

# Assessing the Representativeness of Forest Ecosystem and Growth and Yield Plots in Ontario

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### ABSTRACT

Representativeness is often identified as a criterion for ecological studies and assessments of parks and reserve networks. In this report, an assessment was made of the environmental representativeness of forest plot data from a number of Forest Ecosystem Classification and Growth and Yield surveys in the province of Ontario. The frequency distribution of the survey plots was examined in terms of selected climatic, soils, and topographic gradients. In addition, the distributions of plots were evaluated against Hills' Site Regions and new climatic classifications (or regionalizations) that were generated for the province. Undersurveyed climatic domains were identified, and recommendations were made as to the design and location of future Forest Ecosystem Classification and Growth and Yield survey plots.

### RÉSUMÉ

La représentativité est souvent un critère des études écologiques et de l'évaluation des réseaux de parcs et de réserves. Le présent rapport évalue la représentativité écologique des données compilées dans des parcelles forestières de l'Ontario dans le cadre d'un certain nombre d'études portant sur la classification des écosystèmes forestiers et sur l'accroissement et le rendement. Les auteurs ont examiné la distribution de fréquence des parcelles d'étude en fonction de gradients climatiques, pédologiques et topographiques choisis. Ils ont en outre évalué la distribution des parcelles en comparaison des *Site Regions* de Hills et ont établi de nouvelles classifications climatiques (ou de nouveaux groupements régionaux) pour la province. Ils ont identifié des domaines climatiques mal connus et ont formulé des recommandations sur la conception et l'emplacement des futures parcelles d'étude de la classification des écosystèmes forestiers et de l'accroissement et du rendement.

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# ASSESSING THE REPRESENTATIVENESS OF FOREST ECOSYSTEM AND GROWTH AND YIELD PLOTS IN ONTARIO

## INTRODUCTION

As used in this study, representativeness refers to the assessment of how adequately a plot or a system of plots represents the range of environmental variation in a given region. The term representativeness implies that a subset of a population is taken, such that all or most of the characteristics found in the total population are present (Mackey et al. 1988). If this statement were true of Ontario forest plots, the full range of climatic, topographic, and soil conditions occurring in Ontario forests would be sampled. When new plots are to be established, it is imperative to know what environmental/biological regimes are adequately sampled, undersampled, or absent. In addition, when currently available data are analyzed, it is important that the degree of representativeness be known. If samples are unrepresentative, then the full range of forest types may not have been recognized. Representativeness is also a requirement for the development of statistical correlation models, i.e., where plot data are spatially extended by correlating plant distribution and performance with physical environmental gradients.

A compilation of forest monitoring and research plot data has occurred under the aegis of the Bio-environmental Indices Project (BIP) (Mackey and McKenney 1994). The BIP is a major collaborative initiative of the Canadian Forest Service (CFS), the Ontario Ministry of Natural Resources (OMNR), and several other institutions, including the Canadian Wildlife Service and The Australian National University. Part of the collaboration with the OMNR has involved compiling Forest Ecosystem Classification (FEC) and Growth and Yield (G&Y) plot data, and appending to the data sets estimates of long-term climate for each point of survey.

The BIP has developed spatially based, provincewide climate models for Ontario.<sup>1</sup> These consist of interpolated climate surfaces that provide the capacity to estimate *ex situ*, with an error term, long-term climate for any location in Ontario where latitude, longitude, and elevation are known. In addition, the BIP has created a provincewide digital elevation model (DEM) of the province. DEMs are computer-based representations of topography, and are comprised of the regular grids of latitude, longitude, and elevation that are used in Geographic Information Systems (GIS) for terrain analyses. Using specialized software, these climate surfaces can be coupled to the DEM to

generate gridded estimates of the monthly climate variables. These capabilities provide new opportunities for the climatic analysis of existing and new forest plot data in a spatial framework.

The new climatic model enhances the capacity to derive empirical relations between the distribution, abundance, or performance of plants, and the physical environmental determinants of biological response. Climate provides the first-order inputs that define the thermal, moisture, and radiation regimes at a location. Estimates of long-term mean monthly minimum and maximum temperature, total precipitation, and daily radiation can therefore be used as indices of these primary environmental regimes. Statistical models can then be applied to quantify the probability of occurrence or performance of plant species as a function of climatic parameters (see Mackey and Sims 1991, Mackey 1994).

The purpose of this report is to assess the representativeness of FEC and G&Y plots with respect to derived climate classifications and quantification of the environmental space in Ontario. Environmental space refers to the multidimensional range of environmental conditions that encompass a region. Included in the assessment are regions of Ontario that are forested or could potentially be forested (e.g., areas cleared for agriculture). Based on the results of the representativeness assessment, some recommendations as to the potential location of future plots are given. Due to the ongoing nature of the OMNR's FEC, Ecological Land Classification, and Growth and Yield programs, some recommendations may already have been implemented.

## An Overview of Methods

Various methods were employed to investigate how FEC and G&Y plots are distributed geographically and with respect to topographic and climate features. The plot locations were mapped in a GIS to display their geographical distribution. Occurrences of site attributes, such as topographic position, mode of deposition, Soil Moisture Regime, and Soil Texture Class, were tallied for each FEC survey. Underrepresented "site-types" were identified in each region from this exercise.

Another technique involved plotting estimates of climate generated at each forest plot on two-dimensional

<sup>1</sup> Mackey, B.G.; McKenney, D.W.; Yin-Qian, Y.; McMahon, J.P.; Hutchinson, M.F. Site regions revisited: A climate analysis of Hills' site regions for the province of Ontario using a parametric method. Canadian Journal of Forest Research. (In press.)

histograms of the province's climate. This approach identified survey gaps in terms of particular climate variables.

A PC-based Environmental Domain Interrogation System (EDIS) was developed and used to assess representativeness. With this approach, plot locations were mapped within Hills' Site Regions and newly developed climate classifications of the province. The number of plots in each class (i.e., a Site Region or climate class) were summed and a Plot Proportion Index (PPI) was calculated ( $PPI = \text{percent plots} / \text{percent area of the class}$ ). The PPI is a relative measure of how well a class is sampled by the plots. EDIS will be available in the future on request from the authors. All of these techniques are described further in the report.

## CURRENT DISTRIBUTION AND CHARACTERISTICS OF PLOTS

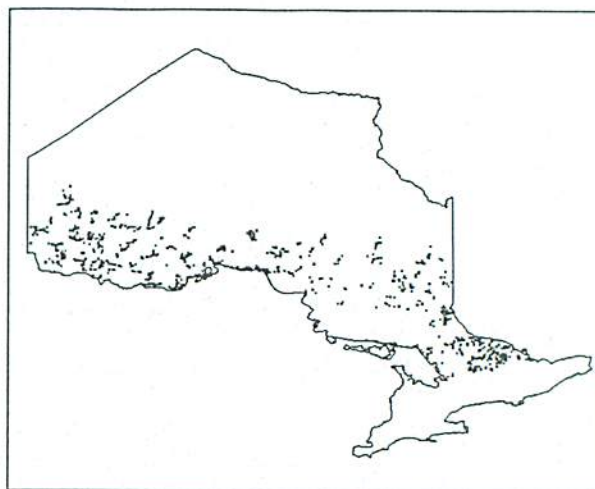
### Forest Plots

Two types of forest plot data were used in this assessment; Forest Ecosystem Classification data and various Growth and Yield data. The FEC survey data were originally established to provide a basis for classifying forest ecosystems. These data have provided useful information for making management decisions regarding wildlife, recreation, and timber harvesting. The FEC system is based on a onetime measurement of a network of mature, natural forest stands over 50 years of age, although some younger and some second-growth forests were also sampled. Numerous site, soil, vegetation, and forestry attributes were measured within 10-m x 10-m plots. A number of FEC-related surveys have been conducted over the last 10 years by both federal and provincial government researchers. In establishing the FEC plot networks, an attempt was made to sample across the entire range of landform features, slope positions, soil textures, and moisture conditions (Sims et al. 1989, Sims and Uhlig 1992), and to ensure that the different surveys used similar methodologies (e.g., a standard plot size). The BIP project has collated over 4 100 FEC plots distributed across the province (3 635 of which had geositional information at time of writing, Table 1 and Fig. 1). Sampling and FEC system development is currently ongoing in the Central, Northwest, and North-east regions.

**Table 1.** FEC data sets.

| Data set                       | Contact                            | Number of plots |
|--------------------------------|------------------------------------|-----------------|
| Northern Region (Claybelt) FEC | P. Uhlig, OFRI *                   | 250             |
| Central Region FEC             | B. Chambers, OMNR                  | 1 144           |
| Northeast Region FEC           | P. Uhlig, OFRI                     | 225             |
| Northwest Region FEC           | Richard Sims, CFS-Sault Ste. Marie | 2 167           |

\* Ontario Forest Research Institute.



**Figure 1.** Distribution of the 3 635 Forest Ecosystem Classification plots across Ontario.

The G&Y data sets compiled for this report differed considerably in their content and purpose. A total of 1 797 historical plots contain data from typical growth and yield studies, as well as thinning, fertilizing, and girdling trials on both natural and planted sites (Table 2 and Fig. 2). Generally, tree mensuration and tree quality data have been recorded for each plot. Some data sets contain information about plot soil attributes and topographic features as well. The plot information collected was usually the minimum necessary to complete the study, and most studies contain repeat measurements over time. However, compared to the FEC data, there is less methodological consistency between surveys.

### Data Sets

Compiling and organizing the data sets in preparation for analysis was difficult, time-consuming, and confounded by a number of tasks, including:

1. Identifying which data sets existed, the custodians of the data, and the data's availability. The project was fortunate in that custodians responded generously to requests for survey data.
2. The condition of the data sets varied considerably. Some data were not stored in a computer format, and some required considerable preprocessing before they could be entered into the database.
3. In order to estimate climate it was critical that the longitude, latitude, and elevation (XYZ) of each plot be known as accurately as possible. If the XYZ coordinates had not been recorded, then the

**Table 2.** Growth and Yield data sets.

| Data set             | Contact                             | Number of plots | Location              | Studies          | Origin                 |
|----------------------|-------------------------------------|-----------------|-----------------------|------------------|------------------------|
| Beckwith Hardwoods   | J. Matuszyck<br>OFRI*               | 209             | Southern Ontario      | Growth, thinning | Natural, cutover       |
| Beckwith Softwoods   | J. Matuszyck<br>OFRI                | 268             | Southern Ontario      | Growth, thinning | Plantation             |
| Kimberly Clark       | J. Matuszyck<br>OFRI                | 119             | Longlac               | Growth and Yield | Natural                |
| Kirkland Lake        | J. Matuszyck<br>OFRI                | 49              | Kirkland Lake         | Growth           | Plantation             |
| OFRI Pine            | J. Matuszyck<br>OFRI                | 31              | Northeastern Ontario  | Growth           | Plantation             |
| OFRI Spruce          | J. Matuszyck<br>OFRI                | 243             | North central Ontario | Growth           | Plantation             |
| Spruce Falls         | D. Smith<br>OFRI                    | 184             | Kapuskasing           | Growth and Yield | Natural, cutover       |
| Gogama TRIM**        | N. Maurer<br>OMNR                   | 31              | Gogama                | Growth and Yield | Natural and plantation |
| von Althen Walnut    | G. Mitchell<br>CFS-Sault Ste. Marie | 10              | Harriston             | Growth, thinning | Plantation             |
| von Althen Hardwoods | G. Mitchell<br>CFS-Sault Ste. Marie | 90              | Southern Ontario      | Growth           | Natural, cutover       |
| American Can         | B. Payandeh<br>CFS-Sault Ste. Marie | 194             | Hillspoint            | Growth and Yield | Natural                |
| Algonquin Polar      | J. Rice<br>OFRI                     | 369             | Algonquin Park        | Logging damage   | Cutover                |

\* Ontario Forest Research Institute.

\*\* Tree Ring Increment Measurement.

accompanying descriptive information was used to locate the plots using the 1:50 000 National Topographic Map Series. Even if the XYZ had been recorded, the coordinates were rechecked using the topographic and plot location maps.

4. A major effort was put into standardizing the coding between surveys. This was less of a problem for the FEC data, although there were some significant differences in the categories of soil, vegetation, and topography. For both FEC and G&Y, a minimum attribute data set of key variables was developed. Most of these were available at all FEC plots, but there were fewer G&Y plots that carried all desired variables (this is not surprising given that the G&Y surveys were conducted by a combination of private and government organizations over a longer period of time).

## METHODS

### Plot Distributions I: Geographic, Topographic, and Soil Attributes

The distributions of FEC and G&Y plots are shown in Figures 1 and 2, respectively. The FEC data are concentrated in a band through the center of the province. Three geographic gaps (that current sampling is filling) are apparent: namely, the north shore of Lake Huron, the far north, and southern Ontario. The absence of plots from the south is due to a lack of natural vegetation cover in the region, and delays in the start-up of a FEC sampling program there. The northern limit to the plots coincides with what is commonly referred to as the northern limit of productive forests, or the "commercial tree line". However, from an ecological perspective this boundary is

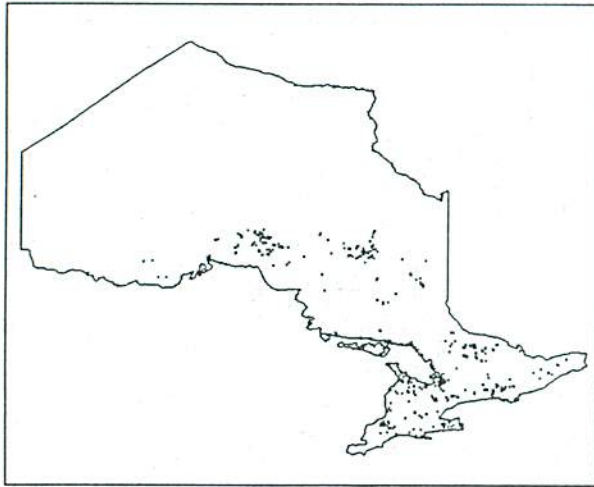


Figure 2. Distribution of the 1 797 Growth and Yield plots across Ontario.

somewhat arbitrary. Analysis of ecological relations of existing FEC data will be hampered by the lack of both northern and southern context. Predictive modeling is enhanced if data samples are available from the extremes of environmental gradients. Consideration should be given to (a) collating and georeferencing historical records and establishing new surveys of southern forests and (b) instigating new ecological surveys in the vegetation communities of the far north.

Figures 3–6 show frequency histograms for topographic position, mode of deposition, Soil Moisture Regime, and Soil Texture Class, respectively. These are key variables in the minimum attribute data sets and were consistently recorded at each FEC plot. Very few G&Y sites had these data recorded and hence histograms are not presented.

The histograms provide a quantification of how the plots were distributed over these four environmental variables. These data alone do not enable a quantitative assessment of their representativeness. Ongoing work within the BIP is aimed at developing the computerized geographic database needed for this analysis, based upon a new digital elevation model of Ontario (*see* Mackey et al. 1994), existing Ontario Land Inventory (OLI) data, and other source data. Analysis of representativeness, based on these data, will be presented in a later report. In order to ensure commonality in nomenclature and descriptions across surveys, it may be necessary, in the future, to group existing classes of both mode of deposition and Soil Moisture Regime.

Figures 3a–e show the results for topographic position. The Northeast Region and the Clay Belt have relatively few sites on upper slope positions, whereas the Central and Northwest regions have a wider spread. While “level”

sites have large sample sizes, the “mid” to “toe” slope positions have relatively few samples. When all surveys were combined the lowest number of samples occurred in the “depression” category, perhaps because these are often classed as “level” sites. General knowledge suggests that the skewed distributions of topographic samples reflects the Clay Belt’s generally low relief. Similarly, the greater number of samples on upper slopes in the Northwest Region could simply reflect the more rugged terrain found there. However, as noted above, definitive assessments of representativeness must await ongoing terrain analyses based on the new DEM of Ontario.

The frequency distributions for mode of deposition are shown in Figures 4a–e. Ideally, the frequency distribution should match the geographic coverage of each depositional category. The OLI contains information at sufficient resolution to address this question on a regional basis. OLI data for the Northwest Region is presently being analyzed toward this end. However, some general comments about representativeness can be made here. Figure 4a shows that, from all surveys, only 25 plots are on bedrock substrate and just one is on boulder pavement. These generally reflect less productive or desirable sites in terms of wood production. However, these site conditions are relatively common and hence are presently undersampled. Ecologically, they are an important component of forest ecosystems and warrant greater attention. The Northwest Region has a large number of samples on glacial and glacial–fluvial substrates. This reflects to some degree that the distributions of these categories are not even across the province. However, new surveys in the other regions should consider closely whether these substrate categories are present and ensure that they are adequately sampled. The tallies reveal that colluvial and aeolian have very small numbers. While these modes are uncommon, the small sample sizes are clearly inadequate. Organic sites appear to have a relatively high number (421); however, the large amount of organic soils in the province suggest that they are also undersampled.

The histograms for Soil Moisture Regime are shown in Figures 5a–e. The Clay Belt has only a small number of plots from the Dry to Moderately Fresh categories, while the other regions have relatively fewer plots on the moister site conditions. This again is partially explainable by regional differences in soil moisture. However, because wetter sites can be less productive for wood, there may be a bias in these samples that future surveys should examine.

The frequency distributions of soil texture classes are given in Figures 6a–e. These data were derived by ranking the textures according to the dominant texture of the soil profile’s C Horizon (Sims et al. 1989, Mackey et al.

### Topographic positions

1. Crest
2. Upper slope
3. Mid slope
4. Lower slope
5. Toe slope
6. Depression
7. Level

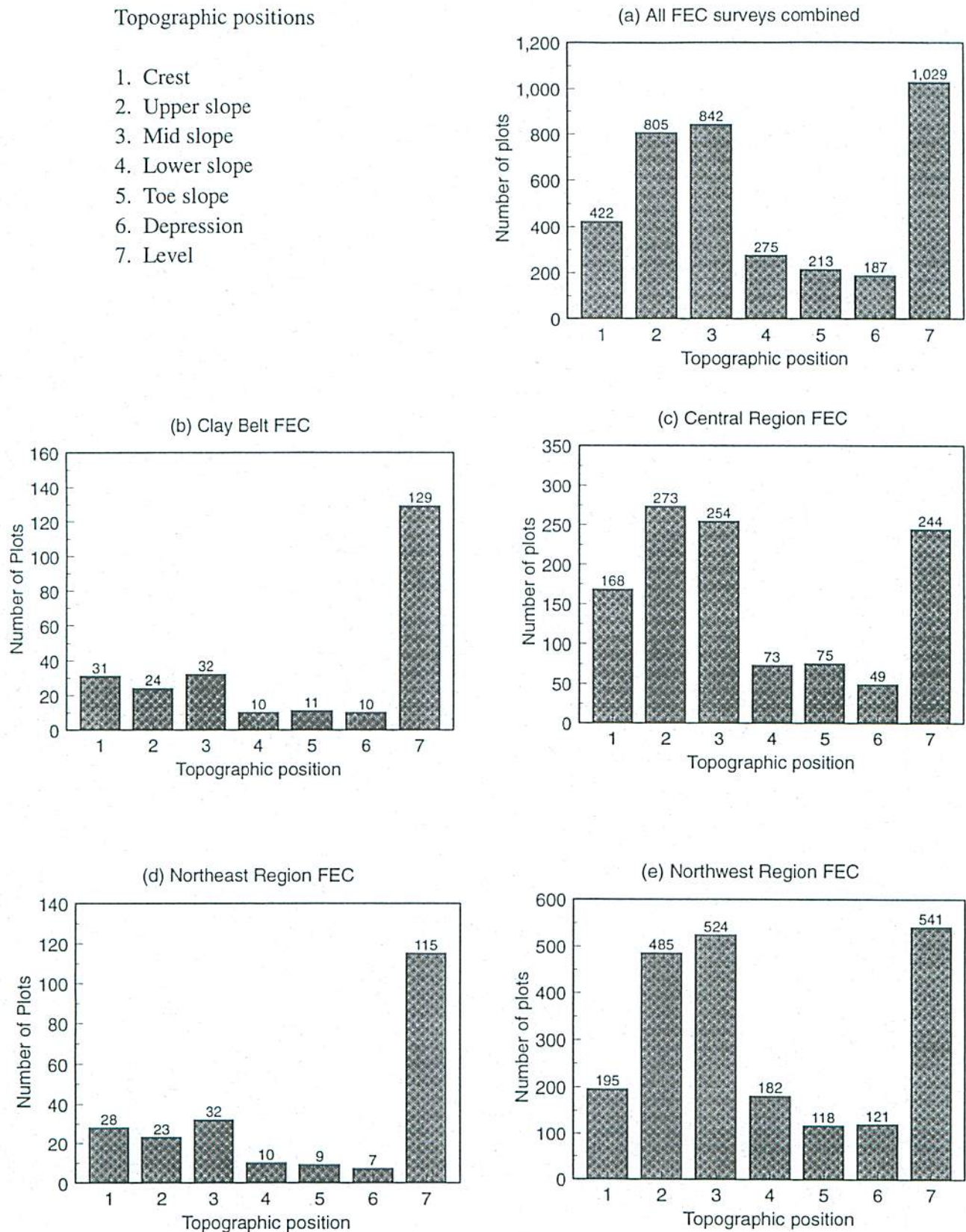
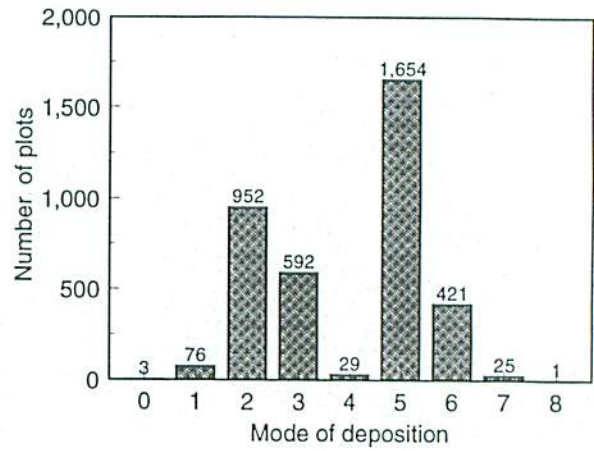


Figure 3. Distribution of FEC plots with respect to topographic position. Note the differences in y-axes.

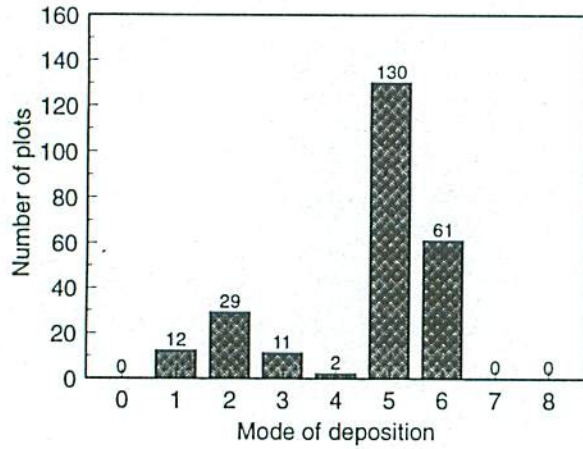
# Modes of deposition

0. Colluvial
1. Fluvial
2. Glacial-Fluvial
3. Lacustrine
4. Aeolian
5. Till (morainal deposits)
6. Organic
7. Bedrock
8. Boulder Pavement

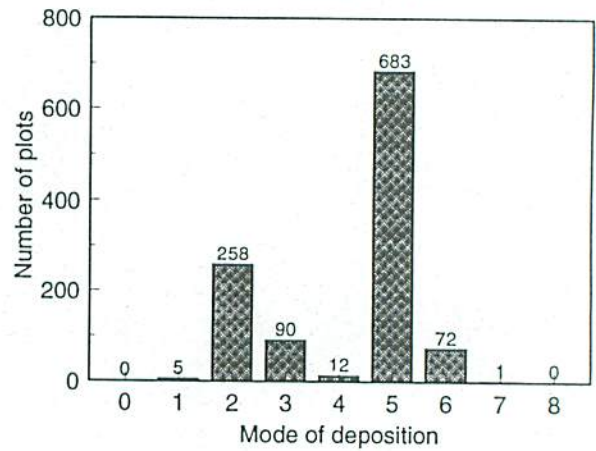
(a) All FEC surveys combined



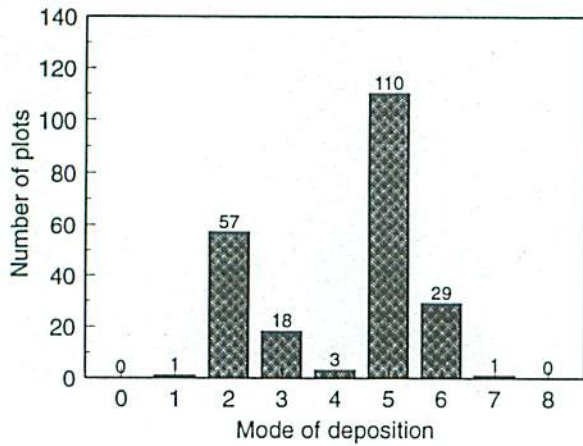
(b) Clay Belt FEC



(c) Central Region FEC



(d) Northeast Region FEC



(e) Northwest Region FEC

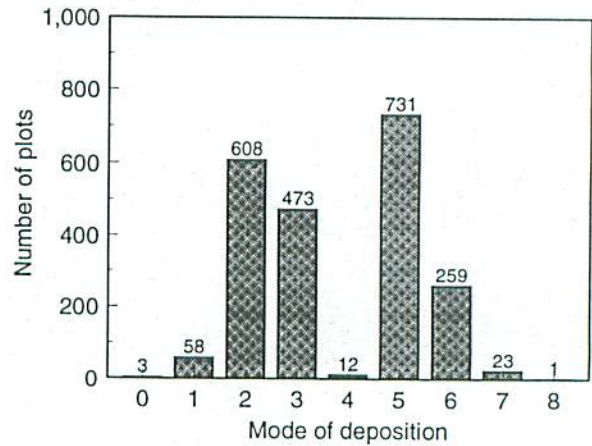


Figure 4. Distribution of Ontario FEC plots with respect to mode of deposition. Note the differences in y-axes.

# Soil Moisture Regime

0. Dry/Moderately Dry
1. Moderately Fresh
2. Fresh
3. Very Fresh
4. Moderately Moist
5. Moist
6. Very Moist
7. Moderately Wet
8. Wet
9. Very Wet

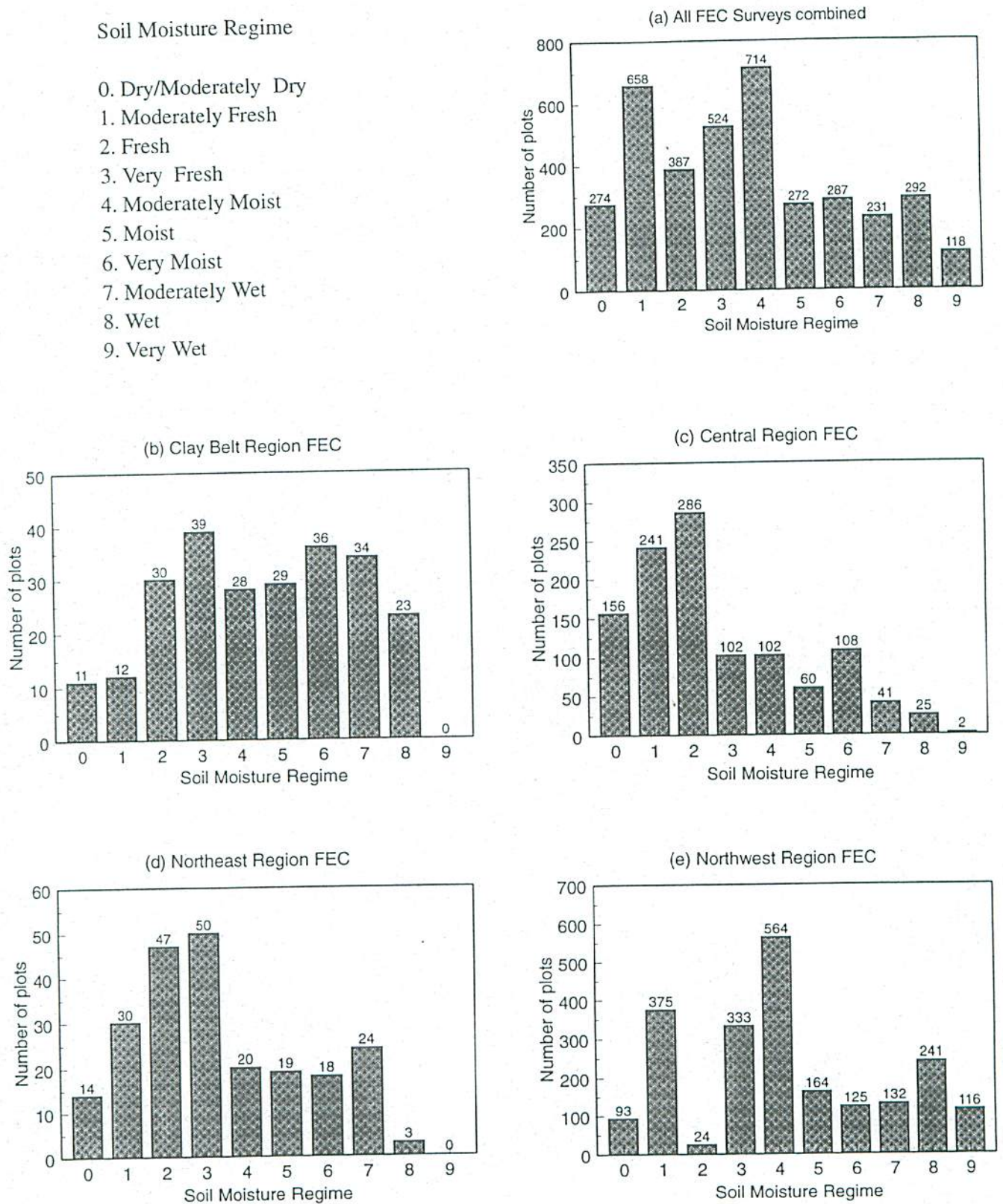


Figure 5. Distribution of Ontario FEC plots with respect to Soil Moisture Regime. Note the differences in y-axes.

# Texture classes

1. Bedrock (shallow soil  $\leq 20\text{cm}$ )
2. Coarse sandy (vcs, cs, mS, Lvcs, Lcs, Lms)
3. Fine sandy (fS, vfs, Lfs)
4. Coarse loamy (Lvfs, L, all SL, all SiS)
5. Fine loamy (CL, SiCL, all SCL)
6. Silty (Si, SiL)
7. Clayey (C, SiC, SC)
8. Organic (Of, Om, Oh  $\geq 40\text{ cm}$ )

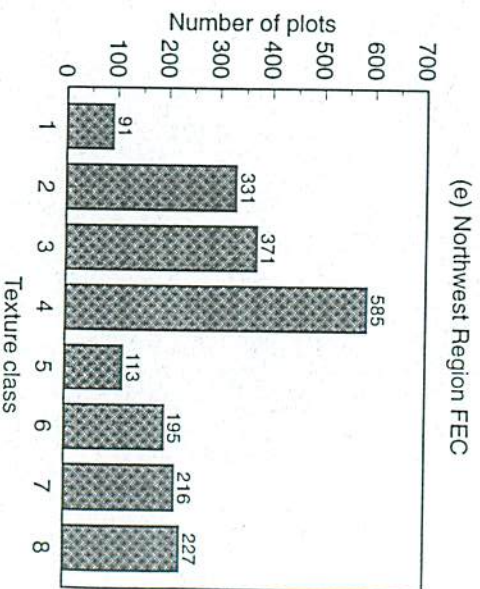
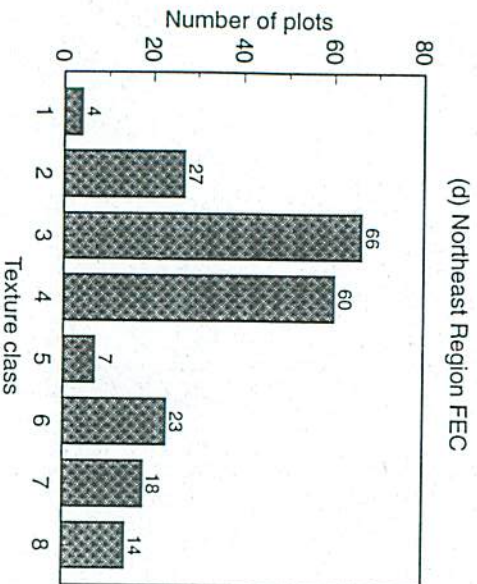
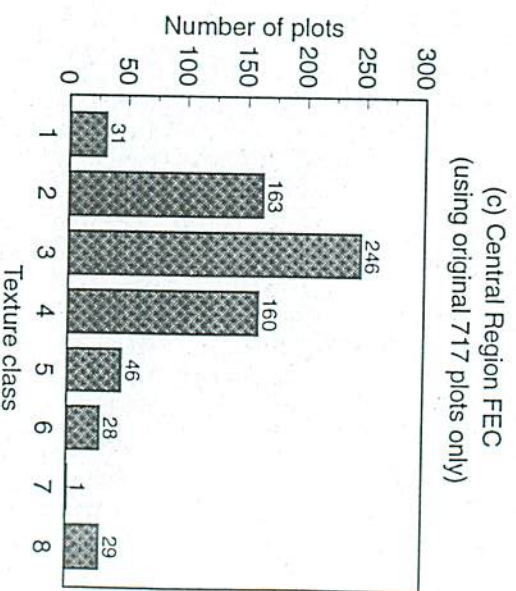
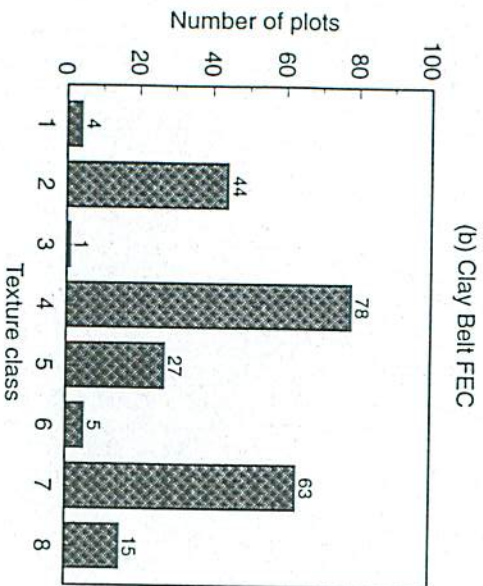
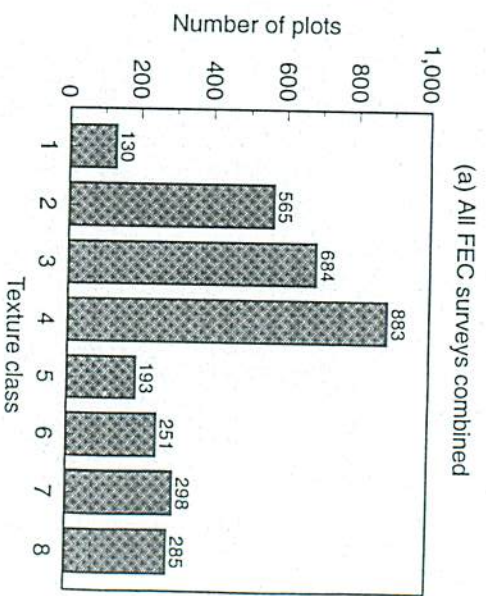


Figure 6. Distribution of Ontario FEC plots with respect to Soil Texture Class. Note the differences in y-axes.

1993<sup>2</sup>). The overall pattern in Figure 6a indicates a possible bias toward more productive forest sites, and against less productive, but still ecologically significant (abundant), soil conditions. Sites with Texture Classes 1 and 5 have the lowest number of plots. Class 1 (Bedrock) is most likely undersampled and the low frequency of Class 5 (Fine loamy) might reflect its geographic uncommonness.

### Plot Distributions II: Two-dimensional Climate Domain Analysis

As previously noted, the Ontario climate model now permits the estimation of long-term mean monthly climate (temperature, moisture, and radiation regimes) for any location in the province for which the latitude, longitude, and elevation are known. By coupling these surfaces to the digital elevation model of Ontario, estimates of climatic parameters were generated for each point on a 1-km regular grid of the province. The two pieces of software used to do this were BIOCLIM (Nix 1986) and ONTCLIM<sup>3</sup>. For this exercise, data were excluded north of 52° N latitude so that only the potential productive forest zone of Ontario was analyzed (see Fig. 7). This subset of the full grid for Ontario generated 500 461 grid points with 40 climate variables at each point. Estimates of climate were also generated for each of the FEC and G&Y plot locations.

The two climate variables chosen to illustrate the two-dimensional climate domain analysis were the growing degree-days (total heat units) for the growing season, and

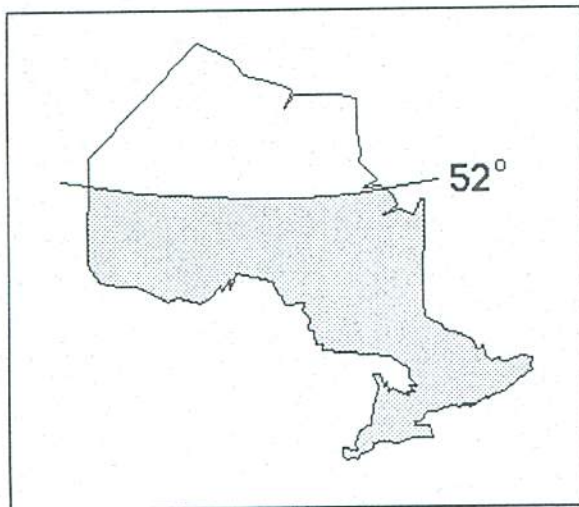


Figure 7. Ontario south of 52° N latitude, as used in the climate domain analysis.

the precipitation for the growing season (mm). The 500 461 values of growing degree-days were plotted against the 500 461 values of precipitation to produce a scatter plot of these two climate variables for Ontario. The scatter plot represents the growing degree-days and precipitation climate domain for this portion of the province. The same two climate variables were also plotted against each other for the 3 635 FEC and the 1 797 G&Y locations. The climate domains of the survey plots were then overlaid on the scatter plot (Figs. 8 and 9, respectively), enabling the climatic distribution of the survey plots to be compared to the actual climatic domains found in the productive forest zone of Ontario.

In Figures 8 and 9, the FEC plots are clumped more closely together in climatic space relative to the G&Y plots. The G&Y plots, although less numerous, occur over a greater climatic distribution. There are portions of the climate regime of Ontario that are not represented in the FEC and G&Y data sets for these two climate variables. Areas lacking sampling in the FEC plots tend to be warmer and wetter, while within the G&Y plots it is the cooler and drier growing season portions of Ontario that are not represented. These results reflect that FEC plots are located to a greater extent in northern parts of the province relative to the G&Y plots (Figs. 1 and 2). Note that Figures 8 and 9 represent climatic space. Thus a warmer position in the figure does not necessarily indicate a more southern position in space, just as a wetter position in the figure may be anywhere on a map. Additional analyses are required to identify the geographic location of the underrepresented climatic areas. Although the climate domains of any of the other 40 climate variables may be plotted two-dimensionally, this method is limited in that many climate variables cannot be assessed quickly and easily at the same time.

### Plot Distributions III: Assessing the Representativeness Against Environmental Classifications

#### *Environmental Domain Interrogation System*

The Environmental Domain Interrogation System (EDIS) is a decision support tool being developed as part of the Bio-environmental Indices Project. EDIS can be used to evaluate representativeness by calculating the extent to which plots or a network of polygons (e.g., parks) sample an environmental classification. Plot or polygon positions are overlaid onto a previously developed classification

<sup>2</sup> Mackey, B.G.; Sims, R.A.; Baldwin, K.A.; Moore, I.D. Spatial analysis of boreal forest ecosystems: Results from the Rinker Lake case study. in M.F. Goodchild, L.T. Steyaert, B.O. Parks, Cranes, Johnson, Maidment and S. Glendinning, eds. GIS and Environmental Modeling: Progress and Research Issues. GIS World Books. (In press.)

<sup>3</sup> Developed by J.P. McMahon, as reported in Mackey et al. (See Footnote 1).

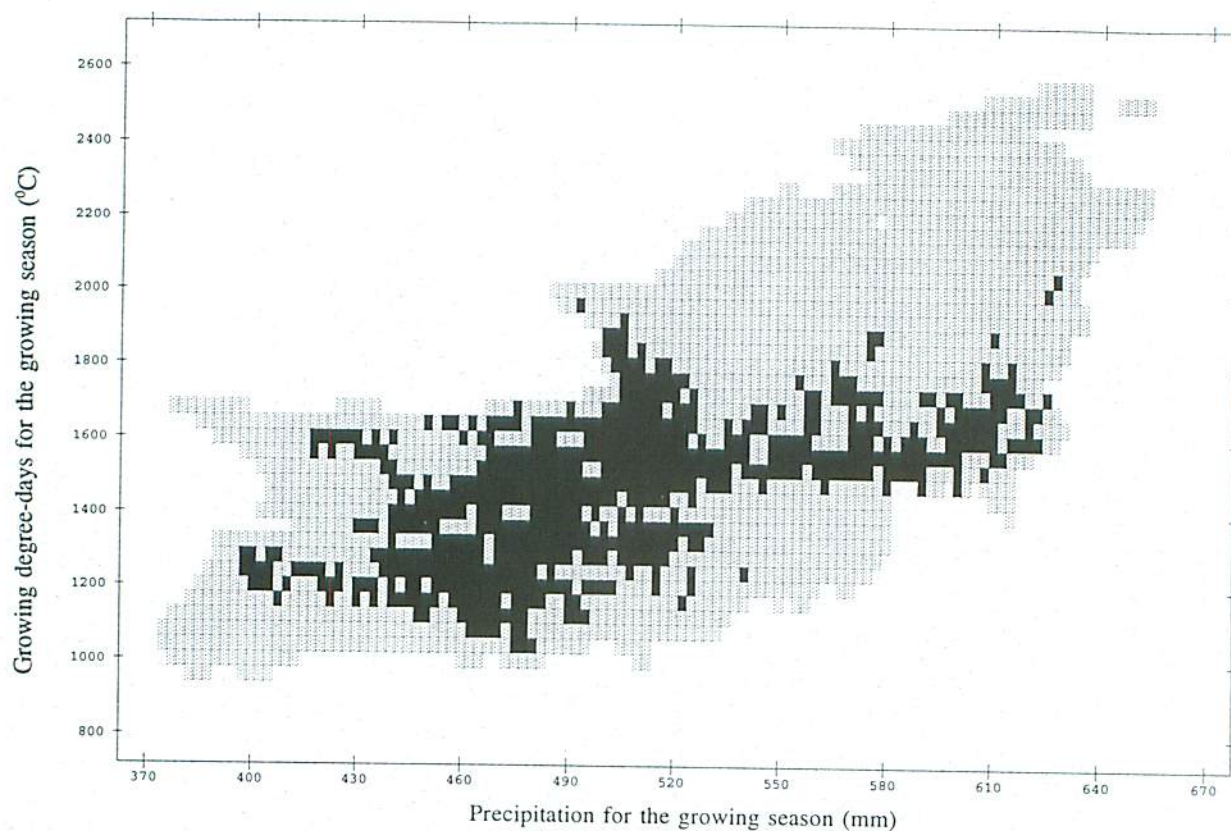


Figure 8. Climatic distribution of the FEC plots ( ■ ) within a climate domain of Ontario south of 52° latitude.

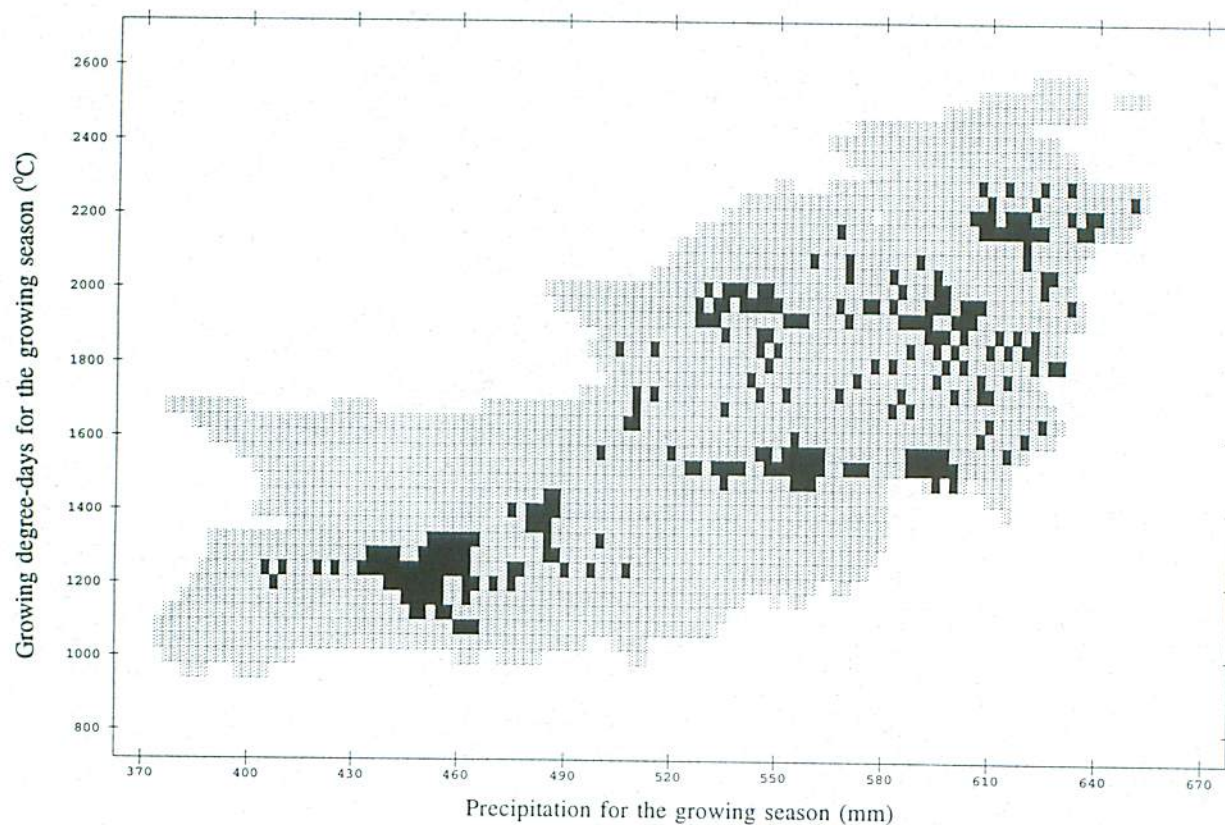


Figure 9. Climatic distribution of the G&Y plots ( ■ ) within a climate domain of Ontario south of 52° latitude.

grid. The number of plots that occur in each class are summed, or if polygons are used, the relative area of each class captured by the polygon is calculated, and a log file of results is produced. EDIS was used to assess the representativeness of the FEC and G&Y forest plots in terms of an existing environmental regionalization, and of the two new classifications generated from the Ontario Climate Model and the 1-km resolution DEM of Ontario.

### **Hills' Site Regions**

Hills' Site Regions (Hills 1959, 1961) represented a significant development in the recognition of ecological gradients within the province. Hills recognized that the space/time distribution of radiation, temperature, water, and nutrients were prime determinants of both ecosystem structure and function, and land use productivity (*see* Appendix 1). Despite the primacy Hills gave to these environmental regimes, the technology of the day restricted his ability to directly map these physical gradients. Rather, regional physiography and vegetation pattern were used as the major indicators of ecological response. Regional boundaries were mapped at a small scale, based on the author's considerable field experience, reconnaissance surveys, available data, etc. Large-scaled mapping of finer ecological units was derived from vegetation/landform patterns discerned by air photo interpretation. The Hills' Site Regions were explicitly intended to reflect major climatic gradients in the province. The mapped regions are areas of land within which the response of the vegetation follows a consistent pattern. Each specific type of land within a region is also expected to follow a characteristic plant succession pattern.

### **New Ontario Climate Classifications**

New climatic classifications for Ontario (*see* Appendices 2 and 3) were generated using the computer based classification method developed by Mackey et al. (1988, 1989). These classifications are discussed in detail elsewhere.<sup>4</sup> Briefly, the method involves the following:

- (a) Generation of gridded estimates of selected long-term, mean monthly climatic parameters by coupling the 1-km DEM of Ontario to the climate surfaces developed within the Ontario Climate Model. Gridded estimates were generated for eight climatic parameters:
  - growing degree-days for Period 3 (total growing season) in °C;
  - total precipitation for Period 3 in mm;
  - total precipitation for Period 1 (3 months prior to the growing season) in mm;

- duration of the growing season in days;
  - mean maximum temperature of the hottest month in °C;
  - mean minimum temperature of the coldest month in °C;
  - mean temperature of the hottest quarter in °C; and
  - mean precipitation of the hottest quarter in mm.
- (b) This data matrix of 756 104 grid cells (the entire province x eight climatic variables) was analyzed using the nonhierarchical, agglomerative classification procedure ALOC found within the statistical package PATN (Belbin 1993). This is essentially a clustering algorithm where cells are grouped on the basis of similar climatic values rather than on the basis of geographic adjacency. Hence, cells can belong to the same group but occur as outliers within a region dominated by another group. This distinguishes the method from traditional climatic regionalizations, which invariably map homogeneous regions with no outliers.
  - (c) Any number of classes can be generated and mapped — from 1 (i.e., all grid cells allocated to a single climate class) to *n* (the number of grid cells). The optimum number of classes is user defined in relation to the problem at hand, but ideally by comparison with biological distribution data (Mackey et al. 1989). The extent to which the climatic regions correlate with potential biotic response can then be explicitly examined. The procedure is otherwise based on objective statistics and, being explicit, is repeatable.
  - (d) Statistics, based on each class' mean climatic values, can be used to measure the interclass similarities — thereby constructing a hierarchical perspective of the classification.

Classifications generated using this method have advantages over the two-dimensional climate domain analysis. In particular, as the multivariate analysis summarizes all eight climatic variables into a single dimension, the geographic distributions of the climate classes can be readily mapped.

Two classifications were selected to assess the representativeness of the FEC and G&Y plots. The 14-class climate classification was selected as it most closely matches the number of groups in the Hills' regionalization, thereby facilitating comparison. The 49-class climate classification provides a spatially finer framework for analysis on a more regional level.

<sup>4</sup> Mackey et al. (*See* Footnote 1).

## EDIS RESULTS

The results of the EDIS analysis are contained in Figures 10–14. Each figure consists of a classification map and a table containing the analysis of the plot distributions for that classification. A Plot Proportion Index (PPI) was developed as a relative measure of representativeness between classes. The PPI allows comparison of classes based on the relative number of plots in, and the relative area of, each class. The PPI of each class was calculated by dividing the percentage of plots in the class by the percentage area of the class. As the PPI approaches 0, the class is not well represented because there are few plots relative to the area of the class; as the PPI increases, the class is better represented. When the PPI is near 1, the relative proportion of plots in the given class is roughly equivalent to the relative area of the class (i.e., percentage of plots = percentage of area).

The Hills' Site Regions and the 14- and 49-class climate classifications contain classes where either productive forest or mature, undisturbed forest do not occur. Hence some classes are undersampled simply because all sites within them fail the survey selection criteria. For both the FEC and G&Y plot systems, these classes comprise the far northern portion of the province. For the FEC only, these classes occur in the southernmost portions of the province.

The EDIS analysis using Hills' Site Regions (Fig. 10) reveals that Site Regions 1E, 2E, and 2W were not represented and regions 6E and 7E were only scarcely represented by FEC data. The region that had the highest representation is 4W, with 10 percent of the FEC plots in a class that covers only 2.2 percent of the province (PPI = 4.5). There were no G&Y plots in Site Regions 1E, 2E, 2W, 3S, 4S, and 5S. Region 6E had the highest representation of G&Y plots, with 23 percent of the plots in 6.1 percent of the province (PPI = 3.8).

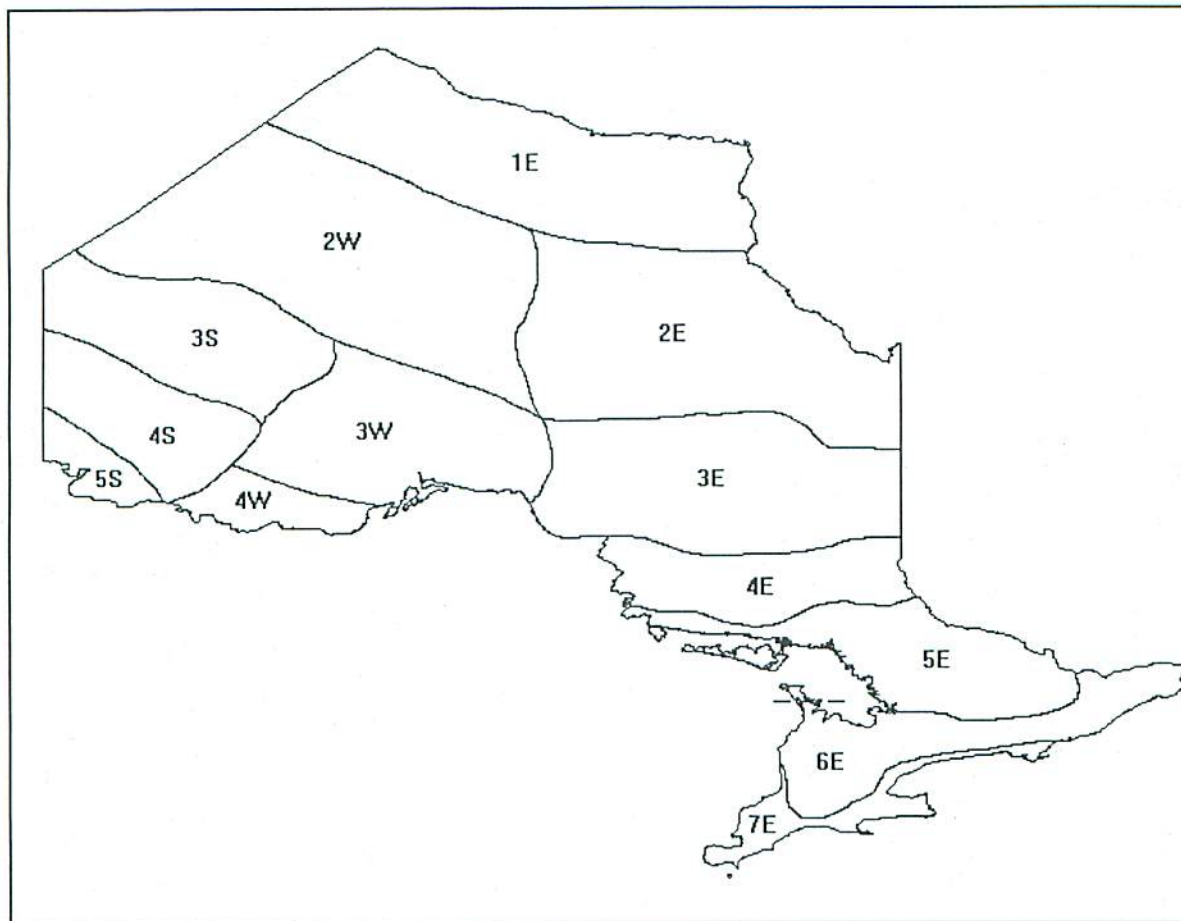
Classes 13 and 14 of the 14-class climate classification (Fig. 11) were not represented by either the FEC or G&Y data sets. As well, no G&Y plots were contained within Class 10. In contrast, Class 10 had the third highest representation by FEC data (PPI = 3.0), being surpassed only by Classes 3 and 6, which had PPIs of 3.2. The most represented class with respect to the G&Y data was Class 3, with 21 percent of the total plots in 2.9 percent of the province (PPI = 7.2).

The EDIS results using the 49-class climate classification were broken down by OMNR regions (Figs. 12–14). Central and Southern regions are displayed together (Fig. 12), with the boundary between them omitted, but following almost exactly the northern boundary of Classes 6 and 9 from Georgian Bay toward Ottawa. The Northeast and

Northwest regions are presented in Figures 13 and 14, respectively. There is overlap of classes across regions and some of the classes occur in disjunct patches, sometimes in two different regions. In the Central and Southern regions (Fig. 12), Classes 1 through 6, 9, 11, 12, 14, and 17 had no FEC plot occurrences. Class 22 had the highest representation of FEC plots (PPI = 6.6). The G&Y plots covered most of the classes in the southern and central portions of the province to some degree, except for Classes 1, 14, 18, 25, and 30. Relative to the other classes, Class 21 had the highest percentage of plots per percentage area (PPI = 17.5). In the Northeast Region (Fig. 13) the FEC plots occurred within all of the most southern classes, but were least represented in Class 25 (PPI = 0.2) in the south. The FEC plots were most represented in Class 18 (PPI = 6.0), even though the plots physically occurred in the Central Region near the Québec border (Fig. 1) and not at all in the Northeast Region. No G&Y plots were represented in Classes 18, 25, 30, 31, and 34 (PPI = 0); the most represented was Class 28 (PPI = 4.4). In the Northwest Region (Fig. 14), the FEC plots were not represented in Classes 43 and 45 (PPI = 0), were poorly represented in Classes 36 and 42 (PPI = 0.2), and were most represented in Class 34 (PPI = 5.7). The G&Y plots were least represented in Classes 29, 32, 34, 37, 40, 41, 42, 43, and 45 (PPI = 0) and most represented in Classes 26 and 35 (PPI = 3.9). In both the Northeast and Northwest regions, no plots occurred at all in the far northern climate classes.

## CONCLUDING COMMENTS

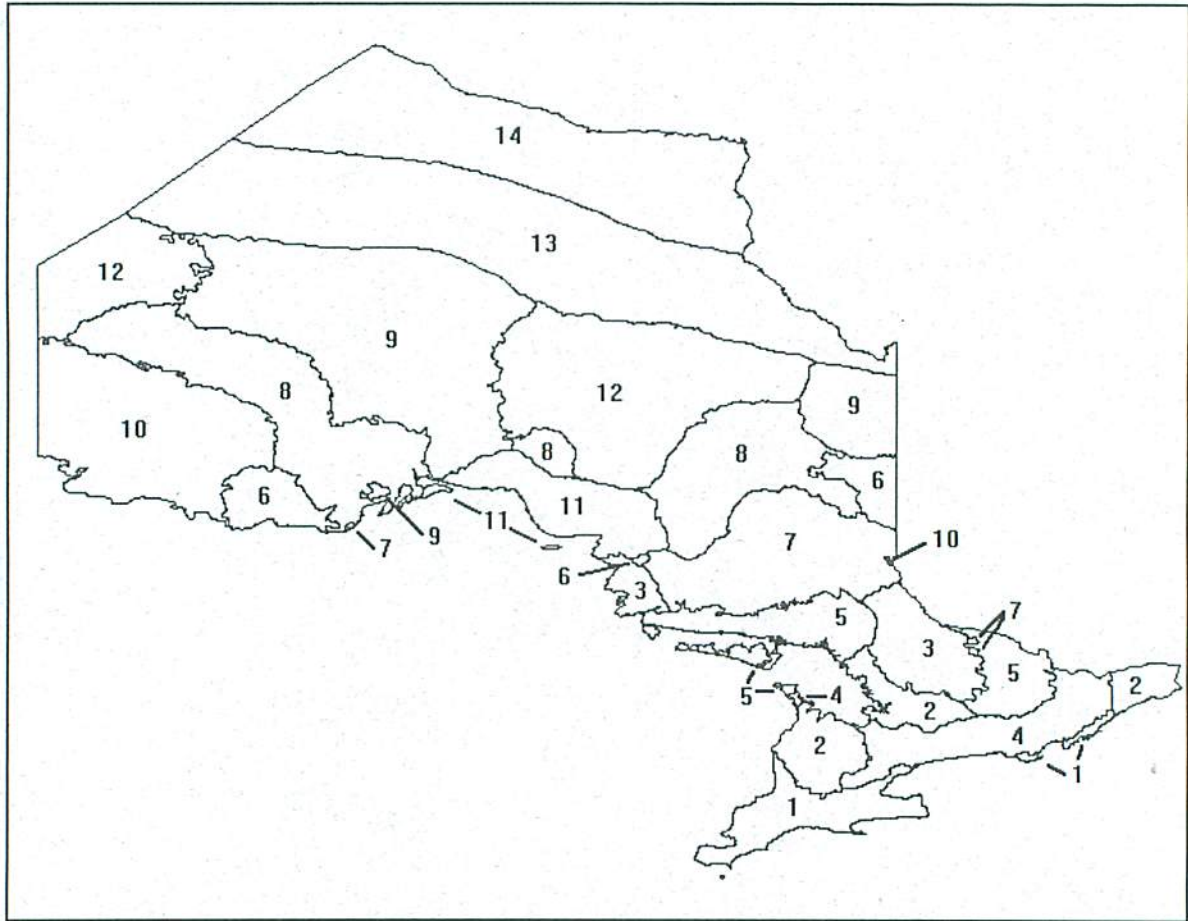
1. The establishment of a network of forest plots (for either onetime measurements or ongoing monitoring) should be based on a survey design that explicitly considers the distribution of plots in relation to key physical environmental gradients—climate is particularly important. To better quantify and understand species' responses, attention should be given to sampling landscapes across the entire gradient and not just within those environmental domains considered optimum for wood production.
2. In many respects Ontario is not data poor. There are literally thousands of previously collected forest plot data besides the FEC and G&Y data described in this report. These include genecological studies, wildlife surveys, herptofauna surveys, and forest insect and disease surveys. The process of compiling these data and analyzing them climatically offers new opportunities for turning data into information. Given this, the following general recommendations are offered:
  - a) All site data collected in the future should be accurately georeferenced (i.e., latitude, longitude, and elevation) using Global Positioning System (GPS) technology, if available.



| Class                                    | 1E   | 2E   | 3E   | 4E  | 5E  | 6E   | 7E   | 2W   | 3W  | 4W  | 3S  | 4S  | 5S  |
|--|------|------|------|-----|-----|------|------|------|-----|-----|-----|-----|-----|
| Number FEC plots                         | 0    | 1    | 592  | 325 | 661 | 5    | 3    | 0    | 918 | 361 | 158 | 470 | 122 |
| %  | 0    | 0    | 16   | 8.9 | 18  | 0.1  | 0.1  | 0    | 25  | 10  | 4.3 | 13  | 3.4 |
| Number G&Y plots                         | 0    | 0    | 561  | 29  | 422 | 420  | 77   | 0    | 279 | 9   | 0   | 0   | 0   |
| %  | 0    | 0    | 31   | 1.6 | 23  | 23   | 4.3  | 0    | 16  | 0.5 | 0   | 0   | 0   |
| (x10 <sup>4</sup> km <sup>2</sup> ) area | 11.2 | 14.0 | 11.5 | 5.2 | 7.2 | 5.9  | 2.3  | 15.8 | 8.3 | 2.1 | 6.9 | 4.7 | 1.3 |
| %  | 11.6 | 14.5 | 11.9 | 5.4 | 7.5 | 6.1  | 2.4  | 16.4 | 8.6 | 2.2 | 7.2 | 4.9 | 1.3 |
| FEC PPI*                                 | 0    | 0    | 1.3  | 1.6 | 2.4 | 0.02 | 0.04 | 0    | 2.9 | 4.5 | 0.6 | 2.7 | 2.6 |
| G&Y PPI                                  | 0    | 0    | 2.6  | 0.3 | 3.1 | 3.8  | 1.8  | 0    | 1.9 | 0.2 | 0   | 0   | 0   |

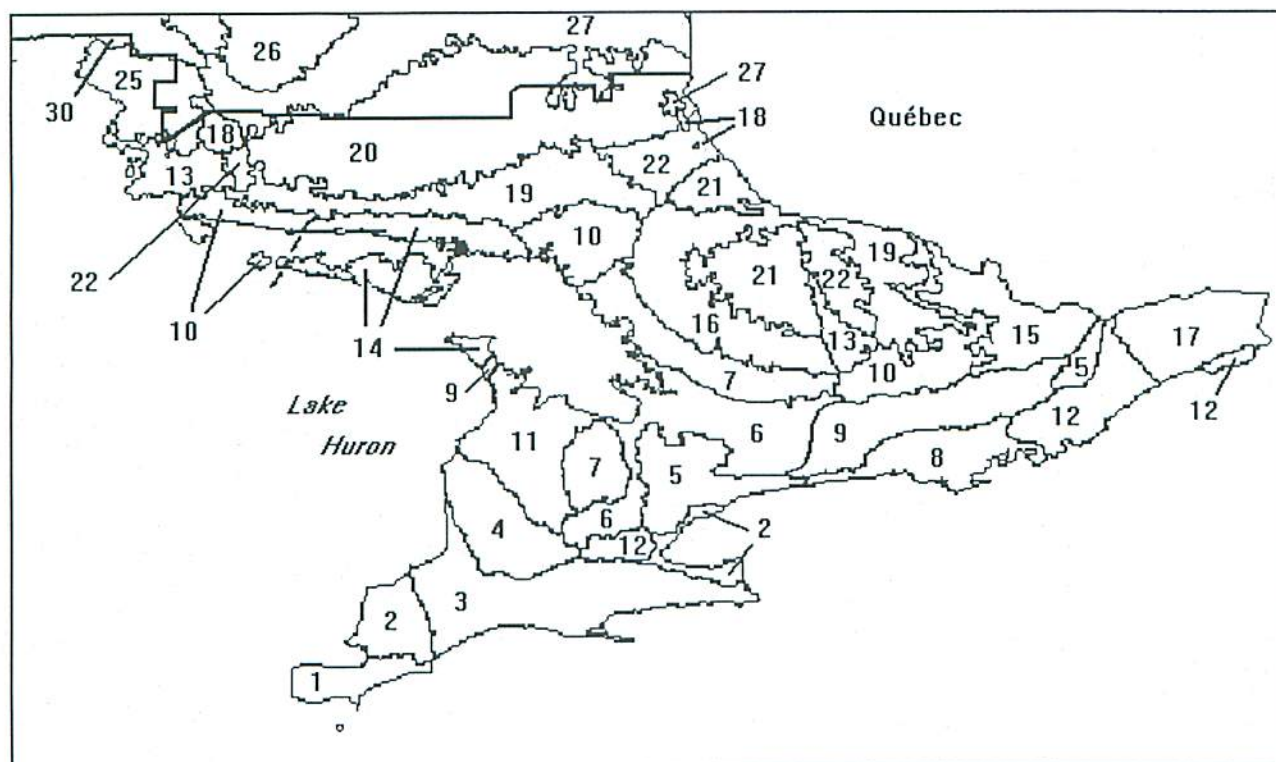
\* PPI = Plot Proportion Index (% plots/% area)

Figure 10. EDIS analysis of plot distribution for Hills' Site Regions.



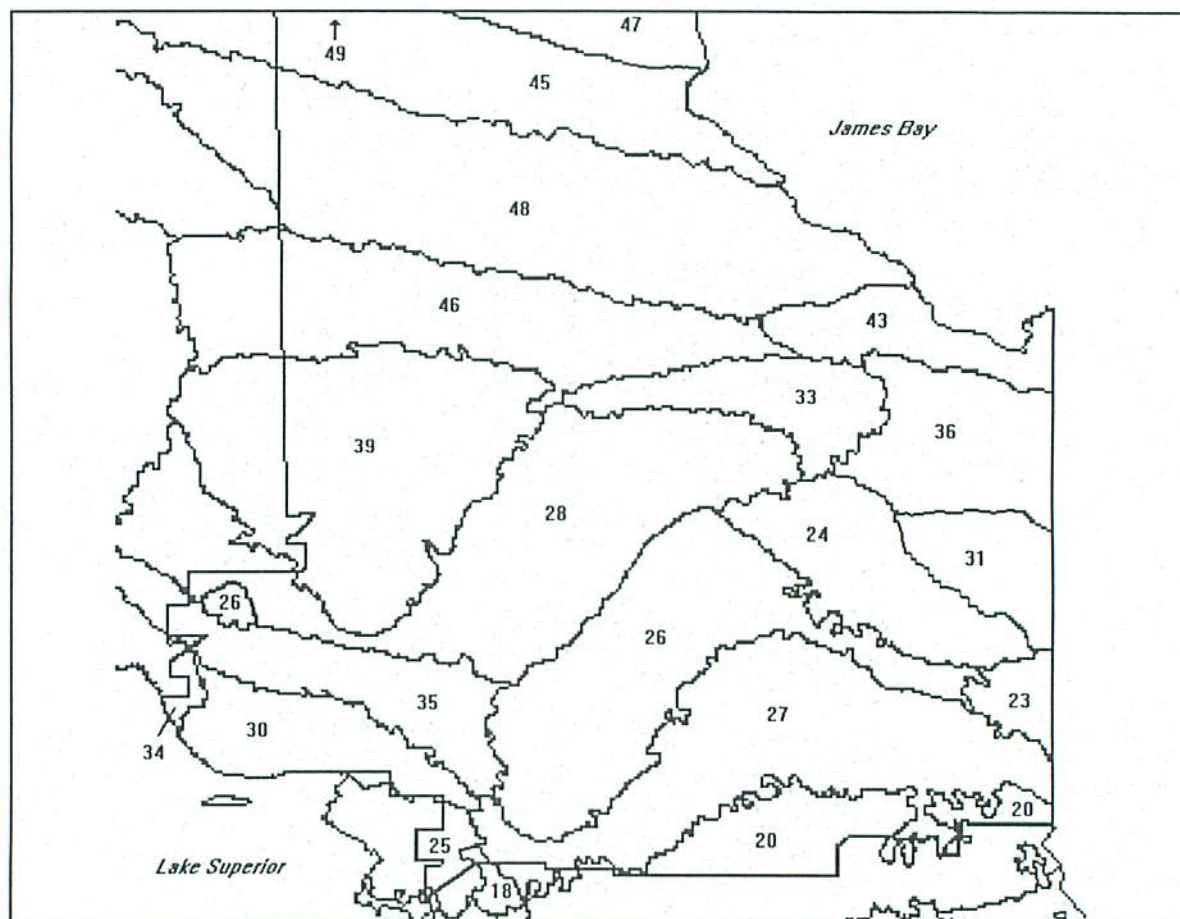
| Class                                       | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8    | 9    | 10  | 11  | 12   | 13   | 14  |
|---|-----|-----|-----|-----|-----|-----|-----|------|------|-----|-----|------|------|-----|
| number<br>FEC plots                         | 1   | 36  | 341 | 14  | 271 | 278 | 468 | 851  | 227  | 797 | 214 | 137  | 0    | 0   |
| %   | 0   | 0.9 | 9.4 | 0.4 | 7.5 | 7.6 | 13  | 23   | 6.2  | 22  | 5.9 | 3.8  | 0    | 0   |
| number<br>G&Y plots                         | 91  | 218 | 372 | 192 | 43  | 12  | 148 | 480  | 58   | 0   | 73  | 110  | 0    | 0   |
| %   | 5.1 | 12  | 21  | 11  | 2.4 | 0.7 | 8.2 | 27   | 3.2  | 0   | 4.1 | 6.1  | 0    | 0   |
| (x10 <sup>4</sup> km <sup>2</sup> )<br>area | 2.8 | 3.5 | 2.8 | 3.3 | 4.2 | 2.3 | 5.9 | 11.8 | 13.9 | 7.2 | 3.0 | 12.1 | 14.6 | 9.5 |
| %   | 2.9 | 3.6 | 2.9 | 3.4 | 4.3 | 2.4 | 6.1 | 12.2 | 14.3 | 7.4 | 3.1 | 12.5 | 15.1 | 9.8 |
| FEC<br>PPI                                  | 0   | 0.3 | 3.2 | 0.1 | 1.7 | 3.2 | 2.1 | 1.9  | 0.4  | 3.0 | 1.9 | 0.3  | 0    | 0   |
| G&Y<br>PPI                                  | 1.8 | 3.3 | 7.2 | 3.2 | 0.6 | 0.3 | 1.3 | 2.2  | 0.2  | 0   | 1.3 | 0.5  | 0    | 0   |

Figure 11. EDIS analysis of plot distribution for the 14-class climate classification.



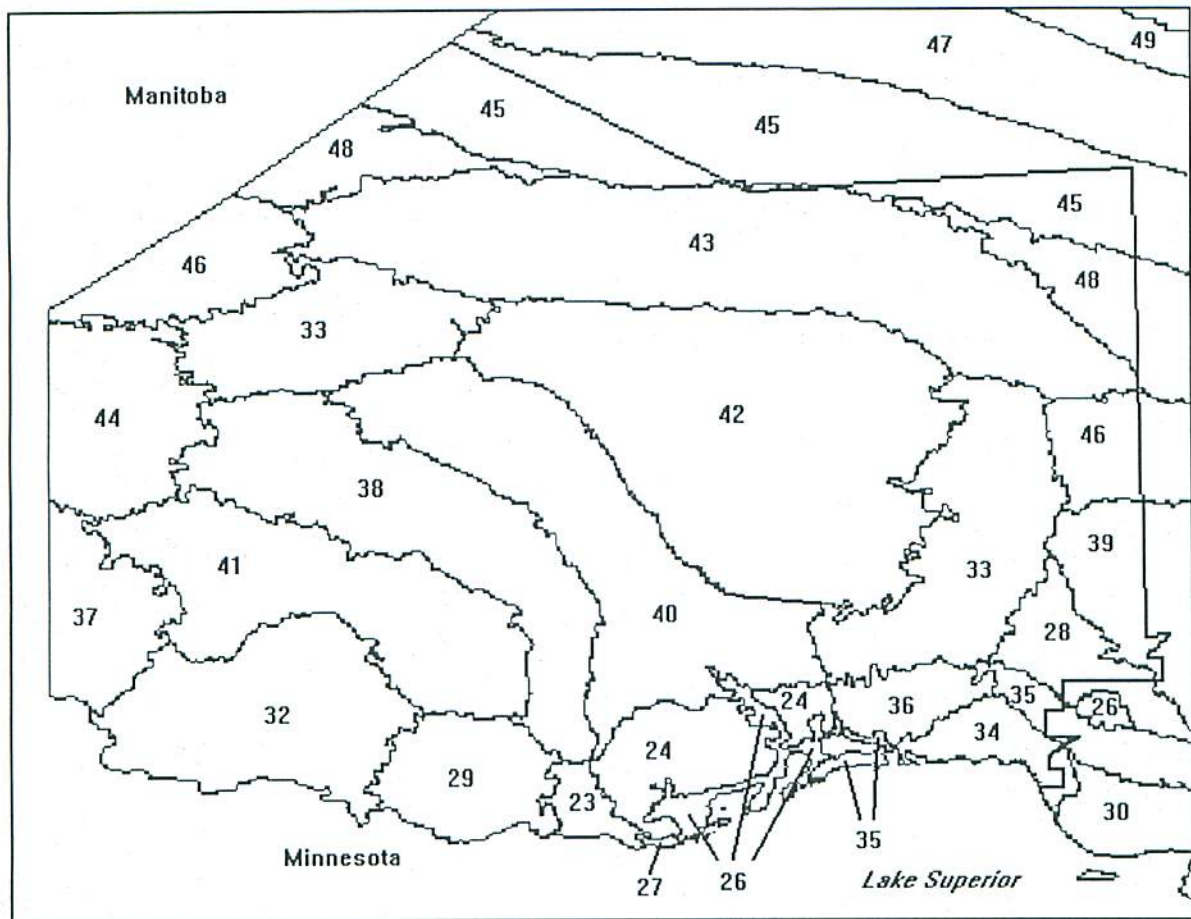
| Class                                       | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10  | 11  | 12  | 13  | 14  | 15  | 16  | 17  | 18  | 19  | 20  | 21   | 22  | 25  | 27  | 30  |
|---|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|-----|-----|-----|-----|
| number<br>FEC plots                         | 0   | 0   | 1   | 0   | 0   | 1   | 29  | 2   | 0   | 92  | 0   | 0   | 41  | 0   | 62  | 93  | 0   | 20  | 124 | 158 | 151  | 168 | 2   | 205 | 18  |
| %   | 0   | 0   | 0   | 0   | 0   | 0   | 0.8 | 0.1 | 0   | 2.5 | 0   | 0   | 0.4 | 0   | 1.7 | 2.5 | 0   | 0.6 | 3.4 | 4.3 | 4.2  | 4.6 | 0.1 | 5.6 | 0.5 |
| number<br>G&Y plots                         | 0   | 14  | 56  | 19  | 27  | 19  | 41  | 24  | 20  | 12  | 63  | 23  | 73  | 0   | 1   | 11  | 14  | 0   | 30  | 31  | 253  | 47  | 0   | 111 | 0   |
| %   | 0   | 0.7 | 3.1 | 1.1 | 1.5 | 1.1 | 2.3 | 1.3 | 1.1 | 0.7 | 3.5 | 1.3 | 4.0 | 0   | 0.1 | 0.6 | 0.8 | 0   | 1.6 | 1.7 | 14   | 2.6 | 0   | 6.2 | 0   |
| (x10 <sup>4</sup> km <sup>2</sup> )<br>area | 0.3 | 0.5 | 1.4 | 0.6 | 0.7 | 1.1 | 1.0 | 0.6 | 0.9 | 1.3 | 0.8 | 0.7 | 0.5 | 0.8 | 0.6 | 1.0 | 0.6 | 0.1 | 1.6 | 2.8 | 0.8  | 0.7 | 0.6 | 2.9 | 1.0 |
| %   | 0.3 | 0.5 | 1.4 | 0.6 | 0.7 | 1.1 | 1.0 | 0.6 | 0.9 | 1.3 | 0.8 | 0.7 | 0.5 | 0.8 | 0.6 | 1.0 | 0.6 | 0.1 | 1.7 | 2.9 | 0.8  | 0.7 | 0.6 | 3.0 | 1.0 |
| FEC<br>PPI                                  | 0   | 0   | 0   | 0   | 0   | 0   | 0.8 | 0.2 | 0   | 1.9 | 0   | 0   | 0.8 | 0   | 2.8 | 2.5 | 0   | 6.0 | 2.0 | 1.5 | 5.3  | 6.6 | 0.2 | 1.9 | 0.5 |
| G&Y<br>PPI                                  | 0   | 1.4 | 2.2 | 1.8 | 2.1 | 1.0 | 2.3 | 2.2 | 1.2 | 0.5 | 4.4 | 1.9 | 8.0 | 0   | 0.2 | 0.6 | 1.3 | 0   | 0.9 | 0.6 | 17.5 | 3.7 | 0   | 2.1 | 0   |

Figure 12. EDIS analysis of plot distribution for the 49-class climate classification (Central and Southern regions).



| Class                                       | 18  | 20  | 23  | 24  | 25  | 26   | 27  | 28   | 30  | 31  | 33  | 34  | 35  | 36  | 39  | 43  | 45  | 46  | 47  | 48  | 49  |
|---|-----|-----|-----|-----|-----|------|-----|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| number<br>FEC plots                         | 20  | 158 | 118 | 278 | 2   | 205  | 205 | 116  | 18  | 16  | 140 | 125 | 83  | 10  | 118 | 0   | 0   | 0   | 0   | 0   | 0   |
| %   | 0.6 | 4.3 | 3.2 | 7.6 | 0.1 | 5.6  | 5.6 | 3.2  | 0.5 | 0.4 | 3.9 | 3.4 | 2.3 | 0.3 | 3.2 | 0   | 0   | 0   | 0   | 0   | 0   |
| number<br>G&Y plots                         | 0   | 31  | 3   | 49  | 0   | 226  | 111 | 271  | 0   | 0   | 34  | 0   | 91  | 24  | 25  | 0   | 0   | 0   | 0   | 0   | 0   |
| %   | 0   | 1.7 | 0.2 | 2.7 | 0   | 12.6 | 6.2 | 15.1 | 0   | 0   | 1.9 | 0   | 5.1 | 1.3 | 1.4 | 0   | 0   | 0   | 0   | 0   | 0   |
| (x10 <sup>4</sup> km <sup>2</sup> )<br>area | 0.1 | 2.8 | 0.6 | 2.3 | 0.6 | 3.2  | 2.9 | 3.3  | 1.0 | 0.6 | 4.9 | 0.6 | 1.3 | 1.7 | 3.1 | 6.1 | 6.6 | 4.0 | 5.7 | 4.6 | 2.6 |
| %   | 0.1 | 2.9 | 0.6 | 2.4 | 0.6 | 3.3  | 3.0 | 3.4  | 1.0 | 0.6 | 5.1 | 0.6 | 1.3 | 1.8 | 3.2 | 6.3 | 6.8 | 4.1 | 5.9 | 4.7 | 2.7 |
| FEC<br>PPI                                  | 6.0 | 1.5 | 5.3 | 3.2 | 0.2 | 1.7  | 1.9 | 0.9  | 0.5 | 0.6 | 0.8 | 5.7 | 1.8 | 0.2 | 1.0 | 0   | 0   | 0   | 0   | 0   | 0   |
| G&Y<br>PPI                                  | 0   | 0.6 | 0.3 | 1.1 | 0   | 3.9  | 2.1 | 4.4  | 0   | 0   | 0.4 | 0   | 3.9 | 0.7 | 0.4 | 0   | 0   | 0   | 0   | 0   | 0   |

Figure 13. EDIS analysis of plot distribution for the 49-class climate classification (Northeast Region).



| Class                                       | 23  | 24  | 26   | 27  | 28   | 29  | 32   | 33  | 34  | 35  | 36  | 37  | 38  | 39  | 40  | 41  | 42  | 43  | 44  | 45  | 46  | 48  |
|---|-----|-----|------|-----|------|-----|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| number<br>FEC plots                         | 118 | 278 | 205  | 205 | 116  | 160 | 386  | 140 | 125 | 83  | 10  | 51  | 197 | 118 | 157 | 249 | 59  | 0   | 0   | 0   | 0   | 0   |
| %   | 3.2 | 7.6 | 5.6  | 5.6 | 3.2  | 4.4 | 10.6 | 3.9 | 3.4 | 2.3 | 0.3 | 1.4 | 5.4 | 3.2 | 4.3 | 6.9 | 1.6 | 0   | 0   | 0   | 0   | 0   |
| number<br>G&Y plots                         | 3   | 49  | 226  | 111 | 271  | 0   | 0    | 34  | 0   | 91  | 24  | 0   | 7   | 25  | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| %   | 0.2 | 2.7 | 12.6 | 6.2 | 15.1 | 0   | 0    | 1.9 | 0   | 5.1 | 1.3 | 0   | 0.4 | 1.4 | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| (x10 <sup>4</sup> km <sup>2</sup> )<br>area | 0.6 | 2.3 | 3.2  | 2.9 | 3.3  | 1.2 | 2.5  | 4.9 | 0.6 | 1.3 | 1.7 | 1.0 | 3.2 | 3.1 | 3.1 | 2.9 | 6.3 | 6.1 | 1.6 | 6.6 | 4.0 | 4.6 |
| %   | 0.6 | 2.4 | 3.3  | 3.0 | 3.4  | 1.2 | 2.6  | 5.1 | 0.6 | 1.3 | 1.8 | 1.0 | 3.3 | 3.2 | 3.2 | 3.0 | 6.5 | 6.3 | 1.6 | 6.8 | 4.1 | 4.7 |
| FEC<br>PPI                                  | 5.3 | 3.2 | 1.7  | 1.9 | 0.9  | 3.7 | 4.2  | 0.8 | 5.7 | 1.8 | 0.2 | 1.4 | 1.6 | 1.0 | 1.3 | 2.3 | 0.2 | 0   | 0   | 0   | 0   | 0   |
| G&Y<br>PPI                                  | 0.3 | 1.1 | 3.9  | 2.1 | 4.4  | 0   | 0    | 0.4 | 0   | 3.9 | 0.7 | 0   | 0.1 | 0.4 | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |

Figure 14. EDIS analysis of plot distribution for the 49-class climate classification (Northwest Region).

- b) Attempts should be made to accurately georeference previously collected site data so that climatic variables can be appended. This will add value to the data by allowing new analyses at relatively minor cost.
  - c) Attempts should be made to standardize nomenclature and data collection protocols without undermining the specific purposes of individual researchers. This would help minimize costs in the longer run. Agreement should be set on a minimum attributed data set that all surveys must collect (with additional attributes for specialist surveys).
3. There is no simple answer to the question of how many samples are needed within a given climatic domain. This is partly a function of the interdomain topographic and substrate heterogeneity. If the survey data are to be analyzed using inferential statistics (e.g., regression analysis) then a minimum sample size of 50 would be advisable. Once this criterion is met, a PPI equal to or greater than 1 would be desirable for each class. Consequently, any climatic region with less than 50 samples could be considered undersampled. However, given time and budgetary constraints, priority should be given to surveying climatic regions that have the fewest number of existing samples.
  4. Table 3 lists the classes that are considered under-represented relative to the other classes within each classification for the FEC plots. A sample size of 50 was taken as the threshold for determining the classes that have a representative sample. The under-represented classes have been ranked according to their PPI, thereby indicating their priority for new surveys. It is recommended that future FEC plots be located in those areas of the province where these classes occur. Ongoing FEC sampling is currently attempting to fill some of these gaps.
  5. Table 4 details undersampled classes (minimum sample size of 50 plots), thereby identifying localities for future G&Y survey. The underrepresented classes have been ranked according to their PPI, indicating their priority for new surveys. At the time of this report, current sampling techniques within the OMNR Growth and Yield Program are now standardized in order to integrate data attributes across studies, and an attempt is being made to adequately sample environmental space (Ontario Forest Research Institute 1993). In physical space, the G&Y plots were absent from northwestern Ontario (Fig. 1). Such plots do exist in northwestern Ontario; however, data sets or plot locations were not available to the authors at the time of this report.
  6. Climate is a major driving force determining the structure, composition, and functioning of plant communities. When there are areas in climatic space that are not represented by forest plots, there may be plant species, associations of plants, or ecosystems that are also not sampled or are undersampled. The EDIS analysis can be used to locate these undersampled climate classes of Ontario. Some of these lie within areas where productive forests do not currently occur (i.e., agricultural land, urban areas, or other nonforest lands). Further investigation is needed to identify the areas that are poorly sampled in terms of these climatic domains, but meet the criteria for FEC or G&Y plots. Digital coverages of the climate classes used in this report are available from the authors on request.

## NOTES

1. The collections of forest research plots analyzed in this report were never intended to be all-encompassing surveys of biodiversity. As with Forest Resource Inventory data, there are pressures to make greater use of data beyond its original intended uses. Recent

**Table 3.** FEC plot location recommendations.

| Classification                  | Underrepresented classes   |
|---------------------------------|--|
| Hills' Site Regions             | 1E, 2W, 2E, 6E, 7E.  |
| 14-class climate classification | 1, 13, 14, 4, 2.   |
| 49-class climate classification | 1, 2, 3, 4, 5, 6, 9, 11, 12, 14, 17, 43, 44, 45, 46, 47, 48, 49, 8, 25, 36, 30, 31, 7, 13, 18. |

**Table 4.** Growth and Yield plot location recommendations.

| Classification                  | Underrepresented classes  |
|---------------------------------|---|
| Hills' Site Regions             | 1E, 2E, 2W, 3S, 4S, 5S, 4W, 4E.   |
| 14-class climate classification | 10, 13, 14, 6, 5.   |
| 49-class climate classification | 1, 14, 18, 25, 29, 30, 31, 32, 34, 37, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 38, 15, 23, 33, 39, 10, 16, 20, 36, 19, 6, 24, 9, 17, 2, 4, 12, 5, 8, 7, 22. |

advances in technology, and accessibility to previously unavailable analytical tools, make it possible to derive additional and unexpected information from these data. The intention of the authors has not been to be critical of previous studies, but to help identify possible areas for future surveys.

2. Within the FEC and G&Y programs, there are ongoing efforts to refine commonalities between data sets, and to adequately sample poorly represented areas. There may be portions of Ontario that are now adequately sampled, but have not been analyzed in this report.
3. The recommendations in this report are focused on representing the climatic regions of Ontario in biological surveys. Ideally, all environmental factors that determine species' responses and distributions should be mapped and adequately sampled. Future efforts will be directed to refine representative analysis by incorporating other spatial data, such as province-wide terrain, soil, and substrate classifications.

## ACKNOWLEDGMENTS

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**Appendix 1.** Summary of Hills' Site Regions (*from Hills 1959*).

| Site Region                | 1E                   | 2E                     | 3E                    | 4E                     | 5E                     | 6E                              | 7E                              | 2W                     | 3W                    | 4W                     | 4S                          | 5S                        |
|----------------------------|----------------------|------------------------|-----------------------|------------------------|------------------------|---------------------------------|---------------------------------|------------------------|-----------------------|------------------------|-----------------------------|---------------------------|
| Mean An Temp (°C)          | -7 to -3             | -3 to -0.5             | -1 to -2              | 1 - 3                  | 3 - 6                  | 6 - 7                           | 7 - 8                           | -4 to -2               | -2 - 1                | 1 - 2                  | 0 - 2                       | 2 - 3                     |
| Mean Growing Season (days) | 135                  | 135 - 152              | 140 - 169             | 160 - 180              | 175 - 189              | 189 - 196                       | 196 - 210                       | 135 - 140              | 140 - 155             | 154 - 165              | 152 - 168                   | 168 - 170                 |
| Annual Precip. (cm)        | 51 - 58              | 58 - 69                | 66 - 76               | 71 - 91                | 71 - 102               | 71 - 102                        | 71 - 86                         | 51 - 58                | 61 - 71               | 61 - 67                | 56 - 71                     | 56 - 66                   |
| Forest Climate Type        | mid-humid, subarctic | mid-humid, cold-boreal | mid-humid, mid-boreal | mid-humid, warm-boreal | mid-humid, warm-boreal | mid-humid Great Lakes hardwoods | dry-humid Great Lakes hardwoods | dry-humid, cold-boreal | dry-humid, mid-boreal | dry-humid, warm-boreal | moist subhumid, warm boreal | moist subhumid continentl |

**Regional Vegetation Types:**

- 1E Open boreal forest of lichen-black spruce woods with closed stands along the more deeply entrenched stream courses.
- 2E Conifer and mixedwood stands boreal species found on well drained ridges and protected valleys. All other sites support scrubby stands of jack pine, black spruce, larch.
- 3E Stands of spruce, fir, poplar, birch on fresh sites with mod. sloping terrain. White and red pine on sand ridges. American elm and white cedar in protected valleys only.
- 4E Extensive pine forests of red pine (shallow and exposed ridges), white pine (more retentive sites) and jack pine (on sites after fire).  
Protected slopes and valleys have hard and red maple and yellow birch.
- 5E Hard maple, yellow birch, hemlock, white pine generally on fresh sites. White spruce and fir on fresh clay and cooler valleys. Black spruce and larch in cool, wet areas.
- 6E Beech, hard maple, hemlock on normal/fresh sites, with oak and hickory on warmer/fresh sites. Oak, ash on hot/dry sites, hard maple, oak, ash on normal sites and white pine, elm, ash on cold/dry sites. Hemlock, yellow birch or spruce, white cedar on wet sites.
- 7E Warm/drier soil - oak, chestnut      Warmer/fresh,moist - tulip, walnut      Warmer/wet - sycamore,tulip  
Normal/drier - oak, hickory      Normal/fresh,moist - hard maple,beech,oak      Normal/wet - oak, ash  
Colder/drier - hemlock, yellow birch      Colder/fresh,moist - elm, ash, oak      Colder/wet - spruce,fir,cedar,ash
- 2W Black spruce on moist sites. Mixed stands of white and black spruce, balsam fir and poplar.
- 3W White spruce, balsam fir, aspen and white birch on well drained sites. White and red pine on upland sites.
- 4W White pine and white spruce common on well-drained sites. Red pine on site with various conditions. Red maple on warmer upland slopes.
- 4S White spruce, balsam fir, aspen and balsam poplar (boreal species) on well-drained sites. Bur oak on drier sites.
- 5S White spruce, balsam fir, poplar and birch on well-drained sites. Bur oak and elm on dry, clay sites. Occurrences of basswood and red and green ash on warmer sites.

Note : See Mackey et al.<sup>1</sup> for a comparison of the climatic characteristics of Hills' Site Regions with the new Ontario Bio-climate Method.

**Appendix 2.** Summary of the 14-class Climate Classification.

| Climatic variable<br><br>Class | Mean total precip.<br>Period 1<br><br>(mm) | Mean total precip.<br>Period 3<br><br>(mm) | Mean growing degree-day<br>Period 3<br>(°C) | Mean growing season duration<br>(days) | Mean min. temp. of coldest month<br>(°C) | Mean max. temp. of warmest month<br>(°C) | Mean mean temp. of warmest quarter<br>(°C) | Mean precip. warmest quarter<br>(mm) |
|--------------------------------|--|--|---|--|--|--|--|--------------------------------------|
| Class 1                        | 195  | 611  | 2 219                                       | 231                                    | -11                                      | 27                                       | 20   | 240                                  |
| Class 2                        | 211  | 599  | 1 867                                       | 214                                    | -15                                      | 25                                       | 19   | 255                                  |
| Class 3                        | 200  | 575  | 1 573                                       | 191                                    | -20                                      | 25                                       | 17   | 281                                  |
| Class 4                        | 189  | 546  | 1 980                                       | 217                                    | -15                                      | 26                                       | 19   | 227                                  |
| Class 5                        | 179  | 516  | 1 688                                       | 199                                    | -19                                      | 25                                       | 18   | 236                                  |
| Class 6                        | 137  | 518  | 1 297                                       | 174                                    | -26                                      | 24                                       | 16   | 289                                  |
| Class 7                        | 168  | 498  | 1 447                                       | 180                                    | -23                                      | 25                                       | 17   | 258                                  |
| Class 8                        | 124  | 459  | 1 296                                       | 171                                    | -27                                      | 24                                       | 16   | 265                                  |
| Class 9                        | 115  | 453  | 1 134                                       | 164                                    | -29                                      | 23                                       | 15   | 275                                  |
| Class 10                       | 85   | 457  | 1 544                                       | 182                                    | -26                                      | 25                                       | 17   | 268                                  |
| Class 11                       | 158  | 487  | 1 169                                       | 174                                    | -24                                      | 22                                       | 15   | 257                                  |
| Class 12                       | 103  | 404  | 1 233                                       | 168                                    | -28                                      | 23                                       | 16   | 242                                  |
| Class 13                       | 87   | 385  | 1 018                                       | 158                                    | -30                                      | 22                                       | 14   | 244                                  |
| Class 14                       | 73   | 338  | 817   | 146                                    | -31                                      | 20                                       | 13   | 223                                  |

**Appendix 3.** Summary of the 49-class Climate Classification.

| Climatic variable<br><br>Class | Mean total precip.<br>Period 1<br>(mm) | Mean total precip.<br>Period 3<br>(mm) | Mean growing degree-day<br>Period 3<br>(°C) | Mean growing season duration<br>(days) | Mean min. temp. of coldest month<br>(°C) | Mean max. temp. of warmest month<br>(°C) | Mean mean temp. of warmest quarter<br>(°C) | Mean precip. warmest quarter<br>(mm) |
|--------------------------------|--|--|---|--|--|--|--|--------------------------------------|
| Class 1                        | 174                                    | 616                                    | 2 472                                       | 239                                    | -9                                       | 27                                       | 21   | 248                                  |
| Class 2                        | 177                                    | 587                                    | 2 310                                       | 234                                    | -10                                      | 27                                       | 21   | 232                                  |
| Class 3                        | 202                                    | 623                                    | 2 185                                       | 230                                    | -11                                      | 26                                       | 20   | 243                                  |
| Class 4                        | 224                                    | 624                                    | 1 987                                       | 223                                    | -12                                      | 26                                       | 19   | 240                                  |
| Class 5                        | 167                                    | 542                                    | 2 028                                       | 220                                    | -13                                      | 26                                       | 19   | 232                                  |
| Class 6                        | 194                                    | 572                                    | 1 917                                       | 216                                    | -14                                      | 26                                       | 19   | 244                                  |
| Class 7                        | 213                                    | 590                                    | 1 775                                       | 209                                    | -16                                      | 25                                       | 18   | 254                                  |
| Class 8                        | 209                                    | 559                                    | 2 057                                       | 223                                    | -13                                      | 26                                       | 19   | 208                                  |
| Class 9                        | 199                                    | 531                                    | 1 918                                       | 214                                    | -16                                      | 26                                       | 19   | 221                                  |
| Class 10                       | 187                                    | 530                                    | 1 727                                       | 202                                    | -19                                      | 25                                       | 18   | 238                                  |
| Class 11                       | 227                                    | 607                                    | 1 835                                       | 217                                    | -13                                      | 25                                       | 18   | 248                                  |
| Class 12                       | 196                                    | 584                                    | 2 086                                       | 220                                    | -15                                      | 26                                       | 20   | 239                                  |
| Class 13                       | 200                                    | 553                                    | 1 530                                       | 192                                    | -19                                      | 24                                       | 17   | 262                                  |
| Class 14                       | 176                                    | 505                                    | 1 662                                       | 205                                    | -17                                      | 24                                       | 17   | 212                                  |
| Class 15                       | 171                                    | 507                                    | 1 878                                       | 207                                    | -19                                      | 26                                       | 19   | 229                                  |
| Class 16                       | 209                                    | 602                                    | 1 694                                       | 201                                    | -19                                      | 25                                       | 18   | 278                                  |
| Class 17                       | 191                                    | 600                                    | 1 978                                       | 214                                    | -17                                      | 26                                       | 19   | 266                                  |
| Class 18                       | 181                                    | 536                                    | 1 441                                       | 181                                    | -24                                      | 24                                       | 16   | 285                                  |
| Class 19                       | 176                                    | 511                                    | 1 643                                       | 193                                    | -21                                      | 25                                       | 18   | 243                                  |
| Class 20                       | 170                                    | 493                                    | 1 472                                       | 181                                    | -23                                      | 25                                       | 17   | 248                                  |
| Class 21                       | 205                                    | 589                                    | 1 579                                       | 191                                    | -20                                      | 25                                       | 17   | 292                                  |
| Class 22                       | 180                                    | 528                                    | 1 562                                       | 187                                    | -22                                      | 25                                       | 17   | 270                                  |
| Class 23                       | 143                                    | 518                                    | 1 305                                       | 174                                    | -26                                      | 24                                       | 16   | 287                                  |
| Class 24                       | 132                                    | 477                                    | 1 232                                       | 170                                    | -27                                      | 24                                       | 15   | 271                                  |
| Class 25                       | 202                                    | 552                                    | 1 303                                       | 180                                    | -22                                      | 23                                       | 15   | 275                                  |
| Class 26                       | 138                                    | 467                                    | 1 311                                       | 173                                    | -25                                      | 24                                       | 16   | 255                                  |
| Class 27                       | 158                                    | 486                                    | 1 389                                       | 176                                    | -25                                      | 24                                       | 16   | 260                                  |
| Class 28                       | 132                                    | 432                                    | 1 240                                       | 170                                    | -27                                      | 24                                       | 15   | 244                                  |
| Class 29                       | 109                                    | 520                                    | 1 447                                       | 180                                    | -25                                      | 25                                       | 17   | 291                                  |
| Class 30                       | 178                                    | 508                                    | 1 161                                       | 175                                    | -23                                      | 21                                       | 14   | 264                                  |
| Class 31                       | 130                                    | 509                                    | 1 159                                       | 167                                    | -28                                      | 23                                       | 15   | 291                                  |
| Class 32                       | 89                                     | 492                                    | 1 604                                       | 185                                    | -24                                      | 25                                       | 18   | 281                                  |
| Class 33                       | 108                                    | 429                                    | 1 190                                       | 166                                    | -29                                      | 23                                       | 15   | 258                                  |
| Class 34                       | 138                                    | 470                                    | 1 106                                       | 174                                    | -24                                      | 20                                       | 14   | 251                                  |

(con't)

**Appendix 3.** Summary of the 49-class Climate Classification (concl.).

| Climatic variable<br>Class | Mean total precip.<br>Period 1<br>(mm) | Mean total precip.<br>Period 3<br>(mm) | Mean growing degree-day<br>Period 3<br>(°C) | Mean growing season duration<br>(days) | Mean min. temp. of coldest month<br>(°C) | Mean max. temp. of warmest month<br>(°C) | Mean mean temp. of warmest quarter<br>(°C) | Mean precip. warmest quarter<br>(mm) |
|----------------------------|--|--|---|--|--|--|--|--------------------------------------|
| Class 35                   | 145                                    | 467                                    | 1 208                                       | 173                                    | -25                                      | 23                                       | 15   | 251                                  |
| Class 36                   | 118                                    | 464                                    | 1 082                                       | 165                                    | -28                                      | 22                                       | 14   | 270                                  |
| Class 37                   | 73                                     | 418                                    | 1 590                                       | 184                                    | -26                                      | 25                                       | 18   | 248                                  |
| Class 38                   | 105                                    | 455                                    | 1 353                                       | 173                                    | -27                                      | 24                                       | 16   | 276                                  |
| Class 39                   | 109                                    | 402                                    | 1 249                                       | 170                                    | -27                                      | 24                                       | 16   | 230                                  |
| Class 40                   | 119                                    | 459                                    | 1 241                                       | 168                                    | -29                                      | 24                                       | 16   | 277                                  |
| Class 41                   | 89                                     | 464                                    | 1 481                                       | 179                                    | -26                                      | 24                                       | 17   | 273                                  |
| Class 42                   | 116                                    | 453                                    | 1 140                                       | 163                                    | -30                                      | 23                                       | 15   | 282                                  |
| Class 43                   | 97                                     | 413                                    | 1 062                                       | 160                                    | -30                                      | 22                                       | 15   | 260                                  |
| Class 44                   | 89                                     | 412                                    | 1 384                                       | 174                                    | -28                                      | 24                                       | 17   | 251                                  |
| Class 45                   | 80                                     | 370                                    | 950   | 154                                    | -30                                      | 21                                       | 14   | 239                                  |
| Class 46                   | 95                                     | 390                                    | 1 193                                       | 166                                    | -29                                      | 23                                       | 16   | 241                                  |
| Class 47                   | 73                                     | 347                                    | 839   | 148                                    | -31                                      | 20                                       | 13   | 228                                  |
| Class 48                   | 85                                     | 378                                    | 1 045                                       | 159                                    | -30                                      | 22                                       | 14   | 239                                  |
| Class 49                   | 72                                     | 319                                    | 759   | 142                                    | -31                                      | 19                                       | 12   | 214                                  |