

Spatial Patterns in Natural Second-Growth
Stands of Coastal Western Hemlock

by

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INTRODUCTION

Silvics and Importance of the Species

Densely stocked second-growth stands of coastal western hemlock (*Tsuga heterophylla* [Raf.] Sarg.) between 30 and 50 years of age arising from natural regeneration appear to be spatially aggregated. Is this visual impression an accurate observation? Are the largest and most rapidly growing stems clumped? What structural changes have occurred as a result of mortality? As mortality occurs, are the remaining stems becoming more or less aggregated? Is there discernible pattern to the mortality? Are the residual dominant stems becoming more or less clumped? The intent of this investigation is to examine spatial patterns in natural stands of coastal western hemlock between about 30 and 50 years of age. These stands are in a developmental stage characterized by crown closure, intense competition, and very little understory vegetation. This stage has been described by Oliver (1979) as "stem exclusion." It is beyond the scope of this study to assess factors of causality for the patterns which have been measured.

A fundamental characteristic of western hemlock stands (like other populations of plants or animals) is their spatial pattern; and many concepts of phytosociology are based on the assumption that

individuals of most plant populations are distributed at random (Goodall 1952). Although much work has been performed to assess results of cultural manipulations in western hemlock (Atkinson and Zasoski 1976), there is a near total lack of spatial pattern information on coastal western hemlock at any age of its development. In part because of the lack of understanding of spacing, responses to both fertilizer and/or density adjustment operations are still unresolved (Atkinson and Zasoski 1976). Similarly, neither crown nor root competitive indices of reliable accuracy exist, and modelling and simulation of western hemlock stand dynamics are in their infancy. Knowledge of spatial pattern is crucial in determining stand dynamics -- the phytosociological interaction among trees. If pattern can be determined in natural stands, it can be mimicked or compensated for in managed stands to provide insight on results of silvicultural operations.

The spatial pattern or spatial distribution of vegetation is typically categorized as aggregated (i.e., clumpy, patchy or contagious), random or regular. When individuals are distributed at random, the following ratio should equal unity:

$$\frac{\text{mean distance from a random point to nearest individuals}}{\text{mean distance between a randomly selected individual and its nearest neighbor}}$$

This ratio will be greater than unity when individuals are aggregated and less than one when the spatial distribution is regular (Pielou 1974) (Appendices 1 - 6).

The pattern of a population dispersed over a continuum has two properties: intensity and grain (Pielou 1974). The intensity of a pattern is high if a wide range of densities occurs; conversely, it is low if the density contrasts are slight. The pattern is coarse-grained if its patches and the spaces among them are large; in the converse case, the pattern is fine-grained. Indices of non-randomness based on point-to-plant and plant-to-plant distances are a measure of the intensity of spatial pattern.

Western hemlock is an important tree species of the Pacific Coast and Rocky Mountains of North America. Its latitudinal range spans nearly 1800 miles from its southern limit of northern California (Munz and Keck 1959) to the southwestern tip of the Kenai Peninsula of Alaska (Vierick and Little 1972). Although its elevational distribution is quite broad - sea level to 7000 feet (Harlow and Harrar 1959) - western hemlock's best development occurs between sea level and 2000 feet (Fowells 1965). It occurs on nearly all major landforms of the Pacific slope region. The one prerequisite appears to be adequate moisture. Western hemlock thrives in a mild humid climate where frequent fog or precipitation occurs during the growing season. Best stands are located in the humid coastal regions (Fowells 1965). Within the *Tsuga heterophylla* zone, it is a major dominant in the climax overstory and commonly plays the role of pioneer in colonizing recently-bared land.

The commercial importance of western hemlock to the Pacific Northwest region is second only to Douglas-fir (*Pseudotsuga menziesii*

[Mirb.] Franco). It accounts for roughly 25 percent of the region's softwood growing stock (Beswick 1976). The dramatic increase in western hemlock stumpage prices has allowed both private and public resource managers to intensify the degree of cultural practices applied to western hemlock stands. Managed stand operations and silvicultural prescriptions are being performed with little understanding of the developmental dynamics occurring within natural stands. It is the intent of this study to contribute information aimed at remediating that situation.

Study Objectives

This investigation will examine the spatial distribution in selected second-growth western hemlock stands in coastal western Washington. The stands studied varied between 42 and 50 years of age in 1978. Measurements were made in 1970 and 1978. Specific objectives of this investigation are:

1. To examine the spatial pattern of all living stems when the stands were 34 to 42 years old.

Specific hypothesis #1: Spatial pattern is aggregated according to Pielou's (1959) index of non-randomness, as will be discussed later.

2. To examine the spatial pattern of those trees which died in an eight-year period during their fourth decade (between 1970 and 1978).

Specific hypothesis #2: Spatial pattern is aggregated according to Pielou's index.

3. To examine the spatial pattern of those trees alive at ages 42 to 50.

Specific hypothesis #3: Spatial pattern is being reduced (i.e., becoming less aggregated) according to Pielou's index.

4. To examine the spatial pattern of those trees alive in 1978 which exhibited greatest diameter growth.

Specific hypothesis #4: Spatial pattern is tending toward regularity according to Pielou's index.

5. To examine the spatial pattern in mixed stands of western hemlock and western redcedar (*Thuja plicata* Donn.) or Douglas fir.

Specific hypothesis #5: Spatial pattern of each species is patchy and the patches are separately aggregated according to Pielou's index.

6. To examine the spatial pattern by crown classes for those trees alive in 1970.

Specific hypothesis #6: Spatial pattern is aggregated in lower crown classes and less patchy in upper crown classes according to Pielou's index.

Literature Review

Detection of Pattern

Three components define the structure of vegetation: the horizontal arrangement of species, i.e., the spatial pattern or distribution of individuals; the vertical arrangement of species, i.e., the stratification of the species; and, finally, the abundance of each species expressed in terms of either density or yield.

Clark and Evans (1955) stated that spatial pattern of individual members of a population of organisms is of obvious importance in the analysis of population behavior. Knowledge of pattern is crucial to understanding processes which affect stand development. Much effort is currently expended attempting to develop simulation models of stand development and competitive indices of individual tree species (Mitchell 1969; Arney 1972; Opie 1972; Moore et al. 1973).

Silvicultural prescriptions for managed stands should be made with a prior understanding of the dynamics in natural stands. Regardless of one's silvicultural objective, knowledge of a species' pattern of development is essential.

Gleason (1920) tested natural distributions of organisms for conformity to random expectation. He utilized the binomial distribution and concluded that patchiness of individuals of a species occurred in an apparently uniform area. Steiger (1930) studied plant distribution on the Nebraska prairie, subdividing into "high prairie"

and "low prairie" areas. The experimental design, which may have biased his results, was later questioned by Curtis (1955). Hanson (1934) studied plant count data on the Native Prairie of western North Dakota. Blackman (1935) performed the initial critical analysis of plant counts and attempted to fit the Poisson series to his observations. Clapham (1936) showed that individuals of a great majority of species do not follow the Poisson form of distribution. Pielou (1977) supported this conclusion and attributed the unsuitability of the Poisson distribution to its very restrictive assumptions. The Poisson distribution, which is most likely to be valid at low density values, assumes the maximum number of individuals a unit could contain is the same for all units and that the expected number per unit is the same for all units.

A pattern of a population is considered to be random if all sampling units contained an equal number of "elementary habitable sites," each with equal probability of containing exactly one individual (Pielou 1974). The critical assumption is that the expected number of occupants is the same for all sampling units. From that assumption, three others follow:

1. All individuals are independent of one another. They do not attract or repel one another, nor do they compete for space since their density is everywhere too low for crowding.
2. Every sampling unit is equally hospitable to the species. There are no "good" or "bad" locations since all are equal.

3. The expected number of individuals per sampling unit is the same for all individuals and sampling units, regardless of any size differences among individuals or sampling units.

Archibald (1948) noted that the assumption of random distribution of plant numbers did not agree with views held by many plant ecologists. She demonstrated that the distribution of some plants would better be described on the hypothesis of aggregation. In cases when a Poisson series would not fit the data, a good fit was often obtained using the contagious series introduced by Neyman (1939). This viewpoint was later supported by Evans (1953) who concluded that the Neyman Type A contagious distribution was generally best for plant count data.

Dynamics of Pattern

Trees in a forest are examples of organisms which have a continuum of space that they can occupy. In an aggregated pattern, most of the individual-to-neighbor distances are short within-clump distances. A randomly-placed point would most likely fall in one of the large spaces separating the clumps, and therefore be a long way from the nearest individual. It makes no difference in a random pattern whether distance is measured from a randomly-located point or from a randomly-selected individual. The expected distance to the nearest neighboring individual is the same in either case. In a regular pattern, the distance from any individual to its nearest

neighbor definitely has a greater expectation than the distance from a random point to its nearest individual.

It is the conclusion of many scientists that a contagious (aggregated) spatial pattern of individuals in vegetation is a common feature. Random patterns are far less common, while occurrence of a regular pattern is very rare (Watt 1947; Archibald 1948; Ashby 1948; Clark and Evans 1955; Jones 1955-6; Kershaw 1963; Greig-Smith 1964; Kershaw 1973; Payendeh 1974; Pielou 1974).

Evidence is accumulating which suggests an overall reduction in pattern (i.e., the components become less aggregated) as a community stabilizes. Whitford (1949) stated that the degree of aggregation is a function of stand age and implied that old stands have less non-randomness than young stands. Cooper (1961), using data on ponderosa pine (*Pinus ponderosa* Laws.) forests in northern Arizona, concluded that trees in young stands are randomly distributed with a slight tendency toward a uniform distribution as the stand matures. He found no evident tendency toward clumping of individuals at any development stage of the stand. Greig-Smith (1952), in his study of the primary rain forests in Trinidad, showed little aggregation and association between species where a disturbance occurred many years ago; however, he found significant evidence of aggregation in recently-disturbed areas. Kershaw (1958), in an investigation of structure in a grassland community, showed a trend of decreasing intensity of pattern reduction in his analysis of spatial pattern in a community

of sand dune vegetation. One report was made of an observation of a regular distribution of trees in savanna vegetation of the Sudan (Kershaw 1963).

Spatial Patterns in Western Hemlock

Evidence suggests that the spatial pattern of western hemlock natural reproduction depends on micro-site. Historical information indicates extreme variability in amounts and depths of slash, in occurrence of fire, and in amount of brush competition following early logging operations in the Pacific Northwest. Western hemlock is a prolific seeder and produces some seed every year. Heavy seed crops occur every three to four years (Fowells 1965). It releases its seed continuously from late summer to the next summer. The distance to which seed is disseminated is a function of: height of tree, topography, air movement, seed characteristics (size, weight, wing form), season of dissemination, and actions of birds and rodents (Soos and Walters 1963). The pattern of regeneration in natural stands of coastal western hemlock has been observed to be aggregated (Lynch and Schumacher 1941; Berntsen 1955; Harris 1967). A benefit of clumping would be mutual shading and reduced evapotranspiration. Western hemlock regeneration tends to be most successful on downed logs (i.e., "nurse logs") and rotting slash (Berntsen 1955; Day 1964; Fowells 1965; Harris 1967; Scott et al. 1976). Sites suitable for germination may evolve over a period of many years, producing a mosaic of tree

ages within a stand -- resulting in even-aged pockets with the stand.

Competition between individuals is very intense during this period of stem recruitment. Koyama and Kira (1956) and Yoda et al. (1957) showed that self-thinning was a density-dependent process. Initial high densities increased the variance of growth rate of individual plants, accelerated competitive interaction between adjacent growing individuals, and finally resulted in high mortality. Pielou (1974) stated that if mortality is density-dependent, the pattern of the survivors becomes reduced or less aggregated.

Measurements of Pattern

Spatial distribution of a plant population is a fundamental characteristic, but difficult to describe in precise meaningful terms. Analysis of pattern through use of various indices of non-randomness is a quantitative adjunct to the descriptive aspect of vegetation investigations. Several methods have been developed for expressing spatial pattern in quantitative terms. The two general categories for these methods are 1) quadrat sampling and 2) distance or "plotless" sampling.

Quadrat sampling methods consist of choosing random placed or contiguous quadrats and counting the total number of points within each plot. An index of clumping based on the variance to mean ratio was suggested by David and Moore (1954). Pielou (1977) stated that this index was applicable to organisms that occur only in discrete

habitable units which are clearly defined. This is not the case for trees in a forest which have a continuum of space that they can occupy. The same limitation is applicable to the index of mean crowding and the index of patchiness developed by Lloyd (1967). Another disadvantage of Lloyd's index of patchiness is that it is dependent on quadrat size. This same limitation exists for Morisita's (1959) index of dispersion. Perhaps the most serious objection to quadrat methods is that they involve an excessive amount of sampling.

To avoid the effects of quadrat size and reduce amount of sampling and calculations, use of distance measure sampling was developed. Hopkins and Skellam (1954) proposed an index of non-randomness, "coefficient of aggregation," which uses the ratio of the mean of squared distances between random points and nearest neighbor to the mean of squared distances between random individuals and nearest neighbor. Both means are based upon the same number of measurements. Clark and Evans (1954) devised an index of non-randomness utilizing the nearest neighbor method. Their procedure involved choosing random points and measuring the distance to nearest neighboring individuals. The average of these distances together with point density are used to calculate their index value. Pielou (1959) developed an index of non-randomness using point-to-plant distances. Her sampling procedure consisted of selecting random points and measuring the squared distance to the nearest individual. The index of non-randomness, α , is the produce of π times the density times the average of the squared distances.

There are definite advantages and disadvantages associated with each of the indices described. The hypothesis of random dispersion based on quadrat sampling has been tested by several methods that are essentially valid; however, they involve an excessive amount of sampling and the results are strongly influenced by the size of the quadrat used for data collection. Of the three indices of non-randomness, Pielou's index has been determined to be the best measure combining high sensitivity with a minimum amount of calculation (Payendeh 1970; Stauffer 1977). A FORTRAN IV computer program is available to calculate Pielou's index of non-randomness (Stauffer 1976).

METHODOLOGY

Study Area

The study areas are a portion of the permanent plot inventory being maintained by the Regional Forest Nutrition Research Project (R.F.N.R.P.) of the College of Forest Resources, Institute of Forest Resources, University of Washington; and cooperative landowners in the Pacific Northwest. Western hemlock stands analyzed in the present study for spatial patterns were restricted to the Olympic Peninsula of western Washington to maintain a geographic uniformity. Criteria utilized in study area selection included: similar macroclimate, approximately equivalent age, pure or predominantly western hemlock species composition, and accessibility.

Three of the sites are approximately 30 kilometers north of Grays Harbor, Washington. One is near Lake Crescent and the other, approximately 30 kilometers west of Lake Crescent (Figure 1). Each installation consists of six 0.04 hectare (0.1 acre) plots. Initial stocking varied from 1384-3855 stems per hectare (570-1560 stems per acre). One-hundred-year site index of the plots ranged from 132 to 197 feet (Anon. 1976). Three installations (numbers 3, 15 and 80) are approximately 42 years of age (1978) and two (numbers 4 and 9) are approximately 50 years old (1978) (Table 1). Elevations of all plots are under 300 meters (1000 feet) with a gentle undulating

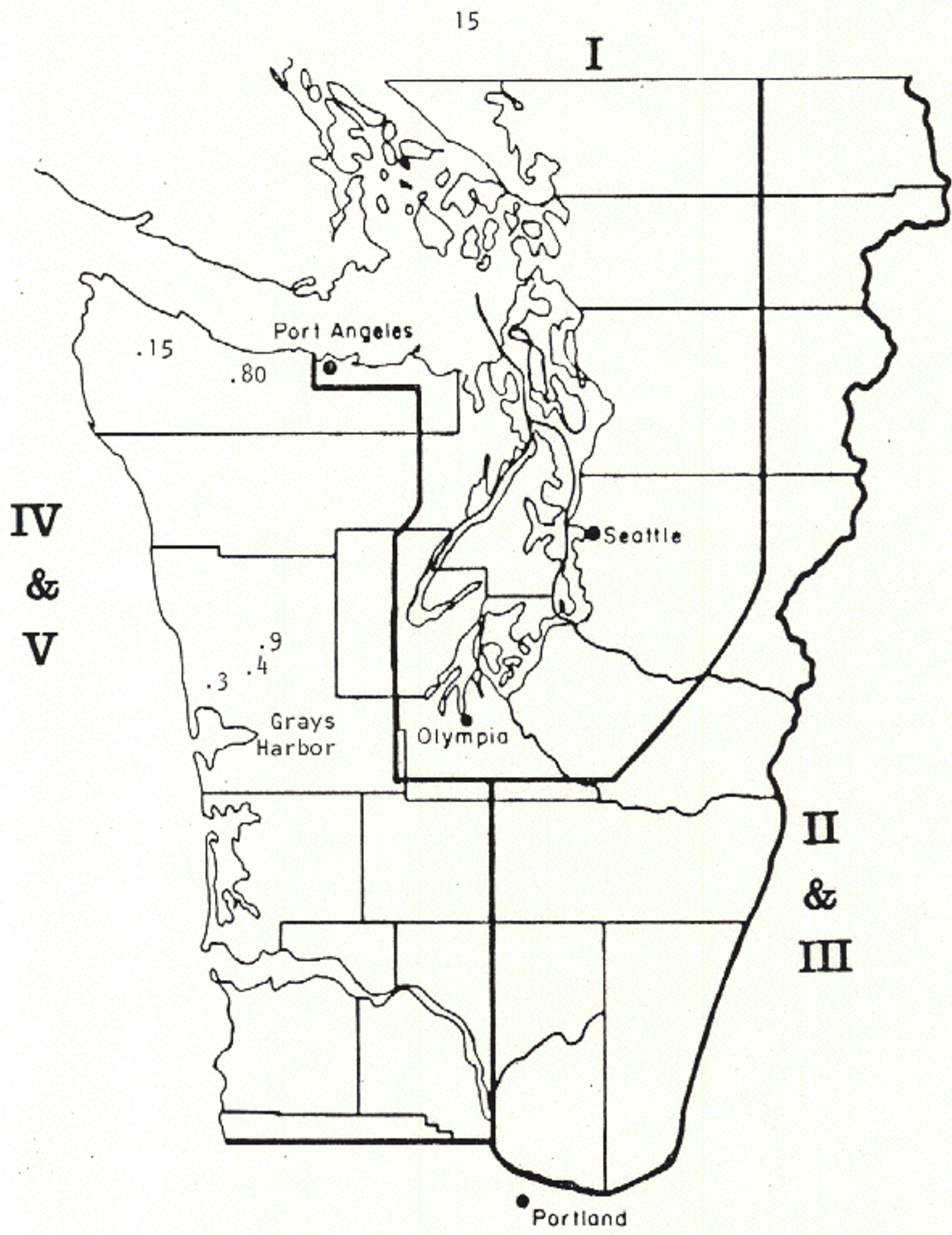


Figure 1. Map of site locations.

Table 1. Installation summary. WH = western hemlock; DF = Douglas-fir; RC = western redcedar; OC = other conifers; H = hardwoods.

Inst.-Plot	Species Composition	Total Trees per Hectare	100-Year Site Index	1978 Total Age
3-13	WH - All	1977	162	42
-14	WH - All	2718	143	43
-15	WH - 2694 OC - 74	2768	154	41
-16	WH - 2298 OC - 50	2348	157	42
-17	WH - 2446 H - 25	2471	172	42
-18	WH - All	2521	166	42
4-19	WH - All	1409	168	50
-20	WH - All	1384	187	50
-21	WH - All	1458	178	49
-22	WH - All	1532	187	50
-23	WH - All	1483	189	50
-24	WH - All	1927	185	49
9-49	WH - 1557 RC - 395 DF - 25	1977	165	49
-50	WH - 1557 RC - 889 H - 25	2471	165	50

Table 1 (cont.)

Inst.-Plot	Species Composition	Total Trees per hectare	100-Year Site Index	1978 Total Age
9-51	WH - 1507 RC - 568 DF - 25 H - 25	2125	180	49
-53	WH - 1507 RC - 1211	2718	152	48
-54	WH - 1310 RC - 568 H - 49	1927	164	50
15-85	WH - 1656 RC - 173 DF - 74 H - 99	2002	181	42
-86	WH - 1532 RC - 222 DF - 25 H - 346	2125	192	43
-87	WH - 1013 RC - 198 DF - 124 H - 172	1507	189	43
-88	WH - 1186 RC - 248 DF - 49 H - 49	1532	182	42
-89	WH - 1285 RC - 173 DF - 75 H - 49	1582	197	42
-90	WH - 1236 RC - 173 DF - 74 OC - 25 H - 74	1582	181	42

Table 1 (cont.)

Inst. Plot	Species Composition	Total Trees per Hectare	100-Year Site Index	1978 Total Age
80-475	WH - 1669 DF - 173 OC - 25 H - 247	3114	132	42
-476	WH - 2941 RC - 25 DF - 99 H - 790	3855	145	40
-477	WH - 1680 DF - 346	2026	140	41
-478	WH - 1507 DF - 445 H - 25	1977	146	43
-479	WH - 2545 RC - 25 DF - 247 H - 99	2916	140	43
-480	WH - 2372 DF - 148 H - 25	2545	163	41

aspect. Precipitation is heavy, 178-279 centimeters (70-110 inches) per year, mostly in the form of rain. Soils are unglaciated, deep and fertile. The areas can be generally characterized as excellent for tree growth.

Field Procedures

The 0.04 hectare plots were established in 1970 by R.F.N.R.P. Any conifer or hardwood whose diameter breast height (dbh) exceeded 3.94 centimeters (1.55 inches) in 1970 was permanently tagged. Species, crown class (as described by Smith 1962) and dbh were recorded. In 1978, this author collected stem map and age data on all trees present at time of plot establishment. Age data was obtained by coring trees at dbh using a standard increment borer. From plot center, azimuth information was obtained by either staff compass or plane table. Distance measurements were made using a 100-foot tape calibrated to the nearest 0.1 foot (Figure 2).

Data Analysis

A computer record for each tree within a plot was established. It was comprised of the following variables: installation number, plot number, tree number, species, crown class (1970), dbh (1970), dbh (1978), vigor class (alive, dead standing and dead downed), and tree location. Trees within each plot were subdivided into several categories to test specific hypotheses previously introduced:

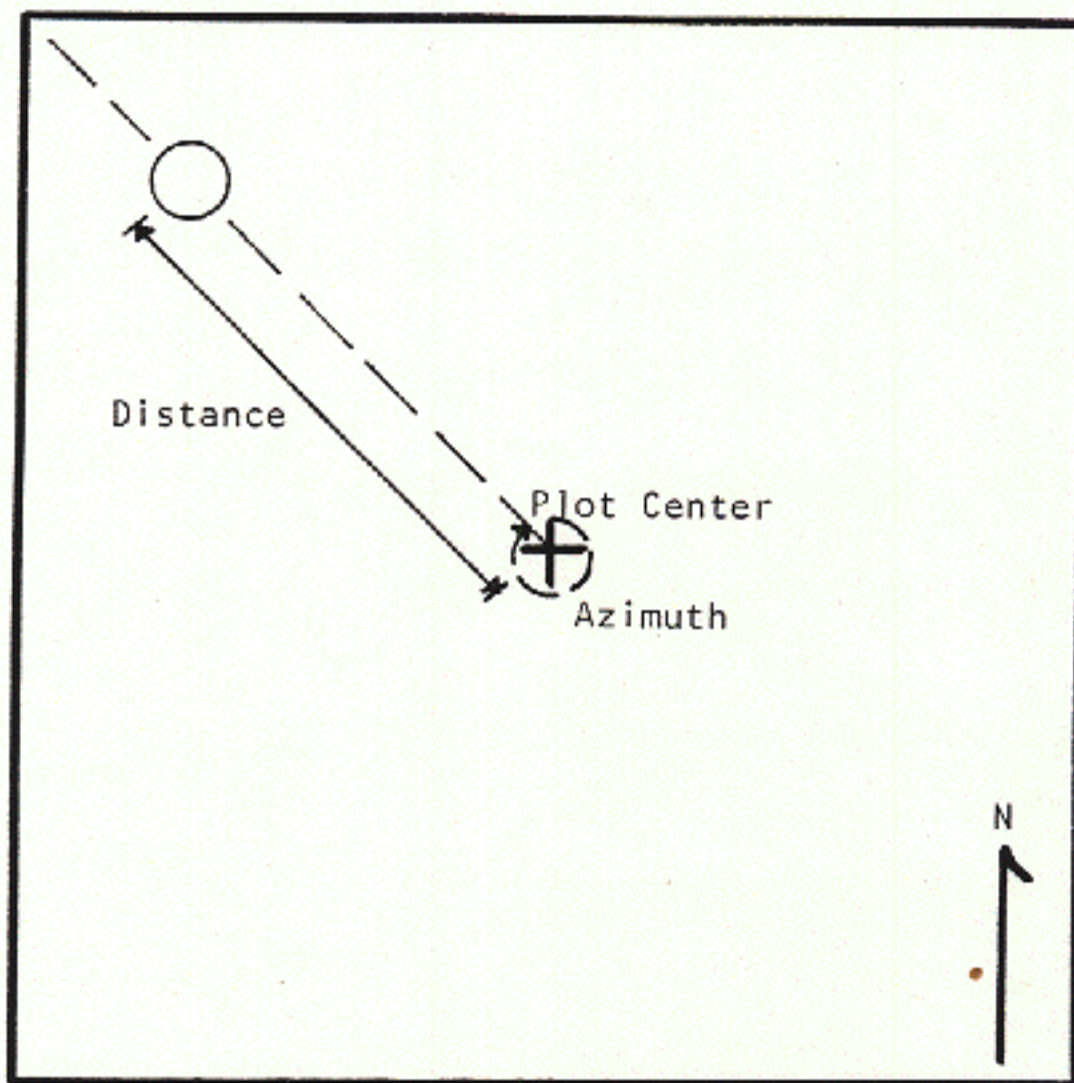


Figure 2. Schematic of stem mapping procedure.

1. trees alive in 1970 - utilizing vigor class and location;
2. trees which died during period 1970-1978 - utilizing vigor class and location;
3. trees alive in 1978 - utilizing vigor class and location;
4. trees exhibiting greatest diameter growth during period 1970-1978 - utilizing vigor class and $dbh\ 1978 > dbh\ 1970 + 1.4$ (choice of dbh criterion discussed in subsequent section);
5. species differences - utilizing species, vigor class and location;
6. crown class differences - utilizing crown class, vigor class and location.

The records for each plot were compiled and processed using a locally modified version of Stauffer's (1976) FORTRAN IV computer program (Appendix 7) which calculates Pielou's (1959) index of non-randomness, *alpha*.

Pielou's index of non-randomness, *alpha*, is:

$$\alpha = \pi \rho \bar{w}$$

where ρ = point density per unit area

\bar{w} = average squared distance between a sample of randomly chosen points and nearest neighboring individuals

It has been shown (Pielou 1959; Mountford 1961) that in a random distribution, *alpha* has an expected value of unity. In an aggregated

distribution, *alpha* would be expected to be significantly greater than one, whereas in a regular distribution, *alpha* would be expected to be significantly less than one.

Statements concerning the index of non-randomness for the spatial patterns of trees in each plot are based on *alpha* calculation tests performed at the 99.98% significance level. Based upon the application of Bonferroni's inequalities (Feller 1968), this allows a statement of significance to be made for the entire collection of 30 plots at the 99.0% significance level. At the 99.98% confidence level, limiting index values are:

1. index values greater than 1.080 denote aggregation;
2. index values between 1.080 and 0.923 denote randomness;
3. index values less than 0.923 denote regularity.

These conservative values for a sample of 2,000 random points were calculated using an approximation discussed by Pielou (1959). Some indices of non-randomness were calculated on a basis of less than ten trees. This author feels that indices based on such small samples are unreliable; therefore, those indices were omitted from the analysis.

Prior to calculating Pielou's index of non-randomness, two preliminary tests were performed on Stauffer's program. The first involved the test for the effect of sample size. Stauffer (1978) routinely uses a sample of 200 random points to generate an index value. A test for sensitivity to sample size was performed at sizes of 200, 500, 1,000 and 2,000 random points. No significant

differences between sample means were detected. However, the variance of the sample using 2,000 points was much smaller. Consequently, all indices of non-randomness reported in this study are based on a sample of 2,000 random points. The second test was of the effect of plot size. A sample of indices calculated on a plot size of 0.04 hectare was compared with a sample generated on a plot size of 0.02 hectare. No significant difference was found between the two. All index values in this investigation were calculated on trees within 0.04 hectare plots established by R.F.N.R.P.

RESULTS AND DISCUSSION

Thirty coastal western hemlock plots in western Washington were stem mapped in 1978. Using a locally modified version of Stauffer's (1976) FORTRAN IV computer program, the index of non-randomness for each plot was calculated. Based upon the specific hypotheses previously introduced, the following determinations of spatial distribution (i.e., tests for pattern) in 30 study plots were performed:

1. test for pattern of trees alive in 1970;
2. test for pattern of trees which died during the period 1970 - 1978;
3. test for pattern of trees alive in 1978;
4. test for pattern of trees with greatest diameter growth between 1970 - 1978;
5. test for pattern in mixed species plots;
6. test for pattern by crown class category of trees alive in 1970.

Factors which contribute to the spatial distribution of trees in a forest are many. They include variables such as: physiology of the species, inherent genetic variability, seed dispersal and regeneration characteristics, site quality, age of stand, shade tolerance, micro-site variations, and the influence and occurrence of biotic disturbances. It is beyond the scope of this investigation to perform

a critical examination of any causal factors. Where appropriate, hypotheses will be offered of possible contributing elements to the patterns which have been measured.

Test for Pattern of Trees Alive in 1970

Table 2 displays the indices of non-randomness for the 30 plots. Twenty-one of 30 indices denote aggregation and nine of 30 indicate randomness (99.0%) (Figure 3). Seven of those nine random indices occur within the older installations.

Plot 80-478 and all the plots of installation 9 have a substantial component of a minor species. Full investigation of these mixed species plots occurs in a subsequent section; however, information germane to this portion of the study is discussed herein. Plot 80-478, a plot with a random spatial pattern, has a 23% (by total number of stems) component of Douglas-fir. When each species is examined separately, the western hemlock component has an index value of 1.299 and the Douglas-fir, 1.174. Both indices denote aggregation (99.98%). The index values of the western hemlock component of plots 9-49 and 9-53 (also shown to have a random pattern when both species are considered) denote aggregation (99.98%). Thus, when considering only the western hemlock component of all plots, 24 of 30 indicated aggregated spatial patterns in 1970; and six of 30, randomness (99.0%).

Table 2. Non-random indices for trees alive in 1970.
 (* indicates random pattern [99.98%]).

<u>Inst.-Plot</u>	<u>1978 Total Age</u>	<u>Index Value</u>
3-13	42	1.520
-14		1.650
-15		1.396
-16		1.610
-17		1.310
-18		1.873
15-85		43
-86	1.205	
-87	1.130	
-88	1.465	
-89	0.959*	
-90	1.192	
80-475	43	
-476		1.473
-477		1.105
-478		1.068*
-479		1.256
-480		1.089
4-19		50
-20	1.041*	
-21	0.997*	
-22	0.943*	
-23	0.961*	
-23	1.211	
-24		
9-49	50	1.040*
-50		1.353
-51		1.295
-52		0.973*
-53		1.031*
-54		1.172

99.98% Confidence Limits

<u>Regular Pattern</u>	<u>Random Pattern</u>	<u>Aggregated Pattern</u>
	0.923	1.080

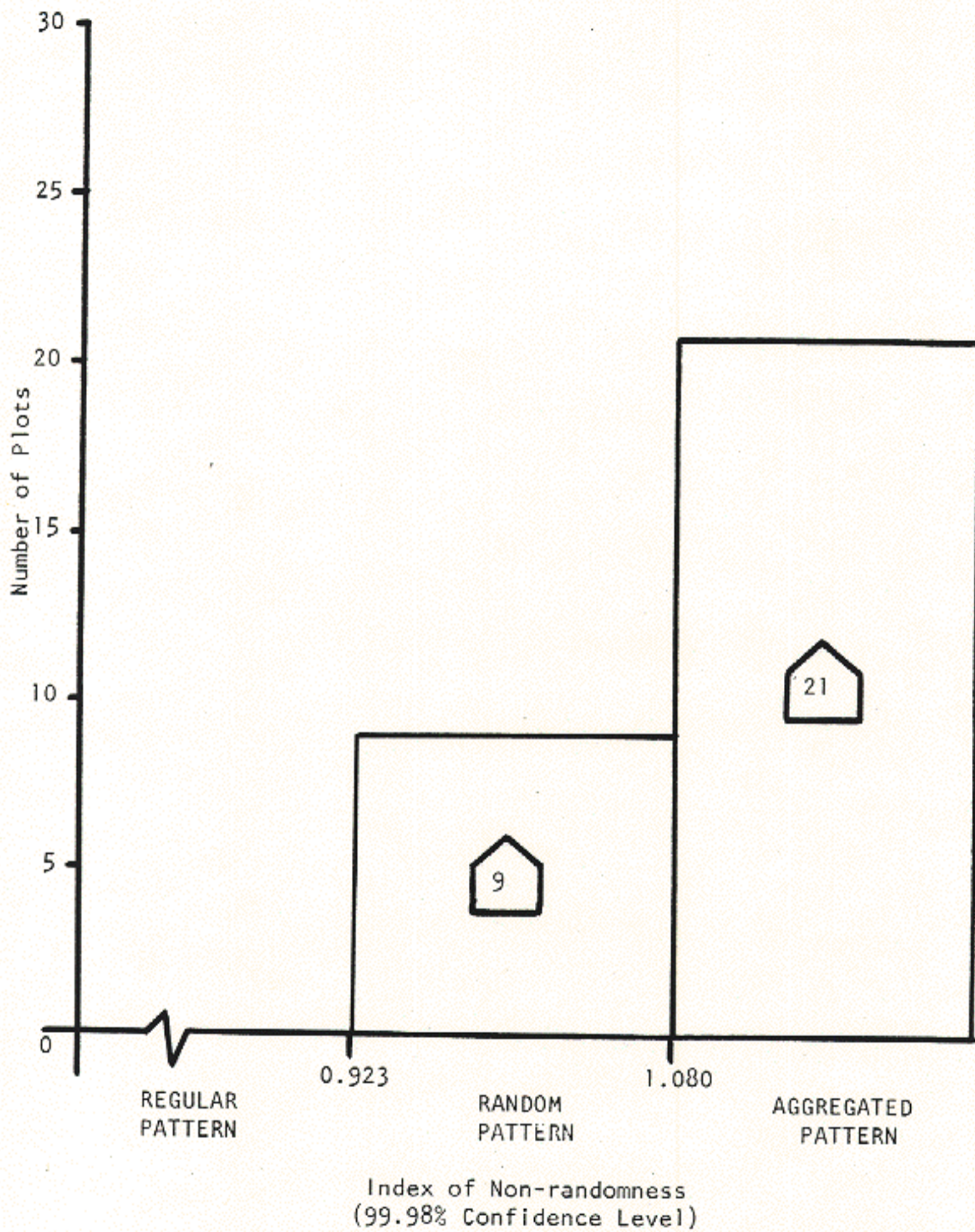


Figure 3. Trees alive in 1970; pattern versus number of plots.

Others have noted that the initial spatial pattern of western hemlock tends to be aggregated. Fire history and post-logging conditions of the area favored an initially aggregated stand (Franklin and Dyrness 1973). It has been determined that western hemlock seedlings tend to occur in clumps (Lynch and Schumacher 1941; Berntsen 1955; Harris 1967). Downed logs and rotting slash provide the most favorable sites for western hemlock germination and successful regeneration (Lynch and Schumacher 1941; Berntsen 1955; Day 1964; Harris 1967; Scott et al. 1976). During the developmental period of a stand characterized by intense competition for the available light, moisture and nutrients, a considerable amount of self-thinning occurs. The surviving stand members then enter a period of stem exclusion during which crown stratification and expression of dominance occur. Initiation and duration of this phase are a function of species, site factors and disturbances.

This investigation is pertinent to the dynamics occurring within that phase. The spatial pattern of the western hemlock trees alive in 1970 (stand age 34 to 42 years) appears to be aggregated. Twenty-one of 30 plots have an index of non-randomness denoting aggregation and nine of 30, randomness (99.0%). Seven of the plots have a substantial minor species component. Considering only the western hemlock component of each plot, 24 of 30 plots have an index value showing aggregation (99.0%). Five of the six remaining plots which have an index value denoting randomness (99.0%) occur with the older installations.

Test for Pattern of Trees Which Died During the Period 1970-1978

Table 3 displays the indices of non-randomness for the 30 plots. Twenty-eight of 30 denote aggregation and two of 30, randomness (99.0%) (Figure 4). Examining the mortality by species in plot 80-478 reveals that both western hemlock and Douglas-fir mortality components denote aggregation (99.98%). Consequently, the western hemlock mortality for the 30 plots is aggregated in 29 of 30 cases (99.0%).

Knowledge of mortality is essential if one is to understand the silviculture of young stands and is probably of nearly equal importance in management planning (Staebler 1953). Mortality occurring during the period 1970 - 1978 is aggregated.

Nearly all, 88.9%, of the mortality occurred within lower crown classes. In several instances, all the suppressed crown class category has died. This evidence questions the notion that western hemlock, because of its relative tolerance of shade, can survive for long periods suppressed in the understory. Without proper planning to capture and utilize mortality, much of a stand's gross growth potential is lost.

Test for Pattern of Trees Alive in 1978

Table 4 displays the indices of non-randomness for the 30 plots. Fourteen of 30 indices denote aggregation, nine of 30 indicate

Table 3. Non-random indices for trees which died 1970-1978. (* indicates random pattern [99.98%])

<u>Inst.-Plot</u>	<u>Index Value</u>	<u>Inst.-Plot</u>	<u>Index Value</u>
3-13	1.500	4-19	1.616
-14	1.610	-20	1.435
-15	1.561	-21	1.633
-16	1.353	-22	1.099
-17	1.308	-23	1.261
-18	1.580	-24	1.284
15-85	1.327	9-49	1.168
-86	1.086	-50	1.116
-87	1.503	-51	1.367
-88	1.258	-52	1.349
-89	1.556	-53	0.962*
-90	1.258	-54	2.261
80-475	1.487		
-476	1.895		
-477	1.191		
-478	1.063*		
-479	1.649		
-480	1.286		

99.98% Confidence Limits

<u>Regular Pattern</u>	<u>Random Pattern</u>	<u>Aggregated Pattern</u>
	0.923	1.080

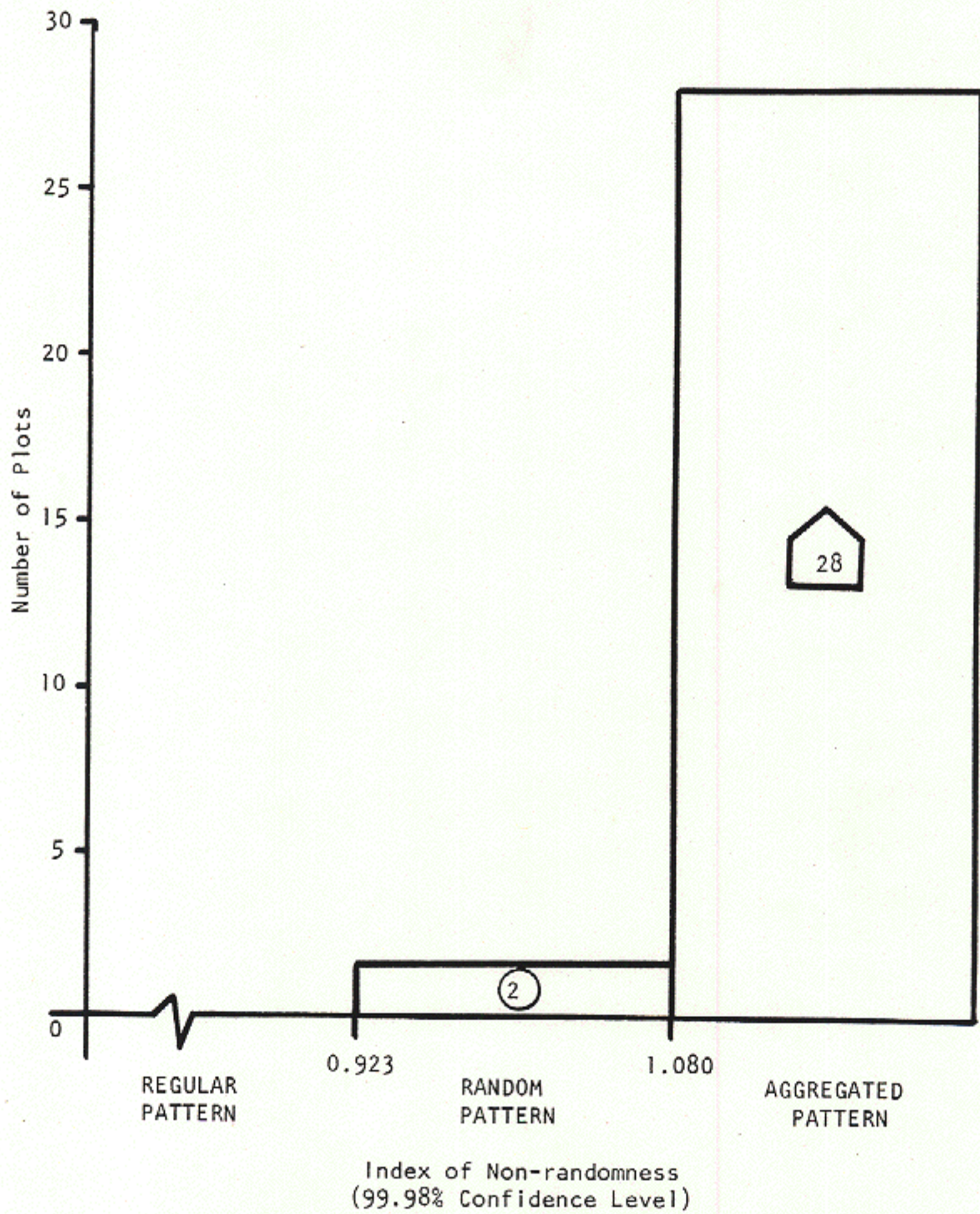


Figure 4. Mortality during period 1970-1978; pattern versus number of plots.

Table 4. Non-random indices for trees alive in 1978.
 (* indicates random pattern [99.98%];
 # indicates regular pattern [99.98%]).

<u>Inst.-Plot</u>	<u>Index Value</u>	<u>Inst.-Plot</u>	<u>Index Value</u>
3-13	1.202	4-19	1.108
-14	1.220	-20	0.921#
-15	1.123	-21	0.935*
-16	1.371	-22	0.889#
-17	1.167	-23	0.901#
-18	1.456	-24	1.034*
15-85	0.945*	9-49	0.913#
-86	1.081	-50	1.233
-87	1.057*	-51	1.192
-88	1.215	-52	0.836#
-89	1.001*	-53	0.895#
-90	1.119	-54	1.118
80-475	0.947*		
-476	1.337		
-477	1.035*		
-478	0.922#		
-479	1.043*		
-480	0.939*		

99.98% Confidence Limits

<u>Regular Pattern</u>	<u>Random Pattern</u>	<u>Aggregated Pattern</u>
	0.923	1.080

randomness, and seven of 30 indicate regularity (99.0%) (Figure 5). Twenty-nine of 30 1978 index values are less than their corresponding 1970 values ($p < .001$) (Appendix 8). One index of 30 is approximately the same as its 1970 value. The comparison of 1970 to 1978 values used a minimum index value differential of 0.005 to allow for the inherent variability of the non-random indices.

Pielou (1974) stated that if mortality occurs at random, the population's patchiness will remain constant. But if mortality is density-dependent, i.e., if crowded individuals are less likely to survive than isolated ones, patchiness will show a downward trend as time passes and the population dwindles. Such is evidently the case with coastal western hemlock. Nearly all 1978 index values are less than their 1970 counterparts. This supports Whittaker's (1953) suggestion of increasing regularity of population distribution leading to a more uniform climax stand. Of the nine 1970 index values indicating randomness, seven have 1978 index values indicating regularity (99.0%). Of the nine 1978 index values indicating randomness, seven had index values of aggregation in 1970.

Some ecologists have stated that occurrence of a regular pattern in a natural forest stand is a rare phenomenon (Ashby 1948; Jones 1955-6; Kershaw 1963; Greig-Smith 1964). An observation of regular distribution of trees in savanna vegetation of the Sudan was made (Kershaw 1963). In this instance, the regular pattern was thought to be related to root competition for available water. While soil water is probably not the limiting factor in coastal western hemlock

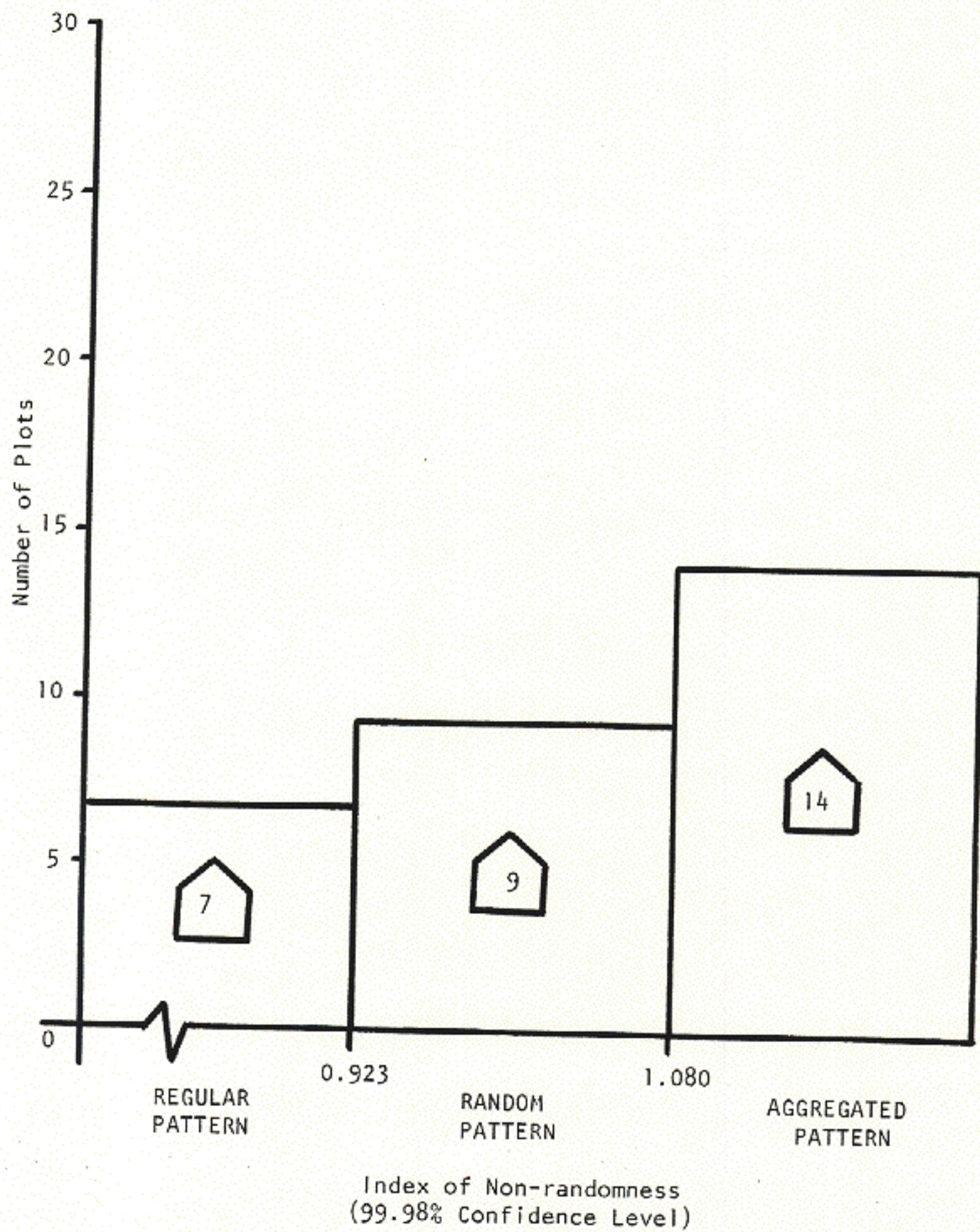


Figure 5. Trees alive in 1978; pattern versus number of plots.

stand development during much of the year, root competition for physical growing space is conceivably an important element. Considering the trees alive in 1978, 14 of 30 have index values of aggregation, nine of randomness, and seven of regularity (99.0%). Thus, evidence from this study suggests that:

1. there is a trend in spatial pattern development from aggregation, through randomness, toward regularity,
2. regular spatial pattern is not as uncommon as previously reported (Figure 6).

Test for Pattern of Trees with Greatest Diameter Growth (1970-78)

Table 5 displays the indices of non-randomness for the 30 plots. Seven of the indices are based on samples of less than ten trees. Excluding those seven indices from the total of 30, eight of 23 index values denote aggregation; four of 23, randomness; and 11 of 23, regularity (99.0%) (Figure 7).

An arbitrarily chosen criterion of six rings per inch for radial growth was used to denote those trees with greatest diameter growth. To fulfill that growth requirement, the dbh of a tree in 1978 must be greater than its 1970 dbh by more than 3.56 centimeters (1.4 inches). It is felt that six rings per inch is a reasonable radial growth rate for a young, healthy, vigorous western hemlock. The most rapidly growing trees tended to be regularly distributed.

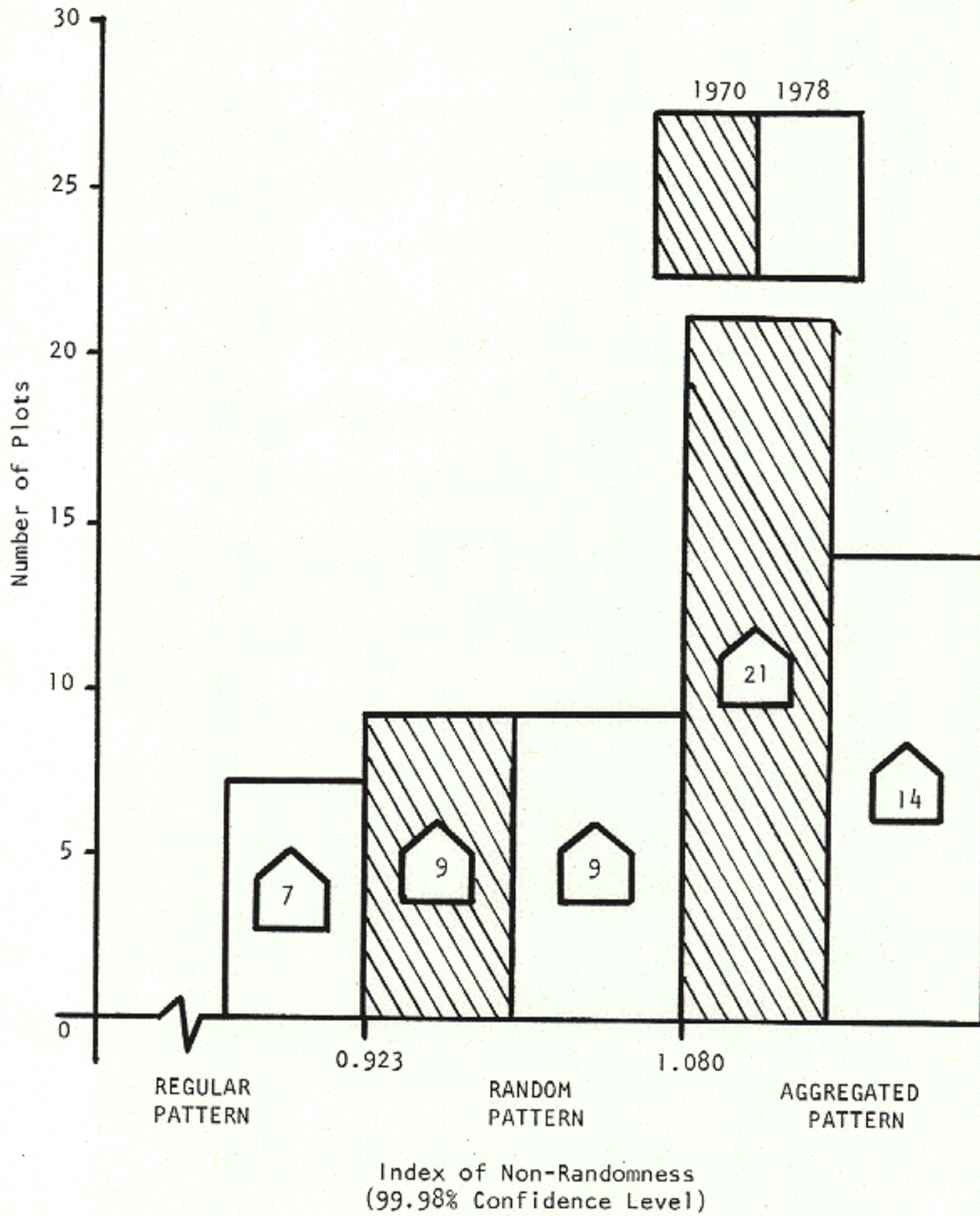


Table 6. Trees alive in 1970 versus trees alive in 1978; pattern versus number of plots.

Table 5. Non-random indices for trees with greatest diameter growth (1970-78). (* indicates random pattern [99.98%]; # indicates regular pattern [99.98%]; indicates index value based on sample of less than ten trees).

<u>Inst.-Plot</u>	<u>Index Value</u>	<u>Inst.-Plot</u>	<u>Index Value</u>
3-13	0.890#	4-19	1.003*
-14	0.757#	-20	1.410
-15	1.635	-21	<u>1.307</u>
-16	0.971*	-22	<u>1.218</u>
-17	1.081	-23	<u>1.892</u>
-18	0.781#	-24	<u>0.867#</u>
15-85	<u>1.013*</u>	9-49	0.885#
-86	<u>1.399</u>	-50	0.711#
-87	<u>1.385</u>	-51	1.590
-88	1.013*	-52	1.610
-89	0.842#	-53	0.887#
-90	0.798#	-54	<u>1.116</u>
80-475	0.810#		
-476	1.136		
-477	0.906#		
-478	1.082		
-479	0.962*		
-480	1.450		

99.98% Confidence Limits

<u>Regular Pattern</u>	<u>Random Pattern</u>	<u>Aggregated Pattern</u>
	0.923	1.080

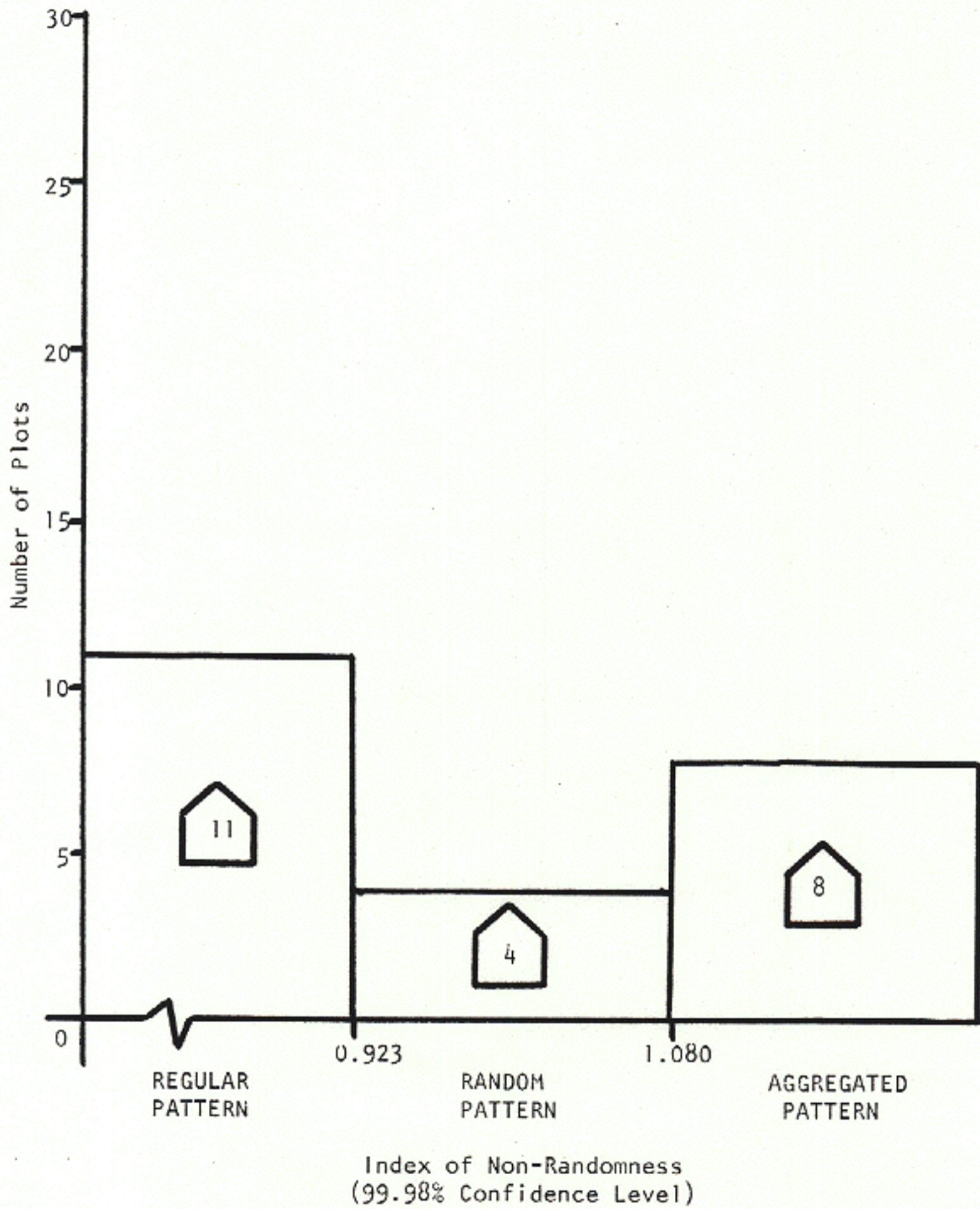


Figure 7. Trees with greatest diameter growth; pattern versus number of plots.

Test for Pattern in Mixed Species Plots

The plots which have a substantial secondary species component are: 80-478, 9-49, 9-50, 9-52, 9-53, 9-54. Table 6 displays the indices of non-randomness for those plots. The minor species component of plot 80-478 is Douglas-fir. The minor species component of these other plots (all in installation 9) is western redcedar.

Although the number of plots which have mixed species components is comparatively few, the information provided by them is noteworthy. Of the trees alive in 1970, four of seven plots have index values denoting randomness when both major and minor species are jointly considered. When each species is separately examined, ten of 14 indices denote aggregation and four of 14, randomness (99.0%). This agrees with the finding previously discussed for the entire 30 plots. To suggest whether the cause is competition between species or slightly dissimilar habitat requirements would be purely speculative.

Mortality occurring during the period 1970 - 1978 in mixed species plots follows the general trend observed in all plots. The index of non-randomness for all species shows five plots with aggregated indices and two with random indices (99.0%). Four of 14 component indices were calculated on a basis of less than ten sample trees; these have been omitted from the analysis. Seven of ten plots have aggregated indices; one of ten, random; and two of ten, regular indices when mortality is categorized by species' components. The two regular indices are associated with the western redcedar

Table 6. Non-random indices for mixed species plots.
 (* indicates random pattern [99.98%]; # indicates regular pattern [99.98%]; indicates index value based on sample less than ten trees).

<u>Inst.-Plot</u>	<u>Index All</u>	<u>Index Major spp.</u>	<u>Index Minor spp.</u>
<u>Trees Alive in 1970</u>			
9-49	1.040*	1.087	1.225
-50	1.353	1.312	1.019*
-51	1.295	1.279	1.085
-52	0.973*	0.931*	1.223
-53	1.031*	1.114	1.059*
-54	1.172	1.317	0.982*
80-478	1.068*	1.299	1.174
<u>Mortality During 1970 - 1978</u>			
9-49	1.168	1.232	1.321
-50	1.116	1.387	0.884#
-51	1.367	1.423	1.136
-52	1.349	1.796	0.893#
-53	0.962*	0.988*	1.146
-54	2.261	2.571	1.490
80-478	1.063*	1.087	1.277
<u>Trees Alive in 1978</u>			
9-49	0.913#	0.921#	1.247
-50	1.233	1.222	0.990*
-51	1.192	1.201	1.701
-52	0.836#	0.888#	1.801
-53	0.895#	1.010*	1.129
-54	1.118	1.246	1.327
80-478	0.922#	1.129	1.206
<u>Trees with Greatest Diameter Growth</u>			
9-49	0.855#	0.819#	--
-50	0.711#	0.736#	--
-51	1.590	1.577	--
-52	1.610	2.578	--
-53	0.877#	0.852#	--
-54	1.116	1.176	--
80-478	1.081	0.837#	1.329
<u>99.98% Confidence Limits</u>			
<u>Regular Pattern</u>	<u>Random Pattern</u>	<u>Aggregated Pattern</u>	
	0.923	1.080	

component of plots 9-59 and 9-52. If two species have nearly identical habitat requirements, but one was able to tolerate greater departures from the optimum conditions than the other, then one would expect the more tolerant species would be widespread in its occurrence and the less tolerant to be patchy.

For the trees alive in 1978, the index of non-randomness for all species shows three with aggregated indices and four with regular indices. Ten of 14 indices denote aggregation; two of 14, randomness; and two of 14, regularity when categorized by species' components.

All six plots in installation 9 have 1978 index values for the western hemlock component which are less than their 1970 counterparts ($p < 0.002$) (Appendix 9). This follows the trend observed in the previous section. Five of the six plots in installation 9 have 1978 minor species index values greater than their 1970 counterparts ($p < 0.04$) (Appendix 10). This is attributed to the location of the minor species' mortality. When peripheral western redcedar trees died, surviving redcedar trees became more aggregated. When the mortality occurred within the redcedar patch and the mortality was regularly spaced, the resulting redcedar pattern was less aggregated. Such was the occurrence of mortality within plot 9-50.

None of the plots in installation 9 had a minor species component which fulfilled the diameter growth criterion. Nearly all the western redcedar was restricted to the lower crown classes where survival rather than rapid growth is of importance. Therefore,

the number of suitable plots for analysis is insufficient to warrant further discussion.

Test for Pattern by Crown Class Categories - Trees Alive 1970

Table 7 displays the indices of non-randomness for the 30 plots. Examination of pattern by crown class is based upon a subjective assessment of crown size and light interception. The categories used are the four common classes as defined by Smith (1962). Dominant and codominant classes have been combined into the "upper" class category and intermediate and suppressed into the "lower" category. The table shows that for the upper crown category, 13 of 30 indices denote aggregation; ten of 30, randomness; and seven of 30, regularity. For the lower crown category, 25 of 30 indices denote aggregation and five of 30, randomness (Figure 8).

For mixed species plots, the following crown class categories were constructed: major species upper category, minor species upper category, major species lower category, and minor species lower category. When considering the major species upper category, one of seven indices indicate aggregation; four of seven, randomness; and two of seven, regularity. Examining the minor species upper category reveals that two of two indices denote aggregation. Five of the six plots with a component of western redcedar did not have a minor species upper stratum present. Considering the major species lower crown category, seven of seven indices indicate aggregation. For the

Table 7. Non-random indices for trees alive (1970) by crown classes. (* indicates random pattern [99.98%]; # indicates regular pattern [99.98%]; indicates index value based on sample less than ten trees.)

Inst.-Plot	Index All	Index Upper	Index Lower
3-13	1.520	1.236	1.326
-14	1.650	1.307	1.687
-15	1.396	0.972*	1.892
-16	1.610	1.099	1.930
-17	1.310	1.084	1.175
-18	1.873	1.483	1.473
4-19	1.259	1.120	<u>1.552</u>
-20	1.041*	0.919#	1.350
-21	0.997*	1.091	0.957*
-22	0.943*	0.799#	1.146
-23	0.961*	0.897#	1.214
-24	1.211	0.902#	1.188
9-49	1.040*	0.861#	1.002*
-50	1.353	0.969*	1.392
-51	1.295	1.295	1.251
-52	0.973*	1.031*	1.060*
-53	1.031*	0.865#	1.065*
-54	1.172	0.991*	1.484
15-85	1.154	0.932*	1.239
-86	1.205	1.069*	1.281
-87	1.130	1.112	1.419
-88	1.465	1.220	1.255
-89	0.959*	1.038*	1.180
-90	1.192	1.133	0.971*
80-475	1.149	0.875#	1.206
-476	1.473	1.059*	2.105
-477	1.105	1.038*	1.250
-478	1.068*	0.993*	1.238
-479	1.256	1.140	1.259
-480	1.089	1.093	1.220

99.98% Confidence Limits

Regular Pattern	Random Pattern	Aggregated Pattern
	0.923	1.080

Table 7 (cont.)

Inst.-Plot	Index All	Index Upper Class		Index Lower Class	
		Major spp.	Minor spp.	Major spp.	Minor spp.
9-49	1.040*	0.900#	--	1.406	1.168
-50	1.353	0.927*	--	1.790	1.013*
-51	1.295	1.189	--	1.262	1.651
-52	0.973*	1.051*	--	1.116	1.141
-53	1.031*	0.837#	<u>1.089</u>	1.088	0.944*
-54	1.172	0.935*	--	1.444	1.082
80-478	1.068*	1.041*	1.154	1.416	--

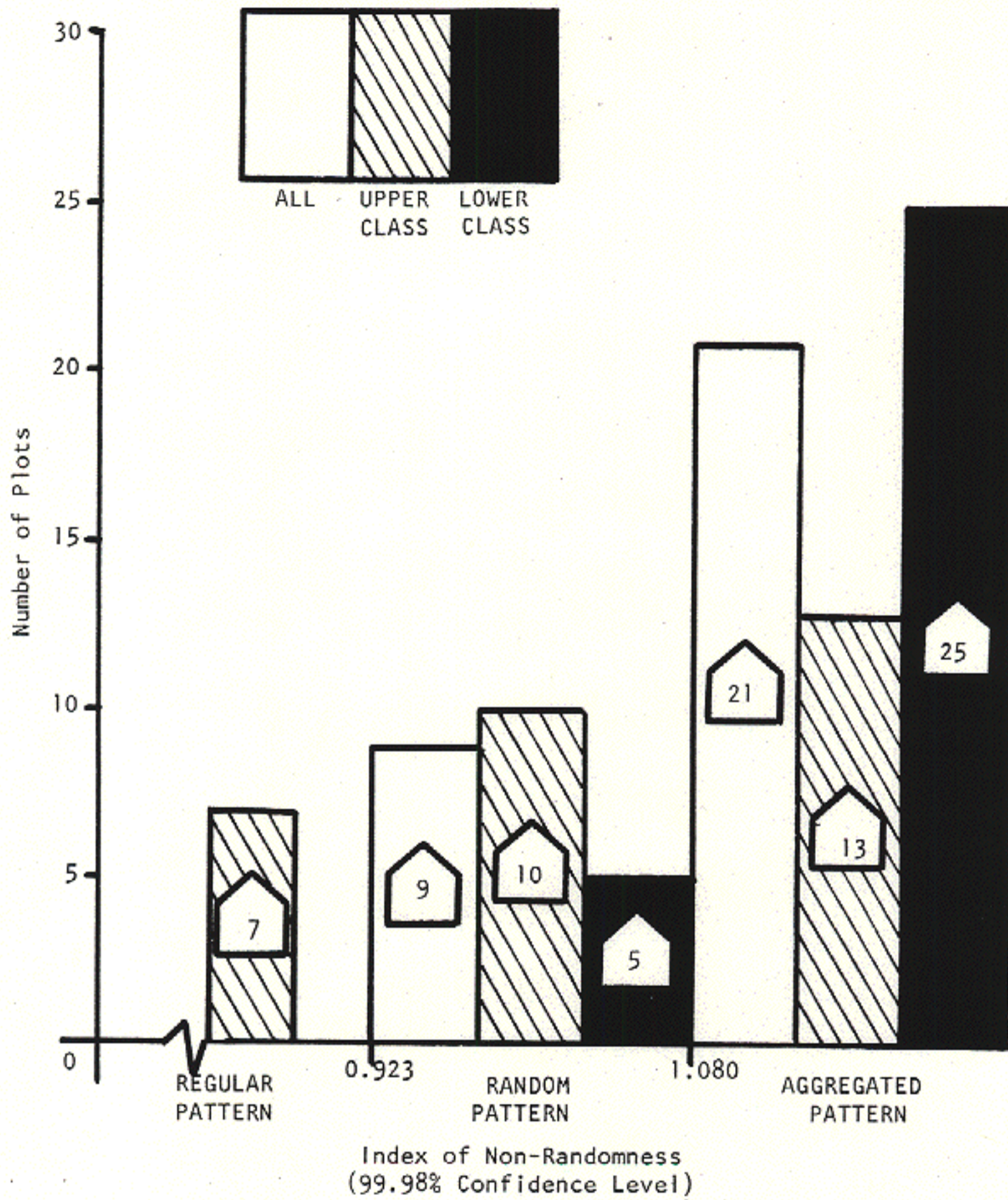


Figure 8. Trees alive in 1970 by crown classes; pattern versus number of plots.

minor species lower crown category, four of six indices denote aggregation and two of six, randomness. Plot 80-478 had no Douglas-fir component in the understory.

Evidence suggests that the pattern of all trees alive in 1970 is more aggregated than the pattern of the upper crown class category and less aggregated than the pattern of the lower crown class category. Further, the pattern of the lower category is considerably more aggregated than the pattern of the upper crown classes.

This spatial relationship could have developed because of two possible dynamic situations. First, within each clump, one or two trees would gain the competitive advantage through superior height growth. The resulting spatial distribution would be tending toward regularity in the upper crown classes and aggregation in the lower crown classes. The second possibility might be that the upper crown class trees achieved their competitive superiority because of an age differential. Lower crown class trees being younger would have developed in spaces between and among upper category members of the stand. Age by crown class (Figures 9, 10) analysis suggests the latter hypothesis. Age of the upper crown class category was found to be significantly older than the lower crown category ($p < .001$) (Appendix II). Moreover, the spatial distribution of the lower crown category being more aggregated than that of all trees further suggests the latter hypothesis. If the former hypothesis were valid, the pattern of all trees would tend to be more contagious than the pattern of the lower crown class category (Figure 11).

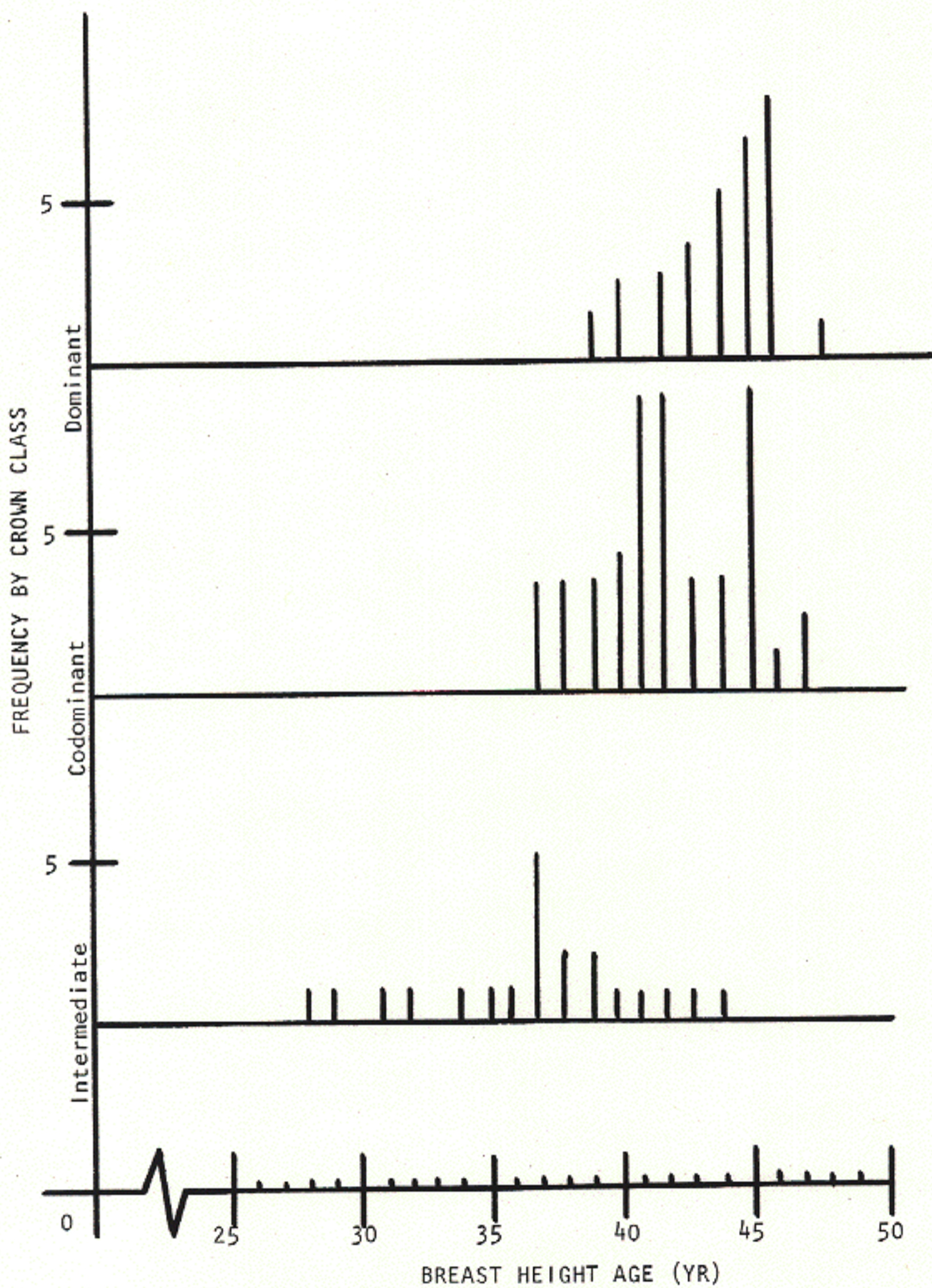


Figure 9. Age distribution by crown class (Plots 4-22 and 4-23).

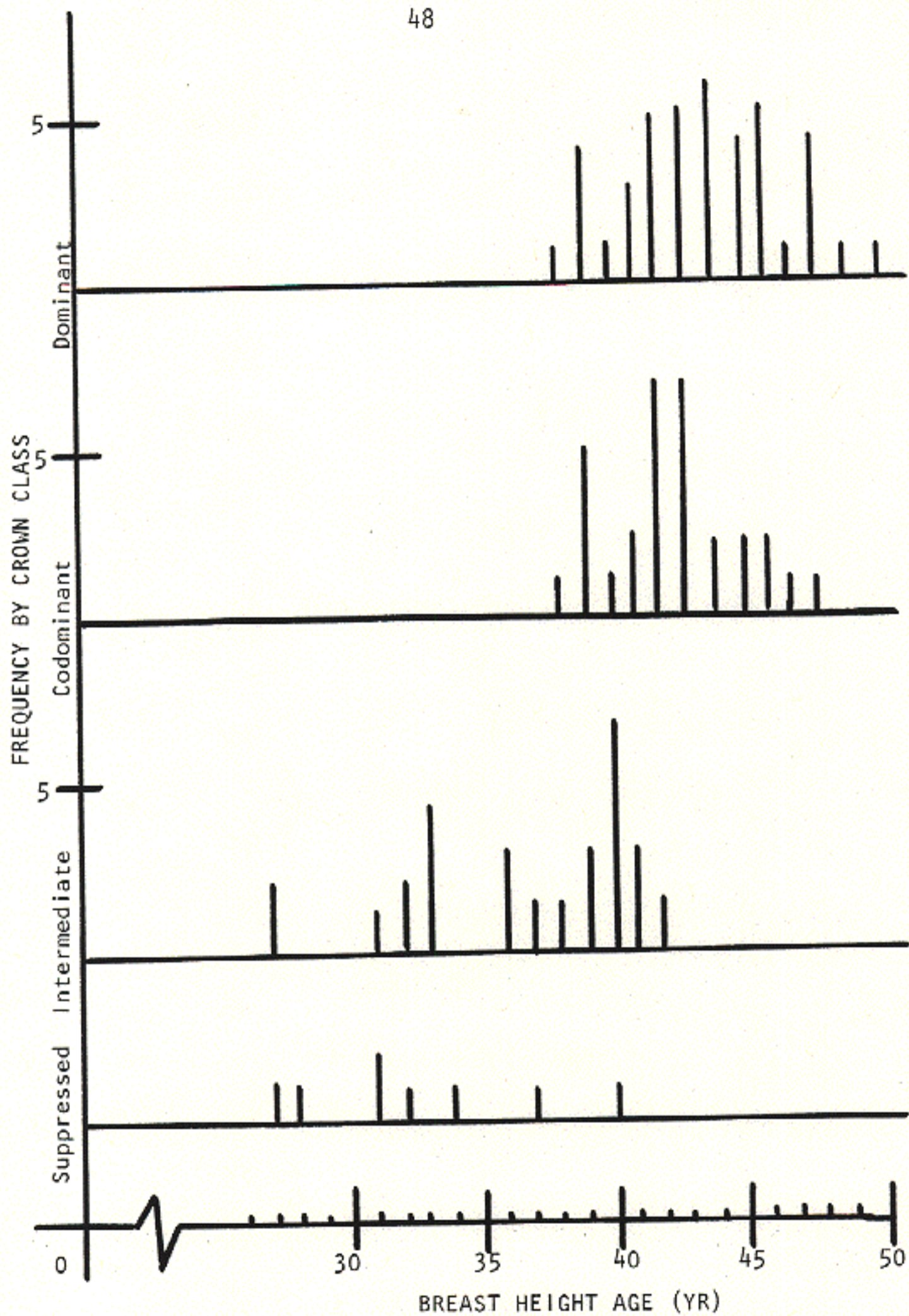


Figure 10. Age distribution by crown class (Plots 9-52 and 9-53).

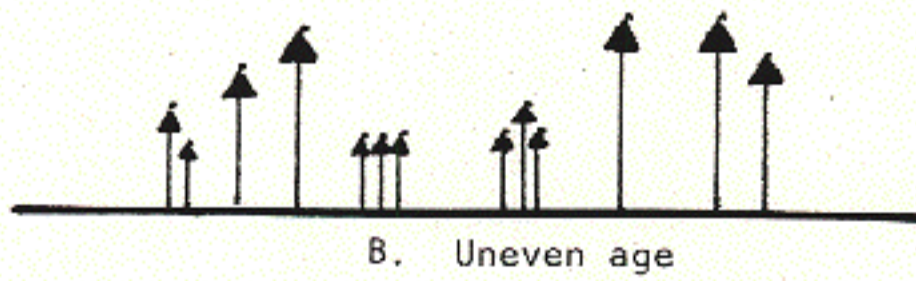
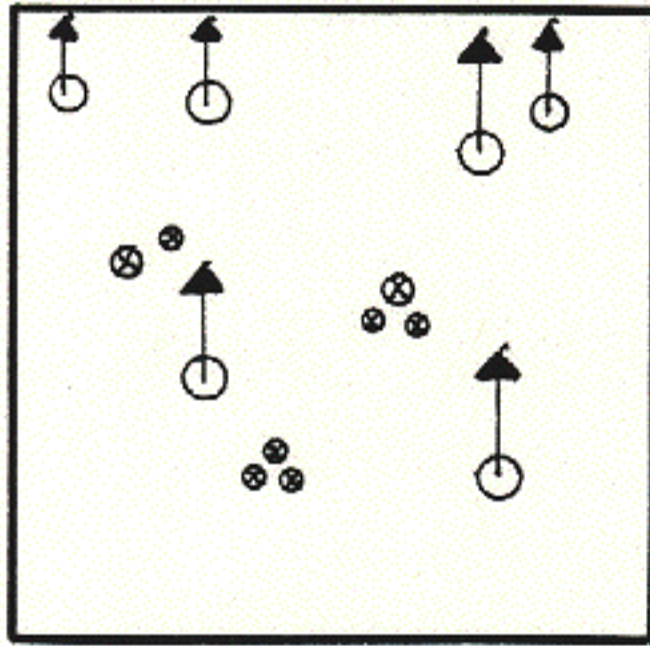
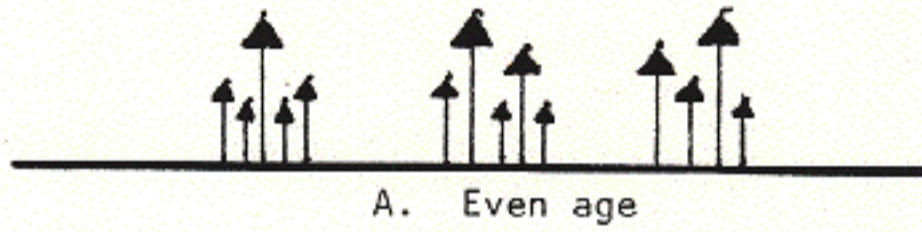
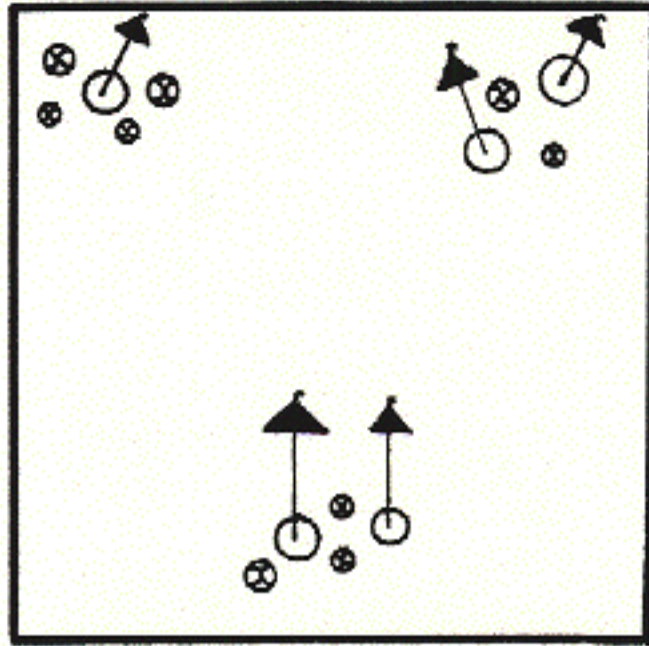


Figure 11. Two hypothetical development patterns.

Indications of age variation using breast height increment core analysis must be tempered with the possibility of missing rings which may be most prevalent on lower crown class individuals. It is known that trees when suppressed often do not produce an annual ring over the entire bole of a tree (Larson 1956). Therefore, it became necessary to find a method to account for potentially non-existent rings. In many cases, it was possible to date cores by locating the annual ring produced following the freeze of November, 1955. Rings produced during the 1956 growing season were generally much small or had abnormal amounts of summerwood. This finding concurs with the study of Stubblefield and Oliver (1977). Time needed for individuals to reach breast height is a common consideration in explaining age variation (i.e., all stems are of equal age; it simply took lower crown class individuals longer to reach breast height). This is questionable, since suppressed stems at stand age of 45 to 50 years logically would have been in the upper crown classes at an early age in order to survive. Mortality is very extreme in natural stands of coastal western hemlock and generally removes lower crown class individuals. It is unlikely that several individuals could have been suppressed at early ages and survived 50 years.

Crown class categories were not revised when measurements were taken in 1978. Consequently, evaluation of pattern in crown class categories for trees alive in 1978 is not feasible. The assumption that all surviving trees retained their relative crown canopy position is not considered valid.

CONCLUSIONS

The primary purpose of this investigation was to measure and analyze the spatial pattern in natural stands of coastal western hemlock during a developmental period of stem exclusion. Causality of the measured patterns was beyond the scope of this study.

The spatial pattern of coastal western hemlock is aggregated. Prior studies present evidence that the pattern of western hemlock regeneration is patchy. During the initial developmental stage, competition between individuals is intense and a considerable amount of self-thinning occurs.

Mortality in natural stands of coastal western hemlock is extreme and concentrated within lower crown classes. The spatial pattern of this mortality is aggregated, indicating a density-dependent relationship.

The surviving members have a spatial pattern which is less contagious than the pre-mortality pattern. On several occasions, residual stand pattern became regular. Previous studies stated regular pattern to be a very rare phenomenon.

The trees exhibiting the greatest diameter growth in western hemlock stands tend to have a regular spatial pattern. That this pattern should develop is intuitive; factors contributing to its causality were not measured.

Within a mixed species stand of coastal western hemlock and western redcedar or Douglas-fir, the spatial pattern of each species

is aggregated and the patches are separately contagious. The mortality within each species is aggregated. Residual stand members have a pattern which is less patchy.

When individuals within a stand are grouped within upper and lower crown classes, members of the former category have a spatial distribution which tends toward regularity. Lower crown individuals have an aggregated spatial pattern which is possibly the result of a significant age difference between upper and lower crown classes.

During the course of this investigation, several questions arose which remain unanswered. The following is presented solely to possibly provide some direction for future research:

1. The primary question involves causality of spatial pattern. Certainly, because of the interactive complexity of variables in stand development, no one single factor is solely responsible. Nonetheless, if valid modelling techniques for stand simulation are to be developed, factors controlling the dynamics of natural stand development must be identified and quantified.

2. Is the indicated breast height age differential between crown classes valid? Could the apparent difference be an artifact of increment core analysis? Historical information indicates extreme variability in amount and depths of slash and occurrence of fire following early logging operations. Sites suitable for germination may have evolved over a period of years, creating a mosaic of stem

ages within a stand. A destructive sampling study in coastal western hemlock may reveal valuable insight on this question.

3. What degree of root grafting is present in overstocked natural stands? How does grafting affect competitive relationships within the stand? What effect would extensive grafting have on dynamics of stand pattern?

4. The patterns measured in this investigation are applicable to natural coastal western hemlock stands during one developmental period. What patterns or trends develop later in stand age? Is it valid to intuitively suggest that autogenic processes promote a trend toward regularity and allogenic processes promote a trend toward aggregation?

5. How well can these findings be extrapolated to even-aged plantations of more intensive management?

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Appendix 1

Example of a Random Spatial Pattern

PROGRAM: PIELOU'S INDEX OF NONRANDOMNESS

DESCRIPTION: THIS PROGRAM CALCULATES THE PIELOU'S INDEX OF NONRANDOMNESS

$\text{ALPHA} = (\text{PI}) (\text{RHO}) (\text{OMEGA})$

WHERE

RHO=POINT DENSITY PER UNIT AREA

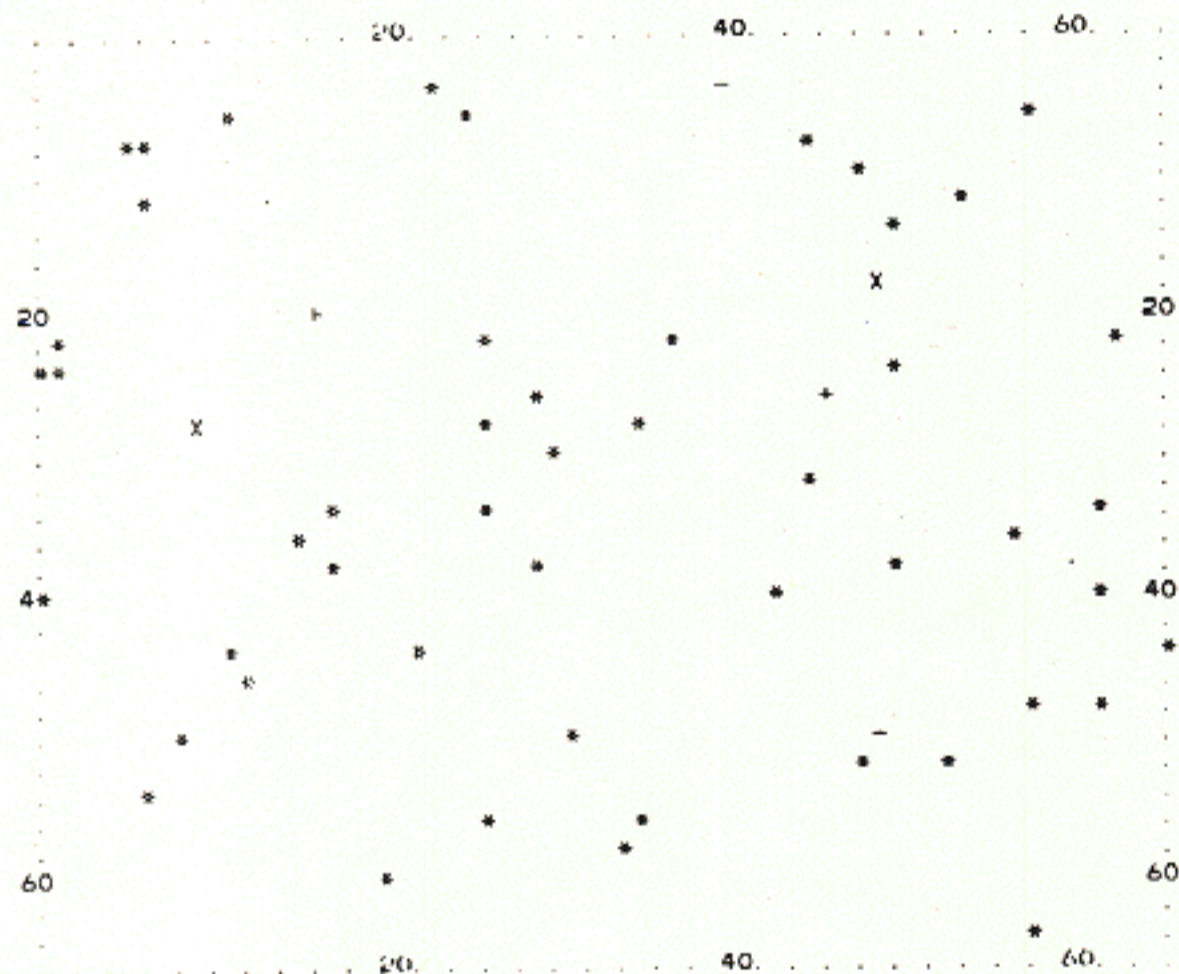
OMEGA=AVERAGE SQUARED DISTANCE BETWEEN A RANDOMLY CHOSEN POSITION AND THE NEAREST POINT

AUTHOR: E. C. PIELOU

PROGRAM DESIGNER: H. R. STAUFFER

MODIFIED JAN 1979, T. F. BROWN

SITE:



PLOT WIDTH= 66
 PLOT LENGTH= 56
 NUMBER OF TREES= 58
 NUMBER OF SAMPLES= 2000
 ALPHA= .977
 /OMEGA= 23.894

Appendix 2

Example of a Random Spatial Pattern

PROGRAM: PIELOU'S INDEX OF NONRANDOMNESS

DESCRIPTION: THIS PROGRAM CALCULATES THE PIELOU'S INDEX OF NONRANDOMNESS

ALPHA=(PI)(RHO)(OMEGA)

WHERE

RHO=POINT DENSITY PER UNIT AREA

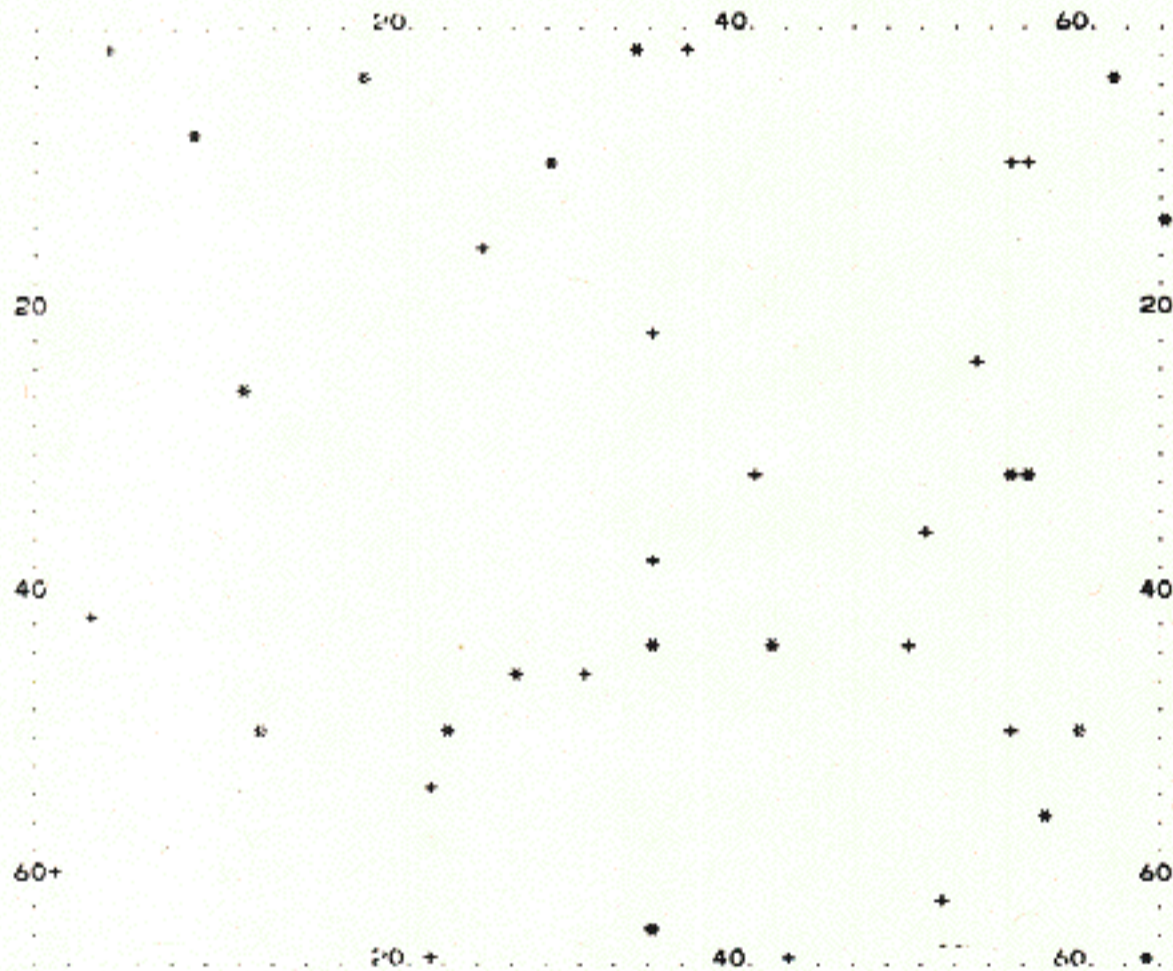
OMEGA=AVERAGE SQUARED DISTANCE BETWEEN A RANDOMLY CHOSEN POSITION AND THE NEAREST POINT

AUTHOR: E. C. PIELOU

PROGRAM DESIGNER: H. R. STAUFFER

MODIFIED JAN 1979 , T. F. BROWN

SITE:



PLOT WIDTH= 66
 PLOT LENGTH= 66
 NUMBER OF TREES= 37
 NUMBER OF SAMPLES= 2000
 ALPHA= .990
 /OMEGA= 37.091

Appendix 3

Example of an Aggregated Spatial Pattern

PROGRAM: PIELOU'S INDEX OF NONRANDOMNESS

DESCRIPTION: THIS PROGRAM CALCULATES THE PIELOU'S INDEX OF NONRANDOMNESS
 $\text{ALPHA} = (\text{PI}) (\text{RHO}) (\text{OMEGA})$

WHERE

RHO=POINT DENSITY PER UNIT AREA

OMEGA=AVERAGE SQUARED DISTANCE BETWEEN A RANDOMLY

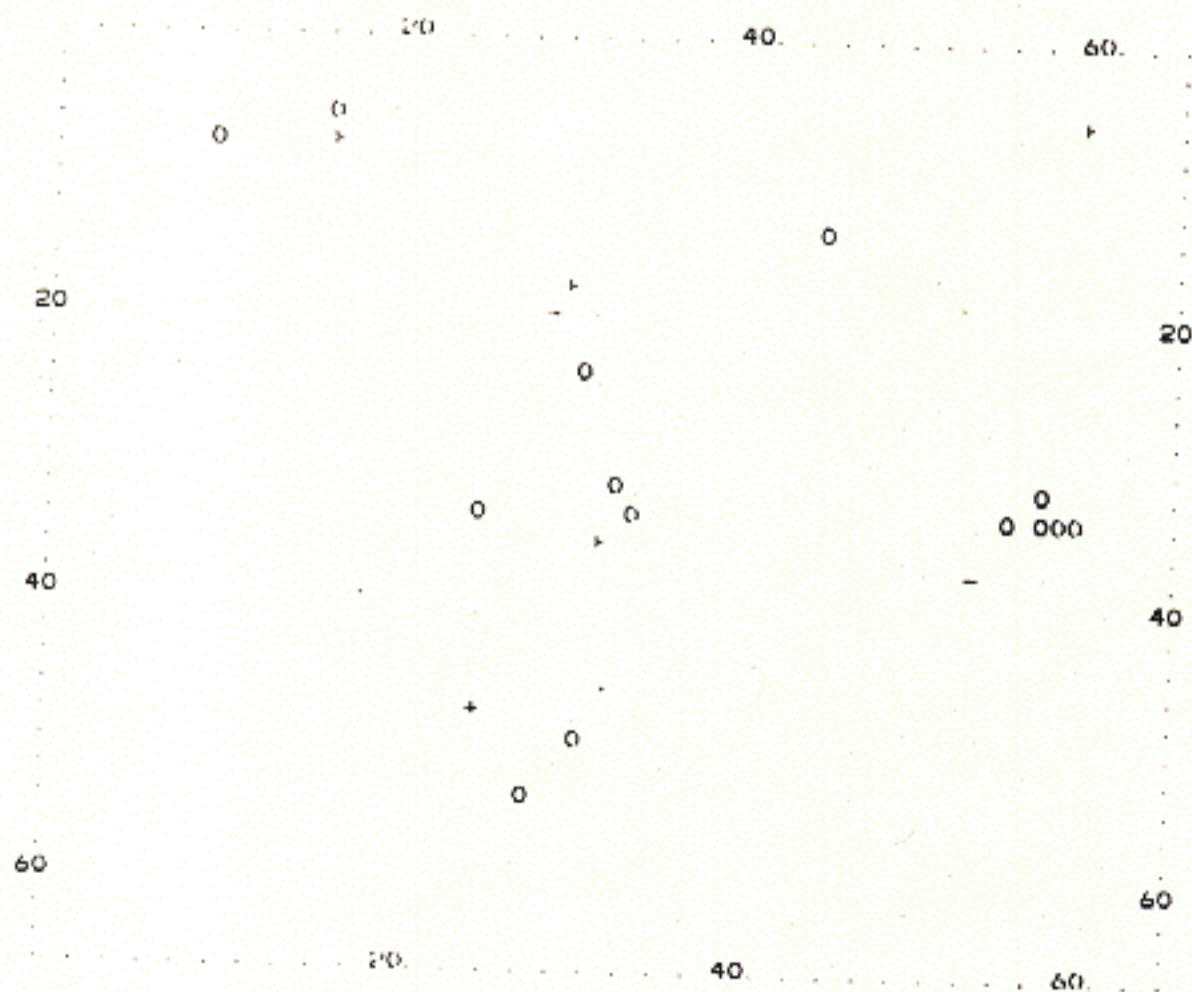
CHOSEN POSITION AND THE NEAREST POINT

AUTHOR: E. C. PIELOU

PROGRAM DESIGNER: H. K. STAUFFER

MODIFIED JAN 1979, T. F. BROWN

SITE:



PLOT WIDTH= 66
 PLOT LENGTH= 66
 NUMBER OF TREES= 20
 NUMBER OF SAMPLES= 2000
 ALPHA= 1.876
 /OMEGA= 117.500

Appendix 4

Example of an Aggregated Spatial Pattern

PROGRAM: PIELOU'S INDEX OF NONRANDOMNESS

DESCRIPTION: THIS PROGRAM CALCULATES THE PIELOU'S INDEX OF NONRANDOMNESS

$\text{ALPHA} = (\text{PI}) (\text{RHO}) (\text{OMEGA})$

WHERE

$\text{RHO} = \text{POINT DENSITY PER UNIT AREA}$

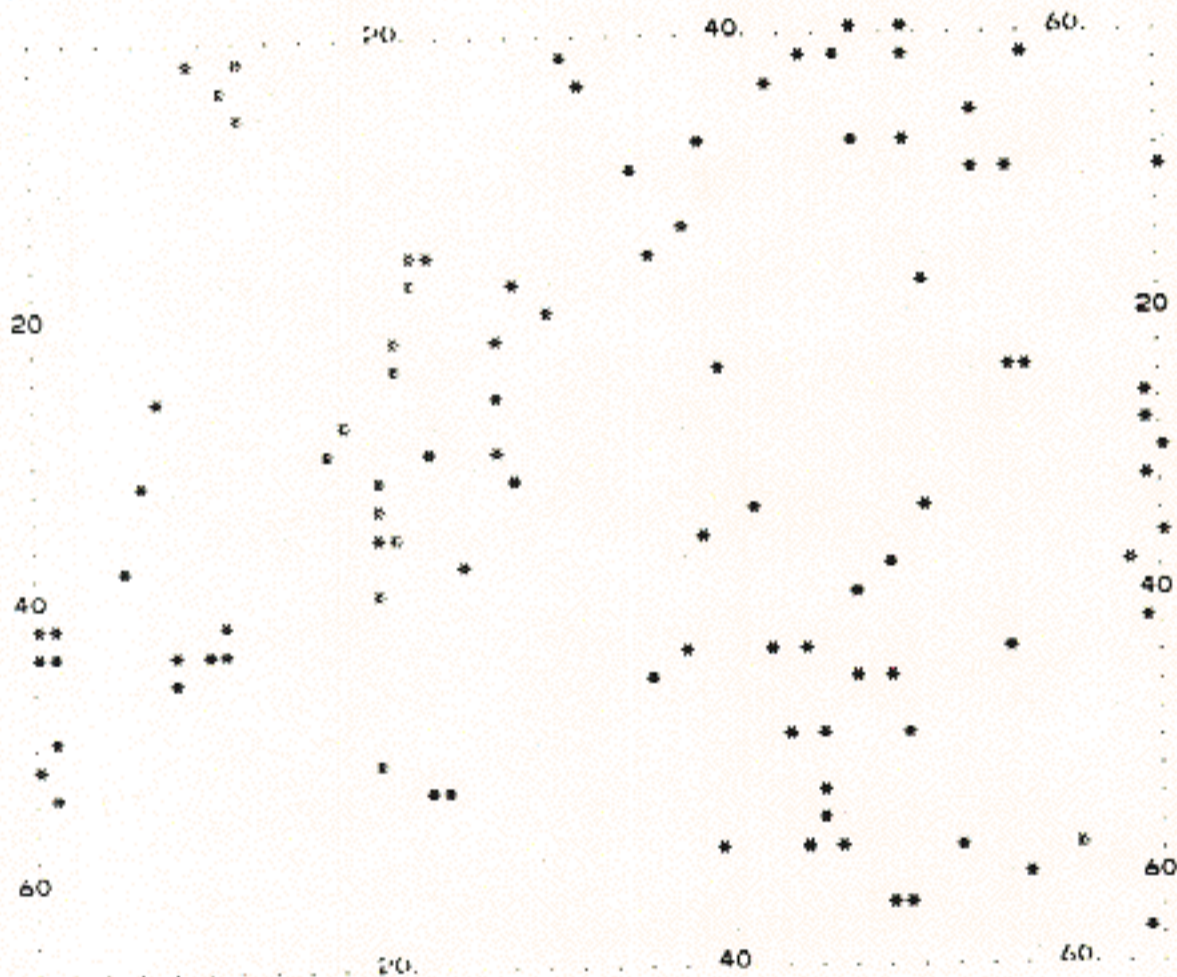
$\text{OMEGA} = \text{AVERAGE SQUARED DISTANCE BETWEEN A RANDOMLY CHOSEN POSITION AND THE NEAREST POINT}$

AUTHOR: E. C. PIELOU

PROGRAM DESIGNER: H. B. STAUFFER

MODIFIED JAN 1979, T. F. BROWN

SITE.



PLOT WIDTH= 66
 PLOT LENGTH= 66
 NUMBER OF TREES= 103
 NUMBER OF SAMPLES= 2000
 ALPHA= 1.875
 /OMEGA= 25.243

Appendix 5

Example of a Regular Spatial Pattern

PROGRAM: PIELOU'S INDEX OF NONRANDOMNESS

DESCRIPTION: THIS PROGRAM CALCULATES THE PIELOU'S INDEX OF NONRANDOMNESS

ALPHA=(PI)(RHO)(OMEGA)

WHERE

RHO=POINT DENSITY PER UNIT AREA

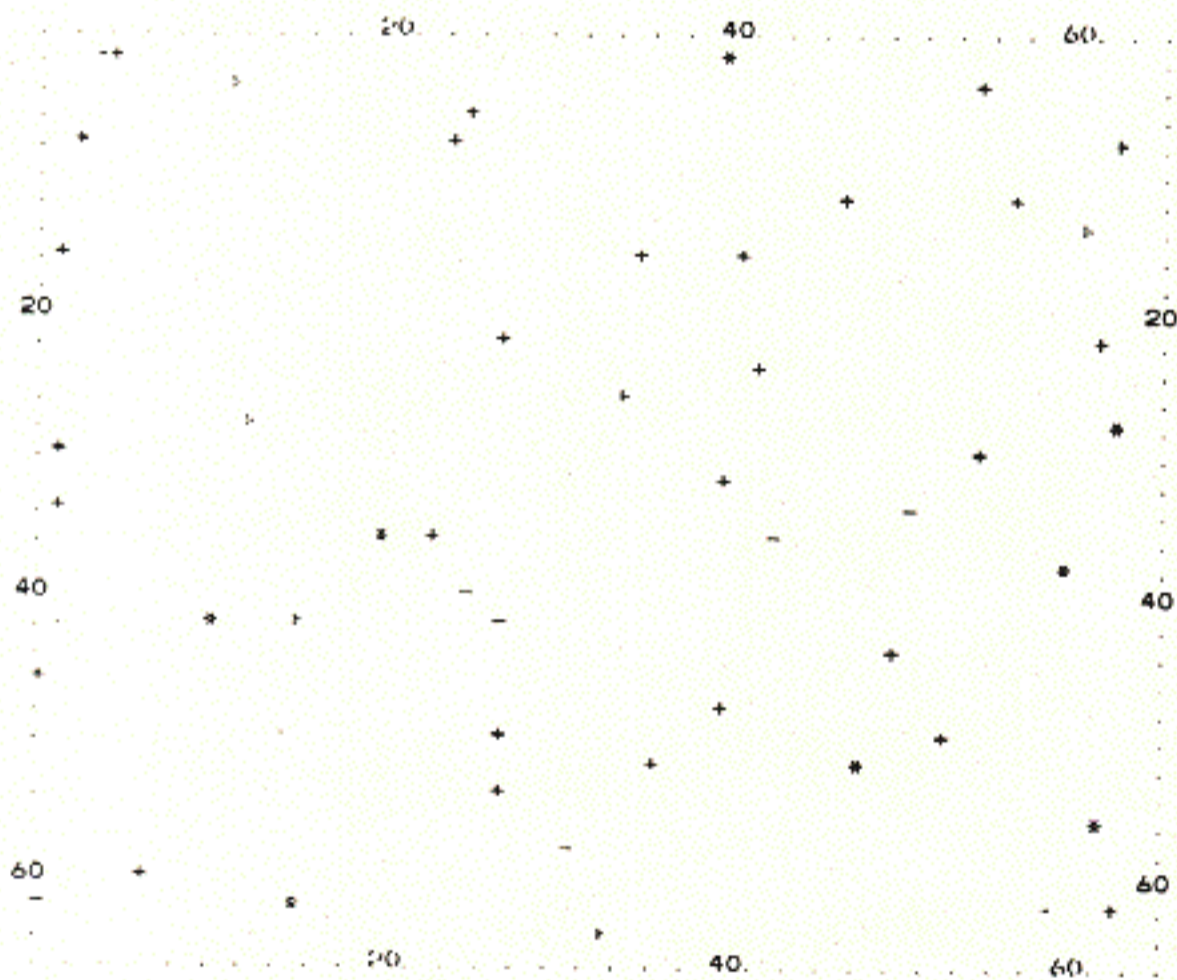
OMEGA=AVERAGE SQUARED DISTANCE BETWEEN A RANDOMLY CHOSEN POSITION AND THE NEAREST POINT

AUTHOR: E. C. PIELOU

PROGRAM DESIGNER: H. B. STAUFFER

MODIFIED JAN 1979 . T. F. BROWN

SITE



PLOT WIDTH= 65
 PLOT LENGTH= 65
 NUMBER OF TRACES= 50
 NUMBER OF SAMPLES= 2000
 ALPHA= .941
 /OMEGA= 23.677

Appendix 6

Example of a Regular Spatial Pattern

PROGRAM: PIELOU'S INDEX OF NONRANDOMNESS

DESCRIPTION: THIS PROGRAM CALCULATES THE PIELOU'S INDEX OF NONRANDOMNESS

$\text{ALPHA} = (\text{PI}) (\text{RHO}) (\text{OMEGA})$

WHERE

$\text{RHO} = \text{POINT DENSITY PER UNIT AREA}$

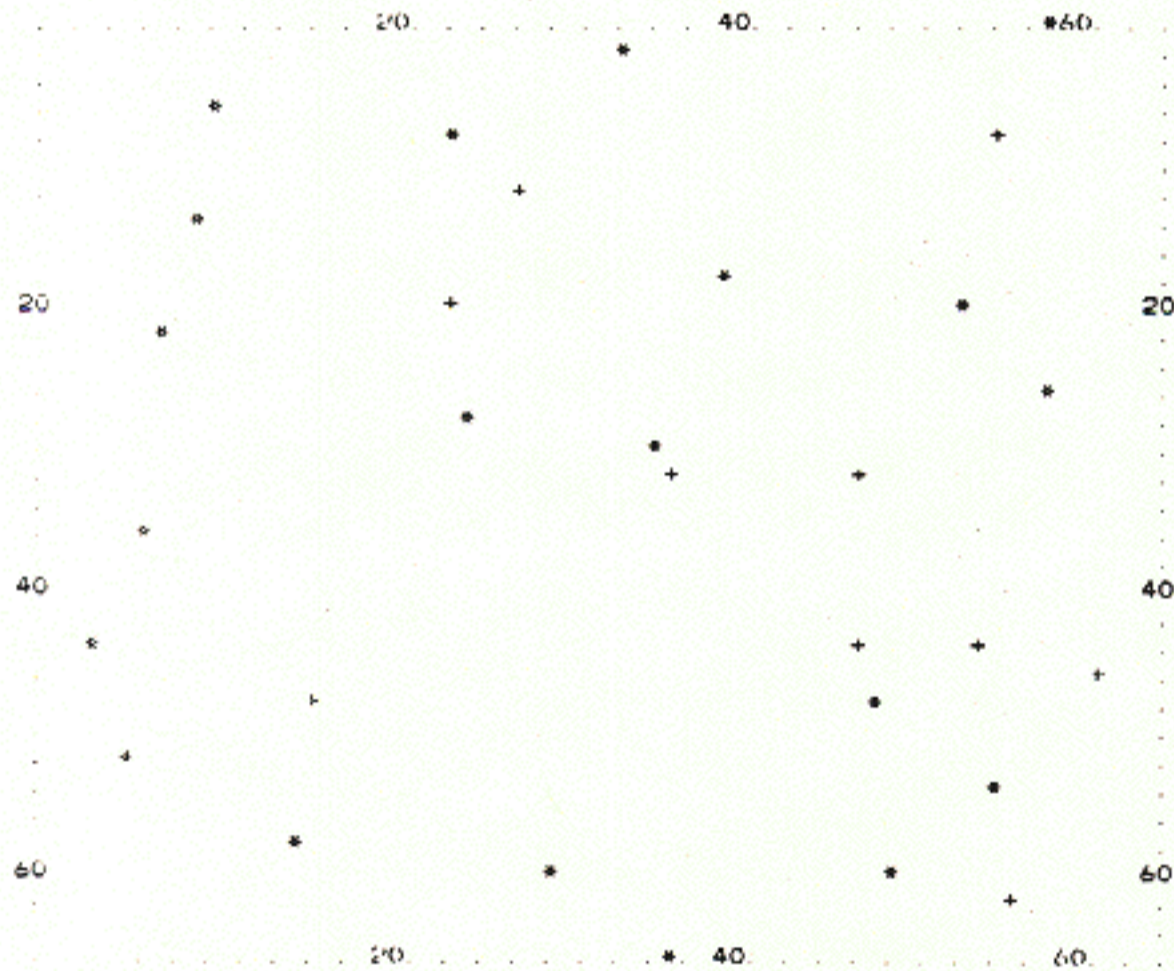
$\text{OMEGA} = \text{AVERAGE SQUARED DISTANCE BETWEEN A RANDOMLY CHOSEN POSITION AND THE NEAREST POINT}$

AUTHOR: E. C. PIELOU

PROGRAM DESIGNER: H. R. STAUFFER

MODIFIED JAN 1979, T. F. BROWN

SITE



PLOT WIDTH= 60
 PLOT LENGTH= 60
 NUMBER OF TRIALS= 10
 NUMBER OF SAMPLES= 2000
 ALPHA= .803
 /OMEGA= 34.281

Appendix 7

Locally Modified Version of Stauffer's (1976) PTEST

```

ZRINF                                M. L. RINEHART
ACCOUNT, /000000, M)KI, B
MAP (OFF)
FTN, OL=0, R=0, I=0.
LGO.

PROGRAM TPLD) (INPUT, OUTPUT, TAPE5=INPUT, TAPE6=OUTPUT)
COMMON/A/NOROWS, NOCOLS, I, X(300), Y(300)
COMMON/R/IS(100)
INTEGER PINST, PPLOT, SS
DISTSB(A, B, C, D) = (A-C)*(A-C)+(B-D)*(B-D)
80 SEED=CLOCK(0, 0)
CALL RANSET (SEED)
DUMMY=RANF((SEED))
I=0
READ(5, 10)NOROWS, NOCOLS, NOSAMP, PINST, PPLOT, SS
10 FORMAT(5I5, 1I2)
C ... NOROWS = PLOT LENGTH
C ... NOCOLS = PLOT WIDTH (X)
C ... NOSAMP = NUMBER OF RANDOM SAMPLES FOR P-TEST
C ... PINST, PPLOT ARE THE FIRST INST AND PLOT NUMBER OF A SERIES OF
C ... DATA THAT ARE OF THE SAME PLOT SIZE AND SS CODE.
C ... SS = DECISION CODE FOR THE PLOT SYMBOLS. ANY OF 5 SYMBOLS MAY BE
C ... USED. SS=0 IS DEFAULT AND MEANS TO USE '*' FOR ALL POINTS.
C ... SS=1 ALLOWS THE USE OF MORE THAN ONE SYMBOL AND REQUIRES THE USE
C ... OF SUBROUTINE SYMBOL.
100 READ(5, 11)INST, IPLOT, NTRT, NUM, NSP, NCC, NAGE, D70, D7B, IVIG, XIN, YIN
11 FORMAT(4I5, 13, 12, 15, 2F5, 1, 15, 2F5, 1)
IF (EOF(5))120, 9
9 CONTINUE
IF (IPLOT NE PPLOT) GO TO 110
IF (INST NE PINST) GO TO 110
I=I+1
X(I)=XIN
Y(I)=YIN
IS(I)=I
C ... IVAR = THE VARIABLE THAT YOU WISH TO USE FOR THE SYMBOL ROUTINE
C ... IN THIS EXAMPLE, IVAR=NSP, THE SPECIES WILL BE USED
IF (SS.EQ.1)CALL SYMBOL(I, IVAR)
GO TO 100
110 MDATA=I
120 CONTINUE
C ... IF YOU WISH TO SKIP THE FOLLOWING CALCULATIONS, THEN INSERT THE
C ... FOLLOWING CARDS:
C 125 ALPHA=.99 9
C 126 GO TO 260
C
C ... CALCULATE PIFLOU'S INDEX OF NONRANDOMNESS
130 PI=3.14159
RHO=FLOAT(I)/FLOAT(NOROWS*NOCOLS)
SUM=0.0
DO 150 J=1, NOSAMP
B=FLOAT(NOCOLS)*RANF(0, 0)
C=FLOAT(NOROWS)*RANF(0, 0)
XMIN=.999999 0
DO 140 JI=1, J
E=DISTSB(X(JI), Y(JI), B, C)
140 IF (E LT XMIN) XMIN=E
150 SUM=SUM+XMIN
OMEGA=SUM/FLOAT(NOSAMP)
ALPHA=PI*RHO*(1-OMEGA)

```


Appendix 7 (cont.)

```

C . . . . WRITE (OUTPUT)
      WRITE(6,155)
155  FORMAT(1111)
      WRITE(6,160)
160  FORMAT(///,* PROGRAM: PIELOU'S INDEX OF NONRANDOMNESS*)
      WRITE(6,170)
170  FORMAT(/,* DESCRIPTION: THIS PROGRAM CALCULATES THE PIELOU'S INDEX
      * OF NONRAND(MINI-((:*)
      WRITE(6,180)
180  FORMAT(* ALPHA=(PI)(RHO)(OMEGA) *)
      WRITE(6,190)
190  FORMAT(* WHI-K(=*
      WRITE(6,200)
200  FORMAT(* RHO=POINT DENSITY PER UNIT AREA*)
      WRITE(6,210)
210  FORMAT(* OMEGA=AVERAGE SQUARED DISTANCE BETWEEN A RANDOMLY
      * CHOSEN POSITION AND THE NEAREST POINT*)
      WRITE(6,250)
250  FORMAT(/,* AUTHOR: E. C. PIELOU*)
      WRITE(6,260)
260  FORMAT(/,* PROGRAM DESIGNER: H. B. STAUFFER*,T90,*MODIFIED JAN 1979
      * , T. F. BRUHN*)
265  CALL PLOT
      WRITE(6,270) NROWS,NCOLS,I,NOSAMP,ALPHA,OMEGA
270  FORMAT(//,* PLOT WIDTH=*,I4,/,* PLOT LENGTH=*,I4,/,* NUMBER OF TRE
      *ES=*,I4,/,* NUMBER OF SAMPLES=*,I4,/,* ALPHA=*,F8.3,/,* /OMEGA=
      **,F8.3)
      IF(MDATA.NE.1) GO TO 280
      DO 271 J=1,300
      X(J)=Y(J)-0.0
      IS(J)=J
271  CONTINUE
      I=1
      X(1)=X1N
      Y(1)=Y1N
      IVAR=NO
      IF(SS.EQ.1)CALL SYMBOL(I,IVAR)
      PLOT=IPLOT
      PINST=INST
      MDATA=0
      GO TO 100
280  STOP
      END
      SUBROUTINE SYMBOL(I,IVAR)
      COMMON/B/ IS(300)
C . . . . AS AN EXAMPLE, THIS PROGRAM WILL PLOT A DIFFERENT SYMBOL FOR EACH
C . . . . SPECIES. IT COULD BE DONE JUST AS EASILY FOR CROWN CLASS, AGE,
C . . . . DIAMETER CLASS, ETC. IN THIS EXAMPLE:
C . . . . * = WESTERN HEMLOCK (NSP=1)
C . . . . * = KNUGLAS-FIR (NSP=2)
C . . . . * = K(=) CEDAR (NSP=3)
C . . . . * = SPKUCE/TRUE FIR (NSP=4)
C . . . . * = MISC. HARDWOODS (NSP=5)
      IS(I)=IVAR
      RETURN
      END
      SUBROUTINE PLOT
      COMMON/A/NROWS,NCOLS,NOTREE,X(300),Y(300)
      COMMON/B/ IS(300)
      DIMENSION MATRIX(60,68),IA(10),IAST(5)
      DATA IA(1)/111,111,111,111,111,111,111,111,111,111/
      DATA IBLANK,IP(POINT)/1H,1H./
      DATA IA/1H0,1H1,1H2,1H3,1H4,1H5,1H6,1H7,1H8,1H9/
      I1=NROWS/2+1
      I2=NROWS/2+2
      I3=NROWS/2+3

```

Appendix 8

Analysis Results: Values for 1970 versus 1978
Paired 't' Test - Indices of Non-Randomness

Time	Mean	S.D.	C.V. (%)	d.f.	Calc. 't'	P(t)
1970	1.229	0.2302	18.7	29	8.272	0.9999
1978	1.072	0.1577	14.7			

Appendix 9

Analysis Results: Values for 1970 versus 1978
Paired 't' Test - Indices of Non-Randomness
Western Hemlock Component Inst. 9

Time	Mean	S.D.	C.V. (%)	d.f.	Calc. 't'	P(t)
1970	1.173	0.1554	13.2	5	5.525	0.9987
1978	1.081	0.1603	14.8			

Appendix 10

Analysis Results: Values for 1970 versus 1978
Paired 't' Test - Indices of Non-Randomness
Western Redcedar Component Inst. 9

Time	Mean	S.D.	C.V. (%)	d.f.	Calc. 't'	P(t)
1970	1.099	0.1032	9.4	5	2.283	0.9644
1978	1.366	0.3208	23.5			

Appendix II

Analysis Results: Two Sample 't' Test for Age Differences

<u>Crown Class</u>	<u>Mean</u>	<u>S.D.</u>	<u>C.V. (%)</u>	<u>d.f.</u>	<u>Calc. 't'</u>	<u>P(t)</u>
Installation 4, Plots 4-22 and 4-23						
Degrees of Freedom Adjusted for Unequal Variances						
Upper	44.21	2.024	4.58	27	6.559	0.9999
Lower	37.41	4.43	11.83			
Installation 9, Plots 9-52 and 9-53						
Degrees of Freedom Adjusted for Unequal Variances						
Upper	43.66	3.366	7.70	68	8.815	0.9999
Lower	36.06	4.846	13.44			