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REGENERATION DEVELOPMENT ON LODGEPOLE PINE CUTOVERS IN THE UPPER FOOTHILL FORESTS OF WEST-CENTRAL ALBERTA

by

GERALD H. LINFIELD

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

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Date March 7, 1985

ABSTRACT

Patterns of development of regeneration on harvested lodgepole pine (*Pinus contorta* Dougl. var. *latifolia* Engelm.) areas in west-central Alberta were investigated. Data were collected from 2341 millihectare sample plots on 41 cut-blocks southwest of Hinton, Alberta. Only pure lodgepole pine stands, clearcut and scarified from one to fifteen years prior to this study, were sampled.

The data from this chronosequence of cut-blocks were used to evaluate the effects of age (time since harvest, time since scarification), amount of exposed mineral soil seedbed, duff layer thickness, dominant moisture regime, and vegetative competition form and abundance, on development of regeneration. All of these factors were of some importance but because of the heterogeneity [illegible] individual cut-blocks, and homogeneity among cut-blocks, no single site factor, other than age, could be shown to significantly affect the development of stocking or density. Complex interactions among the various site factors are believed to be important regulators of regeneration development but these interaction effects could not be isolated. The factor of greatest and most consistent significance was time since scarification.

Using time since scarification as the predictor variable, a prediction model (±10%) for stocking development was constructed using piecewise linear regression. Stocking increased rapidly on these areas for the first 5 years after scarification but did not change significantly thereafter.

Similarly, development of stand density was extremely rapid the first 4 years after scarification but was fairly stable thereafter. The expected exponential relationship between stocking and density was confirmed and found to be highly significant, but level of stocking could not be used to accurately predict density on these areas. Due to the clumped nature of the distribution of seedlings on these cut-blocks, density was excessive (7,000+ stems/ha) on most adequately stocked cutovers. To achieve lower densities of seedlings and maintain an acceptable level of stocking, a more uniform distribution of seedlings is needed. This might be accomplished using seed tree cuts with broadcast slash burning, or patch scarification.

Germination and establishment of new seedlings on these areas was found to occur throughout the range of ages sampled. The occurrence of ingress decreased rapidly for 6 years after scarification and thereafter was detected on about 5% of the sample plots. This ingress had little net effect on stocking or density changes on cut-blocks sampled in this study but there are indications that the effect is much greater on areas that are not so well stocked. The effect of this continued development on marginally stocked sites, and the management implications, are discussed.

A simple empirical distance measurement technique for estimating stand density was evaluated and found to be ineffective in the highly clumped distribution of seedlings

encountered on these areas. Data obtained in this phase of the study suggest that another distance technique, particularly that developed by Batcheler (1971), the joint-point and nearest-neighbour distance method, may be applicable to estimation of density on regenerating lodgepole pine cutovers.

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1. INTRODUCTION

1.1 Regeneration Evaluation

Delay between harvest and stand establishment decreases the annual allowable cut from a forest by increasing the rotation time to the next harvest. Ensuring prompt regeneration of areas cleared by harvest or natural events is therefore a key component of efficient forest management. It is also important that this regeneration be evenly distributed, sufficiently abundant, and of appropriate species to meet management objectives.

Evaluating the adequacy of regeneration is essential for intensive forest management and requires systematic collection of specific data. Stein (1978) discusses several intensive methods for evaluation of regeneration, including staked-point, plot-count, stocked-quadrat, and distance methods, as well as combinations of these.

The stocked-quadrat method is by far the most popular of these for operational evaluation of regeneration in North America. The other techniques, while suitable for scientific or otherwise intensive investigations, are much too slow and expensive for use on an operational scale.

1.2 Stocked Quadrat Survey

Stocked-quadrat methods were developed primarily to evaluate the distribution of vegetation. The first reported use of this technique for forestry purposes was by

Lowdermilk in 1921 (Lowdermilk,1927; Haig,1931). The stocked-quadrat method is based on the assumption that if a given area is divided into units of such size that one established seedling or tree per unit will fully stock the unit at maturity, then the percentage of units so stocked, regardless of the total number of seedlings per unit, indicates the proportion of the area being utilized for tree growth (Haig,1931). Thus a unit or sample plot is classed as stocked if one or more acceptable seedlings are present, and is considered non-stocked if no acceptable seedling is found.

One limitation of this method is that the estimated stocking, which is a composite value, does not show the pattern of stocked and non-stocked plots. This can be overcome by plotting the location of stocked and non-stocked plots on a map of the surveyed area (Stein,1978).

The Alberta Forest Service (AFS) uses the stocked-quadrat system, with a mapping modification, to evaluate regeneration adequacy in relation to Provincial policy requirements for reforestation.

The Alberta policy and standards for reforestation are summarized (Ferdinand, 1983) as follows:

Reforestation Policy

1. All cutover land must be satisfactorily regenerated within 10 years after harvest.
2. Artificial reforestation treatments, where required, must be completed within 2 years following harvest.
3. Success of reforestation must be measured by a standardized regeneration stocking survey before the end of the 7th year following harvest.
4. Unsatisfactorily-stocked areas identified by the survey must be retreated in the spring of the 8th year and resurveyed before the end of the 10th year.

Reforestation Standards

1. All cutovers must be restocked with a minimum of 800 established, and evenly distributed seedlings per hectare, of acceptable species, age, and quality.
2. Acceptable species include all native conifers, with some limitations on alpine fir (*Abies lasiocarpa* (Hook.) Nutt.), balsam fir (*Abies balsamea* (L.) Mill.), and hardwoods on coniferous sites.
3. Minimum on-site age for established seedling trees after seeding or planting is 2 years for pine and 3 years for all other species.
4. Cutover blocks which contain understocked areas larger than 4 hectares must be treated.

The 1979 Alberta Forest Regeneration Survey Manual (Anonymous, 1979) provides more detail on regulations and procedures for evaluating regeneration in Alberta.

1.3 Problems

Although the regeneration survey system used in Alberta (Anonymous, 1979) is efficient and provides some information about the distribution of seedlings, it is not completely satisfactory. One of the major criticisms of this system is the arbitrary nature of the survey timing.

To investigate the influence of survey scheduling on stocking results, Crossley (1976) and Johnstone (1976a) examined recruitment of seedlings (ingress) on pine sites. Analysis of surviving seedlings showed ingress continuing for up to 13 years after harvest, whereas surveys are usually conducted less than 7 years after harvest. They suggested that the timing of regeneration surveys is critical because of this continued ingress, especially if the survey is to represent the final stocking level of the stand.

Current procedures in Alberta do not attempt to provide information for predicting future levels of stocking. Results of regeneration surveys conducted prior to the 10 year deadline are interpreted directly in terms of regeneration adequacy, irrespective of future stocking development.

This may be a serious problem on areas with low or marginally unacceptable stocking. How will stocking on these areas develop? Will silvicultural treatments be necessary to achieve satisfactory stocking? Are silvicultural expenditures justified or should the survey be conducted again later? These questions, if not answered correctly, can lead to a proliferation of poorly stocked areas or to needless and excessive silvicultural expenditures. Development of regeneration on these areas must be predicted accurately before these questions can be answered.

By regulation, all regeneration surveys must be conducted prior to the end of the 7th year after harvest. Surveys are often conducted earlier than this, usually in the spring when it is easy to locate seedlings before competing vegetation has flushed. Although efficient in terms of locating seedlings, meeting provincial requirements, and in allowing corrective silvicultural intervention, this schedule reduces the number of growing seasons available for establishment of stocking and may, on some sites, result in underestimation of final stocking levels.

An estimate of stocking is a static figure. It represents the stocking at only one point in the development of the stand, usually less than 7 growing seasons after harvest. Because development of stocking may continue for several years after assessment, scheduling of regeneration surveys can have a major influence on the estimate obtained. This static estimate should therefore be used to predict future stocking, with regeneration adequacy evaluated in terms of predicted stocking rather than current stocking.

If this can be done accurately, then scheduling of surveys will be less critical and the resultant estimates will be more appropriate for forest management considerations.

A second criticism of the system involves development of stand density. Under current regulations, provided the stand meets the provincial stocking requirements when it is surveyed, no further evaluation is necessary. In these situations, where stands are adequately stocked 4, 5, or 6 years after harvest, continued development of stocking and density may create stands which are overcrowded by the end of the establishment period.

Ferdinand (1983) suggested that problems of excessive density in lodgepole pine stands (*Pinus contorta* Dougl. var. *latifolia* Engelm.), excepting those of fire origin, have been overrated. Others (Bella,1976,1983; Bella and DeFranceschi, 1978; Crossley,1976; Johnstone,1976a; Smithers,1961) have argued differently.

Bella (1976) and Bella and DeFranceschi (1978) questioned the adequacy of a regeneration survey which did not evaluate stand density. This is particularly relevant to the evaluation of lodgepole pine regeneration which has a tendency to develop and to maintain overly dense stands (Smithers,1961), leading to stagnation, reduced growth, and lower merchantability (Johnstone,1976b).

An estimation of the development of density would allow forest managers to control density where necessary, and to do it at the most economically efficient time.

Bella (1976,1983) and Bella and DeFranceschi (1978) examined the relationship between stocking-percent and seedling numbers. They showed clearly that the expected number of seedlings increased exponentially as stocking-percent increased, and that this relationship was predictable.

The interdependence of stocking and density further emphasizes the need for accurate estimation of the development of stocking since this will influence future density levels. Prediction might be possible using the equations developed by Bella (1976) or it may be necessary to include a density estimate in the regeneration survey programme and to develop regression equations for prediction of future density based on these estimates.

1.4 Solutions

Construction of equations for predicting development of stocking, estimating density during the regeneration survey, and developing equations for prediction of density, would permit more efficient forest management.

By determining patterns of stocking development on various sites, the static estimate obtained by the regeneration survey could be used to predict future stocking levels. With a density estimate and appropriate prediction equations, future development of stand density could be determined.

This type of information would be particularly useful in identifying potential regeneration problems, in rationalizing silvicultural expenditures, and would also permit regeneration surveys to be scheduled with more flexibility.

1.5 Study Objectives

A study was designed with the following objectives:

1. To examine patterns of development of stocking and to attempt to construct predictive regression equations for these patterns.
2. To examine the development of stand density and to explore the possibility of relating stand density directly to stand stocking levels by regression analysis.
3. To relate distance-density estimation to plot-count density estimation and evaluate the distance-density estimation procedure for potential incorporation into the stocking assessment survey.
4. To examine the occurrence of ingress over time and assess its influence on stand development.

2. METHODS

2.1 Study Area

The purpose of this project was to examine the natural regeneration characteristics of lodgepole pine after site preparation within a small study area of uniform climate and geography. Lodgepole pine was selected because it is a major commercial species in Alberta (McDougall, 1982); it has been harvested and studied for a number of years, and provides a wide range of age and site conditions for study. It also regenerates well without planting, so that evaluation of the natural process of regeneration is possible.

Sampling was carried out in the southwest portion of the McLeod working circle of the St. Regis (Alberta) Ltd. forest management area in west-central Alberta (Figure 1). The study area is located in the Edson Forest east of, and adjacent to, the Rocky Mountains. In general the climate is subhumid continental with long, cold winters and moderately mild summers (Dumanski *et al.* 1972) and is similar throughout the study area (Table 1) (Powell and MacIver, 1976).

The McLeod working circle is in the Upper Foothills section (B19c) of the Boreal forest region (Rowe, 1972). Upper Foothill forests are dominated by lodgepole pine with hardwoods sparsely represented by trembling aspen (*Populus tremuloides* Michx.), balsam poplar (*Populus balsamifera* L.), and white birch (*Betula papyrifera* Marsh.) (Rowe, 1972).

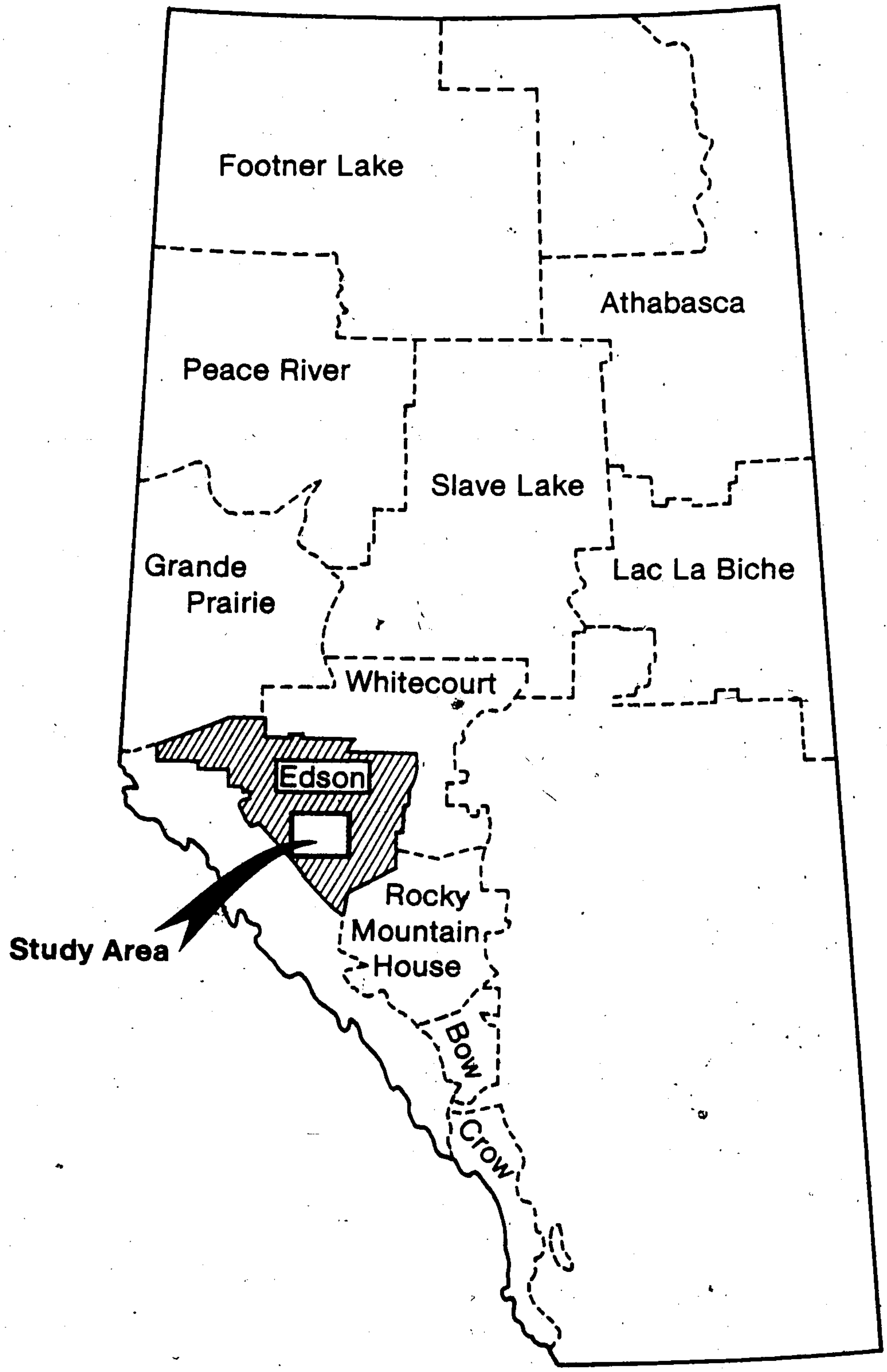

Figure 1. Map of Alberta Forest Districts showing the study area location, in the St. Regis (Alberta) Ltd. forest management area of the Edson forest in west-central Alberta.

Table 1. Selected climatic data for the McLeod Working Circle, St. Regis (Alberta) Ltd. forest management area in west-central Alberta.

(mean) (range)	MAY	JUNE	JULY	AUGUST	SEPTEMBER
Days above -2.2 C	23.7 17.7 - 28.7	29.5 28.4 - 30.0	30.9 30.5 - 31.0	30.8 30.3 - 31.0	***
Temperature C	5.6 1.3 - 8.1	***	13.4 12.3 - 14.4	***	***
Precipitation (mm)	63.0 48.3 - 68.6	***	115.1 99.1 - 132.1	98.6 71.1 - 124.5	62.2 50.8 - 73.7
Water Deficiency (mm)	***	0.3 0.0 - 0.3	***	3.1 0.0 - 19.3	***

From Table 3. J.M. Powell and D.C. MacIver, 1976. Summer climate of the Hinton-Edson area, west-central Alberta, 1961-1970. Can. For. Serv. Info. Rep. NOR-X-149.

High rounded hills and deep valleys characterize the topography of the study area. Elevations of the sampled cut-blocks ranged from 1310 to 1585 metres above sea level.

Soils of the Upper Foothills forest section are mainly glacial and colluvial deposits with mature soils showing podzolic development (Rowe, 1972). Soil development and parent material composition of the study area were extensively evaluated by Dumanski *et al.* (1972). The study area is predominantly in the Rocky Mountain Foothills subdivision of the Western Cordillera physiographic region, and is dominated by the Robb soil association (Figure 2). This association is of Cordilleran till with local colluvial material added. It is medium textured, greyish brown to olive brown in colour, and has a generally low lime content.

Surface drainage of the Robb association is good except on ridges and steep slopes where it may be excessive. Internal soil drainage is good on crest and upper slope positions but is imperfect to poor in lower slope and depressional positions. This is due to the soil composition which is sandy loam to loam in the surface horizons and clay loam to sandy clay loam in the subsoil horizons.

The six soil series of the Robb association were rated by Dumanski *et al.* (1972) according to forest productivity and management limitations. Moisture status for all Robb soils was rated 'good' for lodgepole pine growth; soil erosion hazard was 'moderate' except for Robb 6 which was 'moderate to high'; potential wind-throw hazard was

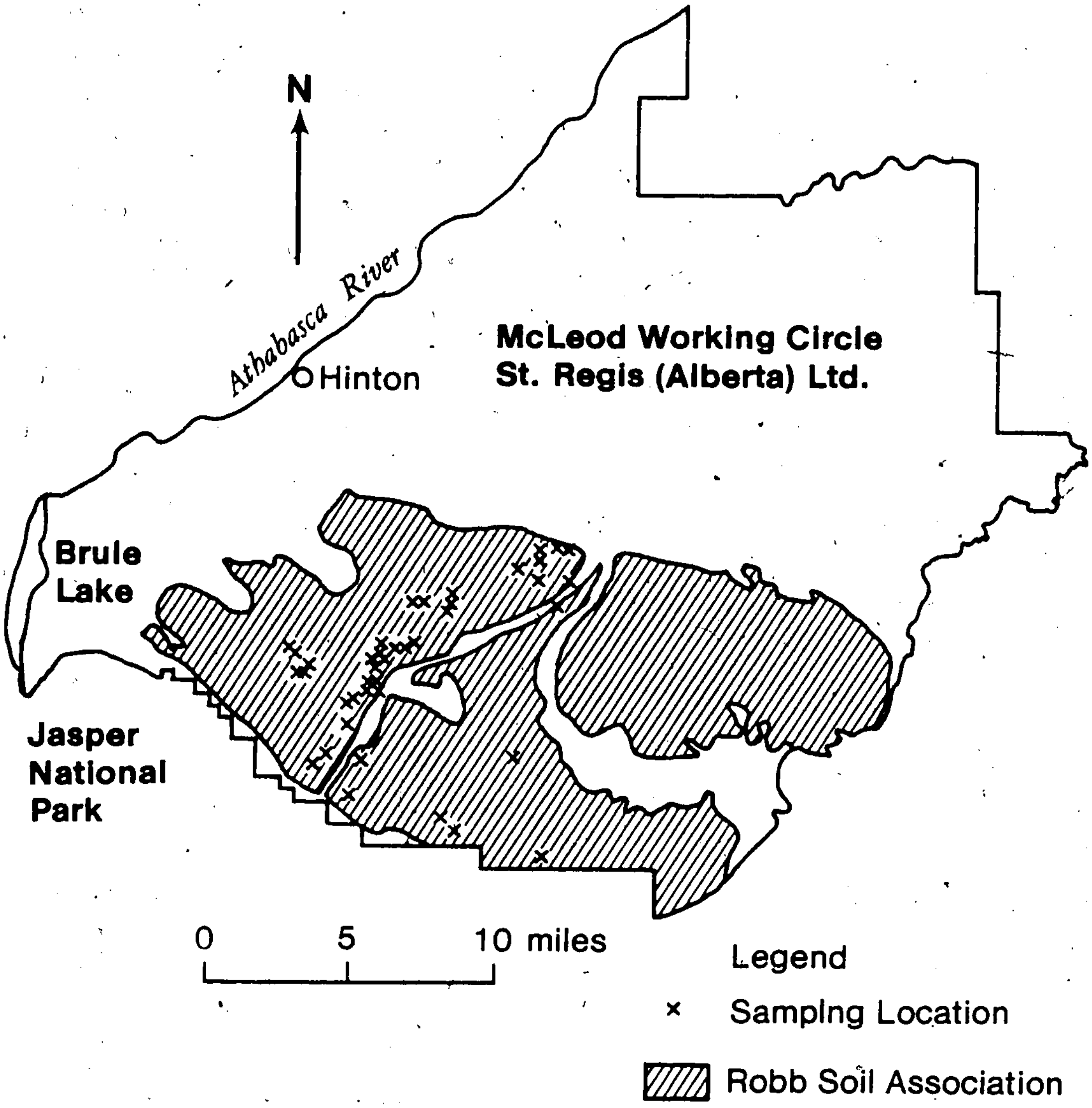

Figure 2. Map of the McLeod working circle of the St. Regis (Alberta) Ltd. forest management area showing the study site locations in relation to the areas dominated by the Robb soil association (modified from Dumanski et al. 1972).

'moderate to high' except for Robb 5 and 6 which were 'high'; and the inferred transplant mortality was 'moderate to low' except for Robb 5 and 6 which were 'moderate'. These are good soils for lodgepole pine, with only minor limitations to establishment, although growth is more rapid on some other soil series of the area. The uniformity of climate and soil type within the study area reduced the inherent variability of the sample and facilitated comparisons among cut-blocks.

2.2 Stocking, Density and Site Evaluation

Evaluation of stocking and density development is usually conducted using a system of permanent sample plots. This is the best method for learning about vegetation changes that take place at a given location over a period of time (Stein, 1978), but it requires the establishment and long-term monitoring of plots. Because long-term monitoring was not possible in this study, an alternative sampling system was needed to obtain data without monitoring delay.

Ellis and Mattice (1974), studied stand development in Ontario using a chronosequential sampling technique whereby areas with similar site conditions, at various stages of development, are sampled concurrently to provide data for a range of development stages for the conditions sampled. This technique was used to sample cut-blocks with similar enviromental conditions and silvicultural histories but which were different in age since harvesting. Assumming that site and treatment effects are sufficiently uniform among the cut-blocks, chronosequential sampling provides stocking data for similar cut-blocks at various stages of development. This information can be used to describe and model stocking development.

Forty-one cut-blocks at various stages of development were sampled. Harvest and scarification dates for each cut-block were determined from the silvicultural records of St. Regis (Alberta) Ltd. The cut-blocks were harvested between 1968 and 1980, representing a range of from 3 to 15 years between the completion of harvest and the survey conducted in the summer of 1983 (Table 2).

These records were also used to determine the specific scarification treatment of each cut-block in the sample. All blocks were site-prepared with a front mounted scarification plough, sometimes in conjunction with anchor chain drags, within 2 years of completion of harvest.

Sample plots were established on each of the cut-blocks using AFS regeneration survey procedures (Anonymous, 1979). Millihectare circular plots were located systematically over the entire cut-block at a density appropriate for the size of the cut-block and the stocking conditions encountered.[1] Stocking, density, and site conditions were evaluated on each plot.

---

[1] Alberta Forest Service regulations for regeneration survey sampling requirements are dependent on the size of the area being sampled and its stocking success (Anonymous, 1979).

Table 2. Age class distribution for sampled cut-blocks and plots, based on years since harvest and years since scarification.

	HARVEST		SCARIFICATION	
YEARS	BLOCKS	PLOTS	BLOCKS	PLOTS
1	-	-	1	65
2	-	-	3	212
3	4	234	3	209
4	4	332	3	248
5	2	168	6	351
6	3	250	3	147
7	6	248	8	398
8	6	270	1	41
9	4	233	2	128
10	1	64	5	200
11	3	96	-	-
12	2	104	2	128
13	2	128	-	-
14	2	132	4	214
15	2	82	-	-
TOTAL	41	2341	41	2341

2.2.1 Stocking Assessment

Stocking class was determined for each plot using 5 AFS stocking classes: not-stocked (0), stocked with acceptable conifer (1), stocked with fir (2), stocked with deciduous (3), and stocked with under-aged seedling (4).

AFS guidelines require one healthy pine seedling at least 2 years of age, one healthy 3-year-old spruce seedling, or two 2-year-old spruce seedlings for acceptable conifer stocking on a plot. In addition, up to 20% of the plots may be counted as stocked if they have at least one healthy 3-year-old fir or commercial hardwood seedling present (Anonymous, 1979).

Each sample plot was re-evaluated using a dichotomous stocking classification of 'stocked (1)' or 'not stocked (0)'. Plots with pine, spruce, fir or hardwood stocking were classed as stocked. Plots with no seedlings, or only under-aged seedlings, were classed as not-stocked. Stocking of each cut-block was then determined using this new stocking classification.

2.2.2 Density Evaluation

Density was evaluated on each plot by a complete count of all seedlings present within the plot. Seedlings were recorded as conifer or deciduous. Only commercial species established after harvest were counted. Advanced growth was not included in the density count because it was rare and of little consequence to stocking or density assessment.

Data were also collected for estimating density using a distance measurement technique (Cooper, 1961). A circular plot, with a radius of 10 metres, was established on each plot centre and was divided into 4 quadrants. In each quadrant the seedling closest to the plot centre was selected, the distance from plot centre to the seedling was measured to the nearest centimetre, and the species, age and height of the seedling were determined. Age to ~~the~~ nearest year was evaluated by branch and whorl counts paying careful attention to lammas and prolepsis growth (Wilson, 1970).

2.2.3 Site Evaluation

Each plot was also evaluated and classified for a number of site variables which had been assessed as factors potentially influencing the development of stocking and density.

Slope

The slope of each plot was measured to within ±5% using a clinometer, and then classified as flat (<6%), 6-10%, 11-15%, 16-25%, 26-35%, or over 35%.

Aspect

The aspect of each plot with a slope greater than 5% was measured by hand compass to within ±5 degrees and classified as North, Northeast, East, Southeast, South, Southwest, West, or Northwest.

Mineral Soil

The degree of mineral soil exposure was estimated for each millihectare plot. Two independent estimates were made and exposure was classified as 0-10%, 10-40%, 40-70%, or 70-100% based on the average of the two estimates.

Duff Depth

The average depth of the duff (L and H horizons) (Anonymous, 1977) on the undisturbed portion of the plot was estimated. A rough classification system of 'less than 7.5 cm', '7.5-15 cm', and 'greater than 15 cm', was used. Each plot was evaluated by estimation and classified. If no undisturbed areas were found on the plot an approximation was obtained from a nearby undisturbed area. Where 100% of the site was bare mineral soil, rock, water, or some combination thereof, duff depth was coded separately as 'no duff'.

Competition

The dominant form of inter-specific vegetative competition was determined for each plot. Four classes were used: no competition, grass, forb, and shrub. Each plot was classed according to the vegetation competing most sucessfully with the tree seedlings on the plot. Taller forms were considered dominant except where the shorter forms were considerably more abundant than the taller forms.

The degree of competition was evaluated using an ordinal scale classification of: none, light, moderate, and heavy. Total ground cover percentage, competition growth form, and competition height, were used to estimate the degree of competition on the site.

Moisture Regime

As a final indicator of site character, a subjective evaluation was made to estimate the dominant moisture condition for each plot. All of the above variables, as well as plot position with respect to the topography of the site, were used in this classification process. Four classes were used: dry, dry to fresh, fresh to moist, and moist to wet.

Although a subjective classification was used for this variable, classification was consistent since all sites were evaluated by the principle investigator and his assistant.

3. ANALYSIS OF SITE VARIABLES

3.1 Scarification

About 84% (1,959) of the 2,341 plots which were sampled were scarified with ploughs and anchor chain drags (Table 3). All plots were scarified, usually with front-mounted scarification ploughs and anchor chain drags, within two years of harvest.

It is reasonable to expect different scarification techniques and delay periods to produce different stocking and site development trends. The possibility that differences in scarification treatment might have a major influence on stocking, ingress, or site parameters was investigated.

There were not sufficient data for each of the alternate scarification treatments (Table 3) to be evaluated individually. The data were, therefore, analyzed to determine if using only plots scarified with anchor chain drags one year after harvest would substantially improve the relationship between years since scarification and the various site parameters.

To determine this, a random sample (1,322 plots) of the data was selected and used to compute Spearman rank correlation coefficients (Zar, 1974) between time since scarification and the various site parameters. These coefficients were compared with similarly computed coefficients for a random sample (1,212 plots) selected from

Table 3. Scarification treatment of the sampled cut-blocks (from silvicultural records of St.Regis (Alberta) Ltd.)

SCARIFICATION DELAY	WITH DRAGS		WITHOUT DRAGS	
YEARS	BLOCKS	PLOTS	BLOCKS	PLOTS
0	3	196	0	0
1	26	1430	2	168
2	7	333	3	214
TOTAL	36	1959	5	382

All scarification was by front-mounted scarification plough 'with', or 'without', rear mounted anchor chain drags.

those plots scarified with drags one year after harvest.

Correlation coefficients would be expected to be higher for this subset if scarification technique or delay period were markedly affecting the sample. No such improvements were found (Table 4). Consequently, the entire data set, irrespective of scarification equipment and delay period, was used in subsequent analyses.

Because some cut-blocks were scarified immediately after harvest and others were left unscarified for up to 2 years, analysis of developmental parameters was based on time since scarification, rather than time since harvest, to make site parameter analysis more consistent.

3.2 Site Parameters

This study did not attempt to determine causative factors of the development of stocking. It was intended merely to identify associated parameters and to evaluate these parameters in relation to prediction of stocking.

Stocking success and classification frequencies for seven site variables are presented in Table 5. Scarification age (Table 4) and stocking success (Table 6) are analyzed with respect to observed site conditions and to site development.

3.2.1 Aspect

Topography was rolling to hilly, resulting in plot frequencies which were evenly distributed over all aspect

Table 4. Spearman rank correlation coefficients for years since scarification versus stocking, ingress, and site variables. A = random sample of the dataset. B = subset consisting of plots scarified with plough and drags one year after harvest.

(r) (n) (sig)	STOCKING	INGRESS	ASPECT	SLOPE	MIN. SOIL EXPOSURE	DUFF	MOISTURE	COMP. TYPE	COMP. DENSITY
YEARS SINCE SCARIFICATION SAMPLE A	.4660 2266 .000	-.3603 2266 .000	.0988 1322 .000	.0766 1322 .005	-.2671 1322 .000	.0605 1322 .028	.0189 1322 .492	.0464 1322 .492	.3380 1322 .000
YEARS SINCE SCARIFICATION SAMPLE B	.3920 1212 .000	-.3113 1212 .000	-.0732 1212 .011	.0422 1212 .142	-.0888 1212 .002	.1054 1212 .000	.0243 1212 .397	-.1378 1212 .000	.1435 1212 .000

r = correlation coefficient
n = sample size
sig = significance level of the correlation coefficient

Table 5. Site variable classification frequencies and percent stocking.

ASPECT

class	freq	percent	stock %
N	137	5.8	62.8
NE	297	12.7	76.1
E	198	8.5	77.3
SE	277	11.8	88.4
S	388	16.6	88.1
SW	269	11.5	90.0
W	58	2.5	93.1
NW	62	2.6	54.8
FLAT	655	28.0	52.5

SLOPE

class	freq	percent	stock %
0-5%	655	28.0	52.5
6-10%	327	14.0	76.1
11-15%	325	13.9	82.8
16-25%	551	23.5	82.9
26-35%	300	12.8	84.0
35+%	183	7.8	84.7

DUFF DEPTH

class	freq	percent	stock %
NONE	184	7.9	55.4
0-7.5cm	1562	66.7	78.8
7.5-15cm	551	23.5	67.7
15-23cm	44	1.9	52.3

MOISTURE REGIME

class	freq	percent	stock %
DRY	335	14.3	72.8
DRY-FRE	1360	58.1	81.4
FRE-MOIST	518	22.1	54.4
MOIST-WET	127	5.4	73.2

COMPETITION TYPE

class	freq	percent	stock %
NONE	96	4.1	37.5
GRASS	478	20.4	75.7
FORBS	621	26.5	66.3
SHRUBS	1146	49.0	79.9

COMPETITION DENSITY

class	freq	percent	stock %
NONE	96	4.1	37.5
LIGHT	984	42.0	64.9
MODERATE	981	41.9	88.7
HEAVY	280	12.0	64.6

MINERAL SOIL

class	freq	percent	stock %
0-10%	1607	68.6	81.6
10-40%	448	19.1	58.9
40-70%	107	4.7	59.6
70-100%	177	7.6	48.6

Table 6. Spearman rank correlation coefficients for stocking versus years since scarification and site variables for a random sample of the data set.

(r) (n) (sig)	AGE	ASPECT	SLOPE	MIN. SOIL EXPOSURE	DUFF	MOISTURE	COMP. TYPE	COMP. DENSITY
STOCKING	.4660 2266 .000	-.1450 1320 .000	.2879 1320 .000	-.2632 1320 .000	-.0490 1320 .075	-.1569 1320 .000	.1229 1320 .000	.2019 1320 .000

r = correlation coefficient
n = sample size
sig = significance level of the correlation coefficient

and slope classes.

Although all aspect classes were evenly represented, it is evident that north, northwest, and flat sites were more poorly stocked (Table 5). Stocking was most abundant on southeast to westerly aspects. Apparently the higher incident solar radiation experienced by these sites does not adversely affect seed germination [illegible] seedling survival. These sites might, in fact, be exhibiting better germination due to higher ground and air temperatures, better cone opening, and more complete seed release.

3.2.2 Slope

Flat sites generally had poorer stocking success than sloping sites (Table 5). Robb soil characteristics result in poor drainage in depressional areas. Consequently, the poor stocking found on some flat sites may be due to flooding of seedlings and germinants. These plots may also be frost prone areas and germinants may be killed before they are well enough established to resist freezing.

3.2.3 Moisture

Climatic and soil characteristics of the region produced an abundance of 'dry to fresh' sites. This one class accounted for 58% of the sites. The 'moist to wet' sites, which totalled only 5.4% of the plots, were primarily restricted to flat valley bottoms and drainage areas.

Moisture regime was negatively correlated with stocking (Table 6); wetter classes showed slightly poorer stocking than drier sites. Chi-square analysis indicated that stocking success was better than expected on the 'dry to fresh' sites and poorer than expected on the 'fresh to moist' sites. The 'dry to fresh' sites were most favourable for germination and survival.

There was no significant correlation of moisture class with age since scarification (Table 4). Moisture class appears to be independent of site age and does not change appreciably as the site develops.

3.2.4 Duff Depth

Duff was generally shallow. Almost 75% of the 2341 plots had less than 7.5cm of duff; only 2% had more than 15cm. Stocking was poor on plots with deep duff and on plots with no duff (Table 5).

Deep duff hinders seedling establishment due to rapid drying of the duff and inability of the radicle to reach mineral soil while the duff is still moist enough to support growth. Absence of a duff layer is also unfavourable for successful germination or survival of pine, probably due to the extreme microenvironment of these sites, to compaction of the soils when the duff was removed, or to erosion. This non-linear influence suggests that the effect of duff depth on stocking is much greater than the Spearman rank correlation coefficient from Table 4 would indicate.

3.2.5 Mineral Soil

Most plots had relatively little mineral soil exposed. Almost 90% of the plots had less than 40% of the soil exposed, and 70% had less than 10% bare soil (Table 5). The majority of the plots, one year after scarification, have between 10% and 40% exposed mineral soil. This is to be expected since the scarification treatments are designed to achieve about 40% soil exposure (Ferdinand, 1983).

Development of tree seedlings and other vegetation, and the resultant deposition of litter, reduces the amount of exposed mineral soil. Consequently, the amount of exposed mineral soil present was strongly correlated with years since scarification.

Figure 3 illustrates the frequency trends found in the 4 soil classes over the age range sampled. The frequency of the 0-10% mineral soil class increases with years since scarification for about 8 years. There is a corresponding decrease in frequency for all other classes.

Stocking success (Table 6) was negatively correlated with the amount of exposed mineral soil. In general, plots with large amounts of exposed mineral soil were more poorly stocked (Table 5). Higher amounts of exposed mineral soil appear to inhibit stocking development, probably for the same reasons suggested for poor stocking associated with the absence of a duff layer. Although mineral soil is often considered a favourable seedbed, it appears to be much better when ameliorated somewhat by shallow duff or light

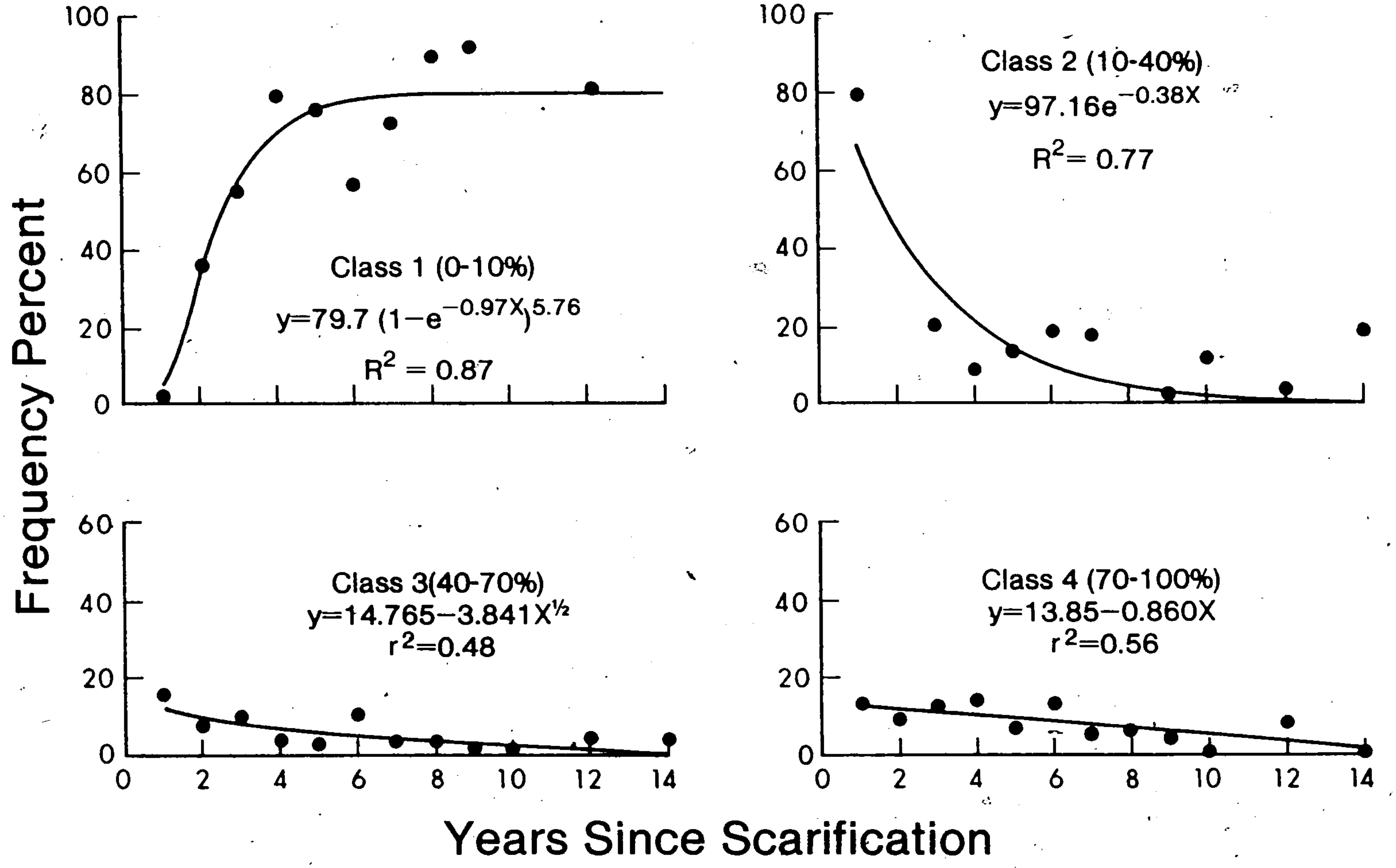

Figure 3. Computed regression trends for changes in the percentage of sample plots in each of 4 mineral soil exposure classes compared with the number of years since scarification.

vegetative competition.

Both stocking and mineral soil exposure were strongly correlated with years since scarification (Table 4).The number of years since scarification therefore has a confounding influence on the stocking/mineral soil relationship.

To examine this, the stocking percentage was determined for each soil class by scarification age (Table 7). Stocking success improves with age and is generally highest where little mineral soil is exposed, especially in the younger age classes.

Since mineral soil exposure tends to be greatest on young sites, the poor stocking associated with high levels of exposed mineral soil is believed to be partly a function of site age since scarification.

The age parameter is expected to be the controlling factor in this relationship, and to be of major importance in determining trends of development of stocking.

3.2.6 Competition Density

Vegetative competition on the plots was predominantly 'light' and 'moderate' (Table 5). Only 12% of the plots had 'heavy' competition. These had lower stocking success than the 'moderate' and 'light' sites, as did sites with 'no competition' (Table 5). The trend of stocking success is therefore non-linear with respect to density of competition. This would be expected since open sites are too severe, and

Table 7. Percent stocking evaluated by mineral soil exposure class and years since scarification.

YEARS SINCE SCARIFICATION	MINERAL SOIL EXPSOURE CLASS			
	0-10%	10-40%	40-70%	70-100%
1	-	-	20	(0)
2	21	8	6	0
3	47	49	29	14
4	78	83	(83)	67
5	90	92	64	50
6	82	93	93	85
7	90	92	100	88
8	97	(100)	(100)	(33)
9	96	75	-	(0)
10	90	88	-	-
12	98	(100)	(100)	92
14	78	88	(100)	(100)

( ) indicate estimates based on fewer than 10 samples.

'heavy' sites are too crowded, for optimum seedling establishment. Competition density is therefore a more important stocking control factor than indicated by the Spearman rank correlation coefficient from Table 6.

The density of vegetative competition was significantly correlated with years since scarification (Table 4). Curves were constructed (Figure 4) to illustrate these relationships.

The majority of plots have 'light' competition immediately after scarification but competition increases as the site ages. There is a slight, but fairly steady, decline in the frequency of plots with no competition.

Much of this development happens within 7 years of scarification but the process is still evident even after 14 years. Density of competition continues to increase long after the sites are stocked.

Because stocking and density of competition both increase with age, the effect of age is partially responsible for the high stocking level associated with the 'moderate' density class and for the relatively successful stocking associated with the 'heavy' class.

Age thus has a confounding influence on the stocking/competition density relationship. Table 8 shows stocking success for each competition density class, broken down by years since scarification. Stocking was generally poorer on the 'no competition' class (32%) but the majority of these sites were on cut-blocks with fewer than 7 years

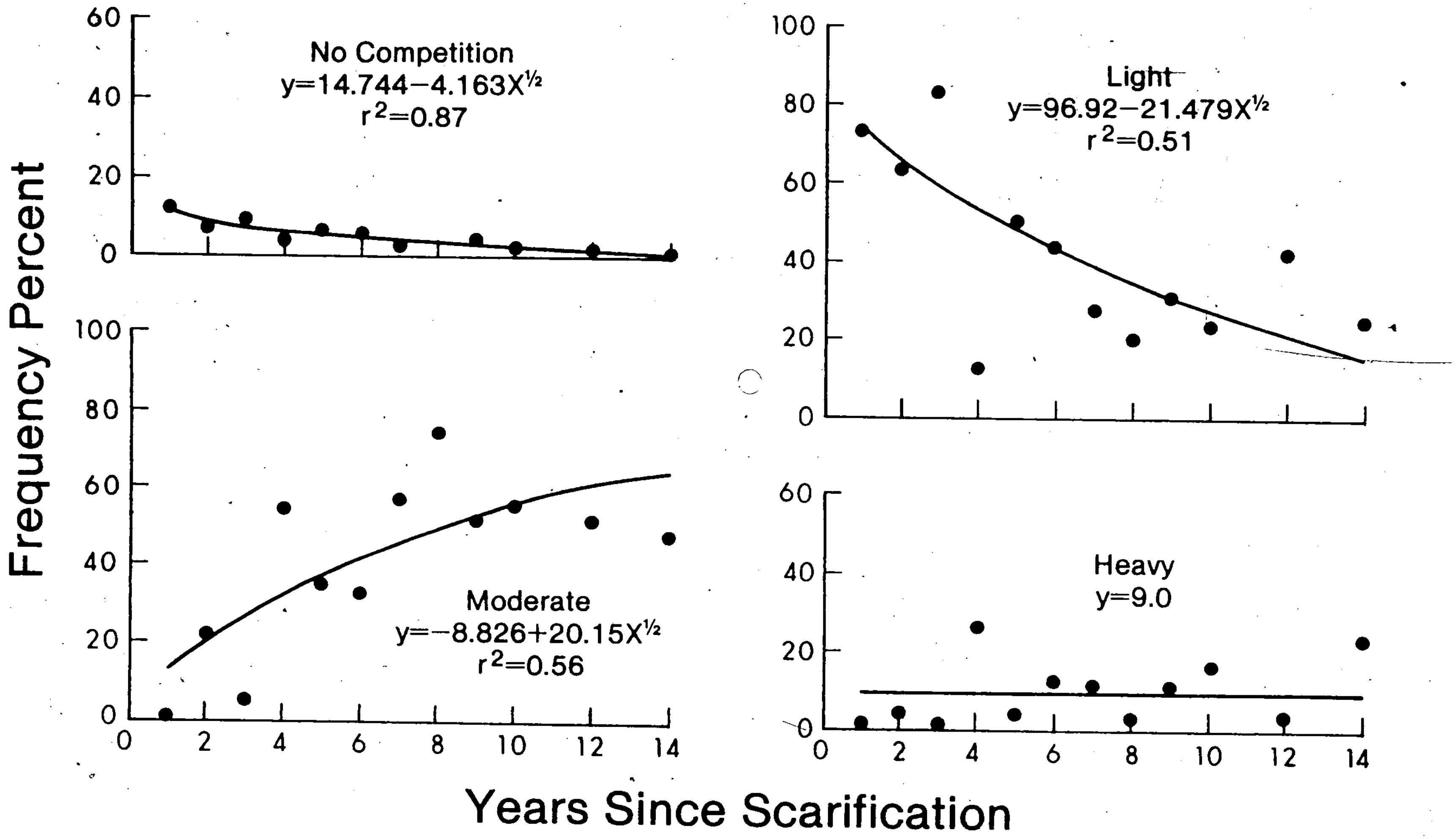

Figure 4. Computed regression trends for changes in the percentage of sample plots in each of 4 competition density classes compared with the number of years since scarification.

Table 8. Percent stocking evaluated by competition density class and years since scarification.

YEARS SINCE SCARIFICATION	COMPETITION DENSITY CLASS			
	NONE	LIGHT	MODERATE	HEAVY
1	(0)	4	-	-
2	0	6	33	(22)
3	0	41	85	-
4	50	85	84	66
5	53	89	90	61
6	90	93	92	39
7	(100)	93	91	81
8	(0)	(88)	100	(0)
9	(0)	91	97	80
10	-	90	94	78
12	(100)	98	98	(86)
14	-	96	90	49

(   ) indicate estimates based on fewer than 10 samples.

growth since site preparation. Stocking success, when evaluated by age class, was generally lower for 'no competition' sites but there was not sufficient data over the entire age range to permit a definitive evaluation of the influence of age on these sites.

Sites with heavy competition showed considerably less stocking than the 'light' and 'moderate' classes for young sites (up to 6 years after scarification), but this stocking differential is much less at later stages of development. Thus, successful stocking on 'heavy' competition sites appears to be a result of the establishment of seedlings prior to the site having developed 'heavy' competition.

3.2.7 Competition Type

The type of competition was correlated with stocking (Table 6), but was not linearly correlated with age since scarification (Table 4).

The 'no competition' class had appreciably lower stocking success than the other competition types, whereas the 'grass', 'forb', 'and 'shrub' types were stocked equally well (Table 5). Thus the significance of this stocking correlation appears to be primarily a function of the 'no competition' category.

The type of competition is, therefore, not as important to successful stocking development as is the presence of competition. As vegetative competition develops it ameliorates severe microenvironmental conditions found on bare sites. Arguments previously presented for duff and mineral soil influences (pages 28,29) apply as well to the effects produced by the absence of vegetative competition.

3.2.8 Age Analysis

To determine the importance of individual site factors on the development of stocking, the confounding influence of age was removed.

Spearman rank correlation analysis of the site parameter/stocking relationships for each of 12 age categories showed no consistent, significant correlation trends (Table 9). Thus, the significance of the stocking/site coefficients previously computed were due, in part, to the confounding influence of time since scarification. The importance of these individual site variables is, therefore, questioned.

Because several of the site variables might have been expected to influence stocking but failed to do so, it is inferred that factor interactions play a major role. Unfortunately, the available data are inadequate for the analysis of such interactions.

Even if these interactions could be determined, use of site variables for prediction of stocking might be impractical. It would require first, that they be assessed, and that the cut-block be stratified according to observed combinations of these site factors. Stocking would then be predicted independently for each stratum of the cut-block.

Table 9. Spearman rank correlation coefficients for stocking versus site parameters, computed for each age class (years since scarification)

(r) (sig)	MIN. SOIL	MOISTURE	DUFF	COMP. TYPE	COMP. DEN
2	-.2813	.0625	.1873	-.0879	.3317
	.001	.701	.006	.202	.000
3	-.1876	.2225	.1560	-.0210	.3087
	.007	.001	.024	.763	.000
4	-.0352	-.1652	.0276	.0281	-.1092
	.582	.009	.666	.666	.086
5	-.2158	-.0064	.2039	.0907	.0347
	.000	.905	.000	.090	.517
6	.0996	-.3886	-.1064	-.0975	-.3036
	.230	.000	.200	.240	.000
7	.0339	-.1779	-.0668	.1092	-.1028
	.500	.000	.124	.029	.040
8	-.4946	.1583	.3857	.5032	.1639
	.001	.323	.013	.001	.306
9	-.6190	.3200	.1705	.1418	.1164
	.000	.000	.054	.110	.191
10	-.0252	.1990	.0267	.0003	-.1053
	.723	.005	.707	.996	.138
12	-.0667	.0602	.0165	-.1114	-.0764
	.454	.500	.853	.211	.392
14	.1424	-.2565	-.3896	.1453	-.4366
	.037	.000	.000	.034	.000

r = correlation coefficient
sig = significance level of the correlation coefficent

This would require a highly complex and cumbersome prediction technique. It would be more desirable to predict stocking development for average cut-block conditions. This might be less accurate, but would be much simpler and more widely applicable.

Thus, site variables were ignored initially, and stocking development was predicted using age since scarification. The general homogeneity of the study area, the inconsistency of site variable correlations, and the dominance of the age factor, suggest that this approach might be adequate for the area sampled and for similar conditions.

4. ANALYSIS OF STOCKING, DENSITY, AND INGRESS

4.1 Stocking Analysis

Chronosequential sampling of 41 cut-blocks at various stages of development provided estimates for the analysis of stocking.

A scatterplot of these estimates (Figure 5) showed two anomalous data points, representing Blocks 6 and 36. Block 6 had suffered severe mortality from girdling damage by hares prior to sampling. Block 36 had highly compacted soils with little or no duff or humus. This cut-block appears to have been a landing area for harvesting operations in adjacent cut-blocks. Consequently, these two cut-blocks were excluded from further analyses of stocking.

Examination of the remaining stocking estimates showed a rapid linear increase until year 5, and thereafter a relatively steady state. A Chapman-Richards growth curve was used to model this development using average cut-block stocking and years since scarification (Payandeh, 1983). To predict development of stocking based on individual plot data, piecewise linear regression analysis was chosen to approximate the Chapman-Richards model. Piecewise linear regression, as described by Neter and Wasserman (1974), is a technique for applying linear regression analysis to data which behave differently in different parts of their range, but which are essentially linear in all parts.

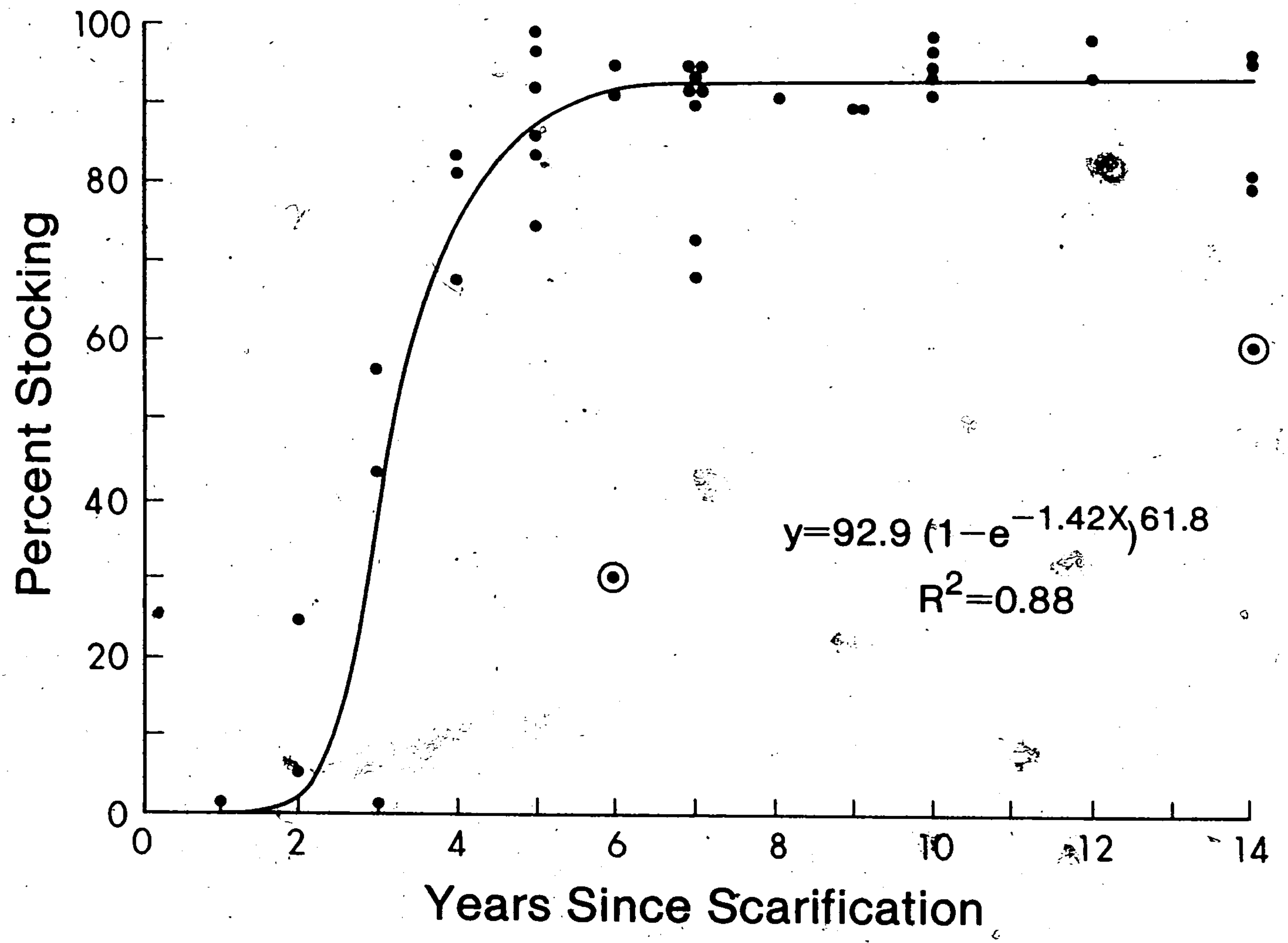

Figure 5. Average stocking for 41 cut-blocks plotted against the number of years since the cut-blocks were scarified.

Each plot observation was treated as a datum, rather than using block averages, to increase the precision of the stocking prediction (Sokal and Rohlf, 1969). The binary dependent variable (stocking(0,1)) was weighted for regression analysis, as suggested by Neter and Wasserman (1974), to equalize the variances. Weighted piecewise linear regression, with an inflection point at 5 years after scarification, was highly significant (P<.001) with computed prediction limits of ±9.5% based on 40 plot observations per cut-block.

This equation can be used to predict stocking development (±10%) for pine cut-blocks throughout the study area (Figure 6). On these sites a very rapid initial increase in stocking is expected, with average stocking predicted to be 91% 5 years after scarification. On these sites the provincial stocking requirement is not only being met, it is being exceeded.

If a stocking estimate for a surveyed cut-block is below the lower prediction limit of this equation, it is probable that at least one of the assumptions necessary for using this equation has been violated. The cut-block is either not representative of those used to develop the equation, or the silvicultural treatment of the block is not consistent with that of the sample. In these situations stocking would not be expected to develop as modelled by the computed regression equation.

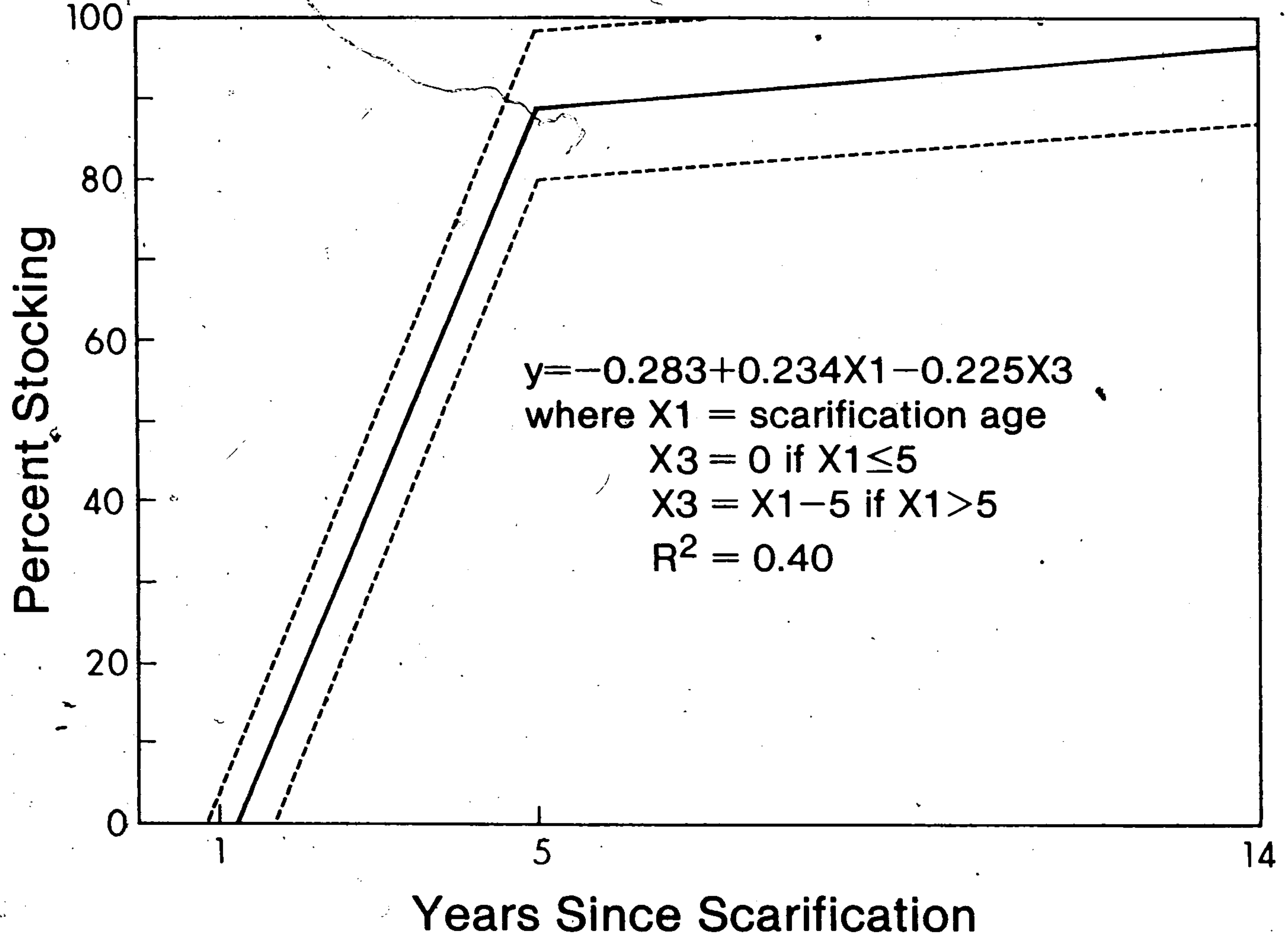

Figure 6. Weighted piecewise linear regression, with 95% prediction limits for stocking, based on the number of years since site preparation.

For example, consider the scattergram (Figure 7) of stocking averages for plots having a 'fresh to moist' moisture regime. This pattern differs markedly from that for average block conditions (Figure 5). Stocking development to an acceptable level tends to be slower on these wetter sites, though final stocking levels are not appreciably lower than average.

4.2 Density/Stocking

Bella and DeFranceschi (1978) showed that the number of seedlings on a site increased exponentially as the stocking level rose. Stocking at these high levels has a dramatic effect on density, and ultimately on stand development.

Thus, to determine if a density problem exists or is likely to develop, a method is needed for estimating present and future density of the cut-block.

Gill (1950) examined the relationship between number of trees and stocking and showed that, for randomly distributed seedlings, these two factors are related as:

$$N = \log(1-P/100)/\log((C-1)/C) \quad \text{where}$$

N = seedlings ha

P = % stocking

C = plots ha

Many authors, however, have shown that natural regeneration is not distributed randomly (Evans, 1953;

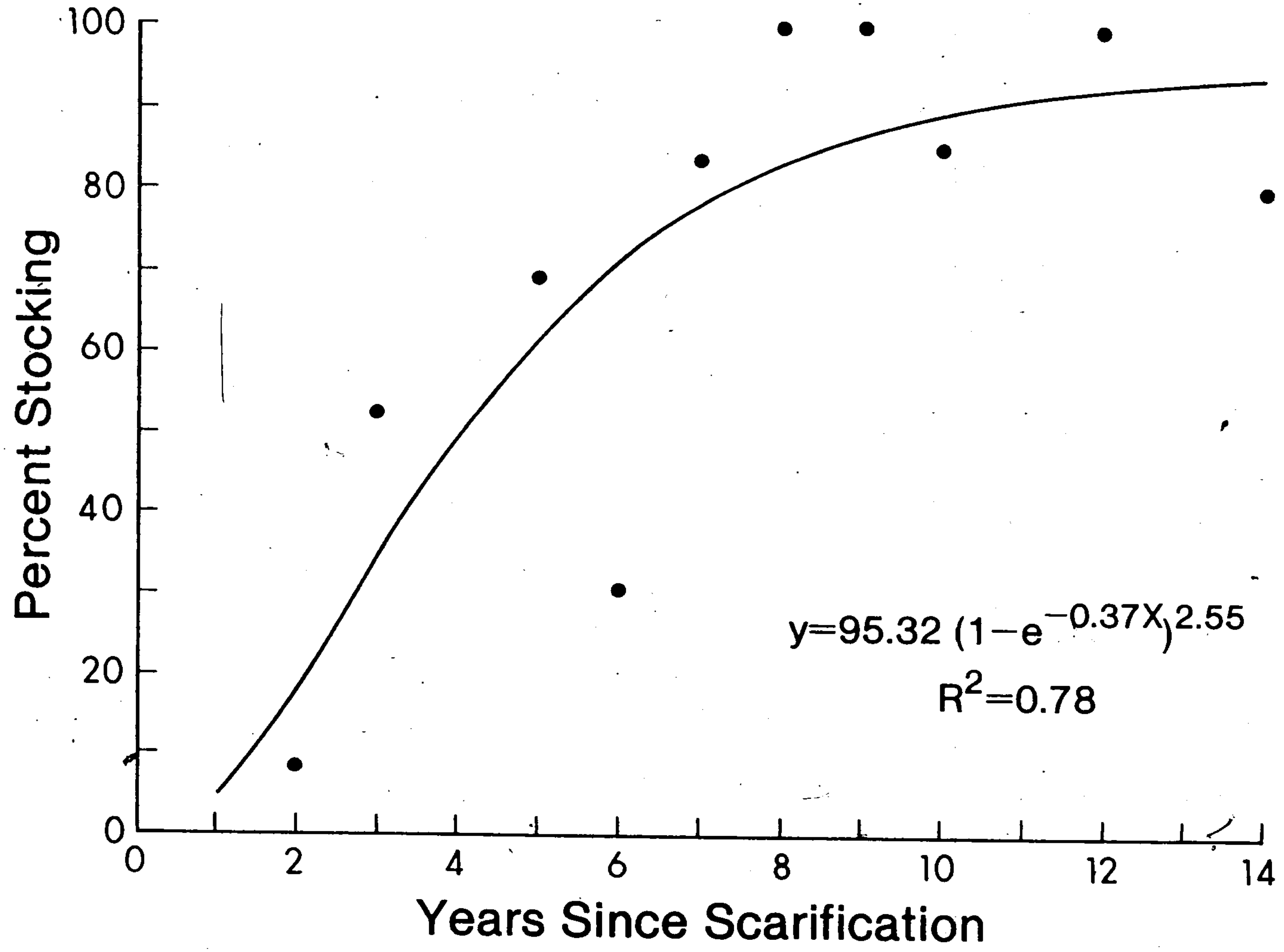

Figure 7. Regression curve for average expected stocking for 'fresh to moist' sample plots, compared with the number of years since the plots were scarified.

Ker, 1954; Bella, 1976; Daniels, 1978) and this has a major effect on the density/stocking relationship.

The empirical relationship between percent stocking and number of trees per hectare was investigated. A scatter plot of these variables for the 41 cut-blocks showed a non-linear trend, with seedling numbers increasing markedly after stocking exceeded 60% (Figure 8).

Seedling densities were transformed to natural logarithms and regressed on percent stocking. The resultant equation was highly significant ($P<.001$) and accounted for 68% of the variation in density ($r^2=0.68$).

A linear approximation for the natural logarithm of Gill's theoretical random distribution was constructed for comparison. Although the curve is sigmoid, the linear approximation is adequate for comparison purposes ($r^2=0.99$). This random distribution curve is much lower than the equivalent equation for the observed stocking/density relationship (Figure 9).

Regeneration on the sites examined in this study was not randomly distributed. Sites which met the 80% stocking requirement of the AFS had several thousand trees per hectare rather than the 1600 expected for a randomly distributed population (Figure 10).

Seedling numbers increase dramatically at high levels of stocking (80%+) and high stocking values were common on these cut-blocks. Many cut-blocks had more than 10,000 stems per hectare. Given that 800 evenly-spaced trees per hectare

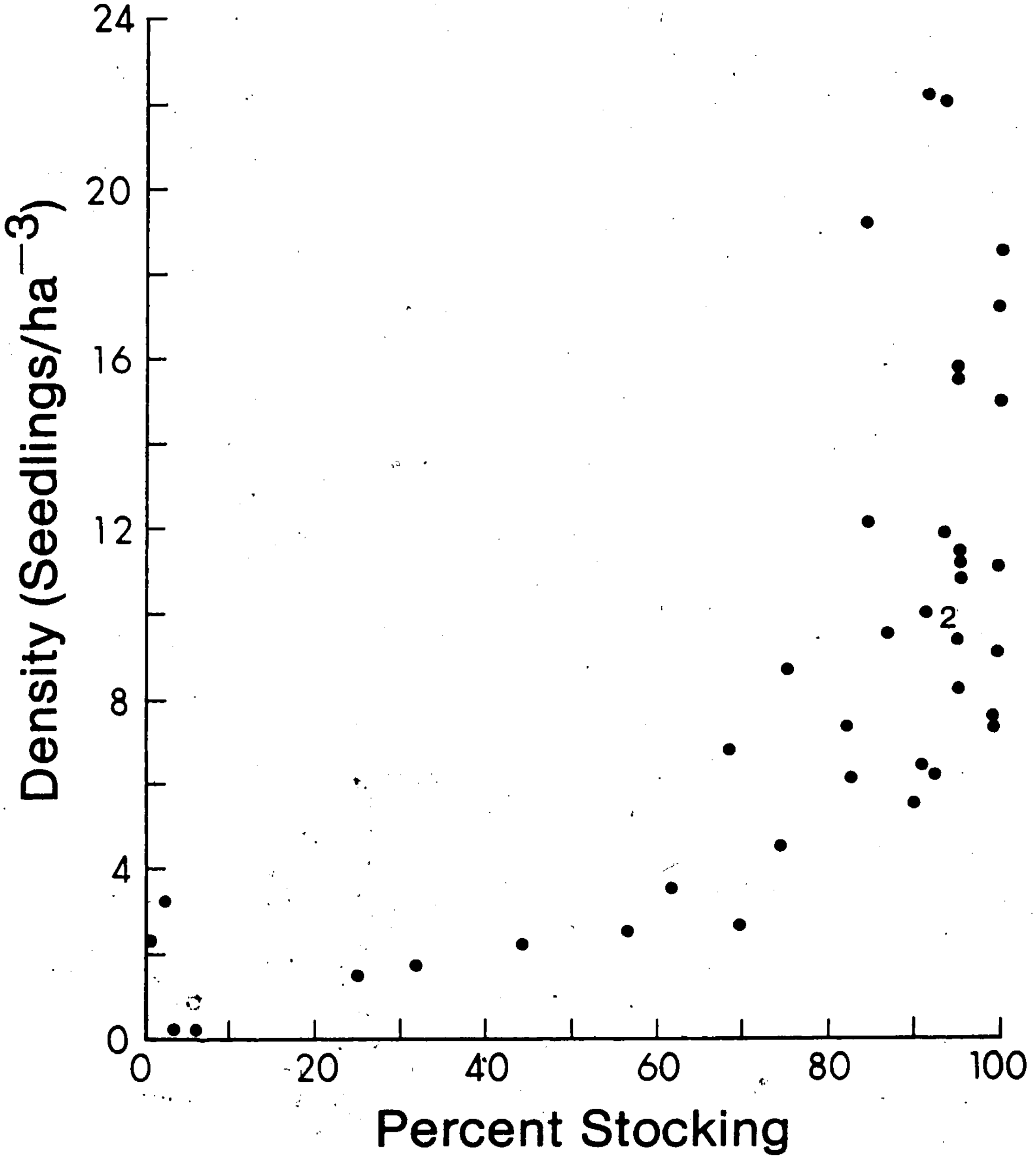

Figure 8. Average number of seedlings per millihectare plotted against average stocking for 41 cut-blocks.

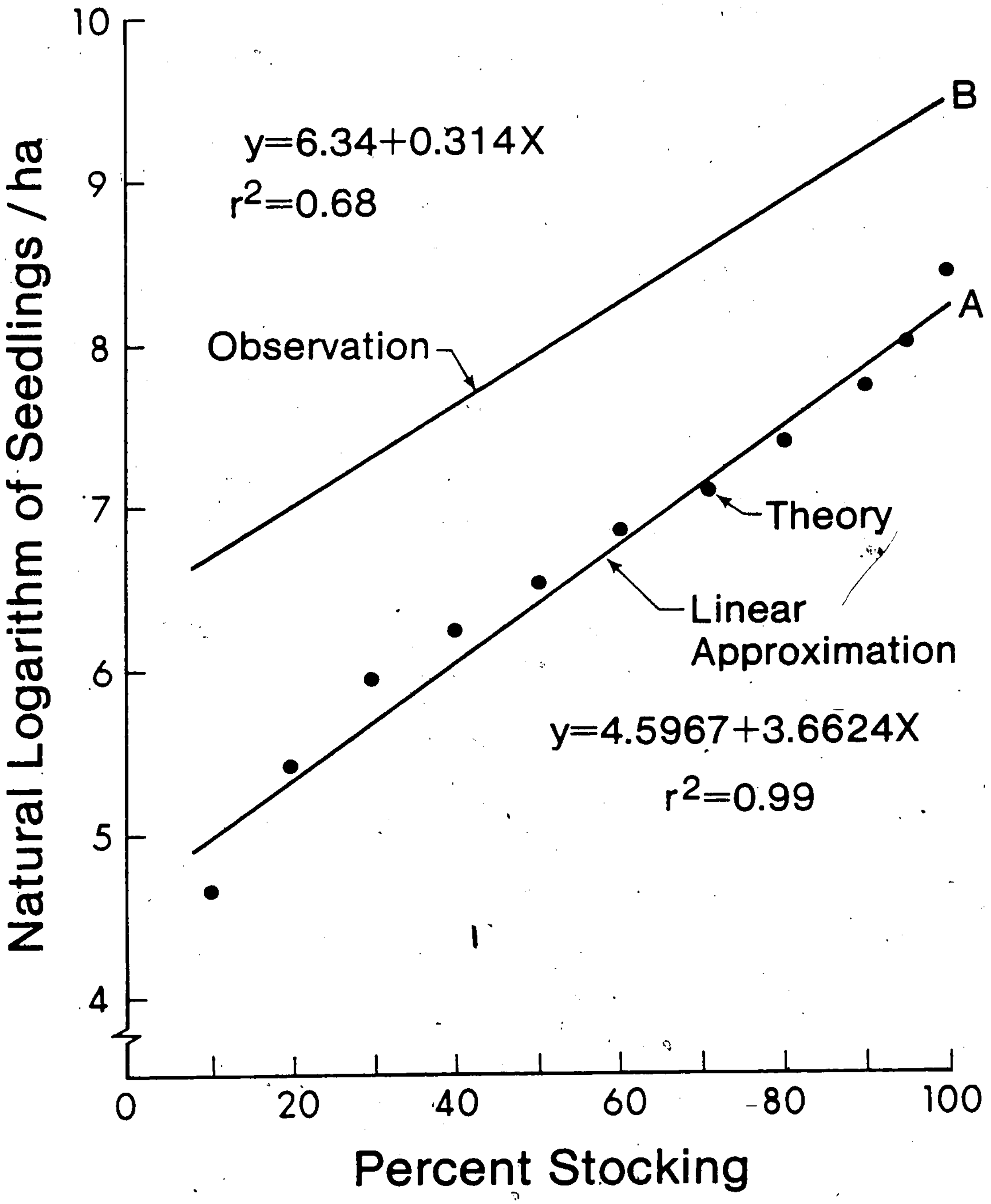

Figure 9. Regression lines for natural logarithm of seedling density (trees/ha) versus percent stocking. A = theoretical relationship for a random spatial distribution of seedlings. B = observed relationship based on density and stocking estimates for 41 cut-blocks.

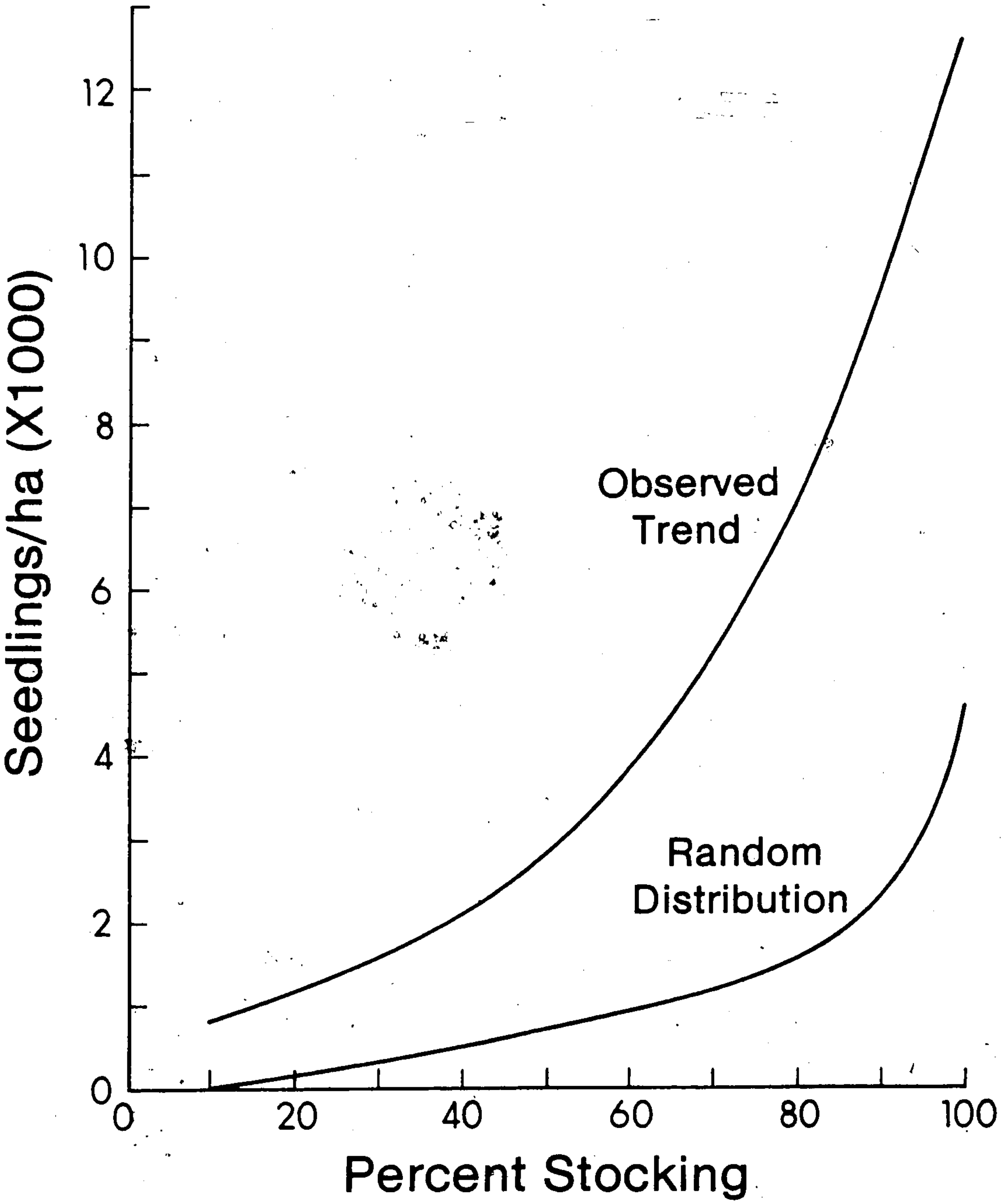

Figure 10. Logarithmic regression lines of Figure 9 transformed and plotted as trees/ha versus percent stocking. A = theoretical relationship for a random spatial distribution of seedlings. B = observed relationship based on density and stocking estimates for 41 cut-blocks.

are needed to produce a fully-stocked stand at maturity (Bella, 1976), densities of this magnitude (10,000+) are probably not necessary or desirable.

Early recognition of density problems, as advocated by Stein (1978) and Bella (1976), should be an integral part of any intensive forest management program. Although the regression equation generated from these data illustrates the interdependence of stocking and stand density, it is not adequate for predicting density. Above 60% stocking the variation in density becomes excessive, and prediction limits for density at high stocking levels are too wide to be of use. Although prediction at lower-stocking levels is much better, density problems are more common at high stocking levels. Consequently, the equation is of little value at an operational level. Because stocking surveys cannot provide sufficiently accurate estimates of stand density, the use of distance measurements for estimating seedling numbers was examined.

4.3 Distance-Density Regression

An empirical distance-density relationship was investigated for estimating and predicting development of stand density. To be effective this method must be simple, economically efficient, and applicable over large, relatively homogeneous populations.

To evaluate this approach, data were collected from 41 naturally regenerating lodgepole pine cutovers. The average number of conifer seedlings per millihectare sample plot, and the average minimum distance from the plot centre to the nearest seedling, was determined for each cut-block, using only plots with at least one seedling present. This restriction was adopted to eliminate the problems associated with having indeterminate distances for plots with no seedlings. Although this underestimates distance and overestimates density, reducing the density estimate in proportion to the percentage of empty plots in the sample should eliminate this bias.

Initial examination of the distance-density scatterplot (Figure 11) revealed heterogeneity of variances for both variables. A logarithm transformation of these data to their natural base (e) eliminated most of this heterogeneity (Figure 12).

Two outlier points were noted on this transformed distance-density scatterplot. These two points represented Blocks 1 and 2 of the sample. These blocks had been surveyed within 2-years of being scarified. They had less than 10% stocking and a density of about 100 trees/ha. Stands with very low densities are of little significance in procedures designed to identify sites that are regenerating too abundantly. Consequently, these blocks were deleted from the distance-density analysis.

The resulting equation (Figure 13) was highly significant ($P<.001$) with a slope of (B) -2.7758. The regression accounted for 82% of the variation found in the

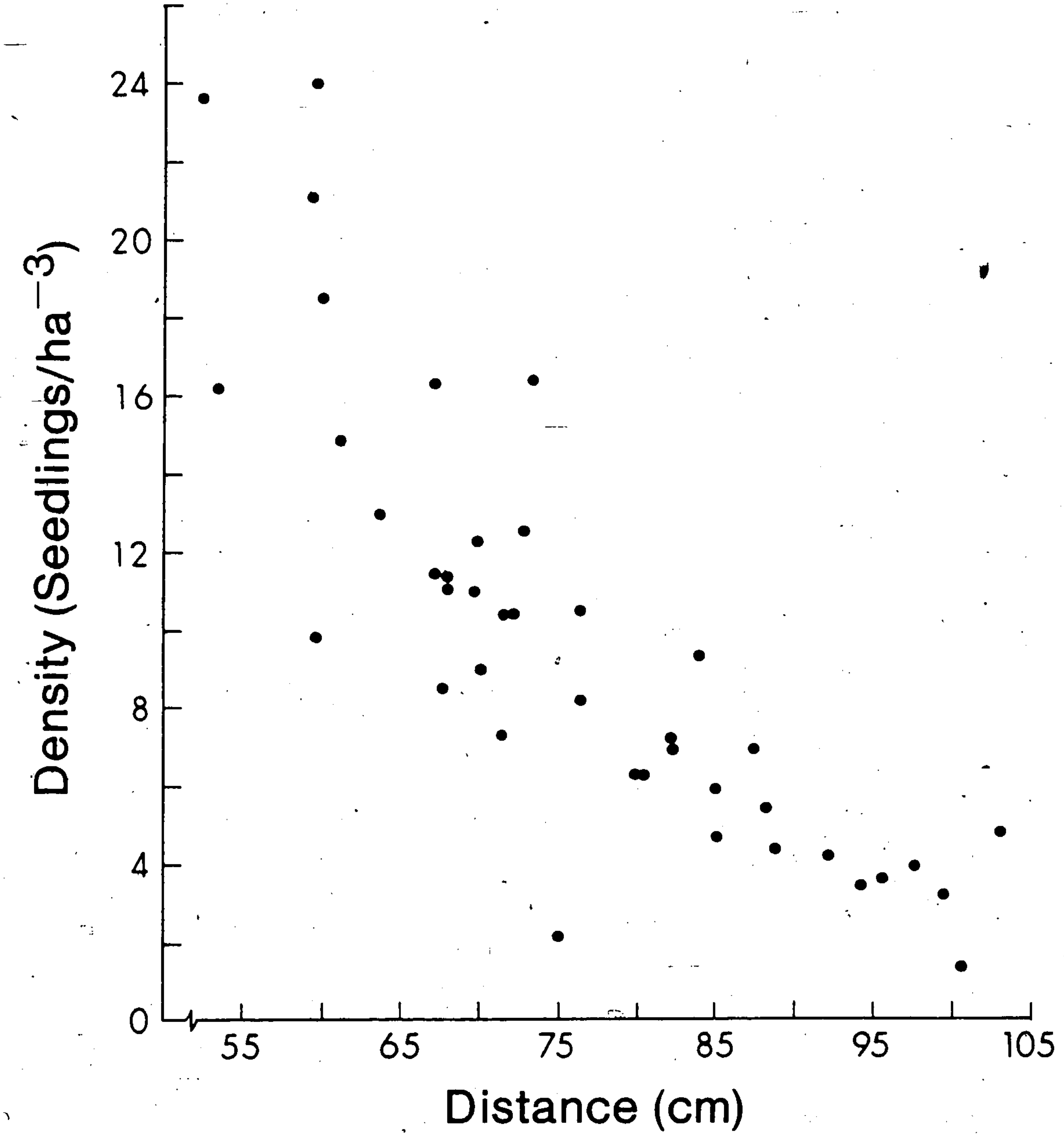

Figure 11. Averages of seedling density (trees/milihectare) for 41 sampled cut-blocks plotted against cut-block averages of distance (cm) from plots centres to the closest seedling in the plot.

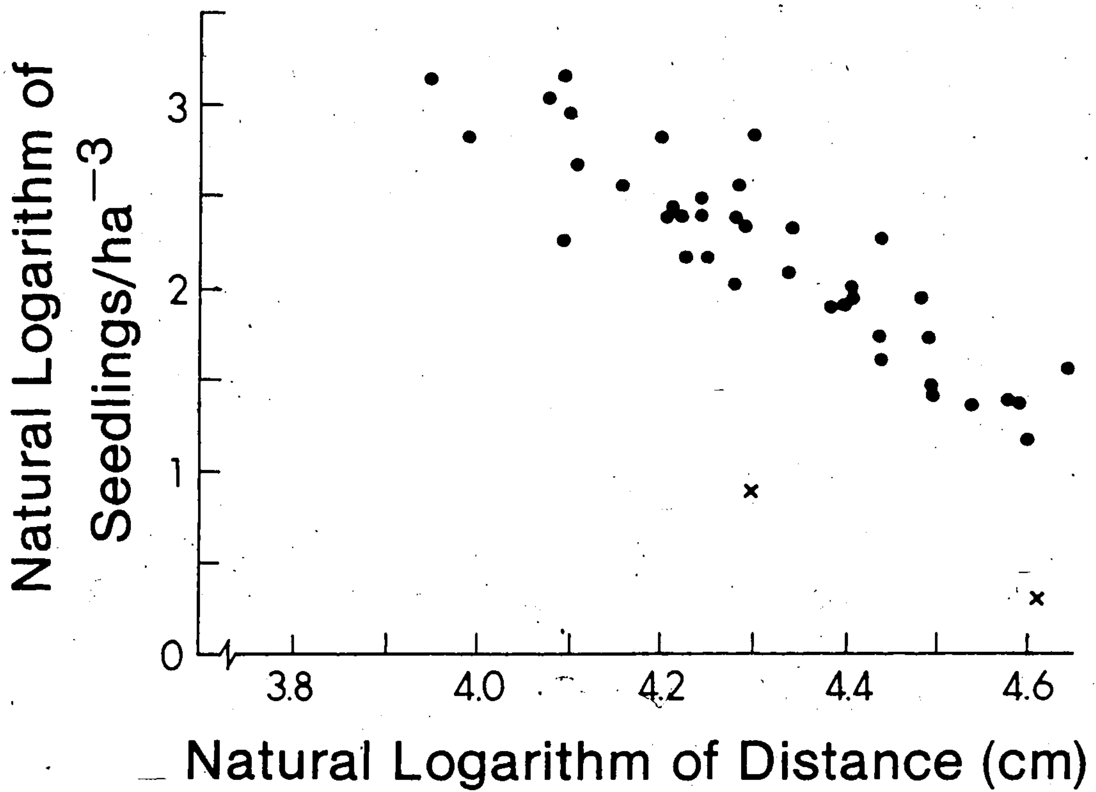

Figure 12. The natural logarithm of average seedling density (trees/millihectare) plotted against the natural logarithm of the average distance (cm) from the plot centres to the closest seedling in the plot, for 41 cut-blocks.

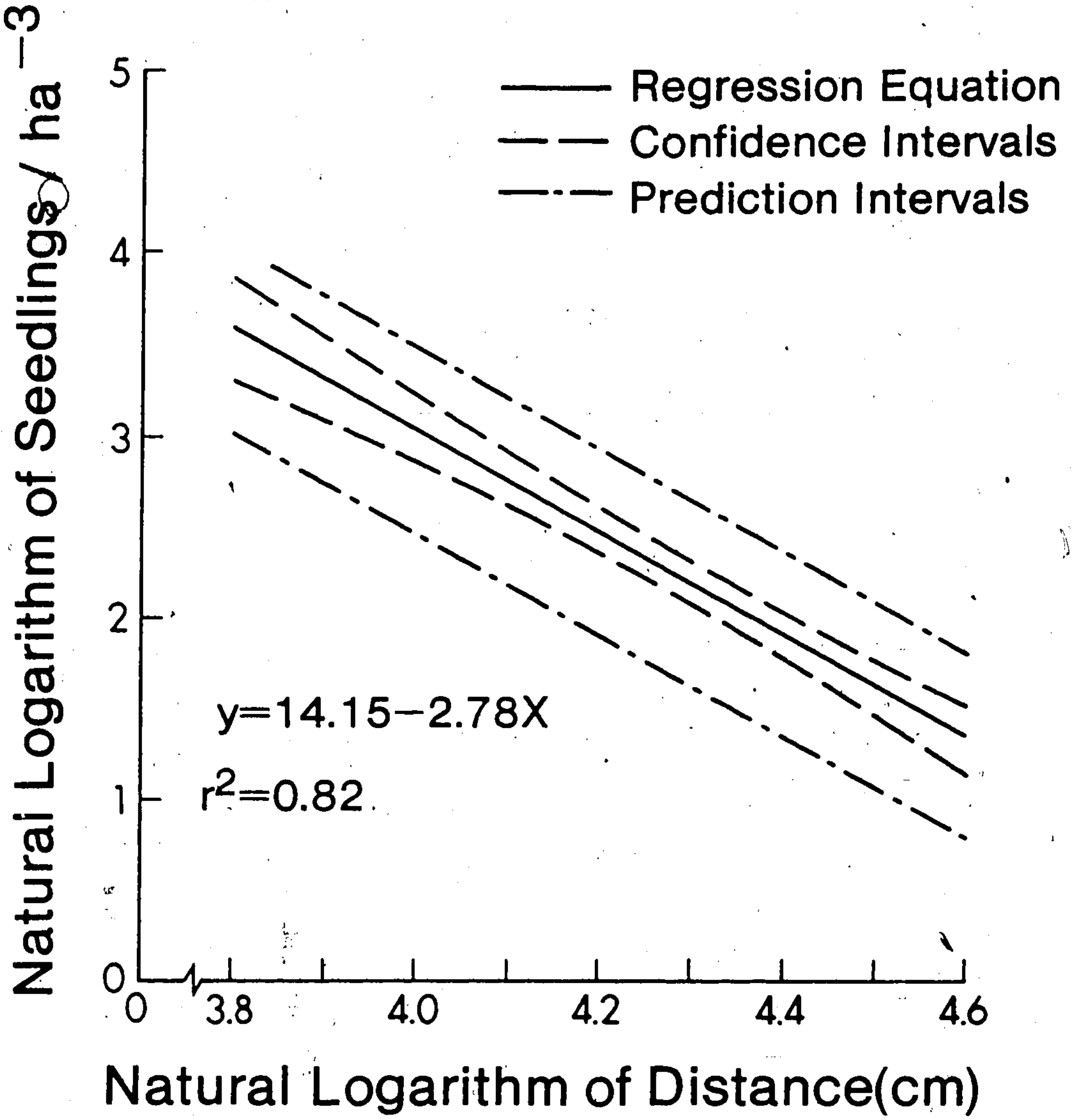

Figure 13. Computed regression line, with confidence and prediction limits (95% level), of the natural logarithm of average seedling density (trees/millihectare) versus the natural logarithm of the average distance (cm) from the plot centres to the closest seedling in the plot.

data (r^2=0.82).

This equation, converted back to the original distance and density units (Baskerville, 1971) is plotted (Figure 14) to illustrate the range of density to be expected for any given average distance.

The resultant equation is not sensitive to changes in distances larger than 80 centimetres, whereas at smaller distances (<50 cm) the predicted density range is unacceptably large (Figure 14). Although the equation is relatively accurate and sensitive near the mean distance (70 cm), for prediction purposes this approach is not adequate. More suitable methods will be examined briefly in the discussion section.

4.4 Ingress Evaluation

Age data collected for seedlings on the sample plots were used to identify the occurrence of ingress. Only a sample of seedlings present on each survey plot was aged. This provides a biased estimate of the minimum level of occurence of ingress. The true level of occurrence may be considerably higher than these data show.

The youngest of the sampled seedlings from each plot was selected and its age was used to determine the year that the seed germinated. Seedlings arising from seeds germinating less than two years prior to the survey were classed as newly recruited seedlings, indicating that ingress was active on that plot.

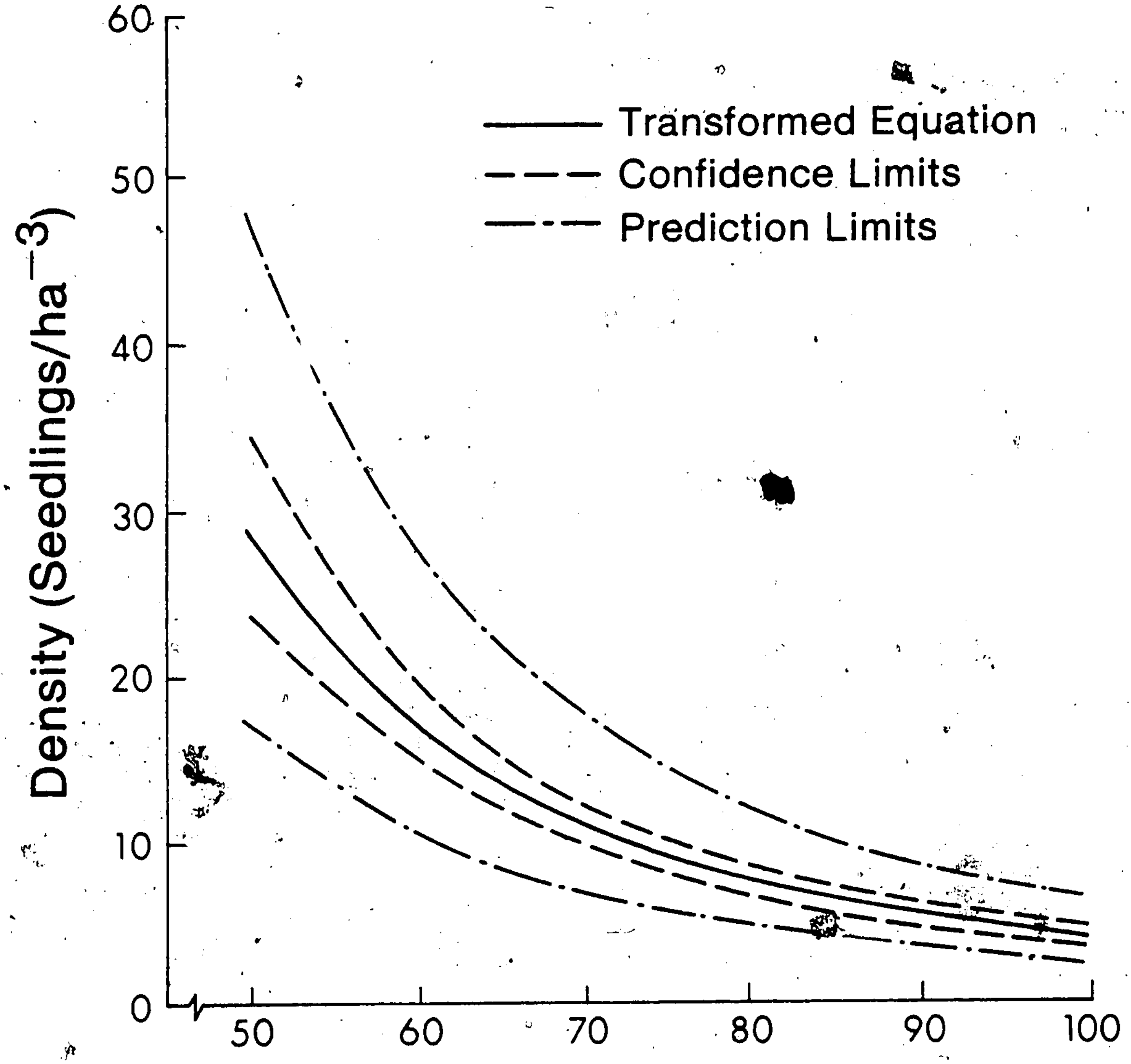

Figure 14. Regression line of Figure 13 transformed to the original distance (cm) and density (trees/millihectare) units using a correction factor suggested by Baskerville (1971).

From the ingress status of each plot the percentage with active ingress was determined for each scarification age class. The pattern of occurrence of ingress was plotted and a curve was fit by regression analysis (Figure 15).

The resulting equation which was developed using data which were transformed to an arcsine frequency percentage, was highly significant ($P<.001$) with $R^2=0.77$.

A large percentage of ingress, especially that occurring more than 5 years after site preparation, does not survive. If it did, density would continue to increase throughout the regeneration phase of development and would increase in direct proportion to the rate of ingress. This did not occur, as shown by Figure 16.

Seedlings that do survive often do not contribute to increased stocking because many of these late germinants occur on plots which are already stocked. However, since stocking continues to increase slightly, some of this ingress must occur on unstocked plots (Figure 17).

It appears, however, that the continuing ingress noted here, and in other studies (Crossley, 1976: Johnstone, 1976a), is of little consequence in the latter stages of development of regeneration. This is a direct result of the poor survival of these germinants on sites already heavily vegetated.

Ingress in the latter stages of regeneration development may, however, be important on poorly stocked sites. Figure 17, which shows ingress on unstocked plots,

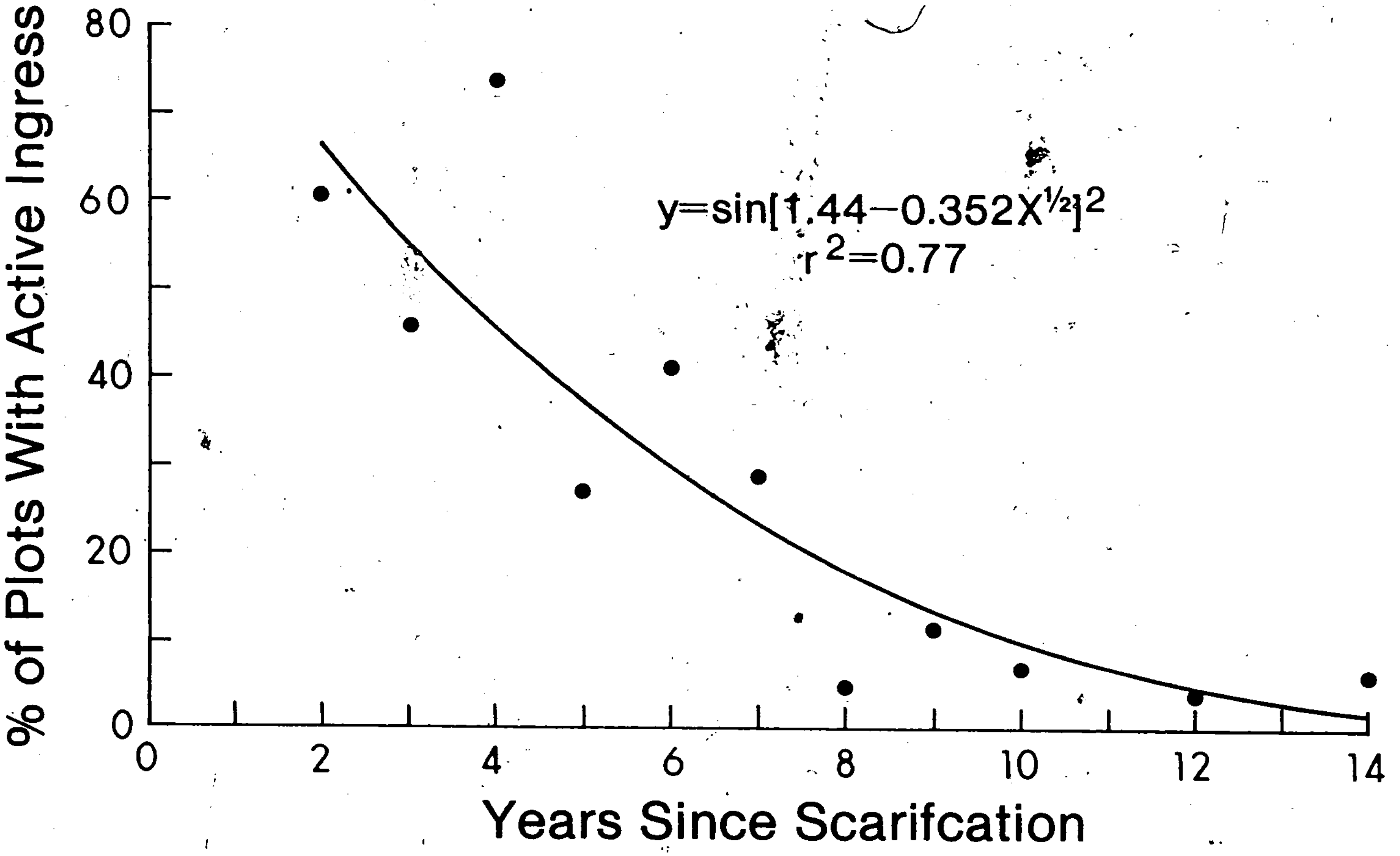

Figure 15. Computed regression curve for the percentage of sample plots on which active ingress was detected, based on the number of years since scarification.

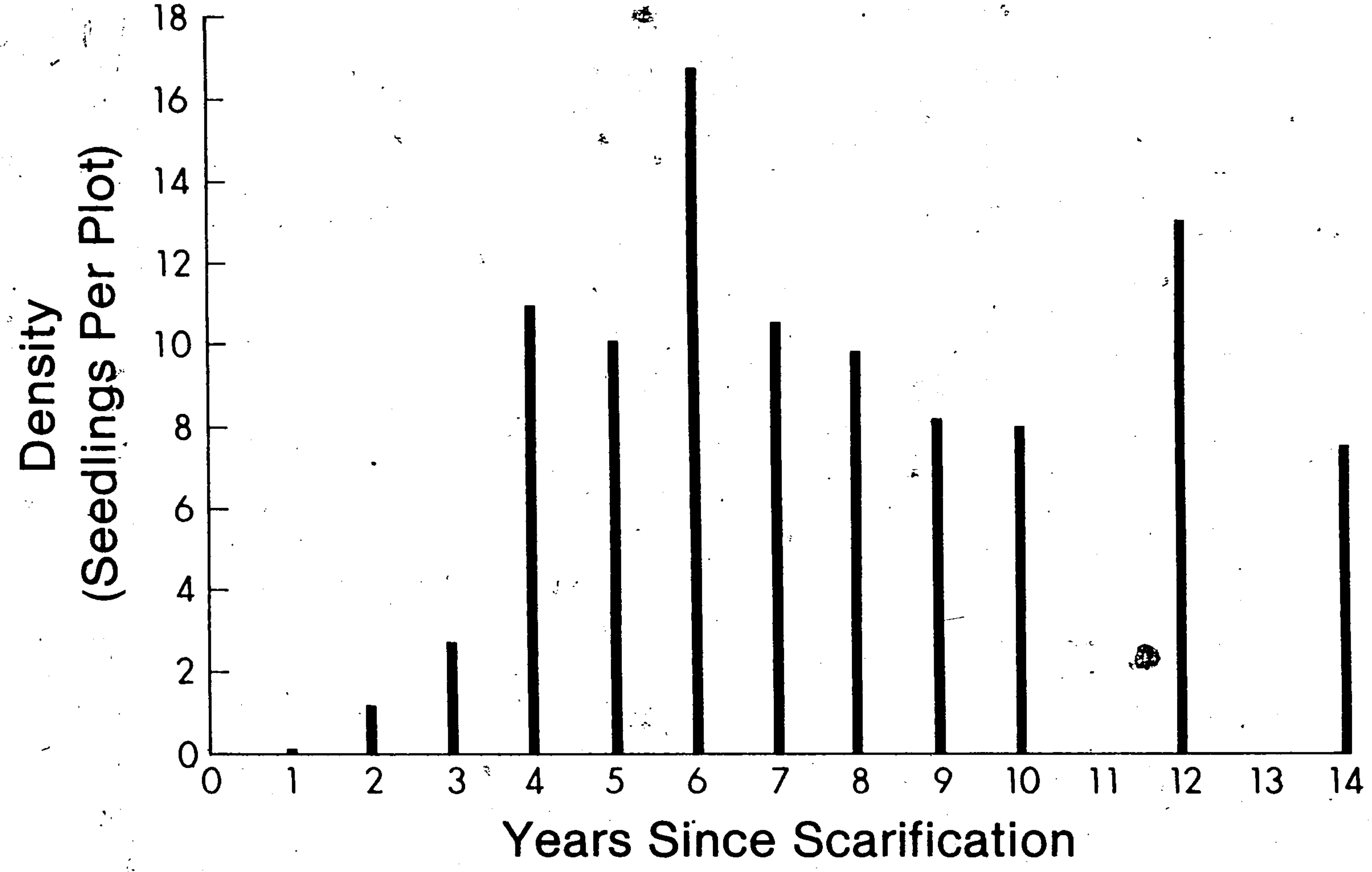

Figure 16. Average number of seedlings per plot, plotted against the number of years since scarification.

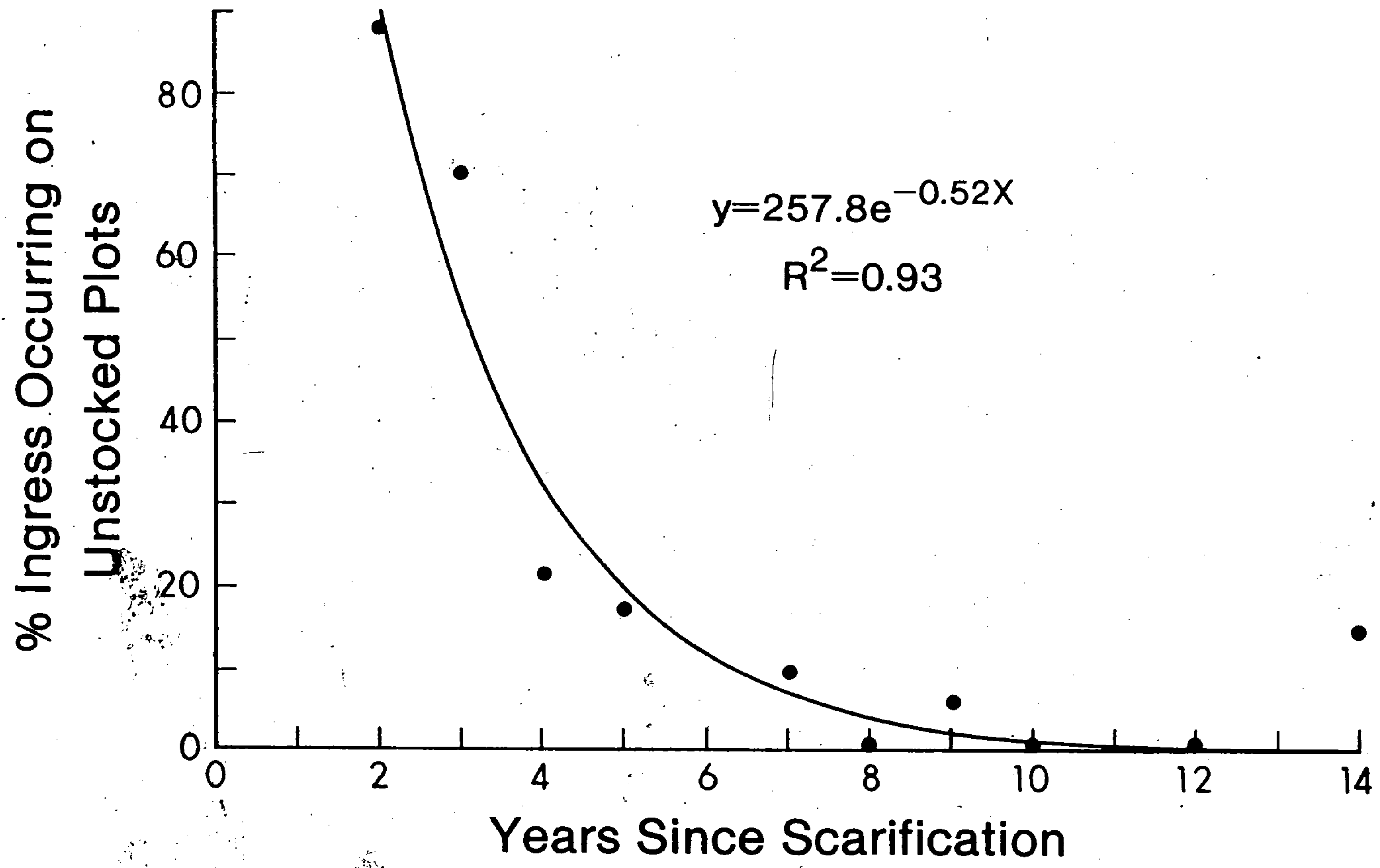

Figure 17. Computed regression curve for the percentage of detected ingress occurring on unstocked plots, based on the number of years since scarification.

has an interesting anomaly at year 14. This anomaly is interpreted as a function of the lower-than-expected stocking found at this age class. As a result there are more available unstocked sites than at the 9, 10, or 12 year age classes. Consequently more of the ingress which occurs results in improved stocking.

5. DISCUSSION

5.1 Ingress

Although several studies designed to determine the rate and timing of seed release from serotinous pine cones (Crossley, 1956a; Ackerman, 1966; Walker and Sims, 1984) have failed to account for the continuation of ingress after the initial two or three years of rapid seed release, there is much evidence (Crossley, 1976; Johnstone, 1976a) to suggest that ingress does, indeed, continue throughout the regeneration phase of stand development.

Data obtained in this study (Figure 15) show that ingress was active throughout the age range studied (up to 14 years after scarification). Although there is no adequate explanation for the occurrence of this ingress, several suggestions have been presented by various authors which may give some indication of the processes involved. Most studies of seed dispersal from serotinous cones on harvested sites suggest that the major portion of seed release occurs within three years of site preparation (Crossley, 1956; Ackerman, 1966; Walker and Sims, 1984). Although a considerable supply may remain within unopened cones after this time, there is no available information on annual seed release in subsequent years.

Given that this seed supply is available, and that losses to predation and biological deterioration are gradual (Ackerman, 1966), this supply should be an important seed source for subsequent ingress.

Crossley (1956a), Ackerman (1966), and Walker and Sims (1984) all found that, as slash settled to the ground over a period of years, unopened cones were continually introduced into the hotter environment near the soil surface. This process, should it be continuous, would definitely aid the slow release of available seed over an extended period.

This might account for most of the observed ingress in the early stages of development of regeneration, but there is some question of the efficacy of this process late in the establishment phase, especially considering the potential for continued loss to predation by squirrels.

Since lodgepole pine is a precocious seed producer, often producing viable seed when only 5 years old, and since these trees have a relatively open cone habit compared with mature trees (Crossley, 1956b), there is a second potential source of seed for the production of late ingress.

Crossley (1956b) suggested that this open cone habit of young lodgepole pine was a physiological phenomenon related to the age of a tree, and that cone serotiny changed as the tree aged. Current speculation, however, suggests that the temperature environment of the cones on young trees may be such that heat loads experienced by these cones are sufficient to break the resin bonds and permit the cones to open [2].

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[2] A.K. Hellum, personal communication, 1984.

Without this additional seed source, ingress developing from the residual seed supply in the slash would be expected to diminish continually as the slash aged. This was not found to be the case. The occurence of ingress from 8 years after scarification through to 14 years after scarification remained relatively constant at about 5% per year (Figure 15).

Thus, the open cone habit of young second growth trees probably contributes significantly to ingress in the later stages of development of regeneration.

Although ingress continues to occur throughout the regeneration phase of stand development, so does mortality. As a consequence, the question of interest to forest managers is "What is the net effect of ingress and mortality on the development of stocking and density?"

5.2 Stocking

The rate and pattern of stocking development are site specific, but cut-blocks are not usually uniform with respect to site conditions. It is therefore necessary to examine the development of stocking under average conditions encountered in the study area, rather than evaluating each site condition separately.

Observed stocking levels which are appreciably lower than prediction limits set for the equation of Figure 6 may indicate potential stocking problems (*e.g.* Block 36). Such sites should either be silviculturally treated to improve stocking, or monitored to determine if development at this lower rate can produce adequate stocking within the permitted 10 year period of regeneration.

If the stocking estimate obtained in the regeneration survey is within the prediction limits of the equation, the assumptions used to develop the equation would appear to be valid for the site. Stocking should then develop at the predicted rate and the expected development pattern would be similar to that of the equation.

From Figure 5 it is evident that development of stocking in the study area was essentially complete 5 years after scarification. As expected, according to seed release patterns found by Crossley (1956a), Ackerman (1966), and Walker and Sims (1984), there was an extremely rapid influx of seedlings within the first 3 years after scarification. By year 4 the sites in this study averaged 11,000 seedlings per hectare (Figure 16).

Because the initial influx of pine seedlings occurred within 3 years of scarification, and because pine seedlings need to be only 2 years old to be counted in the stocking assessment, it follows that most stocking will have occurred within 5 years of site preparation. Thereafter the balance between ingress and mortality appears to maintain a relatively steady state, at least on sites which are favourable for establishment of lodgepole pine, and which are well stocked and densely populated.

It thus appears that on good sites, ingress in the latter stages of development of regeneration does not lead to appreciable increases in stocking or density.

This is contrary to inferences made by Crossley (1976) and Johnstone (1976a) in which proposals for the delay of regeneration surveys were made based on evidence showing that ingress was continuing, and was to some degree surviving, even 15 years after harvest. There appears to be little justification for this argument with respect to areas that regenerate readily. Stocking on these cut-blocks does not change appreciably late in the regeneration phase of stand development (Figure 5). There is, however, evidence to suggest that for some sites, especially those on which stocking development is slow, ingress continues to affect stocking (Figure 5) and subsequently must have some effect on density as well. These may include dry sites during drought periods, wet sites with heavy competition and/or deep duff, and severely exposed sites.

When initial development of stocking is poor the effect of ingress becomes much more important in the latter stages of development of regeneration. For example, Figure 17 shows the percentage of detected ingress occurring on unstocked sample plots. The unusually high incidence of ingress at year 14 is believed to be a result of the relatively low stocking (81%) found in this age class, compared to the 90%+ stocking of the 8 to 12 year age classes. Because there are more unstocked sites available, it is reasonable to expect that a greater percentage of the ingress which does occur and which produces surviving seedlings, will result in increased stocking.

It might, therefore, be wise to reconsider Johnstone's (1976a) recommendation to permit regeneration surveys of marginal sites to be delayed until the end of the 10 year period of regeneration. Development of stocking would be more complete then, and this might lead to a reduction in the need for silvicultural treatments. Sites which did not meet regeneration requirements at the end of this period could then be treated.

Since it is these more poorly stocked sites which, by law, require silvicultural intervention, the problem of monitoring ingress and evaluating its influence, is one of considerable economic importance. If, on these sites, development of regeneration to adequate levels can be expected within a reasonable period of time, then elimination of unnecessary silvicultural expenditures would produce considerable savings.

Sites which are not adequately stocked 7 years after harvest are usually treated by rescarification and/or planting or seeding. As a result, finding enough untreated marginal cut-blocks for a study using chronosequential sampling would be very difficult. Determining the effects of ingress and mortality on these sites, so that development of stocking can be predicted, requires data available only from a series of permanent sample plots. Studies of this sorts have been initiated by the Alberta Forest Service but data are not available yet.

On the sites studied in this project, stocking development followed a predictable pattern. The major stocking problem on these sites was overabundance. This would not, of itself, be of major concern, but because seedling density is an exponential function of stocking success (Bella, 1976), overstocked sites often have an associated density problem.

In a summary article, Alexander (1974) suggests that, under standard forest management conditions, seedling density on regenerating lodgepole pine cutovers is often excessive and does not make good use of the available growing space. Johnstone (1981) recommends that a post-thinning density of 2,000-2,500 seedlings per hectare is reasonable for young stands (<10 years old).

If 2,500 stems per hectare is an acceptable density for young stands it is obvious that stands sampled in this study, many of which had more than 10,000 stems per hectare, have regenerated too successfully. These sites will probably require some form of stocking/density control as suggested by Glen and Ackerman (1978) in their study of similar sites near Prince George, B.C.

Although it is questionable whether poor stocking or overstocking is the more costly management problem, overstocking is the more common condition on lodgepole pine sites. Control of overstocking is, therefore, an important management problem.

There have been several suggestions that stocking can be controlled through post-harvest cone surveys and matching site preparation equipment and intensities to site and seed availability (Ferdinand, 1982). This should, theoretically, be possible, but there is little evidence available to suggest that this has been successful so far.

To date, most efforts appear to have been focused on reducing intensity of scarification rather than altering the type of scarification equipment used. Reducing the number of sites available for seedling establishment should reduce the number of seedlings growing on an area but this will also reduce the level of stocking on the site. A reduction of stocking to some degree would be beneficial on these sites, but reducing the stocking to the required 80% level, without altering the seedling distribution pattern, would still produce about 7,000 trees per hectare (Figure 10).

This relationship between stocking and density is a function of the spatial distribution of the seedlings and the method used to measure stocking. Only by creating a more uniform distribution of seedlings, is it possible to alter the relationship between stocking and density so that an 80% stocked site would have only 2,500 trees per hectare.

Rather than reducing the intensity of currently-used site preparation techniques, with its attendant reduction in stocking, it may be more beneficial to use a different scarification technique. If a more uniform distribution of seedlings can be achieved, then seedling densities can be reduced without reducing stocking levels.

Although research will be necessary to evaluate different techniques, the use of patch scarification on favourable sites might produce the desired results. This would give a more uniform distribution of relatively small scarified areas. Assumming that most regeneration develops on scarified sites, this would limit the size of seedling clumps and would distribute these smaller clumps more evenly over the cut-block.

A second approach, suggested by Beaufait (1962) for regenerating jack pine (*Pinus banksiana* Lamb.), involves the redistribution of seed. Beaufait recommends the use of a seed tree cut, followed by broadcast slash burning. Thus, seed in the slash is destroyed and regeneration is dependent on seed from the seed trees. Cones on the seed trees would then open and the wind-dispersed seed would be distributed evenly over the cut-block, provided the seed trees are located properly. This should result in a more uniform distribution of seedlings.

Both procedures could potentially create more uniform seedling distribution. Since this is a prerequisite for preventing density problems on favourable sites while maintaining stocking success, operational research should be initiated as soon as possible.

5.3 Density

Regardless of the method used to regenerate lodgepole pine cutovers, assessment of seedling density should be a part of the regeneration assessment process (Bella, 1976; Stein, 1978). However, the problem of efficient and economic estimation of seedling density remains to be solved. Warren and Batcheler (1979) argue that the use of traditional seedling count methods are statistically inappropriate because the variances of the estimates are dependent on plot size and population density. In addition, Stein (1978) suggests that these methods are expensive and cumbersome and are no longer widely used. Since there seems to be little incentive to return to this method of density estimation, an alternative must be found.

Unfortunately, density is too variable to be determined accurately using standard stocking survey results (Figure 8), especially if stocking is in excess of 60%. Similarly, the empirical distance/density model constructed in this study was not sufficiently accurate for predicting density except near the population mean.

Since density evaluation remains an important consideration for the intensive management of forests (Bella, 1976; Stein, 1978), it is necessary for other methods of density evaluation to be investigated so that the necessary data can be obtained at a reasonable cost.

Application of distance methods for estimating population density in plant communities was initially restricted to populations of randomly distributed individuals (Pielou, 1959; Kendall and Moran, 1963; Lyon, 1968). Since there is extensive evidence showing that the spatial distribution of tree seedlings is rarely random (Evans, 1953; Ker, 1954; Daniels, 1978; Bella, 1978; Bella and DeFranchesci, 1978), the application of these ramdom distribution models is generally inappropriate for forestry purposes.

A continued need for efficient methods of density and distribution evaluation in phytosociological studies has resulted in the development of density estimation methods which are independent of the distribution pattern of the population being investigated (Warren and Batcheler, 1979).

Of the several methods available, Batcheler's (1971) joint-point-nearest-neighbour distance method appears to be most appropriate for forestry applications. This technique produces an unbiased density estimate regardless of the dispersion pattern of the population, the variances of the estimates are independent of plot size and population density, and the distance measurements provide a means of determining the population distribution pattern in addition to the density. MacLeod and Chaudry (1979) suggest that, with this information, a separate stocking estimates would be unnecessary.

Most importantly, estimation of density requires only two or three measurements per sample plot, and the technique can be adapted to work within any size sampling unit. This is useful in restricting the size of area to be searched for seedlings.

Investigation of this technique should be initiated as soon as possible, using both computer simulation techniques and verification with field studies.

6. CONCLUSIONS

1. The pattern of stocking development observed on the study sites showed a rapid increase until five years after scarification. This was modeled using a Chapman-Richards growth function and a prediction equation for development of stocking was constructed using weighted piecewise linear regression. This equation predicts stocking (±10%) based on the number of years since the site was scarified. This technique for constructing predictive equations for development of stocking was effective, and could be applied to marginally stocked sites as well, when sufficient data are available to develop appropriate equations.

2. The development of density is essentially complete after four years of rapid development immediately following scarification. Although density is exponentially related to stocking, it is highly variable at stocking levels of 60% or more. As a result of the wide confidence limits created by this variability, stocking cannot be used to predict density accurately enough for operational forestry applications.

3. Based on the simple distance measurement technique used in this study, distance cannot be used to predict

density. The resulting equation is not sensitive to changes in average distance when distances are greater than 80 cm, and confidence limits for density are unacceptably wide when distances are less than 60 cm.

4. Ingress occurred on all of the cutovers studied. On favourable sites this ingress had little effect on stocking or density more than five years after scarification. Changing the current schedule for survey of regeneration on these sites is not necessary. Development of stocking and density is essentially complete on these sites before the 7-year survey is conducted.

5. On poorly and moderately stocked areas the development of stocking appears to proceed more slowly than on well stocked areas. Because this development may exceed the 7-year deadline in Alberta for submission of regeneration surveys to the province, it is important to develop predictive curves for stocking. These curves are needed in order to avoid retreating areas which might make it on their own by year ten.

7. RECOMMENDATIONS

1. Batcheler's (1971) joint-point nearest-neighbour distance method should be tested to determine it's usefulness as an estimator of density on regenerating cutovers. This could be done using computer simulation techniques with verification by field study.

2. On the marginally stocked sites regeneration assessments should either be based on relevant prediction curves or they should be delayed until 10 years after harvest to permit maximum development of stocking prior to evaluation. Since ingress continues to affect stocking and density levels on these sites over a much longer period, the need for silvicultural intervention may be reduced. Studies of the effect of this prolonged ingress are presently in progress. The data generated by these studies will facilitate the identification of marginally stocked sites and should permit the construction of equations to predict the development of stocking on them, thus eliminating the need for a second survey.

3. Creating a more uniform distribution of seedlings must be given priority if density problems are to be avoided. One of the major problems identified by this study was the excessive density associated with adequately and

overstocked cut-blocks. The distribution pattern of the seedlings is clumped and results in very high stand densities when stocking is successful. To alter this relationship between stocking and density a more uniform distribution of seedlings is necessary. This might be achieved by patch scarification or by a seed tree cut followed by broadcast burning of the slash. Evaluation of seedling distribution and density, as well as the resultant stocking levels produced by these techniques, is recommended.

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