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Site classification in *Pinus sylvestris* L. forests in southern Finland

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It was examined whether the present site classification method, and especially its applicability to site productivity estimation, could be improved in upland Scots pine (*Pinus sylvestris* L.) forests in southern Finland (1) by developing a classification key based on Two-way Indicator Species Analysis (TWINSPAN), and/or (2) by inclusion of soil texture, stoniness and the humus layer depth more closely in the classification method. TWINSPAN clusters (TW) explained 71 % and forest site types (FST) 64 % of the variation in site index (SI) (H_{100}). When soil texture (TEXT) was added to the regression model, the explanatory power increased to 82 % (SI = TW + TW * TEXT) and to 80 % (SI = FST + FST * TEXT), respectively. Soil texture alone explained 69 % of the variation in site index. The influence of stoniness on site index was significant ($P < 0.05$) on sorted medium sand soils and on medium and finesand moraine soils. The thickness of the humus layer (2–6 cm) was not significantly ($P = 0.10$) related to site index.

It is suggested that the proposed TWINSPAN classification cannot replace the present forest site type system in Scots pine stands in southern Finland. However, the TWINSPAN key may be used to aid the identification of forest site types. The observation of dominant soil texture within each forest site type is recommended.

Tutkimuksessa tarkasteltiin kysymystä, voitaisiinko kasvupaikkaluokittelua, ja erityisesti sen soveltuvuutta puuntuotoskyvyn arviointiin, edistää Etelä-Suomen männiköissä (1) kehittämällä rinnasteiseen indikaattorianalyysiin (TWINSPAN) perustuva luokitteluavain, ja/tai (2) ottamalla maalaji, kivisyys ja humuksen paksuus entistä tarkemmin huomioon luokittelussa. TWINSPAN-klusterit (TW) selittivät 71 % ja metsätyypit (FST) 64 % valtapituusboniteetin (SI) (H_{100}) vaihtelusta. Lisättäessä maalaji (TEXT) regressiomalliin selitysaste kohosi 82 %:iin (SI = TW + TW * TEXT) ja 80 %:iin (SI = FST + FST * TEXT). Maalaji yksinään selitti 69 % valtapituusboniteetin vaihtelusta. Kivisyyden vaikutus valtapituusboniteettiin oli tilastollisesti merkitsevä ($P < 0,05$) lajittuneilla keskikarkean hiekan mailla sekä keskikarkean ja hienon hiekan moreenimailla. Humuskerroksen paksuuden (2–6 cm) ja valtapituusboniteetin välillä ei havaittu tilastollisesti mekitsevää riippuvuutta ($P = 0,10$).

TWINSPAN-menetelmällä kehitettyä luokittelua ei suositella metsätyyppiluokittelun korvaajaksi. TWINSPAN-luokitteluavain saattaa kuitenkin olla hyödyksi metsätyyppien tunnistamisessa. Vallitsevan maalajin tunnistamista suositellaan metsätyypityksen yhteydessä.

Keywords: forest soils, site classification, site types, TWINSPAN, Scots pine, *Pinus sylvestris*.
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1 Introduction

The Finnish forest site classification system has changed relatively little since the theory and system of forest site types was developed by Cajander (1909, 1921, 1926, Nieppola 1986). The most significant change has been the inclusion of climatic vegetation zones into the system in the end of the 1950's (Kalela 1958, 1961). In the past decade, however, several suggestions have been made to improve the classification system (e.g. Oksanen 1984, Kuusipalo 1985, Sepponen 1985, Nieppola 1992, 1993).

The Finnish forest site types have been identified in the field according to the presence and abundance of certain understorey plant species and plant groups (e.g. Cajander 1926, Lehto and Leikola 1987). The identification has been based on vegetation descriptions and no unambiguous classification key has been used. It has been criticized that subjectivity causes occasional misidentification of forest site types yielding inconsistent results among different workers (e.g. Vuokila 1980). Although this has not been a severe problem, a more objective and accurate method would be desirable.

In the past decade a new method of classifying forest sites has been developed in Canada with the aim of minimizing the subjectivity in the identification of classification units (e.g. Jones et al. 1983, Sims et al. 1989, Nieppola et al. 1993). In this method the identification is based on a classification key which requires yes/no decisions on the presence or abundance of certain indicator plant species. Kuusipalo (1985) first investigated this approach in Finland.

Although soil factors have not been used in the identification of forest site types in Finland, they have often been observed in the field to obtain useful additional information about site conditions. These include stoniness (Viro 1947, 1953), degree of paludification (impeded drainage), and humus layer depth in some forest site types (Siren 1955). These factors have been used for silvicultural purposes and to improve site productivity estimation. Several other soil attributes, such as soil texture, pore pattern, and depth to bedrock, have also often been observed for silvicultural and ecological purposes. Instead of using soil factors as supplementary information in the above manner, an alternative approach would be to include some of them in the classification system directly.

The aim of this paper is to investigate whether site classification could be improved in upland Scots pine (*Pinus sylvestris* L.) forests in southern Finland (1) by developing an unambiguous classification key based on indicator plant species, and (2) by inclusion of soil texture, stoniness, and humus layer depth more closely in the classification method. Special attention is given to the applicability of site classification to site productivity estimation.

2 Material and methods

2.1 Data collection

The study material consists of 222 sample plots (50 m × 50 m) established between 1950 and 1956 in mature Scots pine stands in different parts of southern Finland. One of the most important requirements in the collection of the study material was that site productivity could be estimated as reliably as possible by site index (H_{100}) in each stand (e.g. Cajander 1921, 1926, Vincent 1961, Hägglund 1979). Except for six paludified sites and six sites which had stratified soil deposits in the top 30 cm soil layer, the data are the same as in Nieppola and Carleton (1991), who give a more detailed description of the sampling and study area.

In each sample plot the breast height diameter of all trees and the height of the 15 thickest trees were measured. Stand age was determined as the mean age of 3 to 6 dominant trees. Dominant soil texture in the top 40 cm soil profile was observed from a soil pit placed in the centre of each plot (Aaltonen 1941, Viro 1947). The following classification was used (Aaltonen et al. 1949, Ilvessalo 1951): (1) (sorted soils) gravel soils, coarse sand, medium sand, finesand, and silt soils, and (2) (moraine soils) sand moraine, finesand moraine, and silt moraine soils.

Stoniness of the mineral soil was measured by the method of Viro (1953). In the top 30 cm soil profile, the mean penetration of a 1 cm thick rod at 30 systematic locations gave a soil depth index. This was transformed into stoniness volume percentage (Viro 1952). The thickness of the humus layer was estimated as the mean of 10 systematically placed measurements. Forest site type was identified (Cajander 1926) and all the species were listed in each sample plot. For more detailed information on the vegetation data collection, see Nieppola and Carleton (1991).

The nomenclature of the plant species follows Hämet-Ahti et al. (1984) for vascular plants, Koponen et al. (1977) for bryophytes, and Santesson (1984) for lichens. Cup and horn lichens in *Cladonia* sectio *Cladonia* were treated collectively.

2.2 Data analysis methods

Site index (H_{100}), which refers to the dominant tree height at 100 years, was calculated on the basis of dominant height-over-age equations of Gustavsen (1980). For these equations the dominant height, i.e. the mean height of the 100 thickest trees per hectare, was obtained using the height curves of Näslund (1937, Heinonen 1981).

Two-way Indicator Species Analysis (TWINSPAN) (Hill 1979) was carried out for two purposes: (1) to classify sites into groups according to their understorey vegetation composition, and (2) to construct a classification key, based on indicator plant species, that enables new sites to be classified into these groups. TWINSPAN was carried out for presence-absence species data.

One-way analysis of variance was performed in order to investigate how TWINSPAN clusters and forest site types were related to site productivity, as measured by site index (H_{100}). It was also used to explore the relationship between site index and soil texture. The multiple comparison test with the Tukey procedure (Dunnett 1980) was carried out to test the pairwise differences in site index among the classification units. Multiple regression was applied to examine how much variation in site index could be explained jointly by vegetation, as represented by TWINSPAN clusters and forest site types, and the soil variables. In all analyses nominal variables were treated as dummy variables.

3 Results

A total of 110 plant species were encountered in the vegetation dataset. Of these, 59 were herbs, 11 grasses and sedges, 12 dwarf shrubs, 19 mosses, and 9 lichens. Summary statistics for stand characteristics and site variables are shown in Table 1.

3.1 TWINSPAN classification

Six vegetation clusters were produced by TWINSPAN. The classification diagram (Fig. 1) shows the species which best separated the clusters at each TWINSPAN dichotomy. In the diagram forest site types are shown below each cluster in order to approximately illustrate the relations between the two classifications. The actual distribution of sample plots in each TWINSPAN cluster among forest site types is presented in Table 2. The key for the TWINSPAN classification is based on 22 understorey plant species (Fig. 2).

TWINSPAN clusters 1 and 2 represented the most unproductive sites. Their vegetation was dominated by xerophilous plant species, such as *Cladina* spp., *Cetraria islandica*, *Calluna vulgaris*, *Empetrum nigrum*, *Arctostaphylos uva-ursi*, and *Diphasiastrum complanatum*. TWINSPAN clusters 3 and 4 represented intermediate site productivity. The occurrence of *Calamagrostis arundinacea* and *Linnaea borealis* in both of these clusters and *Trientalis europaea* and *Rubus saxatilis* primarily in cluster 4 best separated these clusters from the previous ones. Clus-

Table 1. Summary statistics for stand characteristics and site variables.

Variable	Mean	Min	Max	SD
Age of stand (yrs)	119.7	72.0	210.0	22.5
Dominant height (m)	21.9	15.6	31.2	3.1
Basal area (m^2/ha)	21.2	11.6	36.7	4.2
Site index (H_{100}) (m)	20.5	11.9	30.1	3.4
Stoniness (volume %)	17.1	0.0	74.0	18.1
Humus layer depth (cm)	3.2	0.8	7.0	0.9

Table 2. Distribution of sample plots into TWINSPAN clusters and forest site types. For an explanation of the abbreviations of forest site types, see Fig. 1. N = total number of sample plots.

Forest site type	TWINSPAN cluster 1	2	3	4	5	6	N
ClT	3	-	-	-	-	-	3
CT	74	39	8	-	-	-	121
VT	2	25	42	10	2	-	81
MT	-	-	2	3	8	2	15
OMT	-	-	-	1	-	1	2
N	79	64	52	14	10	3	222

ter 5 included relatively productive sites and it was characterized by mesophilous, relatively herbrich vegetation (Fig. 1). Cluster 6, which represented the most productive sites, included only three sample plots. These plots were not merged with cluster 5, because their vegetation, with more moisture-demanding species and greater species richness, clearly differed from those in cluster 5.

3.2 TWINSPAN clusters, forest site types, and soil texture

In the regression model TWINSPAN clusters explained 71 % of the variation in site index (Table 3). In comparison, forest site types explained 64 % of the variation in site index (Table 4). According to the multiple comparison test, the average site index among TWINSPAN clusters differed significantly ($P < 0.05$) from each other in pairwise comparisons, except for TWINSPAN clusters 4 and 5, and 5 and 6 (Table 3). Similarily, the average site index between the *Calluna*, the *Vaccinium*, and the *Myrtillus* site types differed significantly ($P < 0.05$) from each other (Table 4). The number of stands in the *Cladina* site type, in the *Oxalis-Myrtillus* site type, and in TWINSPAN cluster 6 was too small to show significant site index differences in the multiple comparison test.

Soil texture explained 69 % of the variation in site index (Table 5). According to the multiple comparison test, soil texture classes differed significantly ($P < 0.05$) from each other with respect to site index. The exceptions for this were silt and finesand classes in which there were too few samples for adequate testing.

Site index means calculated for soil texture classes in each of TWINSPAN clusters elucidated how the relationship between soil texture and site productivity was linked to vegetation. The average site index generally increased where soil texture changed from relatively coarse to finer textures in each TWINSPAN cluster (Fig. 3a). Similarly, when the subgrouping was reversed such that TWINSPAN clusters were nested within soil texture classes, the average site index in-

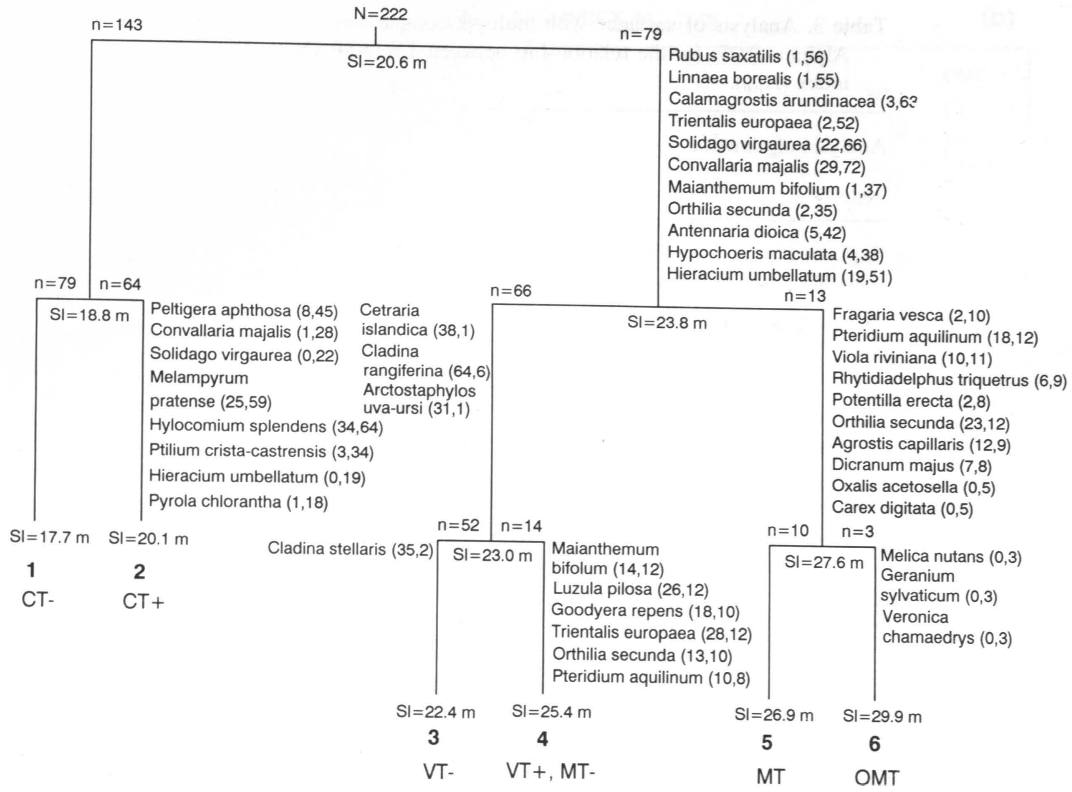

Fig. 1. TWINSPAN classification with the species which were mostly responsible for the separation of the clusters at each TWINSPAN dichotomy. Numbers in parentheses give the frequencies of each species in the left and in the right cluster, respectively. N = total number of sample plots, n = number of sample plots in a cluster, SI = the average of site index (H_{100}) in a cluster. ClT = *Cladina* site type, CT = *Calluna* site type, VT = *Vaccinium (vitis-idaea)* site type, MT = *Myrtillus* site type, OMT = *Oxalis-Myrtillus* site type. The sign after the abbreviated forest site type name refers to a more (+) or less (–) fertile type variant.

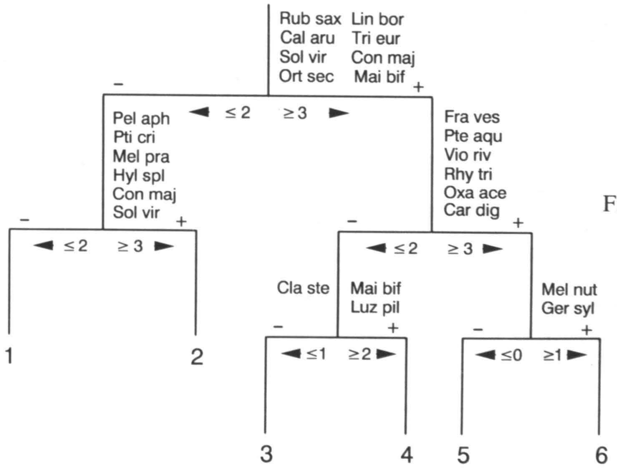

Fig. 2. TWINSPAN classification key. Application rule: Score +1 for each positive indicator species and –1 for each negative indicator species encountered on a site and calculate the sum. Compare this sum to the key score at the division and proceed right or left. Repeat the above through each successive division to determine the final TWINSPAN cluster. For full species names, see Fig. 1.

Table 3. Analysis of variance with multiple comparison test (Tukey-method, Alpha = 0.05) for the relationship between TWINSPAN clusters and site index (H_{100}).

Analysis of variance

Source	D.F	SS	MS	F	Significance
Explained	5	1825.314	365.063	103.25	0.000
Residual	216	763.733	3.536		

$R^2 = 0.71$ $SD_{H100} = 1.88$

Multiple comparison test
Comparisons significant at the 0.05 level indicated by *

TWINSPAN cluster	N	Mean (H_{100})	SD	TWINSPAN cluster 1	2	3	4	5	6
1	79	17.69	1.94						
2	64	20.10	1.88	*					
3	52	22.37	1.91	*	*				
4	14	25.36	1.46	*	*	*			
5	10	26.91	1.87	*	*	*	-		
6	3	29.93	0.29	*	*	*	*	-	

Table 4. Analysis of variance with multiple comparison test (Tukey-method, Alpha = 0.05) for the relationship between forest site types (FST) and site index (H_{100}). For an explanation of the abbreviated names of forest site types, see Fig. 1.

Analysis of variance

Source	D.F	SS	MS	F	Significance
Explained	4	1664.959	416.240	97.74	0.000
Residual	217	924.088	4.260		

$R^2 = 0.64$ $SD_{H100} = 2.06$

Multiple comparison test
Comparisons significant at the 0.05 level indicated by *

FST	N	Mean (H_{100})	SD	FST ClT	CT	VT	MT	OMT
ClT	3	18.05	1.37					
CT	121	18.34	2.06	-				
VT	81	22.56	2.11	*	*			
MT	15	26.81	1.93	*	*	*		
OMT	2	28.99	1.58	*	*	*	-	

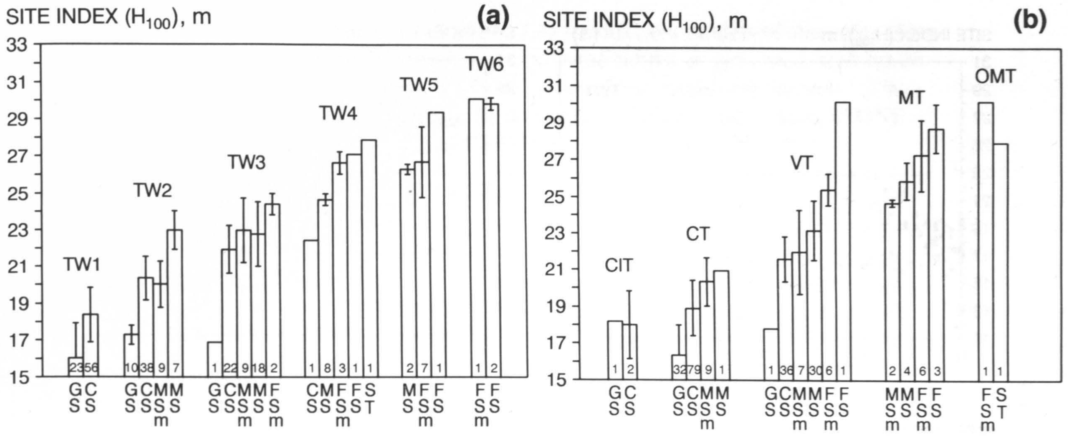

Fig. 3. Site index (H_{100}) average for soil texture class in each TWINSPAN cluster (a) and forest site type (b). The number at the bottom of each bar indicates the number of sample plots. The line bars show standard deviation (SD) of site index values. TW = TWINSPAN cluster. For an explanation of the abbreviated names of forest site types and soil texture classes, see Fig. 1 and Table 5, respectively.

Table 5. Analysis of variance with multiple comparison test (Tukey-method, Alpha = 0.05) for the relationship between soil texture and site index (H_{100}). GS = gravel soil, CS = coarse sand, MSm = medium sand moraine, MS = medium sand, FSm = finesand moraine, FS = fine sand, ST = silt.

Analysis of variance

Source	D.F	SS	MS	F	Significance
Explained	6	1781.341	296.890	79.03	0.000
Residual	215	807.706	3.760		

$R^2 = 0.69$ $SD_{H100} = 1.94$

Multiple comparison test
Comparisons significant at the 0.05 level indicated by *

Soil texture	N	Mean (H_{100})	SD	Soil texture GS	CS	MSm	MS	FSm	FS	ST
GS	34	16.43	1.72							
CS	117	19.71	1.99	*						
MSm	18	21.47	2.20	*	*					
MS	35	23.42	1.84	*	*	*				
FSm	13	26.61	1.99	*	*	*	*			
FS	4	29.04	1.34	*	*	*	*	-		
ST	1	27.87	- - - -	*	*	*	-	-	-	

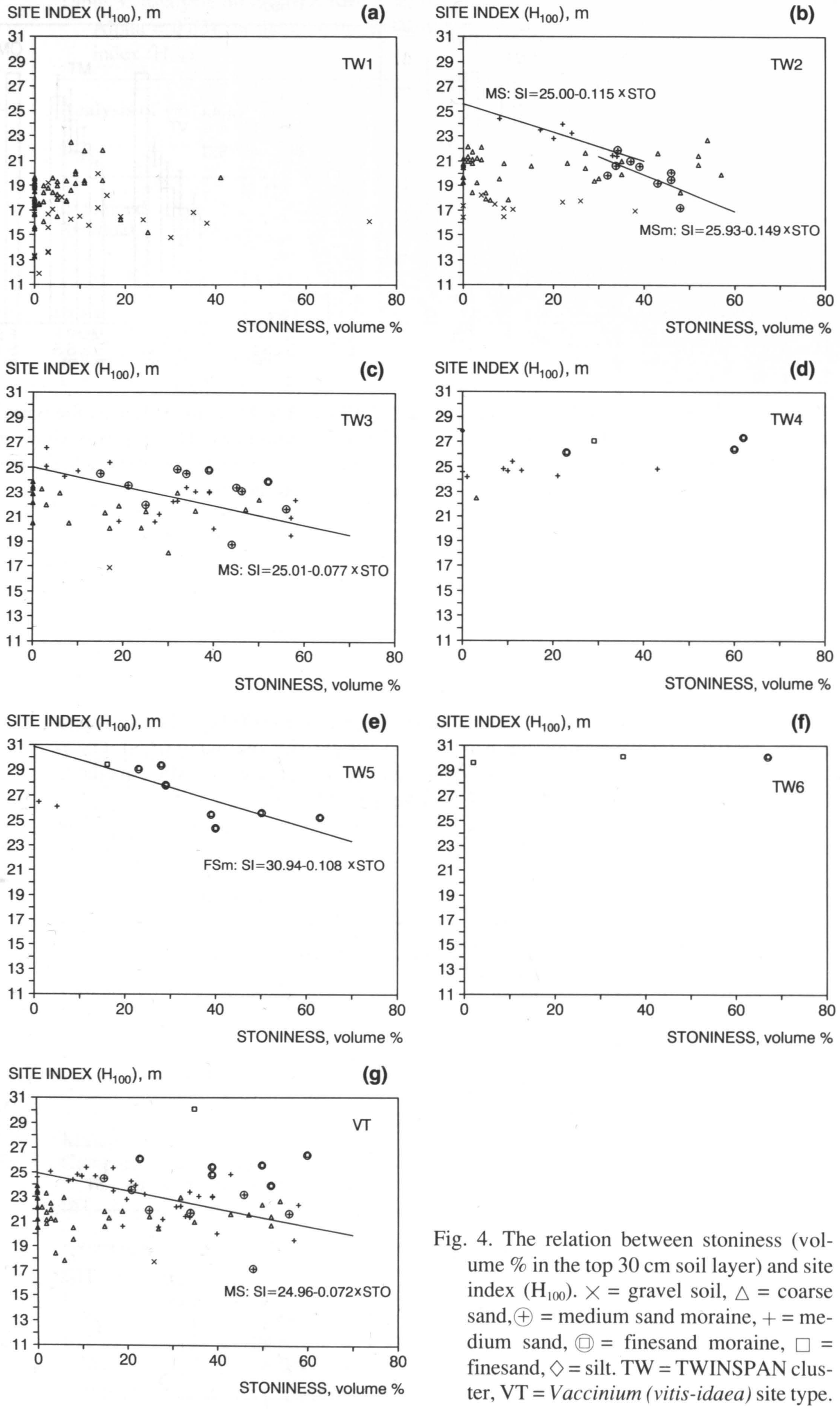

Fig. 4. The relation between stoniness (volume % in the top 30 cm soil layer) and site index (H_{100}). × = gravel soil, △ = coarse sand, ⊕ = medium sand moraine, + = medium sand, ◎ = finesand moraine, □ = finesand, ◇ = silt. TW = TWINSPAN cluster, VT = *Vaccinium (vitis-idaea)* site type.

Table 6. Regression statistics (ANOVA) for different models of site index (SI) (H_{100}) estimation. In each case, only the model is presented here which received the highest R^2-value among all examined models. TW = TWINSPAN cluster, FST = forest site type, TEXT = soil texture, STONE = stoniness. For all F-values P < 0.001.

Model	D.F	MS	F	R^2
SI = TW+TW∗TEXT	20	106.66	47.02	0.82
SI = FST+FST∗TEXT	17	121.37	47.09	0.80
SI = TW+TW∗TEXT+TW∗TEXT∗STONE	35	63.26	31.40	0.86
SI = FST+FST∗TEXT+FST∗TEXT∗STONE	29	73.53	30.91	0.82

creased among successive TWINSPAN clusters. The corresponding results with forest site types were very similar (Fig. 3b). According to the analysis of variance, soil texture had a significant (P < 0.01, F-test) influence on site index in each TWINSPAN cluster except in clusters 5 and 6, and in each forest site type except the *Cladina* site type.

The regression model explained 82 % of the variation in site index when the joint factor of TWINSPAN cluster and soil texture was added to the model (Table 6). In comparison, forest site types accounted for 80 % of the variation in site index when the influence of soil texture was added to the model (Table 6). Thus, the difference between the TWINSPAN classification and the forest site type classification (Tables 3 and 4) levelled out when soil texture was included in the model.

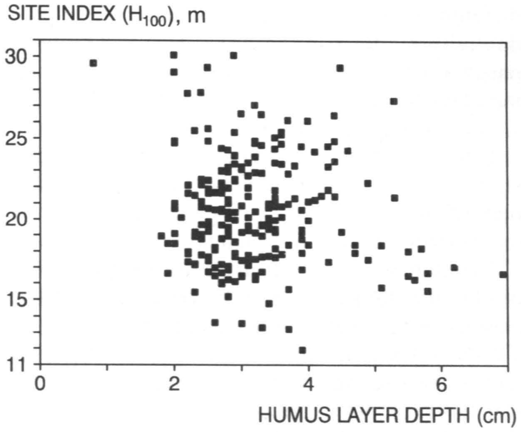

Fig. 5. A bivariate scatter illustrating the poor correlation between the humus layer depth and site index(H_{100}).

3.3 Stoniness and humus layer depth

The influence of stoniness on site productivity was examined by regressing site index on stoniness values (volume %) in each TWINSPAN cluster. This was carried out by soil texture class. In TWINSPAN clusters 1 and 4 stoniness was not significantly (P > 0.05) related to site index (Figs. 4a and 4d). In TWINSPAN cluster 2 the influence of stoniness was significant on sorted medium sand soils and on medium sand moraine soils explaining 82 % (P < 0.01, F-test) and 49 % (P = 0.03) of the variation in site index, respectively (Fig. 4b). In TWINSPAN cluster 3 the effect was significant only on sorted medium sand soils (Fig. 4c) and in TWINSPAN cluster 5 on finesand moraine soils (Fig. 4e). In these subgroups stoniness explained 47 % (P < 0.01) and 57 % (P = 0.04) of the variation in site index, respectively. Among forest site types the influence of stoniness on site index was significant (P < 0.01, $R^2 = 0.41$) only on sorted medium sand soils in the *Vaccinium* (*vitis-idaea*) site type (Fig. 4g).

A multiple regression model in which stoniness was included along with TWINSPAN cluster and soil texture explained 86 % of the variation in site index (Table 6). When forest site types were used instead of TWINSPAN clusters, the model explained 82 % of the variation in site index (Table 6).

The thickness of the humus layer appeared to have no indicator value of site productivity. The Pearson correlation coefficient between the humus layer depth and site index was not significant (r = –0.11, P = 0.10) (Fig. 5).

4 Discussion

An attempt was made in this paper to develop a site classification method that is based on an unambiguous classification key derived from a TWINSPAN analysis, and to compare this classification method, and especially its applicability to site productivity estimation, with the present forest site type approach in Scots pine stands in southern Finland. The classification based on the TWINSPAN allocation key explained the variation in site index slightly better than that was explained by forest site types. The difference in the number of classification units and the differences in their distribution along a site productivity gradient in these two classifications is partly responsible for this result. Nevertheless, the classification derived from the TWINSPAN allocation key appears to be, by this criterion, slightly superior to the forest site type approach. However, it is questionable whether the application of this method would give real improvements over the current forest site type approach.

The increase in objectivity in the identification of classification units may be only minor if the classification was based completely on the TWINSPAN allocation key instead of the current forest site type approach. This is because it was not possible to develop a versatile classification key which would include only species that are all common and easy to observe in the field. The species, used in the proposed key, that may be difficult to find in the field, particularly when occurring in small abundance, include all the mosses and lichens, especially *Peltigera aphthosa*, *Ptilium crista-castrensis*, and *Rhytidiadelphus triquetrus*, and of the vascular plants, *Linnaea borealis* and *Orthilia secunda*.

The TWINSPAN classification was relatively similar to the forest site type classification. However, the match was not perfect. For example, TWINSPAN cluster 4 would be positioned between the *Vaccinium* site type and the *Myrtillus* site type in the current Finnish forest site type system. Consequently, the present knowledge and interpretations concerning different site classification applications, e.g. silvicultural prescriptions, growth and yield tables, resource planning etc., which are strongly linked to the forest site type system, could not be applied directly in the new classification. This would require adjustments which, in some cases, would prerequisite new studies with the new classification.

Although the results in this paper do not justify the use of the TWINSPAN classification in the place of the forest site type classification, the TWINSPAN allocation key may be applied as an aid in the forest site type identification. For example, it could be used to provide some extra guidelines for the identification of unclear site type variants or boderline cases such as those between the *Calluna* and the *Vaccinium* site types.

Soil texture explained a slightly larger proportion of the variation in site index than forest site types. This result somewhat conflicts the current view regarding the ability of soil texture to indicate site productivity in Finland (e.g. Sepponen et al. 1982). One possible reason for this is that the current knowledge is primarily based on studies where the relations between soil texture, forest site type, and site productivity have been examined without adequate site index data (e.g. Ilvessalo 1933, Aaltonen 1941, Urvas and Erviö 1974).

Site index was relatively strongly related to soil texture within each TWINSPAN cluster and within each forest site type. Similarly, it was relatively strongly linked to TWINSPAN cluster and forest site type within each soil texture class. These results suggest that understorey vegetation and soil texture should both be taken into account in site classification. The use of soil texture and other soil factors together with vegetation in site classification has previously been widely supported (e.g. Cajander 1921, 1926, Hills and Pierpoint 1960, Krajina 1965, Carmean 1975). This, so called multifactor approach has been used recently e.g. in North America in studies developing ecosystem classification systems (e.g. Jones et al. 1983, Spies and Barnes 1985, Hix 1988, Ferguson et al. 1989, Sims et al. 1989, Nieppola et al. 1993).

Soil factors and vegetation can be used together in site classification in several ways. Site classification can be based on vegetation, and soil factors can be used as supplementary information in order to assess more accurately different site properties, e.g. productivity. Other possibilities are, for example, to develop a classification in which site types are identified on the basis of soil factors and vegetation simultaneously, or to use soil factors as a basis of classification and to include vegetation to obtain supplementary information of site conditions. Of the above approaches, the first may be most flexible, because the often time-consuming measurements of soil factors are only required where this is necessary for a particular application. In addition, it has an advantage that the delineation of site units in the field is usually easier with vegetation than with soil characters.

Stoniness on mineral soils is mainly included in the Finnish site classification as a factor that reduces site productivity. It is estimated visually or, with greater accuracy, by the method of Viro (1952, 1953) as used in this study. According to Viro (1953), a small proportion of stoniness probably increases soil productivity due to its effect on soil aeration and temperature. However, when the relative abundance of stones exceeds 20 % in the top soil matrix, it starts to reduce site productivity and this effect is greater on poor sites than on fertile sites (Viro 1947, 1953, 1958). In this study the influence of stoniness was significant on sorted medium sand soils and on medium and finesand moraine soils. The relatively small number of sample plots in the vegetation/soil texture subgroups, and especially, the insufficiency of the very stony sites, where stoniness exceeds 60 volume percentage, in the data, probably explains the poor relationship on other soil types. A larger data than that used in this study with sufficient stoniness range would be needed to produce reliable equations for estimating the influence of stoniness on site productivity.

The results showed no statistically significant relation between the humus layer depth and site index in Scots pine forests in southern Finland on sites where the humus layer thickness varied between 2–6 cm. This suggests that the thickness of the humus layer, within this range, is poorly related to the nutrient and moisture conditions that control site productivity in these habitats.

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