WORKING PAPER

A REGIONAL MODEL FOR GENERAL STRESS RESISTANCE OF NORWAY SPRUCE STANDS

Risto Ojansuu

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IIASA
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INTERNATIONAL INSTITUTE FOR APPLIED SYSTEMS ANALYSIS
A-2361 Laxenburg, Austria

PREFACE

One of the focal aims of the environmental impacts work within the Transboundary Air Pollution Project has been to produce regional indicators of the sensitivity of ecosystems, such as soils, lakes and forests, to an increasing pollutant load. As regards forests, it is appreciated that sensitivity can vary at least according to the location, age, and silvicultural state of the forest. However, few quantitative methods have been available for presenting these characteristics of sensivitiy as a regional mapping.

This paper develops a method for estimating the general sensitivity of a forest to air pollution as Stress Resistance Index (SRI), derived from a more widely used Growth Efficiency Index (GEI) and the length of the growing season (LGS). A statistical model is presented for calculating the index over Europe. The index is readily applicable to regional sensitivity mapping, provided that certain characteristics of the environment and the stands are available.

Bo R. Döös
Leader
Environment Program

R.W. Shaw
Leader
Transboundary Air Pollution Project

ABSTRACT

The Growth Efficiency Index (GEI) is used to indicate stand resistance for environmental stress. GEI denotes the annual growth of stem wood per leaf area. Stands under different climates are compared by Stress Resistance Index (SRI), defined as the ratio between GEI and the length of growing season.

The driving variables of the model are environmental variables (1) effective temperature sum, (2) length of the growing season and stand variables, (3) stand age, and (4) ratio of actual to potential basal area. Site productivity is depicted by site index as a function of effective temperature sum. The standard forestry variables are modeled from yield tables as functions of driving variables. Leaf area is approximated with the basal area at crown base. The relationship between basal area at crown base and the standard forestry variables has been developed from forest inventory data.

The model can be used to compare stress resistance of stands at different locations, ages and densities in ordinary scale. The regional implications of the model can be illustrated by mapping the results over Europe using the computerized grid system of the RAINS (Regional Acidification INformation and Simulation) model. The environmental factors incorporated in the model can be estimated to every grid element using a spatial interpolation method. The consequences of different silvicultural policies to the general stress resistance can be presented in form of maps.

ACKNOWLEDGEMENTS

This study was carried out during the Young Scientists Summer Program 1987 in the Acid Rain Project. The task was formulated and the general approach designed by Dr. Annikki Mäkelä. The INKA material was obtained from the Finnish Forest Research Institute. The manuscript has been read by Dr. Annikki Mäkelä and Dr. Pekka Kauppi, whose comments have been very valuable in finding the final form of the study.

SYMBOLS

AGE	= stand age, a
AGEnor	= normalized stand age in relation of the recommended rotation time, %
BA	= basal area of stand, m2/ha
BAcb	= stand basal area below tree crowns, m2/ha
BAp	= potential basal area, m2/ha
BArel	= relative basal area, BA/BAp
dbh	= tree diameter on breast height, cm
E(x)	= expectation value of the variable x
ETS	= Effective Temperature Sum
GEI	= Growth Efficiency Index
la	= tree leaf area, m2
LA	= leaf area per hectare
LGS	= Length of Growing Season
RTrec	= recommended rotation time
SI	= site index
SRI	= Stress Resistance Index
Vi	= annual volume growth per hectare, m3/ha/year
x	= latitude
y	= longitude
Y	= yield, m3/ha
z	= altitude

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A REGIONAL MODEL FOR GENERAL STRESS RESISTANCE OF NORWAY SPRUCE STANDS

Risto Ojansuu

1. Introduction

Forest damages observed from the end of 1970 in Europe and North America have been studied intensively in order to find the primary causes of the phenomenon. A widely accepted view among scientists is that the damages are caused by air pollution. The more detailed influence mechanisms are still under discussion.

The ability of plants to endure air pollution is called stress resistance. A more accurate definition for stress resistance can be found using the terms injury, strain, and stress (Levitt, 1972). Injury consists of all those reactions in a tree which are outside the normal variation of tree properties. Two kinds of injuries can be observed: visible injuries and growth reduction. Damage is an injury which has harmful effects. Strain is any change in the normal behaviour of an organism, either physical or chemical. Stress is an environmental factor capable of inducing potentially injurious strain on an organism. The plant factors affecting the process of injury have been grouped together under the term stress resistance (Levitt, 1972).

It is not possible to define the concept of stress in a strictly biological way so that it would also have a reasonable practical interpretation (see Timmis, 1980; Kauppi, 1984). In practice plants always grow under sub-optimal conditions and a strict interpretation includes all deviations from the optimal environment as stress factors. Therefore, it is necessary to find a practical definition of stress case by case. In this study stress is divided into two parts: (1) natural stress and (2) true stress. Natural stress is caused by site properties and stand characteristics, like stand density and age. True stress, later called only stress, is caused by anthropogenic environmental changes like acid rain and rising carbon dioxide concentration in the atmosphere. According to the definition, normal silvicultural practice (like different stand densities and rotation times) causes true stress only. However, silvicultural practice can have effects on the natural stress resistance.

Although stress resistance can be defined relatively accurately qualitatively, it is difficult to find a quantitative measure for it. The mean level of available carbohydrates during the growth period can be an indicator for resistance, because it reflects the ability of the tree to survive reductions in primary production and provide defensive compounds against pathogens. Waring and Schlesinger (1985) have suggested the concept Growth Efficiency Index (GEI) to describe general stress resistance. GEI is determined as the annual growth of stem wood (Vi) per unit of foliage, for example leaf area (LA).

Stands growing under different climatic conditions may differ in total annual stem growth per unit foliage, yet have the same mean level of carbohydrates available at all times, owing to the fact that the growing seasons differ in length. GEI can thus be used only as an estimate of the mean level of carbohydrates available under constant climatic conditions. Therefore, an index for comparing the stress resistance of stands in different climatic regions should also take care of the variation on the length of growing season. This can be done by dividing the value of GEI by the Length of the Growing Season (LGS). This measure is here called the Stress Resistance Index (SRI), and it is presently used as a measure of the stress resistance of tree stands.

The aim of this study is to develop a regional model in the European scale for SRI as a function of environmental and stand characteristics. The objective is how sensitive forest stands are to the true stress in different regions and under different management regimes. The model should have the following outputs:

1. SRI estimates for different geographical locations
2. SRI estimates for different stand ages
3. SRI estimates for different stand densities

If this information is available, it will be possible to compare the effects of different rotation times and stand densities on stress resistance in various parts of Europe.

The model is identified for Norway spruce (*Picea abies* Karst.), which is the most common and economically valuable tree species in Europe. It is also sensitive to air pollution. Norway spruce has earlier been used in a model for regional risk due to direct impacts of sulfur (Mäkelä *et al.*, 1987). The present model is limited to stands established after regeneration. The minimum stand age in the model is 40 years.

2. General Description of the Model

The definitions SRI = GEI/LGS and GEI = Vi/LA determine the variables needed in the model. LGS is an environmental variable used in the model as a driving variable. The variables Vi and LA should be modeled as functions of environmental and stand variables.

Vi is estimated as a function of stand productivity and the actual state of the stand. The productivity of a forest site is here described with the concept of "site index" (SI); the dominant height at the age of 100 years. Dominant height is a stand variable insensitive to stand density in even-aged Norway spruce stands.

Every site has a maximum potential basal area (BAp). BAp is a function of SI and stand age (AGE). The stand density is described in the model with relative basal area (BArel), which is the ratio between the actual basal area (BA) and BAp. Vi is a function of SI, AGE, and BArel.

SI depends on soil properties and climate. In the regional scale, SI is mainly dependent on the climate and in the local scale, it is dependent on soil properties. In the model, SI is taken as a function of climatic variables only, assuming that the bulk of the error term consists of the effects of soil variation. The Effective Temperature Sum (ETS), which is the annual sum of daily mean temperatures exceeding 5 °C, has been used as the climate variable.

Standard stand variables do not include leaf area measures. It should be estimated as a function of site and stand variables included in the model, here BAp and BArel.

The final structure of the model is presented in *Figure 1.* The driving variables of the model are environmental variables ETS and LGS and stand variables AGE and BArel. SI is then calculated as a function of ETS. BAp is a function of SI and AGE. LA is a function of BArel and estimated BAp. Vi is a function of AGE, BArel, and the estimated SI. GEI is calculated as function of estimated Vi and LA. The final result of the model is the SRI estimate as a function of estimated LA and LGS.

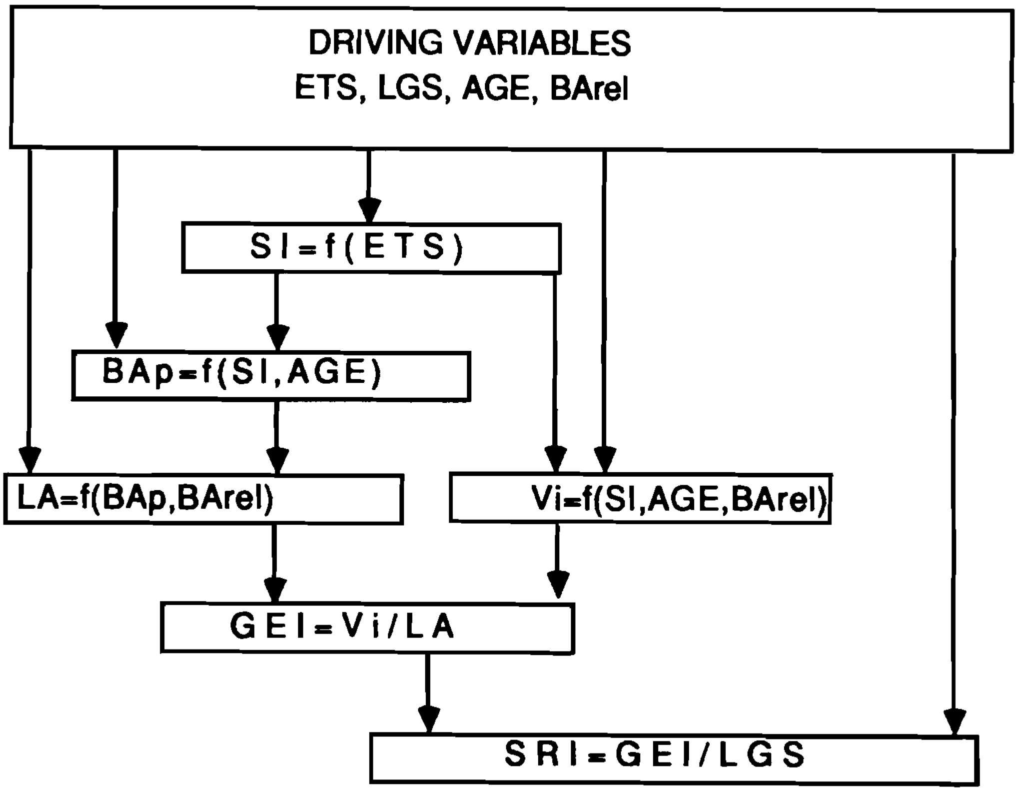

Figure 1. The model for stress resistance index.

In actual forests, acid rain may already have had influence on LA, Vi, and effects of natural stress and true stress are mixed. It is impossible to separate those effects in forest inventory data from polluted areas. Forest inventory data from areas polluted as little as possible should therefore be used. Forest yield tables are also appropriate as they normally concern healthy and well cared forests.

Austrian yield tables (Hilfstafeln, 1975) have been used to estimate the parameters of the models for standard stand variables. The parameters for the other models have been estimated from a Finnish forest inventory material, INKA (Roiko-Jokela *et al.*, 1987). The INKA data set used in this report consists of 68 objectively sampled sample plots, where over 70% of the growing stock volume is Norway spruce. The size of the plots varies, but on average one plot consists over 30 trees and 10 sample trees. The breast height diameter has been measured from all trees. In addition, tree height and the height of crown base have been measured from the sample trees.

3. Submodels

3.1. Site productivity

Site productivity is depicted by SI and the corresponding yield (Y). The effect of the environment on SI is modeled as a function of ETS. The model should have two properties: (1) the site index should achieve the value 0 near the ETS value reached at the polar or sub-polar timberline of Norway spruce, and (2) it should approach the highest possible SI asymptotically. The relationship between ETS and SI has been studied using the INKA material. The estimated model is

$$E(SI) = 53.431 - 35515/ETS \tag{1}$$

and the standard error of the model is approximately 3.5 m.

The model gives the value 0 for SI at the ETS value of 695 d.d. The material also covers regions near to the timberline in Northern Finland, so the estimated value for the timberline should be accurate enough. The asymptote of the model is 53.4 m. Since the highest value of SI in the data is 31 m, the asymptote is a strong extrapolation outside the data set. It seems reasonable, though, in comparison with the fact that the tallest Norway spruce trees recorded in Europe are little over 60 m in height (Sarvas, 1964).

For an unthinned stand Y and its time derivative, Vi, are functions of stand age in a particular site. If SI is the only site variable used, then the potential yield development of different sites can be presented as a function of SI and AGE. The form of this statistical relationship was found by trial and error using the Austrian yield tables (Hilfstafeln, 1975). The final form for the potential yield model is

$$E(Y) = (4.49997-425.42/AGE)*SI(.97410+95.63*AGE) \tag{2}$$

Standard error in comparison with the yield tables is approximately 4%. In the following, the mean annual growth estimates by the Model (2) are presented for 100-year old Norway spruce cultures, in comparison with the corresponding values reported by Vuokila and Väliaho (1980) for planted and thinned Norway spruce stands in Finland.

Model	Site Index, m				
	21	25	27	30	33
	m^3/ha/year				
Vuokila and Väliaho	4.3	5.6	7.0	8.7	10.5
Model (2)	4.6	6.4	7.4	9.1	10.9

The Model (2) thus seems to give reasonable results also for the mean annual growth over the whole rotation time in northern Europe. The estimated development is in good agreement with the Finnish yield table for thinned stands (Koivisto, 1959) (*Figure 2*).

3.2. Stand description

The growth of a fully stocked stand is the first time derivative of the yield development function. So as to extend the model to sparse stands, it has been assumed that if the basal area is over 60% of the potential, the growth of a Norway spruce stand is independent of the stand density. This empirical result has been obtained in thinning experiments concerning young and middle-aged stands in Sweden and Finland (Vuokila, 1985; Eriksson, 1986). For stands with basal area less than 60% of the potential, a heuristic model is used:

$$E(Vi) = \begin{cases} (BArel*2.33)(Y^1-Y^0) & \text{if } BArel \pm .3 \\ (c_1+c_2*.7)(Y^1-Y^0) & \text{if } .3 < BArel \leq .6 \\ Y^1-Y^0 & \text{if } BArel > .6 \end{cases} \tag{3}$$

where $c_1 = (\mathrm{BArel}/.6)^2/\{(\mathrm{BArel}/.6)^2 + (1-\mathrm{BArel}/.6))^2\}$

$c_2 = (1-(\mathrm{BArel}/.6))^2/\{(\mathrm{BArel}/.6)^2 + (1-\mathrm{BArel}/.6))^2\}$

Stand yield consist of the growing stock and the cumulative mortality. The potential growing stock is described in the model in terms of the potential basal area (BAp) as a function of SI and AGE. The empirical relationship was found

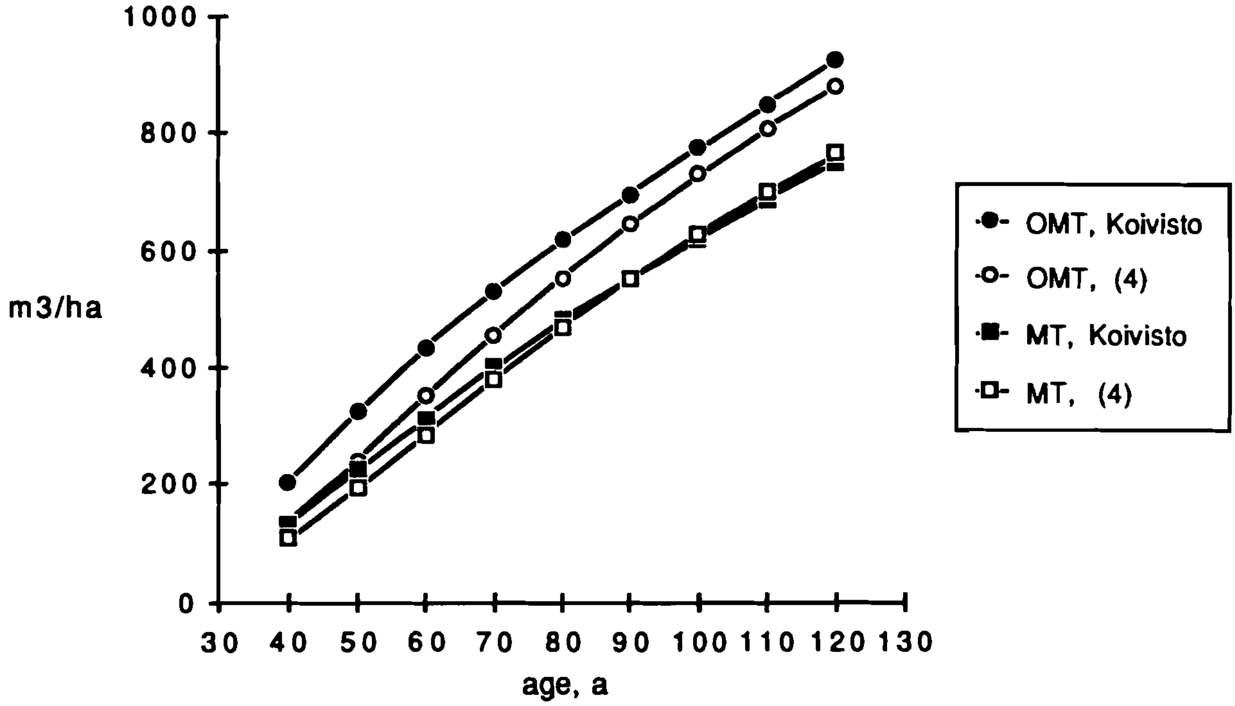

Figure 2. Estimated yield of Norway spruce for thinned stands according to Koivisto (1959) and according to the Model (2). OMT and MT stands for *Oxalis-Myrtillus* site type (SI=26.8) and *Myrtillus* site type (SI=24.8), respectively.

using the Austrian yield tables (Hilfstafeln, 1975). The model is

$$E(BAp) = 23.03 + .01997 * AGE - 1431 * 1/AGE + 1.587 * SI \tag{4}$$

and the standard deviation from the yield tables is 2.4 m^2/ha.

The effects of silvicultural measures on the growing stock concern different rotation times and stand densities. The effect of the rotation time is already implicit in the model in the form of the variable AGE. So as to facilitate comparisons between regions, stand age was normalized relative to the recommended rotation time (RTrec), which varies between regions as a function of ETS (Mäkelä *et al.*, 1987):

$$RTrec = 144.4 * e - .000326 * ETS \tag{5}$$

The stand density is described here by the variable BArel. BArel is 1.0 for fully stocked stands, decreasing with decreasing density.

3.3. Stand leaf area as function of site and stand variables

The simplest way to determine LA would be to establish a statistical relationship between LA and stand and site variables. However, because of a lack of representative stand measurements including LA, the model must be developed indirectly.

One possibility would be to use the statistical relationship between diameter at breast height and leaf area found for several tree species in Southern Appalachian forests (Sollins *et al.*, 1973):

$$la = .160694 * dbh2.129 \qquad (6)$$

where dbh is tree diameter at breast height (cm) and la tree leaf area (m^2). This type of simple relationship has been used in the "gap models" to detect competition for light (Shugart, 1984). At the stand level, this relationship can be approximated as follows:

$$LA = .160694 * BA1.04 \qquad (7)$$

The disadvantage of model (7) is that, it will give the same LA for all stands with the same BA, regardless of site, age, and thinning grade.

The pipe-model theory provides a more theoretical approach to estimate leaf area. The theory, originally developed by Shinozaki *et al.* (1964), states that the cross-sectional sapwood area is proportional to foliage biomass. The theory reasons that each unit of foliage requires a unit pipeline of wood to conduct water from the roots and to provide physical support. Several researchers have found empirical evidence for the theory (Rogers and Hinckley, 1979; Waring *et al.*, 1982; Hari *et al.*, 1986).

The relationship between sapwood area at breast height and leaf area varies widely between tree species (Kaufmann and Troendle, 1981). According to the published reports, there is also within-species variation, probably due to differences in age and site type, but also because of different times of measurement during the year. However, Whitehead (1978) found out that the relationship was independent of spacing in Scots pine (*Pinus Silvestris* L.) stands.

The results of Hari *et al.* (1985) show a linear relationship between tree basal area below crown and different cross-sectional measures of sapwood. Using this relationship and the pipe-model theory, tree leaf area can be estimated by multiplying stem basal area at crown base with a constant. Tree or stand basal area at crown base hence provides a relative measure of leaf area. This was chosen in the present study, because we are only interested in the relative values of SRI.

Material from the Finnish forest inventory data, INKA, was utilized in developing a statistical relationship which predicts the stand-level basal area at crown base (BAcb), M^2/ha, from standard stand level variables. The INKA data set contains information about sample trees on sample plots, including basal area at breast height, tree height, and height at crown base. Tree volume and the basal area at crown base were first calculated for each tree from these measurements, using stem curves and volume equations (Laasasenaho, 1982). The individual-tree values were then converted to stand-level estimates by summing up over the trees and dividing by plot area.

BAcb has a lot of trivial covariation with BA. To eliminate this trivial covariation in the statistical analysis the dependent variable was BAcb/BA. Theoretically, the value of this variable is greater than one in very young stands where the lower boundary of the crown is below breast height. In older stands, it should always be smaller than one. The final empirical model is

$$E(BAcb/BA) = .9377 - .3637*BArel \tag{8}$$

The standard error of the model is .066 and the coefficient of variation is 9%. In other words, the standard error of BAcb is .066*BA, in average in the INKA material .066*23 m^2 $\simeq$ ha 1.5 m^2/ha. Other stand and site variables were not statistically significant. Because the model is only limited to stands older than 40 years, it is not necessary to give theoretically reliable values for very young stands.

4. Results

This report does not include applications of the model in the form of maps, where the results are illustrated in regional scale. Instead some results are presented here as functions of site variables and thinning grade expressed with BArel. Some intermediate results for unthinned stands are presented in Appendix 1 in order to help understand the final results: LA, Vi and GEI, all as a function of SI and AGE.

The final results of the model are the SRI estimates. So as to calculate these, we need independent input in the form of LGS, in addition to the estimates of GEI. However, since LGS is naturally related to ETS, and since SI, in turn, is a function of ETS, a preliminary illustration of model behaviour can be elaborated by expressing both ETS and LGS as functions of SI, and studying model behaviour with respect to SI only. To estimate ETS the inverse function of model (1) is used:

$$ETS = 35516/(53.49-SI) \tag{9}$$

A regression between LGS and ETS was estimated from a data set of ETS and LGS values, which have been generated with the model by Henttonen and Mäkelä (1988). It consists of 63 systematic data points located 100 m above sea level. Therefore,

$$E(LGS) = 96.71 + .06493 * ETS \quad (10)$$

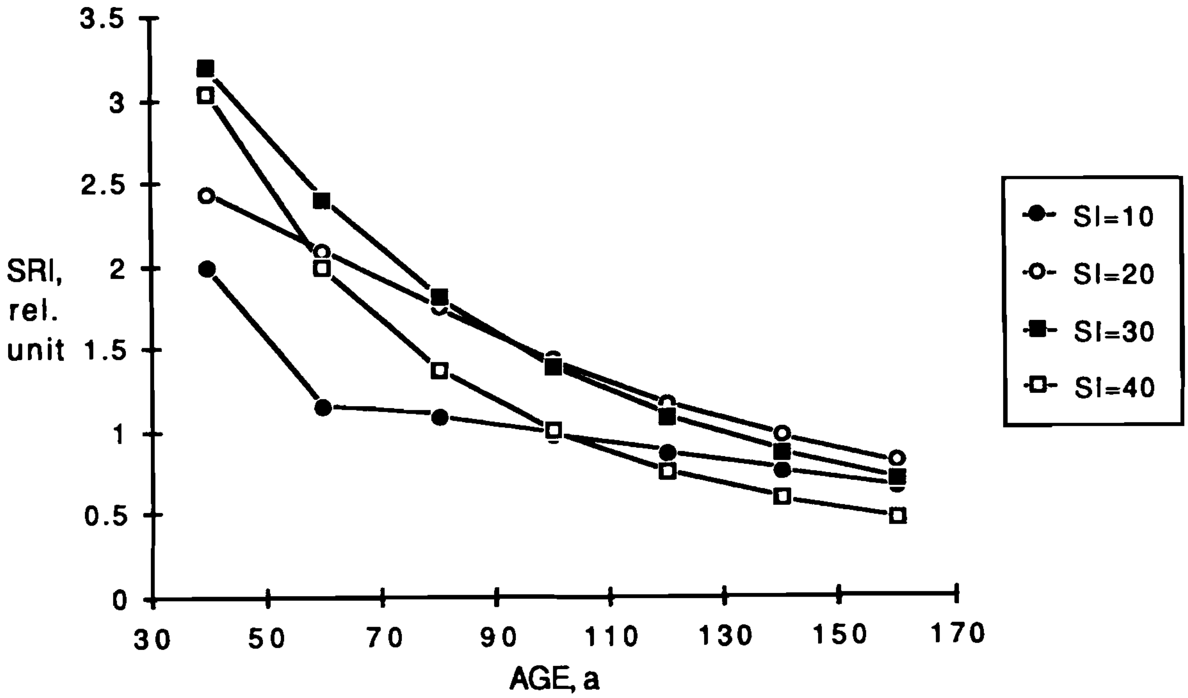

Figure 3. Stress Resistance Index (SRI) as a function of stand age (AGE) and Site Index (SI).

SRI decreases with increasing stand age, on better sites more rapidly than on poor sites (*Figure 3*). In very old stands SRI has the lowest value on best sites. When SRI is examined in relation to the normalized age (AGEnor), the results seem easy to interpret (*Figure 4*). The best sites are relatively more sensitive to variation in rotation time. In stands younger than RTrec, the differences between site classes are large but decreasing with increasing relative age.

The effect of thinnings is illustrated in *Figure 5*. In young and middle-aged stands thinnings have more effect on SRI than in older stands. Increasing the thinning grade affects SRI nonlinearily, such that the greatest marginal effect is achieved when the relative basal area is between 40 and 80% of the potential.

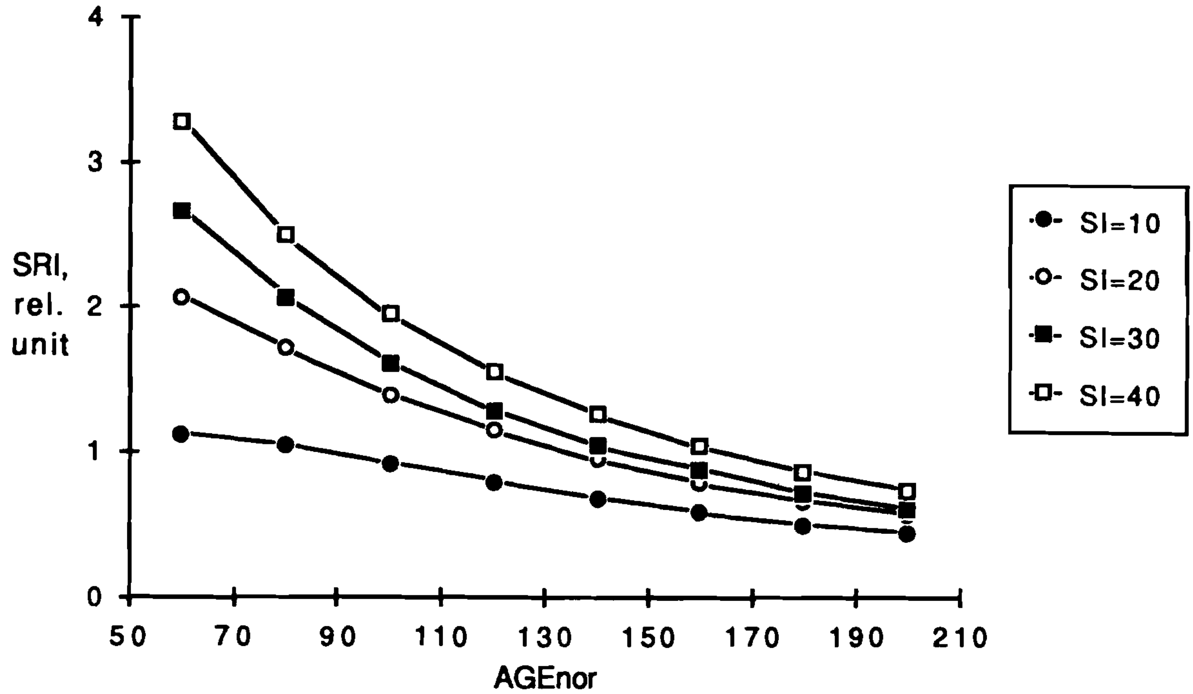

Figure 4. Stress Resistance Index (SRI) as a function of normalized age (AGEnor), expressed with variable AGEnor, and Site Index (SI). The value 100 of variable AGEnor is the recommended rotation time.

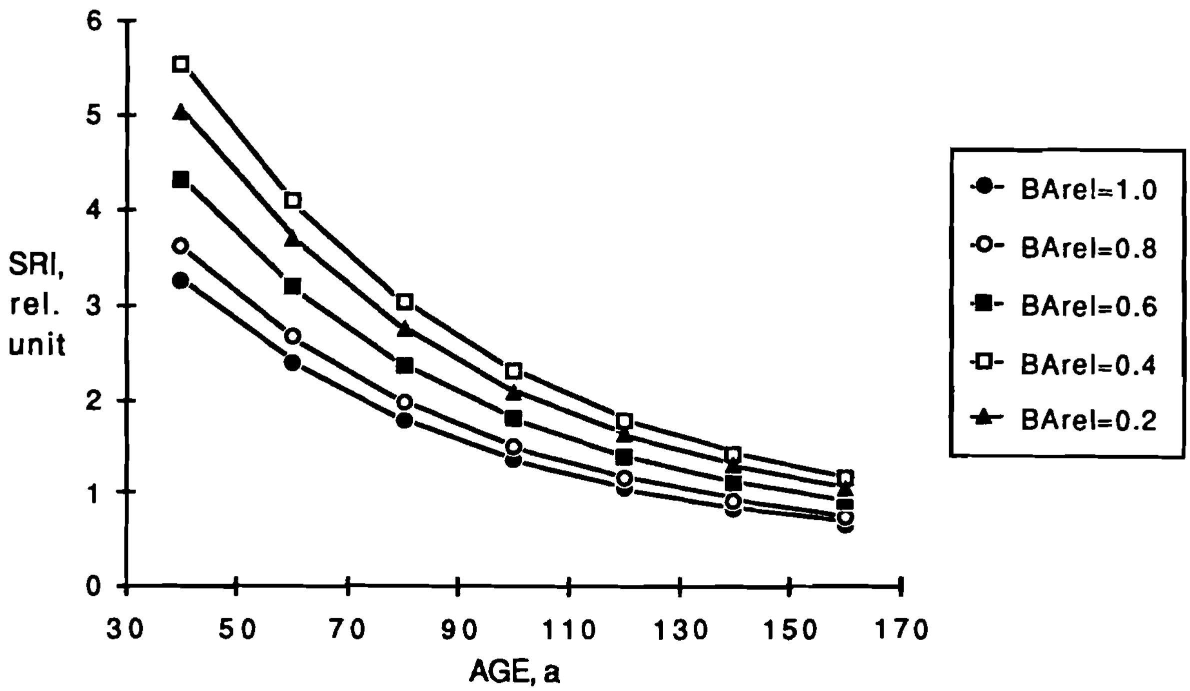

Figure 5. Stress Resistance Index (SRI) as a function of stand age (AGE) and relative basal area (BArel) when site productivity is $10 m^3/ha/a$.

5. Regionalization of the Model (How to Regionalize the Model)

The regional implications of the model can be illustrated by mapping the results over Europe. A computerized grid system suitable for such mapping has been developed by the Acid Rain Project at IIASA, as part of the RAINS (Regional Acidification INformation and Simulation) model. The mapping procedure needs values of the driving variables for every grid element.

Regional stress resistance maps can present the consequences of different silvicultural policies, or they can present the actual situation. Different silvicultural policies can be compared by assigning constant values for the driving variables depicting the state of the stand; AGE and BArel. The different values of the variable AGErel describe the effect of rotation time, and similarly the variable BArel incorporates the effect of thinning grade.

For the illustration of the actual situation we need, in addition, actual stand data for every grid element. Using average values provided by forest inventories, we get an estimate for the mean stand. Because the relationship between SRI and standard stand variables is nonlinear, and because there is a lot of variation in the stand variables, the SRI estimates for the mean stands are biased and uninformative. In order to get more valuable estimates for the actual situation, we need information about the two-dimensional distribution of stand ages and relative densities in all grid elements. With such data, the distribution of SRI can be estimated for every grid element.

The environmental factors incorporated in the model are the effective temperature sum, ETS, and the length of the growing season, LGS. These can be calculated regionally using a spatial interpolation method which accounts for altitude based on regression and moving averages (Ojansuu and Henttonen, 1983). The method has been installed for whole of Europe (Henttonen and Mäkelä, 1988). In this extension, the values of monthly mean temperature and total precipitation are calculated as functions of the three-dimensional spatial coordinates, on the basis of data from about 750 weather stations in Europe. The primary results are further elaborated, so as to calculate unbiased ETS estimates and estimates for LGS.

The regionalized model for SRI, calculated as function of the three spatial coordinates [latitude (x), longitude (y), and altitude (z)] and stand variables, AGE and BArel, is illustrated in *Figure 6*.

6. Discussion

The objective of this study has been to develop a model for the stress resistance of Norway spruce stands for regional analysis. The usefulness of the model depends on (1) how realistic the underlying concept, SRI, is, and (2) how reliably it has been modeled.

The components of SRI, Vi ($m^3ha^{-1}a^{-1}$), LA (m^2ha^{-1}), and LGS (a), are all measures on the absolute scale, and so is SRI (ma^{-2}). SRI allows us to compare

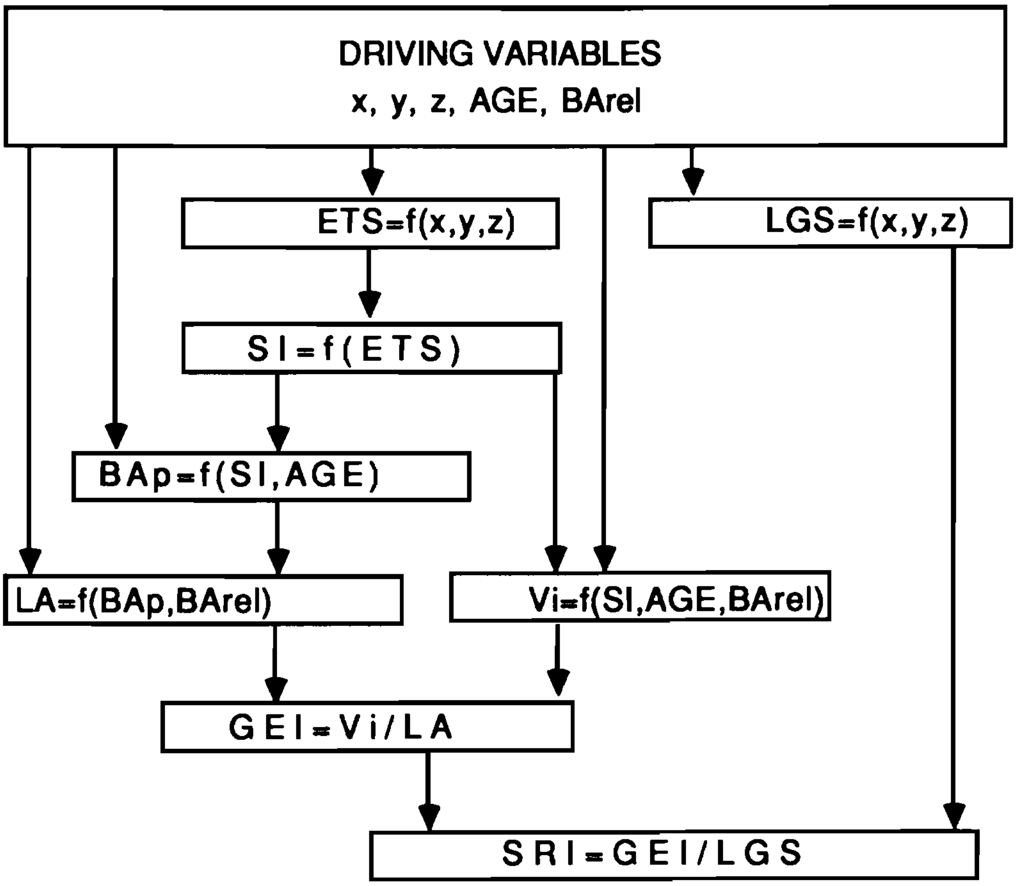

Figure 6. Stress Resistance Index (SRI) as a function of coordinates [latitude (x), longitude (y), and altitude (z)], AGE and BArel.

stands of different locations, ages and densities. However, all we know about the relationship between actual stress resistance and SRI is that SRI increases with increasing stress. In other words, SRI is a description of stress resistance on the ordinal scale. Therefore it only allows us to rank different stands in relation to their stress resistance, or alternatively, to find which types of stands have the same stress resistance.

The results presented above seem quite logical as regards SI, AGE and BArel. However, for instance the effect of stand density seems unexpectedly small in old stands, partially contradicting for instance the conclusions of Kuusela (1987). One reason for this is perhaps that SRI does not take into consideration the injury risks caused indirectly by some extreme silvicultural programs. In very dense stands with no thinnings natural mortality is going on. Harmful insects and pathogenic fungus reproduce rapidly on the dead trees. Therefore the risk of injuries is considerably higher in unthinned stands than in slightly thinned stands, although stress resistance of unthinned stands is only a bit smaller than in slightly thinned stands. On the other hand, the risk of wind damages increases with lower stand densities. A similar risk occurs in very dense stands after heavy thinnings.

A number of factors may cause uncertainty in the sub-models. First the data sets are quite unrepresentative for models describing the whole of Europe. The model describing the stand, in terms of yield, annual volume growth, and potential basal area, are based on Austrian yield tables only. However, the amplitude of those tables is large enough to cover the variation of SI in Europe; furthermore, when testing the suitability of the yield model to Northern Europe against Finnish yield tables, no big differences were found.

The effect of stand density on the volume increment was modeled in a very simple way, based on some empirical results from young and middle-aged Norway spruce stands (Vuokila, 1985; Eriksson, 1986). Some reports indicate that the relationship between volume growth and stocking grade changes with stand age (Assmann, 1970), such that volume growth of old stands can be positively correlated with stocking grade in dense stands also. This means that the estimated effect of low stocking grade on Vi and thus on RSI can be too optimistic in old stands. It is possible that in stands older than the recommended rotation time, stocking grade has no effect on SRI. The volume increment model for sparse stands, with relative basal area lower than 60%, is similarly a very heuristic extrapolation.

The formulation of the potential basal area model is unsatisfactory if we are interested in stands younger than 40 years. This is crucial especially as regards the best sites where the rotation times are only about 60 years.

The data for the model of the basal area at crown base only consist of site indices from 8 m to 30 m, which is not sufficient for many sites in Central Europe. In particular the results for lowlands in Central Europe are extrapolations from the data. In order to compensate for this lack of data, a careful model formulation has been employed, involving the ratio between basal area at crown base and that at breast height, which is used as the dependent variable and the ratio between basal area and potential basal area, used as the independent variable.

Appendix 1

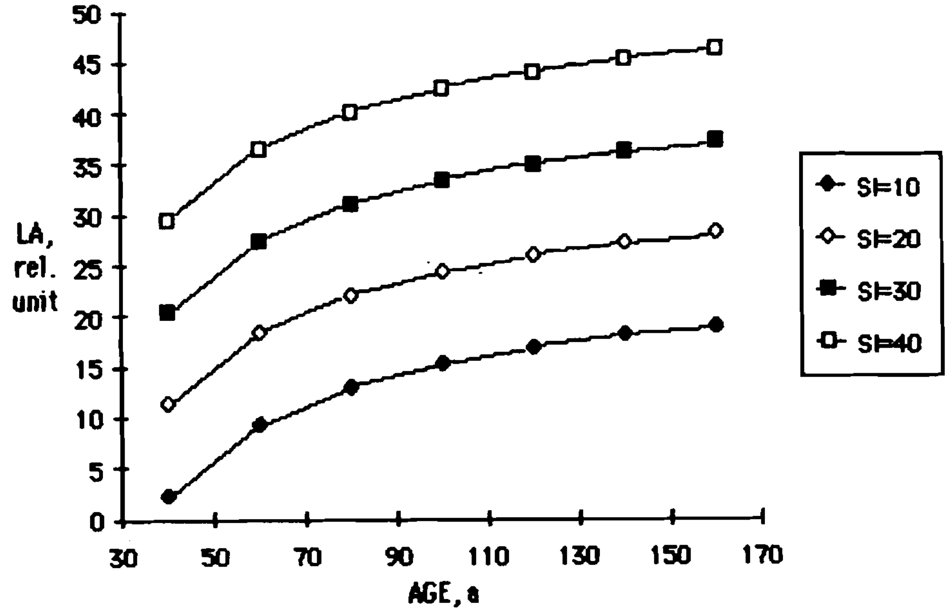

Figure i. Relative Leaf Area per hectare (LA) as a function of stand age and Site Index (SI).

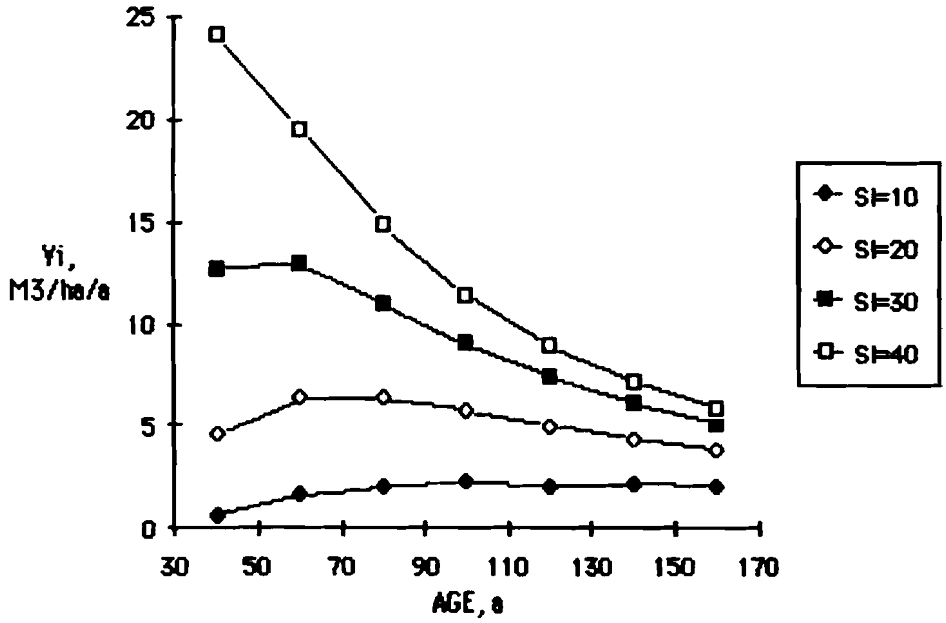

Figure ii. Stand volume growth (Vi) as a function of age and Site index (SI).

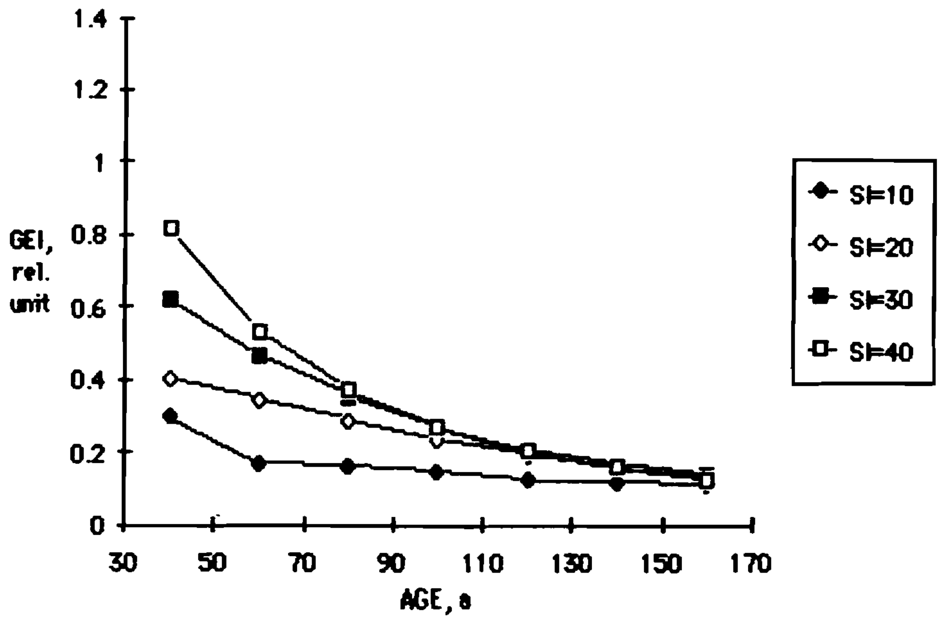

Figure iii. Relative Growth Efficiency Index (GEI) as a function of stand age and Site Index (SI).

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Please note the following changes in WP-89-22.

Page ix, the symbols should be m^2 and m^3 instead of m2 and m3.

Page 4, 2nd para, line 1 and last para, line 5, also page 6, line 1 - instead of Hilfstafeln, 1975, should be Marschall, 1975.

Page 5, Equation (2) should be the following:

$$E(Y) = (4.49997-425.42/AGE)*SI^{(.97410+95.63*AGE)} \tag{2}$$

and Equation (3) should be the following:

$$E(Vi) = \begin{cases} (BArel*2.33)(Y^1-Y^0) & \text{if } BArel \leq .3 \\ (c_1+c_2*.7)(Y^1-Y^0) & \text{if } .3 < BArel \leq .6 \\ Y^1-Y^0 & \text{if } BArel > .6 \end{cases} \tag{3}$$

Page 6, Equation 5 should be the following:

$$RTve = 144.4*e^{-.000326*ETS} \tag{5}$$

Page 7, Equation (6) should be the following:

$$la = .160694*dbh^{2.129} \tag{6}$$

and Equation (7) should be the following:

$$LA = .160694*BA^{1.04} \tag{7}$$

Page 16, in the reference list, the second reference should be:

Eriksson, H. (1986). Hög- eller Låggallring (High or low thinning). *Sveriges Skogvårdforbunds Tidskrift* **2**, 3–18.

And also the fifth reference should be Marschall, J. (1975). Hilfstafeln für die Forsteinrichtung. Osterreicher Agrarverlag, instead of Hilfstafeln für die Forsteinrichtung. Marschall Julius 1975.