SILVA FENNICA 1985, vol 19 n:o 2: 185–196

ON THE USE OF TREE STAND PARAMETERS IN ESTIMATING LIGHT CONDITIONS BELOW THE CANOPY

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Seloste

PUUSTOTUNNUSTEN KÄYTÖSTÄ METSIKÖN VALAISTUSOLOJEN ESTIMOINTIIN

Saapunut toimitukselle 4. 3. 1985

Especially in forest vegetation studies, the light climate below the canopy is of great interest. In extensive forest inventories, direct measurements of the light conditions are too time-consuming. Often only the standard tree stand parameters are available. The present study was undertaken with the aim to develope methods for estimation of the light climate on the basis of readily measurable tree stand characteristics. The study material includes 40 sample plots representing different kinds of more or less mature forest stands.

In each forest stand, a set of hemipherical photographs was taken and standard tree stand measurements were performed. A regression approach was applied in order to elaborate linear models for predicting the canopy coverage. The total basal area of the stand alone explained 63 % of variance in the canopy coverage computed from hemispherical photographs. A coefficient representing the relative proportion of spruce in the stand increased the explanatory power into 75 %. When either the stand density (stems/unit area) or dominant age of the stand was included into the model, increment of the explanatory power into 80 % was achieved. By incorporating both of the preceding predictors, an explanatory power of 85 % was reached.

1. INTRODUCTION

In forest ecosystem research, particularly in studies focused to the understorey vegetation, light climate below the canopy has to be taken into account in the site characterization. The technique based on hemispherical photographs enables one to characterize the light climate of a site reliably (Hill 1984, Evans & Coombe 1959, Anderson 1964, Pope & Lloyd 1974, etc.) When the number of sites under study is large the method is rather time-consuming since the trees are not evenly distributed and it is therefore necessary to photograph each forest site more than once. In very large invertories such as the National Forest Inventories, only standard parameters of the tree stand can be measured. When these data are to be analyzed, one can either neglect the light climate in site characterization or estimate it roughly by using the available tree stand measurements. In forest vegetation studies, only average estimates of the light climate are necessary, since the interest is in light reaching the community and not the fate of light within the community.

The present study was undertaken with the aim to develope simple empirical regression models for predicting the light climate on the basis of standard tree stand parameters. Regression estimates can be applied to site characterization e.g. in *a posteriori* analyses of large vegetation data sets such as those collected during the National Forest Inventories. Although the relationships between the radiation extinction and tree stand structure have earlier been confirmed (e.g. Monsi & Saeki 1953, Kellomäki & al. 1980, Ross 1981), this study reports the possibilities and problems involved in approximating light climate when only incomplete data of the stand structure are available.

This study is an independent, methodical part of research project carried out in co-operation with the Finnish Forest Research Institute and financed by the Academy of Finland. The author is grateful to Mr. Teuvo Levula and Mr. Pekka Tamminen for the measurements of the standard tree stand parameters, and to Prof. Eino Mälkönen for valuable contribution to the study. The author also wishes to thank Prof. Matti Leikola and Prof. Paavo Pelkonen for their comments on the manuscript. Computing work was carried out by the author in the University of Uppsala, Institute of Ecological Botany. The author wishes also to thank the swedish contributors, Prof. Eddy van der Maarel, Dr. Colin Prentice and Ms. Päivi Hennola.

2. MATERIAL AND METHODS

The study material was collected during the summer 1984. Ordinary field work (see e.g. Kuusipalo 1983) was first performed, and sampling of the plots included into accurate site analysis was done on the basis of these data. The size of the whole data set is 410 forest stands, and among them 40 stands were included into the subsample. Sampling was done in such a way that pine-dominated, spruce-dominated and mixed stands representing different forest site types were incorporated. Sample plots were located in the districts of Mikkeli and Luumäki, southern Finland. Descriptive data of the subsample are presented in Table 1.

In each forest stand, the following standard measurements on tree stand properties were made by a research group of the Finnish Forest Research Institute: total basal area and basal areas of different tree species (relascope method), dominant height of the stand (sample trees), dominant age of the stand (annual rings of sample trees at 1.3 m above soil level), and diameter at 1.3 m. In addition, the author calculated all trees higher than 1 m present on each 16×16 m sample plot to get an accurate estimate for local stand density. More information about the measurement methods are given by Tamminen (1982).

On each sample plot, 8–12 hemispherical photographs were taken from different random points. The measuring system consisted of an Olympus Fish-eye lens, a camera and a 0.3 m tripod. The recommendations by Anderson (1964, 1971) were followed in the different phases of the light measurements to get an average percentual canopy coverage value for each forest stand.

The computing work was done with IBM computer using GLM (General Linear Model) and STEPWISE (Stepwise Regression analysis) procedures of the programme package SAS (SAS User's Guide: Statistics, 1982). In the data analysis, average canopy coverage of the stand was treated as response variable and the tree stand parameters as predictors. As a first step, a preliminary stepwise regression analysis (forward selection, maximum r^2 criterion) was performed in order to select the best predictors. After that, the model was eleborated in order to find best possible regression estimate of the canopy coverage (maximum r^2 and smallest possible number of predictors). The residuals were examined.

Table 1. Descriptive data of the study sample.
Taulukko 1. Kuvailevaa tietoa tutkimusaineistosta.

Dominant tree *Pääpuulaji*	Forest site type – *Metsätyyppi* OMT+	OMT	OMT−	MT	MT−	VT	VT−	CT	Total *Yhteensä*
Norway spruce *Kuusi*	3	3	4	7	2	1			20
Scots pine *Mänty*		2	1	3	3	7	2	2	20
Total *Yhteensä*	3	5	5	10	5	8	2	2	40

Parameter *Tunnus*		Mean *Keskiarvo*	Standard deviation *Keskihajonta*	Minimum *Minimiarvo*	Maximum *Maksimiarvo*
Canopy coverage *Latvuspeittävyys*	(%)	75.1	7.9	53.7	87.1
Total basal area *Pohjapinta-ala*	(m^2)	26.0	5.7	14.0	37.0
Pct spruce *Kuusen %-osuus*		50.1	43.5	0.0	100.0
Dominant age *Puuston ikä*	(years)	73.4	23.4	30.0	151.0
Stems/plot *Runkoa/näyteala*		47.6	26.5	8.0	125.0

3. RESULTS

As a result of the preliminary stepwise selection, the following variables were incorporated into the model as predictors: total basal area of the stand,basal area of spruce, dominant age of the stand and stand density (stems/plot). No other variables fulfilled the selection criteria. Both raw and arcus sin-transformed values of the canopy coverage were used as response variables during the stages of model elaboration. Arcus sin-transformation gave slightly better result, as far as the r^2 value is concerned. The difference was, however, so small that in the following models raw value is used in order to make the estimation more simple.

The relationship between canopy coverage and total basal area is presented in Figure 1. Explanatory power is about 63 % and the residuals quite large. Since the main tree species, Norway spruce (*Picea abies* (L.) Karst.) and Scots pine (*Pinus sylvestris* L.), evidently differ from each other in terms of crown structure and needle biomass, it was concluded that one ought to stress the proportion of spruce in the total basal area. This was done in such a way that the total basal area was weighted by coefficient representing the percentage of spruce. After elaboration by maximizing the explanatory power, weighting coefficient **S** was derived as follows:

(1) If basal area of spruce aquals zero, then **S** = 0.5 (this means that predominance of pine prevails).

(2) if basal area of spruce in the stand is greater than 49 % the total basal area, **S** = 1.

(3) Otherwise, **S** = 0.75.

The model can be presented as follows:

(4) Canopy coverage = **S**. Total basal area.

Since the new relationship appeared to be a curvilinear one, a logarithm transformation of the predictor variable was done:

(5) Canopy coverage = $\log_{10}$ (**S**. Total basal area).

The relationship between the response variable and the estimator constructed above is presented in Figure 2. Explanatory power is now about 75 % and the range of residuals much less wide than in the preceding figure. Increment of the model arises from the fact that the shading effect of spruce is stronger than that of pine. Hence simple stressing of the former give reasonable and unsophisticated formula to be used in rough *a posteriori* estimation of the light climate when only relascope measurements are available in the data set.

The model was elaborated further by incorporating the dominant age of the stand into the model. (Fig. 3) With this model, explanatory power of 80 % was achieved. The highest residuals were encountered with pure pine stands with the total basal area less than 15 m^2. When the dominant age was replaced by the stand density (Fig. 4), almost equal explanatory power was reached. Now the highest residuals were found with stands characterized by a dense undergrowth associated with a normal stand of dominant trees. It seems likely that both models account for a substantial part of eachother's residual variance. Therefore a model was constructed, in which all predictor variables were included. The result is presented in Figure 5. Explanatory power was almost 85 %. This was the very best model involving all of the four variables selected by stepwise procedure. The highest residuals were encountered with stands characterized by a mature but sparse growing stock of pine together with dense undergrowth. Residual plot of the preceding model is presented in Figure 6. Residual pattern seems to indicate some abnormalities that may require corrective attention (see e.g. Anscombe & Tukey 1963). It is possible that canopy coverage values are more likely overthan underestimated in the middle sequence of the axis but the situation is more balanced near both poles of the axis. On the basis of the presented data, however, further corrections were not possible. Anyway, the model is reasonable and reliable enough to be used for predicting.

Table 2. Correlations between the variables.
Taulukko 2. Muuttujien väliset korrelaatiot.

	1.	2.	3.	4.	5.	6.
1. Canopy coverage *Latvuspeittävyys*	1.00					
2. Total basal area *Pohjapinta-ala*	0.79	1.00				
3. Basal area of pine *Männyn pohjapinta-ala*	−0.50	−0.39	1.00			
4. Basal area of spruce *Kuusen pohjapinta-ala*	0.70	0.71	−0.90	1.00		
5. Dominant age *Puuston ikä*	−0.56	−0.39	0.36	−0.43	1.00	
6. Stems/plot *Runkoa/näyteala*	0.44	0.19	0.21	−0.09	−0.13	1.00

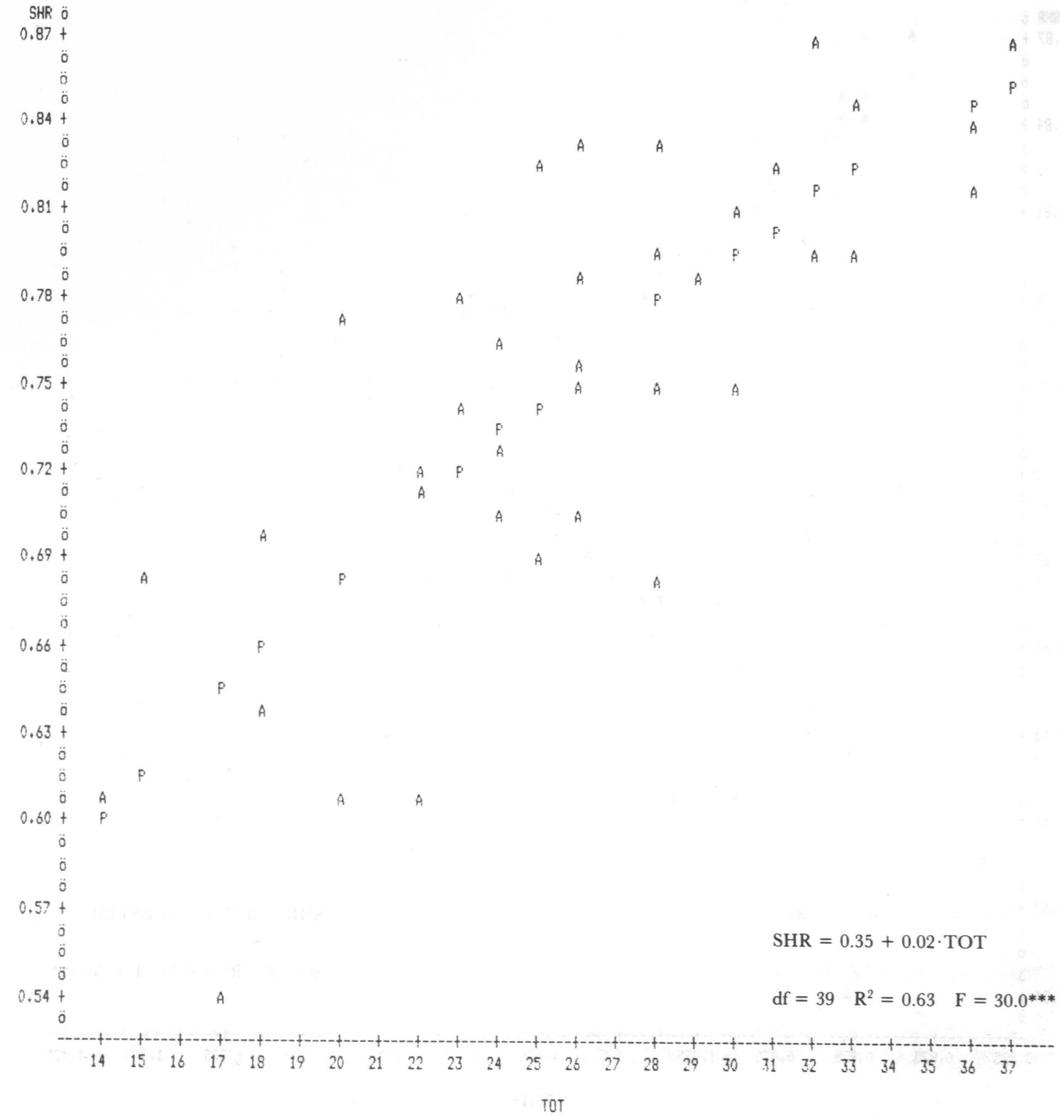

Figure 1. Regression between the canopy coverage (SHR) and total basal area (TOT). Legend: A = observed value P = predicted value. Note: 26 observations hidden.
Kuva 1. Latvuspeittävyyden (SHR) ja kokonaispohjapinta-alan (TOT) välinen regressio. Selitykset: A = havaittu arvo P = ennustettu arvo. Huomautus: 26 peittynyttä havaintoa.

Correlation matrix of the variables involved is presented in Table 2. Since there exist rather strong mutual correlations among the predictor variables, the model cannot be interpreted as a causal one (cf. Kuusipalo 1984). However, because the main emphasis is on predicting the light regime rather than explaining it, mutual correlations are acceptable (cf. e.g. Leskinen 1977).

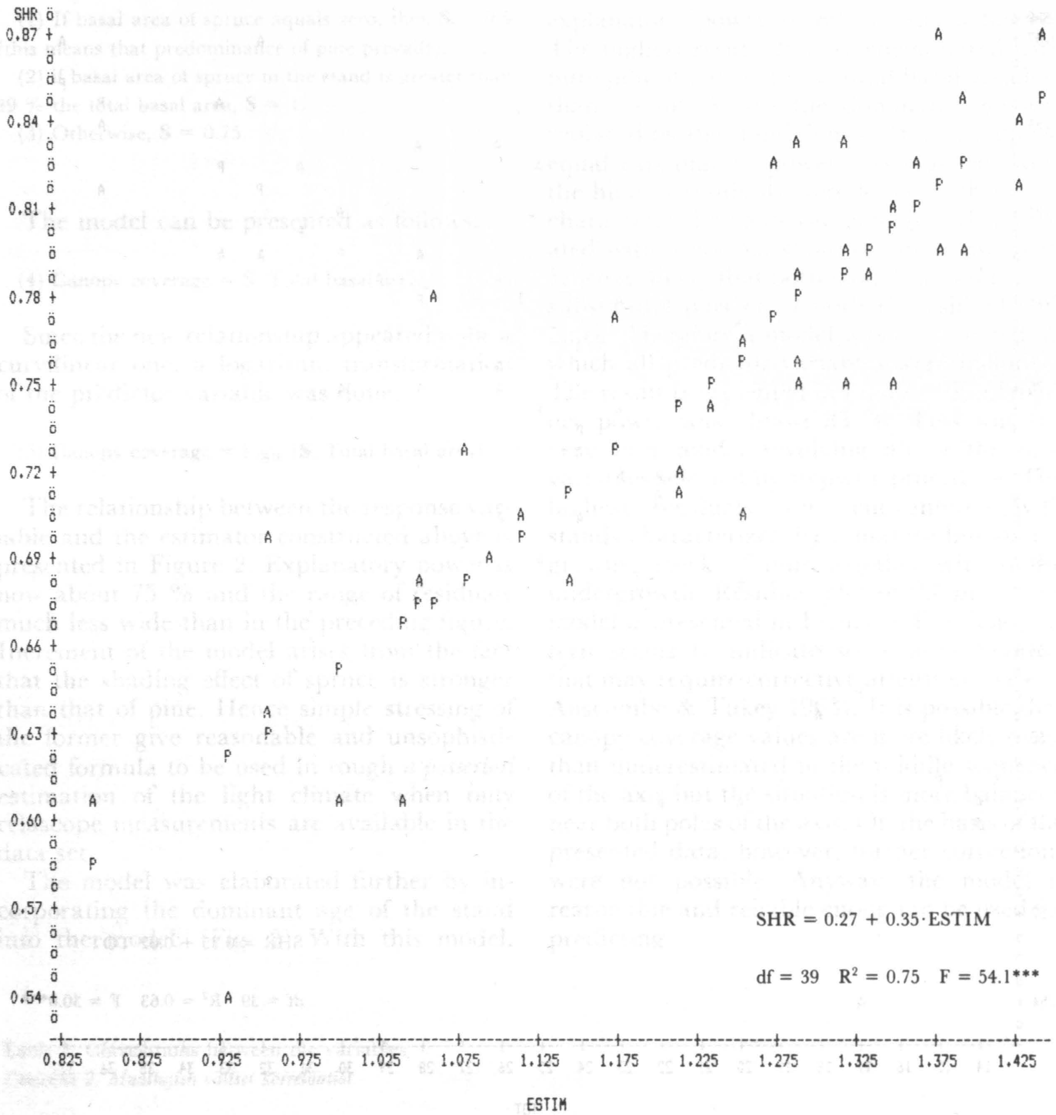

Figure 2. Regression between the canopy coverage and estimate ESTIM = $\log_{10}$ (S·TOT). For further explanation, see the text.
Legend: A = observed value P = predicted value.
Note: 18 observations hidden.

Kuva 2. Latvuspeittävyyden ja estimaatin ESTIM = $\log_{10}$ (S·TOT) välinen regressio. Tarkempi selitys tekstissä.
Selitykset: A = havaittu arvo P = ennustettu arvo.
Huomautus: 18 peittynyttä havaintoa.

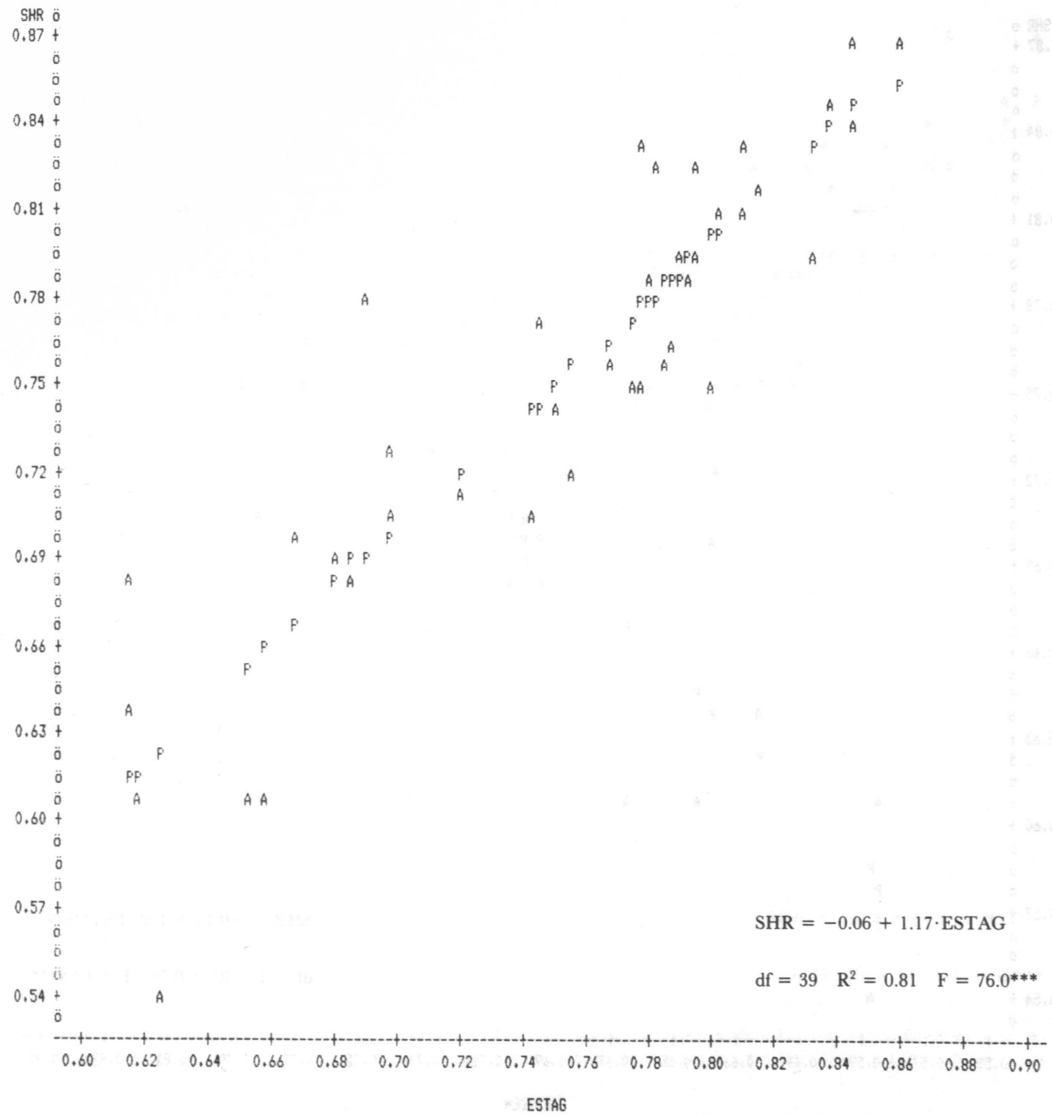

Figure 3. Regression between the canopy coverage and estimate ESTAG = 0.35 + 0.38·ESTIM − 0.001·AGE (dominant age). For further explanation, see the text.
Legend: A = observed value P = predicted value.
Note: 9 observations hidden.

Kuva 3. Latvuspeittävyyden ja estimaatin ESTAG = 0.35 + 0.38·ESTIM − 0.001·AGE (puuston ikä) välinen regressio. Tarkempi selitys tekstissä.
Selitykset: A = havaittu arvo P = ennustettu arvo.
Huomautus: 9 peittynyttä havaintoa.

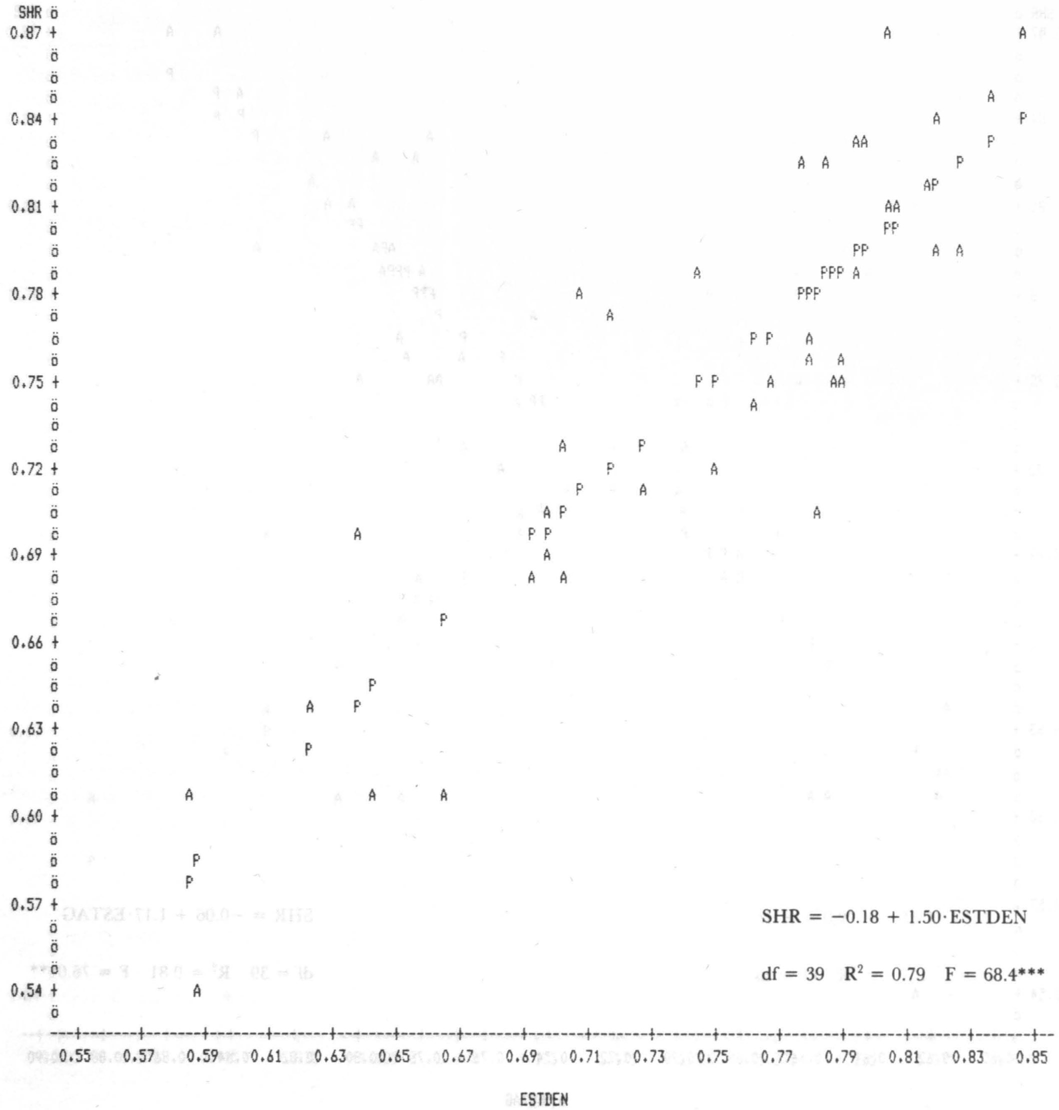

Figure 4. Regression between the canopy coverage and estimate ESTDEN = 0.17 + 0.38·ESTIM + 0.07·$\log_{10}$(DEN), where DEN = density (stems/plot). For further explanation, see the text.
Legend: A = observed value P = predicted value.
Note: 10 observations hidden.

Kuva 4. Latvuspeittävyyden ja estimaatin ESTDEN = 0.17 + 0.38·ESTIM + 0.07·$\log_{10}$ (DEN) välinen regressio. (DEN = tiheys runkoa/näyteala). Tarkempi selitys tekstissä.
Selitykset: A = havaittu arvo P = ennustettu arvo.
Huomautus: 10 peittynyttä havaintoa.

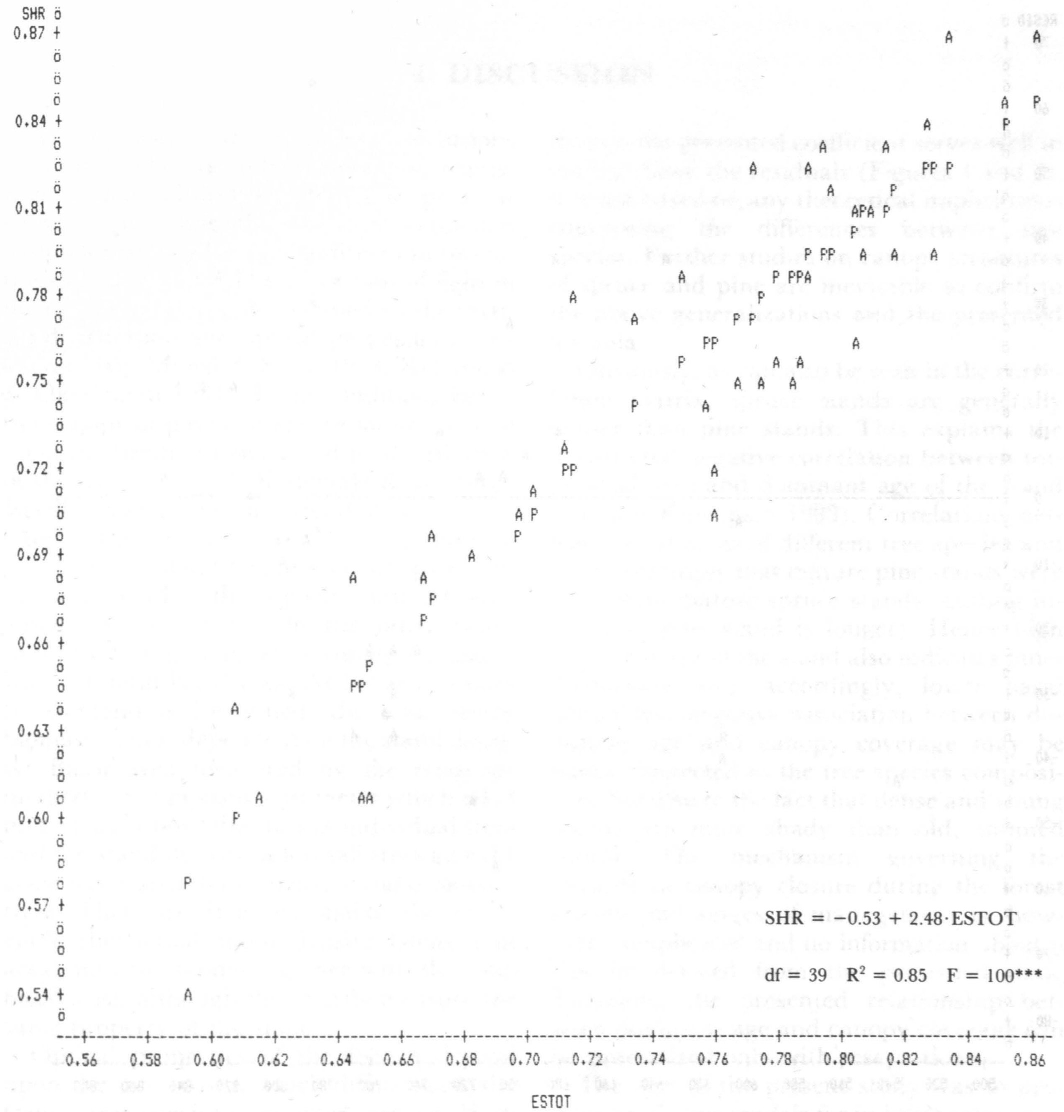

Figure 5. Regression between the canopy coverage and estimate ESTOT = 0.30 + 0.34·ESTIM + 0.001·AGE + 0.06·$\log_{10}$(DEN). For further explanation, see the text.
Legend: A = observed value P = predicted value.
Note: 6 observations hidden.

Kuva 5. Latvuspeittävyyden ja estimaatin ESTOT = 0.30 + 0.34·ESTIM − 0.001·AGE + 0.06·$\log_{10}$(DEN). Tarkempi selitys tekstissä.
Selitykset: A = havaittu arvo P = ennustettu arvo.
Huomautus: 6 peittynyttä havaintoa.

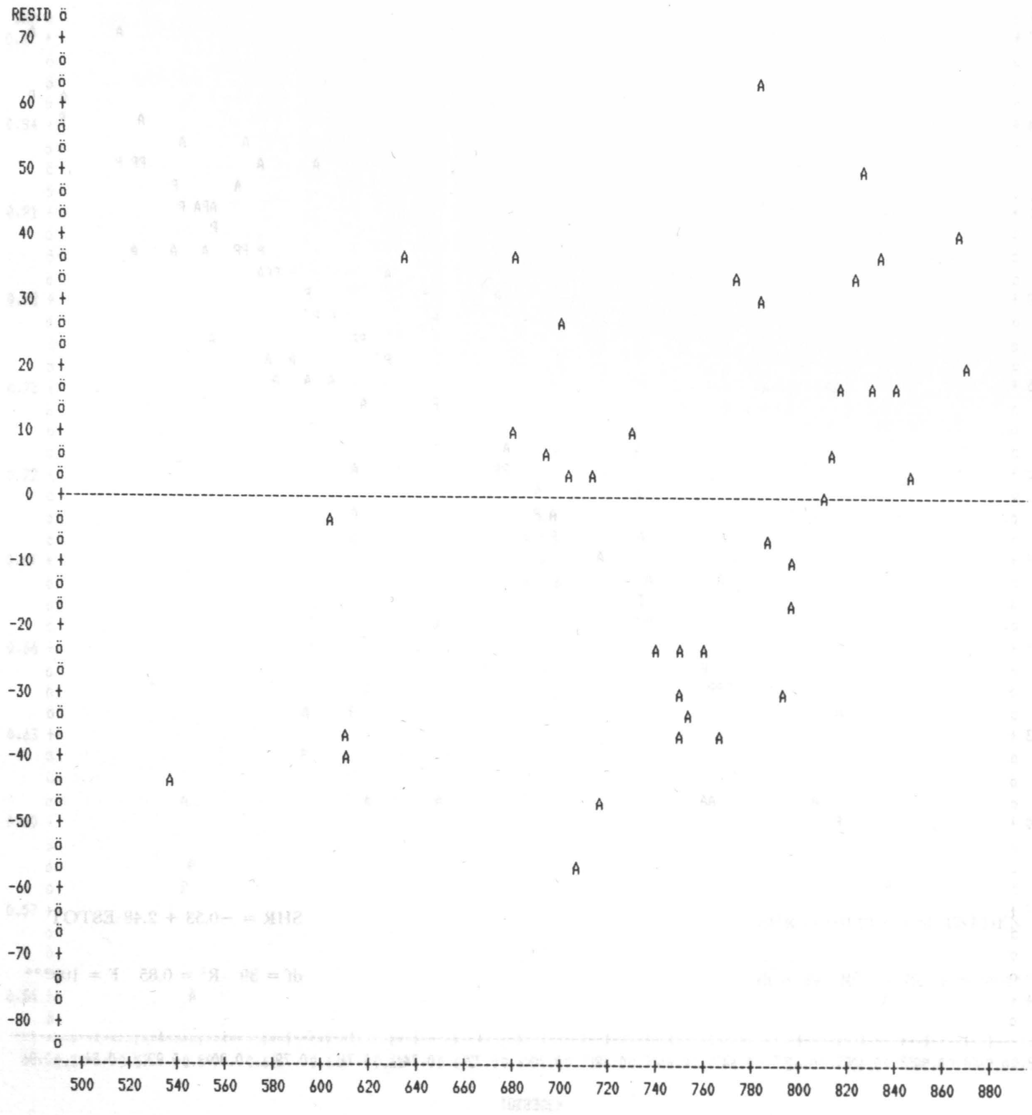

Figure 6. Residuals of the model in Fig. 5 plotted against the canopy coverage values.
Kuva 6. Kuvan 5 regressiomallin residuaalien riippuvuus latvuspeittävyyden arvoista.

4. DISCUSSION

As emphasized above, causal conclusions ought not to be drawn from predictive regression models. However, refering to previous studies concerning the radiation extinction within forest stands, some indirect interpretations can be made. The extinction of light in the canopy system is determined by the vertical distribution and optical properties of the foliage (e.g. Monsi & Saeki 1953, Kellomäki & Oker-Blom 1981). Light conditions below the canopy of pine and spruce forests depend upon the needle biomass and its distribution in the tree crown (cf. Kellomäki & al. 1980). Needle biomass of an individual tree is related to the size of the tree. No close association between stand height and canopy coverage was found in the present study (cf. Kellomäki & al. 1980). On the other hand, canopy coverage was very strongly associated with the total basal area. As far as an entire forest stand is concerned, the total needle biomass in also dependent on the stand density. Basal area measured by the relascope method is a composite parameter which takes into account both the sizes of individual trees and the stand density: a few tall trees give the same basal area than a dense stand of smaller trees. Therefore, it is reasonable also to include the actual stand density (stems/unit area) into the model together with the total basal area, although they partly measure the same property of the stand.

Optical properties of the foliage depend upon the tree crown, which differs markedly from a tree species to another (see e.g. Horn 1971). Optical properties of needles (colour, size, pattern) are also important. In the present study, a simple empirical correction coefficient was derived to standardize these between-species differences. The presented formula (Fig. 2) implies an assumption that the shading effect of a more or less pure pine stand is only half of that of a more or less pure spruce stand, if basal area is normalized.

Intermediate cases were settled simply by giving the coefficient a value just between those of pure stands. It should be noted, that most of the forest stands in Finland are nearly monocultures, i.e. characterized by a clear predominance of either spruce or pine. Although the presented coefficient serves well in cutting down the residuals (Figures 1 and 2), it is not based on any theoretical implications concerning the differences between tree species. Further studies on canopy structures of spruce and pine are inevitable to confirm the above generalizations and the presented formula.

Obviously, as can also be seen in the correlation matrix, spruce stands are generally denser than pine stands. This explains the unexpected negative correlation between total basal area and dominant age of the stand (see also Kuusipalo 1983). Correlations between basal areas of different tree species and stand age imply that mature pine stands were older than mature spruce stands (cutting interval of pine stand is longer). Hence high dominant age of the stand also indicates pine-dominance and, accordingly, lower basal area. Clear negative association between dominant age and canopy coverage may be partly connected to the tree species composition, but also to the fact that dense and young stands are more shady than old, thinned stands. The mechanism governing the changes in canopy closure during the forest growth and stages of management is, however, complicated and no information about it can be derived from the presented data. Therefore, the presented relationship between dominant age and canopy coverage can be generalized only with reservations.

The aim of the present study was to produce predictive models for indirect extrapolation of light conditions in different kinds of forest stands. A basic assumption involved in this study is that light climate can reliably be measured on the basis of hemisphere photographs (see e.g. Anderson 1964, Horn 1971, Pope & Lloyd 1974). Accepting this, the models seem to serve quite well as practical tools of site characterization, when only standard measurements of the tree stand characteristics are available. However, as stressed in the examination of residuals, dense undergrowth associated with a sparse stand of dominant trees may seriously distort the estimation results. As far as site characterization is concerned, one must keep in mind that canopy structure governs not only the illumination level below the canopy but also ecological factors such as microclimate and soil properties. Particularly in comparisons between pine- and spruce-dominated sites, these should be taken into account.

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SELOSTE

PUUSTON STANDARDITUNNUSTEN KÄYTÖSTÄ METSIKÖN VALAISTUSOLOJEN ESTIMOINTIIN

Metsäekosysteemiä ja varsinkin pintakasvillisuuden ja kasvupaikan välisiä suhteita tutkittaessa on välttämätöntä ottaa huomioon pintakasvillisuuden saaman valon määrä. Metsikön valaistusolot määrää ensisijaisesti puuston rakenne. Valon määrän suora mittaaminen, samoin kuin latvuspeittävyyden tarkka arviointi, on liian hidasta sovellettavaksi laajamittaisiin metsäinventointeihin. Aiemmin, esimerkiksi valtakunnan metsien inventointien yhteydessä kerättyjä aineistoja analysoitaessa käytettävissä ovat ainoastaan kentällä mitatut puuston standarditunnukset. Tämän tutkimuksen tarkoituksena on kehittää menetelmiä valaistusolojen arvioimiseen helposti mitattavien ja useimmissa aineistoissa käytettävissä olevien puustotunnusten pohjalta.

Kussakin koemetsikössä (40 koealaa) latvuspeittävyys laskettiin keskiarvona sarjasta kalansilmäobjektiivilla otettuja taivaankansivalokuvia. Latvuspeittävyyttä käytettiin riippuvana muuttujana ja puustotunnuksia selittäjinä muodostettaessa regressiomalleja valoilmaston estimointiin. Puuston pohjapinta-ala yksin selitti 63 % latvuspeittävyyden vaihtelusta. Kun regressiomalliin lisättiin kuusen osuutta kuvaava korjauskerroin, selitysaste nousi 75 %:in. Runkoluku ja valtapuuston ikä nostivat selitysasteen 85 %:in ja molemmat erikseen 80 %:in.