A PROCEDURE FOR COMPARING ALTERNATIVES IN PLANTING TREE SEEDLINGS

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Abstract.--A simple procedure has been developed for comparing alternatives in the planting of tree seedlings. It uses a specially designed work sheet and takes into account costs, survival and anticipated production of wood. The rationale for the procedure is outlined and some illustrative examples are given.

Résumé.--On a mis au point une méthode simple pour comparer les possibilités dans le plantage de semis d'arbres: sur une feuille de travail spécialement conçue à cette fin, on tient compte des coûts, de la survie et de la production ligneuse prévue. La méthode est expliquée et illustrée d'exemples.

INTRODUCTION

In any planting project, decisions have to be made about the type of nursery stock and planting system to be used. These decisions should take into account costs, silvicultural considerations, and site-related factors including the anticipated production of wood.

Currently there is no generally accepted method for evaluating and comparing the economics of alternatives in planting seedlings. Present cost estimates are frequently based on incomplete data, and they tend to be difficult to compare. Hence, selecting the best planting option is often difficult.

The project described here[2] was undertaken to develop a practical procedure for day-to-day use whereby individuals making reforestation decisions can compare alternatives in a consistent manner and select the most appropriate option.

A simple graphical procedure was developed which involves using a specially designed worksheet. The procedure takes into account performance (survival) variability, which has important economic consequences: variability costs money, and the reduction of variability is as important an objective as average performance improvement.

Variability of performance can be reduced not only by improved control, but also by improved predictability. Both of these require that plantation performance be measured better and monitored more effectively than it generally is now.

FACTORS IN PLANTING DECISIONS

Uncertainty and lack of information

Reforestation through planting, and particularly its economic aspect, is a complex subject involving facts, uncertainties and opinion. Some factors, particularly costs, can be quantified quite readily. For example, the cost of seedlings, containers, special processing, planting (particularly where planting is contracted) and sometimes even site preparation, can be accurately determined. Factors related to sites and seedlings are more difficult to quantify.

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[2]This paper is based on the study "Comparison of Alternatives in Planting Seedlings" which was prepared by B.C. Research for the Silviculture Branch of the B.C. Ministry of Forests in 1979.

While good descriptions of planting sites are generally obtainable, descriptions of planting stock tend to be qualitative rather than quantitative, and this is restrictive from the point of view of analysis. It would be desirable to use quantitative terms such as height, weight, root/shoot ratio, stem diameter and moisture stress (osmotic pressure) in describing the seedlings being planted.

In general, only one-year survival data are currently collected following planting: additional examinations are rare, and the condition of planted trees (height, morphological condition: poor, fair, good) is usually not recorded. Hence, only limited data are available on early survival and growth.

Even more uncertain than survival and early growth is the ultimate productivity of a site, both in terms of the time to harvest (rotation) and the volume of harvestable wood. This must be estimated by foresters using their experience and judgment. From an economic point of view such estimates are essential, since wood production is usually the most important objective of regeneration.

It must be recognized that there will always be considerable variability associated with survival and growth. This uncertainty could be reduced to some extent by measuring variables which are known to affect performance, although this is not always possible in practice. However, there will always be variables at work (e.g., weather, insects, mammals and disease) whose presence and effects may not be known or quantifiable. Variability will, therefore, remain an inevitable fact of life, although it can be reduced with better information, measurement and control.

The approach taken in this study was by no means an attempt to quantify any of the uncertainties. Rather, an attempt was made to identify the key factors to be considered, be they accurately quantifiable or largely judgmental, and to link them through simple relationships to produce some overall performance measure, such as "investment per cubic metre of mean annual increment". Thus, the purpose of the study was to produce a framework whereby key factors could be recognized and combined. The estimate of their actual values in specific situations is the task of the forester.

Foresters differ widely in their viewpoints on preferred stock types, levels of stocking, and planting practices. Advocates of particular planting systems are often able to produce evidence in the form of data (survival, growth rates, etc.) and photographs (seedlings, root structures, etc.) to support their preferred system, and to point out the shortcomings of "competing" systems. This may involve:

- selecting evidence to support a particular argument;
- "comparing apples and oranges" (e.g., different types of stock planted on different sites);
- presenting incomplete data (e.g., not including all cost components);
- producing explanations for poor performance (e.g., poor nursery stock, frosted tops, .. .).

On the other hand, there are often legitimate ambiguities in the results of experiments, even when they are designed to compare alternatives. Also, the results of operational plantings are often markedly different from experimental ones. Hence, it is difficult to draw firm objective conclusions.

While large volumes of data on planting are available, comparatively little conclusive information has been (or can be) obtained from them to assist in making planting decisions. The principal reason for this is the lack of performance criteria and a comprehensive, generally accepted set of measurements in experimental and operational planting projects.

Performance Criteria

There are several criteria which could be used to compare alternative planting options.

Survival

This is a commonly used criterion and obviously a critical one. However, it is incomplete in that it says nothing about costs, the quality of the surviving stock, the volume of wood to be expected from the site and the time taken to produce it. Thus, while survival is certainly a necessary component of measurement, by itself it is not sufficient for comparing planting alternatives.

Cost per hectare

The cost per hectare of establishing a stand is a criterion which includes both costs and survival. Its shortcomings are that it depends on the level of stocking selected (i.e., the greater the level of stocking, the higher the cost) and it does not reflect the volume of wood to be produced from a site or the time taken to produce it. Nevertheless, it is felt that this criterion can be useful provided that it is not used in isolation.

Cost per unit of harvestable lumber

This criterion takes into account survival, costs, and the anticipated production of wood from a site. The only factor missing is the time to produce the wood. Like the foregoing, this criterion could also be of interest.

Cost per unit of mean annual increment

This criterion takes into account survival, costs, volume of wood and rotation. It gives the costs of establishing an average annual rate of wood production. This is considered to be the most useful criterion since the ultimate objective of planting is to ensure that a site produces the largest possible volume of merchantable wood annually as economically as possible (consistent with hydrological, wildlife and other environmental considerations).

One theoretical shortcoming of the criterion is that it does not include any reference to the quality of wood produced (i.e., market value). While this may be desirable, it would be difficult to implement in practice. Not only is the future value of wood unknown, but the relative values of different types of wood can change with respect to each other. Hence, such a criterion would not be constant over time, and could rate alternatives differently depending on market price estimates. Nevertheless, such a criterion may be of interest in certain economic studies.

Common Factors in Reforestation Decisions

Numerous questions have to be answered before reforestation decisions are made. For example:

- Should a site be replanted or should it be allowed to regenerate naturally?
- Should a site be burned over or scarified in order to promote natural regeneration?
- What species and type of stock should be planted on a particular site?
- If the preferred stock is unavailable, is it better to wait perhaps two years until it is available or should some other stock type be used?
- How do the relative costs of understocking (necessitating replanting) and overstocking (necessitating juvenile spacing) affect the number of seedlings to be planted?
- How much improvement in performance (e.g., survival) is required to compensate for the extra cost of some form of site treatment or special type of planting stock?

Although the questions to be answered are many and varied, they involve consideration of only a relatively small number of factors. These can be grouped under five headings, as outlined below.

Planting objectives

The first requirement in making reforestation decisions is to set a clear, quantitative objective of what is to be achieved on a site in terms of established seedlings and, ultimately, the production of wood. Depending on the potential for natural regeneration, targets can be set for what is to be achieved through planting.

Excessive stocking will result in higher planting and future site tending costs, and possibly in a decreased volume of merchantable lumber. On the other hand, insufficient stocking will result in lost production of wood. Therefore, in setting stocking targets, upper and lower limits of stocking must also be set, and these must take into account both silvicultural factors and costs.

Costs

Costs are clearly of major consideration in reforestation decisions. They can be considered in two groups, "variable" costs and "fixed" costs.

The variable cost per seedling (cents per seedling) is the marginal cost of planting an additional seedling and is the sum of costs such as:

- production cost of the seedling in the nursery, including seed, tending, lifting;
- the cost of containers or special treatments such as mud-packing;
- the cost of packaging, storage and transportation;
- the cost of planting.

The fixed cost per site (dollars per hectare) is the "set-up" cost of establishing a plantation on a particular site. It is the sum of costs such as:

- site preparation (burning, scarifying);
- access to the site (plowing roads of snow in the spring, bulldozing washed-out roads, helicopter air-lifting onto the site, etc.);
- the expected cost of corrective action as a result of being outside the specified stocking limits (i.e., cost of fill-in or thinning).

It is not necessary to estimate the future value of wood (a relatively meaningless task, in view of the length of time involved). There is no argument about whether or not to replant--that decision has been made in the affirmative in light of general social, economic and environmental considerations. The problem is to replant in the most cost-effective way possible.

Survival

The percentage of seedlings surviving to become an established stand is the most critical silvicultural variable in planting decisions.

Survival results are almost always reported only as averages. It would also be desirable (and relatively easy) to estimate standard deviations to provide a measure of the range of variability to be expected in seedling survival and the potential cost of this variability as a result of overstocking or understocking.

Furthermore, existing survival data do not explicitly reflect the fact that survival is related to seedling and site parameters. Such information has to be available if meaningful comparisons of alternatives are to be made.

Production

In estimating the volume of wood which can be produced on a particular site, three variables have to be considered:

- Number of crop trees (i.e., the number of mature, merchantable trees to be harvested) should be related to the planted seedlings only, and not reflect any natural regeneration. In situations where both of these factors are at work, they should be considered as two separate components of reforestation.

- Volume of wood per mature tree is obviously a key factor in estimating the yield of wood from a particular site.

- Rotation age is another key factor which determines the yield of wood from a particular site.

Volume and rotation together determine the production potential of a site. These factors may differ according to species and stock type, and the resulting differences in production potential may influence the planting alternative selected.

Variability (uncertainty)

Variability is an important though seldom recognized factor in reforestation decisions, and one which costs money.

Two major factors relating to uncertainty are considered important in this context:

- Dispersion coefficient of survival (ratio of standard deviation to average survival);

- Off-target costs if the initial planting is outside acceptable limits (the cost of fill-in below the lower stocking limit and the cost of extra spacing above the upper stocking limit).

AVAILABLE DATA

Cost Data

Accurate data on costs are generally obtainable from comprehensive cost accounting systems which allocate the costs of labor, materials and overheads to the various phases of seedling production at each nursery. However, careful thought must be given to making the best use of cost information. The problem centres on the fact that the cost of a particular type of planting stock varies from year to year according to the nursery producing it and the volume of stock produced. These differences can be in excess of 100%. There are differences in nursery facilities and growing environments, and they can be affected by weather and other natural conditions in different ways.

Hence, it is not considered appropriate to use stock costs directly from accounting systems for comparing planting alternatives. To do so could result in decisions which might reflect isolated production peculiarities. Consequently, in any given year and for every type of stock, it would be more meaningful to use a weighted average of the costs at a group of nurseries which produce seedlings of comparable quality.

Even this may not be entirely satisfactory if there are large fluctuations in average costs from year to year. In that case, some kind of moving average, possibly over a 3-year period, may be appropriate. While it is certainly necessary to reflect cost differences in comparing alternatives, it is not meaningful to let isolated short-term factors affect long-term decisions. There is no clear-cut solution, and the answer is a matter of judgment.

Silvicultural Data

Good silvicultural data (survival, growth) are much more difficult to obtain than cost data. A great many data are available on survival but they have to be used with great caution to avoid "apples and oranges" comparisons because of differences in species, type and quality of stock, site, local conditions and other factors. While some of these differences can be identified retrospectively, many will remain unknown.

Most operational survival data relate only to first-year survival, and are not associated with any indication of plantation quality. Furthermore, "old" survival data, though providing information on several years' survival, may be limited in their usefulness because of changes in planting stock quality in more recent years. Another complication is that there may be gaps in the production of major stock types, and hence no continuity of data.

To overcome these difficulties, a major long-term program of operational performance measurement should be implemented. It is suggested that about 1% of the annual seedling production be involved.

A central feature of the program would be (as part of some regular planting projects) the planting of seedlings of one or two stock types which are different from the type being planted in the project. This could be done quite easily when the planting program is being set up, and well established statistical techniques on experimental design could be taken into account. In each planting project, seedlings of the different stock types should be as similar as possible with respect to seedlot, tending, lifting, etc. In this way differences in performance due to stock type could be determined with considerable confidence.

The cost of variation

It is rarely recognized that costs are incurred because of variations in performance. If performance is consistent (i.e., predictable), it is much easier (and cheaper) to achieve planned objectives than if it is not.

For example, suppose that two stock types are available, both costing the same and having the same average survival (70%) but different ranges of survival (standard deviations of 5% and 10%, respectively). Suppose further that it is desired to establish 700 seedlings/ha (i.e., plant 1000 per ha), and that the stocking is considered satisfactory if it is between 600 and 800 (i.e., fill-in costs are incurred below 600 and thinning costs above 800). If 1000 seedlings are planted, 700 will survive on average with either type of stock. However, as is illustrated in Figure 1, the performance of the more predictable stock will be outside the specified limits only 4% of the time, while the less predictable stock will be outside those limits 32% of the time.

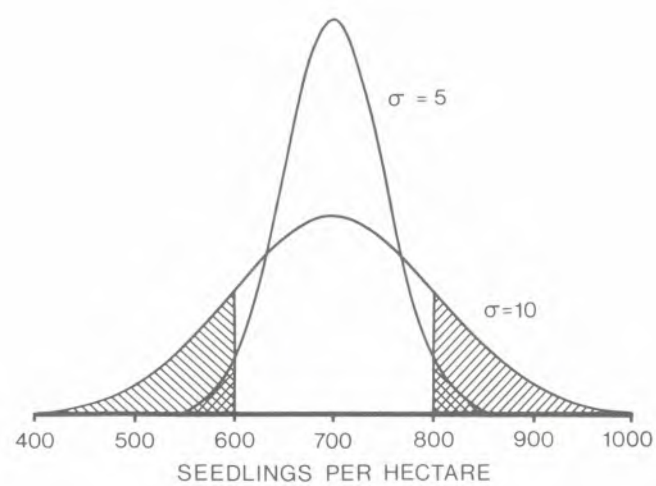


Figure 1. Variability in the number of established seedlings if 1000 are planted per hectare with 70% average survival (normal distribution).

Clearly the less predictable stock is far more costly in practice than the more predictable type, although their costs appear to be identical at the planting stage. In fact, it may be that a lower but more consistent rate of survival is preferable to a higher but more variable one.

Standard deviations in survival are typically in the order of 20%, so that the situation is actually much more extreme than that shown in the example. Thus, it is seen that variation in performance can be very costly, and that it is economically desirable to reduce it as much as possible.

The factors affecting variation in performance can be considered to fall into three groups:

- factors related to the production and planting of stock: these can be minimized by improved nursery and planting practices;
- site-related factors: while these cannot be controlled, the effects of site characteristics can be estimated statistically and hence taken into account in making improved predictions of performance;
- unknown and random factors: these are uncontrollable in principle (e.g., weather, pests) or in practice (e.g., not measurable or not understood at present).

Improvements can be made for the first two:

- by improved production procedures and quality control;
- by improved measurement and statistical (prediction) procedures.

A METHODOLOGY FOR COMPARING ALTERNATIVES

General Form

The central requirement of this project was to develop a method for comparing alternative planting options which takes into account the key factors involved and, at the same time, is practical and easy to use. The need for elaborate computation was to be avoided.

During the developmental stages of this project, several different approaches were explored. These included the use of various formulae and precalculated reference tables. In the end, however, an essentially graphical procedure was judged to be the most practical.

The graphical approach has a number of major advantages over other alternatives:

- it requires only a ruler and pencil (no formulae, tables or calculating devices);
- it provides a visual indication of what is being done, a "feel" for the importance of various factors and the sensitivity of the results to changes in them;
- plotting two or more alternatives on the same page provides an immediate visual comparison;
- because of the simplicity of the approach, numerous alternatives can be explored in a matter of minutes.

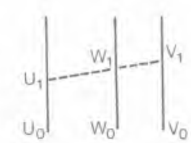
A graphical approach is obviously not as accurate as one based on computation; however, this is not considered to be a disadvantage here. Forestry is by no means an exact science, and a graphical approach certainly allows an acceptable degree of precision.

The method developed consists essentially of a series of nomograms. Nomograms have long been recognized in science and technology for the ease with which they can be used to solve specific mathematical formulas (e.g., Levens 1948). In recent years their popularity, like that of the slide-rule, has declined drastically in favor of computers, electronic calculators and other sophisticated gadgetry.

The nomograms used consist basically of combinations of two types of simple alignment charts:

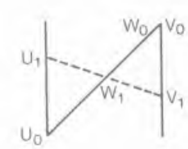
a) The first type consists of three parallel lines and solves equations of the form:

$$f_1(u) + f_2(v) = f_3(w)$$



b) The second type (a Z-chart) solves equations of the form:

$$f_1(u) = f_2(v) \cdot f_3(w)$$



In each case the scales are graduated in such a way that a straight line cutting the scales will determine three points whose values satisfy the given equation.

Procedure and Work Sheet

The procedure for comparing alternatives generally uses five groups of variables as inputs. These are combined to produce several measures of plantation cost whereby the preferred alternative can be selected. An overview of the procedure is shown in Figure 2.

For two of the input groups, better estimating procedures should be developed than are currently available:

- First, there are no guidelines at present for estimating off-target costs. It would be desirable to produce such guidelines, perhaps in the form of a table. Such a table could provide estimates of over-stocking and understocking costs for a range of different site types.

- Second, better procedures are required for estimating survival. As has been indicated, relationships should he derived which take into account stock- and site-related variables affecting survival.

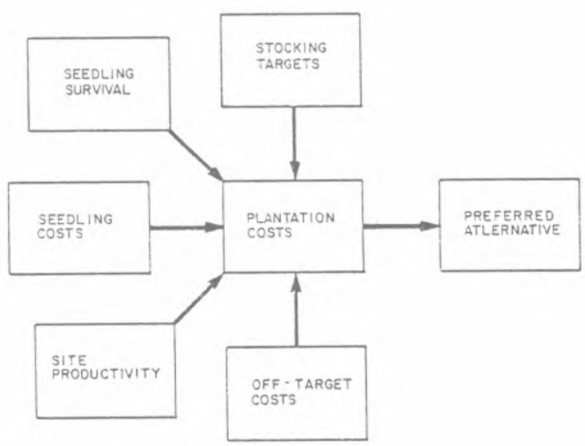


Figure 2. Comparison of alternatives in planting: an overview.

The procedure for comparing planting alternatives is set out on both sides of a single work sheet (Appendices A and B):

- The front contains a table for recording the values of the factors describing each alternative and also the results.

- The reverse contains several groups of alignment charts.

It should be noted that, of the five work sheet figures (alignment charts), two are "complex" in the sense that their function involves more than simple arithmetic: Figure 2 calculates probabilities and Figure 5 is a yield table, based on the formula:

$$V = 4.6 \times 10^{-5} D^{1.8} H^{1.08}$$

where V = volume of the tree in m^3;
D = diameter at breast height in cm;
H = height in m.

This formula produces good volume estimates for most of the major tree species in British Columbia.

The other three figures on the work sheet involve only addition, multiplication and division. It was considered useful to include them in the procedure not so much because they solve complex arithmetical operations, but because of their illustrative function in comparing alternatives.

ILLUSTRATIVE EXAMPLES

As an illustration of the methodology, and to suggest the wide range of questions it can assist in answering, two hypothetical examples are given here.

Selection of Stock

Suppose that a decision has to be made as to which of the following three stock type alternatives should be used to replant a site:

	Survival S	Survival σ	Nursery Cost
1) conventional 2-0 bare-root	70%	20%	10¢
2) conventional container stock	70%	15%	12¢
3) special stock	80%	10%	22¢

The site is expected to produce trees of 30 m high and 50 cm in diameter at a rotation of 60 years using conventional stock (1, 2). The special stock (3) is assumed to be superior, producing trees 10% higher and with 10% greater diameter at the same rotation.

The planting objective is to establish 1000 seedlings per ha so as to end up with 250 crop trees at rotation. If fewer than 800 trees are established, replanting would be required at a cost of $300; if more than 1300 are established, thinning would be required at a cost of $100 per ha in excess of the normal cost of juvenile spacing.

By using the work sheet (Appendix A), one can draw the following conclusions:

- If we consider planting cost P alone, the bare-root stock is cheapest, followed by the conventional container stock, with the special stock being the most expensive.

- If we consider the total planting project cost T, which includes an allowance for off-target costs, the bare-root and conventional container stock cost the same, with the special stock still the most expensive.

- If costs are related to site production by using criteria J and K, the special stock is found to be the most economical in spite of the fact that its cost of production is double that of bare-root.

- Since J and K are considered to be the most appropriate criteria, the special stock should be chosen.

Survival Improvement to Justify Extra Stock Cost

As another variation of the basic example, suppose that there is a choice between planting conventional container stock and special container stock costing 6c more per seedling. What improvement in survival is needed to justify the extra cost?

From the basic example, the cost of the conventional container stock is known to be $834.

In the work sheet in Appendix B, alternatives for the special container stock are evaluated for S = 75%, 80%, 85%.

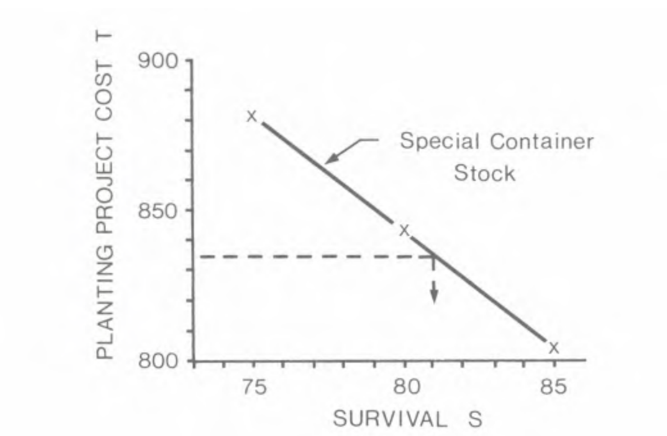


Figure 3. Chart to determine required survival rate for special stock, such that the total planting project cost is the same as that which would be incurred if conventional container stock were used.

By simple graphical interpolation (Fig. 3), it is seen that the planting project cost of the special container stock at 81% survival is the same as that of the conventional container stock. Thus, the extra cost of the special stock requires a survival of 81% (or better) for it to be economically competitive with the conventional stock at 70% survival.

CONCLUDING COMMENTS

It is felt that the methodology developed in this project has the potential to be useful in the field on a day-to-day basis. It is simple yet appears to incorporate all the necessary key variables. The methodology incorporates as a factor the concept of performance variability, which has considerable economic importance.

As has been discussed, major programs of large-scale operational measurement should be implemented to monitor continuously the performance of stock types, planting procedures, etc. It is recognized that extensive operational trials are already carried out, hut these have specific objectives. What is suggested here would be done as a matter of routine for purposes of on-going measurement and control.

It was also pointed out that one of the measurement problems involved in planting is that the seedlings planted are not described in quantitative terms. This would, of course, be necessary as part of an on-going operational monitoring system. The required measures certainly do exist, but they are not widely used. It is felt that a group of experienced foresters could readily select a suitable set of measures. While there would undoubtedly be debate as to what constituted an "ideal" set of measures, it is felt that some practical compromise should be possible. The economic benefits would be considerable.

LITERATURE CITED

Levens, A.S.
1948. Nomography. John Wiley & Sons, New York. viii + 176 p.

APPENDIX A — WORK SHEET

COMPARISON OF ALTERNATIVES IN PLANTING SEEDLINGS

This work-sheet provides a basis for comparing the costs of alternatives in planting seedlings. The variables to be taken into account are shown in the table below and are defined at the bottom of the page. For each alternative, one line in the table is to be completed.

In general, the variables marked by arrows (↓) are the ones required as inputs, and they must be known or estimated. The remaining variables are determined by simple arithmetic as indicated, or by use of the alignment charts on the back of this page.

The alignment charts are designed to satisfy the relationship between groups of three variables as shown in the corresponding 'ovals". For example, Figure 5i relates H, D, V. Thus, given the values of any two variables in a group, the value of the third variable is obtained by using a ruler and pencil to draw a line through the two given values.

In comparing alternatives, the values of the variables for each case are recorded in the table below, and the required lines are drawn on the alignment charts. Thus, the difference between the alternatives will be apparent both numerically and graphically.

ALTERNATIVE #1	ALTERNATIVE #2	ALTERNATIVE #3
Conventional 2-0 bare-root.	Conventional container stock.	Special stock.

PROJECT	
REGION	Vancouver
DISTRICT	Maple Ridge
OPENING	92G82-27
NUMBER	P92G4-27
DATE	10 May 79
NAME	Lost Creek

ALT #	STOCKING TARGETS					SURVIVAL			PLANT
	N_T ↓	N_U ↓	N_L ↓	n_U $100(\frac{N_U}{N_T}-1)$	n_L $100(1-\frac{N_L}{N_T})$	S ↓	σ ↓	d (σ/S)	N_P Fig 1
1	1000	1300	800	30	20	70	20	.29	1430
2	"	"	"	"	"	70	14	.20	1430
3	"	"	"	"	"	80	10	.13	1250

ALT #	OFF-TARGET COSTS				
	A_U Fig 2	A_L Fig 2	B_U ↓	B_L ↓	B $A_UB_U+A_LB_L$
1	.15	.24	100	300	87
2	.06	.16	"	"	54
3	.01	.06	"	"	19

ALT #	PRODUCTION POTENTIAL OF SITE						
	N_C ↓	H ↓	D ↓	V Fig 5 i	W Fig 5 ii	R ↓	M Fig 5 iii
1	250	30	50	2.1	520	60	8.7
2	"	"	"	"	"	"	"
3	250	33	55	2.7	680	60	11.3

ALT #	SEEDLING COSTS			
	c_1 ↓	c_2 ↓	c_3 ↓	C $c_1+c_2+c_3$
1	.10	.20	-	.30
2	.12	.20	-	.32
3	.22	.20	-	.42

ALT #	PLANTATION COSTS					
	P Fig 3 i	F ↓	Q B+F	T Fig 3 ii	J Fig 4 i	K Fig 4 ii
1	430	320	407	837	1.60	97
2	460	320	374	834	1.60	97
3	530	320	339	869	1.28	77

STOCKING TARGETS

- N_T – Stocking target (number of successfully established seedlings per hectare).
- N_U – Upper limit of stocking.
- N_L – Lower limit of stocking.
- N_P – Number of seedlings to be planted per hectare.
- n_U – Percentage by which upper limit exceeds the desired stocking: $n_U = 100(N_U/N_T - 1)$.
- n_L – Percentage by which lower limit falls short of the desired stocking: $n_L = 100(1 - N_U/N_T)$.

SURVIVAL

- S – Average percent survival of seedlings.
- σ – Standard deviation of survival (%).
- d – Dispersion coefficient ($d = \sigma/S$).

PRODUCTION POTENTIAL OF SITE

- N_C – Number of crop trees to be harvested per hectare.
- H – Height of crop trees (metres).
- D – Diameter of crop trees (centimetres at breast height).
- V – Volume of wood per mature tree (cubic metres, average for all species).
- W – Wood production (cubic metres per hectare).
- R – Rotation period (years to maturity).
- M – Mean annual increment (cubic metres of wood per hectare per year).

OFF-TARGET COSTS

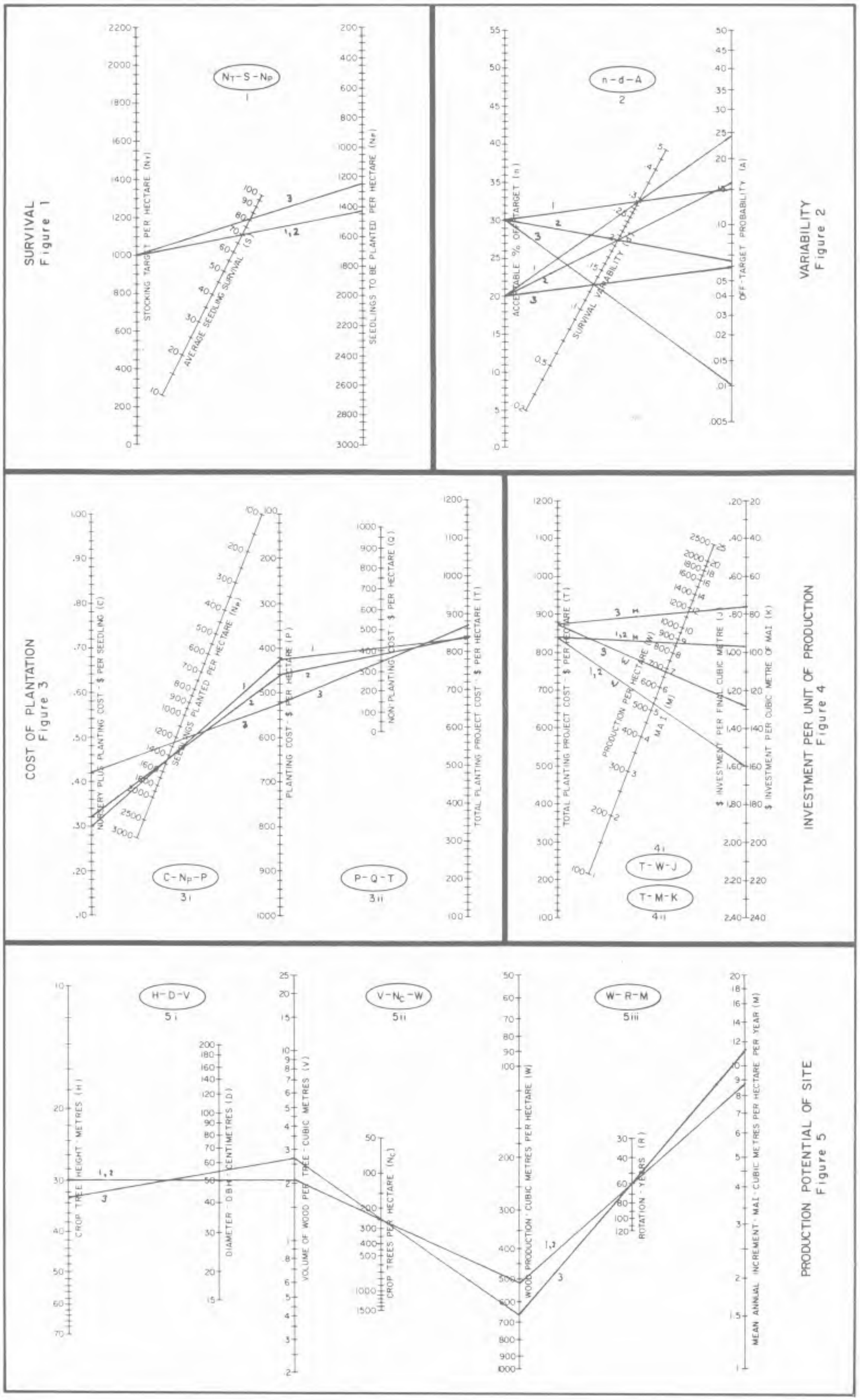
- A_U – Probability of exceeding N_U.
- A_L – Probability of not meeting N_L.
- B_U – Cost incurred if the upper limit of stocking is exceeded (thinning, loss of quality, ...).
- B_L – Cost incurred if the lower limit of stocking is not met (replanting, loss of production, ...).
- B – Expected cost of being outside the specified stocking limits: ($B = A_UB_U + A_LB_L$).

SEEDLING & PLANTATION COSTS

- c_1 – Nursery cost per seedling including all production costs (seeding, tending, containers, lifting, packaging, land-rent, overhead, ...).
- c_2 – Planting cost per seedling including all field-related costs (planting, transportation, ...).
- c_3 – Extra cost (eg. special treatment) per seedling.
- C – Cost per planted seedling: ($C = c_1 + c_2 + c_3$).
- P – Planting cost per hectare.
- F – Site preparation costs per hectare (burning, scarifying, access, establishment period tending, ...).
- Q – Non-planting costs per hectare including site preparation and failure to be within specified stocking limits: ($Q = F + B$).
- T – Total planting project cost per hectare.
- J – Present investment (cost) required to obtain one cubic metre of wood at rotation.
- K – Present investment (cost) required to establish one cubic metre of mean annual increment.

(cont'd)

APPENDIX A (concl.)



APPENDIX B — WORK SHEET

COMPARISON OF ALTERNATIVES IN PLANTING SEEDLINGS

This work-sheet provides a basis for comparing the costs of al ternatives in planting seedlings. The variables to be taken into account are shown in the table below and are defined at the bottom of the page. For each al ternative, one line in the table is to be completed.

In general, the variables marked by arrows (4) are the ones required as inputs, and they must be known or estimated. The remaining variables are determined by simple arithmetic as indicated, or by use of the al ignment charts on the back of this page.

The al ignment charts are designed to satisfy the relationship between groups of three variables as shown in the corresponding "ovals". For example, Figure 5i relates H, D, V. Thus, given the values of any two variables in a group, the value of the third variable is obtained by using a ruler and pencil to draw a line through the two given values.

In comparing al ternatives, the values of the variables for each case are recorded in the table below, and the required lines are drawn on the al ignment charts. Thus, the difference between the al ternatives will be apparent both numerically and graphical ly.

ALTERNATIVE #1	ALTERNATIVE #2	ALTERNATIVE #3
Special Container Stock: S = 75 %	Special Container Stock: S = 80%	Special Container Stock S = 85%

PROJECT	
REGION	Vancouver
DISTRICT	Maple Ridge
OPENING	92 G 82 - 27
NUMBER	P92G4 - 27
DATE	10 May '79
NAME	Lost Creek

# ALT	STOCKING TARGETS					SURVIVAL			PLANT	OFF-TARGET COSTS				
	N_T ↓	N_U ↓	N_L ↓	n_U $100(\frac{N_U}{N_T}-1)$	n_L $100(1-\frac{N_L}{N_T})$	S ↓	σ ↓	d (σ/S)	N_P Fig 1	A_U Fig 2	A_L Fig 2	B_U ↓	B_L ↓	B $A_UB_U+A_LB_L$
1	1000	1300	800	30	20	75	14	.19	1330	.06	.15	100	300	51
2	"	"	"	"	"	80	14	.18	1250	.05	.13	"	"	44
3	"	"	"	"	"	85	14	.16	1180	.03	.10	"	"	33

# ALT	PRODUCTION POTENTIAL OF SITE							SEEDLING COSTS				PLANTATION COSTS					
	N_C ↓	H ↓	D ↓	V Fig 5 i	W Fig 5 ii	R ↓	M Fig 5 iii	c_1 ↓	c_2 ↓	c_3 ↓	C $c_1+c_2+c_3$	P Fig 3 i	F ↓	Q B+F	T Fig 3 ii	J Fig 4 i	K Fig 4 ii
1								.12	.20	.06	.38	510	320	371	881		
2								"	"	"	"	480	"	364	844		
3								"	"	"	"	450	"	353	803		

STOCKING TARGETS

- N_T - Stocking target (number of successfully established seedlings per hectare).
- N_U - Upper limit of stocking.
- N_L - Lower limit of stocking.
- N_P - Number of seedlings to be planted per hectare.
- n_U - Percentage by which upper limit exceeds the desired stocking: $n_U = 100(N_U/N_T - 1)$.
- n_L - Percentage by which lower limit falls short of the desired stocking: $n_L = 100(1 - N_U/N_T)$.

SURVIVAL

- S - Average percent survival of seedlings.
- σ - Standard deviation of survival (%).
- d - Dispersion coefficient (d = σ/S).

PRODUCTION POTENTIAL OF SITE

- N_C - Number of crop trees to be harvested per hectare.
- H - Height of crop trees (metres).
- D - Diameter of crop trees (centimetres at breast height).
- V - Volume of wood per mature tree (cubic metres, average for all species).
- W - Wood production (cubic metres per hectare).
- R - Rotation period (years to maturity).
- M - Mean annual increment (cubic metres of wood per hectare per year).

OFF-TARGET COSTS

- A_U - Probability of exceeding N_U.
- A_L - Probability of not meeting N_L.
- B_U - Cost incurred if the upper limit of stocking is exceeded (thinning, loss of quality, ...).
- B_L - Cost incurred if the lower limit of stocking is not met (replanting, loss of production, ...).
- B - Expected cost of being outside the specified stocking limits: $(B = A_UB_U + A_LB_L)$.

SEEDLING & PLANTATION COSTS

- c_1 - Nursery cost per seedling including all production costs (seeding, tending, containers, lifting, packaging, land-rent, overhead, ...).
- c_2 - Planting cost per seedling including all field-related costs (planting, transportation, ...).
- c_3 - Extra cost (eg. special treatment) per seedling.
- C - Cost per planted seedling: $(C = c_1 + c_2 + c_3)$.
- P - Planting cost per hectare.
- F - Site preparation costs per hectare (burning, scarifying, access, establishment period tending, ...).
- Q - Non-planting costs per hectare including site preparation and failure to be within specified stocking limits: (Q = F + B).
- T - Total planting project cost per hectare.
- J - Present investment (cost) required to obtain one cubic metre of wood at rotation.
- K - Present investment (cost) required to establish one cubic metre of mean annual increment.

(cont'd.)

APPENDIX B (concl.)