

Effect of Weather and Climatological Background on Snow Damage of Forests in Southern Finland in November 1991

Reijo Solantie

Solantie, R. 1994. Effect of weather and climatological background on snow damage of forests in Southern Finland in November 1991. *Silva Fennica* 28(3): 203–211.

Snow damage to forests in Southern Finland in November 1991 is examined in relation to meteorological conditions. The combined effect of different factors proved to be necessary for severe damage. First, the snow load, in terms of precipitation, should exceed a certain limit. The limit can be set for weak or moderate damage at about 40 mm and for very severe damage at about 60 mm. Secondly, temperature at the time of precipitation should be above 0 °C, so that snow on twigs becomes slightly wet in order that it should attach to twigs during the subsequent period with temperature below 0 °C. On the other hand, temperatures exceeding 0.6 °C prohibit damage by permitting the snow load to fall. Wind speeds exceeding 9 ms⁻¹, as observed 15 m above ground, were strong enough to dislodge the snow which is not attached, and thus reduce the damage. There are few statistics either of snow damage or of the relation between the snow damage and precipitation. However, there is a causal connection between snow damage and heavy snowfalls. Therefore, the regions with a high frequency of heavy snowfalls, as indicated by orographical features and occurrence of thick snow cover, were investigated.

Keywords snow damage, snow, precipitation, winter, climate, snow cover, storms.

Author's address Finnish Meteorological Institute, Box 503, FIN-00101 Helsinki, Finland. Fax +358 0 192 9537, E-mail achim.drebs@fmi.fi

Accepted November 22, 1994

1 Introduction

In Southern Finland, snow damage to forests occurred on November 20th and 21st, 1991 in the connection with the passage of a depression. Snowfall attached to trees, which subsequently broke. The occurrence of snow damage has been verified by local authorities, and weather conditions have been analysed prior to and during the occurrence of damage. The study has been restricted to the province of Uusimaa, a coastal belt of 60 km in width adjacent to the Gulf of Finland. Damage occurring farther north-east was excluded from this study. The risk of heavy snowfalls as a function of orographical precipitation and thick snow indicating potential risk of the occurrence of snow damage in the province of Uusimaa in both space and time was also examined (Section 4).

2 Damage in Forests

The regional extent and intensity of damage was studied in the province of Uusimaa by interviewing forest engineers, who acted as local advisers. There is at least one advisor in each of the 26 forest management associations in the province. In a few cases only did the author need to resort to advisers of neighbouring associations. The areal coverage was practically total.

The interviews were made by phone in summer 1992, with each discussion including following points:

- 1) Species which suffered; most, least
- 2) What was the size of largest trees broken?
- 3) What the height of the breakage?
- 4) The topography of the places of damages (valley, hill, slope, plain)
- 5) Regional distribution of damages, 1) within the district of the adviser, 2) adjacent regions
- 6) The stage of damage: serious damage means several broken large stems (diameter over 15 cm at the breast height) on a damaged site, typically 10 to 20 stems per hectare, i.e., about 4 % of the total.

Following the definition of serious damage (item 6) it cannot be said that the damage 1991 was

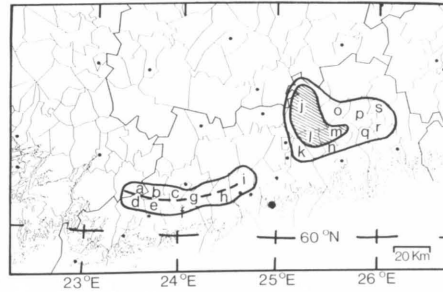


Fig. 1. The distribution of the most severe damage (according to local forest advisers). The bold line denotes the boundary of the province of Uusimaa; thin lines denote the commune boundaries. The hatched area in the east denotes the region of the most severe damage, whereas at the broken line in the west the damage was greatest on a north-south direction. Regions with damage are denoted by letters referring to communes and their parts (SE = south-eastern etc.): a) Kisko SE, b) Karjalohja S, c) Lohjan kunta S, d) Pohja N, e) Karjaa N, f) Inkoo N, g) Siuntio N, h) Kirkkonummi N, i) Espoo N, j) Mäntsälä, p) Myrskylä k) Sipoo N, l) Pornainen, m) Askola, n) Porvoon kunta N, o) Pukkila, p) Myrskylä, q) Pernaja N, r) Liljendal, s) Lapinjärvi NW.

either “destructive” or even “very severe” contrary to the case of the winter 1958–1959 (Suominen 1963)

Serious damage was reported to have occurred in the following communes, or parts of communes by compass directions (N, E, S, W): Kisko SE, Pohja N, Karjalohja S, Lohjan kunta S, Inkoo N, Siuntio N, Kirkkonummi N, Vihti S, Espoo N, Askola, Pornainen, Pukkila, Pernaja, Lapinjärvi, Liljendal, and Mäntsälä; regions denoted by Italics suffered most (Fig. 1). Damage occurred to a great variety of tree species. Only lime seemed to be unaffected. Traces of damage were of various kinds:

- 1) Medium size stems of Scots pine, Norway spruce and birch, 15–20 m tall, were broken at a height of 4 to 7 m, and the crowns had fallen to the ground (Fig. 2).



Fig. 2. A broken stem of a medium sized Scots pine.



Fig. 3. Bent stems of deciduous trees and a broken crown of a Scots pine, hanging by some remaining strands to the standing stem.



Fig. 4. Small uprooted stems of Scots pine.

- 2) Stems of young Norway spruce and birch in the height range of 5 to 10 m were broken at the height of 2 to 4 m; broken crowns hung from some remaining strands to the standing stem (Fig. 3). Typically, in summer 1992 birches attained full foliage but needles of pine were turning yellow.
- 3) Small Scots pines on rocks, height 3 to 6 m, were uprooted (Fig. 4).
- 4) Stems of different deciduous species and of 5 to 10 m in height were bent with and without visible fractures (Fig. 3).
- 5) Many old dead twigs were broken from most tree species.

3 Predominating Weather Conditions

Meteorological data consists of observations made by the Finnish Meteorological Institute, and stored in its data base. Weather events were examined from synoptic charts, made every 6 hours by central unit of the weather forecast service; the maps of Figs. 6 to 8 have been made by the author. Values of meteorological parameters above the normal height of observations, as well as the height of the condensation level and the tilt of the warm front, have been evaluated by the author using recorded data from Jokioinen observatory (60°49' N, 23°29' E). Sea surface temperatures have been estimated by the author from routine maps, made by the Marine Research Institute.

The damage was caused by meteorological events associated with a depression, the centre of which moved from the Baltic to the north-western corner of Lake Ladoga over the north-western corner of Estonia, the Gulf of Finland and the south-eastern corner of Finland (Fig. 5). The velocity of the depression centre was 12 to 13 kmh⁻¹; it entered the Gulf of Finland on Nov. 18 at 18 UTC and reached the Finnish mainland on Nov. 19 at 14 UTC. The route of the depression centre also delimits the warm front's extension at ground level in advance of the depression centre. In connection with the passage of the depression, snow fell first as warm front precipitation and continued as occlusion front precipi-

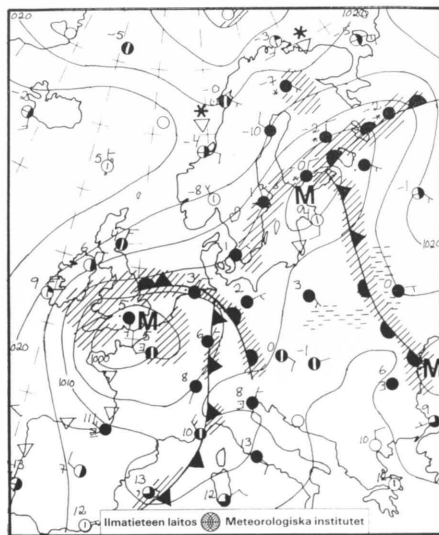


Fig. 5. The synoptic chart for 19th November, 1991, 0600 UTC (Finnish Meteorological Institute).

tation. Considering that the surface temperature of the Baltic was mostly 7 to 9 °C (Marine Research Institute), thus exceeding by 6 °C even the air temperature of the warm sector, much moisture was transferred from the sea to clouds before the depression centre reached Finland.

Precipitation during the event exceeded 30 mm in a belt just north of the route of the depression centre (Fig. 6). In this belt, the lowest layer with northerly winds was very thin. The lower, moist part of the warm air mass which released precipitation and which had south-easterly winds, extended so low that the orographical effect could influence precipitation. Therefore, the pattern of the most abundant precipitation was not exactly parallel to the path of the depression centre but its western part ran parallel to the coastline at a distance of 10 to 30 km.

In the cold air mass beneath the warm front, the horizontal distribution of ground surface temperature was influenced by the sea in two ways. The archipelago sea was very warm, from 6 °C at the mouth of the Gulf of Finland to 5 °C to the 26th longitude in the east. Consequently, there

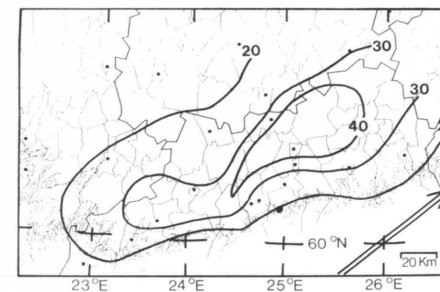


Fig. 6. Observed precipitation (mm) during the 48 hrs period beginning on the 19th November, 1991, 0600 UTC. The path of the depression centre is shown in the right lower corner.

was a coastal belt with a maximum air temperature above 0.6 °C. This belt was narrow because a cold air mass with offshore winds formed the lowest stratum. This belt narrowed eastwards (Fig. 7), which is in agreement with decreasing sea water temperature in that direction (Marine Research Institute). Eastwards of the town of Porvoo at the 26th longitude, the coastal belt with $T > 0.6$ °C became broader again due to the vicinity of the warm front.

The large gradient of air temperature in the cold air mass at the coast up to the 26th longitude, enhanced the corresponding air pressure gradient, which in turn increased wind speeds along the coast. The high wind speed near to the coast, dislodged the snow from the twigs, which well explains the fact that damage was not serious east of Helsinki where the zone of dangerous temperatures extended to the coastline. Consequently, it seems that on the basis of wind observations the crucial wind speed that prohibited the damage was about 8 to 10 ms⁻¹ (which in fact corresponds to the lower crucial wind speeds in the sheltered places where trees actually broke).

In the damaged area, the thawing period lasted 16 to 19 hours with the highest temperatures attaining 0.2 to 0.6 °C. Snow fall began before temperature rose above 0 °C, and continued for 48 hours. As temperature again fell below 0 °C, the wet snow, which had fallen earlier, froze to the twigs. The new, dry snow could only remain on the twigs if the wind was not too strong. In

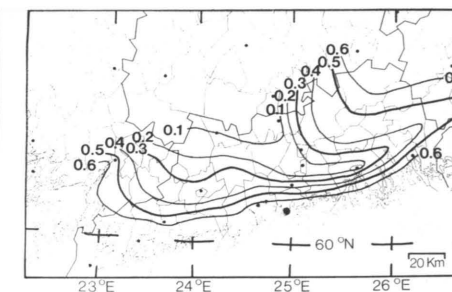


Fig. 7. Isotherms of observed maximum air temperature (°C) during the 48 hrs period beginning on the 19th November, 1991, 0600 UTC.

the areas of serious damage, the total precipitation during the event amounted to 30–45 mm. Allowing for the measuring error of solid precipitation, the actual total precipitation was 35 to 55 mm; about 30 % of this amount fell after the thaw period. The serious damage mostly occurred at locations in which topography resulted in reduced wind speeds and so the fallen snow remained on the twigs. Consequently, the precipitation which had fallen before the end of thawing, was not enough to break stems, whereas the total precipitation was. This conclusion agrees well with the experience from snow damage in 1959 according to which the degree of damage (Suominen 1963) ranged from light to the very serious with the increase of attached precipitation (incl. rime) from 30 to 60 mm (Solantie and Ahti 1980). This corresponds to an increase in the load from 100 to 200 kg on a tree with twigs extending 1 m away from the stem. The evidence suggests that the main cause for the breaking of stems was a downward-directed pressure. Most of stems were broken at the height at which this pressure was largest, i.e. just below the crowns. The crucial value of the pressure on the cross sections of the stems seems to be of the order of 50 000 Pa (i. e. half of the atmospheric pressure).

Towards the end of the precipitation period, the wind slackened so that the snow was not dislodged from the twigs. Consequently, the breaking of stems reached its maximum as the

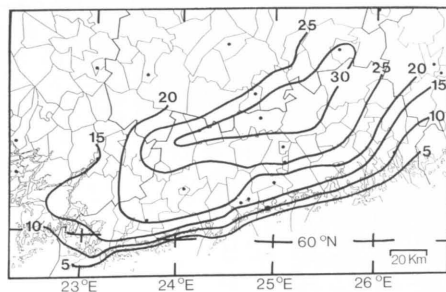


Fig. 8. Snow depth (cm) on 21st November, 1991, 0600 UTC.

precipitation was ceasing. This occurred at 20 UTC on November 20 in the westernmost damage areas and 16 hours later in the eastern part of the province. At that time, the ground had a snow cover of about 20 cm (Fig. 8). Already on the evening of November 22, warm air spread over southern Finland, and the snow melted rapidly. Comparing the areal distribution of snow damage (Fig. 1), the areal distribution of observed precipitation R during the event (Fig. 6) and maximum temperature T (Fig. 7) within the damaged area, it can be concluded that serious damage occurred in regions where R exceeded 30 mm and $0.3\text{ }^{\circ}\text{C} \leq T \leq 0.5\text{ }^{\circ}\text{C}$. The region which suffered most, corresponds approximately to the conditions $R \geq 40\text{ mm}$ and $0.35\text{ }^{\circ}\text{C} \leq T \leq 0.45\text{ }^{\circ}\text{C}$. However, independently of values of R and T , a coastal belt up to 10 km wide avoided damage due to wind.

4 Regions with a High Risk for Great Snowfalls As Potential Areas of Common Snow Damage

In Finland, regions with a high risk of snow damage are situated for the major part in high regions of eastern and northern Finland. However, in southern and western Finland there are also some specific regions where heavy snow-

falls suggests a great potential risk of snow damage. The province of Uusimaa on the south coast is one such region; snow damage was observed there in 1958–1959, 1984–1985 and 1991–1992 particularly in two subregions called the “coastal ridge” and the “inland ridge” (Fig. 10). The first one was more severe than the two latter. The risk of heavy snowfalls in this province is related to the amount of orographical precipitation, as the wind blows onshore (Solantie 1975). There are no systematic observations or statistics of the snow damage over long periods. When examining regional patterns and the recurrence of such damage, the only recourse is to consider the influence of terrain on precipitation and the statistics of heavy snowfalls and snow depth.

Snow damage can occur only when a crucial snow load (incl. rime) is exceeded. In Finland, precipitation and snow depth in winter are closely connected to the orographical features of terrain (Solantie 1975). Within a specific area such as the province of Uusimaa, where the duration of winter is uniform, the frequency of large snow depths on March 15 is mainly determined by precipitation and thus also by orographical features. Observations of precipitation in winter are less accurate and numerous than those of snow depths or height values of terrain. Consequently, particular attention has been given in this study to the relationship between the estimator of the enhancement of precipitation due to orography, and the frequency of large snow depths.

Within the province Uusimaa the terrain ascends towards the northwest or north. Consequently, the orographical addition to the precipitation is largest with on shore winds, from the south-east. During snowfalls, on shore winds are more common than the others (Solantie 1975, p. 6).

The orographical enhancement of precipitation, P , during onland winds, is here approximated by

$$P = P_{SE} + P_r \tag{1}$$

Here, the following notations have been used:

- P = the relative increase of the precipitation, due to the orography,
- P_{SE} = the slope (or inclination) effect

P_r = the coastal effect

Further, the r.h.s. terms in (1) are approximated as follows: For instance, if $P = 100\%$, then the precipitation due to the orography equals the background precipitation, i. e. that without the orographic effect.

$$P_{SE} = a \cdot K_{SE} \tag{2}$$

$$P_r = b \cdot r(s) \tag{3}$$

Here, the values of the terms are as follows:

$a = 23\text{ }(\% \text{ m}^{-1} 10^3 \text{ m})$, (Solantie 1975, p. 23)

K_{SE} = the slope of the terrain in a southeast-northwest direction ($\text{m} \cdot 10^{-3} \text{ m}^{-1}$); south-east is here understood as the sector from 67° to 202° which is the most important for orographical precipitation; the computation of the numerical value is explained in Fig. 9.

$r(s)$ = the relative effect of the coastal convergence as given in Fig. 9. The maximum is found 20 km northwards from the coast. Within the belt of 10–30 km, an average value of 0.75 will be applied

$b = 53\%$, obtained by dividing the value of P_r in a belt of 10–30 km from the coast as 39% (Solantie 1975, p. 22) by $r(s = 10-30) = 0.75$ (Fig. 9). This value is valid only when the wind is $\pm 45^{\circ}$ to the coast. Otherwise $b = 0$.

The previous values give:

$$P_{SE} = 23 \cdot K_{SE} \text{ and } P_r = 39\% \text{ (within the belt of 10–30 km).}$$

The values of K_{SE} are greatest at the “inland” and “coastal” ridges and particularly at the axes of the ridges (Fig. 10b). The coastal ridge lies about 10 to 30 km from the coast, i.e. in the belt where also $r(s)$ is greatest. The boundary of the province of Uusimaa runs just north of and parallel to the axis of the inland ridge, thus lying in a belt where the ascent of terrain decreases steeply towards the northwest.

We next compare the previous estimates of the orographic affect and the parameter S for the occurrence of great snow depths. The latter is given as the frequency of those years when the snow depth on March 15th exceeded 60 cm.

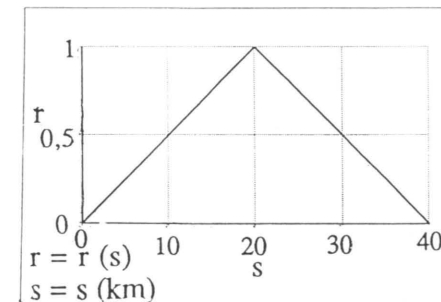
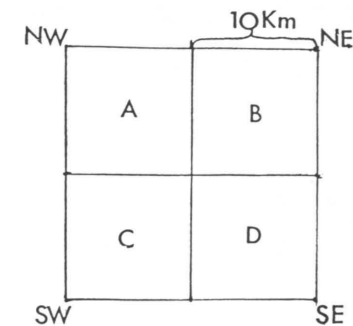


Fig. 9. Upper: The calculation of orographical effects.

The sloping effect during southeasterly winds K_{SE} in grid A is calculated as the mean of the slopes from B to A, from D to A and from C to A by using the mean heights of grid squares and distances between their midpoints. Lower: The coastal orographical coefficient for precipitation r as a function of the distance s (km) from the coast line.

Values of S were computed for 20×20 km grids from observations for the period 1919–1977 (Meteorological yearbooks of Finland 1960–1984, Meteorologische Jahrbücher für Finnland 1937–1959). The results are shown in Fig. 10a.

For the comparison, we use the following estimator

$$\hat{S} = 0.15 \cdot P + c \tag{4}$$

Here c is taken to be 7.4 for grid points north of the coastal axis (shown in Fig. 10b). Otherwise, i.e. for more coastal points, a value of $c = 4.4$ gives a better fit.

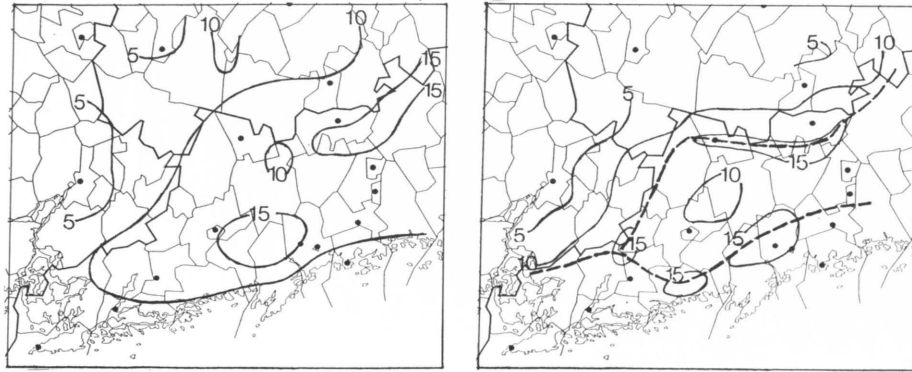


Fig. 10. (a) Observed frequency of snow depth in excess of 60 cm (S , %). (b) Estimated frequency of snow depths in excess of 60 cm (\hat{S} , %). See text for explanation. Broken line represent axes of the coastal and inland ridges.

The estimates are shown in Fig. 10b. They resemble the observed values in Fig. 10a.

Thus, the coastal and orography terms, as expressed here, explain the distribution of the exceptional snow depths.

The values of S are about 60 % of the frequencies of the cases in which the measured 5 days' increase of the water equivalent of the snow cover exceeds 40 mm. Noting that severe snow damage is avoided in some cases of heavy snowfall, the values of S in Figs. 10a and 10b not only give the relative regional differences in snow damage risk but also present the actual risk level, although only a very rough one.

The snow load is sufficient to break individual large stems if the water equivalent of the snow cover increases by 40 mm or more during five-day periods (between observations on fixed calendar dates).

During a 25-year observation period such five-day increases occurred on average every five years in the province of Uusimaa and every three years in the province of Kainuu (the province most prone to snow damage). In other parts of Finland excluding some higher regions, such five-day increases of over 40 mm occurred every 8 to 17 years. For five-day increases of 30 to 39 mm, the occurrence was on average every 5 years (Solantie and Ahti 1980). Consequently, these

observed frequencies agree well with the fact that in the province of Uusimaa the mean value of P (%) is about 30 percentage points greater than in the major part of the southern and middle Finland.

The mean orographical addition to precipitation during on shore winds as a percentage of the unaffected precipitation in the province of Uusimaa, is about 60 % on the coastal ridge and about 40 % on the inland ridge. Such high values must be significant when considering snow damage. In 1991, the snow damage was confined to the coastal ridge, whereas in winters 1958–1959 and 1984–1985 stems were broken by snow on the inland ridge. Consequently, snow damage occurred on the ridges in each of the three latest cases of damage within the province. This is in agreement with the regional distribution of heavy snowfalls within the province although due to the lack of systematical observations of snow damage, statistics do not necessarily reveal this fact.

References

- Finland. Ilmatieteen laitoksen tiedonantoja 28. 69 p.
- & Ahti, K. 1980. Säätekijöiden vaikutus Etelä-Suomen lumituhoihin v. 1959. Summary: The influence of weather in the snow damage for forests of South-Finland in 1959. *Silva Fennica* 14(4): 342–353.
- Suominen, O. 1963. Metsiköiden alttius lumituhoon. Tutkimus Etelä-Suomessa talvella 1958–1959 sattuneesta lumituhosta. Summary: Susceptibility of stands to devastation by snow. Investigation into snow devastation in South Finland in winter 1958–1959. *Silva Fennica* 112(5): 1–33.
- Solantie, R. 1975. Talvikauden sademäärän ja maaliskuun lumensyvyuden alueellinen jakautuma Suomessa. Summary: The areal distribution of winter precipitation and snow depth in March in

Total of 5 references

Submission of Manuscripts Manuscripts should be submitted in triplicate to Silva Fennica, Unioninkatu 40 A, FIN-00170 Helsinki, Finland. Detailed instructions to authors are printed in the first issue each year, and can be found on WorldWideWeb at URL <http://www.metla.fi/publish/silva/SF-Instructions.html/>. Offprints of Instructions are available on request.

Publication Schedule Silva Fennica is issued in four numbers per volume.

Subscriptions and Exchange Subscriptions and orders for back issues should be addressed to Academic Bookstore, Subscription Services, P.O. Box 23, FIN-00371 Helsinki, Finland, Phone +358 0 121 4430, Fax +358 0 121 4450. Subscription price for 1994 is 300 FIM (for subscribers in Finland 200 FIM). Exchange inquiries should be addressed to The Finnish Society of Forest Science, Unioninkatu 40 B, FIN-00170 Helsinki, Finland, Phone +358 0 658 707, Fax +358 0 191 7619.

Statement of Publishers Silva Fennica has been published since 1926 by The Finnish Society of Forest Science. From 1994, the journal is published by the Finnish Society of Forest Science and the Finnish Forest Research Institute. The Finnish Society of Forest Science is a nonprofit organization founded in 1909 to promote forest research. The Finnish Forest Research Institute, founded in 1917, is a research organization financed by the Ministry of Agriculture and Forestry.

Abstracting Articles in Silva Fennica are abstracted and indexed in Agrindex, Biological Abstracts, Current Advances in Ecological Sciences, Current Advances in Plant Sciences, Ecological Abstracts, Forest Products Journal, Forestry Abstracts, International Bibliography of Periodical Literature, Life Sciences Collection.

The Finnish Society of Forest Science
The Finnish Forest Research Institute

Research articles

- Jukka Lippu: Patterns of dry matter partitioning and ^{14}C -photosynthate allocation in 1.5-year-old Scots pine seedlings. 145–153
- Anna Saarsalmi, Eira-Maija Savonen, Teijo Nikkanen, Erkki Lipas & Jouni Mikola: Effect of fertilization on flowering and seed crop in Scots pine seed orchards. 155–176
- Anneli Viherä-Aarnio & Anna Saarsalmi: Growth and nutrition of willow clones. 177–188
- Anu Honkanen: Selection of *Salix myrsinifolia* clones for biomass forestry in Finland. 189–201
- Reijo Solantie: Effect of weather and climatological background on snow damage of forests in Southern Finland in November 1991. 203–211

ISSN 0037-5330

