AN EXAMINATION OF

THE CANADA LAND CAPABILITY CLASSIFICATION FOR

FORESTRY

by

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ABSTRACT

A description of the Canada Land Capability Classification for forestry, and an analysis of data collected in the East Kootenay and Vanderhoof Districts of British Columbia were presented.

A brief description of the climate, geology, physiography and soils in the East Kootenays was given.

A description of the objectives of the land capability for forestry and a survey of the pertinent literature was included.

The determination of Forest Land Productivity, and the accuracy of assigned productivity classes, were reviewed. It was found that the sources of error in productivity determinations included: (1) insufficient plots, (2) problems in defining 'normal' stocking, (3) extrapolation of MAI to a base of 100 years, (4) a strong tendency to select plots on northern aspects, and (5) the exclusion of plots on soils not representative of soil series descriptions.

Two alternative methods for assigning productivity classes were discussed. They were point sampling and regression techniques. Both the point sampling and regression techniques gave results comparable to the conventional method, i.e. MAI determinations based on 1/5th acre plots, within prescribed constraints, and only in the interior of British Columbia. Results obtained from point samples on Vancouver Island were significantly different from those obtained on one-twentieth acre plots.

The assignment of productivity subclasses was discussed. Here the only method presently feasible is a value judgement made by research workers.

The results of the study revealed three areas where further research would result in a more accurate Forest Land Classification. These areas include: (1) the measurement of environmental factors which determine forest productivity, (2) the use of field and greenhouse experiments to establish methods

for determining the relative effect of environmental influences in limiting tree growth, and (3) a more extensive study of the use of various sampling techniques to get a direct measure of productivity in terms of MAI.

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A classification system can prejudice the future. If its criteria are hypotheses without some device for constant and inescapable scrutiny in relation to the fact, the hypotheses become accepted as fact. Such acceptance can mould research into patterns of the past and can limit understanding of even new experiences to concepts based on the knowledge of the past. (Cline, 1961).

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AN EXAMINATION OF THE CANADA LAND CAPABILITY CLASSIFICATION FOR FORESTRY

INTRODUCTION

The purpose of this thesis is to:

1) examine the methods and procedures used to determine the forest land cabability of the land area encompassed by the Elk River Valley and Rocky Mountain Trench south of Canal Flats to the 49th parallel, and

2) suggest some revisions to the system which may result in a more accurate classification.

The Outline of the Canadian Land Capability Classification for Forestry (McCormack, 1965) states:

> "The Canada Land Inventory Program of ARDA (Agricultural Rehabilitation and Development Act) was designed to provide technical information on the alternative uses of marginal and submarginal agricultural lands. Under this program the capabilities for forestry, wildlife, and recreation, as well as agriculture, will be determined."

During the summer of 1966 a forest land capability classification was carried out in the upper Kootenay and Elk River Valleys under the auspices of ARDA. As a result, a considerable amount of information relating forest productivity to edaphic and topographic conditions was obtained.

In February of 1967, a series of test copies of climatic maps, compiled by the Canada Land Inventory, ARDA, were released and used to supplement data made available by the forest land capability classification.

Subsequent to completion of the productivity maps the plot data were summarized by soil series, which form the broad units used in mapping. Standard deviations were calculated for all soil series to define the dispersion of individual values about their mean.

Data collected in the summer of 1967 were used to compare results obtained from the use of 1/5th acre plots and point samples for the determination of mean annual increment (MAI). Data collected in the spring of 1968 were used to compare the results obtained from one-twentieth acre plots and point samples for the determination of MAI.

Regression techniques were used to derive prediction equations for MAI based on measured and estimated environmental influences for the entire area, i.e. the Elk River Valley and Rocky Mountain Trench, the major tree species, and the Great Soil Groups encountered.

The results of the various sampling techniques were compared for accuracy and applicability to the Canada Land Capability Classification for Forestry. It was concluded that a need exists for the development of a sampling system which will be optimum in terms of accuracy and time or cost.

The assignment of productivity subclasses, that is, those factors limiting tree growth, was discussed.

DESCRIPTION OF THE STUDY AREA

LOCATION AND EXTENT

The area is located in the Upper Kootenay and Elk River Valleys in the southeastern corner of British Columbia. It comprises the river valleys and, to a limited extent, the valley walls. In latitude it ranges from 50° 9' north at Canal Flats, south to the 49th parallel, and from 114° 45' west to 116° 12' west.

The land area, in excess of one million acres, generally coincides with that covered by maps 2 to 6 inclusive, of the Soil Survey of the Upper Kootenay and Elk Rivers in the East Kootenay District of British Columbia.

ELEVATION

The elevation of the mapped area ranged from 2,400 feet in the Kootenay Valley to 5,500 feet in the Upper Elk Valley.

CLIMATE

The area can be divided into three climatic zones based on Köppen's Classification (Trewartha, 1954). The zones are:

1) Dsk - Rocky Mountain Trench floor,
2) Dfb - mid elevations of the western face of the Rocky Mountains and lower Elk Valley,
3) Dfc - mid and upper Elk Valley.

The climatic zones correspond to Köppen's "cold-snowy forest climate" with the average temperature of the coldest month below 26.6° F (Fahrenheit) and the average temperature of the warmest month above 50° F.

Precipitation

The entire area is characterized by a winter precipitation maximum. The precipitation ranges from approximately 14 inches in the floor of the Rocky Mountain Trench to about 50 inches in the upper Elk Valley.

The annual precipitation distribution for four selected stations in the study area is illustrated in Figure 1. Table 1 shows the selected stations and the duration of measurements for precipitation and temperature.

Table 1. Selected Climatic Stations and Duration of Measurements for Precipitation and Temperature.

Station	Precipitation Years	Temperature Years
Canal Flats	41	6
Cranbrook	30	30
Elko	30	13
Fernie	30	30

The relationship between isolines for total precipitation and plot locations is shown in Figure 2.

Temperature

The Rocky Mountain Trench and, to a lesser extent, the Elk River Valley provide a pathway for cold continental air masses from the north, particularly in winter, and for heated air masses from the southern plateau of the United States in summer. Thus, it is not surprising that the area experiences a wide range in temperature, from approximately -40°F to 100°F, depending on the year and location.

Figure 1 shows the mean monthly temperatures of the four selected stations.

Figure 1. Summary of Climatological Data for Selected Stations

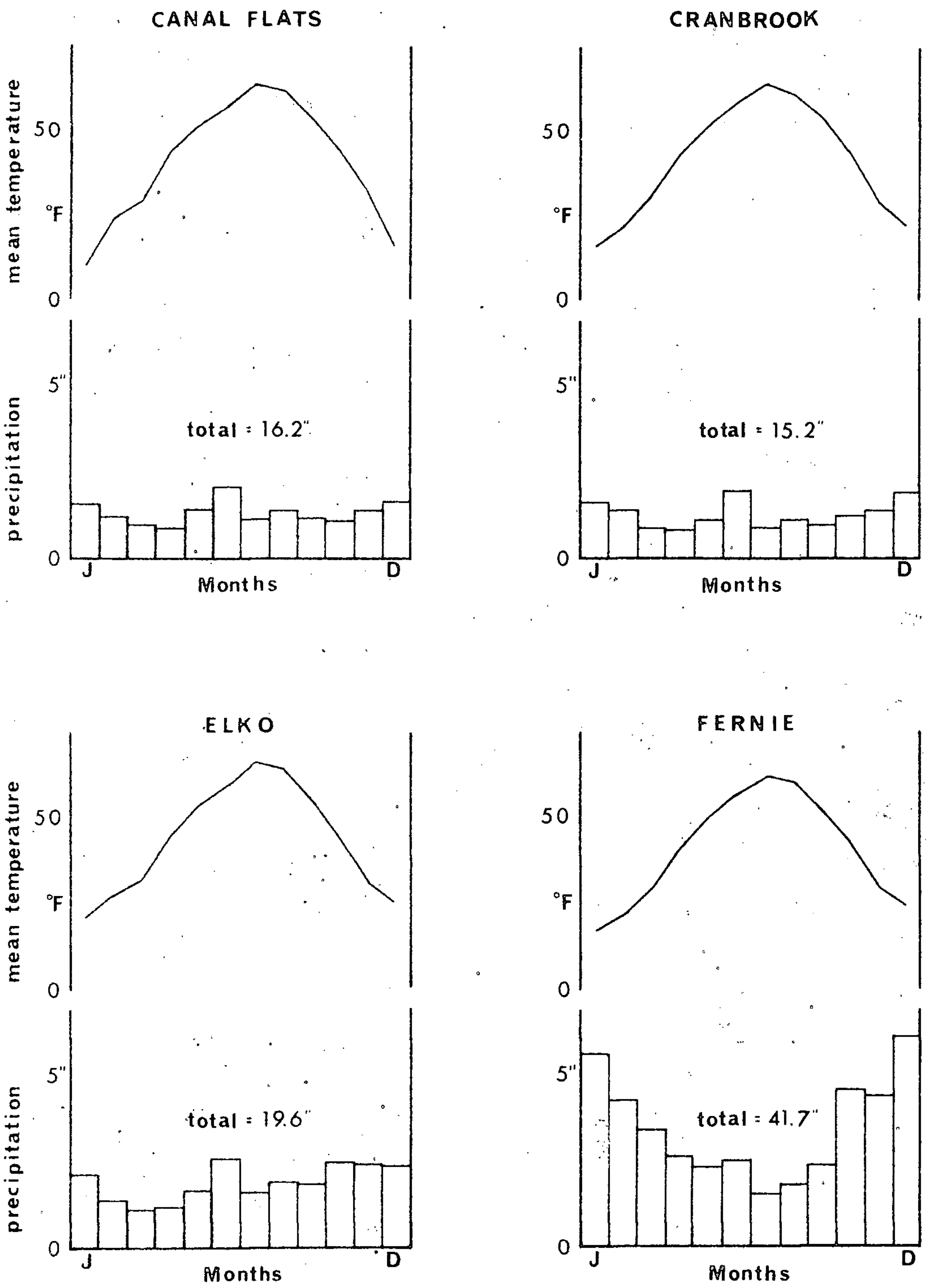
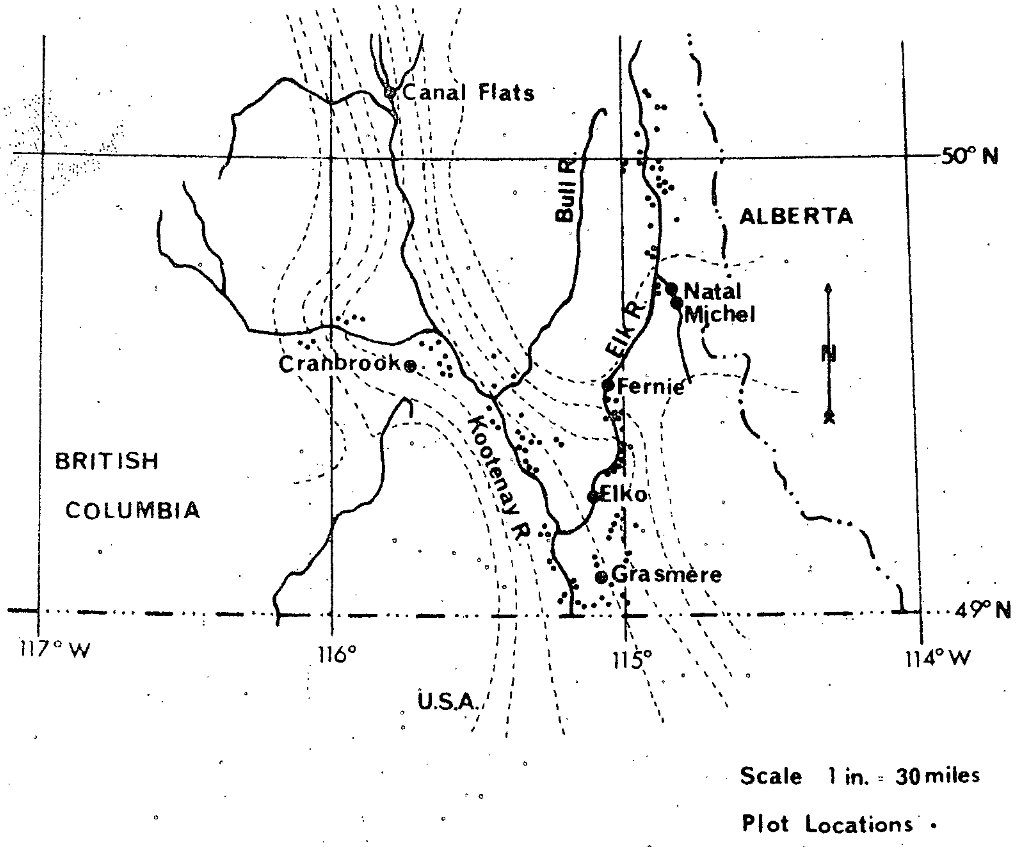


Figure 2. Isolines for Precipitation in inches.



The length of growing season depends on the temperature regime. The growing season begins at approximately 42° F mean temperature in spring and stops when the same temperature is approached in the fall. Based on this assumption, the length of growing season varies from 190 to 130 days.

The relationship between the length of growing season and plot locations is shown in Figure 3.

Water Surplus (after Thornthwaite)

Figure 4 illustrates the relationship between the isolines for water surplus and plot locations. The water surplus ranges from 2 to more than 16 inches.

GEOLOGY AND SOIL PARENT MATERIAL

ELK RIVER VALLEY

In the Elk River area the Rocky Mountains were overthrust from east to west. Limestone and other rock of Paleozoic age were thrust over younger Mesozoic formations. The Elk River eroded along fault lines and has cut through the hard older rocks, exposing the soft, younger formations beneath. The soft nature of the younger formations is probably a factor contributing to the size of the valley, which averages from one to four miles wide (Kelly and Sprout, 1955).

The lower and mid-altitudes of the valley walls are till capped. The till was contributed chiefly by tributary valley glaciers, and thus there is some variation in its composition. The till can be differentiated on the basis of reaction: some being nonclareous, due to a lack of limestone inclusions or

Figure 3. Isolines for Length of Growing Season in days.

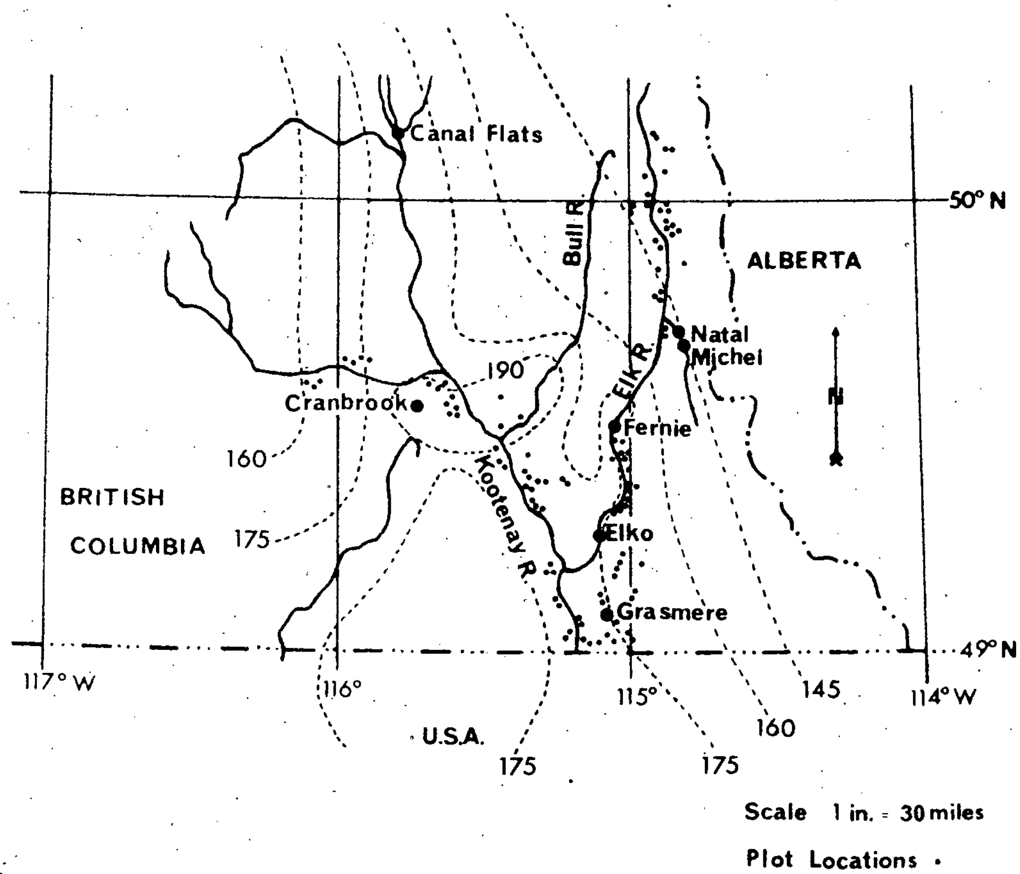
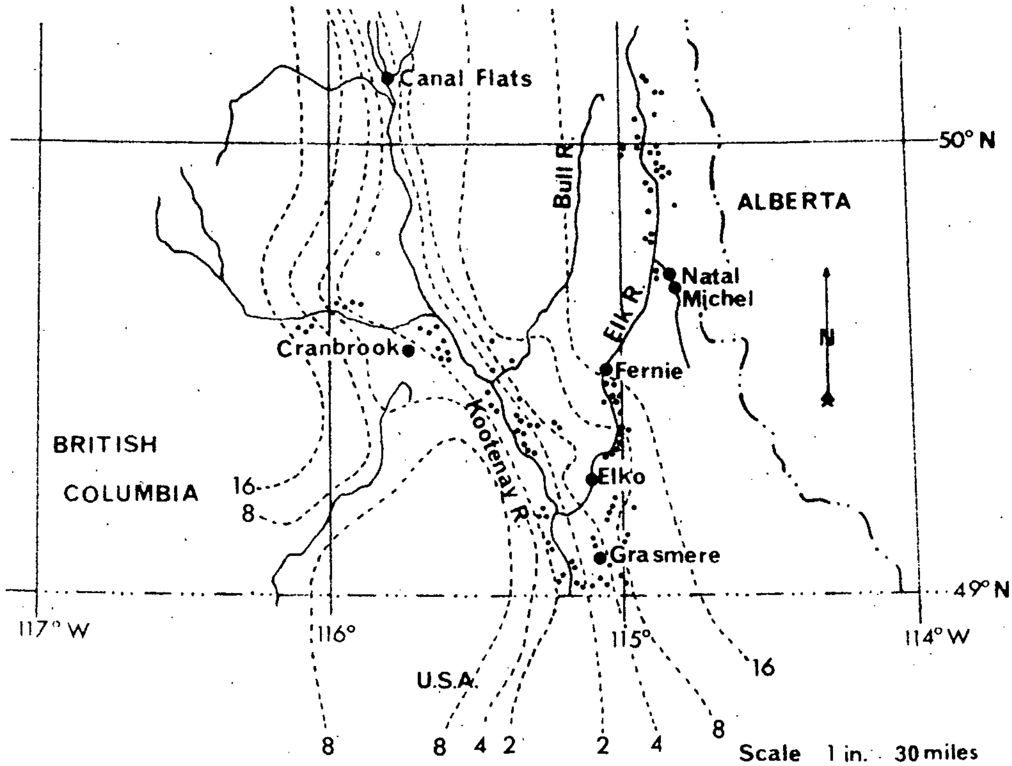


Figure 4. Isolines for Water Surplus in inches.



heavier precipitation, and the remainder being calcareous (Kelly and Sprout, 1955).

Subsequent to, and during the ice retreat in the main valley, the following sequence of events occurred:

1) deposition of calcareous sands,

2) silt and clay deposition in ponded depressions and glacial lakes,

3) kame formation around the margins of glacial lakes,

4) erosion of silts and clays from the till and deposition of outwash,

5) deposition of alluvial sands, silt, and clay on the terraces,

6) deposition of fine-textured materials, from a few inches to six feet in depth, over the gravel bottom lands of the Elk River Valley, and

7) deposition of numerous alluvial fans at the toe of the mountain slopes (Kelly and Sprout, 1955).

ROCKY MOUNTAIN TRENCH

The floor of the Rocky Mountain Trench is comprised mainly of glacial drift, silts, sands, and gravels (Rice, 1917).

The major formations of the Rocky Mountain Trench include:

1) grayish-white, loamy, strongly calcareous till containing grit, gravel, stones and boulders up to fifty feet thick.

2) small areas of weakly calcareous to non-calcareous till derived from the Purcell Mountains,

3) glacial river channels composed chiefly of rounded gravel and stones coated with a thin layer of silt and very fine sand before the channels were abandoned, and

4) small areas of locally deposited strongly calcareous silts in temporary ponds or lakes (Kelly and Sprout, 1955).

Following the ice retreat, the Kootenay Valley became the drainageway of glacial river tributaries which resulted in the deepening of the valley. Subsequently, fans developed at the mouths of tributaries, filling the bed of the Kootenay River to its present level.

Prior to the establishment of vegetation, high winds resulted in a loess capping of non-calcareous rock flour over the Purcell Mountains and Rocky Mountain Trench floor. High intensity precipitation resulted in the formation of alluvial fans at the toe of the mountain slopes (Kelly and Sprout, 1955).

ROCKY MOUNTAINS

The main formations of the Rocky Mountains in the study area include the Kitchener Formation, dolomitic argillite, and the Eager Formation, argillite (Rice, 1917).

PURCELL MOUNTAINS

The main formations of the Purcell Mountains in the study area include the Kitchener Formation, dolomitic argillite, the Creston Formation, argillaceous quartzite, and the Aldridge Formation, argillite and argillaceous quartzite (Rice, 1917).

PHYSIOGRAPHY

ELK RIVER VALLEY

The glaciated Elk River Valley extends north from Natal between two mountain ranges, and southeast from Natal, cutting across several mountain ranges and entering the Rocky Mountain Trench at Elko. The valley is from one half to four miles wide. On each side of the valley the mountains rise to high ridges and summits, exceeding 9,000 feet. The channel of the Elk River is lined with a series of terraces. At the mouths of the side valleys there are masses of rolling moraines originally deposited in the main valley by tributary glaciers (Kelly and Sprout, 1955).

The valley floor is characterized by the presence of lacustrine deposits, alluvial deposits in the river channel, and alluvial cappings on the terraces.

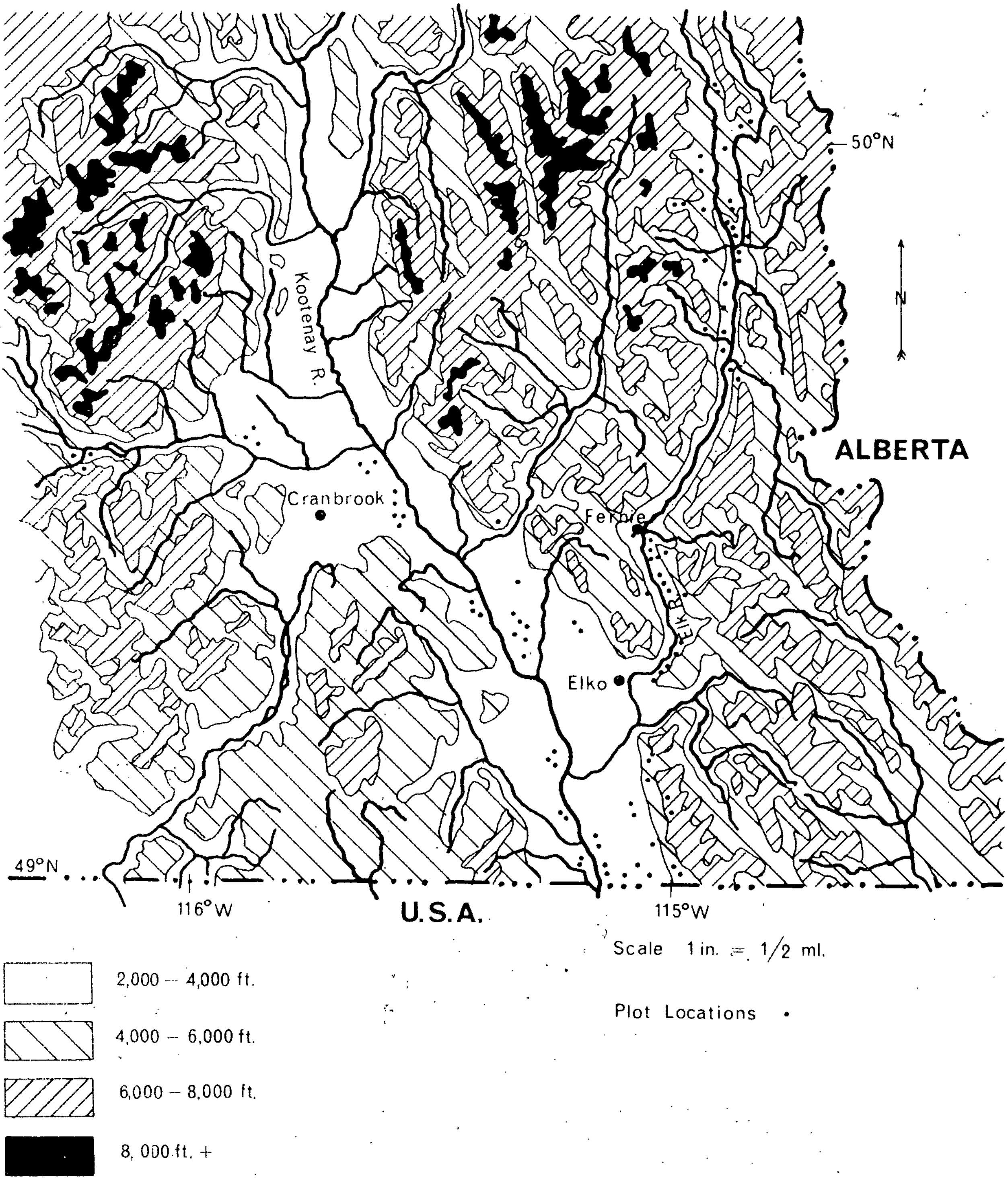
ROCKY MOUNTAIN TRENCH

South of Canal Flats the Rocky Mountain Trench consists of a glaciated valley from 3 to 17 miles wide, with the Rocky Mountains rising abruptly from the valley floor to the east; while to the west, the Purcell Mountains begin as rounded foothills which give way to rugged mountains.

The Rocky Mountain Trench Floor is occupied by a broad gently sloping channel of the Kootenay River, which follows a slightly meandering course. This channel is from one half to two miles wide, with banks up to 100 feet high (Kelly and Sprout, 1955). The river channel is comprised of tree covered second bottoms, treed levees, and grassy and swampy floodplains. On both sides of the channel the topography consists of a rolling till-plain, eroded by flat bottomed glacial river channels and scarred by more deeply cut courses of tributary streams. The till-plain is marked by scattered hills and ridges of exposed bedrock, numerous drumlins, kames, and eskers, and occasional kettle holes and lacustrine deposits. The average till-plain elevation is approximately 2,800 feet, ranging from 2,600 feet at the 49th parallel to 3,400 feet at Canal Flats.

Figure 5 shows the topographic features and plot locations of the study area.

Figure 5. Topographic Map of Study Area.



SOILS

The soils in the study area were surveyed by the B. C. Department of Agriculture. A report, published in 1955, is now out of date as far as the nomenclature is concerned.

The survey involved identification, mapping, description, and classification of soils which occur in the area. The soils were mapped as series, each series being a soil derived from one kind of parent material that occupies one drainage position (Kelly and Sprout, 1955).

The major Great Soil Groups found in the area include Dark Gray, Brown Wooded, Gray Wooded, Acid Brown Wooded, Humic Gleysols, and Regosols.

As complete descriptions of the soil series profiles are included in the soil Survey Report (Kelly and Sprout, 1955), they will not be discussed in detail.

Figure 6 illustrates the modal soil profiles for each Great Soil Group as found in the field. No attempt was made to divide the Great Soil Groups into series, but the profiles cover those most commonly found.

The distribution of soils in the mapped area is shown in Figure 7. The soils are divided into two broad classes: undifferentiated Dark Gray and Brown Wooded Soils, and undifferentiated Gray Wooded and Acid Brown Wooded Soils. Humic Gleysol and Regosols are not shown on the map as they comprise a very narrow strip along the borders of the Elk and Kootenay Rivers and do not cover a sufficient area to be mapped. Detailed maps showing the location of the soil series are contained in the Soil Survey Report (Kelly and Sprout, 1955).

Table 2 illustrates the relationship between soil parent material and soil series by Great Soil Group. The Table is adapted from the Soil Survey Report (Kelly and Sprout, 1955).

Figure 6. Modal Great Soil Group Profiles.

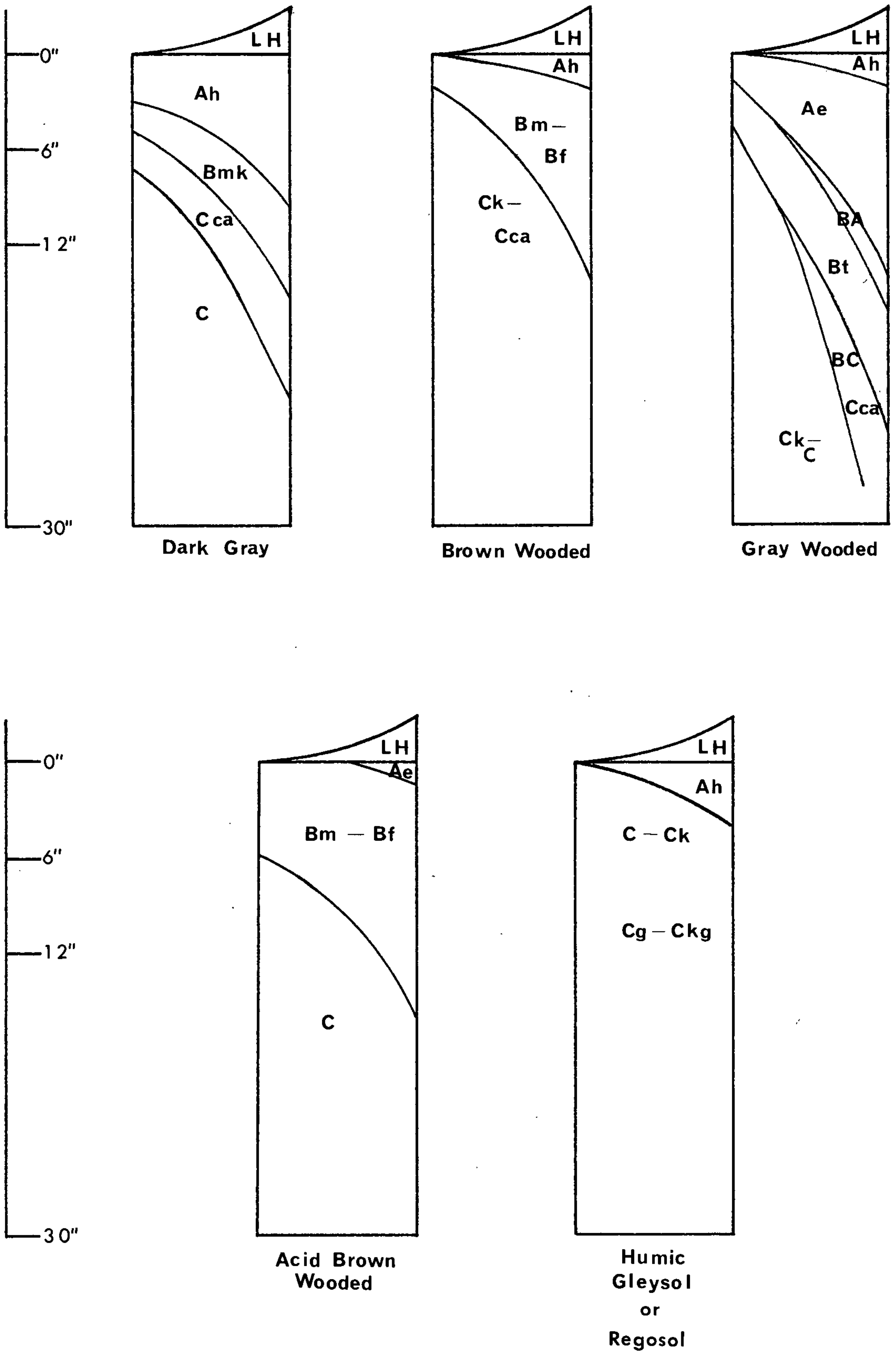


Figure 7. Distribution of Soils.

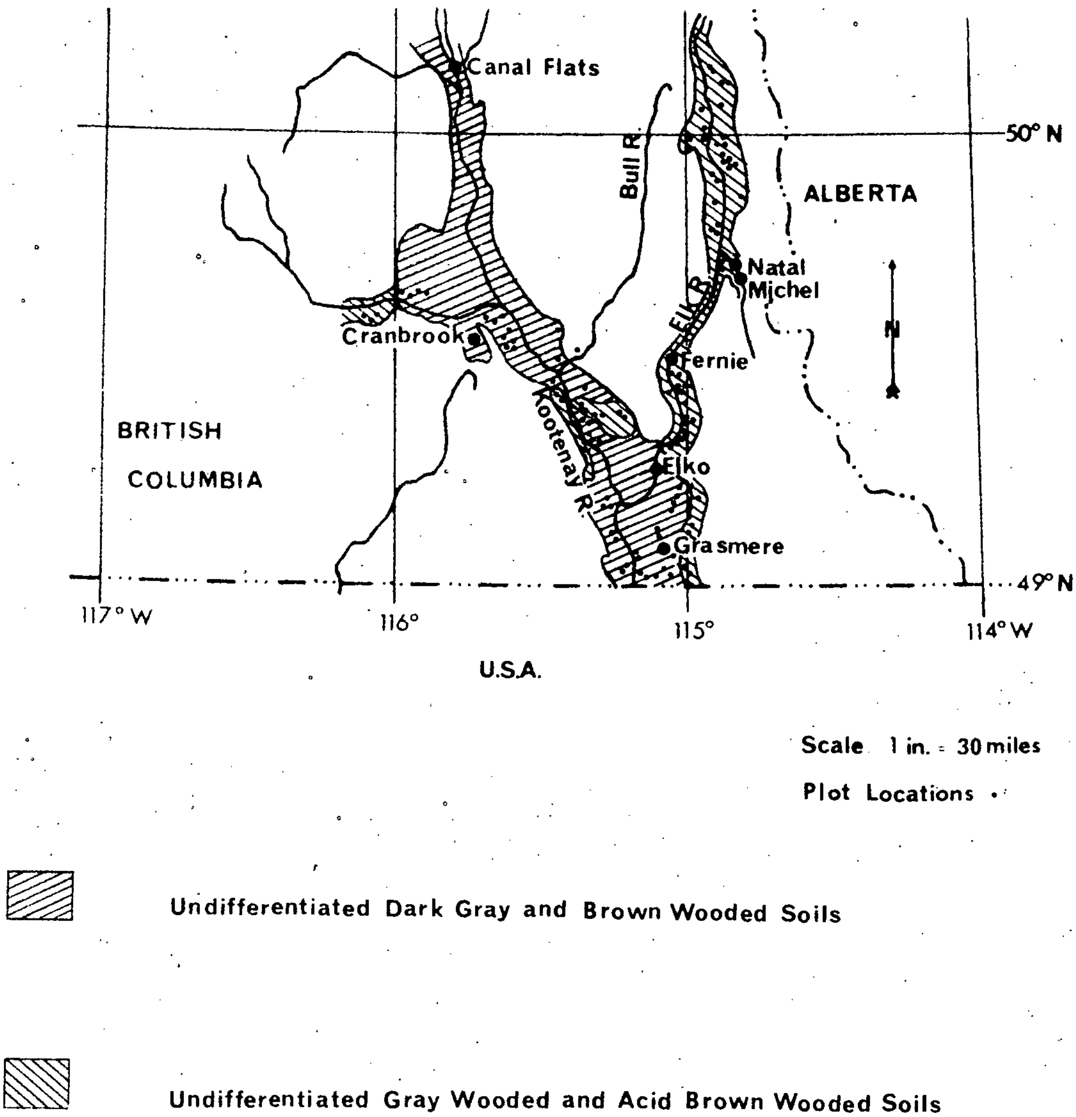


Table 2. Relationship between Soil Parent Materials and Soil Series by Great Soil Group

SOIL PARENT MATERIAL	GREAT SOIL GROUP				
	Glacial Parent Materials				
	Dark Gray	Brown Wooded	Gray Wooded	Acid Brown Wooded	Podzol
Gravelly Glacial River Deposits	Elko$_2$ Hyak$_1$	Elko$_1$ Hyak$_2$ Michel$_1$		Elko$_3$ Michel$_2$	
Sandy Glacial Deposits	Flagstone$_2$	Flagstone$_1$	Crahan$_2$	Crahan$_1$ Oldtown$_2$ Wardrop	
Glacial Till	Wycliffe$_2$	Wycliffe$_1$ Wycliffe$_3$ Wycliffe$_4$	Hosmer Kinbasket Flatbow	Cocato$_1$ Cocato$_2$ Soil A Soil C Soil D Soil E	Soil B
Silt and Clay Glacial River and Lake Deposits	Mayook$_4$	Mayook$_1$	Abruzzi$_1$ Abruzzi$_2$ Hornickle$_1$ Hornickle$_2$ Mayook$_2$ Sparwood	Mayook$_3$	

SOIL PARENT MATERIAL	Post Glacial Parent Materials				
	Brown Wooded	Gray Wooded	Acid Brown Wooded	Regosol	Humic Gleysols and Regosols
Alluvial Fans	Wigwam$_1$ Wigwam$_6$	Wigwam$_4$	Wigwam$_3$	Wigwam$_5$	Crowsnest Salishan$_1$ Salishan$_2$ Wigwam$_2$

Key: 1 or no subscript - corresponds to the type profile

2, 3, 4, 5, and 6 - mapped as a single soil series on the soils map but having a profile that did not correspond to the type profile

TREE SPECIES

The area can be divided into three forest regions based on Rowe's Forest Regions of Canada (Rowe, 1959). The regions are:

1) Grassland - southern Rocky Mountain Trench floor,
2) Montane - northern Rocky Mountain Trench floor and lower slopes of the Purcell and Rocky Mountains,
3) Columbia - Elk River Valley.

Thirteen tree species were encountered in the area, with only four covering any appreciable area. The four major species found were *Pinus ponderosa* Laws., *Pinus contorta* Dougl. var *latifolia* Engelm., *Pseudotsuga menziesii* (Mirb.) Franco, and *Picea glauca* (Moench) Voss. The minor species included *Larix occidentalis* Nutt., *Thuja plicata* Donn, *Pinus monticola* Dougl., *P. albicaulis* Engelm., *Abies lasiocarpa* (Hook.) Nutt., *Betula papyrifera* Marsh., *Populus tremuloides* Michx., *P. trichocarpa* Torr., and Gray, and *Juniperus scopulorum* Sarg.

The four major species can be separated on the basis of geographic location and Great Soil Group. Generally ponderosa pine (*Pinus ponderosa*) and Douglas-fir (*Pseudotsuga menziesii*) were found in the Rocky Mountain Trench on the undifferentiated Dark Gray and Brown Wooded Great Soil Groups, while lodgepole pine (*Pinus Contorta* var. *latifolia*) and white spruce (*Picea glauca*) were found on the undifferentiated Gray Wooded and Acid Brown Wooded Great Soil Groups. White spruce and deciduous species were found on the Humic Gleysol and Regosol Great Soil Groups (Table 7).

DISTRIBUTION OF MAJOR TREE SPECIES IN RELATION TO CLIMATE AND SOILS

In a study of the distribution of Douglas-fir, lodgepole pine, ponderosa pine and white spruce in the Kootenay and Elk River Valleys (Quenet, 1967) it was found that the availability of soil water was the single most important factor determining the range of these species. It was also noted that there was a strong correlation between species distribution and great soil group. These findings substantiate the works of Daubenmire (1943) and McLean and Holland (1958).

LITERATURE REVIEW

The Canada Land Inventory was designed to provide technical information on the alternative uses of marginal and submarginal agricultural land. Determination of the land capability for inventory (McCormack, 1965).

> .... As a general rule the following procedures are recommended:
>
> 1. The separation of the land surface into homogenous units for classification will be on the basis of physical characteristics.
>
> 2. Assignment of each unit to a capability class will be on the basis of all known or inferred information about the unit including sub-soil, soil profile, soil depth, moisture, fertility, landform, climate, and vegetation.
>
> 3. For capability class 1 no limiting factors will be shown. For all other classes the inherent limitations to growth which account for the placement in a given class will be stated in the symbol. The degree of limitation, and not the kind, will determine the class: a given class may embrace units of land with a wide variety of limitations but the degree of limitation to growth of each of them will be the same. Thus the capability class indicates the degree of limitation and the subclass indicates the nature of the limitation.
>
> 4. Both mineral and organic soils will be classified.

5. Associated with each capability class is a productivity class based on the mean annual increment of the best species or group of species adapted to the site, at or near rotation age. Productivity classes are expressed in gross merchantable cubic foot volume to a minimum diameter of four inches inside bark. The productivity here should be that of "normal"; that is, fully stocked stands. Thinnings, bark, and branch wood will not be included.

6. Since this is a capability classification, location, access, or present state will not influence the class designation. Present production, unless it reflects productivity, will only be used as additional information with which to rate the capability.

7. The indicator tree species, or group of species, which are expected to yield the productivity will be shown, when possible.

8. It is realized that, with improved forest management and practices, the productivity classes may change; however, since the capability classes are based primarily on permanent physical limitations to growth they should not change.

A general description of the productivity classes will be included in the discussion of the biological implications of the results of the analyses.

A brief description of the land capability subclasses follows:

Subclasses are class divisions that have the same kind of limitations to forest growth. It must be stressed that only limitations which affect growth are to be considered and recognized only as they affect growth.

For convenience of description the sublcasses may be grouped into limitations due to climate, soil moisture, permeability and rooting depth, fertility or high levels of toxic elements, stoniness and innundation.

Numerous systems for the classification of forest land have been proposed, using many approaches. Forest land classification systems and approaches have been discussed by Brown (1953), Carmean (1954), Coile (1952), Coile and Schumacher (1953), Heimberger (1941), Hills (1949, 1950, 1952, 1960, 1966), Hills and Pierpoint (1960), Holmes (1961), Krajina (1959), Linteau (1955), Lacate (1961, 1965, 1966), Lacate, Sprout, Arlidge and Moss (1965), LaFond (1958), Lemieux (1961), Long (1953), Lutz (1958), McCormack (1965), Rennie (1962), Rowe (1959, 1962), Spilsbury and Smith (1942), and Warrack and Fraser (1955).

The works of Auten (1945), Bajzak (1960), Copeland (1958), Cox and McConnel and Mathew (1958), Della-Bianca and Olson (1961), Duffy (1965), Doolittle (1957), Einspahr (1951), Eis (1962), Linnartz (1963), Meyers and VanDeusen (1960), Ralston (1951), Smith and Ker (1956), and Steinbrenner (1965) have shown rather conclusively that productivity can be predicted from quantitative measurements of environmental factors. The variables measured include total soil depth, effective soil depth, soil horizon depth, soil organic matter content, texture, permeability, drainage, water availability, depth to water table, and topographic factors such as slope, position on slope, exposure, aspect, and microtopography.

It should be noted that the relative effect of environmental factors on productivity varies with the geographic location and species.

To designate productivity classes in a particular area, it is necessary to sample the population of trees occurring on the area. As it is impractical, as well as financially impossible, to carry out a 100-per cent inventory of the land capability for forestry a sample of the population is required in order to obtain a reliable estimate of the population.

The central conception of such a sampling problem is the existence of a population, where a population is an aggregate of unit values, the unit being the object upon which the observation is made, and the value the property observed on that object (USDA, 1962).

It would appear that the greatest problem in obtaining a reliable sample for determining forest land capability is to define the unit of sampling and the variables to be sampled. In short, to define the population.

If a sample representing a specific population contains individuals from a different population, it will no longer represent the original population, because it will fail to give a reliable estimate of the original population.

Given a tract of land, it is possible to define the populations of trees thereon, in a number of ways. The various populations can be defined on the basis of phytocoenoces, climatic zones, soils, physiography, and so on.

The selection of the variables to be measured in order to describe a given population poses a greater problem than that of defining the population itself, due to the fact that the relative effect of environmental factors affecting tree growth varies with geographic location and tree species.

Tisdale and Nelson (1966) define environments as the aggregate of all external conditions and influences affecting the life and development of an organism. They also state that the most important factors known to influence plant growth include:

1) temperature,
2) water supply,
3) radiant energy,
4) composition of atmosphere,
5) soil aeration and composition of soil air,
6) soil reaction,
7) biotic factors, and
8) supply of mineral nutrient elements.

Assuming a population with an identical genetic constitution, and a complete knowledge of the environment, it would be possible to predict productivity with a very high degree of accuracy. However, as the genetic constitution of trees varies both within and between species, a complete knowledge of the environment is impossible. Thus, recognizing genetic variability and a limited knowledge of the environment, one is faced with the problem of reducing genetic variability to a minimum by limiting the population size, and selecting those environmental factors which are important in determining tree growth and which are relatively easily measured.

DETERMINATION OF FOREST LAND PRODUCTIVITY

The variables used to predict forest land productivity included mean annual increment, species composition, elevation, soil drainage, length of growing season, water surplus (after Thornthwaite), per cent slope, depth to lime accumulation, great soil group, and soil parent material.

DESCRIPTION OF DATA COLLECTION

1) Mean annual increment was measured as cubic feet per acre in gross merchantable volume to a minimum diameter of four inches inside bark of that species, or group of species, best adapted to the site.

The determination of mean annual increment (MAI) was carried out as follows:

a) selection of "normal", that is fully stocked, stands with no obvious defects or signs of disturbance,

b) delineation of plots one fifth of an acre in extent,

c) enumeration of species by one-inch diameter classes,

d) determination of mean stand diameter,

e) selection and diameter, height and age measurements of five trees having the mean plot diameter; and, based on these trees determination of the tree of average height and age,

f) determination of the volume of the average tree, volume per plot, and volume per acre,

g) determination of MAI per acre (volume per acre divided by the mean age of the average tree), and,

h) extrapolation of MAI to a 100 year base using Empirical Yield Tables (Fligg, 1960) compiled by the British Columbia Forest Service.

Subsequent to the selection of a stand suitable for productivity determination, the soil was examined in the following manner:

a) the soil was checked for uniformity throughout the plot,

b) if the soil did not coincide with the series description, the plot was eliminated,

c) if the soil met the requirements of a and b a pit was dug to the parent material and the following observations were made:

1) horizon descriptions, depth of each horizon, and total soil depth,

2) texture of each horizon by hand-texturing,

3) soil drainage based on general topographic position, soil profile development, and soil water content at the time of excavation,

4) depth to Cca and/or depth to soluble carbonate deposits as indicated by effervescing when a 10% HCl solution was applied,

5) aspect, slope, position on slope, and elevation,

6) general comments which supplemented the above information and elucidated any apparent inconsistencies in productivity.

It should be pointed out that a description as comprehensive as the one outlined above was the exception rather than the rule. The variations in the data collected may best be demonstrated by two soil profile descriptions:

Plot # 1

Great Soil Group	-	Gray Wooded
Subgroup	-	Orthic Gray Wooded
Soil Series	-	Kinbasket
Soil Drainage	-	No measure
Slope and Aspect	-	8% E
Elevation	-	No measure
Position on Slope	-	No measure
Soil Profile		Ae / Bt 8" well developed
Texture		Sil
Comments	-	Nil

Plot # 71

Great Soil Group	-	Gray Wooded
Subgroup	-	Brunosolic Gray Wooded
Soil Series	-	Flatbow
Soil Drainage	-	Well drained
Slope and Aspect	-	12 to 15% N
Elevation	-	2,800 ft.
Position on Slope	-	
Soil Profile	-	6" 12" 8" 26" + Bf / Ae / Bt / Cca
Texture		SiL GSiL SiCL GSiL
Comments	-	stones scattered throughout profile plot not fully stocked, put in as last resort

The number of plots located on each of the various soil series varied considerably. As a general rule, it was considered that sufficient plots had been located on a particular soil series when the MAI of that series showed a definite trend to fall within a productivity class. There were a number of instances where insufficient plots were located on the soil series due to poor stand conditions, extensive logging, and inaccessability.

Subsequent to the establishment and measurement of the plots, the land surface was separated into homogenous land units on the basis of physical characteristics, and assigned a productivity class. The assignment of the productivity class to the land units was on the basis of the plot measurements and all known or inferred information about the unit including subsoil, soil profile, depth, water availability and retention properties, fertility, landform, climate, and vegetation.

A subclass was assigned to each productivity class. The subclass indicates the limitations which affect tree growth. The assignment of the subclass to the productivity class was on the basis of all known or inferred information about the subsoil, soil profile, depth, water availability, fertility, landform, climate, and vegetation.

ACCURACY OF THE ASSIGNED PRODUCTIVITY CLASSES

As previously stated, it was considered that sufficient plots had been located on a particular soil series when the MAI of that series showed a definite trend to fall within a productivity class. There were, however, a number of instances where insufficient plots were located for reasons already mentioned.

The productivity class assigned to a particular soil series, or land unit, was based on the mean MAI of the plots located on that soil series. Thus, any series having a wide deviation in MAI would show a generalized productivity value. Table 3 shows the mean MAI, standard deviation, maximum and minimum values, and the number of plots for each soil series.

From Table 3 it is evident that:

1) insufficient plots were located on the great majority of soil series to give a sufficiently accurate estimation of productivity, and

2) on those soil series where it was thought that sufficient plots had been located, the standard deviation was so high it was evident that insufficient plots had been located, or the method of selecting plot locations and/or measurement of MAI could be improved.

It must be stated here that the standard deviations associated with each soil series do not necessarily mean that the land units occurring within a particular soil series will have a MAI variation which corresponds to the standard deviation of that soil series. The variation in MAI on a particular soil series should be considerably reduced when the area is mapped into land units. This, however, has not yet been proven.

Alternative methods of sampling and selecting plot locations will be discussed in the section headed 'Alternative Methods for Assigning Productivity Classes'.

The assignment of subclasses to the productivity classes was based on a value judgement made by the research workers engaged on the project, and thus is open to question.

As with all measurements the determination of MAI is subject to error. In addition to the error associated with the measurement of trees on the plot, the method of determining MAI is open to question.

Table 3. Summary of Mean MAI, Standard Deviation, Maximum and Minimum Values, and Number of Plots for each Soil Series.

Soil Series	Mean MAI cu. ft./ac.	Standard Deviation cu. ft./ac.	Maximum & Minimum Values cu. ft./ ac.		Number of Plots
<u>Dark Gray Soils</u>					
Elko$_2$	18.7	4.6	24	16	3
Flagstone$_2$	52.0	49.9	109	16	3
Hyak$_1$	41.5	12.0	50	33	2
Mayook$_4$	19				1
Wycliffe$_2$	44.7	17.4	58	25	3
<u>Brown Wooded Soils</u>					
Elko$_1$	26.5	5.9	38	22	6
Flagstone$_1$	25.5	2.1	27	24	2
Hyak$_2$	38				1
Mayook$_1$	43.0	25.3	82	16	5
Michel$_1$	69				1
Wigwam$_1$	80				1
Wigwam$_6$	51				1
Wycliffe$_1$	39.9	10.5	67	25	12
Wycliffe$_4$	49.0	5.7	53	45	2
Wycliffe$_3$	29				1
<u>Gray Wooded Soils</u>					
Abruzzi$_1$	56				1
Abruzzi$_2$	57				1
Crahan$_2$	87.5	6.4	92	83	2
Flatbow	42.0	7.0	49	35	3
Hornickle$_1$	100.5	0.7	101	100	2
Hornickle$_2$	83				1
Hosmer	76.0	2.8	78	74	2
Kinbasket	42.0	19.0	73	20	6
Mayook$_2$	72				1
Sparwood	59				1
Wigwam$_4$	65				1

Table 3 contd.

Soil Series	Mean MAI cu. ft./ac.	Standard Deviation cu. ft./ac.	Maximum & Minimum Values cu. ft./ ac.		Number of Plots
<u>Acid Brown Wooded Soils</u>					
Cocato$_1$	88.7	22.8	114	57	6
Cocato$_2$	52.3	11.9	66	45	3
Crahan$_1$	76.0	2.8	78	74	2
Elko$_3$	27				1
Mayook$_3$	37				1
Michel$_2$	77.3	31.9	106	43	3
Oldtown$_2$	73				1
Soil A	84.3	20.5	105	64	3
Soil C	99.5	3.5	102	97	2
Soil D	44.5	9.2	51	38	2
Soil E	47.2	12.1	62	33	6
Wardrop	130.5	9.2	137	124	2
Wigwam$_3$	62.0	1.4	63	61	2
<u>Humic Gleysols and Regosols</u>					
Crowsnest	95.6	26.9	137	64	5
Salishan$_1$	69.8	5.7	75	62	4
Salishan$_2$	109				1
Wigwam$_2$	142				1
<u>Podzol Soils</u>					
Cocato$_3$	62				1
Soil B	46.5	12.0	55	38	2
<u>Regosols</u>					
Wigwam$_5$	79				1

The determination of MAI is based on the concept of the "normal" stand, or fully stocked stand. Problems arise when the environmental conditions are such that "normal" does not represent full stocking. It then becomes necessary to make a visual estimate of what constitutes normal stocking for the particular area, and then proceed on this basis. Obviously the accuracy of a visual estimate of "normal" or full stocking is questionable.

The extrapolation of MAI to a base of 100 years could result in a certain degree of error because:

a) at ages below 60 years the growth and yield tables are based on relatively few data, hence subject to error; and,

b) for certain species the MAI obtained in the field was greater than twice the maximum MAI listed in growth and yield tables for that species.

Subsequent work in the central interior of British Columbia revealed that there was a strong tendency to select stands occurring on north, north-eastern, and north-western aspects. This tendency may be explained by the fact that northern aspects have a more favourable water regime, and as such have more fully stocked stands, with a greater growth potential than stands occurring on southern aspects.

As previously stated, plots were not located on soils which did not coincide with the soil series description. Obviously, an area mapped as a single soil series will include areas which do not coincide with the series description. For example, a drumlinized till plain will consist of two distinct soils: the first occurring on the drumlins themselves; the second occurring in the drainage basins between the drumlins. Since the area covered by the drumlins usually exceeds that of the drainage basins, the soil will be mapped on the basis of the soil occurring on the drumlins. Hence, the drainage areas will not coincide with the series description and thus be eliminated as unsuitable for productivity determinations.

The sources of error in the productivity determinations may be summarized as follows:

1) insufficient plots,
2) the problem in defining normal stocking, and ignoring stand density,
3) extrapolation of MAI to a base of 100 years,
4) the strong tendency to select plots on northern aspects, and
5) the exclusion of plots from soils which do not correspond to soil series descriptions.

It has been shown that the data used to map the productivity of individual soil series, (Table 3), have high standard deviations and thus might be expected to give a somewhat inaccurate base from which to assign productivity. Although no study has as yet been undertaken to assess the accuracy of mapped land units, it appears, from a visual examination, that in some instances the assigned productivity class is not in accordance with the true productivity class. It should be stressed that this apparent inconsistency in mapped and true productivity has not been proven.

ALTERNATIVE METHODS FOR ASSIGNING PRODUCTIVITY CLASSES

The Forest Land Capability Classification was designed to rate the productivity of forest land using a system whereby the rating could be compared to that of alternative land uses. It was not designed to provide a complete basis for land management.

The system presently employed is a compromise between a broad regional classification and an intensive management classification. As such it has lost a great deal of versatility and does not fully accomplish either objective. It would appear that two courses of action can be taken; namely, to modify the system to one that fulfils the objectives of a broad regional classification, or to a management classification, but not a combination of both.

POINT SAMPLING TECHNIQUES

It is the author's opinion that a system using point sampling would provide the best foundation for a regional classification of forest land productivity. An outline of the system and its advantages is contained below.

1) Separation of the land surface into homogeneous units based on physiographic units within soil series prior to the field season.

2) Use of a prism to establish an intensive sample, the basal area factor of the prism being such that 5 to 10 trees are selected per point sample (Smith, 1967).

3) Determine MAI in terms of total cubic foot volume per acre.

4) Check the boundaries of mapped land units in the field at the time of plot establishment.

5) Use road cuts and occasional soil pits to aid in the determination of factors limiting tree growth, and check the variability of mapped soils.

In the summer of 1967 a pilot study was undertaken to determine the relative merits of a point sampling system. A discussion of the methods and results is included below.

Productivity measurements were carried out as described in the section headed 'Determination of Forest Land Productivity'. In addition, a point samplé was taken on each plot using the plot centre as the sampling point.

Fifty plots were measured on some thirteen soil series. However, meaningful results could be obtained on only five soil series due to the low number of plots located on the remaining eight soil series.

The method used to determine MAI from the point samples is outlined below:

1) summary of the sampled trees by diameter classes,

2) computation of the number of trees per acre in each diameter class, and total number of trees per acre,

3) computation of the tree of mean diameter,

4) construction of a height-diameter curve based on trees sampled on that soil series during the conventional MAI determination,

5) determination of the height of the mean diameter tree from the height-diameter curve,

6) determination of the volume of the mean tree from volume tables,

7) determination of the total volume per acre (volume of mean tree times the number of trees per acre),

8) determination of the mean annual increment per acre (total volume per acre divided by the mean age of the sample trees), and

9) extrapolation of MAI to a base of 100 years using growth and yield tables compiled by the British Columbia Forest Service.

A sample calculation is included below.

Plot # 2 - Vanderhoof Series - Orthic Gray Wooded on Lacustrine Clay

- Lodgepole Pine

Sample Trees - 2 x 9", 1 x 10", 3 x 11", 2 x 12", 1 x 13", 1 x 15"

Number of Trees per Acre using 20 basal area factor (BAF) prism

$$\text{\# of trees} = \frac{\text{BAF} \times \text{\# of trees sampled in each diameter class}}{\text{Basal Area of each Diameter Class}}$$

eg. 9" diameter class

$$\text{\# of trees} = \frac{20 \times 2}{\frac{22 \times 4.5 \times 4.5}{7 \times 144}} = 90.52$$

Mean Diameter

$$\text{Mean Diameter} = 2\sqrt{\frac{\frac{\text{Total basal area per acre}}{\text{Total \# of trees per acre}}}{\pi}}$$

Construction of Height-Diameter Curve

straight line regression analysis carried out on sample trees to determine line of best fit (see Figure 8)

Determination of Height of Mean Tree

taken from height-diameter curve

eg. diameter = 10.8", therefore height = 91 ft.

Volume of Mean Tree

taken from volume tables = 34.0 cu. ft.

Mean Annual Increment

$$\frac{\text{volume of mean tree} \times \text{total \# of trees per acre}}{\text{mean age of sample trees}}$$

eg. $\frac{34.0 \times 307}{169}$ = 62 cu. ft. per acre/ yr.

extrapolation to base 100 yrs. = 87 cu. ft. per acre/ yr.

Figure 8. Plot of Height over Diameter for Lodgepole Pine on the Vanderhoof Soil Series.

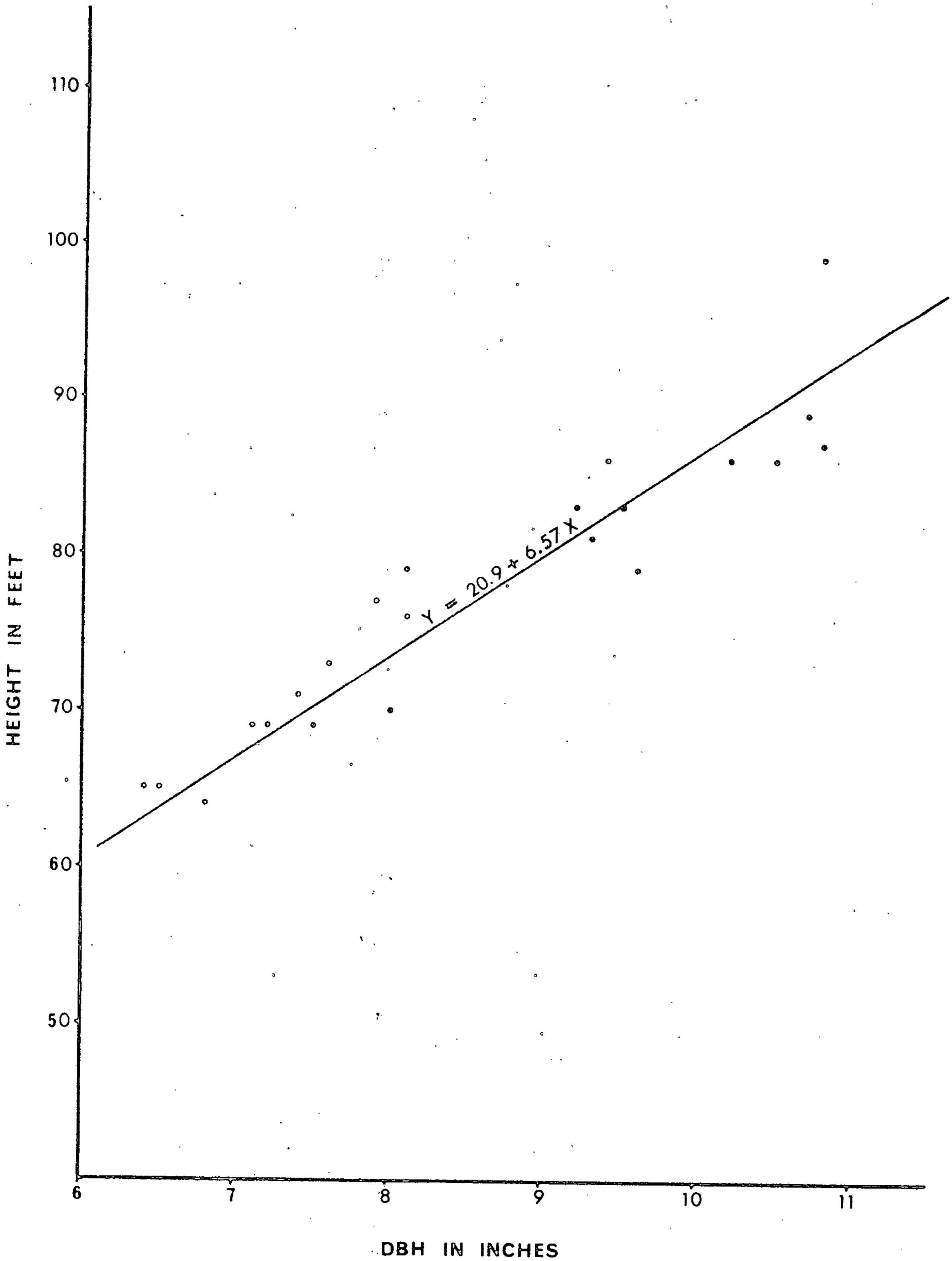


Table 4 contains a summary of results obtained from both the conventional and point sampling methods for determining MAI. The standard deviations for MAI derived from the conventional method included all plots whereas these derived from the point sampling method included only plots containing between 5 and 11 sample trees. It was observed that where the number of sample trees was less than 5 or greater than 11 the MAI derived bore little relation to that derived from the conventional method. However, where the number of sample trees ranged between 5 and 11 the MAIs derived by the conventional and point sampling methods showed a high correlation.

Tables 5 and 6 show a comparison of the conventional and point sampling results on an individual plot basis for two soil series. In Table 5 the number of sample trees obtained by the point sampling method, with the exception of one plot, ranged between 5 and 11, and hence gave a high correlation with the values obtained by the conventional method. In Table 6 four plots had over 11 sample trees and in all cases there was a considerable variation in the MAI values obtained. Similarly, in the case of plot 21, having 4 sample trees, there was a considerable variation in the MAI values obtained by the two methods.

The underlying cause of variation in the MAI values obtained by the two methods, where the number of sample trees taken in the point sample was less than 5 or greater than 11, is relatively simple to explain. An examination of Tables 5 and 6 will show that the number of trees per acre, obtained by the conventional method, ranged from 310 to 555. The tables also show that there is little correlation between the number of sample trees obtained by the point sampling method and the number of trees per acre obtained by the conventional sampling method. This apparent inconsistency may be explained by the fact

Table 4. Summary of Results Obtained from both Conventional (C) and Point Sampling Methods (P) for Determining MAI.

Soil Series	Number of Plots	Number of Trees Measured		Number of Trees per Acre		Mean Annual Increment cu. ft./ acre	
		C	P	C	P	C	P
Beaverley	8	85	7	425	396	60 ± 14.2	60 ± 15.3
Cinema	4	91	9	505	374	59 ± 2.9	58 ± 4.4
Cobb	4	94	9	470	520	70 ± 19.9	75 ± 35.7
Deserters	5	96	9	480	431	85 ± 28.7	80 ± 29.5
Vanderhoof	5	87	8	434	395	61 ± 12.8	66 ± 12.7

Statistics presented include only those plots where the number of trees tallied on the point samples ranged between 5 and 11.

Table 5. Comparison of Conventional (C) and Point Sampling (P) Results on an Individual Plot Basis of the Vanderhoof Soil Series.

Plot #	Number of Trees Measured		Number of Trees per Acre		Volume of Mean Tree cu. ft.		Mean Annual Increment cu. ft./ acre	
	C	P	C	P	C	P	C	P
2	80	11	400	307	24.9	34.0	83	87
3	78	7	390	268	17.9	22.2	60	60
7	102	8	510	412	12.4	17.2	58	67
16	107	8	535	553	9.9	11.0	50	56
33	67	8	335	428	18.2	15.0	55	58
34	82	1	410	45	7.1	20.7	28	10

Table 6. Comparison of Conventional (C) and Point Sampling (P) Results on an Individual Plot Basis for the Cinema Soil Series.

Plot #	Number of Trees Measured		Number of Trees per Acre		Volume of Mean Tree cu. ft.		Mean Annual Increment cu. ft./ acre	
	C	P	C	P	C	P	C	P
9	98	6	490	287	10.9	18.1	55	54
21	77	4	385	118	12.3	20.3	49	25
23	76	13	380	443	20.4	26.5	75	115
24	96	5	480	227	11.1	19.2	61	56
32	91	12	455	803	12.9	12.2	56	92
40	120	9	600	619	12.0	11.6	60	60
51	90	7	450	373	11.6	15.6	61	64
54	62	13	310	451	20.5	16.3	64	88
56	111	12	555	993	13.7	9.1	80	95

that although the number of trees per acre is relatively uniform over all the plots, the distribution of stems within the plots is not uniform.

It might be justifiably argued that, where there is no conventional plot as a check, a point sample count of less than 5 or greater than 11 might reflect full stocking and thus should not be eliminated. This problem can be overcome in either of two ways. A sample count of less than 5 or greater than 11 could be assumed to indicate that the stand was either under or overstocked and thus should not be used for productivity determinations. A second and preferable method would be to establish two point samples a fixed distance apart using each as a check on the other.

A standard chi-squared test (Freese, 1960) was applied to the results contained in Table 4 in order to check the accuracy of the point sampling technique against the accepted conventional technique. Assuming a required accuracy of 10 per cent of the mean MAI obtained by the conventional system, it was found that the values obtained by the point sampling technique were within the required accuracy limits at the 5 per cent probability level provided that the number of sample trees per plot was not less than 5 or greater than 11.

The point sampling system in addition to being as accurate as the conventional system has several distinct advantages. The greatest advantage is the time saving element. It is estimated that 4 to 5 point samples will take the same amount of time as one conventional plot, allowing for a greater number of plots to be located. The increased number of plots will result in a greater coverage of the land units and thus a more accurate estimation of productivity. For example, in the place of a single plot being located on a particular aspect of a drumlin, 4 or 5 plots could be located on various aspects. Specifying 5 to 10 sample trees per plot acts as a control on stocking density by eliminating over or understocked stands.

REGRESSION TECHNIQUES

The determination of forest land productivity by the use of prediction equations based on environmental influences adapts itself more to an intensive management classification. It is not suited to a regional classification on account of the length of time required to investigate environmental influences affecting tree growth. Nevertheless, it was felt that an investigation of the correlation between forest land productivity and environmental influences would prove useful in determining which of the influences were most highly correlated with productivity of the various species encountered. Also, the investigation would show where the methods of data collection were unsatisfactory in terms of their application to statistical analyses.

Eleven variables were used in the productivity predictions, the variables used included MAI, species composition, elevation, soil drainage, length of growing season, water surplus (after Thornthwaite), per cent slope, depth to lime accumulation, great soil group, and soil parent material.

The variables were measured or estimated as follows:

1) MAI was measured in cubic feet per acre as outlined in the section titled 'Determination of Forest Land Productivity'.

2) Species Composition - where species composition was used as an independent variable the stand was considered to be pure if the major species accounted for greater than fifty per cent of the total number of stems per acre; however, in most cases the major species accounted for greater than seventy per cent of the number of stems per acre.

3) Elevation was measured with an aneroid barometer in feet above sea level.

4) Soil drainage was estimated and placed in classes ranging from rapidly drained to imperfectly drained or gleyed. Since it was impossible to measure drainage quantitatively the drainage classes were coded. In this, and all subsequent coding, the author used values ranging from 2 to 15. The code value designated was based on the effect that the particular factor would have on forest productivity, 2 referring to the lowest relative productivity and 15 referring to the highest relative productivity. It should be noted that in no cases were plots located on sites where excess water might be detrimental to tree growth. The codes assigned to the drainage classes were:

a) rapidly drained - 2

b) well drained - 5

c) well to moderately drained - 8

d) moderately drained - 10

e) poorly drained - 13

f) imperfectly drained or gleyed - 15

5) Length of growing season was obtained from climatological maps and recorded in number of days.

6) Precipitation was obtained from climatological maps and recorded in inches.

7) Water surplus (after Thornthwaite) was obtained from climatological maps and recorded in inches.

8) Slope was recorded in per cent.

9) Depth to lime accumulation was recorded in inches.

10) The code values assigned to great soil group were based on the observed correlation between great soil group and forest productivity. The code values assigned were:

a) Dark Gray - 2

b) Brown Wooded - 4

c) Gray Wooded - 8

d) Acid Brown Wooded - 12

e) Humic Gleysols - 15

11) The code values assigned to soil parent material were on the basis of texture and topographic position. Coarse-textured soils were assigned low code values due to their poor water retention properties, except in the case of the flood plains and second bottoms where the poor water retention properties were supplemented by a supply of ground water. The codes assigned were:

a) gravelly glacial river deposits - 2

b) sandy glacial deposits - 5

c) alluvial fans and colluvium - 8

d) glacial till - 10

e) silt and clay glacial river and lake deposits - 12

f) flood plains and second bottoms - 15

Statistical Analyses

Analyses of variance and simple and multiple regression analyses were carried out on the data.

Analyses of variance (Steel and Torrie, 1960) is an arithmetic method of partitioning the total sum of squares into components associated with recognized sources of variation. The total variation of a set of data is the sum of the squared deviations about the general mean of all the measures. The component of the sum of squares not associated with a recognizable source of variation is designated as the error term. The error term corresponds to the measure of variation expected when no treatment or other external influences are present.

In order to test whether treatments belong to the same or different population means, the components of the total sum of squares are divided by the degrees of freedom associated with the particular components, and the ratio of the treatment mean square to the error mean square is calculated. This value is designated as the F value or variance ratio. A significant variance ratio implies that all the treatment means do not belong to the same population mean, but it does not indicate which differences may be considered statistically significant.

Kramer's modification of Duncan's New Multiple Range Test was used to determine significant differences in a multiple comparison of treatment means with different numbers of replications. It should be noted that the validity of Kramer's modification has not as yet been verified.

Simple and multiple linear regressions characterize the straight line relationship between the dependent and independent variables. In the case of a simple regression, the relationship between the dependent and one independent variable is characterized. In the case of multiple linear regressions, the relationship between the dependent and more than one independent variable is characterized. A procedure involving elimination of independent variables was used to determine the best combination of independent variables. The elimination of independent variables is discussed by Kozak and Smith (1965). In brief, the elimination procedure involves the elimination of the variable with the smallest absolute contribution to the variance accounted for by the regression equation.

Other statistics calculated include:

1) Standard error estimate - a measure of dispersion about the regression line,

2) Multiple correlation coefficient - measures the degree of association between the dependent and independent variables,

3) Regression coefficient - rate of change of the dependent variable with respect to the independent variable,

4) Coefficient of determination - defines the proportion of the sum of squares of the dependent variable that can be attributed to the independent variables.

5) Standard deviation - a measure of the dispersion of the individual values about their mean,

6) Maximum and minimum values.

Results and Discussion of Analyses

The results will be dealt with in two sections; namely, the definition of population boundaries, and the prediction of productivity within the different population boundaries.

Population Boundaries

The population boundaries used in the prediction of productivity were:

1) the entire study area,

2) a division of the study area into two populations based on geographic location, i.e. the Rocky Mountain Trench and the Elk River Valley,

3) a division of the study area into four populations based on the major species, i.e. ponderosa pine, Douglas-fir, lodgepole pine, and white spruce,

4) a division of the study area into five populations based on Great Soil Group, i.e. Dark Gray, Brown Wooded, Gray Wooded, Acid Brown Wooded, and Humic Gleysol.

The wide variation in climate and geology necessitated the division of the study into various populations. The author felt that divisions based on geographic location, species, and Great Soil Group were the most logical in terms of the objectives of the study and ease of defining the populations.

Two analyses of variance were carried out on the data. The purpose of these analyses was to determine whether the choice of populations could be justified in terms of biological phenomena.

The first analysis, Table 7, shows the results of Kramer's Modification of Duncan's New Multiple Range Test applied to the ranked species means for all the measured or estimated environmental influences. An examination of the table indicates that Great Soil Group and water surplus gave the best separation of species. Obviously Great Soil Group is easier to define in the field than water surplus, and hence is the preferred population definition. In the second analysis, Table 8, Kramer's Modification of Duncan's New Multiple Range Test was applied to the ranked productivity class means for all the variables measured or estimated. An examination of the table indicates that drainage and Great Soil Group gave the best separation of productivity classes. Again, it

Table 7. Kramer's Modification of Duncan's New Multiple Range Test Applied to the Ranked Species Means for all Variables.

Variable	Species			
Elevation	Pp	Sw	Df	Lp
in feet	2816	3394	3581	4188
Drainage	Pp	Df	Lp	Sw
coded	3.90	4.94	6.78	13.4
Length of	Lp	Sw	Df	Pp
Growing Season in days	146	164	171	178
Precipitation	Pp	Df	Sw	Lp
in inches	16.7	19.2	34.3	41.9
Water Surplus	Pp	Df	Sw	Lp
in inches	2.78	6.33	14.9	19.0
Per Cent Slope	Sw	Pp	Lp	Df
	9.60	12.8	19.8	32.9
Depth to Lime	Pp	Sw	Df	Lp
in inches	12.2	24.3	24.9	29.4
Great Soil	Pp	Df	Lp	Sw
Group coded	3.81	6.89	10.1	13.7
Soil Parent	Pp	Lp	Df	Sw
Material coded	6.77	7.78	8.89	11.1
MAI	Pp	Df	Lp	Sw
in cu. ft.	35.4	43.0	70.6	94.0

Key: those means which are underlined are not significantly different at the 95% probability level,
Those means which are not underlined are significantly different at the 95% probability level.

Pp - ponderosa pine
Df - Douglas-fir
Lp - lodgepole pine
Sw - white spruce

Table 8. Kramer's Modification of Duncan's New Multiple Range Test Applied to the Productivity Class Ranked Means for all Variables.

Variable	Productivity Class (P.C.)					
Elevation	P.C. 6	P.C. 1	P.C. 5	P.C. 3	P.C. 4	P.C. 2
in feet	2717	3100	3501	3716	3820	4144
Drainage	P.C. 6	P.C. 5	P.C. 4	P.C. 3	P.C. 2	P.C. 1
coded	3.41	4.21	6.10	10.3	11.4	13.3
Length of	P.C. 6	P.C. 1	P.C. 5	P.C. 4	P.C. 3	P.C. 2
Growing Season in days	178	175	171	158	153	147
Precipitation	P.C. 6	P.C. 5	P.C. 1	P.C. 4	P.C. 3	P.C. 2
in inches	16.9	20.9	32.5	32.8	38.4	42.9
Water Surplus	P.C. 6	P.C. 5	P.C. 4	P.C. 1	P.C. 3	P.C. 2
in inches	3.29	6.29	13.3	16.0	16.0	19.8
Per Cent Slope	P.C. 3	P.C. 1	P.C. 2	P.C. 6	P.C. 5	P.C. 4
	6.61	9.75	14.8	17.5	26.0	30.9
Depth to Lime	P.C. 6	P.C. 5	P.C. 4	P.C. 3	P.C. 2	P.C. 1
in inches	10.7	20.5	24.4	25.9	32.0	39.5
Great Soil	P.C. 6	P.C. 5	P.C. 4	P.C. 3	P.C. 2	P.C. 1
Group coded	4.12	6.64	8.70	10.7	11.8	13.3
Soil Parent	P.C. 6	P.C. 5	P.C. 1	P.C. 2	P.C. 3	P.C. 4
Material coded	6.39	7.61	8.22	9.22	9.28	9.30

Key: those means which are underlined are not significantly different at the 95% probability level,
those means which are not underlined are significantly different at the 95% probability level.

Productivity class (P.C.)
1 MAI = 111 cu. ft. +
2 MAI = 91 to 110 cu. ft.
3 MAI = 71 to 90 cu. ft.
4 MAI = 51 to 70 cu. ft.
5 MAI = 31 to 50 cu. ft.
6 MAI = 11 to 30 cu. ft.

is obvious that drainage is more difficult to define in the field than Great Soil Group and hence Great Soil Group is the preferred definition.

The definition of population boundaries based on species is justifiable in the light of the different silvical requirements of the species. The sharp climatic break between the Rocky Mountain Trench and Elk River Valley justifies a population definition based on geographic location.

The results contained in Table 8, in addition to justifying the use of Great Soil Group as a population definition, substantiate the method and values used in coding of data. Prior to a detailed discussion of the table, it is necessary to point out that the ranked position of productivity class 1 may, in certain instances, be ignored. An examination of the original data shows, without exception, that those plots giving a productivity class of 1 were located in spruce stands. The stands were located either in the flood plains of the Kootenay and Elk Rivers or at relatively high elevations in the Elk River Valley, and thus comprised two populations. In the analyses these two populations were combined and thus the means for the variables Elevation, Length of Growing Season, Precipitation, Water Surplus, and Soil Parent Material are not meaningful.

From Table 8 it is evident that the coded values for:

1) Drainage are justifiable, as evidenced by the ranking of productivity classes in numerical order from 6 to 1 associated with an increase in coded values from 3.41 to 13.25,

2) Great Soil Group are justified, as evidenced by the ranking of productivity classes in numerical order from 6 to 1 associated with an increase in coded values from 4.12 to 13.25,

3) Soil Parent Material are not justified, as evidenced by the lack of any definite ranking order.

Failure of the coding system for Soil Parent Material may be explained by the fact that although soil texture determines, to some extent, the water retention properties, hydraulic conductivity, and infiltration rate of the soil, it does not reflect the presence of seepage water or climatic conditions. The coding system would work in a uniform climate provided that the effect of seepage water was taken into consideration.

PREDICTION OF PRODUCTIVITY BY USE OF REGRESSION TECHNIQUES

Regression techniques were used to:

1) define how closely MAI varied with the independent variables (correlation coefficient),

2) define the proportion of the variation (sum of squares) in MAI attributable to the independent variables (coefficient of determination),

3) define the relationship between MAI and the independent variables as they act in conjunction with one another, and by themselves (regression coefficient),

4) derive prediction equations for MAI based on the measured or estimated independent variables, and

5) define the accuracy of the prediction equations (standard error of estimate).

PREDICTION OF PRODUCTIVITY BASED ON THE ENTIRE STUDY AREA

The prediction equations were based on all plots irrespective of their geographic location, Great Soil Group, and species composition.

The best equation for determining productivity from the multiple regression equation was:

$$MAI = -72.3 + 3.09\ (\text{Drainage}) + 0.316\ (\text{Depth to Lime}) + 1.60\ (\text{Water Surplus}) + 1.20\ (\text{Great Soil Group}) - 1.10\ (\text{Soil Parent Material}) + 0.429\ (\text{Length of Growing Season}).$$

Where: the coefficient of determination = 74.3%

the standard error of estimate = ± 15.3 cu. ft.

the number of observations = 97

PREDICTION OF PRODUCTIVITY BASED ON GEOGRAPHIC LOCATION

Two regression analyses were carried out. The first was based on data from all plots located in the Elk River Valley; the second on data from all plots located in the Rocky Mountain Trench. The Elk River Valley and Rocky Mountain Trench vary markedly in elevation, climate, species, and soils.

Elk River Valley

The best equation for determining productivity from the multiple regression equation was:

$$MAI = -130.6 + 3.68\ (\text{Drainage}) - 2.63\ (\text{Soil Parent Material}) + 0.975\ (\text{Length of Growing Season}) + 2.61\ (\text{Water Surplus}) + 0.171\ (\text{Depth to Lime})$$

Where: coefficient of determination = 62.4%

standard error of estimate = ± 17 cu. ft.

number of observations = 40

Rocky Mountain Trench

The best equation for determining productivity from the multiple regression equation was:

MAI = −78.8 + 5.11 (Drainage) + 0.305 (Depth to Lime) + 0.249 (Per Cent Slope) − 1.22 (Soil Parent Material) − 2.67 (Water Surplus) + 0.009 (Elevation) + 1.5 (Precipitation) + 0.293 (Length of Growing Season)

Where: coefficient of determination = 66.8%

standard error of estimate = ± 9.72 cu. ft.

number of observations = 50

PREDICTION EQUATIONS BASED ON SPECIES

Four linear regression analyses were conducted. The separate regression analyses were based on data from plots having greater than 50 per cent of the stems per acre of the particular species being analyzed.

Ponderosa Pine

The best equation for determining productivity from the multiple regression equation was:

MAI = −86.5 + 0.036 (Elevation) + 7.04 (Drainage) + 0.38 (Per Cent Slope) − 1.59 (Soil Parent Material)

Where: coefficient of determination = 73.9%

standard error of estimate = ± 9.22 cu. ft.

number of observations = 31

Douglas-Fir

The best equation for determining productivity from the multiple regression equation was:

MAI = 6.72 + 0.365 (Per Cent Slope) + 1.15 (Precipitation) + 1.95 (Drainage) − 1.40 (Soil Parent Material) + 0.719 (Great Soil Group)

Where: coefficient of determination = 60.2%

standard error of estimate = ± 7.46 cu. ft.

number of observations = 18

Lodgepole Pine

The best equation for determining productivity from the multiple regression equation was:

MAI = 41.36 + 3.54 (Drainage) + 0.832 (Water Surplus) - 1.35 (Soil Parent Material)

Where: coefficient of determination = 56.3%

standard error of estimate = ± 14.2 cu. ft.

number of observations = 32

White Spruce

The best equation for determining productivity from the multiple regression equation was:

MAI = -484.0 + 2.50 (Length of Growing Season) + 6.08 (Drainage) + 0.732 (Per Cent Slope) + 9.19 (Precipitation) - 4.96 (Soil Parent Material) - 15.10 (Water Surplus)

Where: coefficient of determination = 89.0%

standard error of estimate = ± 14.90 cu. ft.

number of observations = 16

PREDICTION EQUATIONS BASED ON GREAT SOIL GROUPS

Five linear regression analyses were carried out, the separate regression analyses were based on data from the plots occurring on each Great Soil Group.

Dark Gray

The best equation for determining productivity from the multiple regression equation was:

MAI = -70.77 + 7.32 (Drainage) + 0.031 (Elevation) - 2.68 (Soil Parent Material) + 0.336 (Per Cent Slope)

Where: coefficient of determination = 92.3%

standard error of estimate = ± 5.8 cu. ft.

number of observations = 11

Brown Wooded

The best equation for determining productivity from the multiple regression equation was:

MAI = -18.84 + 2.68 (Precipitation) + 2.98 (Drainage) + 0.430 (Depth to Lime) - 2.87 (Water Surplus)

Where: coefficient of determination = 49.6%

standard error of estimate = ± 11.99 cu. ft.

number of observations = 27

Gray Wooded

The best equation for determining productivity from the multiple regression equation was:

MAI = 9.02 + 2.57 (Precipitation) + 4.33 (Drainage) - 1.73 (Soil Parent Material) - 3.38 (Water Surplus)

Where: coefficient of determination = 70.6%

standard error of estimate = ± 12.4 cu. ft.

number of observations = 20

Acid Brown Wooded

The best equation for determining productivity from the multiple regression equation was:

MAI = -59.69 + 3.13 (Drainage) + 0.479 (Depth to Lime) - 3.77 (Soil Parent Material) + 4.15 (Water Surplus) + 0.63 (Length of Growing Season) - 1.13 (Precipitation)

Where: coefficient of determination = 70.2%

standard error of estimate = $\pm$ 17.0 cu. ft.

number of observations = 30

Humic Gleysols and Regosols

The best equation for determining productivity from the multiple regression equation was:

MAI = 130.7 - 7.44 (Soil Parent Material) + 1.44 (Per Cent Slope) + 4.53 (Drainage)

Where: coefficient of determination = 82.3%

standard error of estimate = $\pm$ 15.0 cu. ft.

number of observations = 9

Before proceeding, it is necessary to explain what is meant by 'The best equation for determining productivity from the multiple regression equation' and the appearance of Soil Parent Material in the equations.

As previously mentioned, a procedure developed by Kozak and Smith (1965), involving the elimination of single independent variables, was used to determine the best combination of independent variables. The best equation for determining productivity from the multiple regression equation is that equation which gives the best compromise between a high coefficient of determination, a low number of inexpensively measured independent variables, and a low standard error of estimate. Table 9 shows the elimination of independent variables from the multiple regression equation for MAI of the entire study area.

An examination of the table shows that equation 4 gives the best compromise between a high coefficient of determination, a low number of independent variables, and a low standard error of estimate. The decrease in the coefficient of determination from equation 1 to equation 4 is 0.004, or 0.4 per cent, whereas the decrease in the coefficient of determination from equation 1 to equation 5 is 0.021, or 2.1 per cent. The number of independent variables in equation 4 has decreased from 9, in equation 1, to 6, and the standard error of estimate of equation 4 is lower than that of any other equation.

It was stated earlier that the failure of the coding system for Soil Parent Material may be explained by the fact that although soil texture determines, to some extent, the water retention properties, hydraulic conductivity and infiltration rate of the soil, it does not reflect the presence of seepage water or climatic conditions. When Soil Parent Material is used in a regression equation in combination with other independent variables reflecting the presence of seepage water and climatic conditions, then the coding system is justified.

COMPARISON OF POINT SAMPLING AND REGRESSION TECHNIQUES FOR DETERMINING FOREST LAND PRODUCTIVITY

It has been shown that the point sampling technique for determining forest land productivity gave a high correlation with the results obtained by the conventional method (Tables 4, 5 and 6).

To determine the accuracy of the regression techniques for determining forest land productivity, the $Wycliffe_1$ Series found on the Brown Wooded Great

Table 9. Elimination of Independent Variables from Multiple Regression Equations for MAI of the Entire Study Area

Equation	CD	SEe	Const	Regression Coefficients								
				Drain	DTL	WS	GSG	SPM	LGS	Elev	%S	Ppt
1	.747	15.49	-50.96	3.48**	.304**	1.21	1.25*	-1.11	.404*	-.004	.046	.313
2	.746	15.43	-43.86	3.80**	.332**	1.67**	1.26*	-1.05	.385	-.004	.043	
3	.745	15.37	-45.29	3.72**	.340**	1.65**	1.28*	- .99	.388	-.004		
4	.743	15.34	-73.22	3.90**	.316**	1.60**	1.20*	-1.10*	.492*			
5	.721	15.91	15.11	4.17**	.317**	.562**	1.32*	-1.02				
6	.709	16.16	9.81	3.68**	.296**	.664**	1.26*					
7	.691	16.57	13.43	4.23**	.341**	.848**						
8	.664	17.69	14.91	4.90**	.486**							
9	.548	19.18	24.51	5.08**								

Key:
- CD - Coefficient of Determination
- SEe - Standard Error of Estimate
- Const - Constant Term, or Y intercept
- Drain - Soil Drainage
- DTL - Depth to Lime
- WS - Water Surplus
- GSG - Great Soil Group
- SPM - Soil Parent Material
- LGS - Length of Growing Season
- Elev - Elevation
- %S - Per Cent Slope
- Ppt - Precipitation

** - Significant at the 99% probability level

* - Significant at the 95% probability level

Soil Group was selected because it had a relatively wide range in MAI and a large number of plots.

The method for determining the MAI values from the regression equation was carried out as follows:

1) the data for all plots located on the $Wycliffe_1$ Series were summarized,

2) the individual plot data were substituted into the equation

MAI = -18.84 + 2.68 (Precipitation) + 2.98 (Drainage) + 0.43 (Depth to Lime) -2.87 (Water Surplus)

3) the standard deviation was calculated.

Table 10 shows the comparison of the results of conventional and regression techniques for determining MAI.

Table 10. Comparison of Results of the Conventional and Regression Techniques for Determining MAI on the $Wycliffe_1$ Series.

Plot Number	MAI Determinations cu. ft./ac.	
	Conventional	Regression
10	38	32
61	67	35
62	30	35
63	45	48
64	37	43
65	39	33
66	38	40
82	39	40
85	40	34
86	25	37
93	25	37
94	53	31
95	45	46
Mean MAI =	40 ± 11.2 cu. ft./ac.	38 ± 5.3 cu. ft./ac.

From Table 10 it is evident that while the regression MAI determinations on an individual plot basis showed, in some cases, a wide variation from the conventional determination, the mean regression MAI was almost identical to the mean conventional MAI and had a smaller standard deviation than the conventional MAI.

Table 11 shows the comparison of results of conventional and regression techniques for determining MAI for those series on which 5 or more plots were located.

Table 11. Comparison of Results of the Conventional and Regression Techniques for Determining MAI on Four Soil Series.

Soil Series	Great Soil Group	MAI and Standard Deviation in cu. ft./ac.	
		Conventional Method	Regression Method
Elko$_1$	Brown Wooded	28 ± 6.2	26 ± 8.9
Wycliffe$_1$	Brown Wooded	41 ± 10.7	38 ± 5.3
Kinbasket	Gray Wooded	42 ± 17.4	49 ± 21.9
Crowsnest	Humic Gleysol	96 ± 26.9	93 ± 27.0

From Table 11 it is evident that while there is some degree of variation between the conventional method and the regression method for determining MAI, the results are sufficiently close to justify the use of regression techniques for determining MAI.

The use of regression techniques for determining MAI has two distinct advantages over the point sampling method. These are:

1) the method allows for productivity determinations on areas where stand conditions preclude the direct measurement of MAI,

2) the collection of soil and climatic data allows for a more accurate assignment of productivity subclasses.

The disadvantages of using regression techniques for determining productivity are:

1) the method is time consuming, taking approximately two hours per plot, and

2) it is more costly, requiring the use of a computer.

RECOMMENDED TECHNIQUE FOR DETERMINING FOREST LAND PRODUCTIVITY FOR THE ARDA LAND CLASSIFICATION

Three alternative techniques for determining forest land productivity have been discussed and compared. From the results of comparisons of accuracy, all give approximately the same accuracy and therefore this is not a consideration in the choice of method.

The major consideration in the choice of techniques appears to be the amount of time required for the measurement of MAI from the stands established on the particular soil series being investigated. For the direct measurement of MAI from presently existing stands, the point sampling technique appears to be superior to the conventional technique. However, subsequent work by the author on Vancouver Island tends to indicate that the point sampling technique gives consistently high MAI values when compared to the MAIs derived from one-twentieth acre plots. Table 12 shows a comparison of derived from point samples and one-twentieth acre plots in the Lake Cowichan District of Vancouver Island. It should be noted that the validity of the use of one-twentieth acre plots for determining MAI has not yet been verified and hence the results obtained from this system may be suspect.

Table 12. Comparison of MAIs Derived from One-twentieth Acre Plots and Point Samples in the Lake Cowichan District of Vancouver Island.

Plot No.	Landform and Soil Parent Material	Stand Age years	Mean Annual Increment* cu. ft. / ac. One-twentieth Acre Plot	Point Sample
1	Alluvial Cone - Alluvium	38	187	133
2	Alluvial Cone - Alluvium	36	205	251
3	Alluvial Fan - Alluvium	38	213	228
11	Alluvial Fan - Alluvium	45	181	215
6	Delta - Alluvium	49	231	250
8	Delta - Alluvium	47	308	253
4	Mountain Side - Ablation Till	48	169	199
5	Mountain Side - Ablation Till	43	197	268
7	Mountain Side - Ablation Till	50	302	360
9	Mountain Side - Ablation Till	48	265	304
10	Mountain Side - Ablation Till	47	199	262

From the preceeding discussion it is obvious that the optimum sampling system, in terms of accuracy and time, for determining the potential MAI has yet to be developed. It may well be that a combination of sampling systems will give the best results; the sampling system used depending upon the local conditions.

Prediction equations can be derived from the direct measurement of MAI using point sampling techniques and measurement of environmental conditions. It is the author's opinion that the additional time required to measure or estimate environmental influences, and to conduct an intensive examination of the soil, does not warrant the advantages resulting from the use of prediction equations in a broad regional classification such as the Canada Land Inventory.

* Douglas-fir

ASSIGNMENT OF PRODUCTIVITY SUBCLASSES

The productivity subclass indicates the nature of the environmental limitations to tree growth. The productivity subclasses are grouped into limitations due to climate, soil water, permeability and rooting depth, fertility or high levels of toxic elements, stoniness, inundation and active erosion.

The assignment of a productivity class is on the basis of all known or inferred information about the subsoil, soil profile, depth, water availability, fertility, landform, climate, and vegetation.

The assignment of a productivity subclass based on limitations due to excess soil water, shallow rooting depth, stoniness, and active erosion is relatively simple and reliable owing to the ease of recognizing these conditions. However, the assignment of productivity subclasses based on limitations due to climate, available soil water, permeability, and fertility or high levels of toxic elements is more complex. This complexity is due to the difficulty in determining the degree to which these factors limit tree growth. In the past, the assignment of subclasses has been based on a value judgement made by the research workers engaged on the project, and thus are open to question.

It was hypothesized that the calculation of a simple regression analysis between MAI and the individual environmental influences would indicate the environmental influence most highly correlated with productivity, and thus be more likely to limit tree growth when deficient or excessive. This approach works in part, but is not entirely satisfactory.

The drawbacks include:

1) there is no significant correlation between MAI and the measured, or estimated, environmental influences on Humic Gleysols and Regosols,

2) where there is no significant correlation between MAI and any particular environmental influence, it is not an indication that this factor does not limit tree growth; the lack of a significant correlation may be due to the fact that the particular factor is uniform within the particular population,

3) where there is no significant correlation between MAI and a particular environmental influence, it is necessary to determine the optimum value of that factor and then, assuming a positive correlation, that factor must be considered limiting at any value below the optimum value; however, the maximum value observed in the field may not be the true optimum,

4) the method provides no indication as to which of two or more factors has the greatest influence in limiting tree growth.

It would appear that to determine the relative effect of various environmental influences on limiting tree growth, it is necessary to isolate each factor and determine its individual effect.

In a study conducted by Quenet (1967) the effect of various concentrations of $CaCO_3$ on the growth of *Pseudotsuga menziesii*, *Pinus contorta* var. *latifolia*, and *Picea glauca* seedlings was investigated. Field observations by the author tended to support the theory that there was a significant relationship between the distribution of the major coniferous species and the $CaCO_3$ concentration of the soils occurring in the Elk and Kootenay River Valleys.

A greenhouse experiment, using naturally occurring soils collected from the area, was set up to determine the effect of varying concentrations of $CaCO_3$ on the growth of Douglas-fir, lodgepole pine, and white spruce.

Based on the results of the study and an examination of the literature, it was concluded that:

1) the pH of the soil does not directly influence the growth response,

2) under alkali conditions the cation, or cations, responsible for the high pH influence the growth response through their effect on the availability of both cations and anions by saturation of the exchange sites and/or by rendering the ions unavailable,

3) the response of Douglas-fir, lodgepole pine, and white spruce varied considerably on the same soils,

4) high $CaCO_3$ concentration depressed the growth of lodgepole pine to a greater extent than it did either Douglas-fir or white spruce,

5) the response of the species to the soils depended, to some extent, upon the growth parameter being measured,

6) seedling mortality was confined to the lodgepole pine seedlings on those soils having a pH of greater than 7.0,

7) for all species there was a significant decrease in root collar diameter, shoot weight, root weight, and height growth from pH 5.7 to 6.0.

The results of this study are useful to a certain degree in assigning productivity subclasses. A statistical analysis of the results indicated that the $CaCO_3$ concentration in the soil plays a role in determining tree growth, and that its effect is most serious on lodgepole pine. It also showed that an increase in pH from 6.0 to 7.4 did not significantly decrease the growth response of any measurement. In addition, it showed that there was a relationship between the effect of $CaCO_3$ and soil texture; the coarser the soil texture the more adverse the effect of a specific concentration of $CaCO_3$.

There is no method available for accurately assigning productivity subclasses. Therefore, it appears that for the present, productivity subclasses will be based on value judgements made by research workers.

RECOMMENDATIONS

The results of this study disclose three areas where further research will result in a more accurate Forest Land Classification. These areas include (1) the measurement of environmental factors which determine productivity, (2) the use of field and greenhouse experiments to establish methods for determining the relative effect of environmental influences in limiting tree growth, and (3) a more extensive study of the use of various sampling techniques to get a direct measure of productivity in terms of MAI.

The Measurement of Environmental Factors for Determining Forest Productivity

The results of the regression techniques for determining productivity showed that this method was as accurate as the conventional method, in spite of the fact that the environmental influences were measured or estimated in a rather crude manner. Refinement of the methods used to measure, or estimate, the environmental influences will lead to a more accurate classification. Also, the measurement of additional factors will undoubtably result in a more accurate classification.

If use of regression techniques for determining forest land productivity is contemplated, the following environmental influences should be measured:

1) total soil depth,
2) effective soil depth,
3) depth of individual soil horizons,

4) soil organic matter content,

5) soil texture, permeability and drainage,

6) depth to water table,

7) soil nutrients,

8) pH of soil horizons,

9) soil water retention properties,

10) rooting depth,

11) climate, including precipitation, length of growing season, temperature regimes, evapotranspiration, and solar radiation,

12) topographic factors such as slope, position on slope, exposure, aspect, and microtopography.

The Determination of the Relative Effect of Environmental Influences in Limiting Tree Growth

The establishment of methods for determining the relative effect of environmental influences on limiting tree growth is the most important problem encountered. Not only is it necessary for land classification, but it is of extreme importance in forest fertilization. Obviously there is little point in expending large amounts of capital to fertilize if some factor other than soil fertility is limiting tree growth.

In order to determine the relative effect of various environmental influences on limiting tree growth, it is necessary to isolate each factor and determine its individual effect and from there proceed to conditions where two or more factors are limiting. This can be done to a limited extent by the use of factorial experiments.

Sampling Techniques for a Direct Measure of Productivity in Terms of MAI

It would be advisable to conduct an extensive study into the relative merits of various sampling techniques in order to develop the optimum technique in terms of accuracy and time or cost.

CONCLUSIONS

The Forest Land Capability Classification for Forestry was designed to rate the productivity of forest land on a basis comparable with alternate uses.

The method of rating forest land productivity comprised the determination of MAI of 'normally' stocked stands on all the soil series represented, a description of the environmental factors influencing tree growth, and the extrapolation of these data based on physiographic and soil boundaries.

The accuracy of the assigned productivity classes was examined. It was found that the sources of error included: (1) insufficient plots, (2) problems in defining 'normal' stocking, (3) extrapolation of MAI to a base of 100 years, (4) a strong tendency to select plots on northern aspects, and (5) the exclusion of plots on soils which did not correspond to soil series descriptions.

The use of point sampling was investigated. It was found that the accuracy of the point sampling and conventional method, i.e. MAI determinations based on 1/5th acre plots, was almost identical, within the constraints prescribed, and only in the Interior of British Columbia. The results obtained from point samples on Vancouver Island were significantly different from those obtained on one-twentieth acre plots.

Soil, physiographic and climatic data from 97 plots located on five Great Soil Groups were analyzed to determine their influence on forest productivity and to derive prediction equations for productivity. Productivity equations gave results comparable to the conventional method, in spite of rather crude measuring techniques.

Based on the results of the conventional, one-twentieth acre plot, point sampling and regression techniques, and the need for determining the optimum method for determining MAI, it was recommended that an extensive study be initiated to determine the optimum sampling technique.

It was found that the only feasible method for assigning productivity subclasses was on the basis of a value judgement made by research workers.

Further research was recommended into (1) the measurement of the environmental factors determining forest productivity, (2) the use of field and greenhouse experiments to establish methods for determining the relative effect of environmental factors in limiting tree growth, and (3) a more extensive study of the use of various sampling techniques to obtain a direct measure of productivity in terms of MAI.

BIBLIOGRAPHY

Auten, J. T. 1945. Prediction of site index for yellow poplar from soil and topography. Jour. For., 43: 662-668.

A.R.D.A. 1967. Maps compiled for the British Columbia Agro-Climatology Committee, A.R.D.A. Dept. Geog., Univ. Brit. Col.

B. C. Dept. Agric. 1965. Climate of British Columbia Meteorological Br., Air Serv. Div., Dept. of Transp. 93 pp.

Bajzak, D. 1960. An evaluation of site quality from aerial photographs of the University of B. C. Research Forest, Haney. Univ. Brit. Col., Faculty of Forestry, MF Thesis.

Brown, W. G. E. 1953. Site classification. Pulp and Paper Mag. Canada. June 1953.

Carmean, W. H. 1954. Site quality of Douglas-fir in Southwestern Washington and its relationship to precipitation, elevation, and physical soil properties. Proc. Soil Sci. Soc. Amer., 18 (3): 330-334.

Cline, M. G. The changing model of soil. Proc. Soil Sci. Soc. Amer., 25 (3): 442-446.

Coile, T. S. 1952. Soil and growth of forests. Advances in Agronomy 4:330-398.

Coile, T. S. and F. X. Schumacher. 1953. Relation of soil properties to site index of loblolly and shortleaf pines in the Piedmont regions of Carolinas, Georgia, and Alabama. Jour. For., 51: 739-774.

Copeland, O. L. 1958. Soil site studies of western white pine in northern Rocky Mountain Region. Proc. Soil Sci. Soc. Amer., 22: 268-296.

Cox, G. S., McConnel, R. C., and L. M. Mathew. 1960. Ponderosa pine productivity in relation to soil and landform in western Montana. Proc. Soil Sci. Soc. Amer., 24: 139-142.

Daubenmire, R. 1943. Vegetation zonation in the Rocky Mountains. Botan. Rev., 9: 325-393.

Della-Bianca, L. and D. F. Olson. 1961. Soil site studies in Piedmont hardwood and pine hardwood upland forests. For. Sci., 7: 320-329.

Doolittle, W. T. 1957. Site index of scarlet and black oak in relation to southern Appalachian soil and topography. For. Sci., 3: 114-124.

Duffy, P. J. B. 1965. A forest land classification for the mixed wood section of Alberta. Can. Dept. For., Publ. 1128: 23 pp.

Einspahr, D., and A. L. McComb. 1951. Site index of oaks in relation to soil and topography in northeastern Iowa. Jour. For., 49: 719-723.

Eis, S. 1961. Tree growth and environmental factors of plant communities. Ph.D. Thesis. Univ. Brit. Col., 232 pp.

Eis, S. 1962. Statistical analyses of several methods for estimation of forest habitats and tree growth near Vancouver, B. C. Univ. Brit. Col., Faculty of Forestry, Forestry Bull. No. 4: 76 pp.

Farrar, J. L. 1960. The use of factor-gradients in evaluating site. Proc. 5th World For. Cong., Univ. of Wash. Seattle, Washington: 524-528.

Fligg, D. M. 1960. Empirical yield tables. B. C. Forest Service, Forest Survey Notes No. 6: 142 pp.

Freese, F. 1960. Testing accuracy. For. Sci., 6: 139-145.

Heimberger, C. C. 1941. Forest site classification and soil investigations on Lake Edward Forest Experimental area. Can. Dom. For. Serv., Silvical Res. Note No. 66: 60 pp.

Hills, G. A. 1950. The use of aerial photography in mapping soil sites. For. Chron., 26 (1): 4-37.

__________. 1952. The classification and evaluation of site for forestry. Ont. Dept. of Lands and For., Res. Publ. No. 24: 41 pp.

__________. 1960. The classification of forest productivity systems (site, ecosystems, biogeocoenoces). Proc. 5th World For. Cong., 527-576.

__________. 1966. The classification of land for multiple land use. Proc. Nat. Comm. on Forest Land., Info. and Tech. Divs., Can. Dept. For., 71-80.

Hills, G. A. and G. Pierpoint. 1960. Forest site evaluation in Ontario. Ont. Dept. of Lands and For. Res., Repr. No. 42: 64 pp.

Holmes, J. R. B. 1961. A preliminary examination of soil depth and topography in relation to basal area in lodgepole pine. Can. Dept. For., For. Res. Br., Mimeo 61-17: 7 pp.

Kelly, C. C., and P. N. Sprout. 1955. Soil survey of the upper Kootenay and Elk river valleys in the East Kootenay District of British Columbia. B. C. Dept. Ag., Rept. No. 5: 99 pp.

Kozak, A., and J. H. G. Smith. 1965. A comprehensive and flexible multiple regression program for electronic computing. For. Chron. Vol. 41 (4): 438-443.

Krajina, V. J. 1965. Biogeoclimatic zones and classification of British Columbia. Ecology of North America. Ed. V. J. Krajina. 1: 1-17.

Lacate, D. S. 1965. Forest land classification for the University of British Columbia Research Forest. Can. Dept. For., For. Res. Br., Publ. No. 1107: 24 pp.

Lacate, D. S. 1966. Wildland inventory and mapping. For. Chron., 42 (2): 184-94.

Lacate, D. S., Sprout, P. N., Arlidge, J. W. C., and A. Moss. 1965. Forest land classification and interpretations for management in the spruce working circle, T. F. L. No. 9, Okanagan Valley, B. C., B. C. Dept. Agric. Soil Survey Div., Kelowna, B. C. Interim Rept., 39 pp.

LaFond, A. 1958. Some soil, vegetation and site relationships of the climatic and sub-climatic black spruce forests in northeastern America. First N. Amer. For. Soils Conf. East Lansing, Mich. 67-74.

Lemieux, G. J. 1963. Soil-vegetation relationships in the northern hardwoods of Quebec. Can. Dept. For., For. Res. Br. Contr. No. 563: 163-176.

Linnartz, N. E. 1963. Relation of soil and topographic characteristics to site quality for southern pines in Florida parishes of Louisana. Jour. For. 61: 434-438.

Linteau, A. 1953. Site classification. Pulp and Paper Mag. of Can., Woodlands Sect. 2-5.

Long, H. D. 1953. Site classification - the site climax as an indicator of site conditions. Pulp and Paper Mag. of Can., Woodlands Sect. 6-7.

Lutz, H. J. 1958. Geology and soil in relation to forest vegetation. First N. Amer. For. Soils Conf. Mich. State Univ. Mich. 75-85.

McCormack, R. J. 1965. Outline of the Canadian Land Capability Classification for Forestry. Prep. for Canada Land Inventory, ARDA. 10 pp.

McLean, A. and W. D. Holland. 1958. Vegetation zones and their relationship to the soils and climate of the Upper Columbia Valley. Can. Jour. Plant. Sci., 38: 328-345.

Meyers, C. A. and J. L. Van Deusen. 1960. Site index of ponderosa pine in the Black Hills from soils and topography. Jour. For. 58: 548-555.

Quenet, R. V. 1967. Species distribution and productivity as related to soils in the Rocky Mountain Trench and Elk River Valley in British Columbia. Unpublished. Univ. Brit. Col., 41 pp.

Ralston, C. W. 1951. Some factors related to the growth of longleaf pine in the Atlantic coastal plain. Jour. For. 49: 408-412.

Rennie, P. J. 1962. Methods of assessing forest site capacity. Int. Soils Conf. N. Z. Int. Soc. Soil Sci., 770-785.

Rice, H. M. A. 1937. Glacial phenomena near Cranbrook, British Columbia. Jour. Geology, Vol. 44 (1): 68-73.

Rowe, J. S. 1959. Forest regions of Canada. Canada Dept. Northern Affairs and Nat. Resources, Forestry Branch. Bull. 123, 71 pp.

Rowe, J. S. 1953. Forest sites - A discussion. For. Chron. Vol 29 (3): 278-289.

Smith, J. H. G. 1967. A procedure for simple definition of land capability for wood growth and estimation of yield. Proc. National Comm. on Forest lands, Can. Dept. For. and Rural Dev. 106-120.

Smith, J. H. G. and J. W. Ker. 1956. Some problems and approaches in classification of site in juvenile stands of Douglas-fir. For. Chron., 32 (4): 417-428.

Spilsbury, R. H. and D. S. Smith. 1947. Forest site types of the Pacific Northwest. B. C. For. Serv., Tech. Publ. No. 30: 46 pp.

Stanek, W. 1966. Occurrence, growth, and relative value of Lodgepole Pine and Engelmann Spruce in the Interior of British Columbia. Univ. Brit. Col., Faculty of Forestry, Ph. D. Thesis, 252 pp.

Steinbrenner, E. C. 1965. The influence of individual soil and physiographic factors on the site index of Douglas-fir in western Washington. Repr. from Forest Soils Rel. in N. A. 261-277.

Tisdale, S. L. and W. L. Nelson. 1966. Soil fertility and fertilizers. 2nd. Ed., The MacMillan Co. N. Y. 694 pp.

Trewartha, G. T. 1954. An introduction to climate. 3rd. Ed., McGraw-Hill Book Co., Inc. N. Y. 402 pp.

U.S.D.A. For. Serv. 1962. Elementary Forest Sampling. U.S.D.A. For. Serv. Agric. Handb. No. 232: 91 pp.

Warrack, G. S. and A. R. Fraser. 1955. Estimation of site quality in juvenile Douglas-fir stands. B. C. For. Serv., Res. Note No. 28: 5 pp.

APPENDIX I

MAIs Derived on Conventional Plots by Soil Series

EAST KOOTENAYS

Soil Series	MAI
Dark Gray Soils	
$Elko_2$	24; 16; 16
$Flagstone_2$	109; 31; 16
$Hyak_1$	50; 33
$Mayook_4$	19
$Wycliffe_2$	58; 51; 25
Brown Wooded Soils	
$Elko_1$	38; 26; 26; 24; 23; 22
$Flagstone_1$	27; 24;
$Hyak_2$	38
$Mayook_1$	82; 48; 43; 26; 16
$Michel_1$	69
$Wigwam_1$	80
$Wigwam_6$	51
$Wycliffe_1$	67; 46; 45; 43; 40; 39; 38; 37; 31; 30; 25
$Wycliffe_4$	53; 45
$Wycliffe_3$	29
Gray Wooded Soils	
$Abruzzi_1$	56;
$Abrizzi_2$	57
$Crahan_2$	92; 83
Flatbow	49; 42; 35
$Hornickle_1$	101; 100
$Hornickle_2$	83
Hosmer	78; 74
Kinbasket	73; 52; 45; 34; 28; 20
$Mayook_2$	72
Sparwood	59
$Wigwam_4$	65

EAST KOOTENAYS Contd.

Soil Series	MAI
Acid Brown Wooded Soils	
$Cocato_1$	114; 110; 97; 86; 68; 57
$Cocato_2$	66; 46; 45
$Crahan_1$	78; 74
$Elko_3$	27
$Mayook_3$	37
$Michel_2$	106; 83; 43
$Oldtown_2$	73
Soil A	105; 84; 64
Soil C	102; 97
Soil D	51; 38
Soil E	62; 61; 48; 40; 39; 33
Wardrop	137; 124
$Wigwam_3$	63; 61
Humic Gleysols and Regosols	
Crowsnest	137; 102; 90; 85; 64
$Salishan_1$	75; 73; 69; 62
$Salishan_2$	109
$Wigwam_2$	142
Podzols	
$Cocato_3$	62
Soil B	55; 38
Regosols	
$Wigwam_5$	79

VANDERHOOF

Soil Series	
Acid Brown Wooded Soils	
Cobb	91; 82; 59; 48

VANDERHOOF Contd.

Soil Series	MAI
Gray Wooded Soils	
Beaverley	82; 76; 68; 59; 56; 47; 46; 45
Cinema	61; 61; 60; 55
Deserters	110; 110; 96; 60; 49
Vanderhoof	83; 60; 58; 55; 50

APPENDIX II

MAIs Derived on Point Samples

VANDERHOOF

Soil Series	
Acid Brown Wooded Soils	
Cobb	122; 82; 55; 41
Gray Wooded Soils	
Beaverley	92; 70; 60; 59; 58; 53; 50; 41
Cinema	64; 60; 56; 54
Deserters	109; 104; 89; 49; 48
Vanderhoof	87; 67; 60; 58; 56