessed using a randomization procedure. All these analyses were performed using BoundarySeer, a commercial software from TerraSeer Inc.

(2) Analyses based on the 1x1km grid data

Lattice-Wombling analyses were also performed using the 1x1km sampling grid data. However, the fine resolution of this data prevented some of the analyses that were performed on 5x5km sampling grid data, such as boundary statistics and spatial boundary overlap, to be carried out. such . Hence, using the 1x1km grid data we performed only the direct spatial overlap between boundary locations as determined by the 30% threshold. These computations were therefore carried out in R.

(3) Multiscale Analysis based on the 1x1km grid data

A hierarchical boundary detector, such as the wavelet analysis, can be used to identify boundaries at multiple scales as a spectral analysis when the absence of stationarity is suspected (Csillag and Kabos, 2002). There are several shapes of wavelet functions and we used the Haar wavelet (Figure 9), which is commonly used in ecology (Fortin and Dale, 2005). The wavelet transform coefficients can also be used to model the structure of relatively homogeneous sub-regions (patches) of an area and the boundaries between these spatially homogeneous areas: relatively homogenous areas require few wavelet transform coefficients of low values whereas contrasting locations (i.e., boundaries) require more coefficients with larger values. Wavelet analysis allows the multiscale analysis of data (Figure 9) using a recursive algorithm that partitions an area into homogeneous areas in a hierarchical way until relative homogeneous sub-areas are obtained. Depending on the spatial structure of the data, only one hierarchical partition will be sufficient enough to create a homogeneous sub-area where a few wavelet transformation coefficients adequately describe the structure; for other sub-areas, it will be necessary to add more partitions.

(4) Analyses based on the 10x10km grid data

To determine the geographical response of 113 breeding bird species (Breeding Bird Atlas of Ontario 2001-2005; Cadman et al., 2007) to *The Land Between*, boundary overlap statistics (minimum spatial distance between boundary types; Fortin and Dale, 2005) were computed based on lattice-Wombling boundaries using the 10x10km resolution breeding bird data in two ways: (1) boundary based on species richness; and (2) the sum of all individual species boundaries.

Results

(1) Analyses based on 5x5km data

Lattice-Wombling boundaries tended to be highly internally organized (Figure 10). Fuzzy classification maps can be found in Figure 11. Table 2 summarizes the sub-boundary statistics for every factor. In each case, boundaries appeared 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 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 coincided with increased elevation within the Algonquin region in the north but *The Land Between* occurs 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 extended 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) is situated 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 contained a proportion of this class.

Forest boundary points appeared to mostly lie along the blue region of the map, with some singletons spread throughout the extent of the map.

Table 2. Boundary Statistics for All Boundaries Based on a 30% Threshold.

Layer	Sub-Boundaries	Singletons	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 resulted in a large amount of water boundary points falsely determining boundaries where there were simply large amounts 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 the blue class delineates a region around the green class, and the blue class appears to be found mainly within the hypothetical region encompassed by *The Land Between*. Boundary points for water occured mainly in the north and mainly between the blue and green classes. A drop-off in boundary points occurred in the red class as the southern portion of the map appears to be relatively homogeneous in water body count.

In contrast, wetlands predominated on the eastern and central portions of the map. The red class, indicative of lower wetland count, occurs 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 appeared 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 were mainly clustered around the middle and north-eastern section of the region, with other points spread evenly across the southern and north-western portions of the map.

Road classes appeared 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 tend to be clustered around highways 11, 401, with some development around highway 35. Boundary points appeared to create edges between different regions of the map, with a few singletons found spread throughout the map.

Boundary Spatial Overlap Analysis

Boundary overlap was used to determine congruence between boundary points (Figure 12). 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 3).

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 3). With the exception of elevation, all other layers showed similar decreases in avoidance when water and wetland bodies we combined into one map.

Table 3. Boundary Spatial Overlap Analysis Based on a 30% Threshold.

Observed	Minimum Distance O_g	Minimum Distance O_h	Mean Minimum Distance O_{gh}	Direct Overlap O_s
Water and Elevation	19833.2*	8102.7*	13967.9*	160*
Water and Wetland	7969*	14249*	6109*	174*
Water and Forest	13476.0*	4371.5	8923.7*	254^{+}
Water and Road	8858.4*	19365.5	13977.0*	179
Wetland and Elevation	9386.6*	18037.9*	13715.3*	144^{+}
Wetland and Forest	9659.2*	4606.9	7133.0	241
Wetland and Road	5949.3*	8698.0	7323.7*	239^{+}
Elevation and Road	9712.0*	7941.0*	8826.6*	191
Forest and Elevation	7732.4*	5879.6*	6806.1*	196
Forest and Road	5810.5*	4299.9	5055.2*	263^{+}
All wet and Elevation	8879.6*	8907.5*	8893.6*	124*
All wet and Road	6002.9*	4928.1	5465.5*	251^{+}
All wet and Forest	3708.4^{+}	4760.3	4234.3	293^{+}

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

(2) Analyses based on 1x1km data

The same lattice-Wombling boundary detection algorithm was used to find boundaries using the 1x1km grid land cover data. There were two reasons for carrying out this new series of analyses: (1) the first series of analyses based on the 5x5km did not include the Eastern part of Ontario, and (2) we wanted our results to be compatible with those of the Breeding Bird Atlas data.

The maps of the amount of area per land class and their corresponding lattice-Wombled boundary locations based on a 30% threshold are showed in Figures 13 to 22. The spatial overlap of the boundaries of forest, water, wetland and alvar (Figure 23) showed that the entire region of The Land Between is composed of multiple small boundaries (in red) as illustrated in the cartoon Figure 5 from Gosz (1993). Therefore this 1x1km grid is too small to determine the outer limit of *The Land Between* but still indicates well the spatial heterogeneity of the entire region, which is one of its major attributes. This highlights the need for a multiscale analysis.

(3) Multiscale Analysis based on 1x1km data

The multiscale analysis consisted of performing a wavelet boundary analysis using wavelets of different sizes (2x2km, 4x4k, 8x8km and 16x16km) as illustrated in Figures 24 to 43. This multiscale analysis revealed that the boundaries occurring at small resolutions (2x2km and 4x4km) are mostly due to the presence of water bodies (lakes, wetlands) and the boundaries at the larger resolutions are due to the presence of forest.

As for the analysis based on lattice-Wombling, the spatial overlap boundary analysis (Figures 44 to 47) at these four scales indicated that at small scales (2x2km and 4x4km) several small boundaries are found within *The Land Between* while larger scales (8x8km and 16x16km) illustrate the outer limits of *The Land Between*. In fact, the 8x8km scale analysis provided outer limits that are comparable to those provided by the 5x5km analysis , but also included the Eastern limit that was missing with the former analysis. The limits illustrated at the 16x16km scale were too coarse to be useful. Hence, to delineate the outer limits of *The Land Between* an approximate 8x8km scale seemed appropriate. To match the breeding bird species responses to the unique environmental conditions of *The Land Between*, we decided that the 10x10km grid resolution of the Ontario Breeding Bird Atlas would be adequate for illustrating landscape boundaries and we performed the final series of analyses with the land cover and species data at this 10x10km grid scale.

(4) Analyses based on 10x10km data

The boundaries were delineated using the lattice-Wombling at the 10x10km using the 30% threshold as showed in Figures 48 to 55. Boundary statistics are summarized in Table 4 and indicate that the agricultural and open areas have the most cohesive boundaries (i.e., the longest boundary), followed by deciduous areas (i.e., second longest).

The lattice-Wombling of all variables considered together is shown in Figure 56, while the spatial overlap of boundary locations is illustrated in Figures 57 and 58. From Figure 56 the southern limit of *The Land Between* was delineated as a region. Furthermore, Figure 57 stresses that *The Land Between* is indeed a spatially heterogeneous area formed by several smaller boundaries due to several different features, and water bodies (including wetlands, bogs, fens) are the most important features. Finally, Figure 58 illustrates the well-defined ecotonal region in the south of *The Land Between* and the less well demarcated northern limit of *The Land Between*.

Table 4. Boundary Statistics for All Boundaries Based on a 30% Threshold.

Layer	Sub-boundaries	Singletons	Max Length	Mean Length	Max Diameter	Mean Diameter	Diameter Length
Agriclear	18**	9**	176*	14.222*	73*	6.722*	0.906**
Alvar	740*	737*	46	1.154**	18	1.062**	0.998*
All Wet	54	27	53*	4.741	21	3.241	0.912
Coniferous	42**	14	42	6.095*	20	4.071*	0.904
Deciduous	48**	17**	42*	5.333*	25*	4.000*	0.916**
Mixed	36**	9**	60*	7.111*	30*	4.500*	0.915**
Urban	42	10	39	6.095	15	3.952	0.852
Roads	50**	14**	58*	5.120*	21	3.640*	0.925
All Layers	**55**	**25**	**48***	**4.164**	**21***	**2.945**	**0.927**

*Test statistic is significantly higher than expected ($p < 0.05$)
** Test statistic is significantly lower than expected ($p < 0.05$)

The boundary spatial overlap analysis (Table 5) confirmed that all forest categories overall well (direct overlap) and that agriculture and open areas are found near roads and water bodies.

Table 5. Boundary Spatial Overlap Analysis Based on a 30% Threshold.

Observed	Min Distance O_g	Min Distance O_h	Mean Min Distance Ogh	Direct Overlap Os
Agriclear & Alvar	0	21748.7*	16732.8*	256
Agriclear & All Wet	8504.43**	15542.2*	12023.3*	114*
Agriclear & Coniferous	11121.1*	17610.6*	14365.9*	83
Agriclear & Deciduous	13650.9*	24309.2*	18980.1*	74
Agriclear & Mixed	23639.1*	24026.5*	23832.8*	63**
Agriclear & Urban	12287.2*	20251.9*	16269.5*	65**
Agriclear & Roads	9353.11	17484.4*	13418.7*	98*
Alvar & All Wet	11784.5*	0	9066.65	256
Alvar & Coniferous	12094.9*	0	9305.44	256
Alvar & Deciduous	11765.7*	0	9052.16	256
Alvar & Mixed	17505.3*	0	13468*	256
Alvar & Urban	14227.2*	0	9441.84	256
Alvar & Roads	10652.7*	0	8195.87	256
All Wet & Coniferous	11813*	10532.5	11172.8*	79
All Wet & Deciduous	12307.4*	10931.6*	11619.5*	84
All Wet & Mixed	16534.3*	11192.9*	13863.6*	73
All Wet & Urban	11454.9	11495.2*	11475.1*	72
All Wet & Roads	8357.25**	8553.74**	8455.49**	96*
Coniferous & Deciduous	10200.3*	11540.5*	10870.4*	87
Coniferous & Mixed	12641.9*	8879.33	10760.6*	105*
Coniferous & Urban	8703.71**	8959.09	8831.4**	109*
Coniferous & Roads	9133.48	10559.8	9846.65	90*
Deciduous & Mixed	8770.84	6227.08**	7498.96**	124*
Deciduous & Urban	12155*	11863.6*	12009.3*	79
Deciduous & Roads	10720.8*	13151.3*	11936*	75
Mixed & Urban	10169.9	14592.2*	12381*	95*
Mixed & Roads	9748.92	17202*	13475.4*	90*
Urban & Roads	5654.81**	6337.6**	5996.21**	153*

*Test statistic is significantly higher than expected ($p < 0.05$)
** Test statistic is significantly lower than expected ($p < 0.05$)

The spatial overlap between all land cover boundaries (Figure 58) and the lattice-Wombled boundaries based on overall bird species richness and the sum of the 113 species are illustrated in Figures 59 and 60. The bird species richness boundaries help to define the northern boundary of *The Land Between* while the sum of individual species boundaries indicates the inherent spatial heterogeneity of *The Land Between* as a whole.

Discussion

The delineation of any boundary requires that a significant portion of homogeneous land on either side of the 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*, 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 northern 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. By narrowing our extent, we were able to remove much of the confounding effect of this secondary nearby boundary.

Based on the 5x5km grid data analysis, boundary delineation of elevation appeared to capture two main features: the ecoregion shift south of *The Land Between*, 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.

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.

Road density is most variable 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. Just south of Orillia to north-west of Kingston, boundary points tend to align well, 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 to water around the Algonquin dome. The congruence of forests to both water body and road boundaries suggests that forest boundary points do tend to 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.

Another land cover type of particular interest in delineating *The Land Between* is the presence of 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 detectable areas in the middle of *The Land Between*.

Conclusion

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 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 o nseveral factors. Hence, the most important environmental variables that influence local spatial heterogeneity (i.e., many small boundaries within *The Land Between*) are the various water bodies (lakes, rivers, wetlands) with which bird species boundaries overlapped, while regional spatial heterogeneity (i.e., the outer limit of *The Land Between*) is mostly determined by the contrast between forested and open areas (e.g., farmlands). Bird species richness matched well the northern part of *The Land Between* while the sum species individual boundaries stressed the importance of *The Land Between* as an ecotonal zone.

References

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Appendix 1. Species present in the study area.

Alder Flycatcher
American Crow
American Goldfinch
American Redstart
American Robin
Baltimore Oriole
Bank Swallow
Barn Swallow
Belted Kingfisher
Black-and-white Warbler
Black-backed Woodpecker
Black-billed Cuckoo
Blackburnian Warbler
Black-capped Chickadee
Black-throated Blue Warbler
Black-throated Green Warbler
Blue Jay
Blue-gray Gnatcatcher
Blue-headed Vireo
Bobolink
Broad-winged Hawk
Brown Creeper
Brown Thrasher
Brown-headed Cowbird
Canada Warbler
Cedar Waxwing
Chestnut-sided Warbler
Chimney Swift
Chipping Sparrow
Cliff Swallow
Common Grackle
Common Loon
Common Raven
Common Yellowthroat
Dark-eyed Junco
Downy Woodpecker
Eastern Bluebird
Eastern Kingbird
Eastern Meadowlark

Eastern Phoebe
Eastern Towhee
Eastern Wood-Pewee
European Starling
Evening Grosbeak
Field Sparrow
Golden-crowned Kinglet
Golden-winged Warbler
Grasshopper Sparrow
Gray Catbird
Gray Jay
Great Blue Heron
Great Crested Flycatcher
Hairy Woodpecker
Hermit Thrush
Hooded Merganser
Horned Lark
House Finch
House Sparrow
House Wren
Indigo Bunting
Killdeer
Least Flycatcher
Magnolia Warbler
Mallard
Marsh Wren
Mourning Dove
Mourning Warbler
Nashville Warbler
Northern Cardinal
Northern Flicker
Northern Harrier
Northern Parula
Northern Rough-winged Swallow
Northern Waterthrush
Olive Sided Flycatcher
Ovenbird
Philadelphia Vireo
Pileated Woodpecker
Pine Warbler
Purple Finch
Purple Martin
Red-breasted Nuthatch

Red-eyed Vireo
Red-tailed Hawk
Red-winged Blackbird
Rock Dove
Rose-breasted Grosbeak
Ruby-crowned Kinglet
Ruby-throated Hummingbird
Ruffed Grouse
Sandhill Crane
Savannah Sparrow
Scarlet Tanager
Song Sparrow
Swainson's Thrush
Swamp Sparrow
Tree Swallow
Turkey Vulture
Upland Sandpiper
Veery
Vesper Sparrow
Warbling Vireo
White-breasted Nuthatch
White-throated Sparrow
Willow Flycatcher
Wilson's Snipe
Winter Wren
Wood Thrush
Yellow- bellied Sapsucker
Yellow Warbler
Yellow-bellied Flycatcher
Yellow-rumped Warbler
Yellow-throated Vireo