Pre-Contact Settlement Pattern in Southern Ontario: Simulation Model for Maize-Based Village Horticulture

Celina Campbell and Ian D. Campbell

Three explanations can be advanced for the patchiness of overall prehistoric horticultural settlement distribution in Southern Ontario: (1) the northward diffusion of horticulture was interrupted by European contact, and the patchiness results from the incompleteness of the diffusion process; (2) the distribution of villages was controlled by cultural influences such as tribalisation, warfare, and trade, so that the patchiness is a result of the heterogeneity of the cultural landscape; or (3) the patchiness is due to the heterogeneity of the physical landscape, especially climate and edaphic conditions.

This paper develops and uses a simulation model of regional site location to examine the relative importance of frost free days, drainage, soil texture, and relief for explaining the site distribution. At a regional scale, ten per cent frost-free days and soil texture are found to be the most useful variables in describing the observed settlement pattern. Thus the third hypothesis, that the patchiness was due to the heterogeneity of the physical environment, may be a sufficient explanation.

Introduction

The prehistoric population distribution in Southern Ontario (Figure 1; Figure 2 shows the place names referred to in this paper) was markedly patchy, with areas of dense occupation (e.g. Huronia and Neutralia) and areas apparently clear of permanent settlements (e.g. Dundalk Uplands and the Bruce Peninsula). Three explanations have been advanced which may explain this patchiness.

Bennett (1955) suggested that horticulture was still extending its range in New England at the time of contact and that social and economic disruptions associated with European contact halted its northward spread. This explanation implies that horticultural systems had not yet reached their climatic limits, and that the patchiness of the distribution was the result of the incompleteness of the diffusion process rather than of any limiting heterogeneity of the landscape.

A second hypothesis is that the site distribution was primarily influenced by cultural processes such as tribalisation, warfare, and the control of trade (Wright, 1966; Lennox and Fitzgerald, 1990; Ramsden, 1978; Hayden, 1978). This hypothesis relates the patchiness to the heterogeneity of the cultural landscape.

A third hypothesis is that horticulture had reached its maximum extent, and was limited by the mean frost-free day and edaphic requirements of maize (Yarnell, 1964; Thomas, 1976; Ridley and Friemuth, 1979; Snow, 1981). Patchiness in the settlement distribution is attributed to the heterogeneity of the physical landscape, especially climate and edaphic conditions. On a local rather than a regional scale, Heidenreich (1971), Konrad (1973), Stevens (1974), and Burgar (1990) have demonstrated that soil texture, drainage, and relief affected prehistoric horticultural village site selection in parts of Southern Ontario, due to the importance of these factors for maize horticulture with aboriginal technology.

These three hypotheses can be explored **through** simulation modelling. If either of the first two hypotheses is correct, there should be only a coincidental and therefore probably very weak relationship between occupation and environment. If the third hypothesis is correct, we should find that those environmental variables which most strongly govern maize productivity show a strong relationship with occupation. This paper will test the environmental hypothesis; even if it is found to be both necessary and sufficient, either or both of the other hypotheses may represent contributing factors.

This study uses 333 pre-historic village sites, discussed in reports available from the Ontario Ministry of Culture and Communications, Heritage Branch, Toronto, Ontario (Figure 1). The list (available in Campbell, 1991) includes all presumed

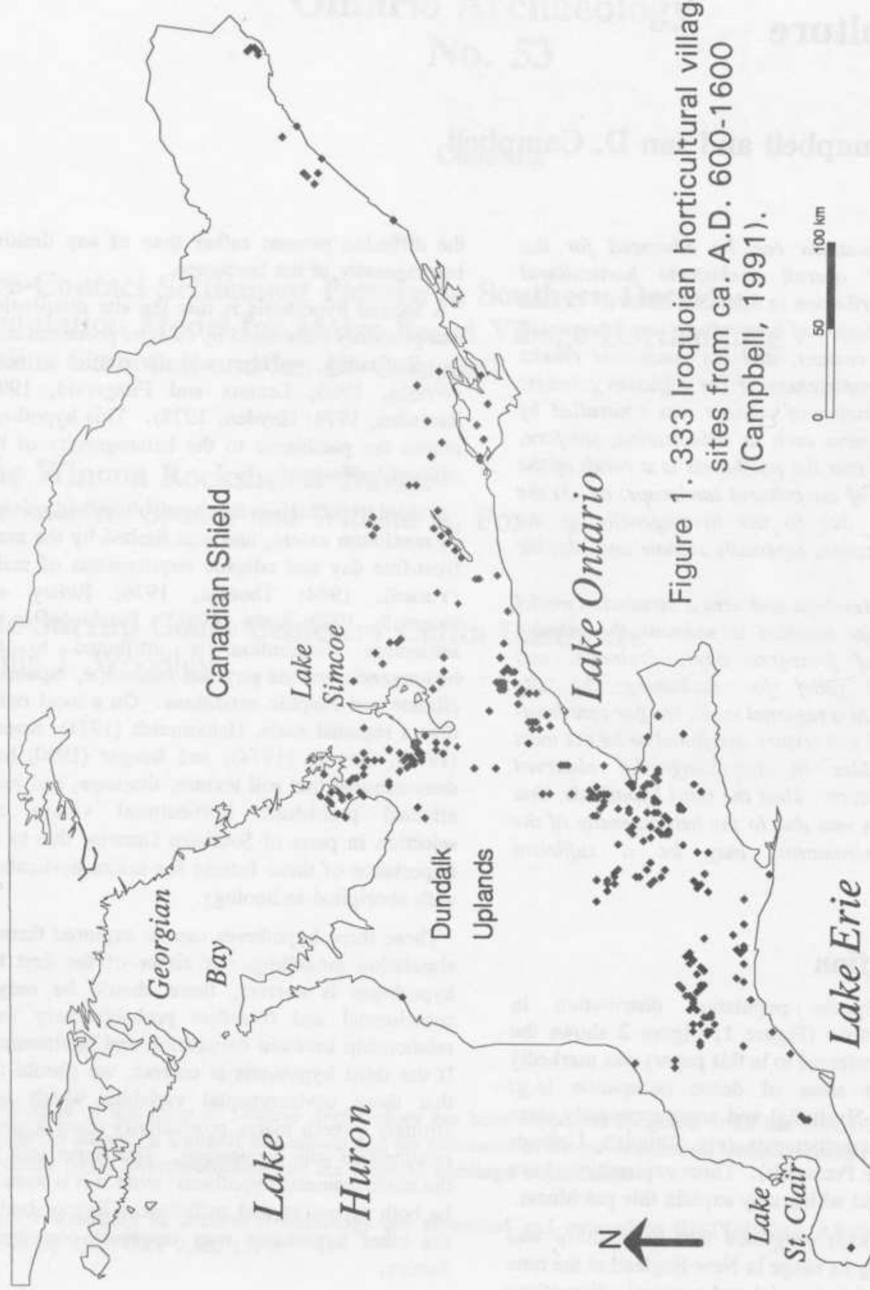

Figure 1. 333 Iroquoian horticultural village sites from ca. A.D. 600-1600 (Campbell, 1991).

Figure 2. Locations mentioned in text

prehistoric village sites in the study area registered on the Ministry's computerised data-base as of August, 1990. For purposes of this study it will be assumed that maize was grown near the village. Fishing, hunting and chert collecting camps are excluded because the locations of such sites were not selected for suitability for maize cultivation, nor were they year-round settlements.

There are undoubtedly many known sites not contained in this data base and many more as yet undiscovered, but this would likely affect more the density of the settlement pattern than the locations of major clusters. Partly for this reason, the spatial scale of this study is limited to large-scale patterns of settlement, rather than specific site locations, addressing questions like "Why was Huronia densely occupied and the Dundalk Upland largely unoccupied?", rather than "Why was a particular site not located one kilometre further up or downstream?"

This paper will: (1) test the hypothesis that heterogeneity of the physical environment was responsible for the patchy settlement distribution; and (2) determine the relative importance of the number of frost-free days, drainage, soil texture, and relief.

Approach: explanation and rationale

In most interactions between human groups and their physical environment, there are many variables; these cannot always be isolated and their interactions cannot always be predicted (Butzer, 1987). Simulation models are tools with which important variables can be isolated and controlled (Ulanowicz, 1988). Simulation results are tested against empirical data to determine the adequacy of the selected variables and their modelled interactions for explaining the observed phenomena. A good match between simulation results and reality does not mean that the variables and relationships used in the model are the ones which operated in reality; rather, it means that those used in the simulation may be sufficient to explain the observed phenomena. In this way, some insight may be gained into the complex interactions in the real world. If the model fails to produce the intended results, this may indicate deficiencies in the model and the assumptions on which it is based (Caswell, 1988).

We constructed a simulation model based on those factors believed to be most limiting to maize horticulture in the region: (1) soil texture, (2) drainage, (3) relief, and (4) frost-free days. In the model, locations are assigned probabilities of occupancy based on these four factors. Simulated sites are placed as a strict function of these probabilities, in order to develop a simulated settlement pattern. Goodness-of-fit between the simulated and archaeological settlement patterns is evaluated with the Simple Matching Coefficient (SMC) and Sorensen's Coefficient of Similarity (SCS). If this model produces a site distribution similar to that found in the archaeological record, then the null hypothesis, that *the prehistoric horticultural village settlement pattern in Southern Ontario is not significantly different from that predicted from the edaphic and climatic limitations on maize horticulture,* will be supported. While this will lend support to the hypothesis that heterogeneity of the physical landscape is responsible for the settlement pattern, it will not invalidate the other two hypotheses.

The edaphic data used here were obtained from the *Soil Associations of Southern Ontario* map (Map scale, 1:633600; Canada Department of Agriculture, 1960), which shows soil texture, relief, and drainage at a scale consistent with that needed for this study. Each edaphic variable contains a number of subclasses. Soil texture was divided into five subclasses: sand or very stony sandy loam, sandy loam, loam, silt loam or clay loam, and clay or rock. Soil drainage contains four subclasses: good, imperfect and variable, poor, and very poor. Relief was divided into seven subclasses: depressional, level, very - gently - undulating, undulating, rolling, moderately - rolling, and hilly. All the soil texture, relief and drainage subclass terms used are in accordance with the Canadian Soil Association classifications (Canada Department of Agriculture, 1960). The frost-free day data compiled in Brown et al. (1980) are from the 1931-1960 Climate Normal, a period which has been recognised as having abnormally low climatic variability (Cook, 1982). Therefore, the climatic data used here is derived from maps prepared for this study using the Canadian Climate Normals 1951 to 1980 (Environment Canada, 1982). Archaeological village site locations were provided by the Ministry of Culture and Communications, as described above.

Climatic and edaphic variables affecting maize

Several studies have shown that frost-free days, drainage, soil texture, and relief were important variables for prehistoric maize production in Southern Ontario, and thus may help in understanding the settlement pattern (Heidenreich, 1971; Konrad, 1973; Stevens, 1974; Sykes, 1980; Burgar, 1990; Yarnell, 1964).

While there is little ethnographic information on the frost-free day requirements of the prehistoric strains of maize, there are several ethnographic references to the length of the growing season they required. The growing season would have started with planting, and ended with maturation, which could be as late as the first fall frost. Since maize is highly frost-sensitive (Brown et al., 1980) it is unlikely that a good harvest could be obtained if the crop was not mature by the time of the first fall frost. Similarly, we can assume that planting did not occur prior to the last spring frost. Hence the growing season in areas where spring and fall frosts are a major concern was most likely limited by the period from the first day in spring when no further spring frosts could be expected to the first day in fall when no further frostless days could be reasonably guaranteed. This period is still considered useful today in determining modern planting dates (Brown et al., 1980). Hence, although it may be a slight overestimate, the modern frost-free season can be used as the ethnographic growing season. Ethnohistoric accounts (Sagard, 1939; Lafitau, 1724, 2; Kalm, 1935) indicate that maize needed -- 90 to 120 days to reach maturity and thus probably required the same minimum number of frost-free days.

In his discussion of the frost-free day requirements of prehistoric maize in the Great Lakes region, Yarnell (1964) assumed that mean frost-free day conditions were the same in the past as they are at present. Such an assumption is risky because research done since 1964 has shown that climate continually changed during the period under study (Bernabo, 1981; Campbell and McAndrews, 1991; Cermack, 1971; Edwards and Fritz, 1987; Gajewski, 1987). However, although climate has changed, there is no indication that it was ever any warmer than today during the period under study. Therefore the modern climate can be used for modelling the *maximum* extent of prehistoric horticultural settlements.

Demeritt's (1989) study in Maine suggests that variability in the length of the frost-free season may have limited maize to where it could be *predictably* grown, thereby limiting settlement to areas where maize crops were *reliable.* The most important weather condition for farmers is predictability (Thompson, 1975; National Research Council, 1976). Crops are selected, planted, tilled, irrigated, picked, and stored based on anticipated conditions. Short term and long term climatic variability can result in catastrophic harvest failures. Prehistoric farmers, with their heavy dependence on a single crop and poorer storage technology, would have been even more dependant on climatic predictability than their modern counterparts.

Given the importance of predictability, the predictability of the number of frost-free days may have been as important as the actual mean number of frost-free days (Demeritt, 1989). The ten per cent probability of frost-free days (the minimum number of frost-free days that can be expected nine years out of ten) is perhaps the best measure of predictability at a time scale appropriate to slash-and-burn farmers. The mean number of frost-free days is a measure of the suitability of a site for horticulture in an average year, or five years out of ten. This means a fifty per cent chance of crop failure in any given year for sites where the mean number of frost-free days is equal to the minimum requirement of the crop. The ten per cent probability of frost-free days, on the other hand, focuses attention on locations which have only one chance in ten of crop failure due to frost in any given year, and therefore will be suitable nine years out of ten. Therefore, the ten per cent probability of frost-free days will be used here; for simplicity, it will be referred to simply as frost-free days.

Moisture-retentive loams are considered by most modern authorities to be preferable, an observation which applies mainly to the American Corn Belt, where drought is a major problem. In Southern Ontario, where drought is less frequent, we may expect a lesser dependence on moisture-retentive soils. Furthermore, Stoskopf (1985:118) notes that dry soils have less temperature inertia, allowing faster warming of the soil in spring, thus prolonging the early growing season in short frost-free season areas. Heidenreich's (1971) analyses of soils in historic Huronia, Stevens' (1974) work in the historic Neutral area, and Konrad's (1973) and Burgar's (1990) work on terminal Iroquoian sites in the Toronto area, show that there was a preference for sites with gentle to rolling topography, sandy loams and good drainage. Fecteau (1985:26) noted that maize can grow on a large variety of soil textures, but prefers well-drained fertile loams.

Although proximity to water may have been important to exact site location (Burgar, 1990), at the regional scale being considered, water is assumed not to have been a limiting factor since any 10 X 10 km square (the resolution of this study; see below) in Southern Ontario contains a lake or stream.

The Model

While an experiment seeks to clarify the dynamics of a system in which only a few selected variables are used and all other factors are somehow controlled (at least theoretically), a model simplifies reality by ignoring factors presumed to be of minor importance, with no attempt at controlling them. Models are most useful in investigating complex systems with a few variables of major importance, and many, perhaps an unknown number, of minor variables which cannot be controlled. By making theory or observation driven selections of input variables and their relationship with the output variables, a simulation model provides a simple system in which the relationships between variables can be explored in ways that are often impractical or impossible in real systems.

Heidenreich (1971) analysed selected conditions for 139 archaeological sites in Huronia, and noted that in the 17th century the Huron showed a marked preference for a certain soil texture, drainage, and relief. He calculated a location quotient (LQ) for soil texture classes, such as sandy loam, in order to estimate Huron soil texture preferences. The LQ compares the frequency of village sites linked with a particular phenomenon to the frequency of that phenomenon within the study area. For example, in order to estimate the relationship between village sites and sandy loam, the following LQ formula was used:

LQ for % of sites on sandy loam sandy loam
% of study area with sandy loam

A LQ over 1.0 indicates a definite preference for a phenomenon; that is, more people chose that phenomenon than one would have expected had the sites been selected randomly. LQs were calculated for soil texture, drainage (Heidenreich, 1971) and relief (Heidenreich, pers. comm., 1991). Similar approaches were used by Konrad (1973) in Metropolitan Toronto and Stevens (1974) in Neutralia.

By modelling the distribution of probabilities of site occurrences in Southern Ontario using LQs developed from the literature, the predictive values of the LQs can be tested. This is necessary because the LQs were originally developed from only small portions of particularly densely occupied and intensively surveyed regions of the province and not from the area as a whole. By testing the simulated probabilities against the real distributions it is possible to evaluate the degree to which these preferences are common to the whole study area.

A second advantage of simulation is the possibility of predicting as yet unknown site clusters. If we simply calculate new LQs based on the larger area we will have done no more than describe the locations of known sites. However, by extending the LQs of densely surveyed regions to poorly surveyed regions, areas for future surveying may be suggested. In this way the model becomes predictive rather than merely descriptive.

Quantification of Variables

As mentioned above, Heidenreich (1971), Konrad (1973) and Stevens (1974) calculated LQs for different areas in Southern Ontario (Table 1)

Heidenreich's (1971; pers. comm., 1991) LQs for soil texture, drainage and relief in Huronia show a clear preference for village location on lighter textured, well drained soils with rolling to moderately steep relief. Konrad's 1973 study of terminal Woodland sites in the Toronto area also calculated LQs for the same edaphic conditions considered by Heidenreich. Konrad also found clear preference for village location on lighter textured, well drained soils with rolling to moderately steep relief. The same overall tendencies in LQs suggests that even in different geographic areas people made settlement choice: based on similar criteria.

Table 1. Location quotients for this study.

Soil Texture	**Heidenreich**	**Konrad**	**Stevens**	**Rating**	**Weighting**
Gravel	0.75	0	0	P	0.25
Sand and Loamy sand	0.69	0.77	0	F	0.75
Sandy Loam	1.49	3.03	0.5	VG	2.6
Loam and Silt Loam	0.46	1.3	1.8	G	1.25
Clay and Clay Loam	0.27	0.84	0.1	P	0.25
Drainage					
Good	1.19	3.77	1.6	VG	2.6
Fair	0.72	0.19	0.1	P	0.25
Poor	0	0	0	VP	0.05
Relief					
Level	0	0	-	VP	0.05
Gentle	0.77	0.41	-	F	0.75
Rolling	1.67	**2.84**	**-**	VG	2.6
Moderately Steep	1.48	2.81	-	VG	2.6
Steep	0	0	-	VP	0.05
Frost-Free-Days					
>90	-	-	-	VP	0.05
91-100	-	-	-	P	0.25
101-110	-	-	-	F	0.75
111-120	-	-	-	**G**	1.25
121+	-	-	-	VG	2.6

Stevens (1974) calculated LQs for soil texture and drainage for Neutral sites inland from the western end of Lake Ontario. These show a preference for heavier loam and silt loam soil textures, rather than the finer textured sandy loams preferred in Huronia and the Toronto area. In the heart of the American Corn Belt, where rainfall is inadequate and temperatures are warmer than in most of Southern Ontario, silt-loams and silty clay loams are ideal soils for maize due to their water-holding capacity. As climatic conditions in Neutralia are intermediate between conditions in the American Corn Belt and those in Huronia and the Toronto area the selection for heavier textured soils may reflect the somewhat drier climatic conditions.

The LQs of the three studies cannot be simply averaged, since the sample sizes were not equal. Instead weights can be assigned to the various categories based on trends in the LQs of the three studies, combined with theoretical expectations. As an LQ of 1.0 indicates neither attraction nor repulsion, values higher than 1.0 should be reserved for desirable site conditions; the more desirable the site condition the higher the value should be above 1.0. Similarly the less desirable the site condition, the closer the value should be to 0. Although each of the three studies shows several LQs of 0, indicating infinite aversion, there is in theory no infinite aversion but rather merely very strong aversion to the site condition. Accordingly, weightings of 0 will not be used here.

Figure 3 is a histogram of the frequencies with which different LQs occur in each of the three studies. We arbitrarily assigned ranges as follows: 0-0.09 Very Poor, 0.1-0.49 Poor, 0.5-.99 Fair, 1.0-1.49 Good, and 1.5-3.75 Very Good. Each of these categories can be assigned the value of the mid-point of its range. Therefore, Very Poor is rated as 0.05, Poor as 0.25, Fair as 0.75, Good as 1.25, and Very Good as 2.6. This preserves the attraction/aversion symmetry about 1.0, as well as eliminating the theoretically indefensible values of 0. The final column in Table 1 shows the LQs of the three studies and the weightings which will be used in the simulation model.

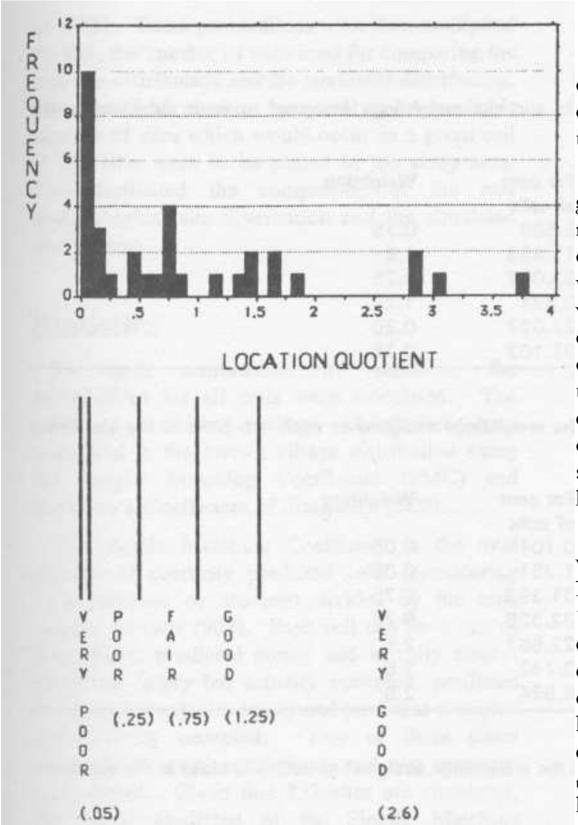

Figure 3. Histogram of location quotient frequencies - see

Frost-free days are harder to assess as they have not been previously studied using LQs. The ethnohistoric literature indicates that maize grew at a lower limit of around 90 days. As discussed earlier frost-free days can be used as a substitute for the ethnographic growing season. Therefore, arbitrarily, less than 90 frost-free days have been assigned a Very Poor (0.05) rating, 91-100 frost-free days a Poor (0.25) rating, 101-110 frost-free days a Fair (0.75) rating, 111-120 frost-free days a Good (1.25) rating and 121 or more frost-free days a Very Good (2.6) rating.

Model Structure

A grid with 962 cells measuring 10.2 by 10.2 km was placed over a basemap of Southern Ontario. This grid allowed the division of the area into manageable units which could be entered into a custom designed hybrid PostScript-Fortran Geographic Information System (G.I.S.) which allowed easier mapping and manipulation of the data.

Tables 2 to 5 list the number of cells and the per cent of cells in which the states of each variable occur, and the weightings that have been assigned to each state in the simulation model.

A single state designation was recorded for each grid square for each variable. Where there was more than one state, in a given cell, the relative coverage of each soil type was assessed, and the values recorded for each variable reflected the whole assemblage occurring in the cell. For example, if good drainage accounted for half of a cell and poor drainage accounted for the other half, the square would be designated as imperfect drainage. If for example a cell contained eighty per cent sandy loam, ten per cent clay and ten per cent sand the cell would have been classed as sandy loam.

The number of ten per cent frost-free days was derived from the Canadian Climate Normals 1951 to 1980 (Environment Canada, 1982). The data were mapped and values for each climatic variable were interpolated for each grid cell where an actual value did not exist. For example, a cell which was coded as having sandy loam soil texture, good drainage, rolling relief and 120 frost-free days would have been coded as 2.6, 2.6, 2.6, and 2.6.

At a given location each variable must exceed some critical value before that site can be considered for prehistoric maize horticulture. For example completely level regions are subject to flooding, even where the soil is well-drained; they also afford poor defense. Heavy soils such as clay were unworkable with prehistoric techniques and would have therefore been wholly unsuitable. Poorly drained sites would have also been unusable, as would sites with too short a frost-free season.

Each variable must have a critical threshold below which a given cell is unlikely to have been used, no matter how good the other variables may be. Furthermore the value of a site which is good for one variable increases rapidly with improvements in the other variables. These observations suggest a multiplicative, rather than additive model.

With an additive model a low value for one variable combined with a top score for a second variable is little different from middling scores for both variables. In a multiplicative model, however,

Table 2. Soil texture conditions in Southern Ontario and the weightings assigned to each sub-class in the simulation model.

Soil texture	Number of cells	Per cent of cells	Weighting
Sand/Very stony sandy loam	53	5.509	0.75
Sandy Loam	168	17.463	2.6
Loam	222	23.077	1.25
Silt loam	56	5.821	1.25
Clay Loam	260	27.027	0.25
Clay	203	21.102	0.25

Table 3. Relief conditions in Southern Ontario and the weightings assigned to each sub-class in the simulation model.

Relief	Number of cells	Per cent of cells	Weighting
Depressional	1	0.104	0.05
Level	13	1.351	0.05
Very-gently-undulating	302	31.393	0.75
Undulating	311	32.328	0.75
Rolling	217	22.557	2.6
Moderately-rolling	36	3.742	2.6
Hilly	82	8.524	2.6

Table 4. Drainage conditions in Southern Ontario and the weightings assigned to each sub-class in the simulation model.

Drainage	Number of cells	Per cent of cells	Weighting
Good	400	41.580	2.6
Imperfect	347	36.071	0.25
Poor	139	14.449	0.05
Very Poor	76	7.900	0.05

Table 5. Frost-free day conditions in Southern Ontario and the weightings assigned to each sub-class in the simulation model.

Frost Free Days	Number of cells	Per cent of cells	Weighting
0-90	92	9.56	0.05
91-100	132	13.72	0.25
101-110	249	25.88	0.75
111-120	228	23.7	1.25
121+	261	27.13	2.6

a low value for any variable lowers the overall weighting of that site no matter how well the other variables rate; two middling scores, on the hand, will produce a middling result. The model therefore used a multiplicative relationship in which the LQs for each variable being used in the given simulation in a given cell are multiplied together, for example: 2.6 x 2.6 x 2.6 x 2.6 = 45.7 (for the case where all four variables are used).

The values obtained in this manner for each cell were summed across all cells and the value for each cell was divided by the total. This yielded values greater than 0 but less than 1 in each cell, for example 0.0021, with a sum across all the cells of 1. These values correspond to the probability of a given site being placed in a given cell; ie, if a single site is to be placed in the study area, there is a 0.21% chance of it falling in a cell with a value of .0021. These probabilities were then multiplied by 333, the number of sites used for comparing the real site distribution and the simulated distribution. Thus the final number for a cell is the probable number of sites which would occur in a given cell if 333 sites were to be placed in the study area. This facilitated the comparison of the real archaeological site distribution and the simulated distribution.

Statistics

For each combination of variables, the probabilities for all cells were calculated. The resulting simulated village distribution was compared to the known village distribution using the Simple Matching Coefficient (SMC) and Sorensen's Coefficient of Similarity (SCS).

The Simple Matching Coefficient is the total number of correctly predicted cells (considering only presence or absence) divided by the total number of cells (962). Each cell can have one of four states: predicted empty and actually empty, predicted empty but actually occupied, predicted occupied but actually empty and predicted occupied and actually occupied. Two of these states represent 'correct' predictions, and two represent mismatches. Given that 333 sites are simulated, the result predicted of the Simple Matching Coefficient under completely random real and simulated site placement with no more than one site allowed in each cell is 0.55. Values greater than 0.55 indicate better than random matches, while values under 0.55 indicate worse than random matches. The maximum value for the Simple Matching Coefficient is 1.0 (perfect agreement in all cells), and the minimum value is 0.30 (since the total number of simulated and real sites together does not equal the number of cells, 30.146 per cent of the cells must remain unoccupied both in the simulation and in reality).

Sorensen's Coefficient of Similarity is a commonly used variant of the Simple Matching Coefficient (Legendre and Legendre, 1983). Sorenson's Coefficient of Similarity is equal to:

$$\frac{2a}{a+b+c}$$

where a=the number of correctly predicted occupied cells, b=the number of cells incorrectly predicted to be occupied, and c =the number of cells incorrectly predicted to be unoccupied.

This formula ignores those cells which are correctly predicted to be unoccupied. This follows the principle common in ecology that the absence of a species in a site may be due to inadequate survey of that site, and thus is uninformative; but its presence is highly informative (Legendre and Legendre, 1983). The lowest value this index can take is 0, and its maximum is 1. The value taken by this coefficient can be interpreted as the percentage of sites occupied either in reality or in the simulation which are occupied in both. Since the simulated placement of a site in a cell which is in reality unoccupied makes that site unavailable for placement in another cell (which may be in reality occupied), each mistakenly placed site counts as two incorrect placements - this is partially balanced by the doubling of the weight of the correctly occupied cells (2a in the formula).

Both these statistics compare the simulated maps with the real map at a cell-by-cell level. This means that the simulated placement of a site in a cell unoccupied in reality but adjacent to another cell which is occupied in reality is counted as incorrect. Here, however, the broad geographical scale used makes it likely that a large number of such 'near misses' will occur; many cells which contain small patches of good soil and climatic conditions will have been coded as having poor soil or climatic conditions, if that is what predominates in the cell. Similarly, many predominantly good cells will have patches of poor soil or climatic conditions. These coding simplifications will lead to a smoothing of the distributions of soil and climatic factors, which will in turn lead to a loss of resolution in the simulation.

Where a small patch of good conditions occurs on the boundary of two cells, there is a strong chance that only one of the two cells will be coded to reflect this good patch, since the coding reflects the predominant conditions of the cells. This is similar to the loss of resolution experienced when converting an image to large squares of uniform colour, as is frequently done to protect the identities of television interviewees who wish to remain anonymous. Although the overall pattern still resembles a human face, all features are somewhat distorted, with widening of some shadows and narrowing of others to fill full squares. Thus, although the simulator is working with 10.2 X 10.2 km cells, the effective resolution is probably somewhat less than this - resulting in a large number of near misses. Since this study is interested in the broad pattern rather than the local detail, such near misses need not be considered entirely wrong. For this reason, a visual comparison of each simulated map with the real map may be more useful than the cell-by-cell comparisons provided by the statistics.

Table 6. Summary of results of simulation.

Variables or Combination of Variables	SMC	SCS
Soil Texture	.770	.340
Drainage	.609	.326
Relief	.606	.231
10% FFD	.656	.210
Soil texture and drainage	.698	.349
Soil texture and relief	.701	.226
Soil texture and 10% FFD	.765	.331
Drainage and relief	.624	.230
Drainage and 10% FFD	.723	.367
Relief and 10% FFD	.789	.185
Soil texture, drainage and relief	.657	.301
Soil texture, drainage and 10% FFD	.758	.355
Soil texture, relief and 10% FFD	.727	.341
Drainage, relief and 10% FFD	.720	.275
Soil texture, drainage, relief and 10% FFD	.755	.337

Results

There are fifteen possible combinations of the variables: soil texture, drainage, relief and frost-free days. Every combination of variables has been simulated using the method presented in the preceeding section. Table 6 is a summary of the Simple Matching Coefficient (SMC) and Sorensen's Coefficient of Similarity (SCS) for all the combinations of variables.

Using Sorensen's Coefficient of Similarity the best simulation is that using drainage and frost-free days (0.367). This simulation (Figure 4) fails to place sites in far southwestern Ontario, along the north shore of Lake Erie, around the west end of Lake Ontario, to the west of Lake Simcoe and along the St. Lawrence. It also incorrectly predicts sites in far eastern Ontario, in the Kawarthas, north of Toronto, on the south shore of Georgian Bay and in the Kitchener-Guelph area. Despite the large number of incorrect placements, the overall pattern is very similar to that on the real site map.

The next highest Sorensen's Coefficient of Similarity is for the simulation involving soil texture, drainage, and frost-free days (0.355). The Simple Matching Coefficient in this simulation (Figure 5) is also among the highest (0.758). Compared to the simulation with drainage and ten per cent frost-free days, this one shows fewer cells incorrectly predicted to have sites along the south shore of Georgian Bay and northwest of Kingston.

The third highest Sorensen's Coefficient of Similarity is for the simulation involving soil texture and drainage (0.349) (Figure 6). The Simple Matching Coefficient is among the lowest (0.698). The low Simple Matching Coefficient reflects the large number of cells in the Dundalk Uplands area which are incorrectly predicted to have sites.

The fourth highest Sorensen's Coefficient of Similarity is for the simulation involving soil texture, relief and frost-free days (0.341) (Figure 7). The Simple Matching Coefficient =0.727. This simulation over-predicts sites along the north shore of Lake Erie, in the Kawarthas and between Lake Huron and Lake Ontario. It under-predicts sites in Huronia and north of Hamilton.

The fifth highest Sorensen's Coefficient of Similarity is for the simulation involving soil texture (0.340) (Figure 8). The Simple Matching Coefficient =0.770. This is the best of the single variable simulations. It over-predicts sites along the north shore of Lake Erie, the east shore of Lake Huron, between Georgian Bay and Lake Ontario and in eastern Ontario. It under-predicts sites around London, around the east end of Lake Ontario and sporadically from Huronia to Kingston.

The sixth highest Sorensen's Coefficient of Similarity is for the simulation involving soil texture, drainage, relief and frost-free days (0.337) (Figure 9). The Simple Matching Coefficient =0.755. This simulation under-predicts sites along the north shore of Lake Erie, north of Hamilton and sporadically from Huronia to Kingston. It over-predicts sites around the periphery of the Dundalk Uplands, north of Lake Ontario and in far eastern Ontario.

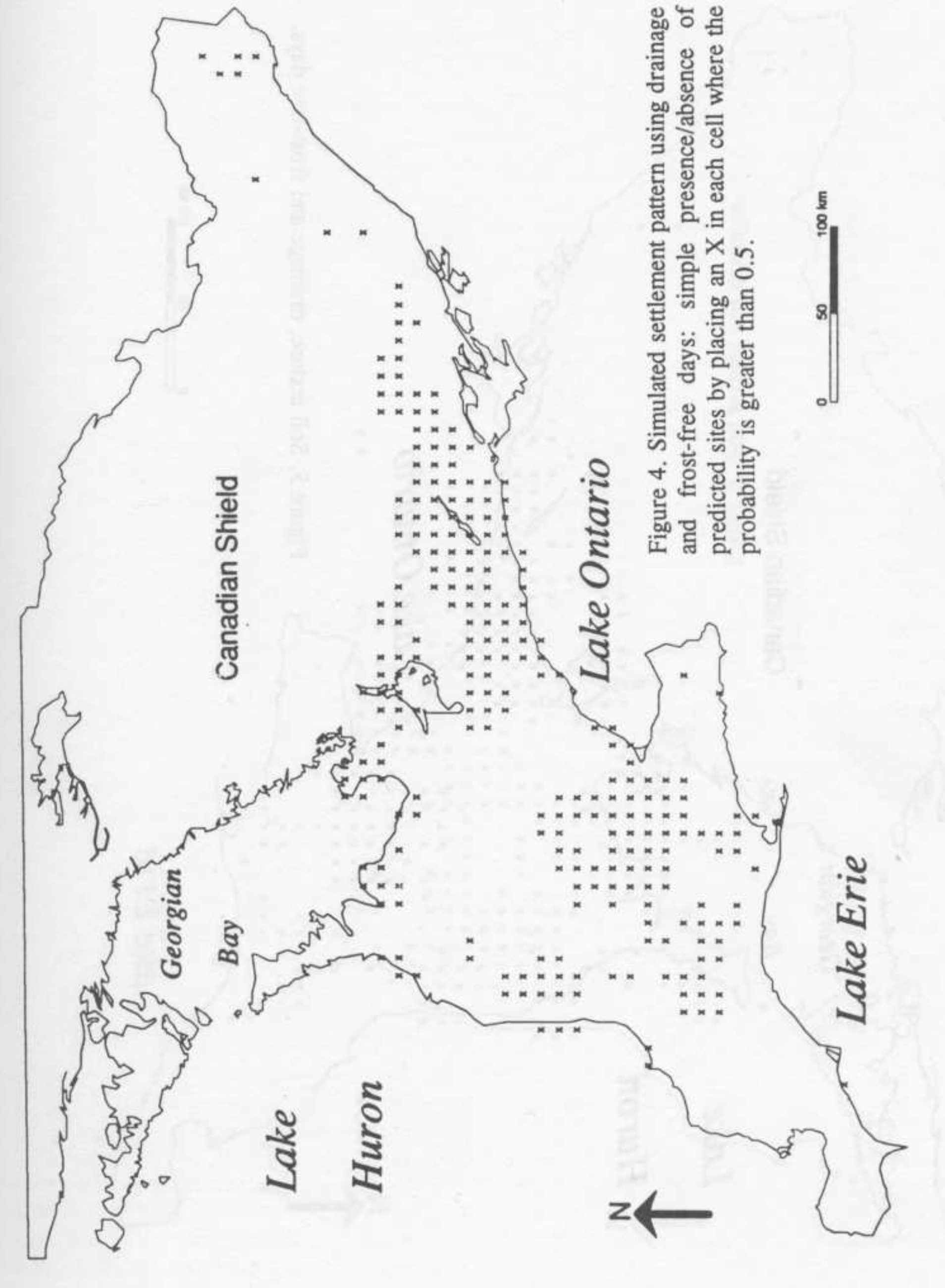

Figure 4. Simulated settlement pattern using drainage and frost-free days: simple presence/absence of predicted sites by placing an X in each cell where the probability is greater than 0.5.

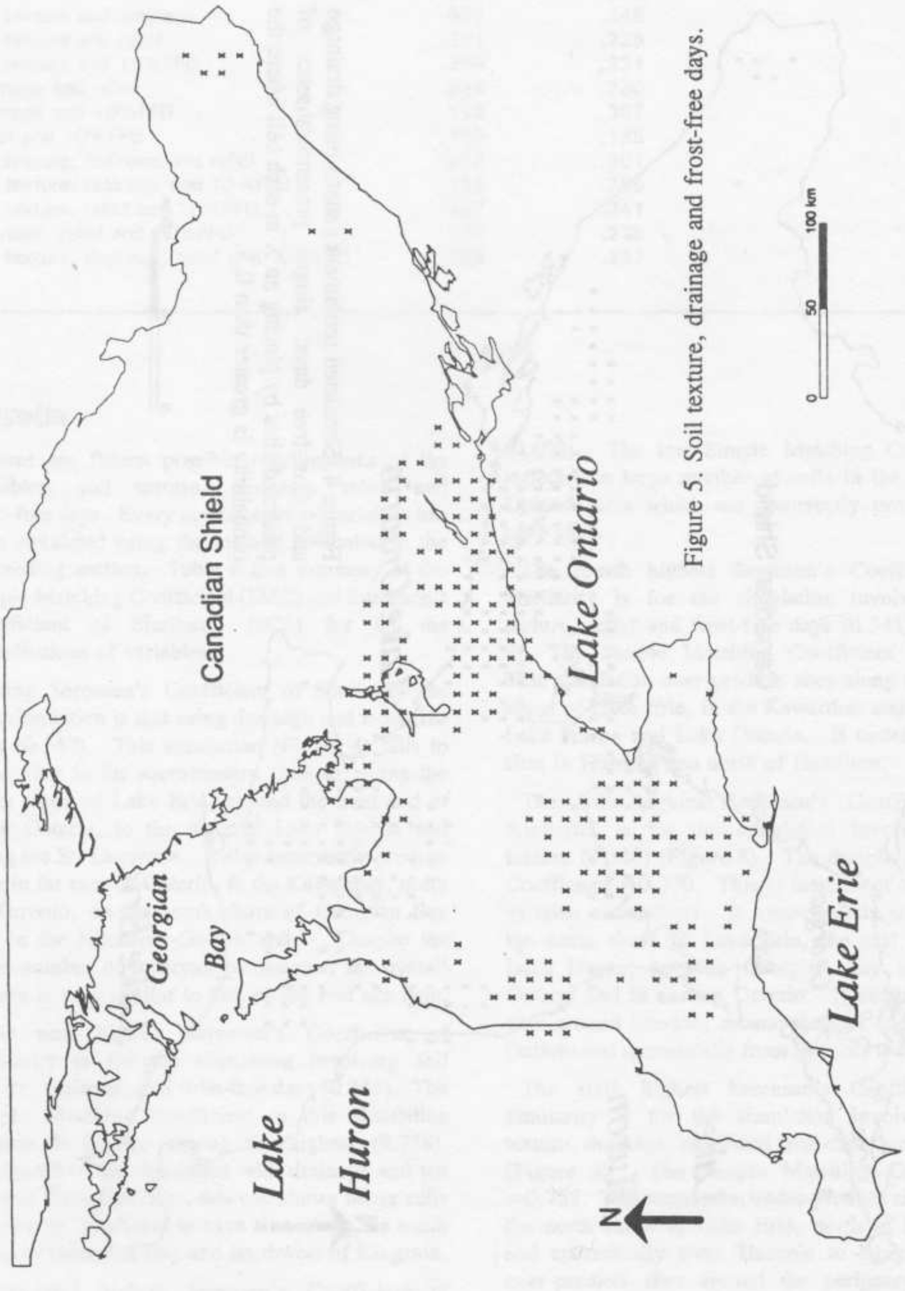

Figure 5. Soil texture, drainage and frost-free days.

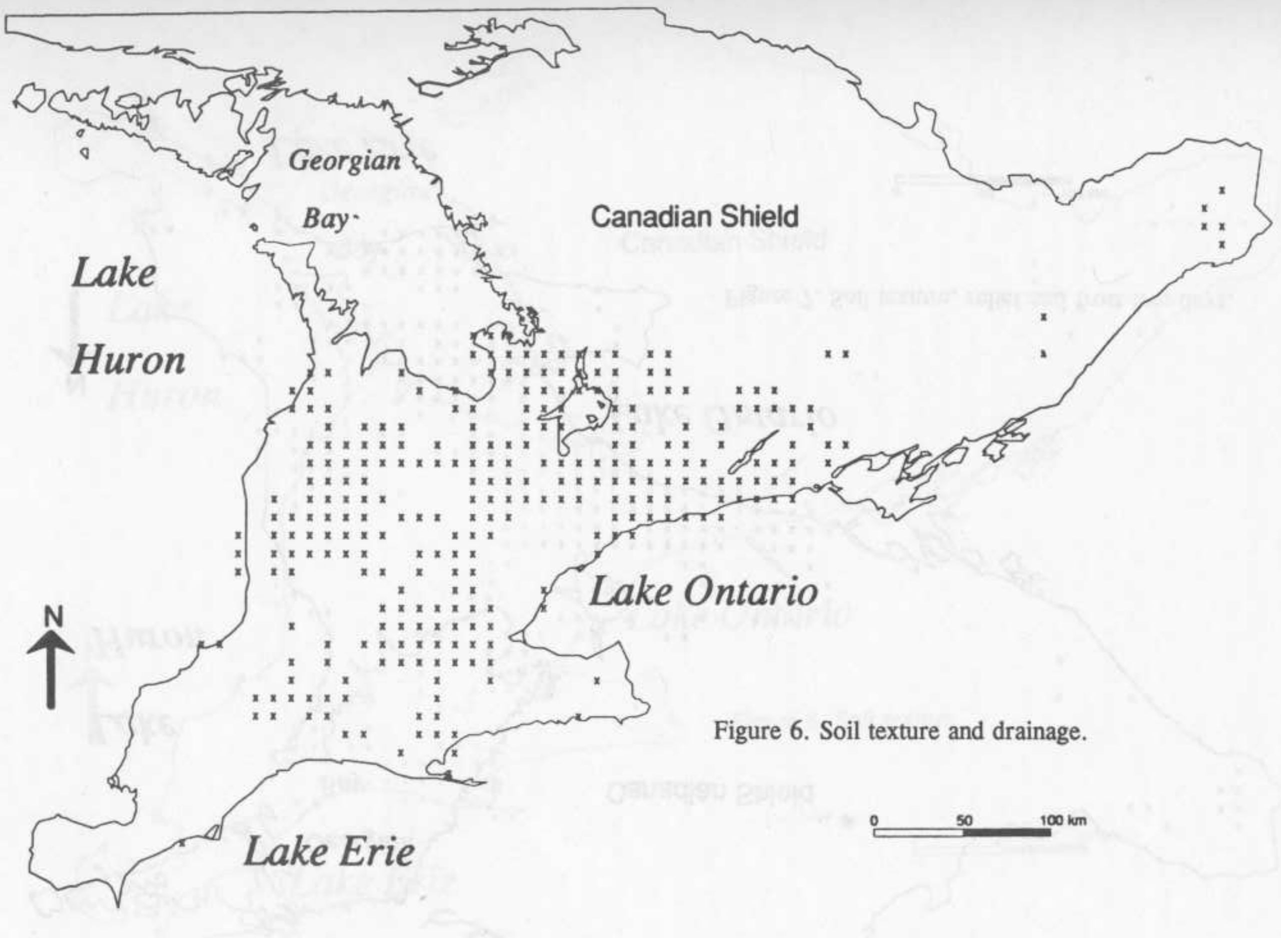

Figure 6. Soil texture and drainage.

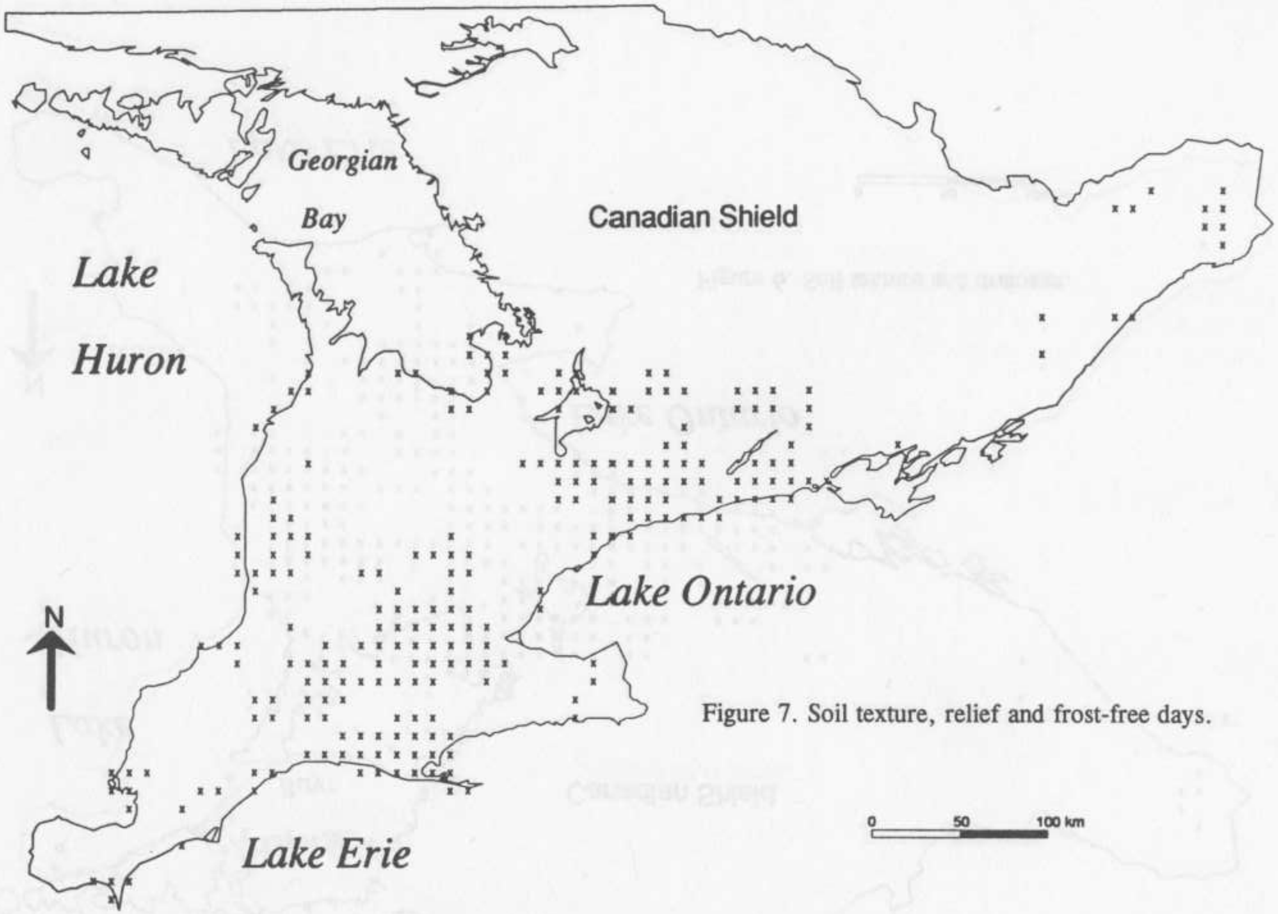

Figure 7. Soil texture, relief and frost-free days.

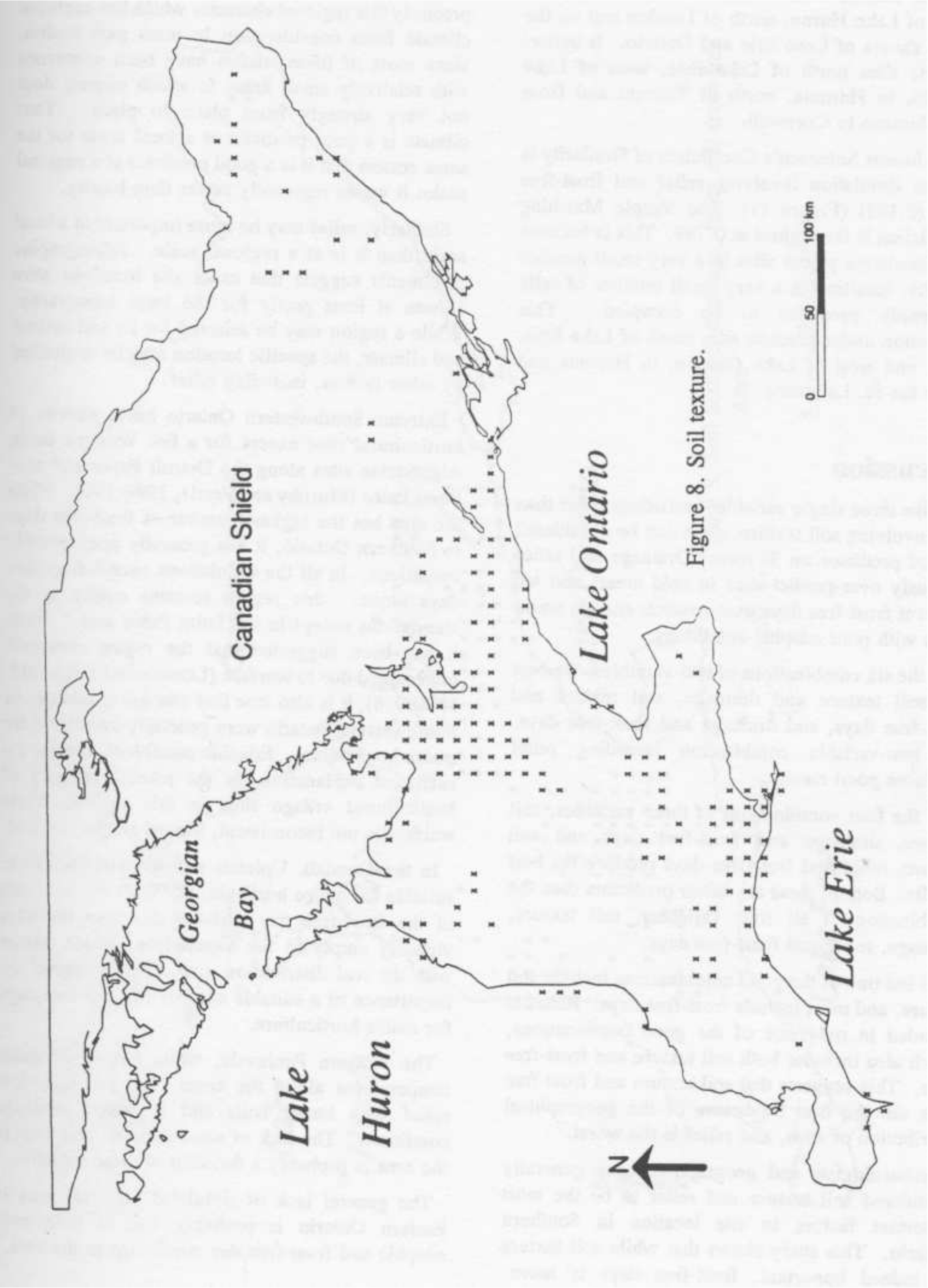

Figure 8. Soil texture.

The second lowest Sorensen's Coefficient of Similarity is for the simulation involving frost-free days (0.210) (Figure 10). The Simple Matching Coefficient =0.656. This simulation strongly over-predicts sites in southwestern Ontario, on the east shore of Lake Huron, north of London and on the North shores of Lake Erie and Ontario. It under-predicts sites north of Lake Erie, west of Lake Ontario, in Huronia, north of Toronto and from Lake Simcoe to Cornwall.

The lowest Sorensen's Coefficient of Similarity is for the simulation involving relief and frost-free days (0.185) (Figure 11). The Simple Matching Coefficient is the highest at 0.789. This is because this simulation places sites in a very small number of cells, resulting in a very small number of cells incorrectly predicted to be occupied. This simulation under-predicts sites north of Lake Erie, north and west of Lake Ontario, in Huronia and along the St. Lawrence.

Discussion

Of the three single variable simulations other than that involving soil texture, none can be considered a good predictor on its own. Drainage and relief seriously over-predict sites in cold areas, and ten per cent frost-free days over-predicts sites in warm areas with poor edaphic conditions.

Of the six combinations of two variables, the best are soil texture and drainage, soil texture and frost-free days, and drainage and frost-free days. No two-variable combination including relief produces good results.

Of the four combinations of three variables, soil texture, drainage and frost-free days and soil texture, relief and frost-free days produce the best results. Both of these are better predictors than the combination of all four variables, soil texture, drainage, relief and frost-free days.

All but one of the good combinations include soil texture, and most include frost-free days. Relief is included in only one of the good combinations, which also includes both soil texture and frost-free days. This suggests that soil texture and frost-free days are the best predictors of the geographical distribution of sites, and relief is the worst.

Archaeologists and geographers have generally considered soil texture and relief to be the most important factors in site location in Southern Ontario. This study shows that while soil texture is indeed important, frost-free days is more important than relief for explaining the larger settlement pattern of Southern Ontario. This climatic variable derives its importance from both the marginality of Southern Ontario for maize and from the regional character of climate. It is precisely this regional character which has excluded climate from consideration in most past studies, since most of these studies have been concerned with relatively small areas in which climate does not vary strongly from place to place. Thus climate is a poor predictor at a local scale for the same reason that it is a good predictor at a regional scale: it varies regionally rather than locally.

Similarly, relief may be more important at a local scale than it is at a regional scale. Ethnographic documents suggest that exact site locations were chosen at least partly for the local topography. While a region may be selected for its soil texture and climate, the specific location may be controlled by other factors, including relief.

Extreme Southwestern Ontario has a paucity of horticultural sites except for a few Western Basin Algonquian sites along the Detroit River and near Point Pelee (Murphy and Ferris, 1990:190). While the area has the highest number of frost-free days in Southern Ontario, it has generally poor edaphic conditions. In all the simulations except frost-free days alone, this region remains empty in the simulations except in the Point Pelee area. While it has been suggested that the region remained unoccupied due to warfare (Lennox and Fitzgerald, 1990:438), it is also true that edaphic conditions in Southwestern Ontario were generally unsuitable for maize horticulture. Edaphic conditions alone are a sufficient explanation for the relative scarcity of horticultural village sites in this region. While warfare is not inconsistent, it need not be invoked.

In the Dundalk Uplands edaphic conditions are suitable for maize horticulture. With the inclusion of the frost-free day variable this area becomes virtually empty in the simulations, which agrees with the real distribution map. This suggests the importance of a suitable number of frost-free days for maize horticulture.

The Niagara Peninsula, while having adequate temperatures along the coast, has generally low relief with heavy soils and imperfect drainage conditions. The lack of simulated and real sites in the area is probably a function of these variables.

The general lack of simulated and real sites in Eastern Ontario is probably due to both poor edaphic and frost-free day conditions in the area.

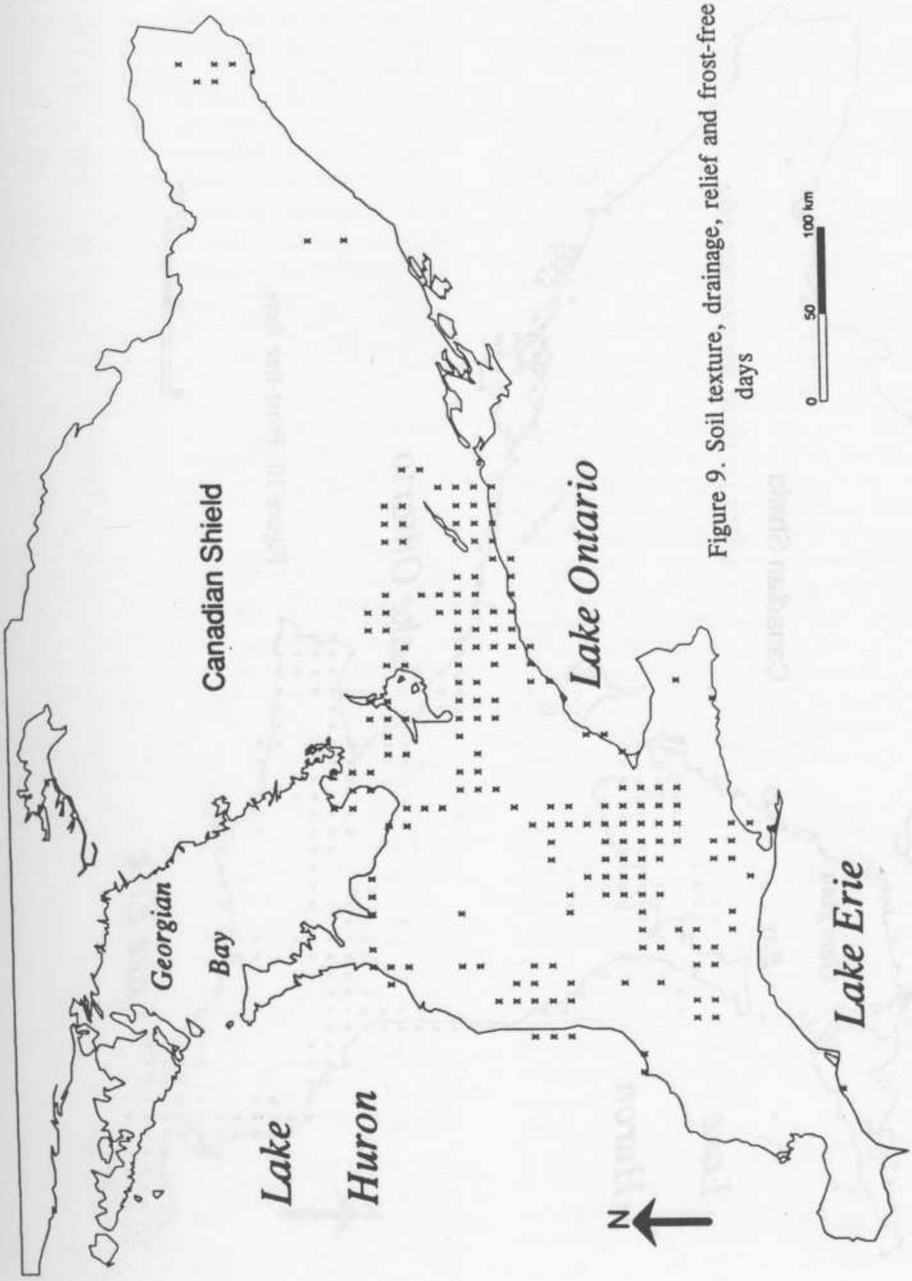

Figure 9. Soil texture, drainage, relief and frost-free days

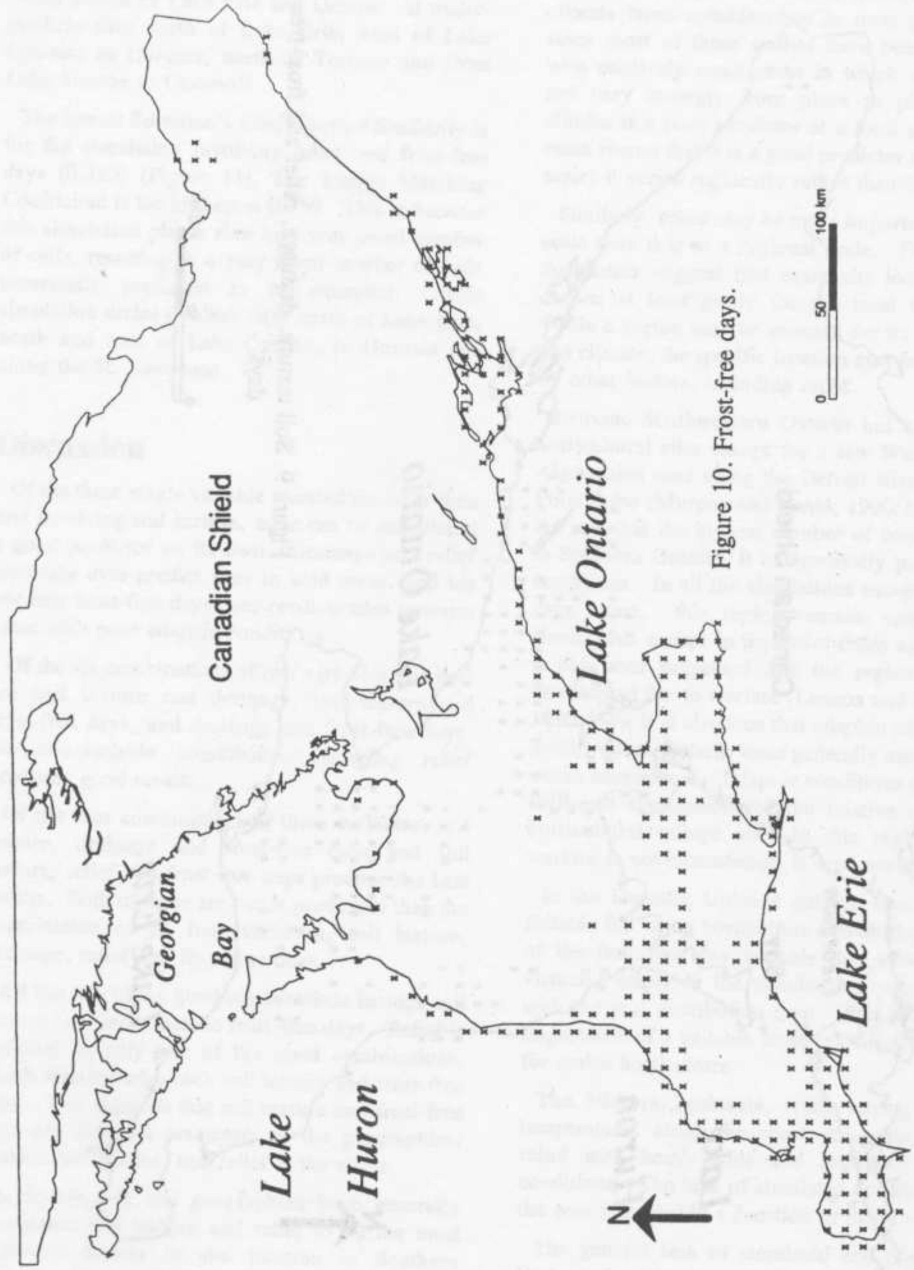

Figure 10. Frost-free days.

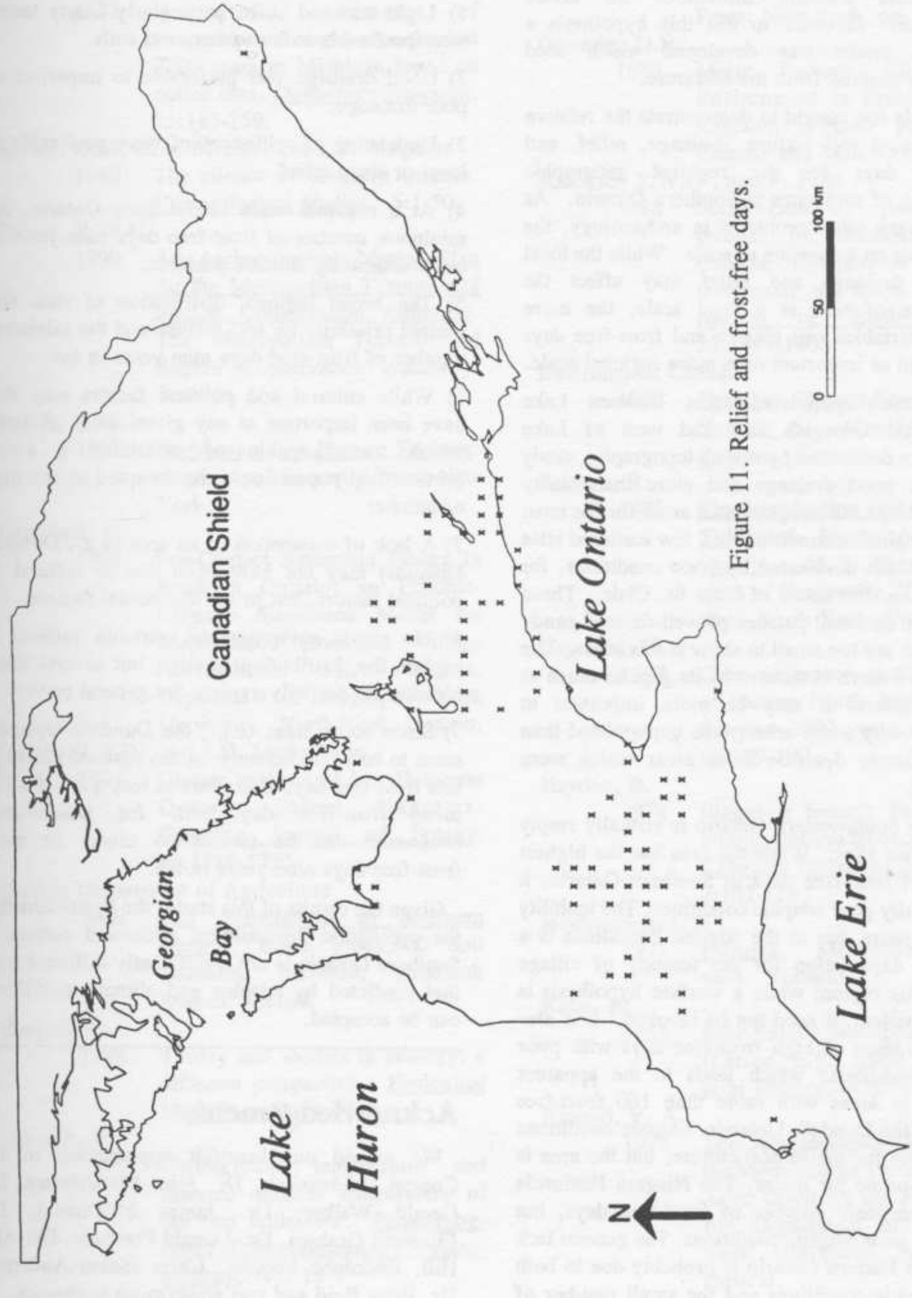

Figure 11. Relief and frost-free days.

Conclusions

The aim of this research was to test the hypothesis that the prehistoric horticultural village settlement pattern in Southern Ontario is not significantly different from that predicted by the edaphic and climatic limitations on maize horticulture. In order to test this hypothesis a simulation model was developed which used weightings derived from the literature.

This study has sought to demonstrate the relative importance of soil texture, drainage, relief, and frost-free days for the regional geographic distribution of such sites in Southern Ontario. As with so many other problems in archaeology, the matter turns on a question of scale. While the local variables drainage and relief may affect the distribution of sites at a local scale, the more regional variables soil texture and frost-free days can be seen as important on a more regional scale.

The densely populated areas between Lake Simcoe and Georgian Bay and west of Lake Ontario are dominated by rolling topography, sandy soils with good drainage and more than ninety frost-free days. Other populated areas for the most part enjoy similar conditions. A few scattered sites occur in areas dominated by poor conditions, for example the sites south of Lake St. Clair. These sites occur on small patches of well-drained sandy soils which are too small to show at this scale. The settlement pattern is defined by its gaps as much as by its clusters; it may be more important to determine why some areas were unpopulated than it is to simply describe those areas which were populated.

Extreme Southwestern Ontario is virtually empty of Iroquoian sites. While the area has the highest number of frost-free days in Southern Ontario, it has generally poor edaphic conditions. The inability to grow maize due to the edaphic conditions is a sufficient explanation for the scarcity of village sites in this region; while a warfare hypothesis is not inconsistent, it need not be invoked. It is also the coincidence of high frost-free days with poor edaphic conditions which leads to the apparent aversion to areas with more than 160 frost-free days. In the Dundalk Uplands, edaphic conditions are suitable for maize horticulture, but the area is too frost-prone for maize. The Niagara Peninsula has an adequate number of frost-free days, but generally poor edaphic conditions. The general lack of sites in Eastern Ontario is probably due to both poor edaphic conditions and the small number of frost-free days in the area. It is worth noting that all of the unoccupied areas suffer from one or more of these defects. This suggests that each region which was suited to maize horticulture was occupied at some time in the last thousand years. These observations lead to the following conclusions:

1) Light textured soils, particularly sandy loam, were preferable to heavy textured soils.

2) Good drainage was preferable to imperfect or poor drainage.

3) Undulating to rolling relief were preferable to level or steep relief.

4) At a regional scale in Southern Ontario, the minimum number of frost-free days nine years in ten is a limiting climatic variable.

5) The broad regional distribution of sites was limited primarily by soil texture and the minimum number of frost-free days nine years in ten.

6) While cultural and political factors may also have been important at any given time, all areas which were capable of sustaining a maize horticultural population were occupied at one time or another.

7) A lack of occupation in an area (e.g., Dundalk Uplands) may not have been due to cultural or political factors, but to environmental factors.

8) No single environmental variable suffices to explain the distribution of sites, but several taken together do partially explain the general pattern.

9) Since some areas (e.g., the Dundalk Uplands) seem to be excluded only on the basis of ninety or less frost-free days nine years in ten; Yarnell's 120 mean frost-free day limit for maize-based economies can be revised to ninety or more frost-free days nine years in ten.

Given the results of this study, the hypothesis that the prehistoric horticultural settlement pattern in Southern Ontario is not significantly different from that predicted by edaphic and climatic conditions can be accepted.

Acknowledgements

We extend our heartfelt appreciation to Dr. Conrad Heidenreich, Dr. John McAndrews, Dr. Gerald Walker, Dr. James McDonald, Dr. Elizabeth Graham, Dr. Donald Freeman, Dr. Alan Hill, Rodolphe Fecteau, Chris Junker-Anderson, Dr. Peter Reid and two anonymous reviewers.

References cited

Bennett, M.K.
1955 The food economy of the New England Indians. Journal of Political Economy, 63:369-397.

Bernabo, J.C.
1981 Quantitative estimates of temperature changes over the last 2700 years in Michigan based on pollen data. Quaternary Research, 15:143-159.

Brown, D.M, G.A. McKay, and L.J. Chapman
1980 The climate of Southern Ontario. Climatological Studies, 5:1-50.

Burgar, R.W.C.
1990 An Archaeological Master Plan for the Metropolitan Toronto and Region Conservation Authority. The Metropolitan Toronto and Region Conservation Authority: Toronto.

Butzer, K.W.
1987 Archaeology as Human Ecology. Cambridge University Press: New York.

Campbell, C.
1991 Pre-Contact Settlement Pattern in Southern Ontario: an Edaphic-Climatic Simulation Model for Maize-Based Iroquoian Village Horticulture. M.A. Thesis, Department of Geography, York University. North York, Ontario.

Campbell, I.D., and J.H. McAndrews
1991 Cluster analysis of late Holocene Ontario pollen diagrams. Canadian Journal of Botany, 69:1719-1730.

Canada Department of Agriculture
1960 Soil Associations of Southern Ontario, Scale 1:663,600 Soil Research Institute, Research Branch: Ottawa.

Caswell, H.
1988 Theory and models in ecology: a different perspective. Ecological Modeling, 43:33-44.

Cermak, V.
1971 Underground temperature and inferred climatic temperature of the past millenium. Palaeogeography, Palaeoclimatology, Palaeoecology, 10:1-19.

Cook, E.R.
1982 A long term drought sequence for the Hudson Valley, New York. In: Climate From Tree Rings. M.K. Hughs, P.M. Kelly, J.R. Pilcher and V.C. Jr. LaMarche (eds.). Cambridge University Press: New York, pp. 163-165

Demeritt, D.B.
1989 Maize Culture, Climate, and Environment in Prehistoric New England. Paper presented at Climate and Man, Ottawa.

Edwards, T.W.D., and P. Fritz
1988 Stable-isotope palaeoclimate records for Southern Ontario, Canada: Comparison of results from marl and wood. Canadian Journal of Earth Sciences, 25:1397-1406.

Environment Canada
1982 Canadian Climate Normals: Frost, Volume 6. Canadian Climate Program: Toronto.

Fecteau, R.
1985 The Introduction and Diffusion of Cultivated Plants in Southern Ontario. M.A. Thesis, Department of Geography, York University. North York, Ontario.

Gajewski, K.
1987 Climatic impacts on the vegetation of Eastern North America during the past 2000 years. Vegetatio, 68:179-190.

Hayden, B.
1978 Bigger is better?: Factors determining Ontario Iroquois site sizes. Canadian Journal of Archaeology, 2:107-116

Heidenreich, C.E.
1971 Huronia. McClelland and Ste-wart. Toronto.

Kalm, P.
1935 Pehr Kalm's description of maize. (Larsen, E.L., transl.). Agricultural History, 9(2):98-117.

Konrad, V. A.
1973 The Archaeological Resources of the Metropolitan Toronto Planning Area: Inventory and Prospect. On file Department of Geography, York University, North York, Ontario.

Lafitau, Father J. F.
1724 Cultivation of the fields. In: Customs of the American Indians, Fenton, W.N. and E. Moore (eds.) The Champlain Society: Toronto.

Legendre, L, and P. Legendre.
1983 Numerical Ecology. Elsevier: Amsterdam.

Lennox, P.A., and W.R. Fitzgerald
1990 The culture and archaeology of the Neutral Iroquoians. In Ellis, C.J. and Ferris, N. (eds.) The Archaeology of Southern Ontario to A. D. 1650. Occasional Publication of the London Chapter, OAS Number 5: London, pp. 405-456.

Murphy, C. and N. Ferris
1990 The Late Woodland Western Basin Tradition in Southwestern Ontario. In Ellis, C.J. and Ferris, N. (eds.) The Archaeology of Southern Ontario to A. D. 1650. Occasional Publication of the London Chapter, OAS Number 5: London, pp. 189-278.

National Research Council
1976 Climate and Food: Climatic Fluctuation and U.S. Agricultural Production. National Academy of Sciences: Washington. D.C.

Ramsden, P.G.
1978 Early European trade among some Ontario Iroquois. Canadian Journal of Archaeology, 2:101-106.

Ridley, T.J., and G. Friemuth
1979 Field systems and frost drainage in the prehistoric agriculture of the Upper Great Lakes. American Antiquity, 44:271-285.

Sagard, Fr. G.
1939 The Long Journey to the Country of the Hurons. (G. M. Wrong, ed.; H.H. Langton, trans.), The Champlain Society: Toronto.

Snow, D.R.
1981 Approaches to cultural adaptation in the Northeast. In: Foundation of Northeast Archaeology, D.R. Snow (ed.), Academic Press: New York, pp. 139-173.

Stevens, M.B.
1974 Neutral Village Site Requirements. M.A. Research Paper, Department of Geography, York University: North York, Ontario.

Stoskopf, N.C.
1985 Cereal Grain Crops. Reston Publishing Company: New York.

Sykes, C.M.
1980 Swidden horticulture and Iroquoian settlement. Archaeology of Eastern North America, 8:45-52.

Thomas, P.A.
1976 Contrastive subsistence strategies and land use as factors for understanding indian-white relations in New England. Ethnohistory, 23:1-18.

Thompson, L.M.
1975 Weather variability, climate change, and grain production. Science, 188:535-541.

Ulanowicz, R.E.
1988 On the importance of higher-level models in ecology. Ecological Modelling, 43:45-56.

Wright, J.V.
1966 The Ontario Iroquois Tradition. National Museum of Canada, Bulletin No. 210. Ottawa.

Yarnell. R.A.
1964 Aboriginal Relationships Between Culture and Plant Life in the Upper Great Lakes Region. Museum of Anthropology, University of Michigan: Ann Arbor, Michigan.

Celina Campbell, Department of Geography, York University.
Ian D. Campbell, Department of Geography, McGill University.