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THE MEASUREMENT OF PHYSIOGRAPHIC FEATURES AND THEIR POSSIBLE SIGNIFICANCE TO FOREST GROWTH

by

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INTRODUCTION

Physiographic features of the environment are recognized as having an important influence on the nature and rate of growth of forest stands. In a relatively descriptive and subjective form, these features are presently receiving much emphasis in forest capability and land classification projects as indicators of variations in basic site potential. Such projects (e.g. see Hills and Pierpoint, 1960; Lacate, 1966) usually are based on a recognition of various geomorphological, landform, or landtype units. These units and the forests growing on them are a manifestation of the combined effects of various individual physiographic factors. The latter are often ill-defined and their specific effects on forest growth poorly understood.

A study was started in the Newfoundland Region in 1968 to investigate the effects of a large number of individual physiographic and edaphic factors on tree growth. Much of the island of Newfoundland is of a rugged character, and it is considered that certain physiographic factors may be important indicators of variation in growth potential.

This first report is concerned mainly with the topographic factors that are being studied, but also includes reference to certain larger-scale, "geographic" features such as latitude and longitude and distance to the sea. For each factor the discussion centers on methods of measurement, possible direct effects on tree growth, and indirect effects via such features as climate (including "exposure"), soil type, drainage, and nutrient supply.

Other features such as geology and soil type which are usually included within the wider concept of land type are not of immediate concern to this report and are only discussed in as far as they are indirectly involved with certain of the topographic features. The direct significance of various soil factors will be discussed in later reports.

Measures of many of the physiographic factors can be obtained from large-scale maps or aerial photographs. Maps are the most useful for measuring those factors which are evaluated in relation to contour lines (e.g. elevation, shape of slope) but aerial photographs can readily be used instead of maps for certain other features (e.g. percentage distance from ridge line, aspect). Details of the methods used to derive values for topographic variables from aerial photographs have been given by Bajzak (1964).

The discussion in this report of the potential significance to tree growth of these physiographic factors should not be taken as any absolute indication of their importance. For any given area, other environmental factors may cause a particular feature to be of no significance or of inverted significance in relation to tree growth. Exact effects within any given set of circumstances can only be determined by the development of quantitative site evaluation or similar studies in which these factors are equated with tree growth in the presence of many other, potentially significant, environmental features.

Quantitative factor evaluation can permit an exact determination (with statistical accuracy attached) to be made of the influence of a given factor, in the presence of all others, on the growth or stand development of a given tree species or forest type in any given area. Thus it is possible to determine which factors affect growth potential in that area and how closely the measured topographic features reflect meaningful variations in site conditions.

Where overall climatic conditions are favourable to tree growth and where there is little topographic variation, none of the factors listed in this report may have any major influence on tree growth. Conversely, where there is a large amount of topographic variation or where exposure to severe climatic conditions is a major factor (as, for example, appears to be the case on Newfoundland's Avalon Peninsula), the topographic variables may constitute direct or indirect measures of a large proportion of the growth variation that occurs.

Many of the factors discussed are well-known and obvious ones. Others have been less widely used and reported, while one or two involve previously unreported methods for their measurement.

PHYSIOGRAPHIC FACTORS

Elevation

Elevation (or height above sea level) is a very simple and obvious environmental factor which nevertheless often has complex interrelationships with other site factors and with tree growth. It is most usually obtained from a contour map, but may also be derived from aerial photographs (provided the heights of a limited number of reference points are known). Simultaneous readings from a pair of barometers, one of which is at a known elevation, may provide a useful alternative means of determining elevation, especially when the exact map location of the sample point is not known. A surveyor's level or a topographic abney level and tape are suitable for obtaining detailed elevation figures for small areas.

An increase in elevation is usually associated with a decrease in growth rate for any particular tree species and, over a larger range, a change in the natural forest type. Its significance is not as a causal factor, however, but as an indicator of changes in many other environmental factors of more direct influence on forest growth. Increasing elevation usually implies increasingly severe climatic conditions, such as greater wind speeds, lower temperatures, and higher rainfall, until ultimately a point is reached beyond which tree growth is no longer possible. Soils at higher elevations are usually relatively poor, with lower nutrient status due to a greater degree of leaching. Total soil depth is often less at higher elevations, particularly on or near ridge top situations, and thus it may be possible for moisture deficits to occur at certain seasons of the year despite the tendency towards higher rainfall in such situations. The usual effects of elevation may sometimes be entirely masked by reverse trends in soil factors which have a relatively greater influence on tree growth.

Aspect

Aspect or bearing is a measure of the direction of greatest exposure. It can be recorded from a map, an aerial photograph, or in the field using a prismatic compass. In the latter case readings are obtained as magnetic bearings which can be converted to true north or grid north bearings by the application of the declination appropriate to the time and place of measurement. Readings will normally be taken in the direction of steepest slope, and may refer to local topography or to larger topographic features surrounding the area.

The only problems that are likely to arise in determining aspect readings relate to ridge top, valley bottom, and perfectly flat situations. For some purposes these situations can be regarded as having no aspect, but for other purposes it may be necessary to assign an aspect reading to them. Flat areas may be assigned an aspect according to the layout of surrounding areas of high and low land. Valley bottoms usually exhibit some degree of slope as indicated by the direction of stream flow, and this direction can be measured as aspect. Ridge top positions are the most difficult to deal with, but it may be possible to assign values according to surrounding higher ridges, or alternatively to assign the aspect reading associated with the poorest growth on the assumption that such sites are fully exposed to the influence of the limiting factors concerned.

Aspect readings in degrees can be related directly to forest growth, but any relationship that is present will appear in a curvilinear form. Since it is not usually convenient to use such relationships in computer analyses of tree/site interrelationships, a method of converting such readings into a linear form has been derived (see Trimble and Weitzman (1956) and Beers, Dress, and Wenzel (1966)). A prerequisite for this conversion is the recognition of that bearing associated with the poorest growth. A bearing 90 degrees from the poorest bearing in a clockwise direction is used as the base for converting the bearings into sines of the angles. For example, if the bearing associated with the poorest growth was found to be southwest, then northwest would become the new zero point, all readings would be adjusted accordingly (for example, north, which was 0°, would become 45°), and the sine conversion would be carried out from northwest in a clockwise direction. The method is illustrated in Figure 1. A constant of 1 is added to all sine values in order to avoid negative data, giving the following results: sine $0^{\circ} = 0.0000, + 1 = 1.0$; sine $90^{\circ} = 1.0000, + 1 = 2.0$; sine $180^{\circ} = 0.0000, + 1 = 1.0$; sine $270^{\circ} = - 1.0000, + 1 = 0.0$. There will thus be a linear scale from 0 for the poorest bearing, through 1.0 for the two intermediate bearings, to 2.0 for the most favourable bearing.

The relevance of aspect readings will vary according to the overall climatic

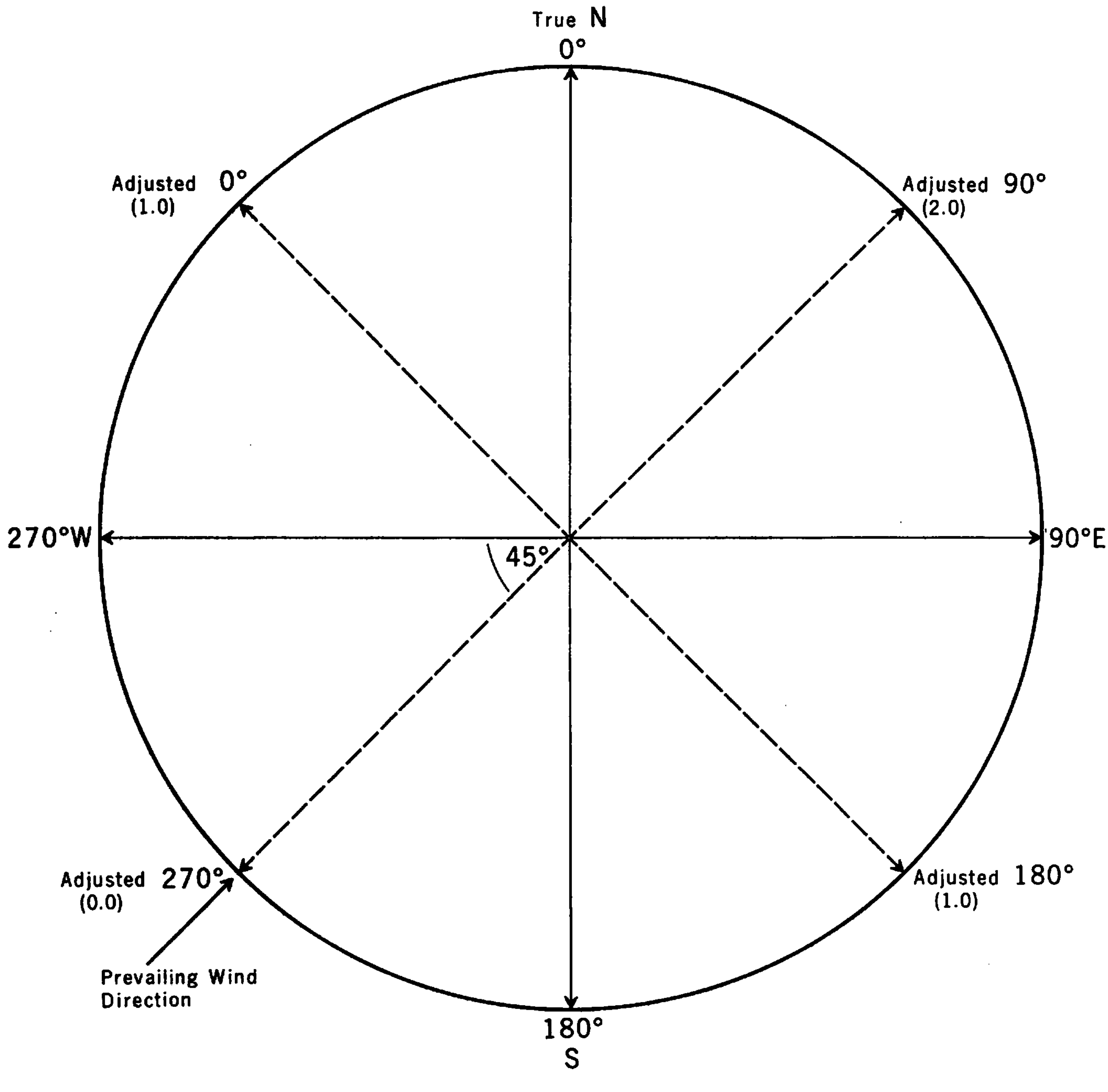

Fig. 1. CONVERSION OF ASPECT READINGS

Prevailing wind direction has poorest growth in example given; azimuth readings therefore commence from NW (Adjusted 0^{o}), true North becomes 45^{o}, etc...

Figures in brackets are values obtained after applying "Sine of azimuth from NW, + 1".

——→ True bearings
---→ Adjusted bearings

conditions in the area concerned. In areas exposed to high winds, the bearing facing the prevailing wind is likely to show the poorest growth, while in hotter and drier climates those bearings exposed to the sun during the hottest part of the day may be the poorest. In the latter case moisture stress is likely to be the direct cause of poor growth. Under less extreme climatic conditions aspect may not be of any practical significance or its effects may be considerably modified by the interaction of several environmental factors.

Percent distance from the ridge line

This is a measure of the distance of a point from the ridge line relative to the total distance from ridge line to valley bottom. Normally it is recorded along the aspect line, i.e. in the direction of steepest slope. Values may be derived from a map or aerial photograph, the measurements required being illustrated in Figure 2. The proportions are usually measured in a horizontal plane, but it is also possible to calculate percent distance from the ridge according to vertical distances from ridge to valley bottom. It is normally easy to recognize ridge lines and valley floors, but a decision as to what size of rise or depression constitutes a ridge or a valley may present a problem. An arbitrary minimum change of 50 feet (i.e the minimum difference that can be recognized from contours on the 1: 50,000 map series) is perhaps the most convenient indication of the presence of a ridge or valley for most purposes, but smaller or larger limits can be established if desired.

Percent distance from the ridge line is a measure of exposure, independent of elevation. When treated as an independent factor it is only likely to be related to tree growth within limited areas where there is no large range in elevation. It may be a very valuable indicator of site potential over larger areas, however, when considered in combination with elevation. Under such

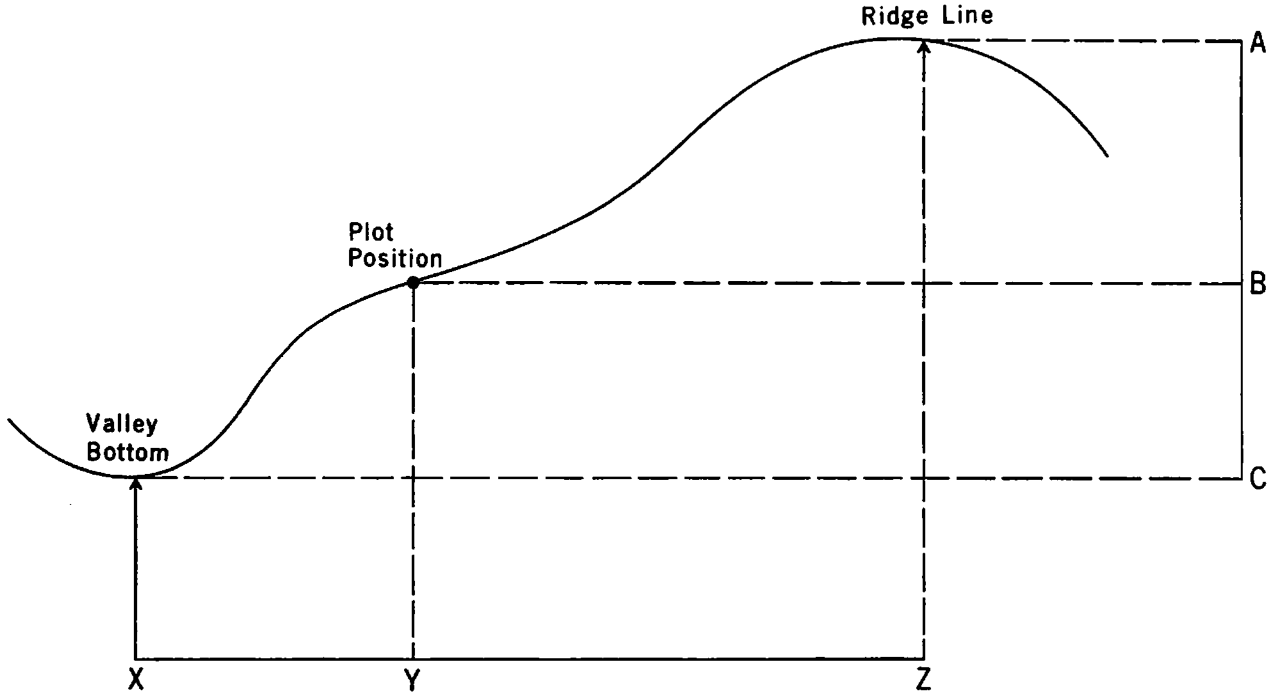

Fig. 2. DERIVATION OF VALUES FOR PERCENT, VERTICAL, AND HORIZONTAL DISTANCES FROM RIDGE LINE.

Percent distance from ridge line (horizontal plane)

$$= \frac{YZ}{XZ} \times 100\%$$

Vertical distance from ridge line
= (Elevation of A) - (Elevation of B)

Horizontal distance from ridge line = YZ circumstances it can add considerable refinement to simple elevation figures, especially where exposure to wind is an important consideration. Distance from the ridge may also be related to trends in soil factors, with the higher values (i.e. valley bottoms) typically being associated with greater soil depths, higher nutrient contents, but also often poorer drainage conditions; many of the opposite conditions are found on or near ridge tops (low percent distance from ridge values). Since this factor is, to a considerable extent, an indirect measure of a number of soil conditions, the local occurrence of non-significant or inverted relationships with tree growth is not uncommon. For example, middle and lower slopes frequently support better tree growth than either valley bottoms or upper slope and ridge positions.

<u>Horizontal distance from the ridge line</u>

This is a simple measure of the distance from ridge line to a point in a horizontal plane (see Figure 2), and as such it is one component used in the determination of percent distance from the ridge line as detailed above. It would normally be determined from a map or aerial photograph, and measured along the aspect line.

Local topographic and soil conditions may create circumstances in which horizontal distance from the ridge is a good indicator of tree growth potential. In a wider context, however, it is probably a less meaningful factor than percent distance from the ridge and therefore not one on which much emphasis need be placed. It may, however, have some value as a factor complementary to percent distance from the ridge.

<u>Vertical distance from the ridge line</u>

This factor is a measure of the elevation difference between a point and the ridge top immediately above the point along the aspect line (see Figure 2).

It is not usually involved in any of the other parameters so far discussed, and it may therefore be a factor worthy of consideration. It can most conveniently be obtained from a contoured map, although field determination using levels or barometers is also possible.

Changes in certain soil factors may be associated with varying vertical distance from the ridge in much the same way as they are associated with percent distance from the ridge, but such relationships are only likely to occur within confined areas where topography is relatively uniform. On a larger scale, vertical distance from the ridge is usually a measure of relative exposure only. Since this factor uses an absolute rather than a relative scale, it may provide useful information when used with percent distance from the ridge and/or elevation values.

Change in elevation per mile

Change in elevation per mile can be defined as the difference in elevation between the highest and lowest points crossed by a line drawn through a given point to appropriate, and equal, distances on either side. The line can be drawn in any direction, although the use of the aspect line is probably the most logical approach. Alternatively, the average or the overall maxima and minima from several lines in different directions may be used. The use of a distance of one mile is entirely arbitrary and any other distance which is considered meaningful may be substituted if desired. Furthermore, values may be obtained 'per mile' over a distance of one mile, or 'per mile' by averaging values over a distance of two miles or more.

This factor is a measure of the overall topographic nature of a given area (i.e. whether it is relatively flat, or rolling, or rugged in character), but bears very little relationship to the position of a point with regard to these topographic features. For a given area of land, change in elevation per mile can have a very similar value whether the point concerned is near a ridge top or a valley bottom. It does not therefore provide any indication of local shelter effects. However, on a larger scale it does provide a comparison between areas of different topographic character and possibly of the average crop performance in such areas.

<u>Percent slope</u>

Percent (or degree) of slope is a further very simple and obvious topographic variable. It can be determined from a map, an aerial photograph, or in the field with a level (commonly an Abney level) or a hypsometer. It can be expressed as a percentage value (0-100%), as a degree of slope (0-90°), or as a gradient (e.g. 1 in 10.0, 1 in 4.5, etc.). 45° — 100%

Percent slope may be correlated with various soil factors depending on local circumstances. A steeper slope will usually imply more rapid drainage, although the significance of this will depend on other factors such as soil texture and the overall topographic position of the point. The development of soil profile morphology may be partly controlled by degree of slope. Very steep slopes are likely to be associated with shallow soil depths, high stone contents, and a high proportion of rock outcrops. Percent slope may be a sensitive indicator of growth potential within an area of relatively uniform soil and topography, but over wider areas it very often becomes compounded with other factors to such an extent that no meaningful relationships remain.

In temperate latitudes the ideal stocking of crops may be dependent on slope. The angle of incidence of light rays and the arrangement of the tree crowns on a moderately steep hillside are such that growth can be maintained on a greater number of stems per (horizontal) acre than on a flat area.

Shape of slope

Shape of slope refers to the configuration of the ground up- and down-slope from a given point. It can be subjectively classified from a map, an aerial photograph, or field observation into three major classes of convex, straight, and concave, with intergrades between them where desirable. A simple means of defining shape of slope in mathematical terms has also been devised and is illustrated in Figure 3. The horizontal distances along the aspect line from a point to fixed vertical distances above and below are measured, and the distance above the point divided by the distance below (i.e. in Figure 3, AB/AC or XY/XZ). This gives an index of more than 1 for convex situations (the greater the reading the more convex is the position), of 1 for straight slopes, and of less than 1 for concave situations. Any convenient vertical distances above and below the point can be used. However, since the 1: 50,000 map series records contours at 50-foot intervals, that figure is often most convenient. Furthermore, in those areas where tree crops rarely exceed 50 feet in height, this vertical interval represents some degree of shelter throughout the complete height of the crop. Where tree crops commonly achieve heights of more than 50 feet, a vertical interval of 100 feet may be more suitable.

The only problem in measuring shape of slope arises where a ridge line or valley bottom occurs at less than 50 vertical feet from the point concerned. Under such circumstances the most accurate picture of slope shape may be obtained by continuing the measurement of distance until the line crosses a different contour from the one on which the point is situated. Thus, for example, when the point is near a valley bottom, distance below the point would be measured past the valley bottom (which may be up to 40 feet below the point) and continued up the other side to a contour 50 feet above the point contour. Similarly

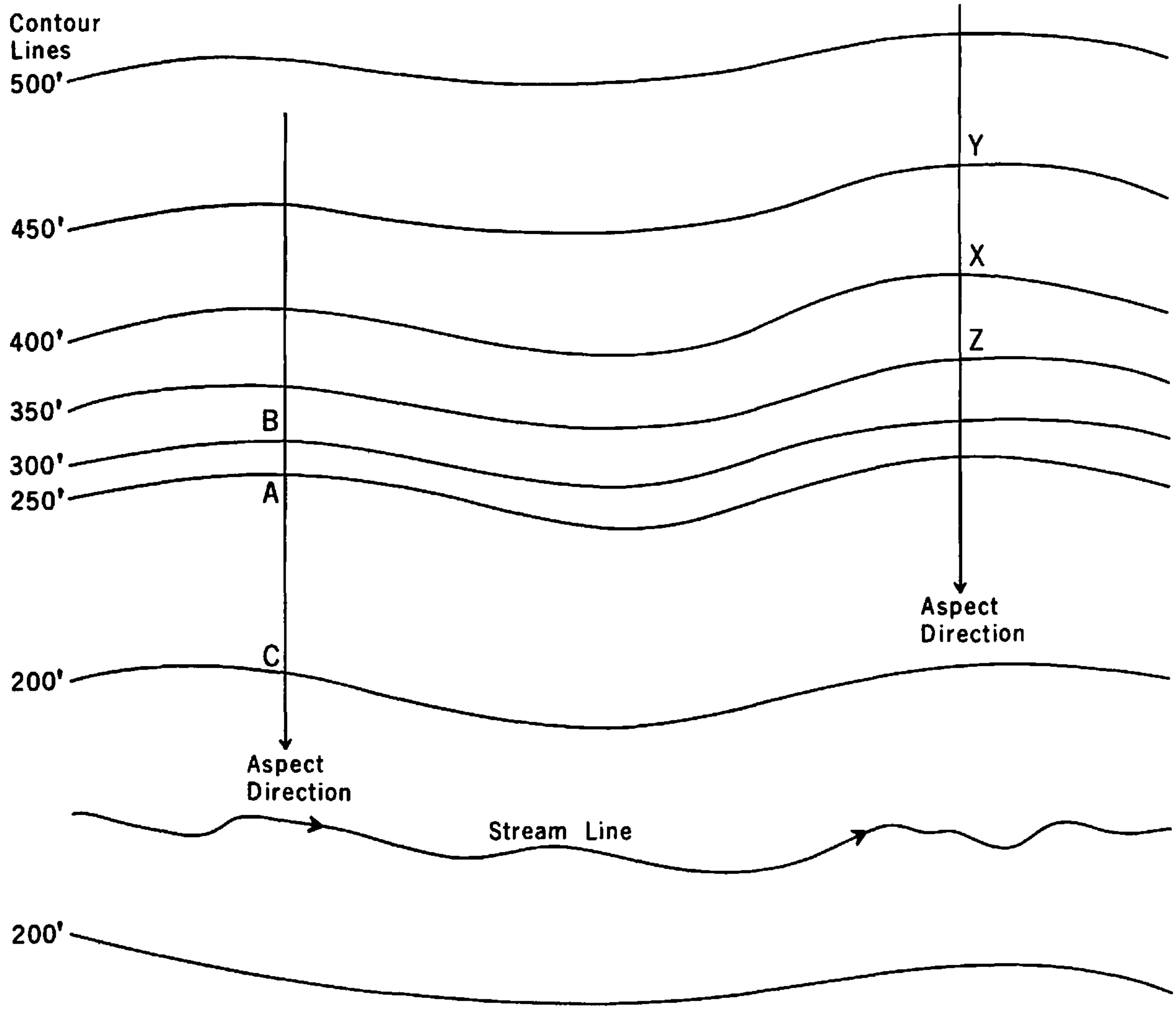

Fig. 3. MEASUREMENT OF SHAPE OF SLOPE

Shape of slope at A

$$= \frac{AB}{AC} = \quad < 1 \quad \text{(concave)}$$

Shape of slope at X

$$= \frac{XY}{XZ} = \quad > 1 \quad \text{(convex)}$$

near a ridge top, distance above the point may be measured across the top of the ridge to a contour 50 feet below the point contour. Repeat occurrences of the point contour are ignored. On very flat areas where there are no features more than 50 feet in height it is usually necessary to set an arbitrary limit to the length of the line. Ideally this limit should correspond to the limits required when calculating shape of contours (see below).

Shape of slope is an indicator of local topographic variation which may modify the influence of other factors. For example, a convex 20% slope is likely to be more freely drained and probably less rich in nutrients than a concave 20% slope. Shape of slope defines the susceptibility of a given situation to exposure at a more localized level than does elevation or percent distance from the ridge. A convex slope is usually more exposed to wind, while a concave slope is more sheltered but also often more susecptible to the development of frost pockets.

Shape of contours

This factor is essentially similar to shape of slope, except that it refers to local topographic variation in a horizontal plane about a given point. It can be derived from the same sources as shape of slope, and may be classified into convex, straight, or concave. It can be measured from a map by constructing a line at right angles to the aspect line through the point (see Figure 4). For convex situations this line cuts contours below the point contour., and for concave situations it cuts contours above the point contour. For concave situations the total length of line (i.e. AB + AC, in Fig. 4) is measured, giving low values for very concave situations up to an arbitrary limit (100 units each side of the point in Figure 4, representing 1,2,3, or more miles, or any other chosen distance) which may be considered straight. For convex situations

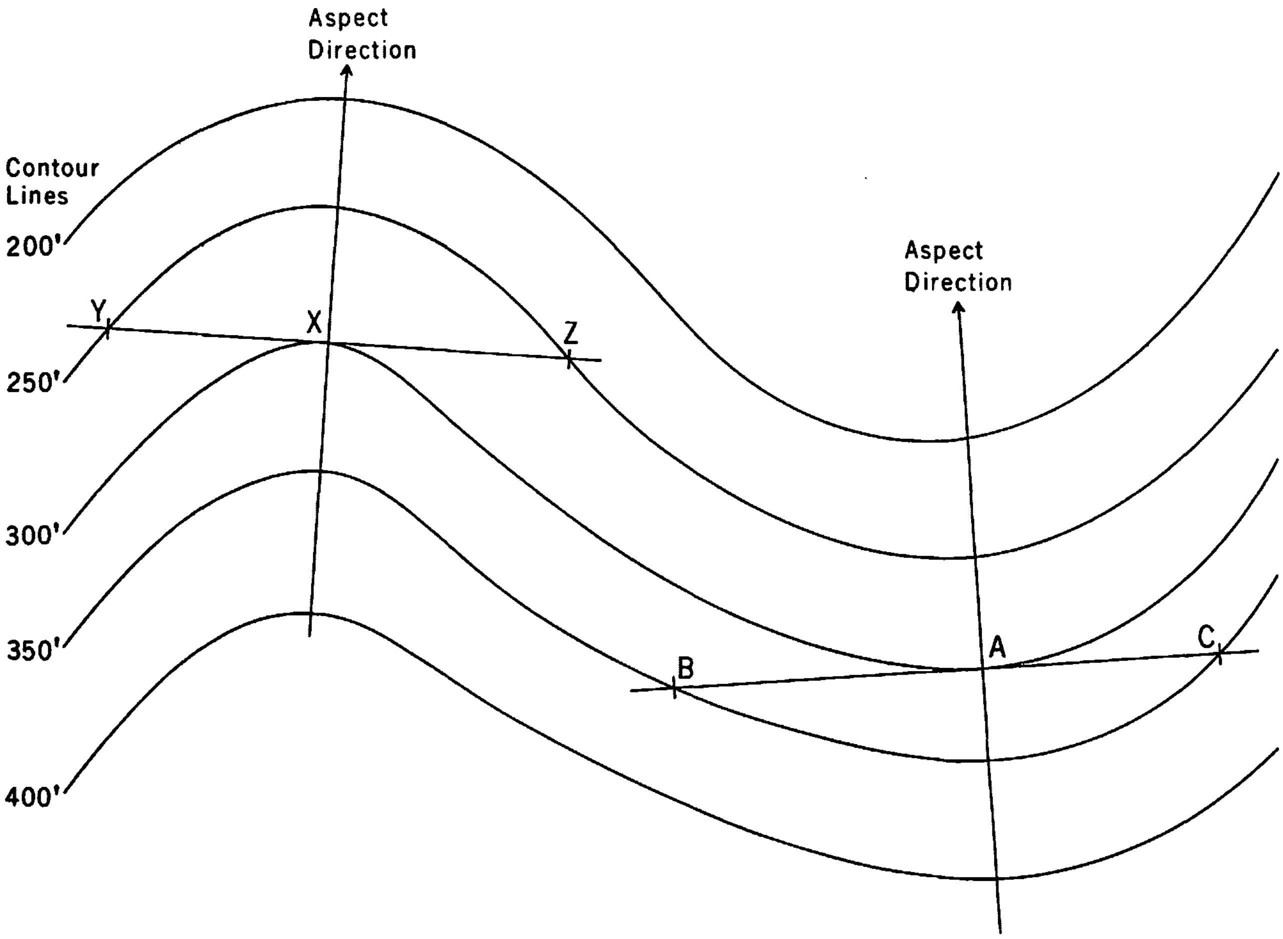

Fig. 4. MEASUREMENT OF SHAPE OF CONTOURS

Shape of contours at A (concave)

= AB + AC (up to an arbitrary maximum of 100 units of distance each side of A).

Shape of contours at X (convex)

= (200-XY) + (200-XZ), with an arbitrary maximum length of 100 units on each side of X.

the same measurements are taken, but in order to distinguish them from concave measurements the distances on each side of the point (XY and XZ in Figure 4) are subtracted from 200 units, thereby giving values of just greater than 200 for slightly convex sites and values approaching 400 for very convex sites. As for shape of slope, crossing and recrossing of the point contour is ignored when measuring the required distances. Occasionally, the contours may be convex on one side of a point and concave on the other. In such cases the convex side is measured and subtracted from 200 units, the concave is measured direct, and the two are then added to give the overall value. If the convexity on one side is more clearly marked than the concavity on the other, then a total value of more than 200 will result, while if the reverse is true the resultant figure will be less than 200. The overall nature of the topography should be used as a guide in fixing the arbitrary limit on length of line to be measured, to ensure that any variation which is meaningful to tree growth is recognized while avoiding using too long a line which would result in most of the data being separated into two groups at either end of the scale.

The relationships of shape of contours to other topographic and soil variables are essentially the same as those for shape of slope, except that variations in a different plane, which may be more or less meaningful according to local circumstances, are being sampled.

Angle to the horizon

This is a measure of the average angle (in degrees) in relation to the horizontal subtended by a line from a point to the skyline, and derived from readings taken on a number of compass bearings. The use of this factor has been tested in Britain (Howell and Neustein, 1966) and some, mostly inexact, relationships with flag tatter rates have been shown. In this work the average values were derived from readings taken from points in 16 principal compass directions. A level or a hypsometer can be used to determine the appropriate angles. This factor is potentially of use in non-forested areas, but cannot usually be measured under forested conditions due to the impossibility of sighting to the horizon from beneath a forest crop. Under the latter conditions it may be possible to obtain a value from map measurements, but such a process would be extremely time-consuming and not worthy of practical consideration.

In open conditions angle to the horizon can be a useful measure of exposure since it integrates the shelter effects of high ground at some distance from the point with somewhat lower ground closer to the point. However, the significance of such shelter effects will vary with the elevation and general climatic conditions of the area conderned. Within relatively limited areas, large angles to the horizon are likely to be associated with valley floors and lower slopes (and usually better tree growth) whereas small angles are associated with ridges and upper slopes (and thus also poorer tree growth).

Distance to the sea

Distance to the sea may be of significance to forest growth under maritime climates. The distance can be measured from a point to the sea at its nearest, and/or to the sea in the direction of the prevailing wind. Furthermore, the term 'sea' may refer to all areas of salt water regardless of whether they be open ocean or enclosed inlet, or, alternatively all enclosed inlets may be discounted (i.e. treated as if they were land) and measurements taken to the nearest area of open sea.

Distance to the sea is a measure of the exposure of an area to the salt-laden and relatively high velocity marine winds. Certain tree species are thought to be susecptible to both of these factors, in particular to the high concentrations of salt. Salt-laden wind may cause poor tree growth in coastal forests and may also affect the species composition of such forests. Needle scorch is commonly encountered in the most exposed coastal regions.

Latitude and longitude

Longitude is not causally related to forest growth in any way, but under certain circumstances it may be an indicator of important climatic differences. Thus it may be related to growth and forest type differences between eastern and western sides of continents, between areas of different rainfall, or in areas such as the western side of the Rocky Mountains where it is correlated with altitude differences.

Latitude is a factor of more obvious significance, being associated with global climatic zones and forest types, and within the forest types to the performance of the individual species. It is not usually sufficiently sensitive to be of value on a more local scale, although it may be a valid indicator of climatic change over an area of relatively uniform soil and topography (e.g. see Della-Bianca and Olsen, 1961). Latitude of origin is commonly an important consideration in phenological and provenance studies of a given species.

Site drainage

Site drainage is a somewhat different type of factor to those already discussed. It can be recognized as an independent factor, but its classification depends on the nature of several other, more basic, topographic factors. Thus it is a complex factor which cannot be measured directly but must be classified on a subjective scale. The classes most commonly recognized are "shedding", "normal", and "receiving", with intergrades where desired. A "shedding" site is one which, on the basis of its topographic features, is considered to lose a high proportion of the soil moisture that it receives. A "normal" site loses about as much soil moisture as it receives, whereas a "receiving" site receives more moisture from all sources than it loses by drainage. These classes are recognized entirely on the basis of topographic features with no regard to the soil conditions which may considerably modify the typical relationships. A shedding site typically occurs on an upper slope, ridge top, or knoll, with at least a moderate slope, convex in shape. A normal site may be on a mid-slope or a relatively flat area, while a receiving site usually occurs on lower slopes and valley bottoms or other depressions, with little or no slope, in concave positions.

Significant relationships between site drainage and tree growth are most common where physical soil factors are uniform. Under such circumstances site drainage will be an indirect measure of soil profile drainage, and will probably be related to various nutrient and moisture regimes, varying accumulations of organic matter, and the development of soil profile morphology. Where soil conditions are not uniform, the effects of site drainage are usually much modified and a clear relationship with tree growth often cannot be established.

"Exposure"

Exposure has already been referred to in a general sense with regard to several of the above factors. Most of them are, directly or indirectly, partial measures of overall exposure conditions and as such they often, either alone or in combination, show valid and reproducible relationships with tree growth. Exposure as one undivided factor may, however, also be determined visually or by the use of tatter flags. A subjective visual assessment and classification into classes such as slight, moderate, high, and severe can be attempted with reference to local topographic and vegetation conditions. However, ratings by different observers are not readily comparable.

The use of rate of tatter of standard cotton flags has been pioneered in Britain (Lines & Howell, 1963) and adopted elsewhere (e.g. Nickerson, 1968) as a means of determining the relative exposure of potential afforestation sites. Good relationships between rate of flag tatter and early plantation growth have been recorded on a number of occasions. Practical or interpretation difficulties centre largely round two aspects of this work, namely the necessity to maintain flags at experimental sites over a period sufficient to obtain reliable tatter values (this is in contrast to all the other factors which have been discussed which require only one field visit or one map measurement), and the present ignorance of the precise meteorological factors affecting flag tatter rates. However, since good relationships between tatter and tree growth have been demonstrated, tatter rates must represent a high proportion of those exposure factors which have an influence on tree growth, and they thus provide a useful silvicultural tool where circumstances permit their establishment.

DISCUSSION AND CONCLUSIONS

All the factors discussed in this report can be valuable indicators of tree growth potential under appropriate circumstances. The majority are easy to measure, and provide objective and reproducible indices of exposure and, indirectly, various soil factors. Those factors which are not measurable, while useful under many circumstances, are not as reliable owing to their involvement with personal judgement.

No single nor any small group of factors can provide a complete measure of all topographic variation potentially significant to tree growth. Unquestionably, however, certain of the factors which have been discussed are of more universal importance than others. The size of area over which they are likely to be meaningful determines much of their worth as indicators of growth potential variation within a site evaluation or land classification system. On this basis the factors may be ranked in general order of importance and those of higher ranking given preference.

A very tentative list might include as the most important, elevation, percent distance from the ridge, aspect, site drainage, and possibly "exposure". Of secondary importance would be vertical distance from ridge, shape of slope and contours, percent slope, angle to horizon (in non-forested areas only), and distance to sea (under maritime climates only), while the lowest rating would include change in elevation per mile, horizontal distance from ridge, and latitude and longitude. More important than any list of this kind, however, is a recognition that local circumstances are of overwhelming importance in this matter, and that a satisfactory list of this type can probably only be constructed with reference to clearly defined areas and with the inclusion of soil factors as well as the topographic ones. Even then, the completed measurements may, and often do, reveal significant and unexpected relationships which were not discernible by visual observation of either site conditions or tree crops.

Certain topographic factors directly influence current forestry practice. Usually this is because of their obvious significance to the operation of machinery for extraction or site preparation, and not because of any recognition of their significance to forest growth. Hopefully, however, when much more exact knowledge of site/tree growth interrelationships is available, the impact of those topographic factors of proven significance to tree and crop performance will be recognized and taken into account by practical forest management.

LITERATURE CITED

Bajzak, D., 1964. Interpreting phytosociologic forest site types from aerial photographs. Can. Dept. Forest., For. Res. Br. Mimeo Rep. 64-N-12; 17 pp.

Beers, T.W., P.E. Dress, and L.C. Wensel, 1966. Aspect transformation in site productivity research. J. For. 64; 691-692.

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

Hills, G.A. and G. Pierpoint, 1960. Forest site evaluation in Ontario. Ont. Dept. Lands Forest., Res. Rep. 42; 64 pp.

Howell, R.S., and S.A. Neustein, 1966. The influence of geomorphic shelter on exposure to wind in northern Britain. For. Comm. Lond. Rep. For. Res. 1964/65; 201-203.

Lacate, D.S., 1966. Wildland inventory and mapping. For. Chron. 42; 184-194.

Lines, R., and R.S. Howell, 1963. The use of flags to estimate the relative exposure of trial plantations. For. Comm. Lond. For. Rec. No. 51; 31 pp.

Nickerson, D.E. 1968. Initial trial of exposure flags on the Avalon Peninsula, Newfoundland. Can. Dept. Forest. Rural Develop., Information Report N-X-21; 17 pp.

Trimble, G.R. and S. Weitzman, 1956. Site index studies of upland oaks in the northern Appalachians. For. Sci. 2; 162-173.