

NODA

Notes

NODA • EDNO



NODA Note No. 12



SEEDWHERE: A COMPUTER TOOL FOR TREE PLANTING AND ECOLOGICAL RESTORATION

Brendan G. Mackey and Daniel W. McKenney

INTRODUCTION

This note discusses the potential application of the SEEDWHERE program to tree planting in southern Ontario. SEEDWHERE, a generic tool to help make biologically sound seed and nursery stock collection and transfer decisions, is available for use anywhere that the appropriate database development has occurred. At the time of writing such data are available for all of Ontario. In the future it will be possible to use the program in other parts of Canada as well.

The program determines the similarity of climate between planting and/or regeneration sites and also across large regions.

Southern Ontario is one of the most settled and developed regions in Canada. The intensity of land use has resulted in broadscale deforestation and a fragmented landscape where native forest vegetation is largely restricted to scattered patches. The characteristic biodiversity of southern Ontario differs from the rest of Canada. Characteristic biodiversity refers to the types of plant, animal, and microorganism species that are found in a region given the prevailing environmental conditions. For example, Hemessen (1994) noted the significance of the Carolinian life zone (Deciduous Forest Region) in southwestern Ontario. Here, native trees consist of hardwoods such as maple (*Acer* spp.), ash (*Fraxinus* spp.), oak (*Quercus* spp.), and hickory (*Carya* spp.), and "Carolinian" species, which reach their northern-most range within or just beyond the region. These species include the tulip tree (*Liriodendron tulipifera* L.), sycamore (*Platanus occidentalis* L.), sassafras (*Sassafras albidum* Nutt. Nees), cucumber tree (*Magnolia acuminata* L.), flower-

ing dogwood (*Cornus florida* L.), and black gum (*Nyssa sylvatica* Marsh.) and are often the target of ecological restoration activities in the most southern areas of Ontario.

Climate is generally recognized as one of the major environmental determinants of plant distributions. Each tree species has genetically inherited tolerances and growth responses to light, heat, moisture, and nutrients (the primary environmental regimes). Climate provides many of the major inputs that define these regimes. Hence, information about the spatial distribution of, and seasonal variation in, precipitation (snow and rain), maximum and minimum temperatures, radiation, and potential evaporation, is needed to understand the vegetation ecology of a landscape.

Figure 1 shows a bioclimatic classification of Ontario. This was generated from the Ontario Climate Model (OCM), which uses Geographic Information System (GIS) technology to generate spatially reliable estimates of long-term, mean monthly climatic parameters.¹ At this 14-group level, southern Ontario stands out as a distinctive bioclimatic domain having longer growing seasons and higher average temperatures (see Table 1, Hills 1960, MacIver and Whitewood 1990). In fact, some parts of eastern Ontario have a climate that is similar to deep southern Ontario.

Previously, it has been difficult to take account of climatic factors in tree planting. This is because climate (i.e., weather averaged over a long time period) is only recorded at a relatively small number of scattered weather stations. While the climate at each station may be known with some accuracy, it is difficult to obtain reliable estimates at other locations in the landscape. The Ontario Climate Model was

¹ Mackey, B.G.; McKenney, D.W.; Yin-Qian Yang; McMahon, J.P.; Hutchinson, M.F. 1995. Site regions revisited: A climatic analysis of Hill's site regions for the province of Ontario using a parametric method. Canadian Journal of Forestry Research. (In press.)



Natural Resources
Canada

Canadian Forest
Service

Ressources naturelles
Canada

Service canadien
des forêts



Ministry of
Natural
Resources

Ministère des
Richesses
naturelles

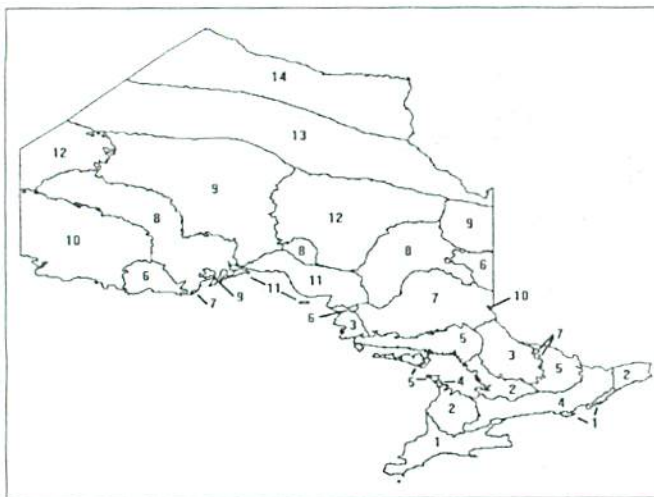


Figure 1. A 14-group climate classification for Ontario.

developed to overcome these problems, and enables spatially reliable estimates of selected bioclimatic parameters to be generated for any location in the entire province. Standard errors associated with the temperature estimates are approximately 0.5° Celsius and ± 10 percent for precipitation.

Given the fragmented nature of southern Ontario's remnant native vegetation, tree planting is an important strategy for restoring the region's characteristic biodiversity. Many benefits accrue from reestablishing stands of rare and endangered native southern hardwoods. These include: increasing the long-term viability of the remaining species and populations; increasing the possible future supply of high quality speciality timbers; providing habitat for associated plants, animals, and microorganisms; and maintaining ecological processes that may otherwise be absent or degraded.

It is possible of course to grow tomatoes on the moon, but only at a cost. Similarly, it is possible to grow many species under conditions far removed from their optimum natural environmental conditions, but the costs of management inputs and degraded plant response can make the enterprise inefficient. Sustainable forestry practices suggest that tree species should be planted in conditions that maximize their genetically inherited environmental responses. This means matching species to their optimum soil and climatic conditions. Planting seed that is maladapted to local climatic conditions can result in decreased growth rates, in-

creased probability of mortality, increased susceptibility to pests, and other dysgenic effects. Thus, the success of artificial regeneration programs can be affected if the climate where seed is planted is significantly different from the source location.

SEEDWHERE METHODOLOGY AND PROGRAM

SEEDWHERE is a PC-based program developed by the Canadian Forest Service (CFS) in collaboration with the Genetic Resource Management Unit of the Ontario Forest Research Institute (OFRI), Ontario Ministry of Natural Resources (OMNR). The SEEDWHERE study is part of a larger CFS project called the Bio-environmental Indices Project (BIP), which is aimed at better quantifying the trade-offs between biodiversity conservation and wood production (Mackey and McKenney 1994). This project is also financially supported by the Northern Ontario Development Agreement and the OMNR's Sustainable Forestry Initiative.

SEEDWHERE is generic in that it can be applied in any region where the necessary spatial database development has occurred. This requires 1) calculation of mathematical climate surfaces based on interpolation of long-term climatic means at a network of stations using the method of Hutchinson (1987) (see Hutchinson and Gessler 1994); 2) a digital elevation model or DEM (DEMs represent the topography of a landscape using a regular grid of elevation points); and 3) the means to couple the DEM to the climate surfaces, thereby generating gridded estimates of the climatic averages. All three steps require specialized computer programs developed by H.A. Nix and colleagues (Nix 1986). The gridded climatic data can be entered into a geographic information system and combined with other environmental, cadastral, or land-use data. Maps showing the geographic distribution of the climatic variables can then be produced.

The temperature and precipitation data are interpolated as a function of longitude, latitude, and elevation. This means that climatic values can be generated for any location where the position and elevation are known. Hence the model can be used to generate 1) values at a point or a network of points, and 2) a regular grid of elevations. The OCM was developed using the Hutchinson procedure, and has been coupled to a new digital elevation model (DEM) of Ontario with a resolution of about 1 km (Mackey et al. 1994).

Table 1. Mean, minimum, and maximum values for SEEDWHERE bioclimatic parameters in southern Ontario.

	Variable 1	Variable 2	Variable 3	Variable 4	Variable 5	Variable 6	Variable 7	Variable 8
Mean	199.7	584.2	2025.4	221.5	11.0	26.0	19.3	237.7
Min.	136.0	502.0	1679.0	200.0	-10.0	23.4	17.5	196.5
Max.	241.0	653.0	2551.0	243.0	18.8	27.7	21.7	267.9

Variables: 1. Total precipitation for Period 1.
2. Total precipitation for Period 3.
3. Growing degree-days above temperature for Period 3.
4. Number of days in growing season.

5. Minimum temperature of coldest month.
6. Maximum temperature of hottest month.
7. Mean temperature of warmest quarter.
8. Total precipitation of warmest quarter.

SEEDWHERE is essentially a special GIS designed to assist in making nursery stock and seed transfer decisions for forest regeneration. The program is based on the assumption that populations of tree species can become genetically differentiated through adaptations to local environmental conditions, in particular to climate. The program was designed to enable the climatic similarity of various locations to be measured, and for maps to be produced that indicate geographic areas and locations with a similar climate. The climate at seed collection sites can be compared with 1) potential regeneration sites, or 2) estimates of climate generated on the 1-km resolution grid covering a region or the entire province.

Currently, SEEDWHERE is using the eight bioclimatic parameters listed in Table 1. They are defined using time periods that relate to the seasonal cycle of trees in temperate and boreal ecosystems (see Figure 2). The climatic similarity is calculated using the Gower metric (Gower 1971), which is defined in Figure 3. This metric summarises the differences between the eight values at two points as an index between 0 to 1, where 0 is most dissimilar and 1 is exactly the same. Thus, when the climate at a location is compared to the gridded estimates of climate, the similarity is calculated and can be mapped. This method of grid matching follows that presented in Booth et al. (1987).

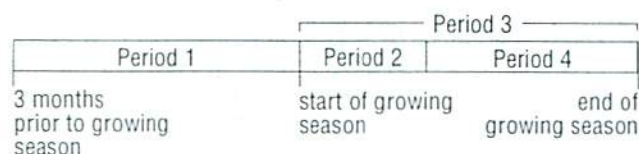


Figure 2. Rules used to define the growing season periods used by SEEDWHERE.

Notes: Period 1 refers to the 3 months prior to the growing season. Period 2 is the first 6 weeks of the growing season. Period 3 is the total growing season. The growing season was defined to start the Julian day number of the last day after 5 consecutive days when the mean daily temperature is at least 5° Celsius. These 5 days begin no sooner than the 1st of March and end by the 31st of July. The end of the growing season was defined as the Julian day number of the first day from August 1st that has a minimum temperature less than -2° Celsius. Period 4 is the difference between Periods 3 and 2. Period 2 or 4 data are not used in the current version of SEEDWHERE.

$$\text{Similarity} = 1 - \left(\frac{1}{n} \cdot \sum_{k=1}^n \frac{|V_{ik} - V_{jk}|}{\text{Range}(k)} \right)$$

where:

n is the total number of climatic attributes.

k is a climatic attribute.

V is the numerical value of the climatic attributes.

i, j are the actual objects being compared (e.g., seedlot or seedlots and grid cells).

Figure 3. The Gower metric used to measure the climatic similarity between two locations, or between a location and gridded estimates of climate.

SEEDWHERE and the Ontario Climate Model are being used by the Genetic Resource Management Program (GRM) of the OMNR to assist in development of better seed transfer zones and genetic management programs for selected tree species within the province. One outstanding research problem is determining critical thresholds (i.e., degrees of dissimilarity) beyond which seed should not be moved. This requires conducting controlled experiments on seed collected from populations across a climatic gradient and careful observation of differences in, for example, growth response. Such studies are presently being conducted by GRM and associated colleagues for a selection of tree species, including black spruce (*Picea mariana* [Mill.] B.S.P.), white spruce (*Picea glauca* [Moench] Voss), jack pine (*Pinus banksiana* Lamb.), white pine (*Pinus strobus* L.), and red oak (*Quercus rubra* L.) (Dr. D. Joyce, pers. comm.). Information from the black spruce study is being used to provide initial calibration data. However, this threshold problem will remain for lesser-studied species, particularly those from the Deciduous Forest Region of southern Ontario.

An alternative approach is to use existing survey data that samples the natural distribution of a tree species to derive an estimate of its potential climatic domain. For example, Mackey and Sims (1993) used the Ontario Climate Model to estimate long-term mean monthly climate at a network of forest plots scattered across northwestern Ontario. Subsequent statistical analysis correlated the distribution of three tree species; black spruce, red pine (*Pinus resinosa* Ait.), and large-toothed aspen (*Populus grandidentata* Michx.) with mean daily temperature of the warmest consecutive three months. This correlation was expressed as a probability. By coupling these results to gridded estimates of this climatic parameter, the probability of occurrence (or the relative climatic suitability) for these three species could be mapped across the region. Graham (1995) has begun to apply a variant of these techniques to southern Ontario tree species using the Ontario Climate Model and the DEM.

For some species, very few survey records may be available. In these cases, a SEEDWHERE approach may be the only feasible analytical procedure. The climate can be estimated at a known location of the species (or average conditions can be calculated based on estimates of climate at a few sites), and then compared to gridded estimates of the climatic parameters. The result will be a map indicating those landscapes that have a relatively similar climate. Such an analysis will indicate locations where establishment of a species using seed from the source location is most likely to succeed (in terms of climate). It also indicates where a possible search for new seed sources of the species could begin. For example, a SEEDWHERE analysis could be applied to a location that is presently treeless to determine where there are climatically similar landscapes that could function as a seed source for reforestation or ecological restoration.

Ultimately, a combination of methods is needed: domain analysis based on existing species location data such as found in herbaria; controlled genecology experiments; and (in the

absence of biological data) analysis of spatial patterns in the controlling physical environmental processes, such as climate. These analytical tools can help ensure that decisions about tree planting, artificial regeneration, and ecological restoration are made inclusive of climatic factors.

APPLICATION OF SEEDWHERE TO TREE PLANTING IN SOUTHERN ONTARIO

The new DEM for Ontario enables useful analysis of bioclimate at both regional and provincial scales. The southern Ontario portion of the DEM has been used here to illustrate the potential of SEEDWHERE to assist in the strategic planning of tree planting in this part of the province.

The southern Ontario section of the DEM was coupled to the Ontario Climate Model to generate gridded estimates of the parameters noted in Table 1. Figures 4 and 5 show gridded estimates for two of the climatic parameters — “length of growing season” and “precipitation during the growing season (Period 3)”. Figures 6 and 7 map the relative climatic similarity across the region based on the climate at the two locations as indicated. The figures cover southern Ontario, from the Bruce Peninsula across and into eastern Ontario. Both analyses assume that seed from a tree species has been collected from each location and the question is, “Where else is the climate similar?”.

The results illustrate a critical point about spatially based bioclimatic analysis; namely, that climatic similarity does not necessarily equate with geographic adjacency — the nearest landscape with the most similar climate may be located some distance from the source location. This is because climate varies as a function of a number of processes, but is particularly influenced by the interaction between the direction of the prevailing weather systems and topography. The interpolation procedure used to generate the Ontario Climate Model explicitly captures many of these effects resulting in a spatially reliable model. Figures 4 and 5 both show the effects of the Great Lakes and elevation in modifying local climate, thereby spatially interrupting (in the case of temperature) broad latitudinal trends.

It is worth noting that the similarity index values are dependent upon the geographic extent of the study. For example, different index values would be generated comparing the climate at a point to the provincial grid versus a regional grid as used here. However, the general trends would remain stable.

CONCLUDING COMMENTS

The Ontario Climate Model and SEEDWHERE can be used in the absence of biological data to assist decision makers and resource managers. The climatic regionalization shown in Figure 1, and the SEEDWHERE analyses in

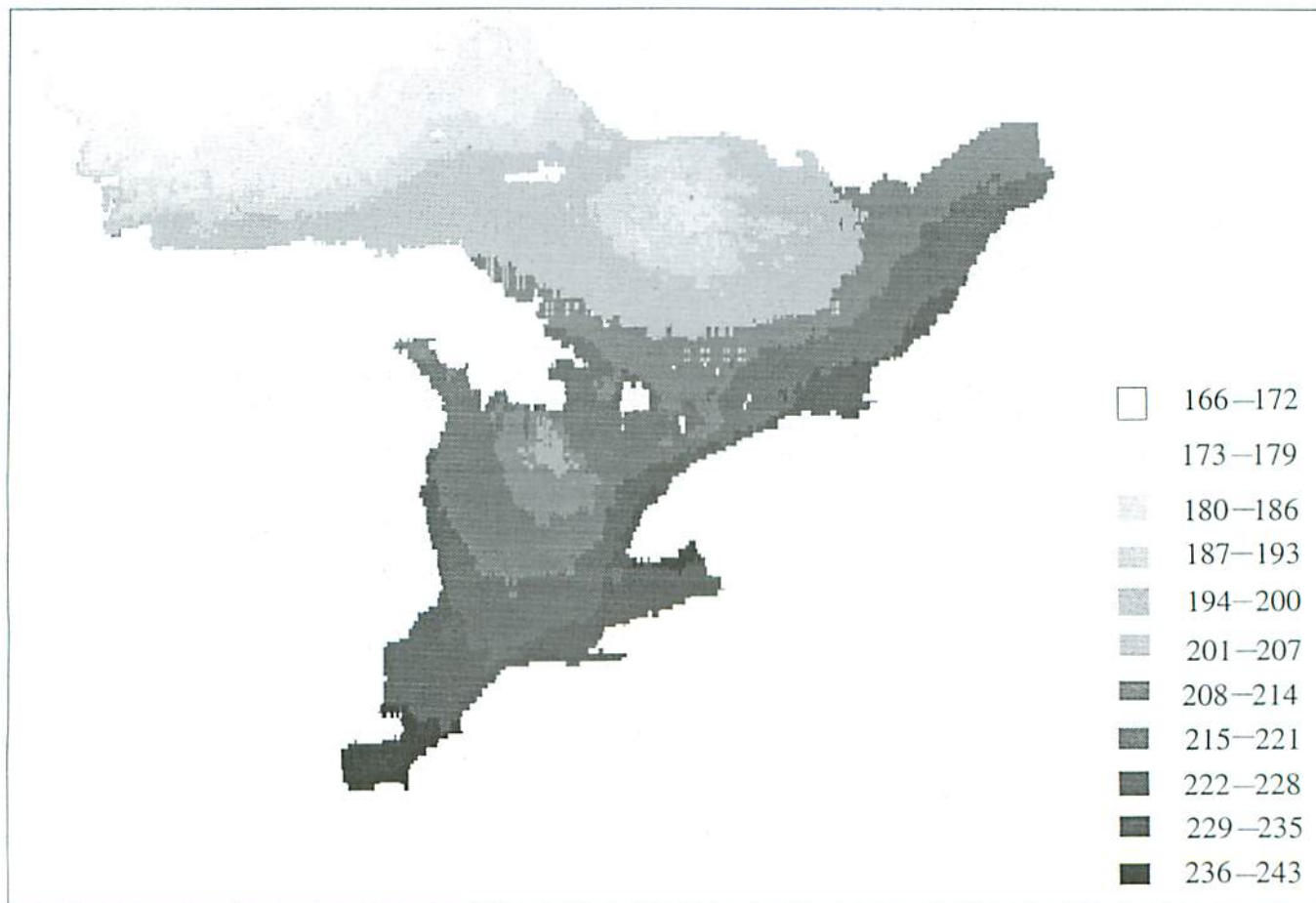


Figure 4. Length of growing season for southern Ontario, generated using the Ontario Climate Model and the 1-km resolution digital elevation model.

Errata - Noda Note No. 12. SEEDWHERE: A Computer Tool for Tree Planting and Ecological Restoration

Please note that Figure 5 on page 5 was printed with an error in the legend. Please replace with the following corrected figure. Sorry for the inconvenience.

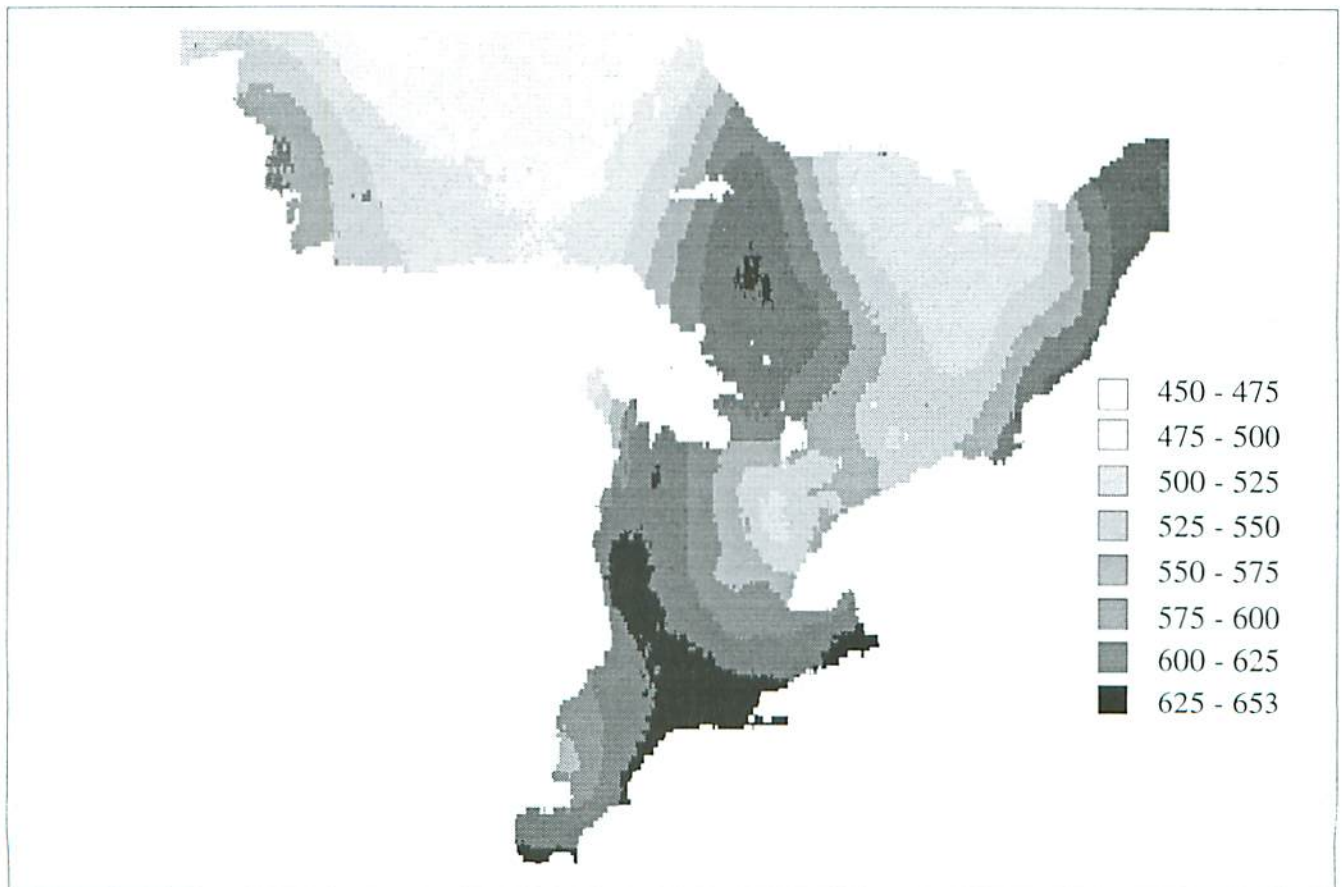


Figure 5. Total precipitation (mm) for period 3 for southern Ontario, generated using the Ontario Climate model and the 1-km resolution digital elevation model.

Figures 6 and 7, define spatial patterns in climate that would be expected to coincide with significant differences in biotic responses (e.g., species distributions, species abundance, plant phenology, and growth rates). However the potential of SEEDWHERE is more fully realised when field data are available to calibrate the climatic response of particular species (e.g., the genecology work of D. Joyce). Computer-based methods do not remove the need for carefully collected field data and professional judgement; rather, they enable value to be added and more useful information to be extracted.

SEEDWHERE, and the Ontario Climate Model that underpins it, are being further developed as new information about species-based responses becomes available, and as new climate surfaces are developed. The parameters listed in Table 1 are based on monthly surfaces of minimum temperature, maximum temperature, and total precipitation. New surfaces are under development for a range of additional parameters, including radiation, potential evaporation, and snow.

It is important to note that SEEDWHERE is modeling climate in relation to mesoscaled topography factors (position and elevation). It is not modeling climate in relation

to microscaled topographic processes, i.e., slope, aspect, and horizon shading. The latter can affect radiation, temperature, evaporation, and hence moisture availability. The mesoscaled models, however, set the primary climatic constraints within which plants operate, and are the appropriate scales to analyse regional climate and the potential distribution and productivity of tree species.

Nonetheless, the effects of finer-scaled processes should ultimately be incorporated, particularly those that relate to plant-water relations. Precipitation is only one component of the moisture regime. The amount of water available to a tree is also a function of evaporation rates (climatically driven), run-on, and run-off (as controlled by topography), and soil water storage. It is possible to integrate climate, soil, and topography to calculate a dynamic water balance (see Moore et al. 1993), but this requires detailed information about site conditions. To make spatial predictions based on these functions requires a similarly fine resolution spatial database for the key soil and topographic attributes. Ongoing research and development within the BIP (Mackey et al. 1994, Mackey et al.²) is aimed at developing the terrain component required to implement these more comprehensive environmental analyses.

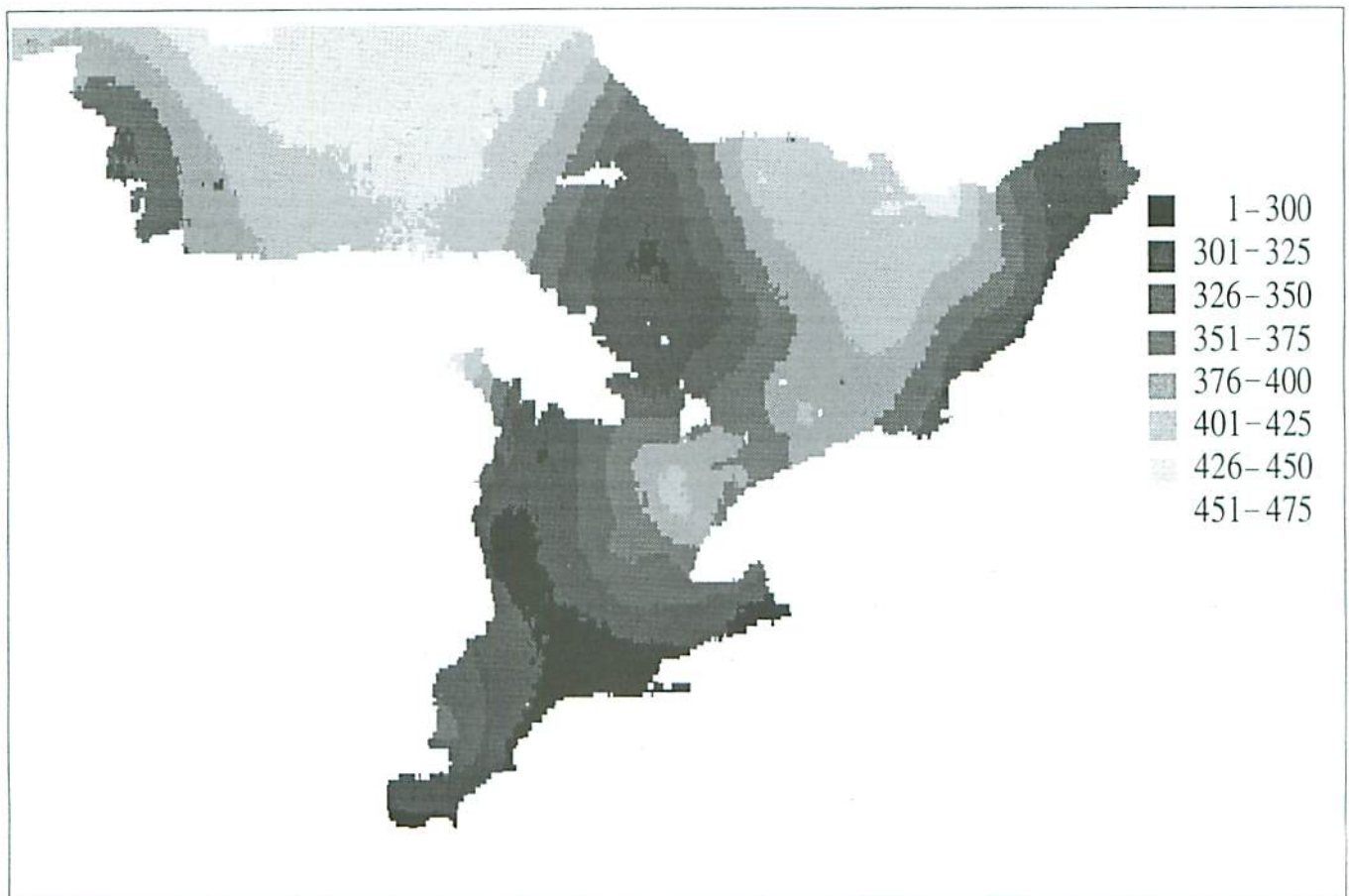


Figure 5. Total precipitation (mm) for Period 3 for southern Ontario, generated using the Ontario Climate Model and the 1-km resolution digital elevation model.

² Mackey B.G.; Sims, R.A.; Baldwin, K.A.; Moore, I.D. 1993. Spatial analysis of boreal ecosystems: Results from the Rinker Lake case study. *in* GIS and Environmental Modelling. Second International Conference/Workshop on GIS and Environmental Modelling Proceedings. Breckenridge, CO. GIS World. (In press.)

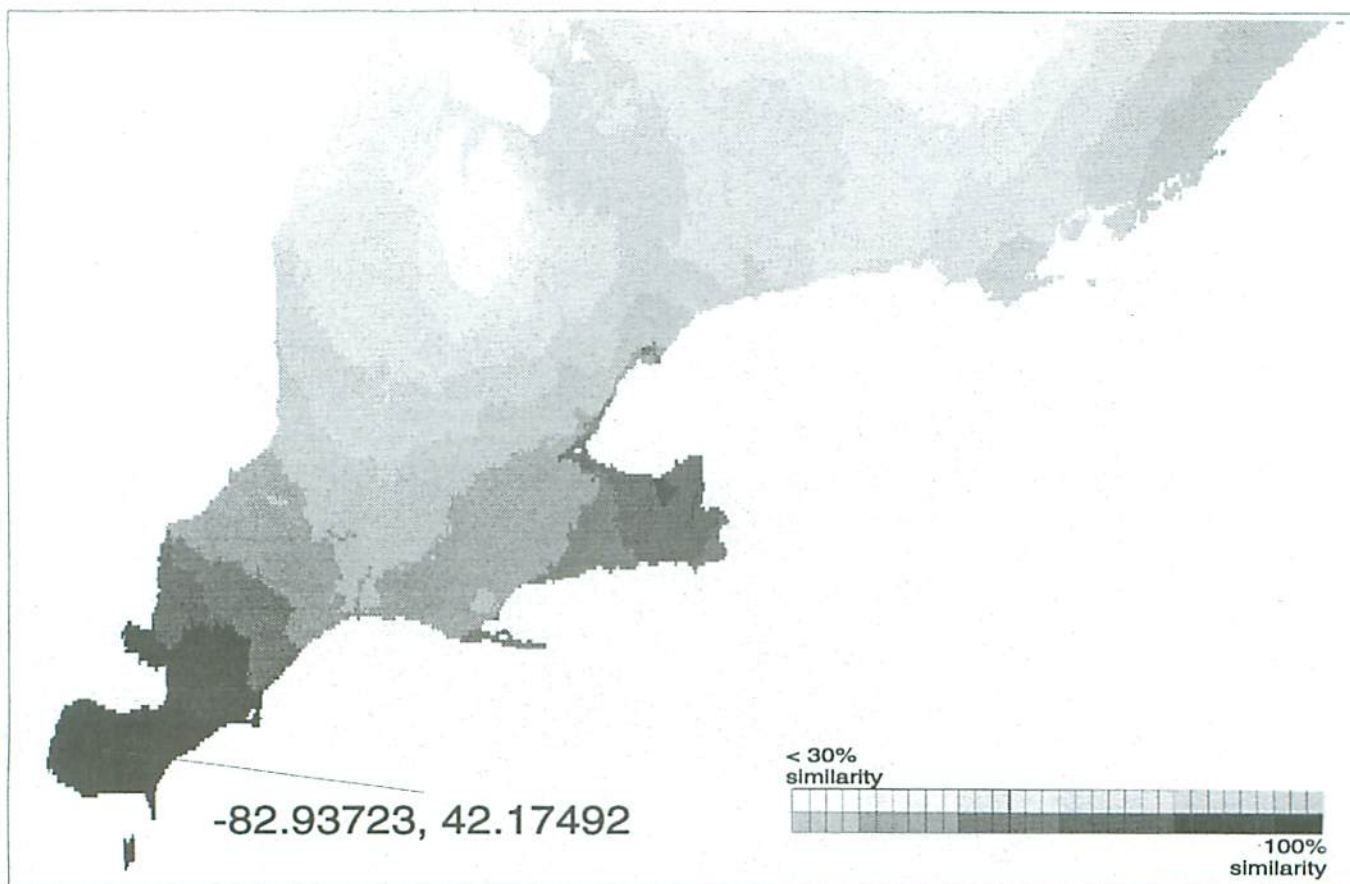


Figure 6. Climatic similarity index for southern Ontario based on climate estimated for the location -82.93723 degrees longitude, 42.17492 degrees latitude.

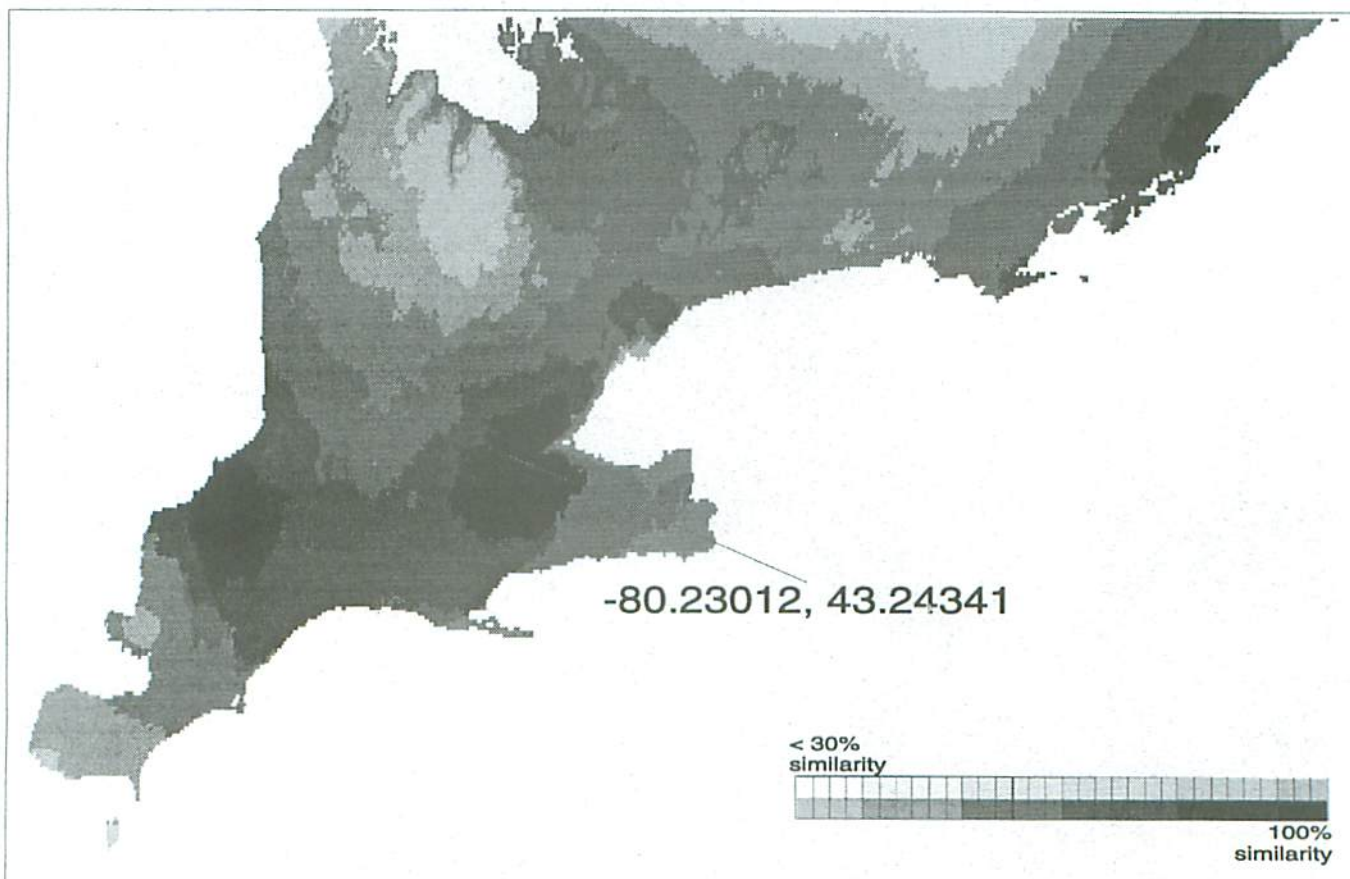


Figure 7. Climatic similarity index for southern Ontario based on climate estimated for the location -80.23012 degrees longitude, 43.24341 degrees latitude.

OBTAINING SEEDWHERE

The SEEDWHERE program, manual, and sample exercise is available on a 3.5-in disk. These may be obtained by completing the form at the end of this note. For individuals working for the Ontario Ministry of Natural Resources, Dr. Dennis Joyce, Genetic Resource Management Program, Ontario Forest Research Institute, Sault Ste. Marie, Ontario, is the point of contact to obtain the model (phone 705-946-2981).

ACKNOWLEDGMENTS

The authors would like to thank Bryan Nippers for programming SEEDWARE and for his assistance in the SEEDWHERE analyses presented here. They also thank Janice McKee and Cheryl Widdifield for preparation of the figures, and Dave Kennington for producing the logo. In addition they would like to acknowledge the financial and intellectual support of Dennis Joyce and Brad Graham (OMNR, Genetic Resource Management Program, Sustainable Forestry Initiative). The Northern Ontario Development Agreement and Tree Plan Canada have also provided financial support.

LITERATURE CITED

Booth, T.H.; Nix, H.A.; and Hutchinson, M.F. 1987. Grid matching – a new method for homoclimate analysis. *Agricultural and Forest Meteorology* 39:241–255.

Gower, J.C. 1971. A general coefficient of similarity and some of its properties. *Biometrics* 27:857–871.

Graham, B.G. 1995. Modelling distributions of rare Carolinian tree species in Southwestern Ontario. Unpublished M.Sc. thesis. University of Western Ontario, London, ON. 147 p.

Hemessen, D.V. 1994. Tree planting in the Carolinian Life Zone of Canada: Current activities, issues and recommendations. Report to the Canadian Forest Service. Tree Plan Canada, Ottawa, ON. 29 p.

Hills, G.A. 1960. Regional site research. *Forestry Chronicle* 36:401–423.

Hutchinson, M.F. 1987. Methods for generation of weather sequences. p.149–157 in A.H. Bunting, ed., *Agricultural Environments: Characterisation, Classification and Mapping*. CAB International, Wallingford, United Kingdom.

Hutchinson, M.F.; Gessler, P. 1994. Splines: More than just a smooth interpolator. *Geoderma* 62:45–67.

Mackey, B.G.; McKenney, D.W. 1994. The bio-environmental indices project: An overview. *Nat. Resour. Can., Canadian Forest Service–Ontario, Sault Ste. Marie, ON. NODA Note No. 1. 5 p.*

Mackey, B.G.; McKenney, D.W.; Widdifield, C.; Sims, R.A.; Lawrence, K.; Szczyrek, N. 1994. A new digital elevation model of Ontario. *Nat. Resour. Can., Canadian Forest Service–Ontario, Sault Ste. Marie, ON. NODA/NFP Technical Report TR-6. 26 p.*

Mackey, B.G.; Sims, R.A. 1993. A climatic analysis of selected boreal tree species, and potential responses to global climate change. *World Resources Review* 5(4):469–487.

MacIver, D.C.; Whitewood, R.D. 1990. Forest climates of Ontario. Parts I and II. Ontario Ministry of Natural Resources, Toronto, ON.

Moore, I.M.; Gallant, J.C.; Guerra, L.; Kalma, J.D. 1993. Modelling the spatial variability of hydrological processes using GIS. In K. Kovar and H.P. Nachtnebel, eds. *Applications of Geographic Information Systems in Hydrology and Water Resources Management. Proceedings of the international conference held in Vienna, Austria, 19–22 April, 1993. International Association of Hydrological Sciences, Wallingford, United Kingdom. 693 p.*

Nix H.A. (1986). A biogeographic analysis of Australian elapid snakes. p. 4–15 in R. Longmore, ed. *Atlas of Australian Elapid Snakes*. Bureau of Flora and Fauna, Canberra, Australia. 115 p.

The views, conclusions, and recommendations contained herein are those of the authors and should be construed neither as policy nor endorsement by Natural Resources Canada or the Ontario Ministry of Natural Resources. This report was produced in fulfillment of the requirements for NODA/NFP Project No. 4208, "Bio-environmental indices: a new approach to trade-off analysis in forest planning".

Additional copies of this publication are available from:

Natural Resources Canada
Canadian Forest Service—Sault Ste. Marie
Great Lakes Forestry Centre
P.O. Box 490
Sault Ste. Marie, Ontario
P6A 5M7
(705)949-9461
(705)759-5700(FAX)

©Her Majesty the Queen in Right of Canada 1995
Catalogue No. Fo 29-41/12-1995E
ISBN 0-662-23693-9
ISSN 1198-2233



This report is printed on recycled paper.

Please send me the diskettes containing the SEEDWHERE manual, exercise, and sample southern Ontario grid.

Forward request to:

Publication Services
Natural Resources Canada
Canadian Forest Service—Sault Ste. Marie
P.O. Box 490
Sault Ste. Marie, Ontario, Canada
P6A 5M7
Fax (705) 759-5700

Name _____
Address _____
City _____
Province _____
Postal Code _____
Country _____

Canada