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A Method of Site Quality Evaluation for Red Alder

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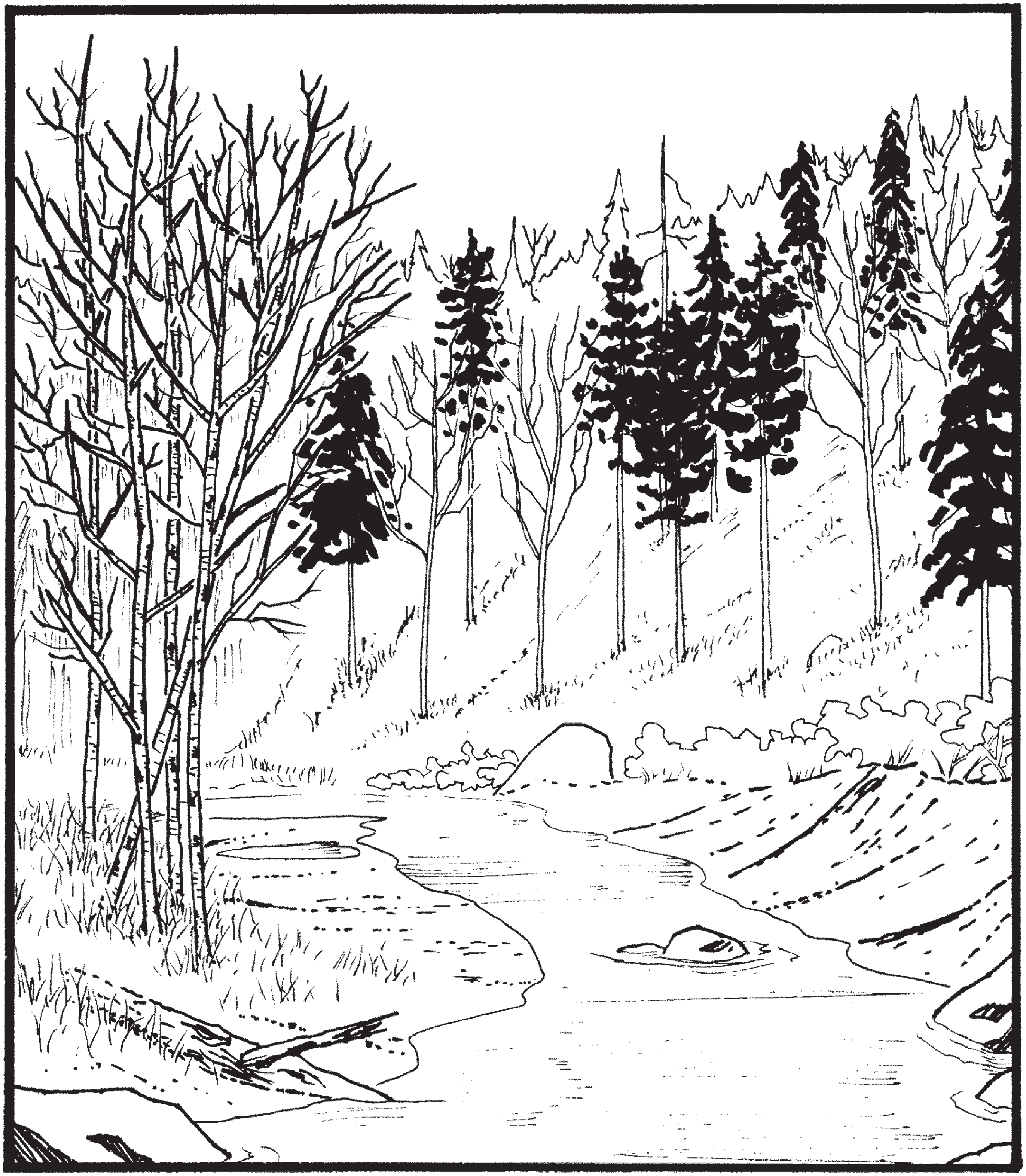

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Abstract

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A field guide to predict site index for red alder (*Alnus rubra* Bong.) was developed for use in western Washington and Oregon. The guide requires the user to evaluate 14 soil-site properties that are grouped into three general factors: (1) geographic and topographic position, (2) soil moisture and aeration during the growing season, and (3) soil fertility and physical condition. Construction of the guide was modeled after a method of site evaluation developed for several southern hardwood species. The red alder model is accurate when used properly. The correlation (r) between predicted and measured site index was 0.97 for the basic data set of 25 plots and 0.96 for the 15 plots used for verification. Estimated site index should be within ± 2 meters of measured site index 95 percent of the time. Use of a second independent data set for model verification resulted in a somewhat lower correlation (r = 0.89) between measured and predicted site index than was achieved with the original data set, but the model continued to meet the accuracy standard of ± 2 meters ($p \leq 0.05$).

Keywords: Site class, site index, guidebooks, models, red alder, *Alnus rubra*.

Contents

Introduction

Forest managers need site-specific information on site quality to make intelligent decisions regarding species selection and management practices. The most commonly used measure of potential site productivity is site index (mean height of upper crown class trees that have been free to grow in an even-aged stand at a specified index age). It is, however, difficult or impossible to accurately assess site index in stands that are uneven aged, mixed species, very young or very old, or on sites where the species of interest is not growing.

Several methods have been developed for predicting site quality for a species when it cannot be directly measured (Mader 1965). The most common methods use: (1) measured soil and site characteristics in a mathematical equation, (2) soil mapping units, or (3) the presence or growth of other plant species. Prediction of site index by use of soil and topographic characteristics in a multiple regression equation (method 1) was popular in the United States from the 1930's through the 1960's; Coile (1952), Ralston (1964), Berglund (1968), and Carmean (1975) provide good reviews of the subject. These studies were useful in identifying the soil and site characteristics correlated with site index. In most studies the selection of variables for the final regression equation was based on mathematical relationships. Composite or transformed variables, as well as simple variables, were often utilized. Many of these mathematical soil-site studies resulted in final prediction equations with high multiple correlation coefficients. The biological interpretation of the resulting complex equations was often difficult, however, and the applicability of the equations was usually limited to small uniform areas. In addition, equations that accounted for the majority of observed variations in site quality could not always be developed. This type of classical soil-site study has been criticized for both mathematical and biological reasons (Broadfoot 1969, Hodgkins 1959, Lloyd and Lemmon 1970) and is currently used much less commonly than in the past. Use of existing soil mapping units or other plant species has been helpful in distinguishing between broad classes of productivity; however, in most cases these approaches have not yielded the desired precision for estimating site quality (Harding and Baker 1983, Mader 1965, Youngberg and Scholz 1949).

In 1977, Baker and Broadfoot of the Southern Forest Experiment Station published a new method of site quality evaluation that combined both subjective and objective approaches. They first evaluated the relative importance of four major soil factors on growth of a particular species. The soil factors were: (1) physical condition, (2) moisture availability during the growing season, (3) nutrient availability, and (4) aeration. Next, they identified (and later quantified) the specific soil-site properties that best described or summarized the effect of each soil factor. They then developed field guides that could be used in evaluating site quality for 14 southern hardwood species; verification with field data indicated high accuracy over a broad range of sites (Baker and Broadfoot 1977, 1979).

This paper presents a set of site evaluation tables for predicting site index for red alder (*Alnus rubra* Bong.) The tables contain 14 soil and site properties organized into three major factors: (1) geographic and topographic position, (2) soil moisture and aeration during the growing season, and (3) soil fertility and physical condition. The red alder model was patterned after Baker and Broadfoot's (1977, 1979) approach; that is, the basic framework was subjectively derived based on an understanding of the site requirements of the species. The model was developed and tested with data from 40 natural stands located over a range of site conditions in western Washington and Oregon.

Field and Laboratory Methods

Forty natural, even-aged, well-stocked red alder stands in western Washington and northwestern Oregon were selected for sampling (fig. 1). Stand ages ranged from 25 to 50 years; mean age of all stands was 36 years. A deliberate attempt was made to sample a wide range of soil conditions and of productivity (table 1). All sampled stands were pure red alder, or when mixed, the other species were not in a crown position to have suppressed past alder height growth. Within each selected stand one 0.10-ha plot was established. Plot boundaries were kept away from roads and did not cross any obvious stand boundaries or changes in stand or site conditions. When soil and stand conditions were fairly uniform, plots were square (31.6 m on each side). Plots along streams or on terraces were rectangular, the long axis of the plot paralleling the stream or the long axis of the terrace. Rectangular plots were 50 x 20 m.

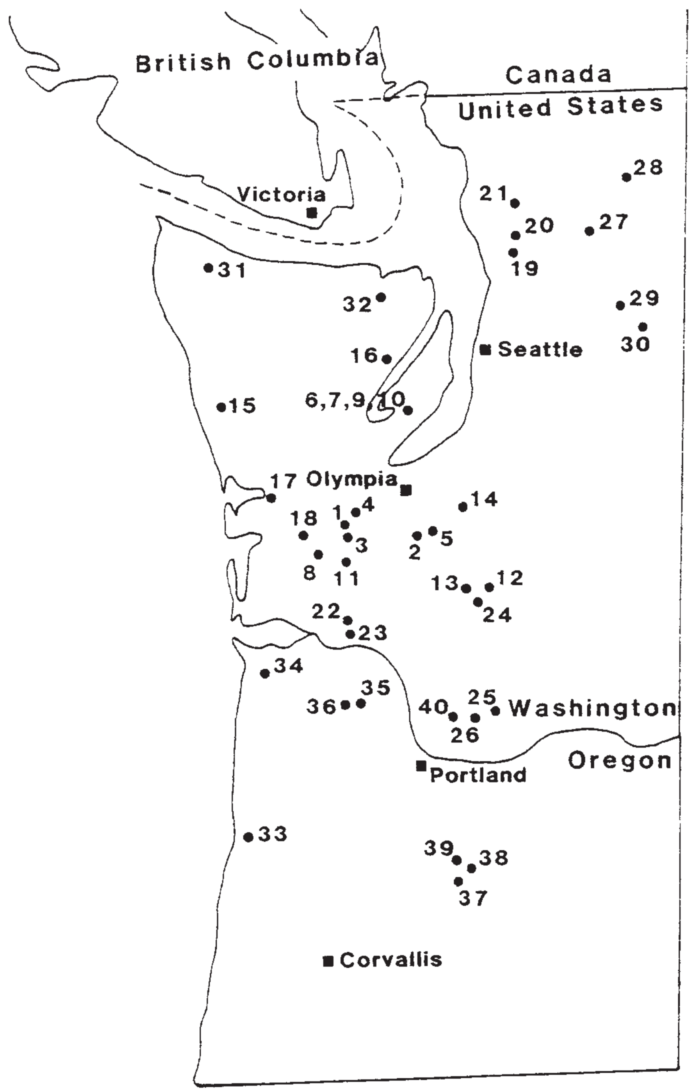

Figure 1.—Location of stands used in red alder site evaluation study.

Table 1—Summary of selected site characteristics on plots taken in red alder stands in western Washington and Oregon

Characteristics	Unit	Range	Mean
SI_{50}	Meters	21.0 - 38.5	28.6
Elevation	Meters	5 - 1025	242
Slope	Percent	0 - 40	13
Soil Conservation Service drainage classes	—	2 - 7	4
Surface soil (0-10 cm):			
Clay	Percent	1 - 49	24
Sand	Percent	1 - 85	33
Organic matter	Percent	.5 - 77.4	14.5
pH	—	4.2 - 6.3	4.9

On each plot, 10 dominant or codominant trees were selected to be measured for site index. Selected trees appeared healthy and free from past top damage. Trees were bored with an increment borer to determine age at breast height; total height was measured with a telescopic abney. Site index (50-year base) was calculated from the equation of Worthington and others (1960).

Physiographic data recorded for each plot included aspect, slope percent, and physiographic position. Depth to water table during the growing season was estimated for sites along rivers and streams and for areas with poor drainage. Associated major and minor vegetation was also recorded along with comments on past history of the site (for example, evidence of burning, logging, or flooding).

In each plot at least two soil pits were dug, and their soil profiles were described. Pits were located on what appeared to be representative microsites; rotting logs, old skid trails, or other nontypical conditions were avoided. Pits were dug to a depth of 1 m or to an impermeable layer, whichever came first. Pit descriptions included depth, structure, texture, color, and coarse fragment content of each horizon. Presence of charcoal or organic debris, and extent of rooting were also noted by horizon. If the two pits on a plot differed in number, type, or texture of the horizons, a third pit was dug and described. All horizons 4 cm or thicker were sampled for bulk density. Soil volume for bulk density samples was determined in the field by use of a water-filled graduated cylinder with a rubber balloon and valve system (Blake 1965); soil weights were determined in the laboratory after samples were dried at 105 °C to constant weight. Bulk density samples were sieved for gravel and rock (>2 mm in diameter) the coarse fragments were weighed and their volume was determined by water displacement. Bulk density was calculated from both nonsieved and rock-free bases.

Two sampling transects were established in each plot. The transects were spaced to divide the plot into equal thirds. Ten sampling points were located on each transect so that there was an equal distance between the sampling points on the line and between the end points and the plot boundary. Sampling points were adjusted as necessary to avoid stumps, large rocks, or other obstacles. At each spot, samples of the forest floor and of mineral soil at 0 to 10 cm, 10 to 30 cm, and 30 to 50 cm were collected. Forest floor samples were collected with a circular template (13 cm in diameter). Heavy-gauge stainless steel tubes (7.5 cm in diameter) were used to extract the mineral horizons on most plots. Some plots were very rocky, however, and sampling spots had to be dug out with trowels and shovels. Soil samples were bulked by sampling layer, brought back to the laboratory, and air dried.

After the soil samples were air dried they were sieved and separated into soil (<2 mm in diameter), small gravel (2 to 8 mm), and large gravel (>8 mm). Each size component was weighed. The soil was then mixed well, and representative subsamples were extracted for determination of selected chemical and physical characteristics. Soil chemical characteristics were determined by the Cooperative Chemical Analytical Laboratory, Corvallis, Oregon, using the following procedures: total Kjeldahl nitrogen (Jackson 1958k Bray #1 extractable phosphorus (Jackson 1958); Walkely-Black organic carbon (Allison 1965k ammonium acetate cation exchange capacity (Jackson 1958); and exchangeable K, Ca, Mg, and Fe by ammonium acetate extraction, atomic absorption spectrophotometry (North Central Regional Soil Testing Committee 1980). Soil texture and pH were determined at the Forestry Sciences Laboratory, Olympia, Washington. Soil texture was determined by the hydrometer method of mechanical analysis (Bouyoucos 1962) with sodium hexametaphosphate as the dispersing agent; all samples were treated with 30 percent H_2O_2 to remove organic matter before particle size analysis. The determination of pH was made with a standard glass electrode on a 1:1 (v/v) mixture of distilled water and soil (USDA Soil Conservation Service 1972). A subsample of the forest floor from each site was dried at 105 °C to constant weight, and the ovendry equivalent weight of the total sample was determined.

Soil series or mapping unit was determined for each plot by comparing mapped information from USDA Soil Conservation Service, Washington State Department of Nautral Resources, USDA Forest Service, or private timber companies, with descriptions obtained in the field. Appropriate local personnel were contracted for assistance when profile descriptions of the soil mapping unit did not match the descriptions obtained in the field. Rainfall from April 1 through September 30 and number of frost-free days were taken from isohyetal maps (Dick 1955). Plot elevations were determined from topographical maps.

Model Construction

Construction of a model to predict red alder site index was accomplished in stages. First, a very general theoretical model, which listed the soil and climatic characteristics that could influence tree growth, was developed. This first model had five major components—soil physical condition, moisture availability during the growing season, soil fertility, soil aeration, and climatic characteristics.

The second step was to plot the relationships between site index and each of the measured variables. The graphs were visually examined, with particular attention given to the maximum values of site index that occurred over the range of values for the independent variable being examined. In addition, a rough tabulation was made for each property of: (1) the known variation in values throughout the natural range of the species and (2) the variation sampled in this study.

The next step in model construction was data analysis for the primary purpose of hypothesis generation. Standard statistical programs (Dixon 1981, Hull and Nie 1981) were used to perform the following analyses:

1. Simple correlation analysis (all possible combinations).
2. Stepwise discriminant analysis of three groups based on low, medium, and high site index.
3. Cluster analysis of the soil and site variables measured and of the individual locations.

The next stages in model construction required determination of the variables most closely related to site index, and for each of these variables determination of the levels associated with high and low site index. Twenty-five of the plots were randomly selected and used as a reference data set to aid in assigning quantitative values to selected variables or site characteristics. The characteristics used in this stage of model development had to meet the following criteria: (1) were theoretically important in modeling growth, (2) had substantial range in observed characteristics (at least ± 20 percent of the mean), (3) had differences in the levels of the characteristic associated with good and poor site index, and (4) were independent of (that is, poorly correlated with) other selected variables. One of the goals of this project was to provide a field guide for site evaluation that could be used by practicing foresters. Thus, when possible without reducing the accuracy of the model, the soil-site properties selected for inclusion in the model were those that could be determined with a minimum of special equipment.

The variable selection process can be illustrated by describing the steps involved in the selection of elevation, the variable with the most weight in the final model. The first theoretical model did not include elevation; it did, however, include several variables closely correlated with elevation such as length of the growing season and growing season temperatures. Generally a variable such as length of the growing season would be preferred over elevation because it more directly measures a property important to tree growth. Because of the varied and rugged topography in the region, however, many more climatic recording stations than currently exist would be necessary to provide good estimates of climatic variables. Thus, the imprecision associated with available estimates of climatic variables negated the theoretical value of having a variable that influenced growth in a direct manner. For research purposes it would be possible to estimate climatic variables from information on elevation and geographic location. This type of calculation did not seem to be warranted as it was unlikely that calculation would increase the accuracy of the relationship. In addition, users of the guide would find it easier to determine elevation than to calculate such variables as number of days in the growing season.

Elevation was highly correlated with site index and was the first variable used in the stepwise discriminant analysis; that is, of the measured variables, elevation was the most effective in separating poor, medium, and good sites. Red alder naturally occurs over a wide range of elevations, and this study sampled sites over much of the range. Thus, elevation was selected as the first variable for the model. Then, because of its high correlation with site index, elevation was determined to have a high weight in the model. Based on graphical analyses, the relationship between site index and elevation was determined to be linear. A line was drawn to correspond to the maximum values of site index (this technique is sometimes called boundary line analysis). The change in site index along this line corresponding to the maximum possible range in elevation was taken as a guide to the maximum number of site points that elevation could account for in the model. Because elevation was correlated with other variables used in the model, however, the whole range in site points observed in this two-variable relationship was not used in the final model.

Selection of the other variables to be included in the model and a preliminary determination of the maximum range in site points associated with each variable followed the same general procedure outlined for elevation.

Once the first set of variables had been selected and quantitative values were assigned, model refinement was basically an iterative procedure. The current version of the model was used to predict site index for the 25 reference plots. Soil-site properties on plots where the difference between predicted and measured site index was large were compared with soil-site properties on plots where the difference was small. This comparison facilitated the identification of the properties or levels of properties that appeared to be associated with poor model performance. Based on this information, the model was changed. The adjusted version of the model was then used to repredict site index for the 25 plots. Model adjustment involved primarily changing the values assigned to the levels of specific properties; however, two additional variables—bulk density and pH—were later added to the group originally selected.

Site conditions considered unsuitable for the species or the minimum and maximum levels for a specific soil-site property were sometimes determined from sources other than the plot data collected for the study. These other information sources included published reports on the silvics of the species (for example, Worthington and others 1962); personal communication with foresters, ecologists, and researchers familiar with the species; and personal observation.

The final model contains 14 soil-site properties divided into three general factors: (1) geographic and topographic position (which includes climatic properties), (2) soil moisture and aeration during the growing season, and (3) soil fertility and physical condition. The site evaluation tables developed from the model are given in tables 2, 3, and 4.

Table 2—Red alder site evaluation guide: factor 1, geographic and topographic position

Soil-site property	Level of property	Site points for each level
Elevation	Less than 100 m	8
	200 - 300 m	7
	400 - 500 m	6
	600 - 700 m	5
	800 - 900 m	4
	1000 - 1100 m	3
	Greater than 1200 m	Unsuitable
Physiographic position	Flood plain	5
	Terrace or bench (includes lower slope positions with slope $\leq$20 percent)	4
	Lower slope positions with slope >20 percent and midslope positions	3
	Depression in landscape, bog, or marsh	2
	Upper slope positions	1
	Ridgetop	0
Aspect and slope	Any aspect when slope 5 percent or less	4
	E or W with slope 10-20 percent; <u>or</u> N, NE, or NW with slope 10-30 percent	3
	S, SE, or SW with slope 10-20 percent; <u>or</u> E or W with slope 25-35 percent; <u>or</u> N, NE, or NW with slope 35-45 percent	2
	S, SE, or SW with slope 25-35 percent; <u>or</u> E or W with slope 40-50 percent; <u>or</u> N, NE, or NW with slope 50-60 percent (Subtract 1/2 for each additional 10-percent increase in slope)	1
Precipitation from April 1 through Sept. 30	Greater than 45 cm	3
	30 - 40 cm	2
	20 - 25 cm	1
	Less than 15 cm	0
Special hazards	None	0
	Frost pocket	–2
	Exposed windy site	–3

Maximum score for factor 1 = 20.

Table 3—Red alder site evaluation guide: factor 2, soil moisture and aeration during the growing season

Soil-site property	Level of property	Site points for each level
Internal drainage	Soil generally well drained and composed of many thin alluvial layers (stratified)	4
	Soil generally well drained and profile contains buried horizons or soil lenses within a horizon that differ in texture from the surrounding horizon, or A and B horizons that differ in sand content by more than 10 percent; or soil moderately well drained	3
	Well drained (without special features); or generally somewhat excessively drained with multiple thin alluvial layers, buried horizons, soil lenses within a horizon that differ in texture from the surrounding horizon or A and B horizons that differ in sand content by more than 10 percent	2
	Somewhat excessively drained (without special features); or somewhat poorly drained	1
	Poorly drained mineral soil; or very poorly drained mineral soil with organic surface layers; or excessively drained mineral soil	0
	Very poorly drained	Unsuitable

Table 3—Red alder site evaluation guide: factor 2, soil moisture and aeration during the growing season (continued)

Soil-site property	Level of property	Site points for each level
Texture	Silt loam, silty clay loam, or loam with at least 40 percent silt	3
	Clay, clay loam, silty clay, or loam with less than 40 percent silt	2
	Sandy clay, sandy clay loam, or sandy loam	1
	Sand or loamy sand	0
Soil depth	Greater than 80 cm without cemented or compacted layers	2
	Between 40 and 75 cm without cemented or compacted layers	1
	Less than 35 cm or deeper soils with cemented or compacted layers within 35 cm of the surface	0
Rock and gravel content (in surface 50 cm)	0 - 25 percent (by weight)	1
	30 - 50 percent	0
	More than 55 percent	–2
Depth to water table (in summer)	1.8 - 3 m	2
	1 - 1.5 m or greater than 4 m	1
	Less than 0.75 m	0

Maximum score for factor 2 = 12.

Table 4—Red alder site evaluation guide: factor 3, soil fertility and physical condition

Soil-site property	Level of property	Site points for each level
Parent material	Young soils composed of water-carried silt deposits; presence of soil layers caused by water deposition not weathering	4
	Some profile development evident but no leached horizons; parent material sedimentary or volcanic rocks (especially soils with low coarse fragment content developed from siltstone, sandstone, shale, or basalt); includes loessial soils if deposits are thick	3
	Some profile development evident but no leached horizons; parent material coarse alluvial, glacial or volcanic deposits (or soils with high coarse fragment content developed from sedimentary or volcanic rocks)	2
	Highly weathered mineral soils with evidence of leaching; or organic soils	1
pH (in surface horizon)	4.6 - 5.5	2
	3.8 - 4.3 or 5.8 - 7.5	1
	3.2 - 3.5	0
	Less than 3.0 or greater than 8.5	Probably unsuitable
Organic matter (in surface 10 cm)	5 to 20 percent	2
	Less than 3 or greater than 25 percent	1
Bulk density	Less than 1.2 g/cm^3	0
	1.4 g/cm^3 or greater	–2

Maximum score for factor 3 = 8.

Most of the measured soil chemical characteristics were not used in the final model. There are several possible reasons for this. First, soil chemical characteristics may have been correlated with more general soil properties that were included in the model. For example, percent organic matter was used in the model with both high and low levels considered suboptimal. High organic matter content was associated with poorly drained soils and with high elevation sites; in both these situations the high organic matter content probably indicates that mineral cycling rates on these sites are low. Cation exchange capacity is another soil property that theoretically would influence tree nutrition and could have appeared in the model. On these sites, however, cation exchange capacity and organic matter content were highly correlated ($r = 0.97$); thus, very little additional information would have been gained by including cation exchange capacity in addition to organic matter content. Second, some differences between soils in chemical characteristics would be accounted for by the categories “Parent material and age” and “pH.” Finally, the majority of forest soils in the Pacific Northwest are considered geologically young and relatively unweathered; thus, mineral deficiencies other than nitrogen may not be common. Because red alder has root nodules capable of fixing atmospheric nitrogen, it is not sensitive to soil nitrogen levels.

Model Validation

The red alder site evaluation model fit the original data well. The correlation between predicted and measured site index was 0.97 for the 25 plots used to quantify the model and 0.96 for the 15 plots used for verification. For the original combined data set, the model accounted for 93 percent of the observed variation in site quality. Freese’s (1960) chi-square test of accuracy indicated that true site index should be within ±2 m of the predicted value 95 percent of the time.

While I was conducting this study, a similar study—with the same purpose of evaluating site quality for red alder—was being independently conducted by another researcher.[1/] The Crown Zellerbach study was conducted in a smaller geographic area than my study area but it sampled sites with approximately the same mean site index (27.6 m vs. 28.6 m) and covered a similar range in values for many of the soil-site properties. For example, the sites in my study had a range in elevation from 5 to 1025 m, the Crown Zellerbach plots from 5 to 950 m. Although the two studies collected information on many of the same variables, different field and laboratory methods were used. In addition, some variables (for example, bulk density) were measured in one study but not in the other. In spite of these differences in measurements and methodology, the data from this second study provided a unique opportunity to further test the red alder soil-site (RASS) model.

[1/] Walter J. Shields, Research Forester, Crown Zellerbach, Wilsonville, Oregon.

Plots from the Crown Zellerbach study were used if they met the following criteria: mean tree age greater than 25 years, within plot range in tree age less than or equal to 5 years, and range in site index between trees less than 2 m. Adhering to these criteria helped eliminate trees with irregular height growth and reduced within-plot variation in site index. Plots were deleted if they had missing values for variables that could not be estimated from other plot information. Other missing or unmeasured variable values were estimated when possible. For example, bulk density was roughly estimated from the moist consistence category assigned to each soil horizon. The RASS model was then used to predict site index for 20 of the Crown Zellerbach plots. The model performed well in the test. The correlation (r) between measured and predicted site index was 0.89. In addition, the model continued to meet the accuracy standard of ± 2 m ($p \leq 0.05$).

Use of the Site Evaluation Tables

The use of the site evaluation tables (table 2, 3, and 4) is straightforward and fairly simple. To evaluate potential site index of an area requires determination of several characteristics of the actual location or position of the site, and of various soil properties. Site points are assigned to different levels of each property. Potential site index is predicted by summing the appropriate site points for all properties. Definitions of the terms used in the site evaluation tables are given in appendix 1.

The red alder model differs from the models developed by Baker and Broadfoot (1977, 1979) in two major respects. First, it places considerable importance on the actual location or position of the site to be evaluated. Working on the southern Atlantic Coastal Plain where climate and topography are relatively uniform, Baker and Broadfoot did not include properties such as elevation, percent slope, aspect, or climatic characteristics; such properties are included in the red alder model. Second, the Baker and Broadfoot models were designed to evaluate each factor independently; this required site characteristics or properties that influenced more than one factor to reoccur in different places in the model. The red alder model evaluates each property only once; thus, the factors are additive rather than independent. For example, factor 2 for red alder (soil moisture and aeration during the growing season) can have a maximum value of 12 points. This should not be interpreted as implying that soil or site characteristics that influence soil moisture and aeration only explain or influence about 30 percent (that is, 12 of 40 site points) of the variation in site quality for red alder. The interpretation should be that the characteristics in factor 2 of the red alder model account for or explain an additional 30 percent of the variation not accounted for in factor 1 (geographic and topographic position), but some soil-site properties in factors 1 and 3 also influence soil moisture and aeration. Similarly, the soil-site properties in red alder factor 3 (soil fertility and physical condition) represent the site characteristics that influence soil fertility and physical condition in addition to the properties considered in factors 1 and 2.

The site evaluation tables for red alder have been set up to predict a maximum value of 40 (site index in meters at 50 years). Factor 1 at its maximum level can account for 20 site points or half the maximum total number of points. The site characteristics in factor 1 can be easily and quickly determined in the field or by using readily available information sources such as topographic maps or weather records. Thus, if a user thinks it desirable to do so, a preliminary rating of sites can be done without determination of soil properties. This preliminary rating may not be correlated with the final or total rating; however, it will indicate the maximum score the site could receive if all the soil characteristics in factors 2 and 3 are at optimum levels. For example, if a site receives 8 points in factor 1 (or a maximum of 20), then the maximum total rating the site could achieve is 28. If a user only wishes to consider planting or managing the species on sites with site index values of 30 m or more, then this site can be deleted from consideration without the necessity of examining the soil.

The site evaluation tables were deliberately designed to require the user to interpolate between site points for many properties. For example, a site at an elevation of 150 m would fall between the categories “Less than 100 m” (worth 8 points) and “200 to 300 m” (worth 7 points). In this case a value of 7.5 points would be reasonable. Similarly, a soil profile with horizons of different textures should receive an interpolated value if the individual textures are associated with different numbers of site points.

If a particular piece of information is not known or is not known very precisely, users should consider using their “best guess.” Which properties have the greatest spread in point values and thus the largest impact on determination of site quality can be determined from an examination of the site evaluation tables. The properties with the greatest influence should be determined or measured accurately. “Best guess” determinations can be based on a knowledge of the most common value or range of a soil or site property. For example, if detailed weather information is not available, precipitation during the growing season is probably in the 30- to 40-cm range unless the area being evaluated is in a rain shadow, along the Pacific Coast, or in a geographic location where orographic precipitation is likely to be significant. For users who are not familiar with estimating various soil properties, spending some time in the field with a soil scientist should be very beneficial for increasing the accuracy of their determinations.

A final word of caution. Users should try to evaluate each property as objectively as possible. If before using the site evaluation tables, the user has “decided” or “knows” that the site is poor, there may be a tendency for subjective decisions to have a negative bias and thus for actual site quality to be underestimated. The reverse is also true. When evaluating a “good” site, users may tend to be overly generous in assigning site points and may overestimate site quality.

Two examples of the use of the site evaluation tables are given below. Appendix 2 contains a sample field worksheet.

Area A to be evaluated is on a northeast-facing slope of 20 percent. Elevation is 45 m, and average precipitation during the growing season is 31 cm. The location is inland (near Olympia, Washington) in a midslope position and does not appear to be subject to any special hazards. The soil is a gravely to very gravely loam in the surface 35 cm, a gravely sandy loam from 35 to 95 cm (a clay pan encountered at 95 cm). Silt content is 25 percent, gravel and rock content is 50 to 70 percent by weight, and the soil is well drained to somewhat excessively drained. The water table is deep, probably at 6 to 8 m. The soil formed from coarse glacial outwash material. Horizons are easily distinguished, but there is no evidence of a leached horizon (A2). In the surface 10 cm, pH is 5.0 and organic matter content is 4.0 percent. No compaction is evident in the surface 50 cm; bulk density in 82 (rock-free basis) is 0.9 g/cm^3.

Factor 1 is easily evaluated for area A (table 5). All the information fits within the specified ranges in site characteristics. Evaluation of some properties in factor 2 requires the user to interpolate. The soil was described as well drained to somewhat excessively drained and was given a rating of 1.5 (that is, halfway between the 1 rating for somewhat excessively drained and the 2 value for well drained without special features). Texture was rated as 1.75 percent. In the surface 35 cm the soil was loam with less than 40 percent silt, which would earn a rating of 2; however, since the texture from 35 to 50 cm was sandy loam, the texture rating for the surface 50 cm was reduced. The observed range in rock and gravel content crossed the level given in the table so the intermediate value of -1 was selected. Determination of the values associated with other properties in factors 2 and 3 was straightforward as no interpolation was necessary.

Summing each factor for area A gives individual factor values of 16, 5.25, and 6 for a total site rating or site index of 27.25 m. Rounding to the nearest meter results in an estimate of 27 m. A quick check of the values assigned to each factor with the total points possible indicates that area A received 80 percent of the maximum for factor 1, 44 percent of the maximum for factor 2, and 75 percent of the maximum for factor 3. Thus, we can conclude: Area A is located in a relatively favorable position in terms of geography and topography (factor 1) moisture availability during the growing season probably plays a major role in limiting growth (factor 2), and the characteristics rated for soil fertility and physical condition (factor 3) had less than optimum but not markedly unfavorable values.

Area B is located on a gently rolling bench southeast of Mount Vernon, Washington, at an elevation of 120 m. Slope averages 7 percent, and the aspect is southeast. The area receives 30 cm of rainfall April 1 through September 30. No special hazards are apparent. The soil is 75-80 cm of loam (silt content 45-50 percent) over slightly weathered sandstone and siltstone. The soil has a rock and gravel content of 10 to 15 percent and is well drained but with downward water movement slowed by the presence of the parent material close to the soil surface. Depth to a true water table is not known, but it is greater than 4 m. In the surface 10 cm, pH is 4.9 and organic matter averages 7.0 percent. Soil is friable to firm; rock-free bulk density in the B2 averages 1.1 g/cm^3

The site evaluation of area B is given in table 6. Two properties required interpolation. Elevation was given a 7.75 rating, as it was closer to the “Less than 100 m” category having an 8 value than the “200 to 300 m” category worth 7 (table 2). Aspect and slope were the other properties requiring interpolation. A southeast aspect on a 7-percent slope was intermediate between “Any aspect when slope 5 percent or less” worth 4 and “S, SE, or SW with slope 10-20 percent” worth 2 and was assigned a value of 3.

Table 5—Site evaluation for area A

Soil-site property and site points by factor					
1 Geographic and topographic position		2 Soil moisture and aeration during the growing season		3 Soil fertility and physical condition	
Elevation	8	Internal drainage	1.5	Parent material and age	2
Physiographic position	3	Texture	1.75	pH	2
Aspect and slope	3	Soil depth	2	Organic matter	2
Precipitation	2	Rock and gravel content	−1	Bulk density	0
Special hazards	0	Depth to water table	1		
Total	16	Total	5.25	Total	6

Total for all factors = 27.25.
SI_{50} = 27 m.

Table 6—Site evaluation for area B

Soil-site property and site points by factor					
1 Geographic and topographic position		2 Soil moisture and aeration during the growing season		3 Soil fertility and physical condition	
Elevation	7.75	Internal drainage	3	Parent material and age	3
Physiographic position	4	Texture	3	pH	2
Aspect and slope	3	Soil depth	2	Organic matter	2
Precipitation	2	Rock and gravel content	1	Bulk density	0
Special hazards	0	Depth to water table	1		
Total	16.75	Total	10	Total	7

Total for all factors = 33.75.
SI_{50} = 34 m.

Rounded to the nearest meter, site index or total site rating for area B was 34 m; this area would be a good site for red alder. It achieved 84, 83, and 88 percent of the maximum values for factors 1, 2, and 3. Thus, although area B was less than optimum in all three factors, no one factor or property was identified as having a large potential impact on growth.

Applicability

These site evaluation tables were developed with data from stands growing west of the crest of the Cascade Range in Washington and northern Oregon (latitude 45°0′ to 48°30′ N). These tables should not be used outside this geographic area until local users determine the applicability of the tables to their site conditions. For example, it would probably be necessary to modify the site points assigned to specific elevations for use in areas substantially north of the Washington-British Columbia border. In addition, when the user encounters site conditions not widely distributed in the Pacific Northwest—such as soil derived from serpentine rocks—the site evaluation tables should not be used until they are tested. Such nontypical conditions were not sampled in the study; thus, the model does not account for them.

This site evaluation guide was developed from plots located on apparently uniform site conditions. Plot boundaries were laid out to avoid changes in slope, aspect, drainage, or other site conditions. The greatest accuracy in prediction of site index will be achieved when users limit their evaluations to areas of similar uniformity. It may be helpful for a user to first roughly map areas that appear to be fairly uniform and then to sample within each of the major divisions or strata. Sampling intensity will vary with the user’s need for precision; however, it should be recognized that soil characteristics can be extremely variable and in some areas it may take several point determinations to accurately assess potential site index.

All plots were in natural unmanaged stands. Actual or apparent changes in site quality for red alder associated with forest management (including plantation culture) are not known. In addition, the model does not take genetic variability of the species into account. Apparent increases in site index may be realized in the future when genetically improved plant materials are used. These apparent increases in site index may result from higher overall growth rates associated with some genotypes or from using genotypes with tolerances for specific site conditions. The site evaluation tables (tables 2, 3, and 4) can be used to rank sites in order of potential site index; however, how accurately the tables will predict the actual site index attained under intensive culture cannot be judged until older plantations are available for evaluation.

English Equivalents

1 cm = 0.394 in
1 cm^3 = 0.061 in^3
1 g = 0.035 oz (avoirdupois)
1 ha = 2.47 acres
1 m = 3.281 ft
1 mm = 0.039 in

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Appendix 1

Definition of Terms Used in Tables

Factor 1

Elevation: Mean elevation aboVe sea level in meters. Should be determined to nearest 25 m.

Precipitation, April 7 through September 30: Can be determined from weather records or maps of rainfall distribution. Users should try to compensate for differences in precipitation between the site being evaluated and the nearest weather station or map averages. In particular, the effect of elevation on precipitation should be taken into account.

Physiographic position:
Flood plain—On a level plain associated with a river system, the width of a flood plain is determined by the size of the river and the associated topography. A site should probably not be considered to be on a flood plain unless it is subject to flooding during high water at least once every 10 to 15 years.

Terrace or bench—Site generally level or somewhat rolling with slope less than 15 percent, and far enough from a river or high enough to be rarely or never flooded. Also includes lower slope positions on side slopes when slope is less than 20 percent. In contrast to midslope positions, sites in this category are considered to be in a generally moisture-gaining position.

Midslope—Includes midslope positions and lower slope positions with slope greater than 20 percent. Such sites are considered to have minimal net change in soil moisture; that is, gains in soil moisture caused by additions from upslope positions would be approximately balanced by losses to sites farther down the slope. Would probably be the most common physiographic position encountered.

Marsh or bog—Depression in landscape with limited downward movement of water, often in a position to gain soil moisture from surrounding area.

Upper slope—Side slope positions just below the top of the hill. Considered to have a net loss in soil water but to be less exposed than ridgetop positions.

Ridgetop—Along top of ridge or hill. Considered to have a net loss in soil moisture and to be the position most exposed to wind. True ridgetop positions are the most unfavorable physiographic positions in terms of tree growth. The user should assign a higher value for physiographic position if the site being evaluated is on top of a hill or ridge but is located on a fairly level plateau, is in a minor depression, or is sheltered by surrounding features. The value assigned should be based on the user's evaluation of water movement and wind exposure.

Special hazards: Recognition of special hazards and assignment of negative site points can best be done by users with knowledge of local conditions. Sites with special hazards would include those located in frost pockets (either natural or created by cutting). Windy, exposed sites—such as those close to the Pacific Ocean without blocking topographic features, or areas in the vicinity of mountain passes—are examples of other conditions that need to be taken into account.

Factor 2

Internal drainage: Well-drained and excessively drained soils should be carefully evaluated for the presence of special soil features; such evaluation can be done from a detailed profile description or from examination of a soil pit.

Texture: As determined from a textural triangle after mechanical analysis. With practice, texture can be estimated fairly well in the field, especially with the use of published definitions of soil textural classes based on feel and field experience (Soil Survey Staff 1975).

Soil depth: Mean soil depth that roots and water can easily penetrate, can be determined by use of an auger or by examination of a soil pit. The user should try to determine effective rooting depth rather than depth to bedrock.

Rock and gravel content: Can be determined by sieving soil samples or by visual and textural examination. If the soil is not compacted and the rocks do not contain a lot of trapped air (for example, pumice or similar material), multiplying the percentage of rock and gravel *volume* by 2 will approximate the percentage of rock and gravel *weight*.

Depth to water table: The average depth to water table during the growing season; can be determined by soil boring or by comparison of site elevation in relation to the water level in nearby streams or lakes. Use of intermittent or very shallow streams to evaluate water table level is not recommended.

Factor 3

Parent material and age: Published soil survey information can be helpful in determining parent material; however, many categories can be easily recognized in the field.

pH: Measure of soil acidity can be determined in the field or on fresh samples in the office with a pH meter or a pH testing kit. Can be estimated from soil survey information if description of mapped soil agrees well with what is observed at the site.

Organic matter: The organic portion of a mineral soil composed of plant and animal remains in various stages of decomposition. Most accurately determined in the laboratory, but with practice can be estimated in the field. Surface soils low in organic matter do not differ much in color from lower layers and generally are light colored. Soils high in organic matter are usually very dark in color and both well-decomposed material (greasy feeling) and partially decomposed materials (origin somewhat evident) can be distinguished.

Bulk density: Measure of soil compaction expressed as ovendry soil weight per unit of volume. Most accurately measured with equipment designed for such determination, but with practice can be estimated in the field. Soils with low bulk density are loose, porous, or friable. Soils with high bulk density are tight and strongly compacted.

Appendix 2

Sample Field Worksheet

Site evaluations for red alder

Site name or number: ______________________

Location: ______________________

Soil-site factors

1		2		3	
Geographic and topographic position		Soil moisture and aeration during the growing season		Soil fertility and physical condition	
Soil-site property	Score for this site	Soil-site property	Score for this site	Soil-site property	Score for this site
Elevation	____	Internal drainage	____	Parent material and age	____
Physiographic position	____	Texture	____	pH	____
Aspect and slope	____	Soil depth	____	Organic matter	____
Precipitation	____	Rock and gravel content	____	Bulk density	____
Special hazards	____	Depth to water table	____		
Total for factor 1 =	____	Total for factor 2 =	____	Total for factor 3 =	____

Total for all factors = __________ .

SI_{50} = __________ m.

Harrington, Constance A. A method of site quality evaluation for red alder. Gen. Tech. Rep. PNW-192. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station; **1986**. 22 p.

A field guide to predict site index for red alder (*Alnus rubra* Bong.) was developed for use in western Washington and Oregon. The guide requires the user to evaluate 14 soil-site properties that are grouped into three general factors: (1) geographic and topographic position, (2) soil moisture and aeration during the growing season, and (3) soil fertility and physical condition Construction of the guide was modeled after a method of site evaluation developed for several southern hardwood species. The red alder model is accurate when used properly. The correlation (r) between predicted and measured site index was 0.97 for the basic data set of 25 plots and 0.96 for the 15 plots used for verification. Estimated site index should be within ±2 meters of measured site index 95 percent of the time. Use of a second independent data set for model verification resulted in a somewhat lower correlation (r = 0.89) between measured and predicted site index than was achieved with the original data set, but the model continued to meet the accuracy standard of ±2 meters ($p \leq 0.05$).

Keywords: Site class, site index, guidebooks, models, red alder, *Alnus rubra*.

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