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Original article

Structure and yield of all-sized and even-sized Scots pine-dominated stands

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Summary — This study is based on material collected in southwestern Finland using a systematic temporary circular plot line survey method. A total of 273 sample plots were included in the study. These plots represented Scots pine (*Pinus sylvestris* L)-dominated stands established on dryish mineral soil sites. In half of the sample plots the stand structure was all-sized (*ie* stem distribution resembled an inverted letter J). Even-sized stand structure (stem distribution resembled a normal distribution) applied in the case of 31% of sample plots while 17% were irregularly uneven-sized in structure. The number of trees per hectare in the all-sized stands was more than twice that of even-sized stands. The mean annual increment increased along with an increase in growing stock volume. The volume in even-sized stands was higher than in all-sized stands but their mean annual increment was equal. Nevertheless, in stands with equal average volume (125 ± 25 m^3/ha), the mean annual increment in all-sized stands was one third higher than in even-sized stands.

stand structure / yield / stem distribution / all-sized / even-sized

Résumé — Structure et rendement de peuplements irréguliers et réguliers à majorité de pin sylvestre. *Cette étude est basée sur du matériel récolté dans le sud-ouest de la Finlande (1951-1953) au moyen d'une méthode statistique à base de placettes d'échantillonnage circulaires temporaires systématiques alignées. L'étude comprenait un total de 273 placettes d'échantillonnage. Ces placettes représentaient des peuplements de pin sylvestre (*Pinus sylvestris *L) établis sur des terrains à sol minéral sec. Dans la moitié des placettes d'échantillonnage, la structure du peuplement était irrégulière (c'est-à-dire avec une distribution des tiges ressemblant à la lettre J inversée). Des placettes d'échantillonnage (31%) représentaient des peuplements réguliers (distribution des tiges ressemblant à une distribution normale) tandis que 17% représentaient une autre structure. Le nombre de tiges par hectare dans les peuplements irréguliers était plus du double de celui des peuplements réguliers (fig 1). L'accroissement annuel moyen a augmenté parallèlement à l'augmentation du volume du matériel sur pied croissant (fig 2). En raison du fait que le volume de peuplements réguliers était plus grand que celui de peuplements irréguliers, leur accroissement annuel moyen était égal (tableau I). Néanmoins, l'accroissement annuel moyen de peuplements irréguliers au volume moyen égal (125 ± 25 m^3/ha) était d'un tiers plus élevé que celui des peuplements réguliers (tableau II).*

structure de peuplement / rendement / distribution des tiges / irréguliers / réguliers

INTRODUCTION

Forests in the boreal coniferous zone often develop into mixed forests of varying structure (Whitmore, 1978; Runkle, 1985; Solomon *et al,* 1986; Pobedinski, 1988; Prentice and Leemans, 1990; Lähde *et al,* 1991). Nevertheless, forest treatment (in the Nordic countries, for instance) has led to modifications of the natural diameter distribution. The practice in the first half of this century was to level out stand structure by removing bigger trees in conjunction with dimension fellings and thinnings from above. Gradually, cuttings were changed towards thinning from below, *ie* of removing smaller trees and thereby levelling out stand structure. Thinning from below became the generally approved practice of stand tending in the Nordic countries in the second half of this century. Nevertheless, the all-sized (all-aged) structure of the forests still persists (Arman, 1965; Skogsstatistik årsbok, 1989; Lähde *et al,* 1992).

The data presented on naturally established stands in Finland, for example, originate from selected stands where the understorey has been neglected or the initially all-sized growing stock has been transformed by cleaning and/or thinning from below to resemble an even-sized stand (Ilvessalo, 1920a, 1920b; Lönnroth, 1925; Lappi-Seppälä, 1930; Koivisto, 1954; Nyyssönen, 1954; Vuokila, 1956). In general, results on the yields of all-sized and even-sized stands based on comparative trials are still not available. National forest inventories, however, give possibilities for yield comparison. This material is characterized by being representative and it depicts the actual situation in the forest.

This study consists of national forest inventory data used to compare the occurrence, structure and yield of all-sized and even-sized Scots pine-dominated stands with and without admixtures of broad leaved trees on dryish mineral soil sites in south-western Finland. The hypotheses applied in the study are as follows: (1) an admixture of broad leaved species has a beneficial influence on the stand growth; and (2) differences in stem distribution have no influence on the stand growth.

MATERIALS AND METHODS

The study is based on the material provided by the 3rd national forest inventory conducted in Finland during the years 1951–1953. The data were collected by a systematic temporary circular plot inventory on dryish mineral soil sites (*Vaccinium* type; see Cajander, 1949) in southwestern Finland (60° – 62°N, 21°–27°E). The mean dominant height (100 thickest trees/ha) was also measured on most of the plots. This was used as a measure of site quality. Sample plots classified as being in the thinning, preparatory, or regeneration stages were selected for closer examination. The silvicultural state had to be good or satisfactory or the stands had to have been untreated for years (Ilvessalo, 1951). A further requirement was that the growing stock had to amount to 40 m^3/ha or more.

Each sample plot represented a particular stand. If a systematically placed sample plot fell on the boundary between 2 stands it was moved to within a uniform stand (Ilvessalo, 1951). Thus, the structure on any plot could not be an admixture of different stands. Plot size was 0.1 ha (1 000 m^2) for trees exeeding 10 cm. A smaller concentric circle (0.01 ha or 100 m^2) was delimited for tallying trees with dbh (diameter at breast height) of 2–10 cm. Small broad leaved trees of vegetative origin were not measured.

In this study, the trees were classified into 9 dbh classes as follows: 1 = 2–6; 2 = 6–10; 3 = 10–14; 4 = 14–18; 5 = 18–22; 6 = 22–26; 7 = 26–30; 8 = 30–34; and 9 = > 34 cm. Scots pine (*Pinus sylvestris* L) and Norway spruce (*Picea abies* L Karst) were kept separate. Broad leaved trees were combined to form the third group. Most of the broad leaved trees were birches (mainly *Betula pubescens* Ehrh and *B pendula* Roth).

The stands were classified according to their stem distribution. Four stands were rejected for the following reasons: 3 were 2-storeyed and 1 sample plot had small trees only. Thus, the material included a total of 273 stands. They were indi-

Table I. Parameters ($\bar{x} \pm$ se) of the stands studied. Results of 2-way analysis of variance and Tukey's test.

Stand structure	*Tree species groups*	*Sample plots*	*Relative growth (%)*	*Volume m^3/ha*	*Mean increment m^3/ha/a*
All-sized	Conifer	71	3.6 ± 0.2[a]	115 ± 7[a]	3.8 ± 0.2[a]
	Mixed	70	4.0 ± 0.2[a]	112 ± 5[a]	4.1 ± 0.2[a]
Even-sized	Conifer	72	2.6 ± 0.1[b]	142 ± 6[b]	3.6 ± 0.2[a]
	Mixed	14	2.8 ± 0.2[b]	129 ± 9[ab]	3.5 ± 0.4[a]
F-value, structure			24.74***	6.78*	2.20
F-value, tree species			1.56	0.79	0.31
Interaction			0.23	0.31	0.53

Values with different small letters differ statistically ($p < 0.05$) from each other.

vidually classified (table I) into 3 main groups as follows (applying the classifications used by Smith (1962) and Daniel *et al* (1979)):

J: All-sized. Stem distribution resembling an inverted letter J; trees present in at least the 4 smallest diameter classes, with the mode in the first or second class;

E: Even-sized. Stem distribution resembling a normal distribution; mode in neither of the 2 smallest diameter classes nor at either end of the distribution.

O: Others (irregularly uneven-sized). This group contained all other structurally uneven-sized sample plots (only some main results are given).

Classifications of another kind have also been used in describing the stand structure. Leemans (1991) and Szwagrzyk (1992), for instance, used the age, height, dbh, and exact tree location as a character.

In addition, the sample plots were divided into 2 tree species groups according to stem number:

A: Conifer stands. No more than 120 broad-leaved trees per ha (average = 30).

B: Mixed (broadleaved-coniferous) stands. More than 120 broad leaved trees per ha (average = 422; basal area 16%).

Comparison of the yield between different stand groups is presented as a mean annual increment (excluding bark) for the total material and for the same average volume class, and as a relative growth (%). The effect of stand structure and tree species composition on different stand parameters was analysed with 2-way analyses of variance. The differences between different group means were tested with Tukey's test. The dependence between mean annual increment and volume in stands with different structure and tree species composition was analysed with regression analysis.

RESULTS

Structure, tree species composition and stem number

About a half (52%) of the stands had all-sized structure, 31% were even-sized, and 17% were other (irregularly uneven-sized) (table I). The average amount of broad leaved trees (stems/ha) varied considerably within the structure groups. The average proportion of broad leaved species was 19% in all-sized mixed stands. The corresponding figure in the other groups was over 30%. The number of stems per ha in mixed stands exceeded that of conifer stands by the amount of broad leaved trees (fig 1). This difference was concentrated in small trees (dbh < 10 cm). The number of stems per ha in all-sized stands was more than

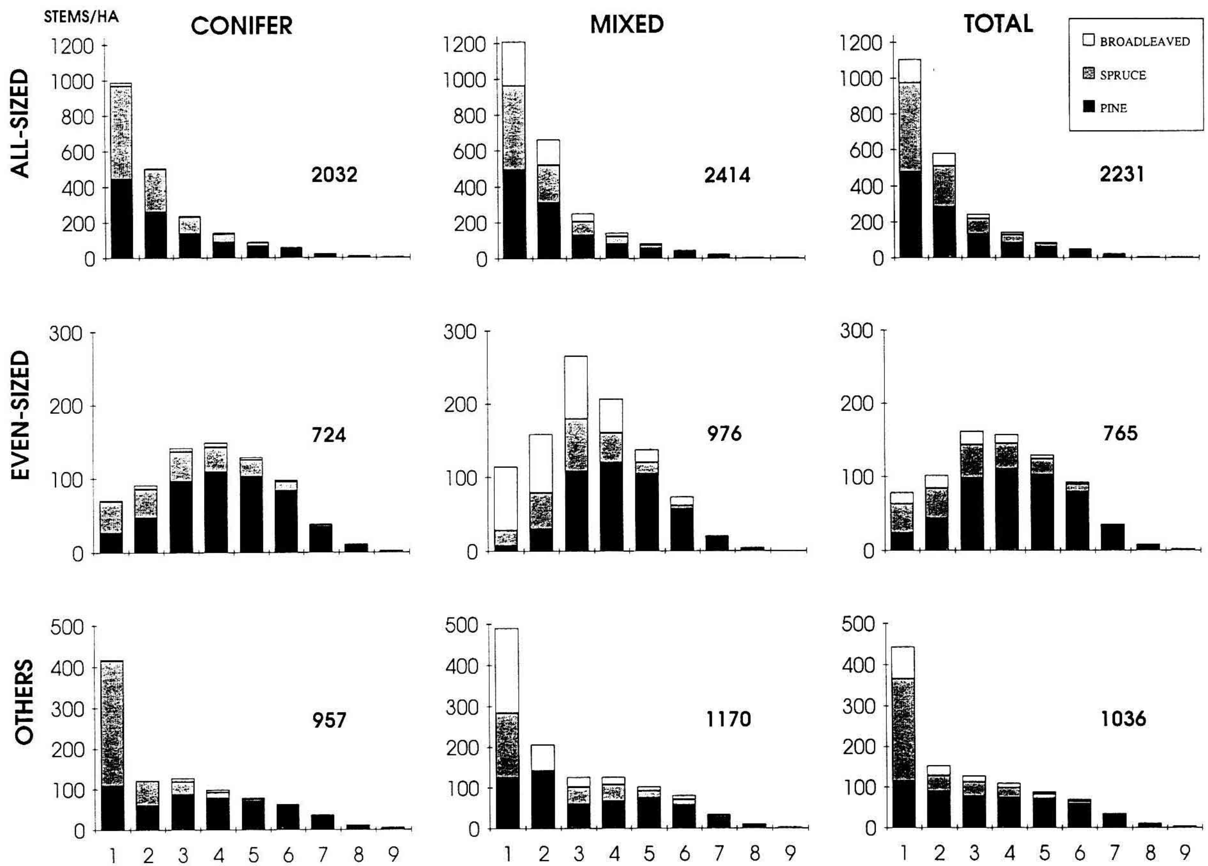

Fig 1. Average stem distribution in stands of different structure and tree species composition. Observe the scales showing stem number in the subfigures. Legends: dbh – classes: 1 = 2–6; 2 = 6–10; …, 9 = > 34 cm. Total stem numbers/ha are given in the subfigures.

double that of the other groups. In even-sized stands, the average number of stems per ha was close to 1 000; of these, small trees (dbh < 10 cm) accounted for slightly more than 200.

Scots pine was the dominant species in all structures and tree species groups (fig 1). Its average proportion varied within the range of 45–70%. On being examined per tree species (Scots pine, Norway spruce and broad leaved species), the stem distributions in all-sized stands, on average, also resembled an inverted letter J. In even-sized and irregularly uneven-sized (others) stands, the stem distribution for Scots pine resembled a normal distribution. In the case of Norway spruce, this applied only to the even-sized mixed stand.

Yield

The largest differences of volume between all-sized stands and even-sized conifer stands were statistically significant ($p < 0.01$) (table I). The latter volume was about 30 m^3 greater than the volume of all-sized stands. The relative growth (%, average of the 5 previous years) in mixed stands was about 10% greater than in conifer stands. The differences were not, however, statistically significant. The average relative growth in all-sized stands was considerably greater than in even-sized stands (table I). In the all-sized conifer stands it was, on an average, 38% higher than in corresponding even-sized stands ($p < 0.01$). In mixed stands the difference was even greater, 43% ($p < 0.01$).

The dominant height ($\bar{x}$ se, m) in all-sized and even-sized stands is presented in the following setting:

All-sized	Conifer	16.2 ± 0.4
	Mixed	16.1 ± 0.3
Even-sized	Conifer	18.1 ± 0.3
	Mixed	17.2 ± 0.4

The dominant height in all-sized stands differed significantly ($p < 0.01$) from that in even-sized conifer stands.

Due to the volume differences between the all-sized and even-sized stands, the differences in mean annual increment (m^3/ha) levelled out (table I). The mean annual increment increased linearly with increasing volume (fig 2). The difference in growth (33%) within the same average volume class (125 ± 25 m^3/ha) in the aforementioned stands was statistically significant ($p < 0.001$), see table II. The mean dominant height was 16.5 m in all-sized stands and 17.6 m in even-sized stands. The difference was significant ($p < 0.05$). The mean annual increment (including bark: average bark percentage 16, Ilvessalo, 1956) in this volume class of all-sized stands was 5.2 m^3/ha or a third higher than in even-sized stands.

DISCUSSION

The generally accepted view in the Nordic countries is that Norway spruce is the most shade-tolerant of the main tree species; next come the birches; and Scots pine is the least shade-tolerant of all. This has lead to the conclusion that only stands dominated by Norway spruce are capable of developing

Table II. Comparison of mean annual increment ($\bar{x} \pm$ se, m^3/ha) in all-sized and even-sized stands with equal average volumes (mean 125 ± 25 m^3/ha).

Stand structure	*Sample plots*	*Mean annual increment excluding bark*
All-sized	38	4.4 ± 0.2
Even-sized	33	3.3 ± 0.2
F-value		13.62***
P		< 0.001

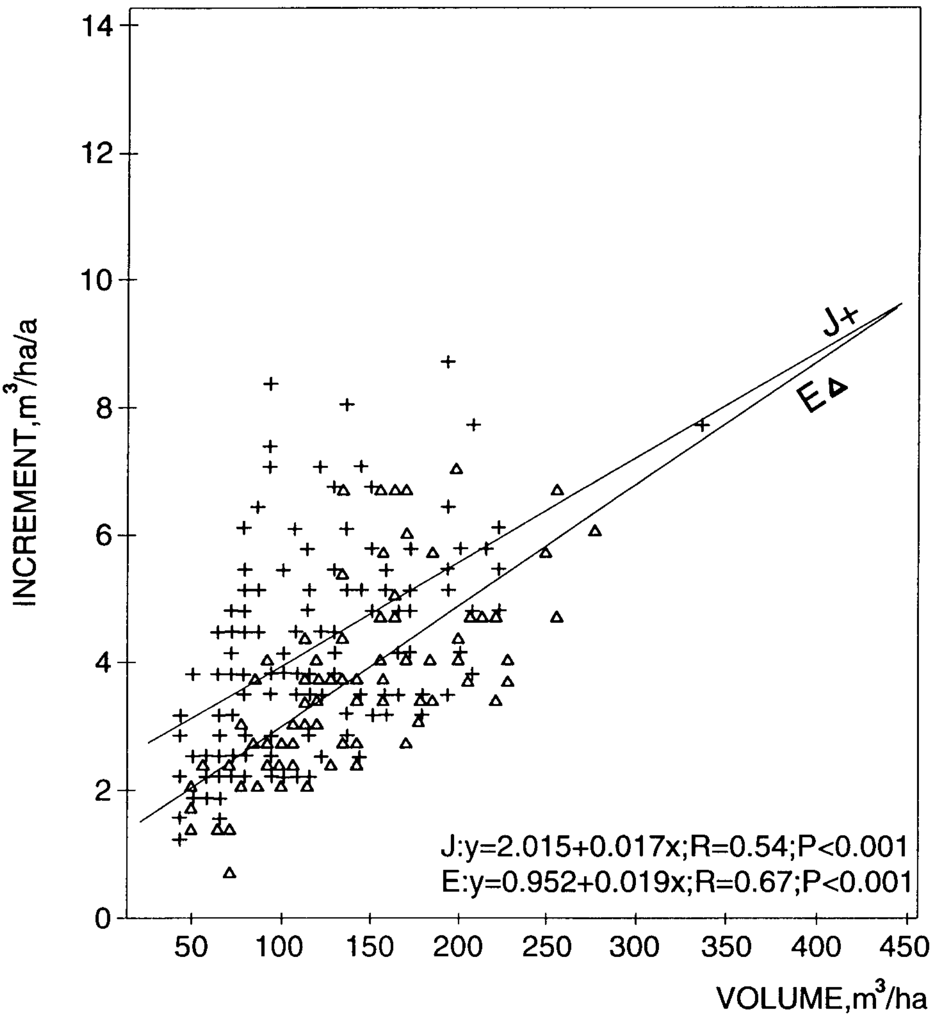

Fig 2. Dependence between mean annual increment and volume in all-sized (J) and even-sized (E) stands.

all-sized (all-aged) structure (Sarvas, 1948; Mikola, 1984). Norway spruce possesses an excellent capacity for recuperation when released from the oppression of the overstorey (Pöntynen, 1929; Cajander, 1934). Birches are also capable of emerging as an understorey, even under Norway spruce (Lähde *et al*, 1991, 1992; Lähde, 1992a, 1992b; Laiho, 1992). As an understorey, Scots pine thrives best under older pines, but can also survive under birch (Laiho, 1992). Scots pine has also been observed to be able to recover fairly well when released (Vaartaja, 1951).

The survival of Scots pine as an understorey is also good on virgin and drained peatlands (Heikurainen, 1971; Hånell, 1984; Gustavsen and Päivänen, 1986; Hökkä and

Laine, 1988; Hökkä *et al,* 1991). As on peatlands, pine-dominated stands on dry mineral soils (especially in the northern regions) are usually uneven-aged and all-sized (Lakari, 1915; Aaltonen, 1919; Lassila, 1920; Huse, 1965; Ilvessalo, 1970; Sjörs and Zackrisson, 1984; Norokorpi, 1992).

According to this study, the pine-dominated forests in southwestern Finland on dryish mineral soils were mainly all-sized in structure, *ie* their stem distribution resembled an inverted letter J. These soils are sufficiently fertile for Norway spruce and birches to be raised alongside Scots pine. Norway spruce and broad leaved species accounted for nearly a half of the stem number.

Observations made in North America indicate that Loblolly pine (*Pinus taeda* L) (Reynolds, 1969) and *Ponderosa* pine (*Pinus ponderosa* Dougl ex Laws) (Roe, 1952; Alexander and Edminster, 1978) can be raised as all-sized stands. According to Foiles (1978), such stands must be logged heavily enough to provide these light-demanding species with sufficient light.

On examining selected research material, Mielikäinen (1980) observed that Silver birch *(Betula pendula)* has a beneficial influence on the growth of stands dominated by Scots pine in southern Finland. According to Mielikäinen, just a small amount of birch (less than 20% of the volume) enhanced the growth of Scots pine. The influence of Downy birch *(B pubescens)* was not as strong. Lappi-Seppälä (1930) and Jonsson (1962) also observed that Scots pine grows better in virgin stands with an admixture of birch than in pure stands.

This study did not reveal any statistically significant differences in growth between mixed (broad leaved-coniferous) stands and conifer stands although the general trend was similar to that reported in the aforementioned studies. Thus, the first hypothesis (that broad leave species would enhance volume growth) was not confirmed. It has previously been observed in the same region that spruce-dominated mixed stands grew better than conifer stands (Lähde *et al,* 1994). The material in the latter study was clearly larger than in this study.

The results of this study showed that relative growth in all-sized stands was about 40% higher than in even-sized stands. This finding was enhanced by the difference in dominant height. Lähde *et al* (1994) have also observed a similar difference in growth of spruce-dominated stands. When stands with the same volume were examined in the present study, the increment in all-sized stands was significantly (33%) higher than in even-sized stands. Thus, the second hypothesis of the study (differences in stem distribution have no influence on growth) was also left unconfirmed. On the contrary, all-sized stands grew clearly better than even-sized stands.

The results of this study indicate that all-sizedness of the growing stock enhances stand yield in pine-dominated stands on dryish mineral soil sites. Lähde *et al* (1994) have observed the same in connection with spruce-dominated stands established on fertile mineral soil sites. This result means that structural all-sizedness should be taken into account as an alternative in the silviculture of pine-dominated stands.

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