

AN ABSTRACT OF THE THESIS OF

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Abstract approved: _____
Signature redacted for privacy.

David W. Hann

The focusing of public attention on the practices of forest managers has resulted in the need for new tools to help explain the results of these practices. The traditional tools of tables and graphs of numerical values require a significant investment in learning the forestry profession. Once the investment is made it isn't always easy to transfer the experience gained in one ecosystem to other forest ecosystems. A tool that can bridge the gap in understanding is a pictorial display of forest components. A pictorial display won't provide the exactitude of traditional methods, but it can provide a basis for promoting the understanding of traditional forms of ecosystem quantification. The VIZ4ST program is such a tool.

VIZ4ST uses L-systems to render forest trees. The L-systems are calibrated to existing architectural relationships to eliminate user bias. VIZ4ST uses an inhibition process to generate coordinates for forest trees. This method is validated with Ripley's $K(d)$ function in nine mapped forest stands and is found to replicate the detected spatial patterns well.

**Generation of an Animation Interface
for the ORGANON Growth and Yield Model**

by

Mark L. Hanus

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Professor of Forest Resources, Department of Forest Resources

Head of department of Forest Resources

Dean of Graduate School

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Generation of an Animation Interface for the ORGANON Stand Development Model.

INTRODUCTION

Visualization is critical to the understanding and analysis of data. Statisticians have explored the various aspects of displaying data from complex analysis procedures, and concluded that the most successful methods are those that render the data in a way most familiar to the user (Cleveland 1993). This is why graphs usually convey a feeling for the data that is lacking in tables, and why the use of color changes the way a graph is interpreted. In forestry the natural unit of display is the tree. Trees are recognizable to everyone even those people that lack formal forestry training. Graphs and tables can convey the state of the forest stand in very particular terms but require education to interpret. Pictures of trees can connect with people to a much greater degree.

The display of the forest stand as a rendered forest scene offers the opportunity of relating with the viewer in a way that isn't possible with tables and graphs. Pictorial scenes allow the viewer to rapidly assimilate information, since the data is presented in a familiar form. Pictorial scenes can't replace the use of tables and graphs since the perception of the stand is greatly influenced by varied aspects of the drawing, such as color and positioning, but they can provide a reference point allowing communication of particulars with tables and graphs.

In scene rendering the scale of resolution of the objects is a function of the scale of the data being displayed, the purpose of the display, and the processing power of the machine displaying the data. As the image moves closer to the viewer the less visible are the spatial patterns between the forest objects, and the more the patterns within the object are visible. Thus no one display will offer everything for every use, and all will require compromise over what is ideal.

The communication of complex situations requires that the ideal visualization tool be free from sources of bias that taint perception of the collected data. The user must have the freedom to display the data in a way that communicates the information contained within it but not so free that perception is manipulated. There is as yet no ideal visualization tool.

The three articles that follow describe a computer program, VIZ4ST, that is designed to work with the ORGANON growth and yield model (Hann et. al, 1993). The first article describes the methods used to generate the forest objects. The article is written for *Simulation* the journal of the Society of Computer Simulation. The audience computer professionals involved in the design of simulation systems. In the article, the application of Lindenmayer systems in the creation of forest objects that can be rendered to the screen to reflect observed inter-individual relationships is discussed.

The second article describes the methods used for generation of the spatial coordinates of the forest objects. This article is intended for *Forest Science*. *Forest Science* is the journal of the Society of American Foresters. The intended audience is the professional forester, or forest researcher. A non-simple sequential inhibitory

coordinate generation process is proposed for coordinate generation and the efficacy of the process is assessed.

The final article is the users manual for the VIZ4ST. It is intended to accompany the released version of the program. The intended audience is the user of the program who is interested in how to use the program to display data and model results. It describes the operation of the software package and its relationship to the ORGANON model.

CHAPTER 2:

Visualization of Forest Stand Structure

Mark L. Hanus and David W. Hann

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CHAPTER 2:**Visualization of Forest Stand Structure****ABSTRACT**

The focusing of public attention on the practices of forest managers has resulted in the need for new tools to help explain the results of these practices. The traditional tools of tables and graphs of numerical values require a significant investment in learning the forestry profession. Once the investment is made it isn't always easy to transfer the experience gained in one ecosystem to other forest ecosystems. A tool that can bridge the gap in understanding is a pictorial display of forest components. A pictorial display won't provide the exactitude of traditional methods, but it can provide a basis for promoting the understanding of traditional forms of ecosystem quantification.

Creating realistic renderings of forest plants, requires the integration of a broad range of scientific results relating to plant form, texture, and color, and its changes through time. The lack of quantitative measurements of these parameters make compromises necessary, but these compromises must not affect the ability to integrate new information as it becomes available.

VIZ4ST (Hanus and Hann 1995) is a computer program allowing the display of forest stand structure on a personal computer. It makes use of commonly collected forest data to display inter-individual relationships in forest stands in a familiar manner.

INTRODUCTION

Decision making in forestry is a data intensive process. The first step in the process involves collecting various measurements from a statistically valid sample of trees from the particular piece of forest land (or "stand") of interest. The ensuing tree list and measurements are then transformed and summarized in many different ways, and the results displayed as tables and/or graphs of numerical values to characterize current structure and condition of the stand. Often forestry decisions will also require the usage of stand development models (Hann and Riitters 1982) to provide accurate and precise predictions of future structure and condition of the stand, with the results again being displayed as tables and/or graphs of numerical values. Finally, these table and graphs are used by the forester to analyze management alternatives in order to reach a final decision concerning the silvicultural practices to be applied to the stand.

However, the increasingly interested and involved public now requires a re-examination of the manner in which the proposed forest practices are communicated to them. The traditional methods of tables and graphs require a significant amount of education before they are fully understood. The differences in various options for forest management are at times subtle, and unless the users of the tables and graphs are familiar with the practices in advance they may be unable to distinguish between alternatives that result in significantly different future conditions. It must be very clear to all parties exactly what a given table, graph or list of sample trees portrays and how it can be expected to change with time.

Photographs can be used to bridge this communication gap but they require the photographer to find a comparable stand and observation point to photograph it from. Many of the new forest practices result in conditions that are not commonly found in the existing landscape. Thus a large amount of time may be required to find and photograph them, and once the stand is located it may be difficult to illustrate the necessary details.

The ability to select the view location and display data, or model results, on an office computer makes examination of subtle aspects of forest practices possible. Computer generation of the forest scene allows the forester to communicate subtle differences in forest structure to persons unfamiliar with the areas and species in question. When coupled with a computer model that predicts the dynamics of future stand development, it also provides a method of experimenting on the forest without actually conducting operations.

Foresters are accustomed to viewing stands from certain angles and distances, and use details of plant structure to formulate management decisions. The use of aerial photographs, especially in stereo pairs, is common. It is expected that building confidence in the ability of the program to replicate natural conditions will be much easier if the scenes produced contain the requisite details and correspond to currently used perspectives. The forester would like to see aerial views, perhaps combined in stereo pairs, as well as views of the stand from the side and interior. Interior views are the most computationally intensive and require regulation of large amounts of information. Currently, they are beyond the scope of personal computers to reproduce

in sufficient detail. Views from outside of the stand can be generated with much less computational overhead since the amount of detail is regulated by distance from the stand.

A key to successful scene rendition is regulation of detail. The detail required by the forester to make management decisions is concentrated in the inter-individual scales. Details of leaves, flowers and fruits although important in some situations are not as important as the relationships of the location of individuals. The complexity of the individual forest objects can be reduced without loss of details relevant to this type of decision making. Thus the use of the scene can be used to regulate the amount of detail required. As processing power increases the amount of visible detail can be increased, or the scope of the rendered scene can be increased, depending on the needs of the user.

VIZ4ST is a computer program for the display of forest stand structure. It operates in the DOS environment, requiring only a VGA graphics card. It takes as input a measured tree list to display a current stand or a predicted tree list, generated by the ORGANON (Hann et al. 1993) stand development model, to display the future conditions of the sampled stand. The tree list must come from a statistically valid sample of the stand and must include each sample tree's species, diameter outside bark 4.5-feet above ground line, total height of the stem, length of the living crown, and the number of trees per unit area that each tree represents. Currently, 23 tree species can be represented in VIZ4ST (Table 1).

TABLE 1. Tree species drawn by the first release of VIZ4ST.

Species Code	Tree Species
011	Pacific silver fir <i>Abies amabilis</i> Dougl. ex Forbes
015	White Fir <i>Abies concolor</i> (Cord. & Glend.) Lindl. ex Hildebr.
017	Grand Fir <i>Abies grandis</i> (Dougl. ex D. Don) Lindl.
021	Shasta Red fir <i>Abies magnifica</i> A. Murr.
022	Noble fir <i>Abies procera</i> Rehd.
081	Incense Cedar <i>Libocedrus decurrens</i> Torr.
098	Sitka spruce <i>Picea sitchensis</i> (Bong.) Carr.
108	Lodgepole Pine <i>Pinus contorta</i> Dougl. ex Loud.
116	Jeffery Pine <i>Pinus jeffreyi</i> Grev. & Balf.
117	Sugar Pine <i>Pinus lambertiana</i> Dougl.
119	Western white pine <i>Pinus monticola</i> Dougl. ex D. Don
122	Ponderosa Pine <i>Pinus ponderosa</i> Dougl. ex Laws
202	Douglas-fir <i>Pseudotsuga menziesii</i> (Mirb.) Franco
242	Western Redcedar <i>Thuja plicata</i> Donn ex D. Don
263	Western Hemlock <i>Tsuga heterophylla</i> (Raf.) Sarg.
312	Bigleaf Maple <i>Acer macrophyum</i> Pursh
351	Red Alder <i>Alnus rubra</i> Bong.
361	Pacific Madrone <i>Arbutus Menziesii</i> Pursh
431	Golden Chinkapin <i>Castanopsis chrysophylla</i> (Dougl.) A. DC.
631	Tanoak <i>Lithocarpus densiflorus</i> (Hook. & Arn.) Rehd.
805	Canyon Live Oak <i>Quercus chrysolepis</i> Liem.
815	Oregon White Oak <i>Quercus garryana</i> Dougl. ex Hook.
818	California Black Oak <i>Quercus kelloggii</i> Newb.

OBJECT DESIGN

All objects have characteristic form, size, texture, and color. Plants consist of roots, stems, branches, leaves, flowers and fruits. Each of the components have their own forms, textures, sizes, and colors which vary by species and by individuals within

the species. The ideal representation of a plant would include exact replicates of these characteristics in their proper relation to one another.

The current structure of a natural system is largely determined by its history. Observed branch pattern is a record of the historical forces exerted on individual parts of individual plants (Fisher 1992). Placement of the plant on the landscape is a function of the history of the location (Rapport 1991). Information on the history of each location is not available to the program and thus surrogates must be used to approximate the effects of time. A stochastic model is used to simulate the uncertain effects of time on the individual, while a non-simple sequential placement process is used to model the location of the plants.

The realistic plant object

For the type of forestry applications of current concern, a realistic rendition of a plant would require realistic renditions of its stem(s), branches, and leaves. Each of these components will require a number of different attributes to create realistic renditions. These attributes can be measured directly in the field or they can be predicted indirectly using regression equations developed through research.

The number of stems a plant may have will depend upon species characteristics and/or historical events that have impacted the individual. Each stem can be characterized by its size and form and by the color and texture of its bark (Harlow and Harrar 1969). In addition to these size attributes, stem form incorporates the degree of

sinuosity and swelling found in the stem. To render realistic branches would require information on the number and placement of primary branches on the main stem, and the size, degree of sinuosity and angle of insertion into the main stem for each primary branch (Fisher 1992). Characteristics for describing higher order branches include their size, frequency and branching pattern (Fisher 1992). Finally, leaves can be described by their number, size, shape, color and placement on branches (Harlow and Harrar 1969).

In nature, patterns of branching change with time and with location on the plant. Some species exhibit different plant architectures depending upon the habitats in which they are found. Other plants may cross over from one architectural form to another during their life span, thus requiring some knowledge of plant age (Fisher and Honda 1979). Changes in the form of conifer crowns with geographic latitude, and social position in the stand have been noted (Koch 1987) for some species. Finally, variations in the color and texture of plants can also reflect historical and current environmental factors, including transients such as the amount of lighting available to the plant.

In their work on tropical plants Hallè et al. (1978) used number of main stems and a description of branching patterns to identify 23 types of plant architectures. The ideal model of a plant would integrate these architectures with measures of the form, size, texture, color, orientation and placement of the stem, branches and leaves, and it would incorporate specific characteristics with species appropriate ranges, and rates of occurrence.

Compromises

The goal of the model is to provide users with a rendering tool for forest stand structure that will run on a personal computer. This goal and the lack of quantitative models for many of the attributes associated with structure for many plant species have required compromises in both the model's capabilities and the rendition of realistic objects. When more advanced processing power becomes available or when new information on the structure of individual plants is derived, the model's structure should be flexible enough to allow new capabilities and structural information to be incorporated into it.

One method of reducing the computational load, is to reduce the amount of detail that the processor is required to carry. This can be done by restricting the range of view distances encompassed by the model. Again, the model should be constructed such that, when additional computational power becomes available, it can be easily modified to allow greater ranges in viewing distance and to reflect the increased detail arising from closer perspectives.

Computationally, the simplest method of rendering trees is to paint geometric solids with a texture pattern defined for each species. The results are fully scaleable, and have a three dimensional structure, but being solid they obscure everything placed behind them, and suffer from aliasing problems, which occurs when the amount of detail painted to the screen is inappropriate for the scene being rendered. In addition to aliasing, objects derived in this manner are solids lacking internal structure. The range

of possible view distances is limited by the inability to observe the stand from within it. However, if the region to be displayed is large and irregular, like a landscape level view, this is a promising technique.

Lindenmayer (1968) described a set of rules for the definition of three dimensional structures that produce more realistic appearing trees with internal detail: he called them L-systems. They were derived from the observation that, in many plant growth processes, structures are regularly repeated. This self-similarity can be exploited to produce an algorithm that replicates the structure of the plant. When the results of the deterministic algorithm are perturbed stochastically each plant is rendered an individual, giving the displayed forest a more natural appearance.

Conifers

The conifer species of the western United States exhibit a monopodial form, characterized by strong apical dominance. Monopodial trees have a central stem from which the primary branches protrude. In the VIZ4ST model, the equations that define the fifteen conifer species (Table 1) assume that the central stem is continuous, unbroken, and parallel to the z-axis. The stem is modeled as an octagonal right pyramid, since the range of display is such that increased detail would not be distinguishable. The size of this pyramid is determined by the measures of diameter outside bark at 4.5 feet above ground line and the total height of the stem. This simple stem model will be replaced by more realistic stem form equations (Hann 1994)

when the viewpoint distance becomes small enough such that this type of detail is recognizable. Finally, the color of the stem is determined by known species characteristics (Harlow and Harrar 1969), while bark texture could be incorporated into VIZ4ST when shorter viewing distances become possible.

In the western United States, the number, placement, size and angle of insertion of primary branches have only been studied in detail for young Douglas-fir (Roeh 1993, Maguire et al. 1994). However, the allocation of primary branches along the stem in most conifers of the western United States is concentrated at whorls (e.g., Maguire et al. 1994). In general, a whorl is added every year from lateral buds set at the end of the previous year's period of height growth. Therefore, whorls are groups of branches that grow from the stem at nearly the same height. Approximate location of these whorls can be determined using existing dominant height growth equations (Hann 1995), and the number of whorls with live branches can be determined from measured crown length.

Calculating the position of and then rendering the branches at each whorl would be very computer intensive and, at the view point distances used in VIZ4ST, the resulting crown would look too dense due to limits caused by pixel size and color range. Therefore, depiction of primary branches was limited to every fifth whorl. The number of branches displayed at each whorl is selected randomly from a truncated normal distribution with a mean of five branches and a range of from three to seven branches. These values can be easily changed when species specific information becomes available.

The angles of insertion for primary branches previously quantified for young Douglas-fir (Roeh 1993) were used for all other monopodial tree species.

Specification of angle of insertion and the height of the branch within the crown are sufficient to define branch length if crown shape relationships are available for use.

Hann and Ritchie (1985) present crown shape equations for many of the tree species of interest and, therefore, they were chosen for use in the model.

Conifers are divided into three general classes, pines, cedars and other conifers, based on their secondary branch and leaf structure. Pines have fewer secondary branches that divide less often than secondary branches on the other non-pine species, and cedars have more secondary branching than other non-pine conifers. For all species, additional secondary branches are added near the tip of the tree to give it a more fully defined form. The pines have needle clusters at the ends of the secondary branches, while the other non-pine species have needles that extend further along the secondary branch into the crown. Appropriate needle colors (Harlow and Harrar 1969) have been selected for each species characterized by VIZ4ST.

Hardwoods

The principal hardwood species of the western United States exhibit three architectural forms, multiaxial, multipodial, and ternary. In addition to the particulars of their architecture, species are defined by differences in stem form, branch form, leaf size, shape, and color.

The primary distinguishing characteristics of hardwoods are their leaves.

Differences in the size, shape, color and texture of leaves provide familiar visual clues to the identity of plant species (Harlow and Harrar 1969). However, drawing every leaf on a tree would require large amounts of processor time. To reduce this, the number of leaves drawn on each branch is made a function of viewpoint distance. Enough leaves are depicted to give a realistic impression without obscuring other details of the tree.

Multiaxial Hardwoods

Trees with multiple stems are classed as multiaxial. Tanoak and canyon live oak are represented as a multiaxial trees. For each multiaxial tree sampled, the number of stems in its clump is selected randomly from a uniform distribution with a range of from two to four central stems, and the number of trees per unit area represented by the sample tree is reduced by the randomly drawn number. All stems in the clump will have the same diameter outside bark above ground line, total height and length of crown. More realistic characterization would require the measurement of additional field data defining clumps of trees. For both species, each stem is then characterized as being multipodial in form.

Multipodial Hardwoods

Multipodial trees have sub-branches that form a nonzero angle with the segment from which they branch. In addition to the single stems of the two multiaxial

species, California black oak and Oregon white oak are rendered in the multipodial form. Because this form is more complex than the monopodial form more information is needed to accurately render it. Height to branches along the stem, the size of the branches, and maximum crown width at a multiple positions are some of the field measurements that would be needed to fully characterize the sampled trees.

Unfortunately, many of these attributes are not measured in current sampling designs.

The thickness of the main stem is defined by the diameter outside bark at 4.5-feet above the ground line. Height to the first branching is defined as $2/3$ of the height to the base of the live crown. For multipodial trees, total tree height defines the upper extent of the crown.

Honda (1971) assumed that each tree segment was straight and had a fixed width. However each segment can be modeled as a frustum of a cone, approximated by a segment of an octagonal right pyramid. A mother segment produces two daughter segments through a branching process, the parameters of which are species and position dependant. The lengths of the two daughter segments produced are a function of the length of the mother segment, and the species of the tree. The mother and the daughter segments are coplaner, and have a constant branching angle. The branch plane of all branches not directly connected to the main trunk are oriented by their relation to the z-axis. These relationships allow the calculation of branch length for a given viewing distance.

The taper of the main stem is the approximated by a cone with the same diameter and total height as the tree, and the size of the stem at the first fork is

calculated using this approximation. The number of branches in the fork is selected with a random selection from a uniform distribution ranging, from one to five branches. The total area of all of the branches at the fork is equal to the area of the main stem at the fork, and is allocated to the branches by means of a truncated normal distribution, with mean equal to the area of the main stem divided by the number of branches at the fork, and coefficient of variation of 0.3. The distribution is truncated at two standard deviations to prevent branches with a negative diameter, or all of the area being allocated to a single branch. The resulting branches taper as a cone with their allocated diameter and a length defined by the distance from the fork to the edge of the crown. The angle at which the branch exits the fork is a function of its size in relation to its neighbors. The largest branches are more nearly vertical than are the smaller branches.

For higher orders of branches the length of the internodal segment is two thirds of the length of the mother segment. The number, size and angles of the daughter segments are derived using the procedures described for the first fork. Branching is terminated when the diameter of the branch diminishes to the point where they can no longer be resolved, or the limit from the crown shape equations is reached.

Ternary Hardwoods

Ternary species branch in multiples of three: bigleaf maple, golden chinkapin, and pacific madrone are rendered in the ternary form. The calculations for ternary species are the most complicated of all of the tree forms. Branching relationships for

tree species in the western United States have not been investigated, nor are they commonly measured. However they can be approximated from crown shape, for a fixed number of bifurcations (Ford 1987).

The thickness of the single main stem is defined by the diameter outside bark at 4.5-feet above the ground line. Height to the first fork is defined as a uniformly distributed random number from twenty to eighty percent of the height to live crown. Total tree height defines the upper extent of the crown, including leaves. Sinuosity of the branches is replicated through the probability of a node containing a live branch.

As with the multipodial species, taper of the main stem is approximated by a cone of the same diameter and height as the tree. The diameters of the branches at the first fork are determined in the same manner as the multipodial species; in this case however, there are always three branches at a fork. Branch areas of daughters at subsequent forks are allocated equally such that each branch has the same diameter. For higher orders of branches the length of the internodal segment is two thirds of the length of the mother segment. The number of daughter segments is fixed at three for the ternary form. The divergence angle of the daughter segments is also fixed for a species, and ranges from 60 to 35 degrees from the direction of the mother. The rate at which the length of the daughter segments decreases is assigned by species, and ranges from two thirds to three eights of the length of the mother segment. Branching is terminated when the diameter of the branch diminishes to the point where they can no longer be resolved, or the limit from the crown shape equations is reached.

Other forest objects

Forest structure consists of other objects in addition to trees. Items such as soil, stumps, snags, logs, rocks, shrubs and herbs also contribute to the overall structure of the stand. VIZ4ST can display these objects if appropriate information is available. Measured coordinates are required for stumps, snags, logs and rocks.

The soil is rendered by painting an appropriate color uniformly over the plot. Textured patterns are used to represent herbaceous vegetation. Two types of herbaceous vegetation are represented, aggregated and dispersed. The plot is divided into 100 cells and each cell is randomly allocated to herbaceous vegetation such that the measured percent cover is achieved. Edges of the resulting patterns are blended with the bare ground color to prevent unnatural edges from attracting the eye. As the viewpoint distance is reduced, it will be necessary to increase the number of classes of herbs until, at very close distances, each species is represented separately.

Stumps are rendered as frustums of a cone with a height of one-foot and a measured top diameter. Snags are rendered as trees of the same species with few branches and no leaves. Rocks assumed to be round, and exhibiting a domed appearance are added next. Natural rock color is quite varied, however to reduce color confusion in the final image rock color is fixed as grey.

For logs, the measured coordinates define the location of the large end of the log. In addition logs require measurements of diameter at the large end and log length.

Logs are drawn as frustums of a cone, and are placed after the placement of trees, stumps, snags and rocks oriented to avoid these objects.

The number of shrub species in the western United States greatly exceeds the number of tree species. To make their display tractable, shrub species are rendered as two classes; large and small leafed shrubs. Three measurements are required to characterize each shrub class; average height, percent cover, and average crown width. The number of shrubs to be allocated on the plot can be computed from percent cover, plot area, and average crown width. Each shrub is then placed randomly on the plot. A fixed template with branches and leaves appropriate to the class is used for each shrub. The template is scaled by average the height and crown width of the shrub. At the distance from which the forest stand is being observed, the amount of detail in smaller plants is very minimal. Decreasing the view point distance will require a finer division of non-tree plant species, and thus more processing time.

OBJECT CONTEXT

The arrangement of forest components in relation to one another is not strictly a random process. It is a record of the history and present condition of the ecological processes acting on the group of plants in the area. Foresters are interested in observing the inter-relationships between the forest objects.

On small scales, the openings resulting from death or cutting may become stocked with shrubs and/or tree seedlings. On larger scales, soil composition and water

flow patterns affect the types of plants growing in an area. The larger the size of the landscape displayed the more difficult it is to define its structure. Restricting the size of the area displayed on the screen limits the type of interactions that are possible to discern. However, it is possible to represent the aspects of stand structure that deal with interactions in a manner that is representative of the measured forest. The key is to display the observable patterns in a way that doesn't bias their interpretation of the display.

The range of scales represented in the sample is determined by the size of the sample plot. Processes that operate on scales significantly different from the plot size will not be detected by the sampling scheme (Boots and Getis 1988). The patterns that the program seeks to portray are those that are reflected in the size of the individuals sampled. Individual patterns of growth can't be reproduced without extensive sampling of the stand, so they are simulated stochastically. The branch pattern on each tree in the forest need not be known if a range of variation in structure for a species or species group can be described, and a stochastic algorithm for realization is developed.

Using measured tree locations

If the location of each of the forest objects are measured then the coordinates can be used to replicate the spatial distribution and the resulting patterns exactly. The location of each tree is described by its "X, Y" coordinates in feet, which must always be positive. The origin of the coordinate system is assumed to be in one of the corners

of the rectangular plot. It is also assumed that each tree has a set of unique coordinates.

Generating unmeasured tree locations

If the coordinates are not measured then they must be calculated by VIZ4ST. Forest stands can originate from planting or natural seeding. In a plantation the trees are usually located on a grid, while the distribution of the trees in a stand of natural origin is much more variable.

The tree list from the sampled stand is converted to reflect either the number of individuals on an acre or, for multiaxial trees, the number of clumps per acre. For non-multiaxial trees, one tree object record is written for each integer in the expansion factor of the tree. For multiaxial trees the expansion factor is reduced by the number of stems in the clump. An additional record is written if a uniformly distributed pseudo-random number between 0 and 1 is less than the fractional part of the expansion factor. The resulting expanded tree list is then sorted in descending order by diameter at 4.5 feet above ground line.

If the stand to be displayed is a plantation, then a grid of points is generated such that every tree or clump of trees has a point. The exact locations of the grid points can be perturbed by a random error specified by the user, which can be estimated by sampling the stand. The tree parameters are then assigned to the point locations randomly.

If the stand is of natural origin then, it is assumed that the trees exist in an area free from the selective influences of physical features such as streams, roads, and rock outcrops. Therefore the trees are allocated across the entire plot. For non-multiaxial trees, each tree is assigned an exclusion zone proportionate to the maximum crown width of an open grown tree (Ritchie and Hann 1985) with the same DBH and species of the subject tree. For multiaxial trees, the exclusion zone is proportionate to one half of the sum of the maximum crown widths for all of the stems in the clump.

To reduce the possibility of an unsolvable situation, the value of the exclusion zone is adjusted by summing all of the calculated crown widths and scaling this sum to the area of the plot. Thus, as the number of trees on the plot increases the area of each exclusion zone decreases. The time required to generate the coordinates for the trees on the plot will increase but as long as the number of trees or clumps on the plot is less than the number of locations for trees or clumps, a solution should always be found.

A pseudo-random number generator is used to assign "X, Y" coordinates to the tree. The coordinates are then checked against all of the placed trees and clumps to ensure that there is no overlap of exclusion zones. Should an overlap occur, the coordinates are rejected and a new random draw is conducted until the zones no longer overlap. This method of coordinate generation is classed as a non-simple sequential inhibition process (Diggle 1979).

VISUAL DISPLAY

The mathematics used to display three dimensional forest objects in two dimensions are from standard graphical procedures (Pokorny and Gerald 1991). The three dimensional scene rendered by the program consists of a square plot 95 feet on a side upon which the forest objects are placed. For plots with sides longer than 95 feet on a side, only the objects that fall in the first 95 feet will be displayed. The view point distance is calculated such that the "X, Y" extents of the scene are contained on the screen. The angles of display available to the user are limited to three, horizontal, an oblique angle of sixty degrees from horizontal, and top-down, so that computational requirements are reduced. To minimize apparent graphical distortion of the plot edges, the plot is oriented such that the observer looks across one of the diagonals, with the origin of the coordinate system located closest to the viewer.

To give the user an idea of the vertical scale of the picture, height poles are drawn at each corner of the scene. The scaled height poles are thirty feet tall and are striped with contrasting colors every five feet. To facilitate the location of forest objects the user can select an option to draw a five by five foot grid in the "X, Y" plane of the scene.

Ray tracing, the preferred method of scene lighting requires extensive computing power when applied to irregular objects such as trees. Large graphics processing systems may spend 24 hours to generate a single image, and the resulting

scenes are very realistic. However, for non reflective surfaces, other techniques generate comparable results.

By sorting the forest objects such that those that are farthest away from the observer are drawn first, subsequent objects obscure the proper amount of detail. Since the objects themselves are not solids, some background detail is visible through their foliage. No processing time is used tracing every screen pixel to determine its proper color. This simplification greatly speeds up the run time of the program. Using this strategy, the forest objects are drawn in the following order: soil, herbs, stumps, rocks, logs, shrubs, trees and snags. Within each type, the objects are drawn such that those furthest away from the viewpoint are drawn first and those closest are drawn last.

Drawing the branches of conifers such that the starting position and ending position is parallel to the observation plane also reduces within object anomalies, and allows the use of coordinate specific color rendering to provide color depth cues. The branches further from the viewer are darkened and those towards the viewer are lightened to give the impression of shading.

Line clipping is another large use of processor time. Pictorial anomalies such as tall objects being drawn on top of shorter objects, when in reality they should protrude through them, require some special processing. No clipping is done within an object. Between objects, a test is made to determine if one object protrudes from another. If they do then the base of the protruding object is clipped to the surface of the other object. This compromise procedure does not allow re-entrant cases. Once all

of these techniques are applied, the great majority of pictorial anomalies are removed at the cost of a little processing time.

DISCUSSION

The number of elements, type of elements, and their spatial arrangement in three dimensions are important components of the habitat requirements for a number of species. A sample of these components of forest structure can be displayed in a familiar form by a scene rendering graphics program. Such a program, operating on a personal computer, can aid in the communication of environmental conditions present in forest stands. If the display is coupled to a stand development model, it can show the results of a variety of management alternatives, thus facilitating discussion of their effects.

The VIZ4ST program is such a scene rendering program. It doesn't rely on the photographic method of actually finding a comparable stand conforming to the structure under consideration. It creates each forest scene directly from the data collected from it, or the model results that represent it. Figure 2 shows three views of a pure Douglas-fir stand created with VIZ4ST. In Figure 1 an even aged Douglas-fir stand is shown from above. This overhead view simulates the view expected from an overhead flight. Two scenes with the origin slightly shifted would allow the stand to be viewed in stereo perspective. In Figure 2 the same stand is viewed from an oblique

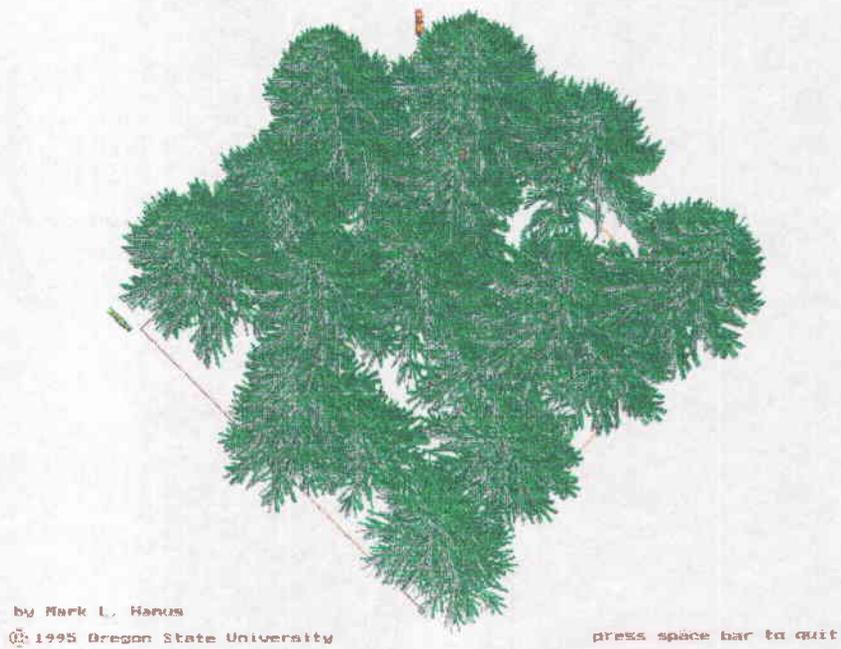


Figure 1. Top down view of an even aged Douglas-fir stand .

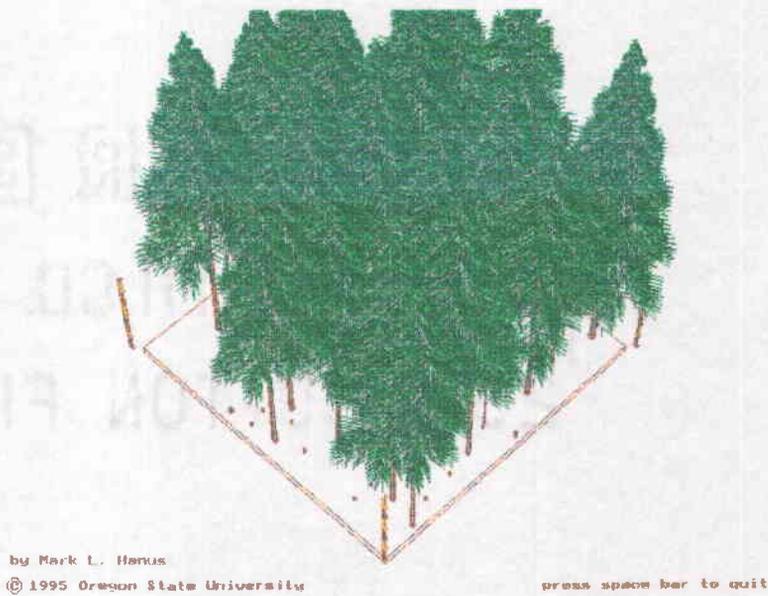


Figure 2. Oblique view of an even aged Douglas-fir stand.

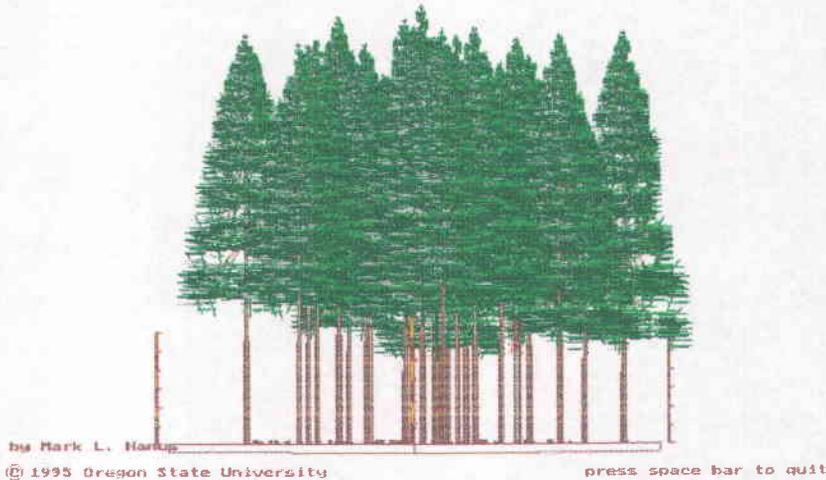
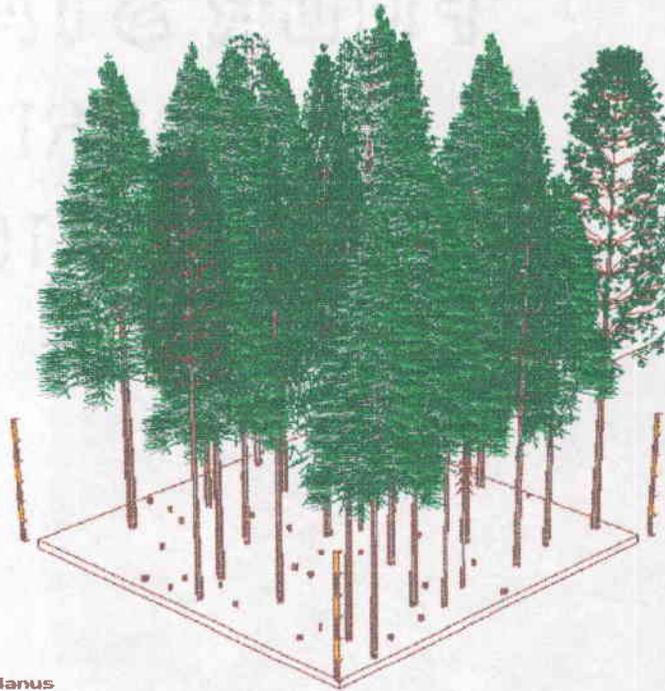


Figure 3. Horizontal view of an even aged Douglas-fir stand.

angle of 60 degrees from the horizontal, and in Figure 3 horizontally. In both figures the stand is viewed across one diagonal.

Examination of forest stand structure in mixed species stands is illustrated in Figure 4 A and B. To facilitate examination of the understory components, the crowns of the overstory trees are removed in the display in Figure 4B. Here the placement of the trees whose crowns are not drawn is "preserved" by the inclusion of their stems, allowing the user to examine features within the stand while retaining an idea of the spatial distribution of the overstory components.

Landscape topography is another aspect of forest stand structure that can be incorporated into the display. The ability to draw the objects on slopes and with physical features such as streams, roads, cut banks, and land slides can provide the forest manager with important information. Providing this capability will require



by Mark L. Hanus

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Figure 4A. Oblique view of an uneven aged mixed species stand.

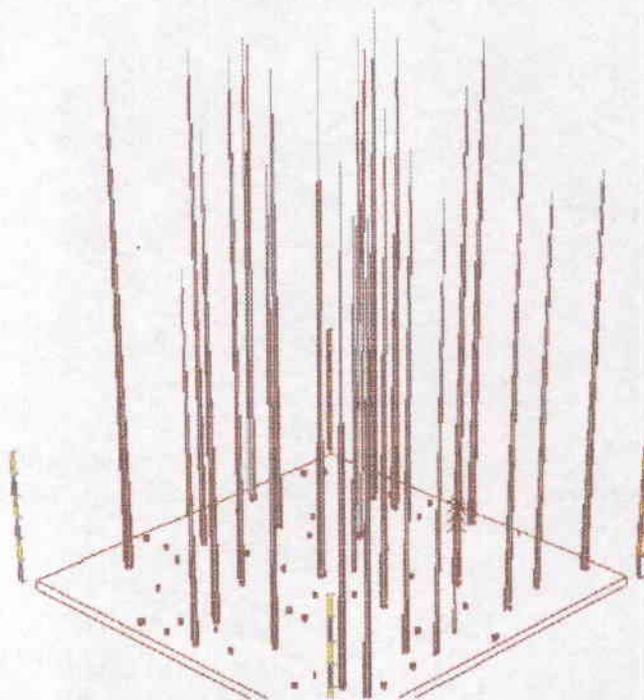


Figure 4B Oblique view of the same uneven aged stand without the canopy.

additional research quantifying the distribution of plants in relation to these features. It is expected that the distribution of plants in the presence of these physical features will be different from their distribution without them.

Along with the addition of new species and topography, there is a need to increase the range of distances and angles from which the stand can be viewed. More computationally intensive routines for clipping and anti-aliasing will be required, thus increasing the demand for processing power.

As it becomes available, the structure of VIZ4ST will allow better information on plant architecture to be incorporated into the program. The ability to process information faster and display more detailed images will make it possible to generate a complete simulated forest scene. In the future it will be possible to "fly" over a simulated landscape, enter the simulated forest look under simulated shrubs, "pick up" a simulated rock and find simulated wildlife. Or it will be possible to guide a class of students through a simulated forest sampling exercise using a forest grown from data they have collected and modeled.

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Chapter 3:

**Reconstructing the Spatial Pattern of Trees
from Routine Stand Examination Measurements**

Mark L. Hanus, David W. Hann and David D. Marshall

For Submission to Forest Science
Society of American Foresters, Bethesda, Maryland,
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Chapter 3:**Reconstructing the Spatial Pattern of Trees
from Routine Stand Examination Measurements****ABSTRACT**

Reconstruction of the spatial pattern of trees is important for the accurate visual display of unmapped stands. The proposed process for generating the spatial pattern is a non-simple sequential inhibition process, with the inhibition zone proportionate to the scaled maximum crown width of an open grown tree with the same breast height diameter of the subject tree. The results of this coordinate generation procedure are compared to stem mapped data from nine natural stands of Douglas-fir at two ages, by the use of a transformed Ripley's $K(d)$ function (Ripley 1977). The results of this validation indicate that the proposed method successfully replicated the spatial patterns of the trees, as measured by the $K(d)$ function, using complete tree lists, in all nine stands, at both ages, and over the range of distances examined. Based on these findings, and the ability to model the effects through time, the non-simple sequential inhibition process has been chosen to generate tree coordinates in the VIZ4ST computer program for displaying forest stand structure.

INTRODUCTION

The broadening of interest in silvicultural activities, coupled with increasingly complex prescriptions, has brought about the need for a method of communicating the structural diversity of stands in a manner understood by a wide spectrum of society. The method must be capable of representing the attributes of stand structure in a way that individuals unfamiliar with forest practices and terminology can readily understand. In order to render an objective representation of stand conditions it must also be free of user influence. An animation display coupled with dynamic models of changes in stand structure and species composition can achieve this goal.

The application of such a display to stands where the locations of the trees are not known requires a method of placing the trees in proper relation to one another. The coordinate generation routine must rely only on information collected during a typical stand examination, and updated by the single-tree type of stand development models (Munro 1974) to which it may be coupled. The candidate primary attributes projected by the single-tree type of stand development models are; diameter at breast height (DBH), species, height, height-to-crown-base, and per area weighting of the tree under the appropriate sampling design (expansion factor). A derived attribute such as tree volume, crown width, or a combination of these primary or derived attributes could also be used if a relationship is found between them and the resulting point pattern.

Historically coordinate generation routines have been used to evaluate alternative sampling schemes (Kaltenberg 1978, Hann & Zumrawi 1991), in simulation

studies of forest harvest machinery (Newnham 1968), and to generate spatial patterns for distance-dependant growth and yield models (Mitchell 1969, Daniels et. al 1979). Three spatial patterns have been assumed in these applications; uniform, random and clumped. A separate measure of the spatial pattern is used to control the coordinate generation routine in these models, usually Pieleu's nonrandomness index (PNI) (Pieleu 1959). PNI is a product of the density and the mean square of the observed distances. It provides a relative measure of the amount of deviation from spatial randomness. PNI must be calculated from at least two independent samples of the forest stand. The dynamics of PNI is not predicted by stand development models, thus making it unsuitable for generating coordinates of projected stands.

The objective of this study is to develop and test a tree coordinate generation method that can be used to create realistic visual characterizations of stand structures predicted by the ORGANON stand development model (Hann et. al 1994) without the need for estimating PNI. In the proposed method, tree locations are modeled as the results of the effects of competition from neighboring individuals. The effect of this competition is expressed in the tree crowns, thus the area surrounding the tree is reflected by the crown width of the tree (Moeur 1993). In stands experiencing light competition, trees with wider crowns will be surrounded by more available space than are trees with smaller diameter crowns. Since models for estimating the maximum extent of the crown of a stand grown tree are unavailable, a scaled maximum crown width of an open grown tree is used as a surrogate.

BACKGROUND

Diggle (1979) identified five models for point pattern coordinate generation processes: the Poisson forest, Poisson cluster process, doubly stochastic Poisson process, lattice-based process, and the Inhibition or Markov point process. Most of these models work with unmarked points, the assignment of the tree attributes being done after the point pattern is generated. This necessitates the development of two algorithms, one to generate the coordinates and another to assign the attributes.

The Poisson forest

The simplest model of point pattern generation is the Poisson forest. The Poisson forest allows points to randomly fall in the area. Points in the Poisson forest model don't exhibit tendencies to occupy any particular regions of the plot, and the placement of each point is independent of the location of the other points on the plot.

The independence of the points make the Poisson forest a poor model for forest conditions. Plants do not grow arbitrarily close to one another. The most common modification of the Poisson forest is the imposition of a minimum distance between points. However this restriction alone doesn't reflect conditions observed in natural stands. To more closely model plant distributions that differ significantly from spatial randomness the Poisson forest can be modified so that two hierarchical "forests" are superimposed upon one another.

Poisson Cluster process

The hierarchical generalization of the Poisson forest is the Poisson cluster process. This model generates point patterns by dividing the points to be placed into a random number of groups. The centers of these groups are placed randomly on the plot. Within each group the individual point locations (daughters) are derived by randomly generating a displacement from the parent center. The main parameters of the Poisson cluster process are the density of the parent centers, the rules for the independent placement of the members of each group, and the number of members in each group. Utilization of this method to duplicate the spatial distribution of a specific stand would require an estimate of these parameters from the population. To display the results of a stand development model would also require a method of modeling them through time.

Newnham (1968) used a Poisson cluster process to generate parent centers for populations of natural stands. The daughters were then located around each center by a Poisson process. After the coordinates were generated, the tree attributes were randomly assigned to the points placed on the plot. Newnham and Maloley (1970) identified the process of random assignment of attributes as the principle weakness of this method. Some of the generated stands had clumps of large trees and small free-growing trees, conditions that failed to reflect those occurring in the sample stands used. They, therefore, developed an algorithm for assigning the attributes in a manner that more closely reflected the conditions of the sampled stands.

In this algorithm, the size of the free area surrounding each point (area of occupancy) was used to determine which attributes from the tree list should be assigned to it. Points with large areas of occupancy are assigned larger diameters than those with small areas. They assumed that trees growing in clumps are more likely to have smaller diameters than those growing in more open areas. Their assessment was that the algorithm didn't produce the anomalies found in strictly random allocation of the attributes. However they didn't test it for its ability to replicate actual stands.

Weise and Glover (1988) modified the Newnham and Maloley stand generator to extend the range of stand densities to which the simulator could be applied. The most significant modification was the use of crown parameters instead of diameter to assign trees to points.

The degree of clumping of the spatial patterns created by these two stand generators are controlled by PNI, thus an estimate of it is required prior to the generation of the coordinates. PNI uses a tree count and an independent sample of distances from random points to the nearest tree. It is easy to construct and sensitive to density changes, but requires at least two independent samples for calculation (Payandeh 1970).

Heterogeneous or Doubly Stochastic Poisson process

Doubly stochastic Poisson processes replace the constant density of the parent centers by the realization of a random process. One method to achieve this is to

transform the randomly generated numbers by variable intensity functions (Diggle 1979). The functions for x and y coordinates need not be the same, however parameterization estimates for them must be made separately. This causes the density of the trees to vary across the plot such that the distribution of trees in the x-direction is independent of the distribution in the y-direction, which is useful for situations where the local density of trees trends in a specific direction.

A disadvantage of this method is that the parameters for the function, as well as the function itself, must be estimated and modeled. The advantage of the method is that it can replicate a wide range of aggregation and dispersion patterns. Diggle (1979) states that there is no method based solely on the resulting point pattern to differentiate a pattern generated by this method and one generated by a contagion or inhibition process.

Lattice process

Lattice processes generate the coordinates by assigning the trees to a grid of points spanning the range of the plot. As a result, the points are spread out over the entire plot. The regular lattice process divides the plot into the same number of locations as there are trees to be placed, and assigns one tree to each location. The lattice does not need to be square: for example, a more closely packed lattice can be achieved by the use of equilateral triangles. Variation can be introduced to the lattice process by allowing trees to be placed randomly placed around each grid point.

Lattice processes have been used primarily to model plantation forests (Newnham and Maloley 1970, Kaltenberg 1978, Hann and Zumrawi 1991). However, they could also be used to model natural stands thinned by a spacing rule.

Inhibition and Markov process

A mechanism that produces regularity in an intuitively more natural way is inhibition. Inhibition assumes that no points may fall closer to any other points than a minimum distance. A simple inhibitory process uses a constant minimum distance, a non-simple inhibitory process uses a functional relationship for the minimum distance. Placing the points on to the plot one by one in a manner that preserves the minimum distance requirement results in a sequential inhibitory process. Natural forest conditions can be modeled by a sequential inhibitory process where the minimum distance is a function of the size of the trees on the plot.

The simple inhibitory process is a special case of the Markov process model. In this model an initial condition, the result of any of the previous models, is modified point by point until no two points fall within the minimum distance. A Markov model depends only on the arrangement of the points on the plot and the inhibition rule. Diggle (1979) and Schreuder et al. (1993) give more information on the Markov model.

Proposed non-simple sequential inhibition process

The proposed coordinate generation process expresses the minimum inhibition distance as a function of the size of the tree, and the trees are placed sequentially on the plot, with the largest tree placed first. Therefore, the proposed method can be classified as a non-simple sequential inhibition process. In this process, plots with a wide range of tree diameters, or a small number of trees, will appear clumped, since large trees will restrict the placement of smaller trees to areas close to one another. Plots with a small range of diameters, or a large number of trees, will result in a more or less uniform spread across the plot. Thus, the proposed non-simple inhibition process has the potential to characterize stands of very different spatial patterns, without requiring an estimate of PNI.

In the proposed method, the inhibition distance is a function of the maximum crown width of an open grown tree with the same species and diameter at breast height as the sample tree of interest. In natural stands of Douglas-fir, it is expected that the size of the crowns reflect the size of the available growing space for each tree. Thus, crown width can be used as a measure of the area of occupancy of each tree. Maximum crown width of an open grown tree is predicted from the diameter and species of the subject tree using previously published equations (Ritchie & Hann 1985).

METHODS

Coordinate generation

The list of sampled trees is first converted to reflect the number of individuals on one acre. This is done by writing one tree record for each integer in the expansion factor of the tree. An additional record is written if a uniformly distributed pseudo-random number between 0 and 1 is less than the fractional part of the expansion factor. The resulting expanded tree list is then sorted in descending order by DBH.

Each tree is assigned an exclusion zone that is proportionate to the maximum crown width of an open grown tree (Ritchie & Hann 1985) with the same DBH and species of the subject tree. To reduce the possibility of an unsolvable situation, the value of the exclusion zone is adjusted by summing the squares of all of the calculated crown widths and scaling this sum to the area of the plot. Thus, as the number of trees on the plot increases the area of each exclusion zone decreases.

A pseudo-random number generator is used to assign "X, Y" coordinates to the tree. The coordinates are then checked against all of the placed trees to ensure that there is no overlap of exclusion zones. Should an overlap occur, the coordinates are rejected and a new random draw is conducted until the zones no longer overlap.

Pattern comparison

The point patterns resulting from the coordinate generation process can be compared to that observed in the stands using a method described by Ripley (1977). It has been applied to forest stands by Cressie (1993) and Moeur (1993) as a measure of deviation from spatial randomness. A distribution function is constructed by counting the number of trees falling within a sliding distance scale that is centered around each tree on the plot.

Ripley recommends restricting the sliding distance scale to values ranging from three times the least significant digit of the distance measurement to one half of the smallest side of the plot. Limitation of the range minimizes bias due to edge effects and round off errors in measurement of the tree position.

Define:

$$K(d) = \frac{A}{n} \sum_{i=1}^n \sum_{j=1}^n \frac{\delta_{ij}(d)}{n}, \text{ for } i \neq j$$

$$\delta_{ij}(d) = 1 \text{ when } d_{ij} \leq d, \text{ and } 0 \text{ otherwise.}$$

where: n is the number of points on the plot, A is the area of the plot, and d_{ij} is the distance between the i^{th} and j^{th} trees on the plot.

In a small plot, edge effects can contribute a considerable downward bias to the estimate, especially as the distance exceeds one half of the plot side. Ripley (1977) suggested that for each pair of points, the proportion of the circumference of the circle centered on one tree, with radius equal to the distance between the two contained within the plot, can be used to correct for this bias.

Define:

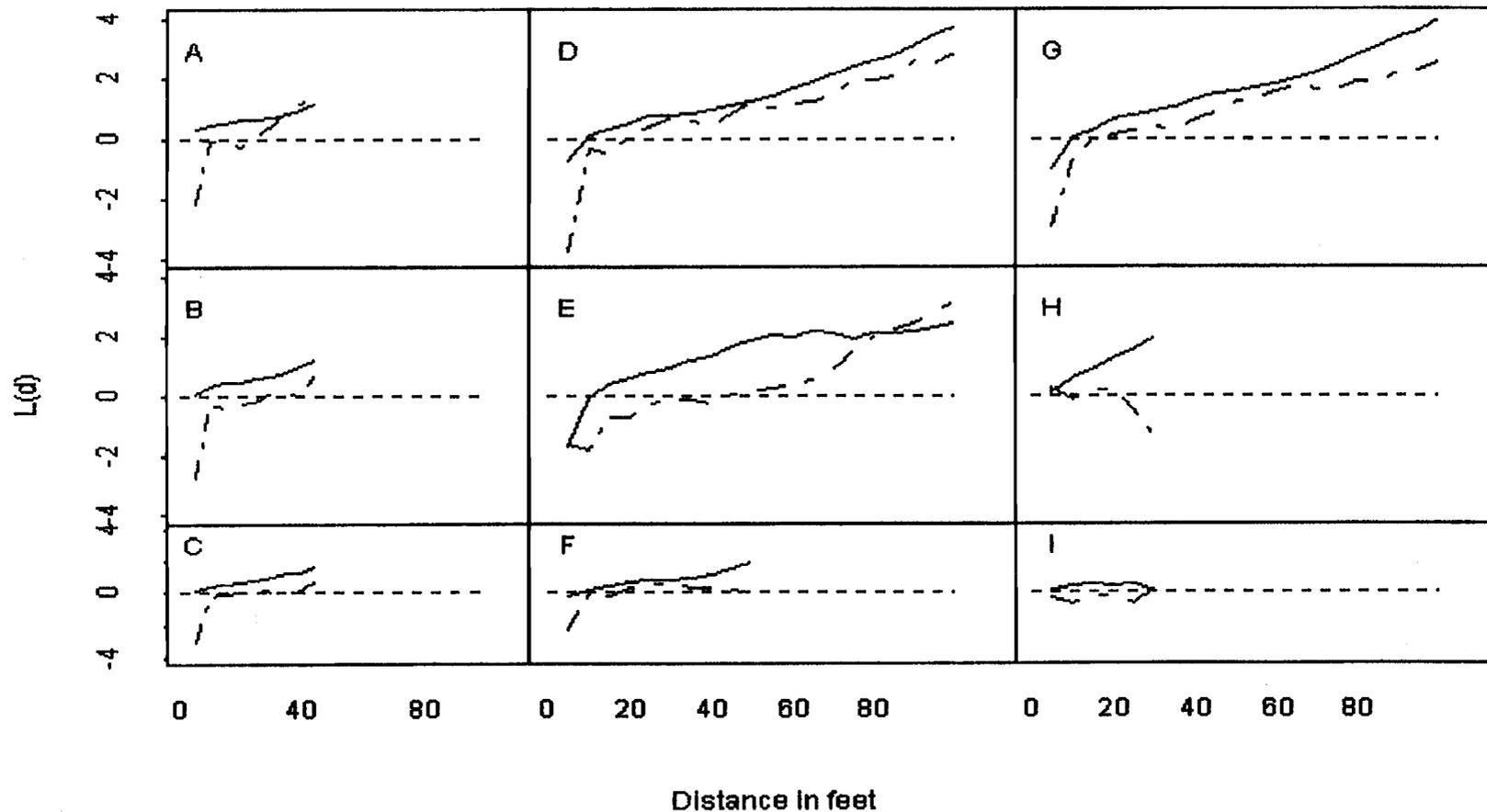
$w(d_{ij}) = 1$ When the circle defined by radius d_{ij} falls entirely on the sample plot,
 and $w(d_{ij}) = 1 / \left(0.75 - \left(\arccos \left(\frac{u_{ix}}{d_{ij}} \right) + \arccos \left(\frac{u_{iy}}{d_{ij}} \right) \right) / 2\pi \right)$ when off on two sides,
 and $w(d_{ij}) = 1 / \left(1 - \left(\arccos \left(\frac{u}{d_{ij}} \right) / \pi \right) \right)$ when off on one side only, where u is the distance
 from the i^{th} point to the nearest side of the plot, and u_{ix} is the distance from the i^{th} point
 to the nearest side of the plot in the x direction, and u_{iy} is the distance from the i^{th} point
 to the nearest side of the plot in y direction.

The number of tree pairs within a distance d of the point is the sum of all of the weights ($w(d_{ij})$) derived from distances less than or equal to d

$K(d) = \frac{A}{n} \sum_{i=1}^n \sum_{j=1}^n \frac{w_{ij}(d)}{n}$, for $i \neq j$. Since d is restricted to one half of the shortest plot side,
 no circle can extend beyond the plot on more than two sides, and therefore the largest
 possible weight is four ($u_{ix} = u_{iy} = 0$).

To stabilize the variance of the $K(d)$ function Besag (1977) proposed a square root transformation of Ripley's $K(d)$, and defined $L(d) = \sqrt{\frac{K(d)}{\pi}} - d$, which linearizes $K(d)$ and stabilizes its variance. The expected value of $L(d)$ for a Poisson process is zero, with $L(d)$ taking on positive values for aggregated patterns and negative values for dispersed patterns. The value of $L(d)$, indicates the difference between the number of points found within the circular area, of radius " d ", centered on one of the points, and the number of points expected from a Poisson process. Therefore, a graph of $L(d)$ over " d " can indicate differences in spatial pattern at different scales. The observed values of $L(d)$ for the mapped plots are displayed in Figure 5.

Figure 5. Plots of the observed $L(d)$ values at the beginning measurement period (solid lines) and ending (dashed lines) measurement period for (A) Hoskins plot 10, (B) Hoskins plot 22, (C) Hoskins plot 26, (D) Black Rock plot 7, (E) Black Rock plot 12, (F) Black Rock plot 16, (G) Black Rock plot 27, (H) Burnt woods plot 1, (I) Burnt woods plot 2. The value of $L(d)$ assuming spatial randomness is plotted as the dotted line.



Simulation Bands

Because there are situations in which the $L(d)$ values at each distance are not normally distributed (Ripley 1977), simulation bands will be used to assess the efficacy of the coordinate generation process. They are calculated from the tree list of each plot by repeated generation of tree coordinates using the proposed non-simple, sequential inhibition process. To characterize these bands, a series of box and whisker plots of $L(d)$ are displayed at five foot increments of "d". The $L(d)$ values from the observed stem mapped data is plotted over the box plots to provide a frame of reference.

To derive the simulation bands, fifty realizations of the point pattern are calculated from each tree list and the $L(d)$ values are generated for them. Initial tests with up to 100 realizations found that there was little change in the inter-quartile range at each distance after about 50 iterations.

The box and whisker plots are constructed such that the box encompasses the middle half of the simulated values in a distance class. The whiskers extend to the most extreme simulated value not more than 1.5 times the height of the box (inter-quartile range) from the boundary of the box. Extreme values may extend beyond the whiskers.

Comparison of the results of the simulations to the actual data is done by noting where the observed $L(d)$ value in each distance class falls in comparison to the simulated values characterized by the box and whisker plot (Figure 6 A through I).

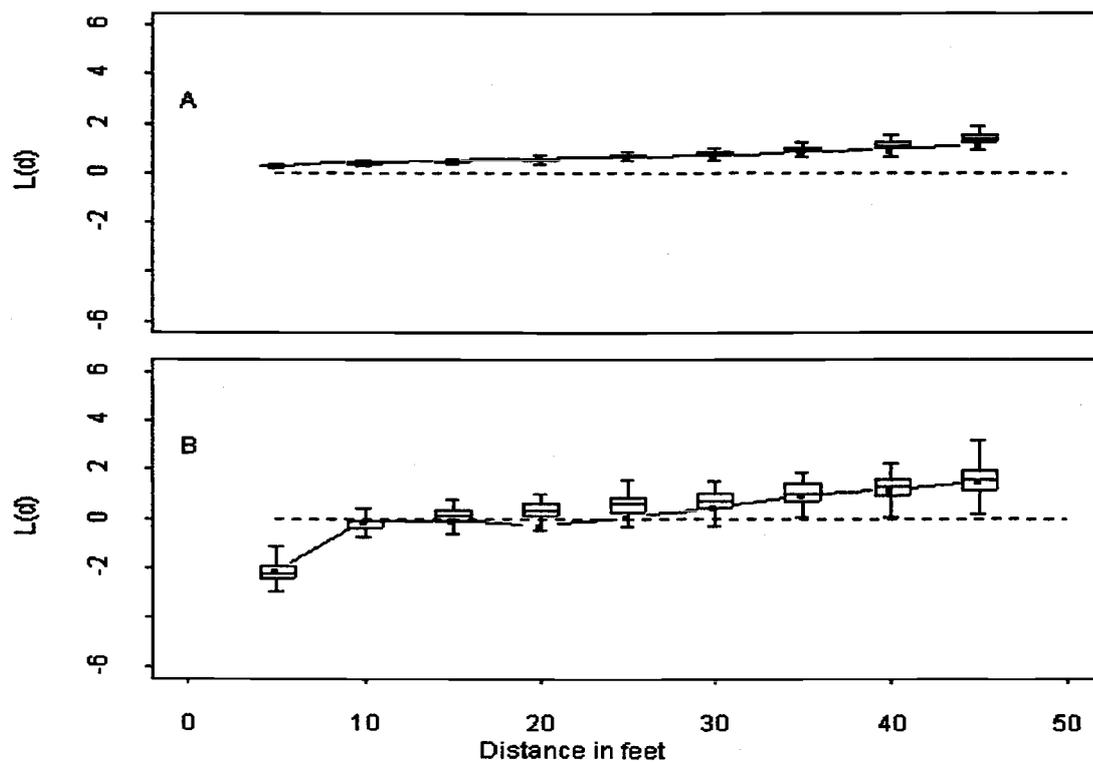


Figure 6A: Plots of observed $L(d)$ values (solid lines) and the associated simulation bands for Hoskins plot 10 at: (A) Total age 20 and (B) Total age 50. The value of $L(d)$ assuming spatial randomness is plotted as the dotted line.

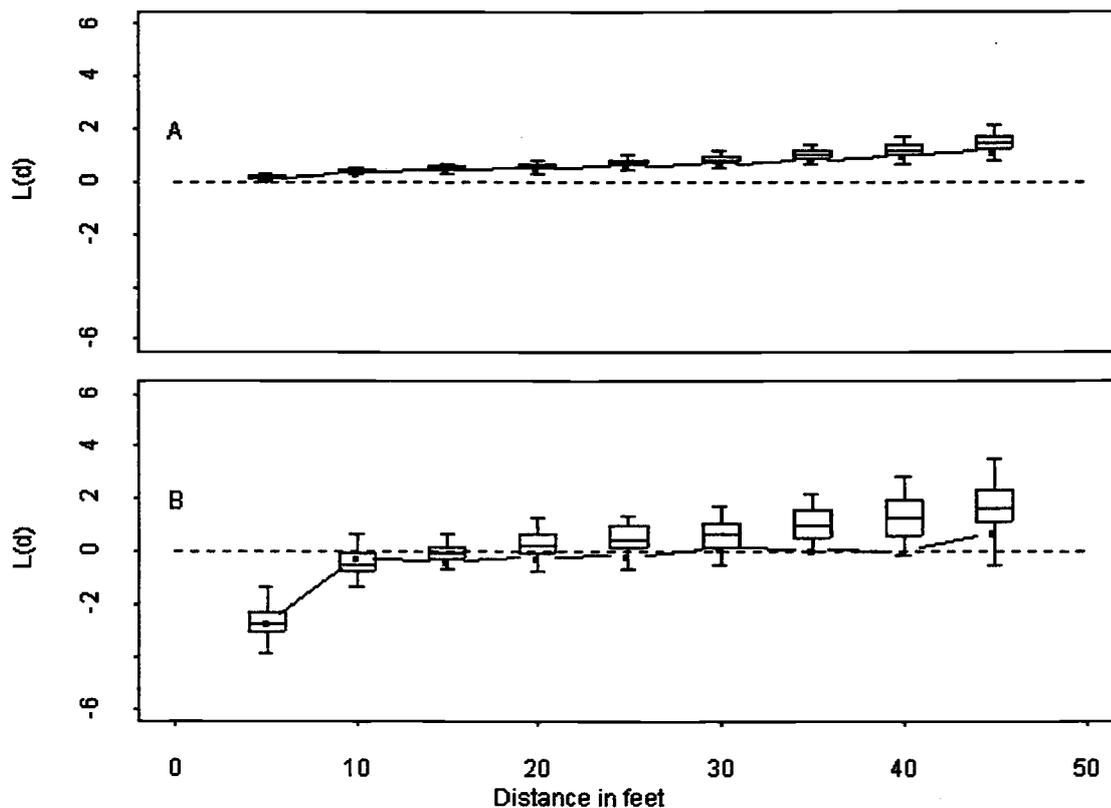


Figure 6B: Plots of observed $L(d)$ values (solid lines) and the associated simulation bands for Hoskins plot 22 at: (A) Total age 20 and (B) Total age 50. The value of $L(d)$ assuming spatial randomness is plotted as the dotted line.

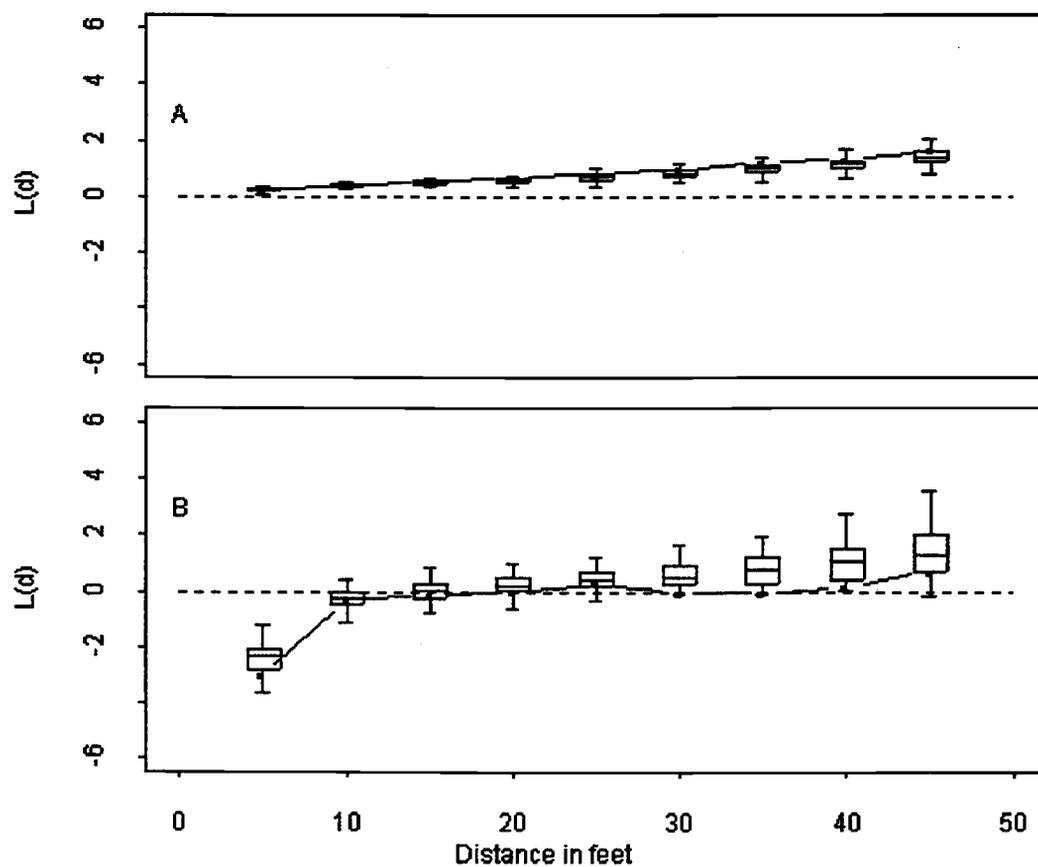


Figure 6C: Plots of observed $L(d)$ values (solid lines) and the associated simulation bands for Hoskins plot 26 at: (A) Total age 20 and (B) Total age 50. The value of $L(d)$ assuming spatial randomness is plotted as the dotted line.

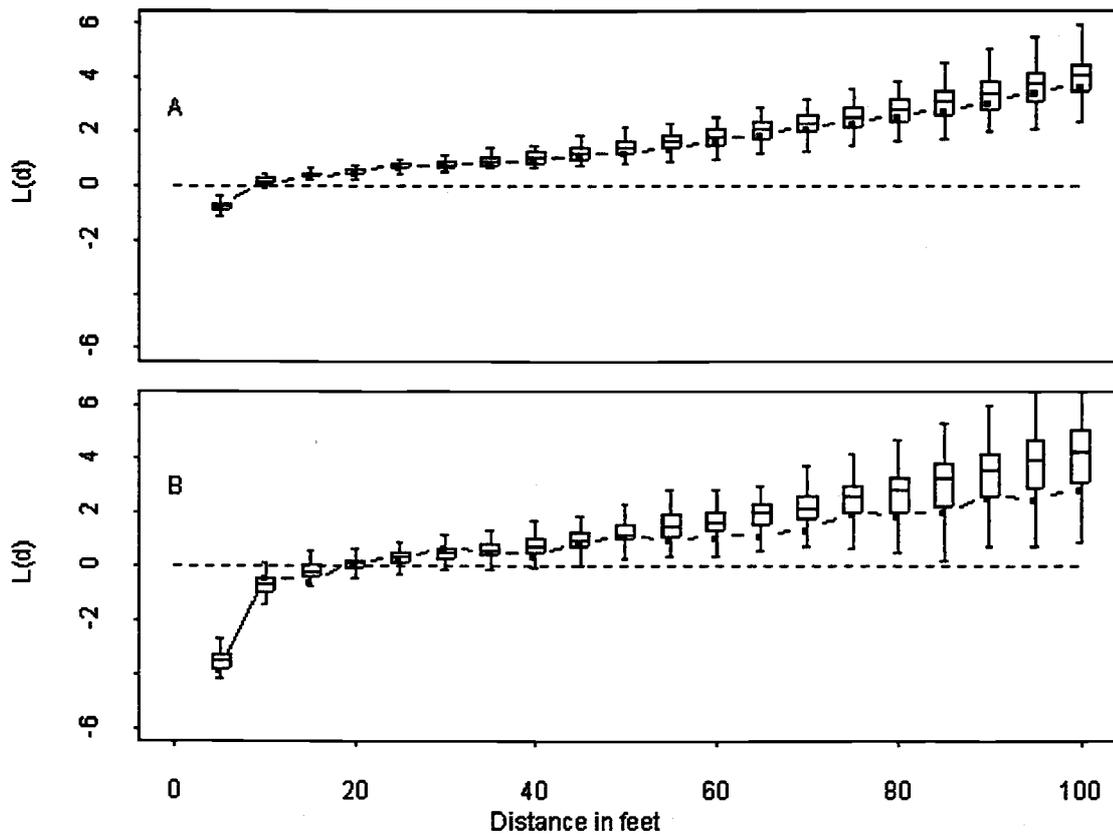


Figure 6D: Plots of observed $L(d)$ values (solid lines) and the associated simulation bands for Black Rock plot 7 at: (A) Total age 39 and (B) Total age 77. The value of $L(d)$ assuming spatial randomness is plotted as the dotted line.

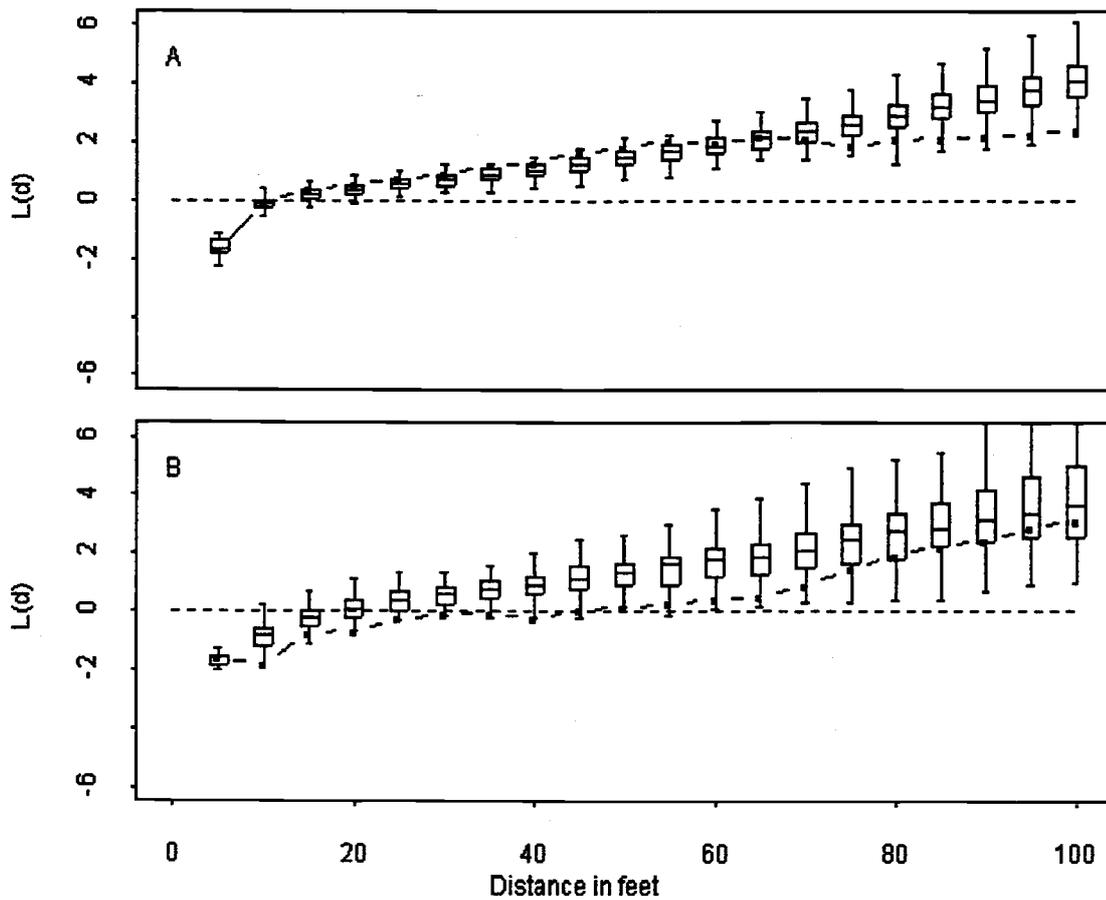


Figure 6E: Plots of observed $L(d)$ values (solid lines) and the associated simulation bands for Black Rock plot 12 at: (A) Total age 46 and (B) Total age 82. The value of $L(d)$ assuming spatial randomness is plotted as the dotted line.

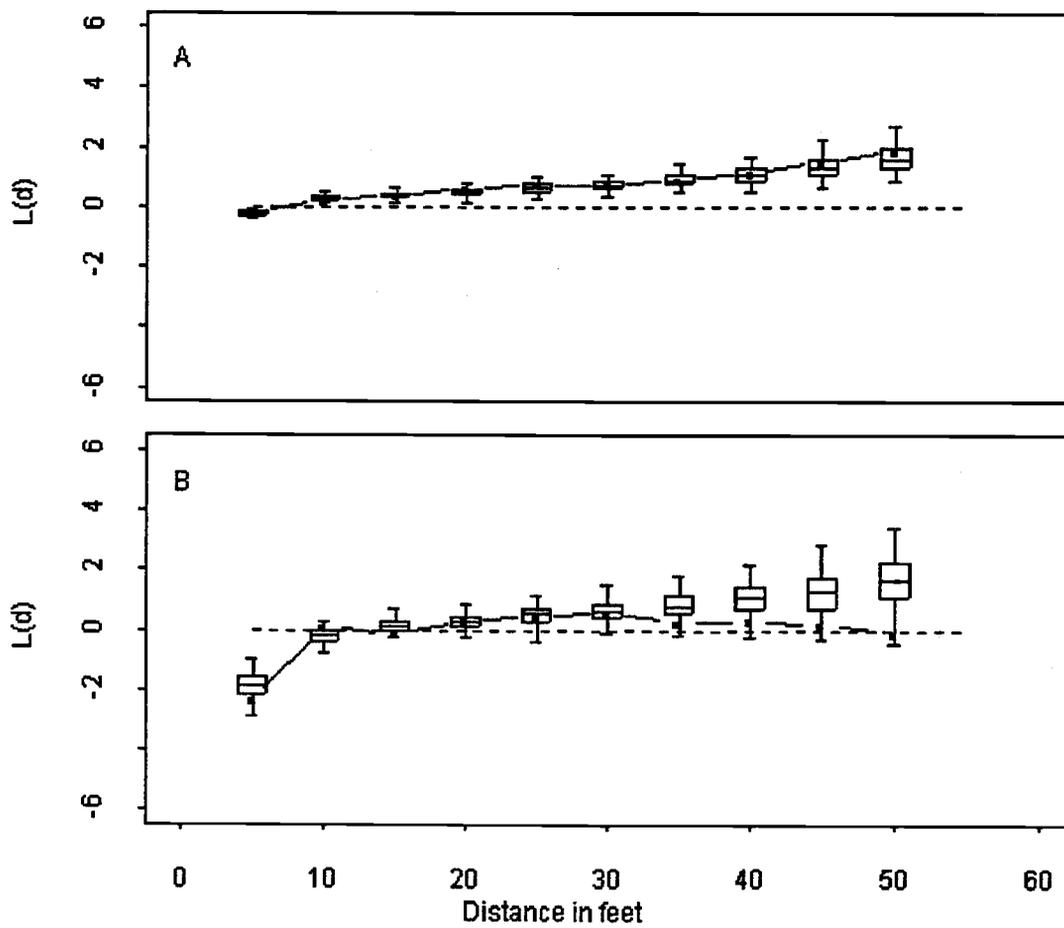


Figure 6F: Plots of observed $L(d)$ values (solid lines) and the associated simulation bands for Black Rock plot 16 at: (A) Total age 47 and (B) Total age 81. The value of $L(d)$ assuming spatial randomness is plotted as the dotted line.

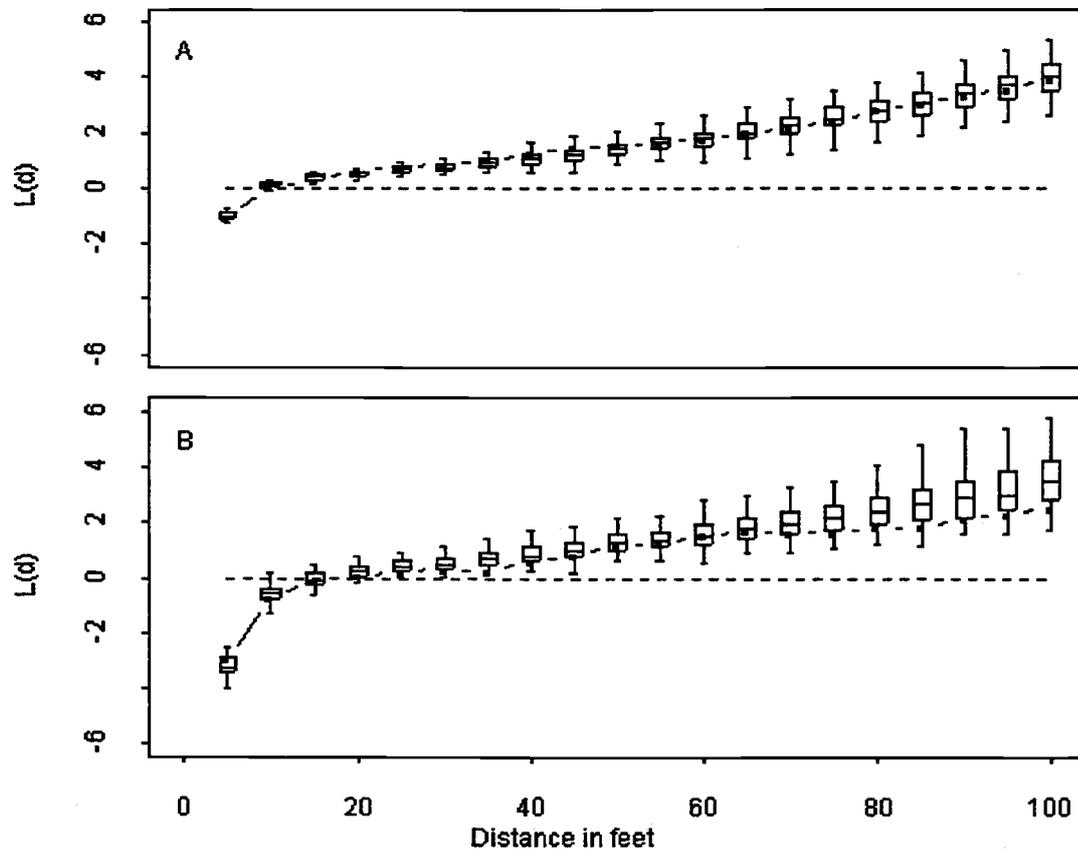


Figure 6G: Plots of observed $L(d)$ values (solid lines) and the associated simulation bands for Black Rock plot 27 at: (A) Total age 47 and (B) Total age 81. The value of $L(d)$ assuming spatial randomness is plotted as the dotted line.

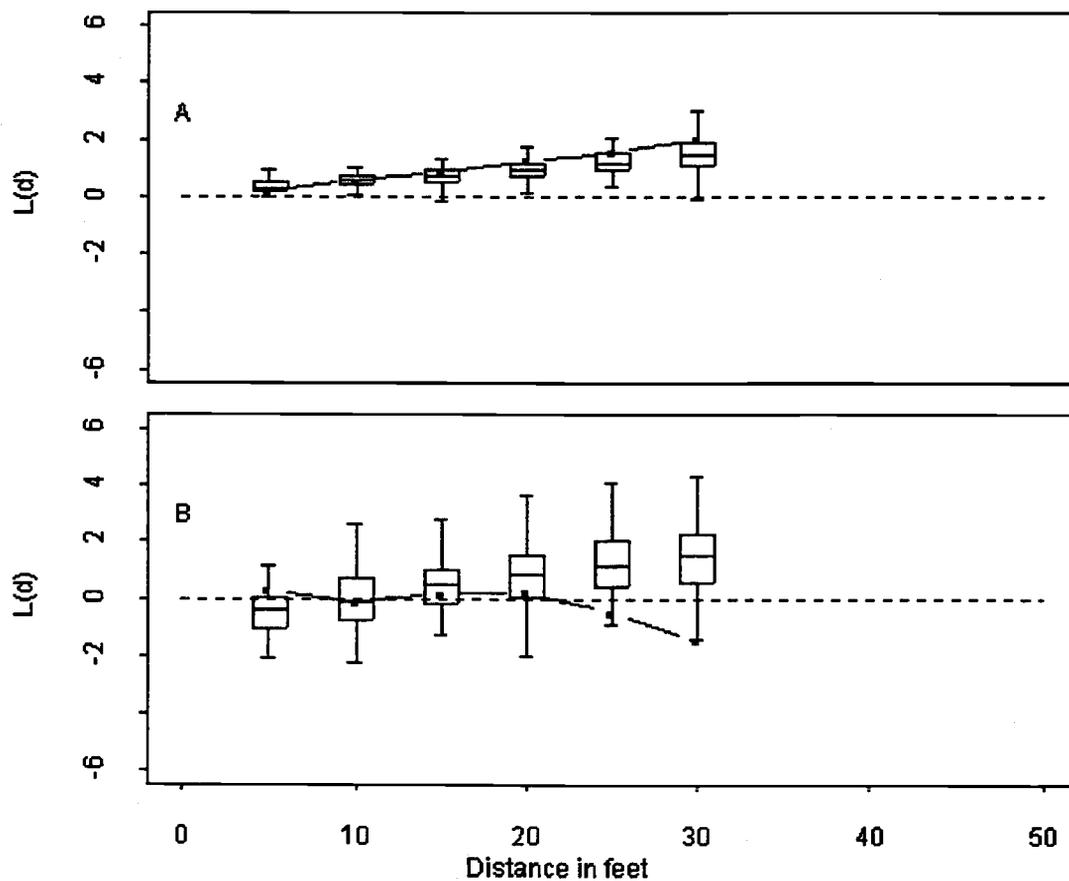


Figure 6H: Plots of observed $L(d)$ values (solid lines) and the associated simulation bands for Burnt woods plot 1 at: (A) Total age 20 and (B) Total age 52. The value of $L(d)$ assuming spatial randomness is plotted as the dotted line.

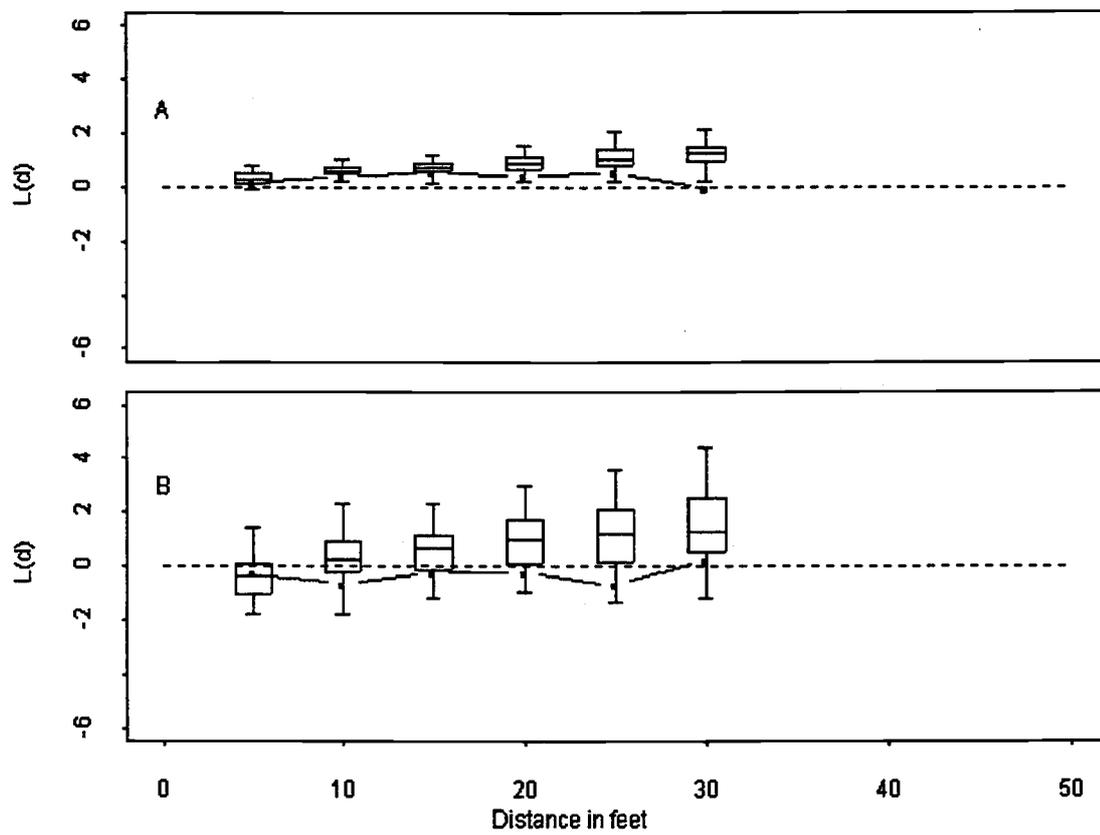


Figure 6I: Plots of observed $L(d)$ values (solid lines) and the associated simulation bands for Burnt woods plot 2 at: (A) Total age 20 and (B) Total age 52. The value of $L(d)$ assuming spatial randomness is plotted as the dotted line.

The more concentrated the simulated box and whisker plot is around the observed L(d) value, the more likely that individual simulation runs will reflect the patterns observed in nature.

Mapped Validation Plots

The data used to assess the efficacy of the coordinate generation routine are from nine stem mapped plots from six long term studies established at three locations in the coast range of Oregon (Table 2).

Table 2. Description of the mapped stands used to assess the efficacy of the coordinate generation routine.

Location	Plot Number	Total age years	Initial Measurement			Last Measurement			
			Number of Trees per Acre	Basal area per Acre	quadratic mean diameter	Total age years	Number of Trees per Acre	Basal area per Acre	quadratic mean diameter
				sqr. feet	inches			sqr. feet	inches
Blackrock	7	39	497	196	8.5	77	219	347	17.0
Blackrock	12	46	326	208	10.8	82	180	328	18.3
Blackrock	16	47	1,024	245	6.6	81	468	336	11.5
Blackrock	27	47	486	212	9.0	81	257	317	15.0
Hoskins	10	20	1,885	134	3.6	50	540	269	9.6
Hoskins	22	20	1,610	158	4.2	50	435	320	11.6
Hoskins	26	20	1,685	122	3.6	50	490	300	10.6
Burnt Woods	1	25	950	214	6.4	51	300	267	12.8
Burnt Woods	2	25	1,020	212	6.2	51	128	279	12.6

They represent all of the mapped plots falling within the forest conditions represented by the western Willamette Valley version of the ORGANON stand development model (Hann et al. 1994). All six installations are in unthinned stands of Douglas-fir that naturally regenerated after logging. Since all of the plots were measured over a 30 to 45 year period, the coordinate generation routine could be evaluated at both the initial and last measurements taken on each plot.

Black Rock

Four of the control plots came from four separate installations established on the 500-acre Black Rock Forest Management Research Area in the George T. Gerllinger Experimental Forest. The Experimental Forest is located near the town of Falls City and is on land managed by the Oregon State Department of Forestry. The four installations were established in 1953 to 1957 by Oregon State University to study the effects of commercially thinning Douglas-fir. Three of the control plots are one-acre in size, while Plot 16 is one-quarter acre in size. The elevation of the plots ranges from 1000 to 1200 feet, and King's (1966) site index ranges from 93 to 128 feet. Three of the plots are on flat ground, while Plot 12 has a slope of 12 percent and a southwest aspect. Plot 12 has experienced root rot damage.

Hoskins

All three control plots from the Levels-Of-Growing-Stock installation near Hoskins were used for this study (Marshall et al. 1992). These plots were established in

1963 by Oregon State University on land owned by Starker Forests as part of a nine installation, five organization cooperative study of thinning response in even-aged Douglas-fir. The Hoskins installation is located approximately 22 miles west-north-west of Corvallis at an elevation of 1000 feet and on slopes of 15 to 55 percent. Its King's (1966) site index is 136 feet. All of the plots are one-fifth acre in size.

Burnt Woods

The final two control plots came from an economic feasibility study established near the hamlet of Burnt Woods. The installation is on land managed by the Oregon State Department of Forestry (Berg 1961). It is located at an elevation of 1030 feet and with a west-south-west aspect, Both control plots are one-tenth acre in size, and their King's (1966) site index is 136 feet.

RESULTS AND DISCUSSION

Spatial patterns in young, even-aged stands of pure species and natural origin have been found to be either random or clumped. A random pattern has been reported for ponderosa pine (Cooper 1961), sand pine (Laessle 1965) and jack pine (Kenkel 1988), while a clumped pattern has been reported for sand pine (Laessle 1965) and loblolly pine (Daniels 1978). In all of these studies, the spatial pattern of the stands moved towards uniformity as they aged. These results conform to studies of

competition which have shown that one sided competition can result in the development of a uniform spatial distribution of the individuals (Ford and Diggle 1981). These results also seem to conform with Moeur (1993) who reported that, in three old, unmanaged, all-aged forests, the large codominant and dominant trees from the original stand have a tendency to be uniformly spaced, while the younger trees are clumped.

The observed $L(d)$ values at the beginning and ending measurement periods for each of the nine plots used for validation are presented in Figure 5. Positive $L(d)$ values indicate that the stands are clumped at distance "d", and negative $L(d)$ values indicate that the stands are uniform at distance "d". Examination of the observed $L(d)$ values for the initial measurements indicates that all of the plots display some degree of clumping at most scales. The plot of the observed $L(d)$ values for the last measurement in each stand show a tendency for the stands to display a less clumped distribution with increasing age. At both ages, all of the plots show increased dispersion at close distances indicating that short range inhibition is occurring. The degree of dispersion increases with age, and therefore average tree size, supporting the assumption that the inhibition relationship is related to tree size.

In Black Rock plot 12 (Figure 5 E) the observed $L(d)$ values for the final measurement cross the observed $L(d)$ values for the beginning measurement at about 70 feet. This is attributed to patchy mortality due to the presence of root rot on a portion of the plot. Hoskins plot 10 (Figure 5 A) also exhibits this cross over at about 35 feet, but no known stand damage accounts for it.

Figure 7 contains the graphs of the mean simulated $L(d)$ values for the stands at the same ages as Figure 5. For the initial measurements, the mean simulated $L(d)$ values exhibit the same form as the observed $L(d)$ values. A trend to a more random distribution of the trees can be seen in the mean simulated $L(d)$ values of the ending measurement period, although the trend is not as pronounced as in the actual values. In Figure 7E there is no crossover of the $L(d)$ values because the current coordinate generation routine does not model the effects of root rot damage. In Figure 7A the crossover of the $L(d)$ values is replicated, and in fact is repeated in Figures 7B and 7C when the observed stands did not cross over. These differences may be the result of the use of scaled predicted maximum crown width of an open grown tree instead of the predicted maximum crown width of a stand grown tree to define the inhibition region in the non-simple sequential inhibition coordinate generation process.

In Figure 6, each graph presents the simulation bands for the initial and last measurements and their associated observed $L(d)$ values. To aid in analysis, the resulting 18 simulation bands were grouped both by plot ages and distances "d", and a count was made of the number of box and whisker plots in each age or distance class for which the observed $L(d)$ value fell within the box, within the box and whisker, or outside the whisker. These counts were then expressed as percentages of the total number of box and whisker plots counted in each age or distance class (Tables 3 and 4).

Figure 7. Plots of the mean simulated $L(d)$ values at the beginning measurement period (solid lines) and ending (dashed lines) measurement period. (A) Hoskins plot 10, (B) Hoskins plot 22, (C) Hoskins plot 26, (D) Black Rock plot 7, (E) Black Rock plot 12, (F) Black Rock plot 16, (G) Black Rock plot 27, (H) Burnt woods plot 1, (I) Burnt woods plot 2. The value of $L(d)$ assuming spatial randomness is plotted as the dotted line.

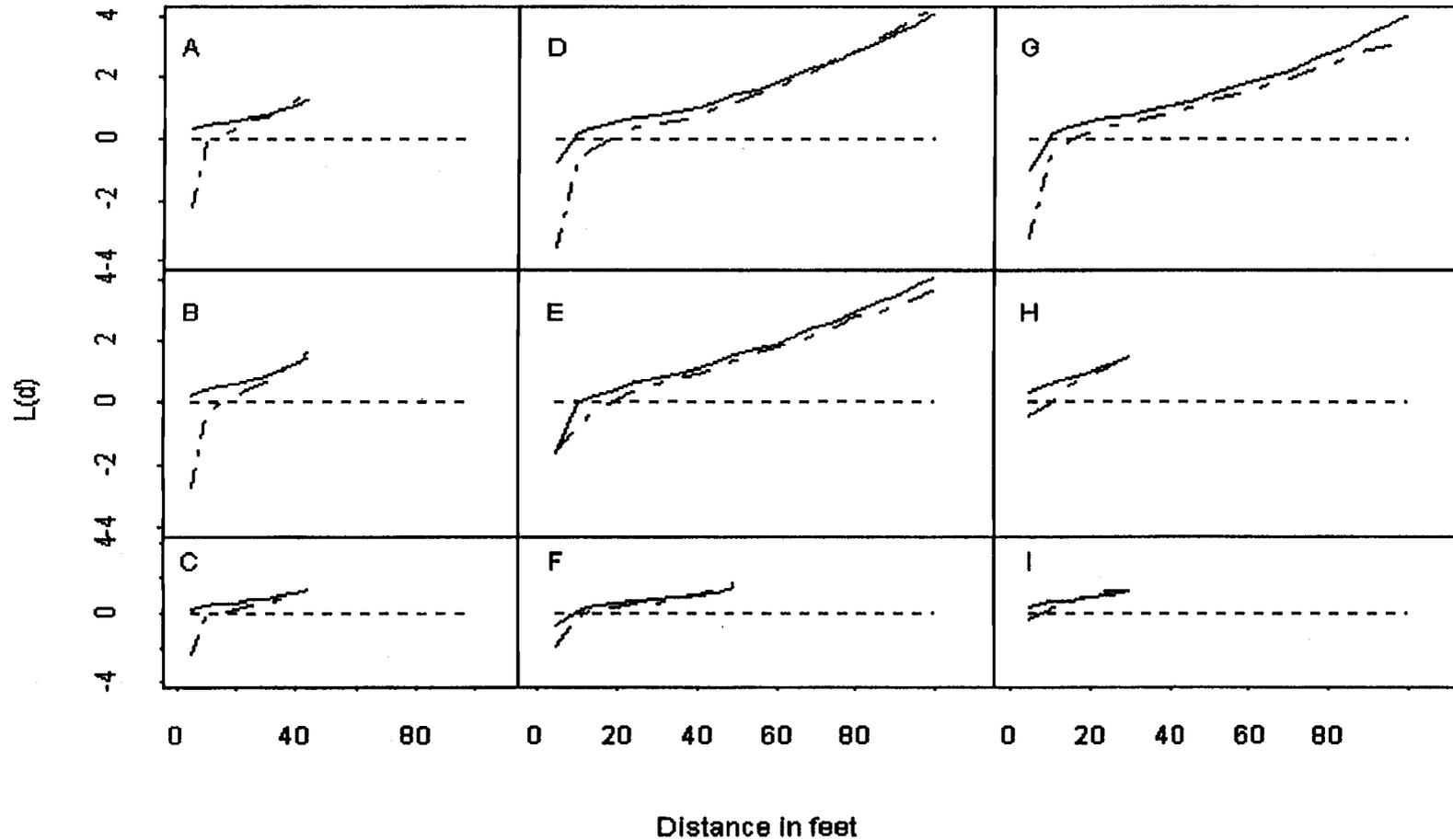


Table 3. Summary across age classes of the box-and-whisker plots found in Figure 6 A through I.

Range in plot ages	Total number of box and whisker plots	Percentage of total box and whisker plots containing observed L(d) values		
		within box	within box or whisker	outside box and whisker
20-25	39	51.3	97.5	2.5
39-52	119	44.5	100	0
77-82	80	30	100	0
All	218	44.5	99.5	0.5

If the proposed non-simple, sequential inhibition process is successful at simulating the actual tree coordinates, then all of the observed L(d) values should fall within their box and whisker plot.

From Figure 6 and Tables 3 and 4, it is evident that the method of coordinate generation using the non-simple sequential inhibitory process produces patterns that reflect the conditions observed in the sampled stands. Over all stands and all ages, the observed values of the L(d) function were outside of the range of L(d) values generated by the coordinate generation routine less than 1 percent of the time. At stand ages of 20 years, only 1 of the observed L(d) values falls outside of the whiskers, and all of the observed L(d) values fall within the whiskers in the older two age classes. These results also indicate that the generated spatial patterns are realistic at the distance scales examined (Table 4).

Table 4. Summary across distance classes of the box-and-whisker plots found in Figure 6 A through I.

Distance class	Total number of box and whisker plots	Percentage of total box and whisker plots containing observed L(d) values		
		within box	within box or whisker	outside box and whisker
5	18	67	100	0
10	18	67	100	0
15	18	61	100	0
20	18	61	100	0
25	18	50	100	0
30	18	44	94.4	5.6
35	14	43	100	0
40	14	36	100	0
45	14	29	100	0
50	8	83	100	0
55	6	50	100	0
60	6	67	100	0
65	6	67	100	0
70	6	67	100	0
75	6	33	100	0
80	6	50	100	0
85	6	33	100	0
90	6	50	100	0
95	6	50	100	0
100	6	50	100	0

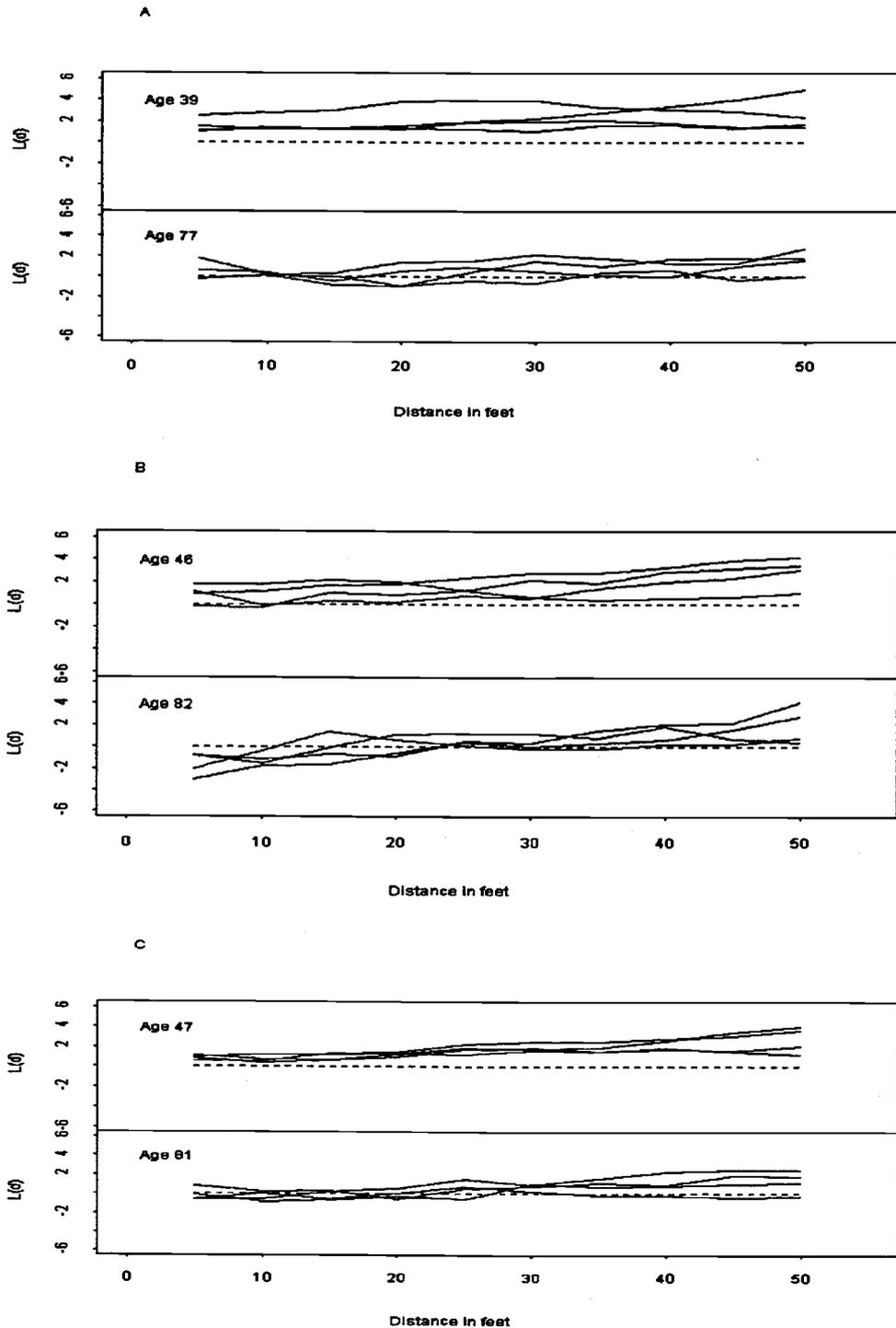
Examination of the width of the simulation bands illustrates the amount of variation in L(d) produced by repeated application of the non-simple, sequential inhibition process to a given diameter distribution. To assess the amount of variability expected within actual stands, the three one acre plots at Black Rock were divided into

quarter-acre subplots and the observed $L(d)$ values for each of the quarter-acre subplots are plotted separately (Figure 8). These results show that the observed $L(d)$ values from the subplots vary more than the patterns generated by the coordinate generation routine. A portion of this increased variation in observed $L(d)$ values is probably due to the fluctuations found in the diameter distributions of the quarter-acre subplots. Figure 8 also illustrates that the subplots also have a tendency to display a less clumped distribution with increasing age. The box plots for the older stands show more variability than those for the younger stands. This is probably due to having fewer points and more places to put them. The tendency to increasing variability in older stands is not a feature of natural stands. To control this in implementing this routine several patterns are generated and their $L(d)$ functions are calculated. From these $L(d)$ functions mean values are calculated and the placement that falls closest to them is used.

The non-simple sequential coordinate generation procedure requires only a tree list to reconstruct the spatial patterns observed in the examined stands. Other methods of coordinate generation require that an independent estimate of the degree of deviation from spatial randomness be made prior to the generation of the point pattern. The non-simple sequential inhibition process coordinate generation procedure also has the ability to replicate a variety of stand conditions.

This analysis was restricted to unthinned natural stands of Douglas-fir. The results indicate that the non-simple sequential inhibitory process, based upon the scaled maximum, open grown crown width, used to generate the coordinates is

Figure 8. Plots of observed $L(d)$ values at the beginning and ending measurements for the quarter-acre subplots on Black Rock plot 7 (A), plot 12 (B), plot 27 (C). The value of $L(d)$ assuming spatial randomness is plotted as the dotted line.



acceptable for the stand conditions examined. A potential refinement to this method that should be developed and tested is the usage of predicted maximum crown width within the crown instead of scaled maximum, open grown crown width.

Based on these findings, the non-simple sequential inhibition process coordinate generation procedure has been used to generate coordinates for unthinned, natural stands in the VIZ4ST visualization program. The VIZ4ST program was designed to display the results of stand samples, as well as the results from stand development models such as ORGANON. The coordinate generation procedure provides VIZ4ST with an objective method of calculating the position of the trees it draws.

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Chapter 4:

USER'S GUIDE FOR THE VIZ4ST PROGRAM

Mark L. Hanus and David W. Hann

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Chapter 4:**USER'S GUIDE FOR THE VIZ4ST PROGRAM**

VIZ4ST is a graphics program for MS-DOS¹. It displays the output from ORGANON, a forest growth and yield model (Hann et al., 1994), as an animated stand of trees. The VIZ4ST program allows you to display forest stand structure based on the results of the model in a form that is easy to visualize. Inclusion of shrubs, rocks, logs, and snags allows you to see a complete picture of forest stand structure. Thirty foot stadia rods are placed at each corner of the plot to provide a vertical scale reference.

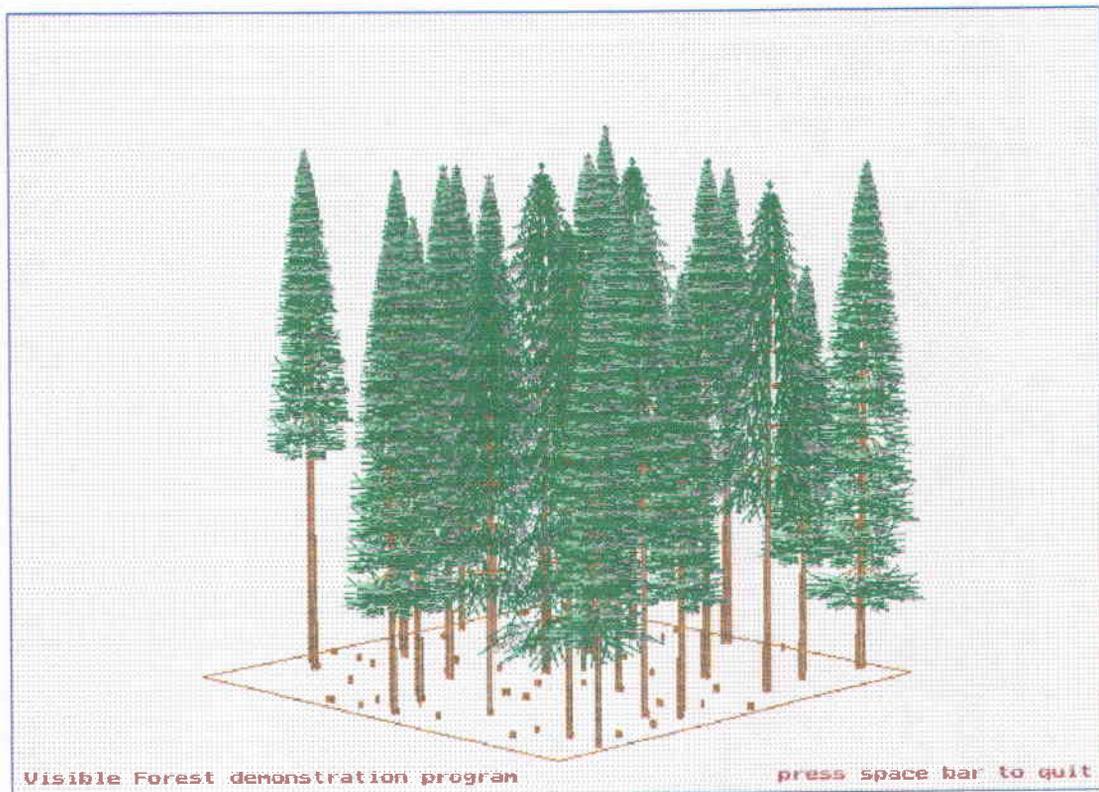


Figure 9. View created by VIZ4ST of the example stand provided with the first release of the software.

¹ MS-DOS and Microsoft-WINDOWS are registered trademarks of Microsoft corporation. BORLAND C++ is a trademark of Borland International.

SYSTEM REQUIREMENTS

The program requires a personal computer running MS-DOS with a VGA (or better) display monitor and about 1Mb of disk space. It will run in MS-DOS version 5.0 or higher. The program was coded in C++ and compiled with Borland C++ version 3.1.

QUICK START

The program is supplied on a single 3.5" floppy disk. The program will run from this disk, but quite slowly. It is recommended that the contents of the floppy disk be copied to a sub-directory on your hard disk created especially for the VIZ4ST program.

The following examples use one of the data files included on the VIZ4ST floppy disk. To start the program from the floppy disk:

1. Put the disk in the drive and move to that drive.
2. Type VIZ4ST and press the enter key. For example from drive A:, type the following:

```
A: <ENTER>
```

```
VIZ4ST <ENTER>
```

3. Fill in the main menu moving between fields using the arrow keys so that it looks like the following:

The Visible Forest	
<p>DISPLAY SELECTION MENU</p> <p>GRID: N</p> <p>HERBS: N</p> <p>SHRUBS: N</p> <p>STEMS ONLY: N</p> <p style="text-align: center;"> <input type="button" value="VIEW"/> <input type="button" value="OBLIQUE"/> </p>	<p>FILE SELECTION FORM</p> <p>INPUT FILE TYPE: <input type="text" value="TREE FILE"/></p> <p>INPUT FILE NAME: <input type="text" value="TREE.FIL"/></p> <p>OUTPUT FILE NAME: <input type="text" value="TREEFILE.OUT"/></p> <p>OUTPUT GRAPHICS FILE NAME: <input type="text"/>.PCX</p>
<p style="text-align: center;">EXECUTION MENU</p> <p style="text-align: center;"><input type="button" value="READ INPUTS"/></p> <p style="text-align: center;"><input type="button" value="GENERATE COORDINATES"/></p> <p style="text-align: center;"><input type="button" value="DRAW STAND"/></p> <p style="text-align: center;"><input type="button" value="EXIT PROGRAM"/></p>	<p style="text-align: center;">FOREST OBJECT FORM</p> <p>UNDERSTORY VEGETATION FILE: <input type="text"/></p>
	<p style="text-align: center;">STAND SELECTION FORM</p> <p>PLOT NUMBER: <input type="text"/> PLOT AGE OR TIME: <input type="text"/></p>
<p>(.....Message Window)</p>	

Figure 10. The main menu of the VIZ4ST program.

4. Select "Read Inputs" by moving with the arrow key or <ALT-R>
5. When "Continue" appears in the Message Window select "Draw Stand" with the arrow key or <ALT-D>

To start the program from your hard disk (this option reduces the run time significantly):

1. Make a sub-directory on your hard disk and copy all of the files on the floppy to that sub-directory (refer to your DOS manual on how to do this).
2. Select the sub-directory and press <ENTER>
3. Fill in the menu and run as before.

The other examples on the disk use the alternate file types. There is an example text file 'FORVIEW1.DAT', and an example ORGANON file 'ORGOUT.DAT'. They can be run by changing the values for INPUT FILE TYPE and INPUT FILE NAME.

OPERATION OF THE PROGRAM

In general use the VIZ4ST program should be run from a hard disk for fastest operation. The program uses the disk to store information under the OUTPUT FILE NAME so there must be some room left to hold the file. These files are fairly small (~16Kb) so little additional space is required. Make a sub-directory, switch to it, and copy all of the files from the floppy into it. If you are using Microsoft-WINDOWS, add a program object to the menu. Consult the Microsoft-WINDOWS manual for information on adding a program object. Collect the data files that you wish to display. Note the plot age designator of the year that you wish to plot. The UNDERSTORY VEGETATION FILE can be created with a text editor prior to the running of the VIZ4ST program.

Execution of the program is started by typing VIZ4ST from the MS-DOS command line or selecting the Microsoft-WINDOWS icon that you created. Select the files containing the data, and the options that you desire, and generate coordinates, then select DRAW STAND to display the selected stand. The screen may be saved by pressing 'S' or 's' while the image is on the screen. The screen can also be saved in

Microsoft-WINDOWS by pressing <ALT-PRINT SCREEN> see the Microsoft-WINDOWS manual for further details. The menu screen may be restored by pressing 'Q' or 'q'.

The VIZ4ST menus are text based windows that allow you to control the simulation run. The main window appears on the screen when the program is first started as the following diagram indicates. You can move from field to field using the arrow keys, the mouse, or by pressing the <ALT> key and the highlighted letter of the command to be executed. The main menu is displayed on the screen while the coordinate generation routine is operating which may take some time to complete depending on the speed of the computer and the number of trees on the plot.

Context specific help is available by pressing the <F1> key. A message will appear at the bottom of the screen that indicates the expected input for the field.

The main menu

After you start the program, by typing VIZ4ST at the MS-DOS prompt or selecting the program icon under Microsoft-WINDOWS, the main menu fills the screen (Figure 8). It is a text screen that allows you to control what is drawn.

Movement through the menu can be done with the mouse, the arrow keys, or pressing <ALT> and the highlighted letter of the command that you want to execute. As an example, pressing <ALT-X> will cause the message "Do you wish to exit the form

(y/n) ?" to be printed in the message window. Answering 'y' will terminate the program and return you to the operating system, answering 'n' will return you to the menu.

At any time that the MAIN MENU is displayed, pressing <F1> will give you a short help message for that area of the menu. The message window at the bottom of the screen alerts you to any required actions as well as the effects of previous actions. When you move to some selection areas (such as VIEW) the valid responses for that area are in lists. Selections from the list are chosen with the space bar. As an example move the cursor to the VIEW selection window with the arrow keys or the mouse. Pressing the <SPACE-BAR> will cause the information window to cycle through the view list.

File selection form

Input file type

This selection allows you to select the data format for the input file to be drawn. There are three valid INPUT FILE TYPES: ORGANON FILE, TEXT FILE, or TREE FILE. They are selected by pressing the <SPACE-BAR> until the proper type appears.

- ♦ **ORGANON FILE** This option selects an ORGANON output file containing a tree list as the input to be drawn. The only portion of the file that the VIZ4ST program reads is the tree list. ORGANON will not

create tree lists without intervention. Instructions for writing the tree list to the output are found in the ORGANON users guide (Hann et. al, 1994).

Each tree record in the ORGANON file consists of a tree number, species, height, crown ratio, expansion factor, height growth, diameter growth, and a user code. The VIZ4ST program uses species, height, crown ratio, and expansion factor to create the desired image. VIZ4ST searches the ORGANON output file for each tree list, determines the age identifier of the tree list, and, if the age identifier matches the age of interest, reads the data. VIZ4ST expects the ORGANON tree list format to be maintained. It will not read tree lists that deviate from the format.

- ◆ **TEXT FILE** This option selects a text file for drawing. It is a tree record file in the format described in Appendix 1.

- ◆ **TREE FILE** This option selects a TREE file for drawing. It is a binary file from a previous VIZ4ST run containing data for forest objects. Saving the display in a tree file will allow you to look at the

stand from alternate view points without the need to recreate the spatial distribution each time.

Output file name

This allows you to specify the name of the file where the forest objects are stored while the program is running. The output file will be in the TREE FILE format, and can be saved for use later.

Output graphics file name

This specifies the file that can be used to save the screen image in PCX format. The PCX file extension will be added automatically by the program. PCX format can be imported into most word processors and paint programs. Microsoft-WINDOWS includes facilities for editing and printing the resulting images check the manual if you need help on the use of these features.

Display selection menu

The DISPLAY SELECTION MENU allows you to control what items are included in the drawing of the forest stand. There are options for including a GRID, HERBS, SHRUBS, and STEMS ONLY. Selecting 'Y' by pressing the space bar next to the option desired will cause that option to be included in the picture.

The GRID option allows you to superimpose a grid on the drawing so that the relative placement of the forest objects can be discerned. The grid is 5' by 5' in the coordinate system of the forest stand and is drawn on the 'X, Y' plane, in red. Vertical scale can be judged with the thirty foot stadia rods placed at the corners of the plot. The rods are striped with five foot stripes.

Selecting the SHRUB or HERB option requires that the UNDERSTORY VEGETATION FILE space in the FOREST OBJECT FORM be filled. The data contained in this file will be drawn to the screen if requested. Adding forest objects to the display increases program run time.

Selecting STEMS ONLY is a way to look at the trees without their crowns. It also allows you to look into the stand to examine the shrub and herb cover.

The angle of view is selected through the VIEW area. The plot is square and the views are all across the diagonal. Thus the top down view shows the plot as a diamond on the screen with the viewpoint centered at the lower vertex. The <SPACE-BAR> toggles through a list of the possible views. OBLIQUE displays the forest stand as if you

were looking down on it from sixty degrees above the horizontal. SIDE displays the stand from the side across one diagonal, and TOP-DOWN from above looking down.

Forest object form

The FOREST OBJECT FORM allows you to specify the UNDERSTORY VEGETATION FILE. This file contains additional data for forest objects such as shrubs, herbs, logs, snags and rocks. Since these objects are not used by ORGANON to model the forest stand they are stored in a separate file.

Understory vegetation file

The VIZ4ST program will not create shrub, herb, tree, snag, or log data. The only way to include these objects in the picture is to enter data into an UNDERSTORY VEGETATION FILE.

The VIZ4ST program does no dynamic modeling. Therefore, the UNDERSTORY VEGETATION FILE must be modeled separately if the display is to reflect changes in the shrub layer through time. This file can be created with any text editor that excludes special characters.

Five keywords are used by the program, they are SNAG, STUMP, SHRUB, HERB, and LOG. In the file one keyword is allowed per line and the keyword must be

the first characters on the line. Following each keyword are the forest object attributes separated by commas.

- ◆ **SNAG** Snags are defined individually, and the SNAG keyword line is of the form:
SNAG, species code (See table 5), x-coordinate in feet, y-coordinate in feet, total height in feet, DBH in inches.

- ◆ **STUMP** Stumps are defined individually and the STUMP keyword line is of the form: STUMP, x-coordinate in feet, y-coordinate in feet, diameter at top of stump in inches.

- ◆ **SHRUB** There are two species classes of shrubs, large leafed ('L') and small leafed ('S'). The SHRUB keyword line is of the form: SHRUB, species class (i.e., L or S), percent cover in shrubs, total height of shrubs in feet, average maximum crown width of shrubs in feet.

- ◆ **HERB** There are two species classes of herbs, clumped ('C') and dispersed ('D'). The HERB keyword line is of the form: HERB, species class (i.e., C or D), percent cover in herbs, total height of herbs in feet.

- ◆ **LOG** Logs are defined individually by their large end diameter and will taper to a point which may extend beyond the boundaries of the plot. The LOG

keyword line is of the form: LOG, x-coordinate in feet, y-coordinate in feet, total log length in feet, diameter of the log at its large end in inches.

Stand selection form

The STAND SELECTION FORM allows you to select which data set you want to draw from the ORGANON FILE. This types of file may contain data from more than a single plot or stand age.

To display ORGANON runs, only PLOT AGE OR TIME is required. For even-aged stands, PLOT AGE OR TIME is the total stand age for the tree list to be drawn. For uneven-aged stands, PLOT AGE OR TIME represents the elapsed time from the start of the run for the tree list to be drawn.

In the TEXT FILE option, both PLOT NUMBER and PLOT AGE OR TIME are required. In this option, PLOT AGE OR TIME designates the measurement period to be drawn.

Because the TREE FILE option contains only data from one stand and time period, it doesn't require a PLOT NUMBER or PLOT AGE OR TIME. The input value will not be used so, you can leave these fields blank when drawing a TREE FILE.

PLOT NUMBER is assumed to be an integer of one to four digits in length. PLOT AGE OR TIME is an integer of one to three digits in length.

Execution menu

The EXECUTION MENU consists of push buttons that execute a portion of the program. Your selection from this menu is made by holding down the <ALT> key and pressing the highlighted letter of the desired action, or by moving the cursor to box containing the command and pressing the <ENTER> key or clicking the left mouse button. As an example <ALT-X> will cause the message "Do you want to exit this form (y/n) ?" to be displayed in the message window. Selecting 'y' will exit the program.

The READ INPUTS button starts the reading of the selected INPUT FILE NAME. The program will return an error if no input file is selected, the file doesn't exist, or it is of the wrong INPUT FILE TYPE

The GENERATE COORDINATES button starts the execution of the coordinate generation routine. If there are previously generated coordinates the program will ask if new ones should be generated. Coordinate generation is divided into two situations, natural stand or planted. The natural stand coordinate generation routine uses the exclusion process described in Hanus and Hann (1995?). The planted stand coordinate generation routine takes the planting density and the error in spacing and generates coordinates by creating a matrix on the spacing that would result in the desired density. The actual location of the individual tree is calculated by adding a random distance, calculated from the error in spacing, and azimuth to the matrix location. Trees in excess of the density are assumed to be ingrowth and are assigned by the exclusion process after the planted locations are filled.

The DRAW STAND button starts the drawing of the stand using the options selected in the DISPLAY SELECTION MENU.

The EXIT button writes a message to the Message Window at the bottom of the screen. The user answers either y or n and the program responds.

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Chapter 5:

DISCUSSION

The display of forest stands as rendered forest scenes offers the opportunity of relating with the viewer in a way that isn't possible with tables and graphs. Pictorial scenes allow the viewer to rapidly assimilate information, since the data is presented in a familiar form. Pictorial scenes can't replace the use of tables and graphs since the perception of the stand is greatly influenced by varied aspects of the drawing, such as color and positioning, but they can provide a reference point allowing communication of particulars with tables and graphs.

In scene rendering the scale of resolution of the objects is a function of the scale of the data being displayed, the purpose of the display, and the processing power of the machine displaying the data. As the image moves closer to the viewer the less visible are the spatial patterns between the forest objects, and the more the patterns within the object are visible. Thus no one display will offer everything for every use, and all will require compromise over what is ideal.

The VIZ4ST program provides a method of displaying forest stands in the western United States that incorporates what is known of the architectural forms of native trees into a program that displays the inter-individual relationships of forest objects. The program removes personal bias in the display of these objects by using quantitative relationships in building the objects it displays.

The communication of complex situations requires that the visualization tool be as free from bias that taint perception of the collected data as possible. The user must

have the freedom to display the data in a way that communicates the information contained within it but not so free that perception is manipulated. VIZ4ST provides such a tool.

VIZ4ST uses a non-simple sequential inhibitory coordinate generation procedure to generate coordinates for the display of forest stands. This process was found to replicate the spatial patterns found in nine pure stands of Douglas-fir.

VIZ4ST provides a method of displaying the results of the ORGANON stand development model that doesn't rely on finding existing stands to serve as surrogates. The program allows the user to investigate various silvicultural prescriptions without conducting operations, and provides a mechanism to communicate the prescriptions to persons without a forestry background. VIZ4ST also provides a groundwork for the development of a more detailed system for the display of finer details of stand structure.

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