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Measurement of spatial change in the forest component of the rural landscape of southern Ontario

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Abstract

Forests are one of the more rapidly changing elements within the rural landscape of southern Ontario. The pattern of change and evolution of forest cover has implications for both biotic and abiotic processes. Spatial change in forest elements provides an important perspective needed to integrate forest information with environmental management, particularly through agro-ecosystem and natural resources planning. Shape, size and spatial pattern are indices of change identified at scales from individual woodlots to their cumulative expression at the regional scale. Changes are illustrated by reference to forest change in three townships representing the three dominant ecoregions of southern Ontario.

Fragmentation of the original forest cover of southern Ontario has produced a pattern of isolated woodlots and forest remnants which form a significant, and often dominant, proportion of the landscape. The environmental and economic significance of these forest 'islands' remains largely unrecognized beyond their role as somewhat limited sources of timber and as wildlife habitats. Wooded areas, however, are one of the most rapidly changing components in the present rural landscape of southern Ontario. They are a biotic resource that interacts in such a way that any change will affect most other ecosystem or landsystem components and processes (such as primary productivity, nutrient cycling, species replacement patterns and extinction rates, and moisture budgets). Furthermore, such changes in woodlots can be related to a range of broader, regional landscape processes associated with soil and water conservation. All evidence indicates that serious land resource degradation will occur with the removal of forests and wooded areas—a process that has far-reaching environmental and, ultimately, economic consequences. With reforestation it is logical to assume that amelioration of land degradation will take place but the nature of, and the changes to, landscape dynamics introduced by such events are much less clearly understood, although they are arguably part of the current dynamics of these rural landscapes. The situation in Ontario now is one of a decline in agriculturally productive land and a corresponding increase in land covered by forest. This paper seeks to identify the trends in this process of forest change from a spatial perspective. This spatial perspective is needed to understand more fully the role of these and other landscape elements such as wetlands and croplands in order that their functional value may be more fully integrated into the development of future landscape management strategies aimed at landscape sustainability and integrity.

This paper focuses on the nature and significance of change in the forest cover of southern Ontario from the time of the first European settlers (1810–60) up to the

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present. The problem is approached from the perspective of change in the size, spatial interrelationships and shape of the remaining forest cover of rural agricultural landscapes. Size and spatial relationships amongst the remnant forest islands provide a perspective to both agroforestry and agroecosystem research. The significance of shape is less obvious, but what is clear is that ecotones—in this case habitats where treelines meet open areas—are subject to more exposure and generally experience different microclimates when compared to the interiors of woodlots. This tends to favour successional change (Ghiselin 1977) which is ultimately reflected in rates and patterns of primary productivity in landscapes with increased edge to area ratios. The distinctiveness and significance of ecotones in landscapes has been extensively reviewed by Hansen and di Castri (1992).

The major research objectives of this paper are twofold: first, to describe, quantify and compare the evolution and change of the pattern of forest 'islands' in southern Ontario between the early 1930s and the late 1970s and, secondly, to relate, in general terms, both land use histories and other environmental factors to these changes in spatial relationships amongst the forest 'islands'. While of significant environmental interest in its own right, this type of basic research data is the starting point for identifying critical thresholds and values where spatial pattern has been shown to be a critical factor in determining, for example, stand viability related to the range of seed dispersal, bird and animal migration patterns, and wildlife habitat (cf. Burgess and Sharpe 1981; Darley-Hill and Johnson 1981; Middleton and Merriam 1983; Johnson and Adkisson 1985). Soil, water conservation and energy-related factors at the island and inter-island scale are assumed to affect related environmental or ecological processes operating at the next higher level of integration—the landscape scale. Since landscapes may be regarded as ecosystems with both horizontal and vertical heterogeneity and processes (Zonneveld 1988), any parameter impinging upon the component land units (such as remnant forest islands) either spatially or temporally must be considered within analytical frameworks designed to examine biological diversity/stability. Increasingly consideration is being given to the importance of scale in understanding complex interacting ecosystems at the landscape level, this being essential for improving the utilization, management and conservation of natural resources.

Historical and ecological context

Historical context

Between 1780 and 1830, land clearance for agriculture and timber in southwestern Ontario was initially limited to a subsistence-type economy which had little effect on forest cover, or at least no greater effect than that perpetrated by the aboriginal occupants (Day 1953; Curtis 1956; Jenness 1963; Bormann and Likens 1979). Government land surveyors parcelled out farm lots in the most expedient manner—gridiron configurations with little regard given to natural continuity in topographic features, soils, vegetation, or watercourses (Gentilcore 1969; Gentilcore and Donkin 1973; Sebert 1980). Early farming practices tended to be extensive rather than intensive since clearance was often also a means of generating a cash income from the sale of timber (Kelly 1971, 1973).

Overcropping with wheat soon exhausted the best lands so that swamp and marsh reclamation became increasingly necessary for continued agricultural development. Though artificial drainage was employed by the mid-1880s in almost all counties in the southwest of the province (Alexander 1974), it was not as universal a modifier of the landscape as the removal of the forests (Kelly 1975). By 1890, the detrimental effects that the loss of woodland for wheat acreage had caused in relation to soil erosion and fluctuations in local water budgets were obvious and have been reviewed elsewhere (Jones 1946; Kelly 1974a, 1976b; Wilson and Ryan 1988).

With the introduction of general mixed farming following the decline in the importance of wheat, fields were reduced in size and enclosed by fences. The Tree Planting Act (1871) and the Ontario Tree Planting Act (1883) were passed in recognition of the need to reforest. Settlers were given incentives to create shelterbelts along fence-lines, driveways and the adjacent country roads, practices that tended to reinforce the gridiron configuration of the original survey (Scott 1979). Native species took hold and created hedgerows along fence-lines, between the non-native species of *Pinus*, *Picea* and *Populus* that were planted. Regeneration of remaining woodlots and preservation/perpetuation of shade trees (especially *Acer* species) continued apace under government incentive plans.

In the central, northern and eastern townships of southern Ontario, the history of settlement and land use is somewhat different due to the regional biophysical endowment. Limited settlement on low-quality soils proved to be unwise as fertility quickly declined and farms had to be abandoned. Many settlements were often only bogus farming operations, the hidden agenda being to secure the valuable timber and then move on. Forest cover was primarily affected through selective cutting of northern hardwoods and pine and also by wasteful slash-and-burn practices, which served to increase the frequency of forest fires (Dixon 1957).

Ecological context

Both natural ecosystems (forests, wetlands and open meadows) and adjacent semi-natural ones (agroecosystems and plantation forests) have constantly been changing in areal extent relative to one another. Such changes were primarily determined by human need for these biological resources but also result from any ecological, aesthetic or scientific value placed upon them, though conservation of these 'non-productive' components has never received much attention (Moss and Davis 1985). Consequently, in populated rural areas where natural and semi-natural vegetation communities coexist, landscapes have become characterized by remnant forest islands isolated by mixed land uses which are usually agricultural, but may also be any other non-forested category (Curtis 1956; Burgess and Sharpe 1981; Middleton and Merriam 1983). Growth and survival of forest species in such islands depends on their ability to compete for limited resources, to tolerate microclimatic changes associated with an increase in edge or ecotone between the trees and open land, and to maintain a balance between 'income' by immigration and 'loss' by extinction. Certain processes normal to large areas of relatively undisturbed deciduous forest may no longer be operative in the current landscape. Recent investigations have cast doubt on the continued existence of mature stands of forests representing the end points of local seres (Auclair and Cottam 1971; Levenson 1976; Lamotte 1983), the present abundance of the more common species (Whitney and Somerlot 1985) and the overall diversity in second-growth stands (Whitney and Runkle 1981; Davis 1986; Nyland *et al.* 1986).

Increasing inter-island distances across open fields may be producing barriers to successful seed dispersal by wind (Fields and Sharpe 1980; Johnson *et al.* 1981; Sharpe and Fields 1982) and by animal vectors between wooded habitat islands and farmland (Wegner and Merriam 1979; Darley-Hill and Johnson 1981; Johnson and Adkisson 1985) such that forest species composition is affected (Auclair and Cottam 1971; Ranney and Carter 1977). Irrespective of the exact mechanism, it has been observed that the species richness in forest stands of Wisconsin (Levenson 1976, 1981), Ohio (Tramer and Suhweir 1975) and Minnesota (Scanlan 1981) was inversely proportional to the degree of isolation from neighbouring stands.

The study areas

The study areas (30 km^2 representative sections of three rural townships shown in Fig. 1) reflect conditions in three distinctive biophysical regions of southern Ontario. The natural vegetation of Wainfleet (surveyed in 1811) contains species typical of the Southern Deciduous Forest Region (Rowe 1959). Soils are predominantly clay, and as the topography presents little in the way of macrorelief, drainage conditions are only fair to good. Swamps and bogs are not uncommon where artificial drainage is not in place. This township lies within the Erie Ecoregion—an ecoregion being a land unit characterized by a distinctively regional climate as expressed by vegetation (Thie and Ironside 1976; Environment Canada 1978). Wellesley Township (surveyed in 1843) lies within The Great Lakes–St Lawrence Forest Region which is typically a mix of coniferous and deciduous species (Rowe 1959). Soils are mainly fine-textured silt, clay sands and sandy loams. Pockets of organics and peat present poor drainage conditions in low-lying

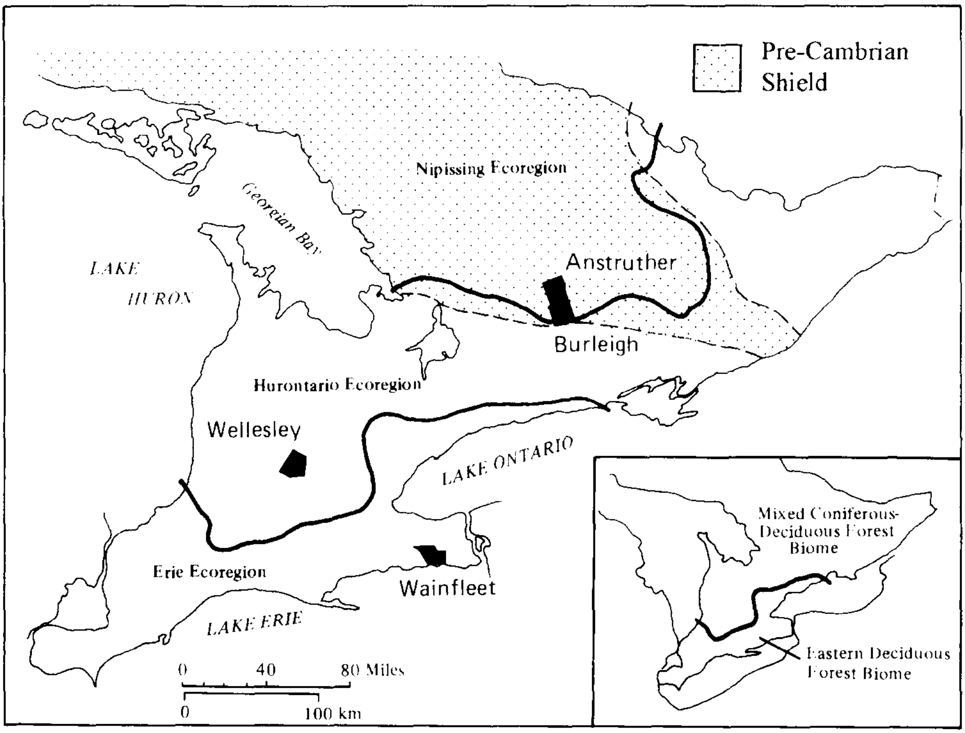

Figure 1. Southern Ontario: major ecoregions and location of townships used in this study

areas (Presant and Wickland, 1971). The third study area is the joint township of Burleigh and Anstruther, which lies on the edge of the Canadian Shield. Numerous swamps, lakes and streams are prevalent, and natural vegetation is of the Great Lakes–St Lawrence Forest Region type (Rowe 1959). The rough stony plain of the Dummer Moraine in Burleigh has excessively well-drained sandy loams. Settlement was slow to gain momentum following the 1822 survey. In Anstruther, the combination of extensive areas of humic ferrisols along with gneiss, schists and limestone outcrops failed to attract settlers to the township when the survey was completed in 1859. The joint township lies wholly within the Nipissing Ecoregion (Environment Canada 1978).

Methodology

To quantify the evolution of forest island pattern and change in spatial relationships amongst the remnant woodlots between the 1930s and late 1970s, air photos were obtained for each township from the Ontario Ministry of Natural Resources, Queen's Park, Toronto. A time series was developed to elucidate spatial and temporal change in the forest islands. Measurement proceeded in three stages:

1. the quantitative description of individual forest islands;
2. measurement of interaction between or amongst forest islands;
3. analysis of regional landscape pattern, emphasizing the dynamics of the forest islands.

All measurements used at each stage of investigation are given in Table 1 and Fig. 2, which summarizes in diagram form the indices used. Equations to quantify the data are presented sequentially in Table 2.

Table 1. Measurements and indices used

Description of individual woodlots
- Measurement of area (a)
- Measurement of edge (p)
- Edge-to-area ratio using island dissection index (DI)

Description of woodlot interaction
- Mean, median size of woodlot and modal number for central tendency and skewness
- Nearest neighbour edge-to-edge distance r_e
- Nearest neighbour centroid-to-centroid distance r_c
- Distance to all other neighbours within a set radius R_e, R_c
- Sum of linkages between pairs of woodlots using a binary connectivity matrix to derive a connectivity index (CI)
- Average measure of isolation for each woodlot using an isolation index (II)

Description of regional landscape pattern
- Landscape dissection index (DL)
- Island distribution index (IDI)
- Size:spacing index (SSI)
- Summation of number of islands
- Summation of amount of edge per total area
- Summation of woodlot area as a percentage of total landscape area

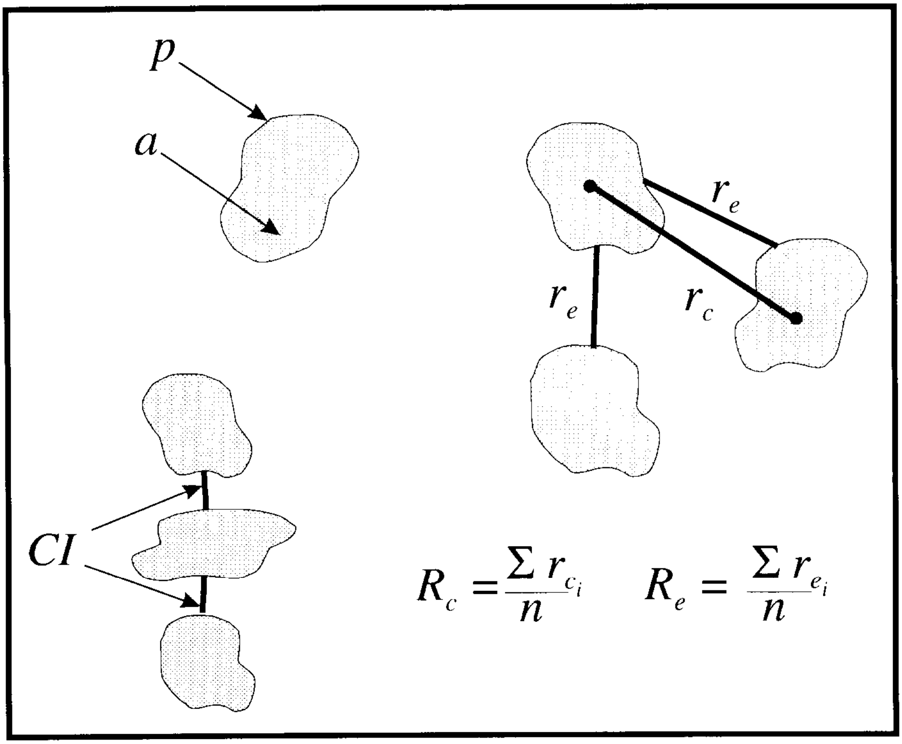

Figure 2. Diagrammatic representation of indices and measurements used

In the first stage (description of individual woodlots) all forest islands were digitized for each of the four time periods. This was done to obtain perimeter and area measurements, later used to produce descriptive statistics for the islands and then to calculate an edge-to-area ratio quantifying the amount of irregularity in the shape of remnant stands (Patton 1975). A forest island dissection index (Equation 1, Table 2), which is an extension of Patton's original formula, was used to compare the amount by which any one island is more dissected than another and, therefore, would have a greater edge to interior habitat (Sharpe *et al.* 1981). Any index greater than 1 is a measure of such irregularity in comparison to an index of 1, which is circular in shape.

The second stage of the methodology relates to the description of woodlot interaction for which numerous measurements must be taken. These are illustrated in Fig. 2. Inter-island distances R_e and R_c are mean distances (in metres) of the nearest edge to edge (R_e) and centroid to centroid (R_c) of all islands within a 1·75 km radius from any single island. This distance seemed a suitable figure, as the range for windborne seeds varies from 0·5 km to 4 km but can be much greater or much less depending on fall velocity of the seeds and windspeed (Johnson *et al.* 1981: 218) and on landscape barriers perceived by animal vectors (Diamond 1974; Oxley *et al.* 1974; Willis 1974; Wegner and Merriam 1979; McDonnel and Stiles 1983). The mean distance (in metres) from any island to its first nearest neighbour is given as r_e (leading edge to leading edge) and r_c (centroid to centroid). Lastly, a

Table 2. Equations used in quantifying island/woodlot pattern and spatial relationships

Forest island dissection index

$$\mathrm{DI} = \frac{p}{(2\sqrt{\pi a})} \qquad \text{(Equation 1)}$$

where DI = forest island dissection index
p = island perimeter (metres)
a = island area (ha)

(*Source*: Sharpe *et al.* 1981: 111)

Isolation index

$$\mathrm{II} = 1/n\sum_{i=1}^{n} d_{ij} \text{ using } R_e, R_c \qquad \text{(Equation 2)}$$

where II = isolation index
d_{ij} = distance between the ith and jth place
R_e = mean distance edge to edge from one island to all its nearest neighbours within the search radius
R_c = mean distance centroid to centroid from one island to all its nearest neighbours within the search radius

(*Source*: Bowen and Burgess 1981)

Landscape dissection index

$$\mathrm{DL} = \sum_{i=1}^{n} \frac{\mathrm{p}}{(2\sqrt{\pi \sum_{i=1}^{n} a})} \qquad \text{(Equation 3)}$$

where DL = landscape dissection index
p = total perimeter (metres)
a = total area of the forest island (ha)

(*Source*: Sharpe *et al.* 1981: 111)

Island distribution index

$$\mathrm{IDI} = 2\bar{r}_c\,(\lambda/\pi) \qquad \text{(Equation 4)}$$

where IDI = island distribution index
$\bar{r}_c$ = mean centroid-to-centroid distance from a forest island to its nearest neighbour
λ = density of forest islands (number per ha)

(*Source*: Bowman and Burgess 1981: 29)

Size:spacing index

$$\mathrm{SSI} = \frac{\bar{r}_c}{\bar{r}_e} \qquad \text{(Equation 5)}$$

where SSI = size:spacing index
$\bar{r}_c$ = mean centroid-to-centroid distance from a forest island to its nearest neighbour
$\bar{r}_c$ = mean edge-to-edge distance from a forest island to its nearest neighbour

(*Source*: Bowen and Burgess 1981: 29)

connectivity index (CI) was tallied for each island. This is the sum of linkages by means of hedgerows, treeline fences, and so on, between pairs or larger groupings of islands, and is calculated by use of an incidence matrix whereby connectivity values for each island range from 0 to n, depending on the number of connections any island has with another. There is no actual formula, rather a contingency table must be designed to display the data. Reference to the work of Lowe and Moryadas (1975) on the geography of movement provides an example of the format.

Interaction amongst the islands involves calculation of an isolation index. The index, II, was adapted by Bowen and Burgess (1981) from an accessibility index prepared by Lowe and Moryadas (1975) and is given in Table 2 as Equation 2. The isolation index calculates the 'accessibility' of a vertex (such as an island) to the ith place. The value of the isolation index is inversely related to the accessibility of that island to all others in the landscape. That is, all other islands can be reached from the most accessible island by a shorter total topological distance than from any other island. Since it measures 'reachability' of one island from all other islands on the basis of the presence or absence of actual links it is not true that the most centrally located island in the study area is necessarily the most accessible one.

The third stage of the methodology addresses the measurement of regional landscape patterns. Since 'edge effect' can influence vegetation composition and structure (Ghiselin 1977; Ranney 1977), total edge (in km) was calculated from individual edges measured for each island. Sharpe *et al.* (1981) modified the dissection index, DI (Equation 1, Table 2), so that the edge:area ratio is cumulative for the entire landscape in which the islands exist. The index developed is the landscape dissection index (DL) and is given as Equation 3 in Table 2. As this is an extension of the island dissection index (Equation 1), the logic behind it is similar.

Measurement of island size and resultant distribution can also be made, which emphasizes the pattern of islands in the landscape. Two indices were suggested by Bowen and Burgess (1981: 29) and have been slightly modified here. The island distribution index (IDI) measures aggregation and is similar in logic to the nearest neighbour statistic (Hammond and McCullagh 1987: 270) while the size:spacing index (SSI) indicates whether the islands are large and well spaced or small and closely spaced. The formula for the IDI is given as Equation 4 in Table 2. IDI $= 1$ in a randomly distributed population, < 1 in an aggregated population and approaches uniformity if the value is close to 2·1491, where woodlots would have maximum spacing, in which case they are regularly distributed in a hexagonal pattern. The formula for SSI is given as Equation 5 in Table 2. A large value indicates forest islands separated by small distances while a small value indicates small islands separated by large distances. Other attributes measured to quantify landscape pattern were number of islands, density of islands and forest land as a percentage of total area.

Results

The research project generated an enormous amount of data. Only the results for Wainfleet Township will be presented in detail. Results obtained for the other two townships are discussed briefly by way of comparison. Full details of these other results are to be found in Moss and Davis (1989). The findings for Wainfleet Township are set out according to the levels of investigation described in the methodology.

Description of individual woodlots

Two remnant forest stands (nos 41 and 11, shaded in Fig. 3) were chosen as representatives for data presentation. Forest Island 41 existed as part of a large tract of black ash and soft maple species and was geographically peripheral to the Wainfleet Marsh in 1811 (Burwell 1811). In 1979 the stand was resurveyed and found to be composed of a mix of hardwoods, situated on slightly acid silt-loam

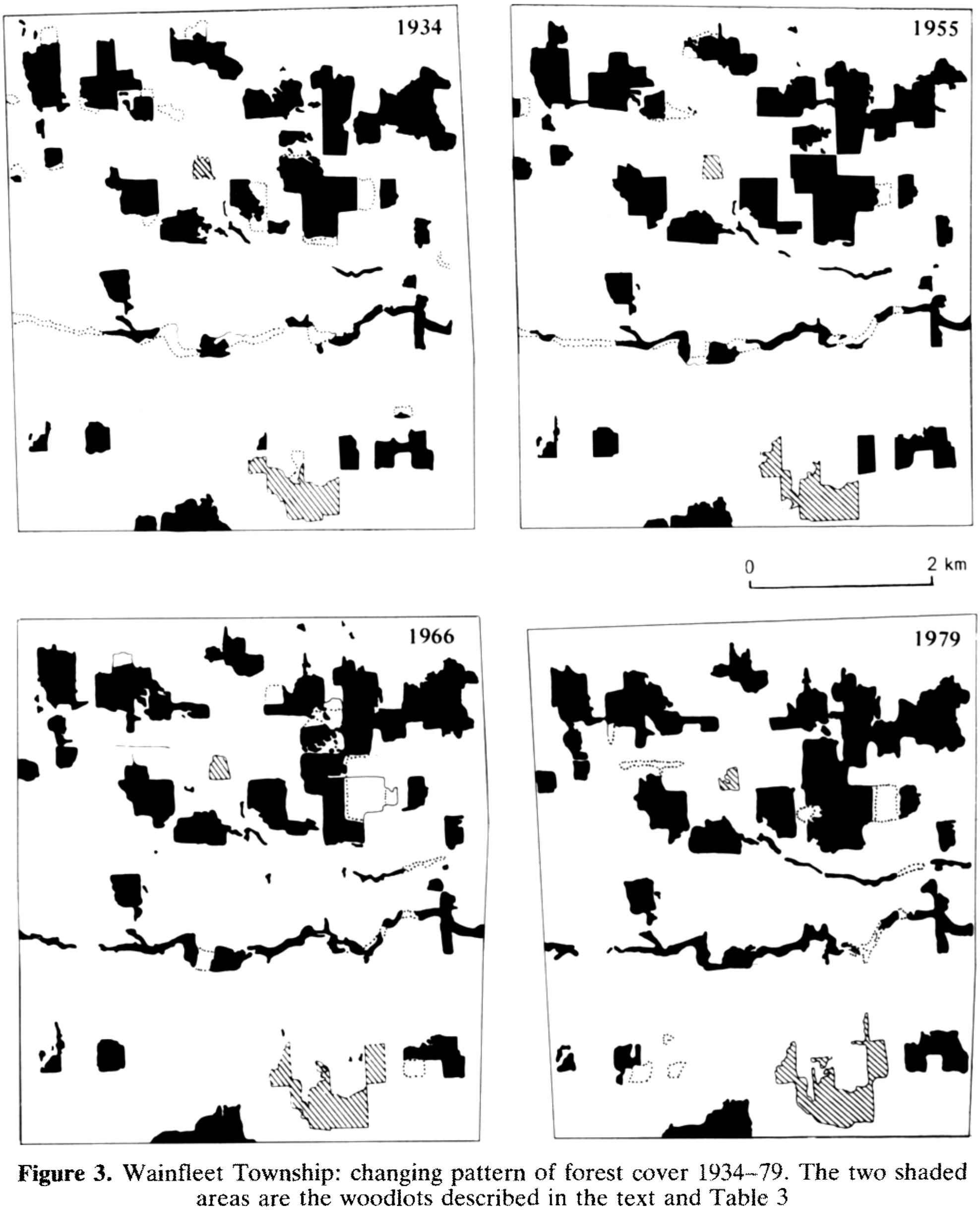

Figure 3. Wainfleet Township: changing pattern of forest cover 1934–79. The two shaded areas are the woodlots described in the text and Table 3

Table 3. Description of individual woodlots in Wainfleet Township, Southern Ontario, 1934–79

Lot No.	Year	p (km)	a (ha)	DI (m)	r_e (m)	r_c (m)	R_e (m)	R_c (m)	CI
41	1934	4·34	32·8	2·18	44	770	738	1403	0
	1955	5·17	37·8	2·39	8	670	852	1667	1
	1966	4·18	41·0	2·12	8	704	474	1336	1
	1979	6·59	55·2	2·50	15	83	863	184	0
11	1934	1·12	4·1	1·56	133	518	613	986	0
	1955	0·90	4·8	1·16	64	686	701	1178	0
	1966	1·29	5·3	1·59	58	672	354	1010	0
	1979	0·89	4·4	1·20	193	609	556	989	0

soils with fair to poor natural drainage (Agriculture Canada 1971; Ontario Ministry of Natural Resources 1978a).

Table 3 shows an increase in both island area (from 32·8 ha in 1934 to 55·2 ha in 1979) and perimeter (from 4·34 to 6·59 km) over the 45-year period and a corresponding increase in the island dissection index (DI). The mean distance to the closest edge of the first nearest neighbours (R_e) within the search radius increased by 125 m (from 738 to 863 m). Mean distance centroid to centroid (R_c), on the other hand, has decreased by 1219 m (from 1403 to 184 m), due to the coalescence of several separate islands, which had formed one large unit by 1979. The connectivity index (CI) points to the isolation of island 41 with respect to other islands in 1934, but with connections appearing years later in 1955 and 1966. By 1979, after the joining of several smaller units, the larger island was left once again without direct linkages (such as hedgerows and treelines) to other wooded areas.

Forest island 11 originally supported a mix of black ash and soft maples, with frequent occurrences of red alder brush, existing on poorly drained soils (Burwell 1811). In 1979, the stand was identified as scattered and barren, with only soft maples present (Ontario Ministry of Natural Resources 1978b). With reference to Table 3, results indicate that a decrease in perimeter (by 0·23 km) has occurred with only a slight increase in area (0·3 ha), although this situation did change during the 1960s. The island dissection index (DI) decreased over the same period (from 1·56 to 1·20), signifying a larger area:edge ratio. Other indices reveal how this island became more isolated in terms of distance to first nearest neighbour (r_e and r_c measures) but the R_e distances have decreased with the R_c remaining more or less constant. Explanation for this may be found in the increase in the number of islands since 1955 (the total number rose from 38 in 1955 to 41 by 1979) as well as an increase in the mean size of these islands (from 9·4 ha in 1934 to 14·0 ha in 1979). The connectivity index (CI) shows no linkages with other islands at any time.

Woodlot interaction

At this level of investigation, all forest woodlots or 'islands' within the 30 km^2 study area were considered, as the purpose was to examine the interaction amongst them. As shown in Table 4, mean island size increased from 9·4 ha to 14·0 ha, though the median size was almost always about half the mean size or less. Such a situation

Table 4. Woodlot interaction in Wainfleet Township, Southern Ontario 1934–79

Year	Mean size (ha)	Median size	$\bar{r}_e$ (m)	$\bar{r}_c$ (m)	$\bar{R}_e$ (m)	$\bar{R}_c$ (m)	CI
1934	9·4	4·1	101	503	540	956	2
1955	11·1	4·8	91	580	573	1058	2
1966	13·8	7·8	124	643	454	950	5
1979	14·0	5·0	112	578	994	1473	9

gives the symmetry of the distribution of individual island size values about the mean a positive skew: thus, large island sizes seem to be the exception in every time period. Mean distances to first nearest neighbours $\bar{r}_e$ (edge to edge) and $\bar{r}_c$ (centroid to centroid) are variable, but mean distances to all other neighbours within the search radius ($\bar{R}_e$, $\bar{R}_c$) have certainly increased when 1934 is used as the baseline and 1979 as the current status. The edge distance (R_e) was 454 m greater while the centroid distance (R_c) was 517 m greater. Interestingly, the connectivity between islands (CI) rose from 2 in 1934 to 9 in 1979.

Regional landscape pattern

Data at this level (see Table 5) show that the number of islands decreased from 47 in 1934 to 37 in 1966 but has since increased to 41. The actual forested area has also increased from 432 ha to 590 ha (that is, by 26 per cent), although in terms of the percentage of the study area within the township that is forested there was a decrease of 3 per cent (from 71 per cent in 1934 to 68 per cent in 1979).

Individual island dissection indices (not shown on Table 5 at this level) ranged from 1·1 to 2·7, with a few cases having a value of 3·0, indicating that the data are positively skewed. The landscape dissection index (DL) has increased; that is, the total edge:area ratio increased, as did the amount of edge per ha, but it was less in 1979 (133 m) than it was in the two previous periods. It may be concluded, then, that the size of the islands is increasing (as indeed Level II presents the data for such a case). The size:spacing index (SSI) indicates that the islands are fairly small and separated by comparatively large distances. The pattern suggested by the island distribution index (IDI) is one of island aggregation—an observation confirmed by the nearest neighbour statistic (IDI). One might conclude this to be contradictory, given the interpretation of the SSI value, but, in a large sea of

Table 5. Regional landscape pattern in Wainfleet Township, Southern Ontario 1934–79

Year	No. of islands	Total p (km)	Study area forested (ha)	p/a (m)	DL	Percentage of township forested	SSI	IDI
1934	47	65	432	127	14·2	71·7	5·0	0·006
1955	38	67	447	149	14·6	63·1	6·2	0·006
1966	37	74	512	155	17·1	62·4	5·2	0·004
1979	41	78	590	133	20·0	68·4	5·2	0·016

agricultural land use, the remnant stands tend to occur as clusters of islands on contiguous tracts of land unsuitable for cultivation. They appear, therefore, as aggregated or clumped when land use in the entire study area is taken into account (by increasing the area, the pattern is affected). The total perimeter or edge habitat increased by 11 km over the 45 years.

Change and its significance

It is difficult to judge the rate at which the original settlers in Wainfleet Township cleared the land and thus began to fragment the forest. This is due to the lack of substantive evidence, apart from agricultural statistics, regarding improved and unimproved land. In 1851 there were 70 'occupiers of land', mostly on farms that were 100–200 acres (40–81 ha) in size. A total of 3071 ha were classified as farmland, which represents about 15 per cent of the total area (20 996 ha). Only 2·3 per cent (481 ha) of all farmland was actually under crops, however, while the rest of the land was either in small orchards, pasture, left fallow or in unimproved conditions such as bush or woodlots (Census of Agriculture of Ontario 1851).

The proportion of cropland and pasture steadily increased over the years to become the most important land use type within the farm holdings. By 1921, the increases were up to almost 50 per cent and 20 per cent for cropland and pasture respectively. After this, the proportion of land devoted to pasture declined but the proportion of cropland (row crops, grains and tame hay) remained reasonably high, though it did fluctuate. With reference to the entire township the greatest clearing of the forest appears to have taken place over a 30-year period (1911–41) when 50–60 per cent of all farmland was either in pasture or crops. The proportion of farmland within the township ranged between 91 per cent of total area in 1911 to 80 per cent in 1941. Since then some farm abandonment has occurred (Census of Agriculture of Ontario 1851–1941).

Moss (1976) estimated that 32·6 per cent of all non-urban land in the Niagara Municipality was subject to the process of secondary succession. These trends of clearance and natural reforestation over time are strongly reflected in the attributes measured on individual forest islands, spatial relationships amongst islands and the regional landscape pattern. The results of a one-sample Chi-square test for the null hypothesis (H_0) that the number of remnant islands in the study area is not significantly related to terrain showed that the alternative hypothesis (H_1) had to be accepted. On wetlands and bottomlands with and without steep slopes where drainage is variable there are more islands present than would be expected by chance alone ($p > 0{\cdot}001$). Thus, remnant or regeneration islands tend to be restricted to non-arable lands.

Summary of results for the three other townships

Forest island remnants in Wellesley were slightly more numerous in 1979 (45) than in the first period of air photo observation, 1949, when there were 37. Islands tend to be small (approximately 9 ha)—smaller than in Wainfleet (14 ha). The median size is 80–90 per cent of the mean size; thus, as in Wainfleet, there are many small islands and very few large ones. Mean distances to all neighbours ($\overline{R}_e$, $\overline{R}_c$) within the search radius have varied only slightly over time, whereas mean distances to first nearest neighbour ($\bar{r}_e$, $\bar{r}_c$) have actually decreased. A mere 18 per cent of the study area in Wellesley remains forested, with over 70 per cent as working farmland, mainly under Mennonite control (Ontario Geological Survey 1981). The landscape dissection index is over four times that of Wainfleet, indicating that the perimeter of the remnant stands has increased at the expense of interior area. Edge habitats are consequently more prevalent and the islands themselves subject to microclimatic change and, therefore, habitat change. Results of a one-sample Chi-square test for differences in remnant island distribution on various terrain/soil types shows that islands exist in greater numbers than would be expected by chance alone ($p>0{\cdot}001$) on poorly drained wetlands and bottomlands. Such areas are presumably inaccessible to drainage technology at justifiable cost in comparison to profits from crop returns.

In Burleigh and Anstruther Townships forest fragmentation is not as severe a problem as elsewhere in southern Ontario since selective logging (first for white pine, later for hemlock) was more important than agriculture. At the level of island interaction in Burleigh, mean island size is extremely large in comparison to Wainfleet (68 ha in 1979), though there are fewer islands (36). The number of islands has increased, from 29 in 1934, while the median size is extremely small (almost 1 ha), suggesting that regeneration following farm abandonment, which was rapid after 1969, is occurring. Nearest-neighbour distances r_e have decreased to 22 m and while the r_c distance has also decreased, it is very much larger in comparison (1146 m); the same situation is true for the R_e and R_c distances. The explanation seems to lie in large island size with separations only due to roads, hydro rights of way, and so on, so that the edges are close but the interiors (centroid-position) remote. The connectivity index is greater than in Wainfleet due to the presence of extended 'arms' from one island to the next in the form of tree lines created by fences to which species were windblown and took root.

At the level of regional landscape pattern, the landscape dissection index is much higher than in Wainfleet (65 compared to 20), as are all other measures of edge. Since most of Burleigh is forested, any cuts or openings over the distance of 30 km (the length and width of the study area) will produce considerable edge values. A large water body, Lake Julian, as well as numerous smaller ones, plus rivers and streams, also contributed to edge measurements. The open areas appear as the 'islands' in a background sea of forests. Indeed, the size:spacing index suggests a truly clumped pattern. The location of the islands, moreover, is not significantly related to soil or terrain type (one-sample Chi-square test accepting H_0 with $p > 0{\cdot}001$).

In Anstruther, the results were much like those of Burleigh, which one would expect given their similarity in terms of biophysical endowments and settlement histories. At the level of woodlot interaction, forest island size, when examined for skewness of values amongst the mean size, are highly positive: there are a few very large islands while the rest are much smaller. Mean size, in fact, was 206 ha in 1979, while island numbers fell from 22 in 1934 to 18 in 1979. The distance measurements r_e, r_c and R_e, R_c were quite similar to those in Burleigh. In Anstruther, the connectivity index was always 0. The township was a little less dissected than Burleigh (DL of 36 in 1979), though again perimeter measures were twice those of Wainfleet. SSI and IDI indices are in keeping with an essentially intact forest area broken only by rights of way for hydro lines, roads, firebreaks, and so on. Numerous large lakes and rivers in the interior of the forest must also be considered in edge measurements since many actually divide the large forest tracts into clearly identifiable lobes. Islands are equally well distributed over all types of terrain and soils, based on the results of a one-sample Chi-square test, accepting the null hypothesis with $p < 0{\cdot}001$.

Discussion

The general picture which emerges in a comparison of the three landscapes is that Wainfleet and Wellesley are more similar to one another than they are to Burleigh and Anstruther. In the former townships, islands are more numerous, tend to be smaller and more distant edge to edge from both their first nearest neighbour (r_e) and all other neighbours (R_e) within a 1·75-km radius. There are very many more isolated remnant islands in Wainfleet and Wellesley than in Burleigh and Anstruther, where the forest cover is more continuous. Where farmland has been cut out of the forest land, it is the former that resembles islands in a sea of trees, rather than the reverse situation, which is normally the case. In all townships, however, there is a progressive increase in the proportion of land under forest cover, evidently both as a result of farm abandonment (currently occurring everywhere except in Wellesley), as well as an increase in natural regeneration stands and plantations.

Such spatial patterns become a critical issue in the long-term viability of some forest islands, since isolation from one another will interfere with seed dispersal (Auclair and Cottam 1971; Johnson *et al.* 1981; Sharpe and Fields 1982) and an increase in edge:area ratios will produce a change in habitat interior microclimate. Identification of such trends within the forested component of the landscape and the raising of questions as to the continued viability of the biophysical characteristics and functions of this component will automatically raise concerns about the changing functional relationship between forested areas and other land use components. By extending the argument about spatial interaction, issues are raised about the continued maintenance and stability of the productive/agricultural biophysical resource bases of the rural landscape.

Conclusion

The transformation of rural landscapes in the wake of both increased agricultural expansion and urban sprawl have led to a high degree of variance in size, numbers and spacing of remnant woodlots, hedgerows, shelter belts and other unique habitats harbouring both wildlife and pest predators. Such large-scale modification of the landscape often translates into a reduced spatial heterogeneity of resource, with hidden and overt environmental costs resulting from altered soil and water conditions (Dahlberg 1992; Rice 1992).

The principal trend observed in this study is that while total percentage forest cover has increased since the 1930s, so also has total perimeter length, primarily through changes in the shape of the remnant forest islands. Increased landscape dissection is most pronounced in those townships with a history of early settlement and a strong and persistent agricultural tradition. An increase in the length of 'edge' per hectare of land increases the possibility of altered microclimates and habitats along this extended ecotone. Successional change is often favoured under such conditions, a situation with implications for landscape rejuvenation both from the point of view of landscape components (such as species change) and landscape processes (primarily productivity rate changes).

Such landscape changes also place these types of results within the theoretical context of island biogeography, which focuses on the balance between 'income' by migration and 'loss' by extinction. This has been shown to provide a reasonable analytical framework for investigating mechanisms influencing diversity of both fauna and flora in fragmented habitats. In southern Ontario, faunal collapse—the net decrease in the number of species in habitat fragments compared with the number of species in the same area when it was part of a larger contiguous tract—has been studied (see Schmiegelow and Nudds 1987; Schmiegelow 1990), as have alterations in forest species richness (Weaver and Kellman 1981; Moss and Davis 1986). The spatial arrangements or patterns of land use heterogeneity, particularly in farming regions where large agribusiness operations and even small family farms put pressure on remaining tracts of forest cover, must be optimized if the goals of long-term sustainability and biological diversity are to be met. Solutions to land use and land resource problems must be addressed by looking at options that relate both agriculture and agricultural practices with other natural land use components both spatially and temporally, at the mesoscale (landscape) level. This study is but one facet of an approach that must become increasingly important if a more holistic view is to be taken of effective and sustainable rural land use planning.

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