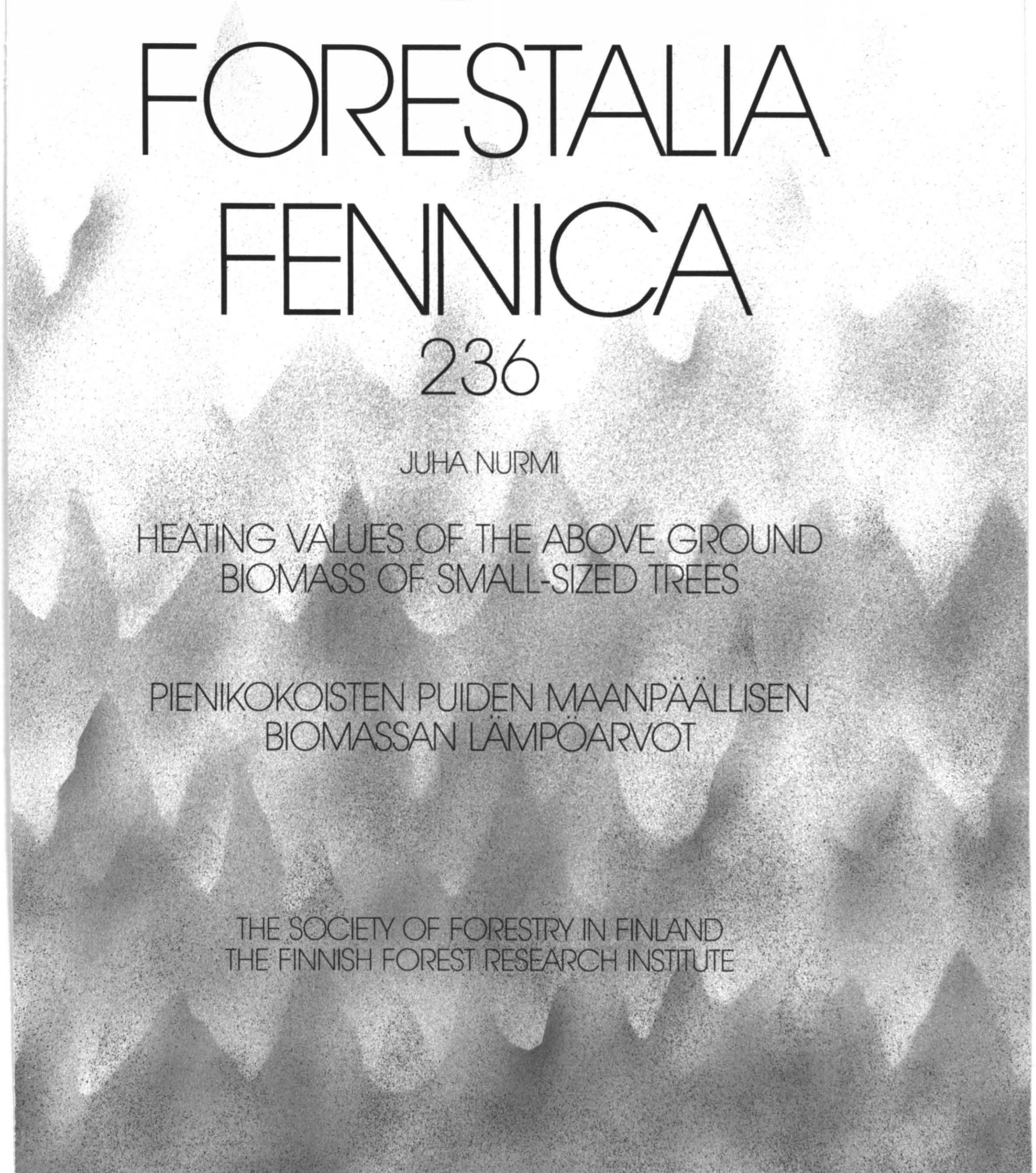


ACTA FORESTALIA FENNICA

236

JUHA NURMI

HEATING VALUES OF THE ABOVE GROUND BIOMASS OF SMALL-SIZED TREES

PIENIKOKOISTEN PUIDEN MAANPÄÄLLISEN BIOMASSAN LÄMPÖARVOT

THE SOCIETY OF FORESTRY IN FINLAND
THE FINNISH FOREST RESEARCH INSTITUTE

ACTA FORESTALIA FENNICA

Acta Forestalia Fennica was established in 1913 by the Society of Forestry in Finland. It was published by the Society alone until 1989, when it was merged with Communicationes Instituti Forestalis Fenniae, started in 1919 by the Finnish Forest Research Institute. In the merger, the Society and Forest Research Institute became co-publishers of Acta Forestalia Fennica.

Prior to the merger, 204 volumes had appeared in Acta Forestalia Fennica, and 145 volumes in Communicationes.

PUBLISHERS – JULKAISIJAT

The Society of Forestry in Finland
Suomen Metsätieteellinen Seura r.y.
Unioninkatu 40 B, 00170 Helsinki
Tel. +358-0-658 707 Fax: +358-0-1917 619
Telex: 125181 hyfor sf

The Finnish Forest Research Institute
Metsäntutkimuslaitos
Unioninkatu 40 A, 00170 Helsinki
Tel. +358-0-857 051 Fax: +358-0-625 308
Telex: 121286 metla sf

AIM AND SCOPE – TAVOITTEET JA TARKOITUS

Acta Forestalia Fennica publishes dissertations and other monographs. The series accepts papers with a theoretical approach and/or of international interest. The series covers all fields of forest research.

Acta Forestalia Fennicassa julkaistaan väitöskirjoja ja muita monografiatyyppisiä kirjoituksia. Kirjoitusten tulee olla luonteeltaan teoreettisia ja/tai kansainvälisesti merkittäviä. Sarja kattaa metsäntutkimuksen kaikki osa-alueet.

SUBSCRIPTIONS AND EXCHANGE – TILAUKSET

Subscriptions and orders for back issues should be addressed to Academic Bookstore, P.O.Box 128, SF-00101 Helsinki, Finland. Subscription price is FIM 70 per issue. Exchange inquiries should be addressed to the Society of Forestry in Finland.

Tilaukset ja tiedustelut pyydetään osoittamaan Suomen Metsätieteelliselle Seuralle. Tilaushinta Suomeen on 50 mk/numero. Seuran jäsenille sarja lähetetään jäsenmaksua vastaan.

ACTA FORESTALIA FENNICA 236

HEATING VALUES OF THE ABOVE GROUND BIOMASS OF SMALL-SIZED TREES

Pienikokoisten puiden maanpäällisen biomassan lämpöarvot

Juha Nurmi

Approved on 15.1.1993

The Society of Forestry in Finland – The Finnish Forest Research Institute
Helsinki 1993

Nurmi, J. 1993. Heating values of the above ground biomass of small-sized trees. Tiivistelmä: Pienikokoisten puiden maanpäällisen biomassan lämpöarvot. Acta Forestalia Fennica 236. 30 p.

The heating values of wood, inner and outer bark, and foliage components of seven small-size tree species were studied. Significant differences were found between species within each component. However, the differences between species for weighted stem, crown and whole-tree biomass are very small. The weighted heating value of the crown mass is slightly higher than that of the stem in all species. The heating value of stem, crown and whole-tree material was found to increase with increasing latitude.

The effective heating value of wood correlated best with the lignin content, inner bark with carbohydrate, and outer bark with carbohydrates and the extractives soluble in alcalic solvents. It is suggested that the determination of the heating value might be used as an indicator of the cellulose content of coniferous wood.

Tutkimuksella selvitettiin pieniläpimittaisen puuston puu-, kuori- ja neulasositteiden lämpöarvot. Erot puulajien välillä olivat merkitsevät kaikkissa kokopuun ositteissa. Puulajien kesken ei havaittu suuria eroja rungon, latvan ja kokopuun painotetuissa lämpöarvoissa.

Kivennäis- ja turvemaalla kasvaneiden puiden lämpöarvoissa havaittiin merkitseviä eroja vain ulkokuoressa. Maantieteellinen sijainti sensijaan vaikutti merkitsevästi useimpien kokopuun ositteiden lämpöarvoihin. Rungon, latvan ja kokopuun lämpöarvot olivat pohjoisessa etelän vastaavia arvoja korkeammat.

Tehollinen lämpöarvo selitti merkitsevästi joidenkin puunositteiden kemiallista rakennetta. Aineisto antaa olettaa, että lämpöarvon määritystä voitaisiin käyttää pikamenetelmänä havupuiden puuaineen selluloosapitoisuuden arvioinnissa.

Keywords: heating value, small-sized trees, whole-tree biomass, wood chemistry.
FDC 262+238

Author´s address: Finnish Forest Research Institute, Kannus Research Station, PL 44, FIN-69101 Kannus, Finland.

ISBN 951-40-1280-1
ISSN 0001-5636

Tampere 1993. Tammer-Paino Oy

Contents

Symbols

A = Scots pine, *Pinus sylvestris*
B = Norway spruce, *Picea abies*
ß = regression coefficient, slope
C = downy birch *Betula pubescens*
D = silver birch *Betula pendula*
E = grey alder *Alnus incana*
F = black alder *Alnus glutinosa*
G = trembling aspen *Populus tremula*
MC = moisture content on fresh mass bases (%)
P = probability
q_v(gross) = calorimetric heating value
q_v(net) = effective heating value of oven dry biomass or net calorific value or, lower heating value of oven dry biomass
q_v(moist) = effective heating value of biomass with moisture
RMS = residual mean square
R^2 = coefficient of determination in multiple regression
r^2 = coefficient of determination in simple regression
$s_{y \cdot x}$ = standard error of estimate of a regression
t = t-value

1 Introduction

On a global scale fuelwood accounts for 5.4 % of the total energy consumption. The corresponding figure for developed countries is only 0.7 % but is as high as 57.9 % in Africa. The more astounding fact is that half of the world population is dependent on the availability of fuelwood and charcoal in their daily living. It has been predicted that 2770 million people will suffer from the fuelwood deficit by the year 2000 (Report of... 1981).

In Finland the share of woodbased fuels in the total energy consumption is (13 %) which is one of the highest in all industrialized countries (Energiakatsaus 1992). This figure includes black liquor and other industrial wastes. The annual production of stemwood is 79 Mm^3/a (Hakkila 1992). When crown, stumps and roots are included the annual biomass production amounts to 126 Mm^3/a. According to the same source 10 Mm^3/a of slash and small-sized trees would be technically harvestable for energy production. This would equal to 6 % of the nations primary energy production.

A literature search was carried out to find out how much is known of the heating values of the temperate region. Some two hundred references were found but a large percentage of them delt with tropical species or gave information on material where tree components or even species were were mixed. Only a small share dealt with the temperate species and an even smaller percentage with genera *Pinus*, *Picea*, *Betula*, *Alnus*, and *Populus*, those which would be directly beneficial to this study. The more important references are reviewed in this context.

The major elemental constituents of wood are carbon, hydrogen and oxygen. The first two are the major combustible elements, whereas oxygen is non-combustible but an essential structural component of cellulose, hemicellulose, lignin and extractives. It is the relative quantity of these chemical compounds that determine the heating value of wood (Wang et al. 1981). According to Kollmann (1951) broad-leaved species have an average carbon and hydrogen content of 49.0 % and 6.0 % respectively. For conifers the figures are 50.7 % and 6.2 %. When carbon and hydrogen combine with oxygen the following reactions take place and energy is released (Kollman 1951):

$$C + {}^{1}/_{2}O_2 = CO + 10.215\text{MJ}$$
$$CO + {}^{1}/_{2}O_2 = CO_2 + 23.616\text{MJ}$$
$$C + O_2 = CO_2 + 33.829\text{MJ}$$
$$H_2 + {}^{1}/_{2}O_2 = H_2O + 141.974\text{MJ}$$

Lignin and resins are rich in carbon and hydrogen and hence have a higher heating value than carbohydrates, such as cellulose and hemicellulose which have a lower concentration of these elements. It follows that those tree components which are high in lignin and extractives should also have high heating values. Since conifers usually have a higher content of lignin and extractives than broad-leaved species they also tend to have slightly higher heating values per unit weight (Howard 1973, Doat 1977 and White 1987). Both Howard and White show that the heating value of wood has a positive correlation with alcohol-benzene extractive content. White in his study also shows heating value to be highly correlated with the lignin content of extractive-free wood.

Thörnqvist (1985) made an ultimate analysis for *Pinus sylvestris*, *Picea abies* and *Betula* sp. which showed the carbon content to be the highest in stem bark and small branches, and the hydrogen content to be lowest in stem bark. The exception to the rule is birch bark, which had the highest concentration of hydrogen. Virtanen (1963) found inner and outer bark to contain 52.0 % and 65.8 % carbon, and 6.0 % and 8.4 % hydrogen respectively. The higher amounts of carbon and hydrogen were caused by the suberin and betulin which were found in high concentrations in birch outer bark (Thörnqvist 1985). Additional elemental information as well as heating values on Central European tree species have been compiled by Kollmann (1951) from a number of German and Swiss sources.

Kollmann (1951) reported effective heating values for cellulose (17.375–18.213 MJ/kg), lignin (25.539 MJ/kg) and resins (35.588–38.100 MJ/kg) and pointed out that genera rich in cellulose (e.g., *Salix* and *Populus*) had relatively low heating values.

Murphey & Masters (1978) isolated cellulose (17.030 MJ/kg), hemicellulose (16.670 MJ/kg) and lignin (21.180 MJ/kg) from red oak (*Quercus rubra*) to determine the heating values of cellulose, hemicellulose and lignin to compare them to that of extractive free wood (19.950 MJ/kg). The proportionate sum of the three components was 17.900 MJ/kg which is only 89.72 % of the heating value of the extractive free wood. The authors suggest that this was caused by the chemical destruction of the bonds during extraction providing an opportunity for oxidation, thus lowering the energy potential of a unit mass of each separate chemical component. Results from a Nigerian study on *Gmelia arborea* by Fuwape (1989) are of different magnitude. The heating value of holocellulose, alpha-cellulose and lignin were 19.715, 19.704 and 25.383 MJ/kg respectively. Although Murphey and Masters were also quoted in the Nigerian study no explanation for the difference in heating values between these two studies was given.

In a another study by Sandala et al. (1981) the heating values of lignin and holocellulose from bark were found to be different for red oak (*Q. rubra*), white oak (*Q. alba*) and black cherry (*Prunus serotina*). Also the values for the holocellulose fraction from inner bark were found to be lower than from outer bark. It was suggested to be caused by an insufficient delignification process. Outer bark had higher lignin concentration — and higher heating value — and a failure in its removal would have made the heating value of the holocellulose from outer bark greater. They also found the heating value of outer bark to be higher than inner bark.

Olofsson (1975) has made one of the most concise reports on the heating values of North European tree species. He studied the stems, whole-trees and logging slash of *Pinus sylvestris*, *Picea abies* and *Betula* sp. He found that the differences in heating value per unit mass were very small between various parts of the tree at the same moisture content. It was also found that in all species the trees from cleaning cuttings had higher heating values than whole-trees from thinnings. This was caused by the higher percentage of needles and branches which had higher heating values than stems. Stems had the lowest values and showed very little difference between species. Logging residue consisted of branches and tops and its heating value lay between the values of stems and branches. Of the three species pine had the highest values for all the assortments except for bark. Olofsson's data has been adapted to the conditions prevailing in Southern Finland by Hakkila (1978). He has tabulated effective heating values for different timber assortments and species at different moisture contents. Energy contents are given both in terms of mass and volume. It is the most referenced publication in this field in Finland. On the other hand slightly lower values were recorded by Fredrikson & Rutegård (1985) for the mixed pine and spruce logging slash components. They reported that small branches with bark and wood had the highest heating value followed by needles, wood and bark.

Howard (1988) compared western hemlock, Douglas-fir and Western redcedar whole-tree and crown material from northwest Washington, USA. He found crown material to contain more energy per unit mass than whole-trees. Western redcedar crown material had a higher heating value than Douglas-fir or hemlock because of its high resin content. In his study Howard also quoted Arola (1977) and Corder (1973) who showed that the bark of Douglas-fir and hemlock had higher heating values than wood, whereas western redcedar wood contained more energy than bark does.

The physical and chemical characteristics of both pines and broad-leaved species growing in the southern United States are well recorded. These studies also provide some information on their fuel characteristics. Howard (1973) found that loblolly pine (*Pinus taeda*) heating values for earlywood, latewood and rootwood were not significantly different. On the contrary, samples from 1-inch top (wood and bark) had significantly lower values. The bark of spruce pine (*Pinus glabra*) decreased in heating value from the base with increasing axial height. It was suggested that this was caused by the increasing proportion of inner bark. The geographic region, growth rate and age of tree and bark density had no significant effect on bark values. Needles had higher values than wood or bark.

The heating values of stems and branches of 6-inch trees of 22 broad-leaved species growing on southern pine sites were studied by Manwiller (Koch 1985). The compiled data indicated that on average wood had a higher heating value than bark. This was also supported by Harris' studies of five southern broad-leaved species (1984 and 1985). He also found that the position in the tree has no effect on heating value. This, however, is not supported by Manwiller who indicated that stemwood has higher values than branch wood and branch bark has a higher heating value than stem bark. Wood from the stump-root system was found to have the highest value of all.

Neenan & Steinbeck (1979) studied 6 to 15 year-old sprouts of nine broad-leaved species from Georgia, USA. They found that differences in the heating values of wood and bark are greater within species than the small but significant difference between species. On average bark had a lower heating value than wood, branches and twigs. Leaves had the highest values of all components. Stringer & Carpenter (1986) pointed out in their study of black locust (*Robinia pseudoacasia*) biomass fuel that it is the leaves that are of key importance in young (2–10 years) whole-tree stems.

More temperate North American pines, spruces and broadleaved species have been studied by Singh & Kostecky (1986) and Musselman & Hocker (1981). The species are not the same in these two studies but they mostly belong to the same genera. Conifers in general were found to have significantly higher heating values than broad-leaved species. Within conifer or broad-leaved species there was no difference between species. Musselman and Hocker did not find any difference among broad-leaved bole and branches either with or without bark. This is contrary to Singh's and Kostechky's results which showed highly significant differences between tree components for both conifer and broad-leaved species.

Geographic location, growth rate, tree age (Howard 1973) and stem diameter (Stringer & Carpenter 1986) are among the factors that heating value does not seem to correlate with. Doat (1977) studied 111 tropical species from Africa, Asia and South America and four temperate species. He found that there was no correlation between wood density and heating value expressed per unit mass.

Clonal research is very much involved with yield. Only minor interest is shown in the clonal effect on heating value. Neenan and Steinbeck also pointed out that differences in yield potential were likely to outweigh variation in heating value. Bowersox et al. (1979) found there to be no difference between *Populus* hybrids, whereas Sastry & Anderson (1980) found four clonal groups with significantly different heating values. The authors of the latter study suggest that the different conclusions drawn were possibly caused by differences in genetic material. Ager et al. (1986) studied 31 willow clones and found heating values to be significantly different.

1.1 The aim

The primary aims of this study are to determine the heating values of tree components of those species that are native to Finland, how heating values relate to wood chemistry, and whether species effect the heating value. On the basis of previous knowledge it is hypothesised that latitude does not affect the heating value, the heating values of all studied tree components are assumed not to be the same for all species. Also, due to the absence of information on the effect of soil type it is hypothesised not to have an effect on the heating value.

From paper making point of view the trees that have a high cellulose content are favourable. It has been shown that cellulose and extractive content do vary with the provenance (Hakkila 1969). One of the goals of the tree improvement has been to select trees with higher cellulose content. Even though Zobel et al. (1989) state that the high cellulose content as a genetic characteristic is poorly inherited it would useful to find a fast and easy method for the determination of cellulose content. Hence, an attempt is made to find out if heating value could be used to determine carbohydrate contents. As mentioned earlier the heating value of cellulose is lower than that of lignin and extractives. This means that high heating value of wood proper is an indication of low cellulose content.

The final aim is to give practical information on the energy content of stem, branch and whole-tree biomass of seven native tree species at different moisture contents for the evaluation and pricing of fuelwood.

The author acknowledges Heikki Leppänen for the selection of sample tree stands, Markku Parhiala for field work, Arto Ketola from University of Joensuu for statistical analysis, Maire Ala-Pöntiö and Keijo Polet for helping with the layout, and Raili Voipio for the chemical analysis. Thanks are due to Professors Pentti Hakkila and Olli Uusvaara from the Finnish Forest Research Institute, Professor Matti Kärkkäinen from Jaakko Pöyry Consulting and Dr. Paul Mitchell from Aberdeen University for guidence and for reading the manuscript, and Jyrki Hytönen for fruitful discussions. Finally, special thanks to Reetta Kolppanen for doing alone all the hard work in the laboratory.

2 Research material and methods

2.1 Selection and handling of sample trees

The study was carried out at the Kannus Research Station. It is located in Central Ostrobothnia where the share of young forests is greater than anywhere else in the country. Thus it was natural that the majority of the study material was gathered from the vicinity of the station. Eleven stands in five locations were chosen to represent the southern material. Also two stands from northern Finland were selected to study the possible geographical effects. All the stands except one were managed by the Finnish Forest Research Institute.

The sample trees were taken for heating value, chemical composition and proportion of wood, inner bark, outer bark and foliage as follows. In southern Finland two Scots pine (*Pinus sylvestris*), Norway spruce (*Picea abies*), downy birch (*Betula pubescens*) and black alder (*Alnus glutinosa*) sample trees were selected from both mineral and organic soils. Silver birch (*Betula pendula*), grey alder (*Alnus incana*) and trembling aspen (*Populus tremula*) trees were taken only from mineral soils as they are seldom found on organic soils. The northern specimens included pine, spruce and downy birch which were collected from mineral soils at their northern growing extent (Figure 1 and Table 1). The individual sample trees were selected on the basis of visual observation by trying to choose the most typical individuals from the stand. No random sampling was used in any situation.

It is well documented that some wood characteristics such as the proportion of juvenile and heart wood, wood density, fibre characteristics and moisture content vary with the relative stem height. This is why the heating values were also

Table 1. Sample tree data.

Species	Tree number	Diameter, cm	Length, m	Soil type	Latitude	Municipality
P. sylvestris	1	9.6	11.7	mineral	south	Kannus
	2	10.7	10.0	mineral	south	Kannus
	3	10.2	6.6	organic	south	Kannus
	4	11.8	6.0	organic	south	Kannus
	5	11.8	7.0	mineral	north	Inari
	6	9.2	5.0	mineral	north	Inari
P. abies	1	8.7	8.3	mineral	south	Kannus
	2	9.8	8.0	mineral	south	Kannus
	3	8.3	7.4	organic	south	Kannus
	4	11.0	10.5	organic	south	Kannus
	5	9.4	13.2	mineral	north	Inari
	6	10.2	7.3	mineral	north	Inari
B. pubescens	1	9.0	10.0	mineral	south	Kälviä
	2	8.8	10.0	mineral	south	Kälviä
	3	8.1	10.8	organic	south	Kälviä
	4	8.6	10.6	organic	south	Kälviä
	5	9.6	7.6	mineral	north	Inari
	6	8.9	6.6	mineral	north	Inari
B. pendula	1	10.2	14.6	mineral	south	Kälviä
	2	10.0	13.1	mineral	south	Kälviä
A. incana	1	7.8	9.0	mineral	south	Kannus
	2	8.0	9.1	mineral	south	Kannus
A. glutinosa	1	11.2	12.0	mineral	south	Kälviä
	2	11.6	12.1	mineral	south	Kälviä
	3	10.2	11.0	organic	south	Himanka
	4	11.8	9.5	organic	south	Himanka
P. tremula	1	9.7	12.7	mineral	south	Kälviä
	2	10.0	14.8	mineral	south	Kälviä

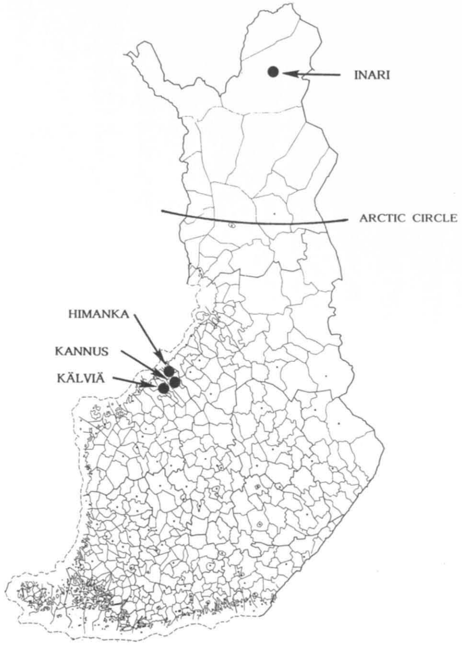


Figure 1. The locations of sampling sites.

studied in relation to the stem height. After delimbing the stem the sample discs were sawn off each stem for heating value and proportion of wood, inner bark and outer bark at relative heights of 10, 30, 50 and 80 %. In this manner more samples were taken at the lower part of the tree where more biomass is concentrated. One to two sample discs of 5–10 cm in length were taken from both sides of the relative height measurement. Wether the disc contained branch wood or not did not matter. Samples for the analysis of the chemical composition were collected in a similar manner. But, only at 20 and 80 % relative heights were used because resources for a more detailed study were not available.

All the branches in the crown were divided into branch sections over and under 5 mm in diameter. The latter one including foliage. Dead branches were excluded because most of the sample trees did not have them in sufficient quantities to supply a single sample. It should be noted that the largest branches on any species practically never exceeded 25 mm measured at the base of the branch. The samples were attained with a chainsaw without bar oil, bow saw and clippers. The entire branch was always included in the sample so that the portions under and over 5 mm were placed in different bags. The samples were placed in a freezer at the research station to prevent deterioration.

Each sample tree was weighed. The stems were weighed by first bucking them at the centre between sampling points i.e. at 20, 40 and 65 % of the relative height. This was done to determine the stem mass that each sample represented and to enable the calculation of weighted heating values. Then all the branches were cut and separated according to the diameter and weighed.

2.2 Preparation of samples

The laboratory handling of the samples included separation of wood, bark and leaf components, drying and milling of the components, pressing the powdered samples into pellets, combustion of the samples in an oxygen bomb calorimeter and extraction of the chemical components.

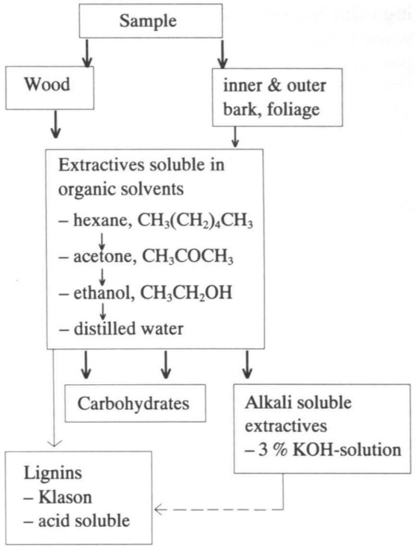
From the practical point of view there is no interest to separate the two bark components. However, from the scientific point the information on the fuel and structural properties of the two bark components of tree species native to Finland is nil. To provide more basic information wood, inner bark and outer bark were separated from each of the stem samples, i.e. discs and whole branches over 5 mm in diameter. Bark was separated from the branches less than 5 mm in diameter as one component. Carefulness in separation was of prime importance and the foundation in gaining reliable data. Species with distinct outer bark were relatively easy to handle. They included pine, spruce, downy birch, and silver birch. But, with grey alder and black alder and trembling aspen the separation was extremely tideous. After separation the samples were dried to constant weight at 102 °C and weighed to find out the proportion of each component at each sample point.

The milling of each entire component e.g. whole discs in the case of the wood component was done with a Retsch SM-1 cutting mill. Stainless steel bottom sieves with 0.5, 1 and 10 mm perforations were used. The sieve with the largest openings was used for primary reduction of the sample followed by milling through either one or both of the finest sieves depending on the consistency of the material. To avoid contaminating the samples with the remnants of the previous samples the mill was always thoroughly cleaned using a vacuum cleaner, pressurized air and brushes.

During bomb calorimetry analysis some fuels may splatter around the bomb if they are burned in powder form. To avoid this problem some of each sample was pelletized with a custom made MKH press manufactured by Keski-Suomen Teräsrakenne Oy. A mould of 14 mm in diameter was used. An attempt was made to make approximately 1 gram samples as the recommended sample size range for the used calorimeter was 0.6–1.2 grams. Five pellets were commonly made from each component.

After pelletizing the remainder of the sample and the pellets were allowed to come to equilibrium moisture content with the surrounding atmosphere over several days. Many laboratories in Finland keep their oven dried samples in a desiccator. However, this method was not used because of the large number of samples and the rapid absorption of moisture into the sample between removing the samples from the desiccator and combustion. It was found much more convenient and secure to determine the moisture content of the sample from the powdered sample with a Mettler PM100 balance equipped with a Mettler LP16 infrared drying unit which gives the moisture content to the nearest 1/100 %. The sample size varied between 0.7–1.2 grams and the selected temperature was 105 degrees. In the calibration of the dryer it was discovered that a drying time of 3.5 to 4.5 minutes was sufficient to bring the sample to a constant weight. Three determinations were made per sample and the average was used to calculate the calorific heating value. The range of moisture contents for the whole study material was 4–8 %. The samples were periodically cross-checked by drying them in a conventional convection oven.

The extraction of chemical components was done at the Finnish Forest Research Institute laboratory in Vantaa. The lignin, carbohydrate and extractive contents were determined in wood and bark components of stem and branch in the following order:



A more detailed description of the procedures used is given by Voipio and Laakso (1992).

However, it is noted here that the extractive composition is given as a percentage of the dry weight of the sample whereas lignin and carbohydrates were determined from the extractive free sample. This means that if the percentage figures are added up the sum will exceed 100% per sample. The chemical composition of each biomass component are given in Appendix 1 by species for those trees listed in Table 1. These figures in Appendix 1 are the arithmetic means of all the sample trees and are separately calculated for the southern and northern parts of the country.

2.3 Determination of the calorimetric and effective heating values.

Three different measures of energy content can be used. Calorimetric heating value (q_v(gross)), effective heating value of oven dry biomass (q_v(net)), also called net calorific value or lower heating value of oven dry biomass, and effective heating value of biomass with moisture (q_v(moist)). Calorimetric heating value is determined in a bomb calorimeter and all other heating values are derived from it. Calorimetric heating value includes the heat of condensation from water created during the combustion of the sample. In free combustion this water escapes with flue gases resulting in a loss of energy. The amount of water is directly proportional to the amount of hydrogen in the combustible matter. To calculate the energy available in the free combustion of oven dry biomass, i.e. effective heating value, one has to know the hydrogen content. The hydrogen analysis was done for all the tree components of each species at the Finnish Forest Research Institute's Central laboratory at Vantaa with a Leco CHN -analyzer. The results are shown in Appendix 2.

All the results in this study are given as effective heating values of oven dry biomass (q_v(net)). It is simply the calorimetric value (q_v(gross)) minus the heat released by the condensation water that is created during combustion. The following formula is used for the calculation:

$$q_v(\mathrm{net}) = q_v(\mathrm{gross}) - 2.45 \times 0.09H_2 \quad [1]$$
$$= q_v(\mathrm{gross}) - 0.22H_2$$

where

2.45 MJ/kg = the latent heat of vaporization of water at 20 °C.

0.09 = a factor that expresses that one part of hydrogen and eight parts of oxygen form nine parts of water

H_2 = the hydrogen content of oven dry biomass.

In practice, however, biofuels always contain some moisture which has to be evaporated in the first stage of combustion. The heat energy for evaporation comes from the burning fuel which lowers the amount of usable energy. This is called the effective heating value of moist biomass which is proportionate to the fuel moisture content in the following way:

$$q_v(\mathrm{moist}) = q_v(\mathrm{net}) - 2.45 \times \frac{MC}{100 - MC} \quad [2]$$

where

q_v(moist) = effective heating value of biomass with moisture (MJ/kg of dry mass)

MC = the moisture content on fresh mass basis (%)

Leco AC-300, a microprocessor-based isothermal-jacket bomb calorimeter, was used to determine the calorimetric heating values. It includes a master cabinet for loading the bomb and the housing of electronics; a control console for operations and date editing; LB-80 analytical balance; and a vessel compartment.

The operation of the calorimeter is as follows. The prepared sample pellet is placed in a tared crucible on a sample pan of the balance. The weight is entered into the memory of the calorimeter. The crucible is placed in a sample holder of the bomb and the fuse is attached. The sample holder is placed in the combustion chamber and closed with the bomb cap. The bomb is pressurized to 3 MPa and placed in the vessel compartment where it is automatically surrounded with water of known volume. The sample is ignited and the water temperature is recorded by the calorimeter. Based on the temperature profile the calorimeter calculates the calorimetric heating value. The moisture content of the sample is entered and the calorimeter calculates the calorimetric value for an oven dry sample. A total of about 2000 determinations were made from the 28 sample trees. The calorimetric values were then converted to effective heating values on dry mass basis using formula 1.

To have constantly accurate readings the equipment has to be calibrated from time to time with a benzoic acid standard the calorimetric heating value of which is known to be 26.4534 ± 0.0037 MJ/kg (Bureau... 1988). When analyzing fossil fuels the nitrogen and sulphur content are often rather high and their effect on the calorimetric heating value has to be taken into consideration. Wood, however, contains so minute quantities of these elements that they can be neglected.

The number of sample trees per species was small (n= 2–6) from the statistical point of view. However, analysis of variance was carried out to see if the data supported the hypothesis on the effects of soil type and latitude on the heating values of whole-tree components. To make the data suitable for the analysis the weighted mean heating values of stemwood, inner bark and outer bark of each sample tree were calculated from those values determined at 10, 30, 50 and 80 % relative heights. When testing the effect of soil type only those species growing both on mineral and organic soils in Southern Finland i.e. Scots pine, Norway spruce, downy birch and black alder were included. Similarly, to test the effect of latitude only those species which grew on mineral soils both in northern and southern Finland, i.e. Scots pine, Norway spruce and downy birch were included, as the northern specimens came only from mineral soils.

The data was arranged in the same manner as above to test the effect of tree species on the heating values of tree components. The analysis of variance and Duncan's multiple range tests were used. Tests were done separately for data from southern and northern trees. In the case of southern sample trees the data from mineral and organic soils was pooled.

The regressions were done separately for wood and the two bark components. For this purpose data from stem and branch components of both southern and northern sample trees were pooled. To overcome the low number of sample trees the species were pooled (n= 30–40). The same method has been applied earlier by Doat (1977) and White (1987). The dependent variables were the percentage of lignin, carbohydrates, extractives soluble in organic solvents and hot water, and alkali soluble extractives. The dependent variables were matched with corresponding heating values. There is one exception to the rule and that is the chemical composition at 20 % relative height. Unfortunately the sampling heights for chemical and calorimetric analysis do not match for the lower stem. Hence, it was decided to use the average q_v(net) value from 10 and 30% relative heights to match with the chemical composition from 20 % height.

It is realized by the author that the data presented in this study is made up of a small number of sample trees. For this reason wood-bark and stem-crown proportions were quoted from larger biomass studies to calculate the weighted heating values of stem, crown and whole-tree biomass. The proportions and the references used are listed in appendix 3. When needed the diameter of 10 cm and/or the height of 10 meters were used on tables or substituted for equations. In some cases no previous information was available for a given component. In that case the data collected in this study was used. Also the proportions of inner and outer bark were determined in this study.

3 Results and discussion

3.1 Heating value of biomass components

Biofuels are made of three basic elements carbon, oxygen and hydrogen. They usually make up 95 % of the chemical composition. When carbon and hydrogen are combusted heat is generated. The higher their share of the combusted material the higher the heat output. Oxygen has a contrary effect and is already present in abundant quantities in the air. Wood and bark are composed of carbohydrates, lignin and a number of extractives, i.e. resins, terpenes and waxes. Carbohydrates are lower in carbon and hydrogen than the other chemical compounds making it lower in thermal energy. The q_v(net) is 17.4–18.2 MJ/kg for carbohydrates, 25.5 MJ/kg for lignin and 35.6–38.1 MJ/kg for resins (Kollmann 1951).

Wood, inner bark and outer bark have different carbohydrate, lignin and extractive contents due to the differences in their physiological origins. From this it follows that q_v(net) is likely to be different for different components. An attempt is made to search for the relations between heating values and the chemical compositions of different tree components.

3.1.1 Wood

The heating values of stemwood of all sample trees of all species are shown as a function of relative stem height in Figure 2. The tree numbers refer to Table 1. Each data point on the figure is a mean of three replicative determinations. The standard deviation of these three replications were small ranging from 0.001–0.085 MJ/kg. This is an indication of well homogenized samples. The corresponding ranges for inner and outer bark were 0.001–0.098 MJ/kg and 0.001–0.305 MJ/kg. In all species q_v(net) approaches homoscedasticity. This indicates a uniform chemical structure along the stem. Also, the deviation around the mean is of the same magnitude for all species.

The effect of soil and geographic factors were tested prior to testing the differences between species. The results on the analysis of variance support the hypothesis that soil type and latitude should not effect the q_v(net) of wood (Table 2.). The hypothesis was rejected only when branch wood was tested against latitude.

Next, the analysis of variance and Duncan's multiple range test were carried out to test if q_v(net) was effected by species. The test statistics support the hypothesis that heating value should not be the same for all species (Table 3). The heating values of coniferous wood were significantly different from each other as well as

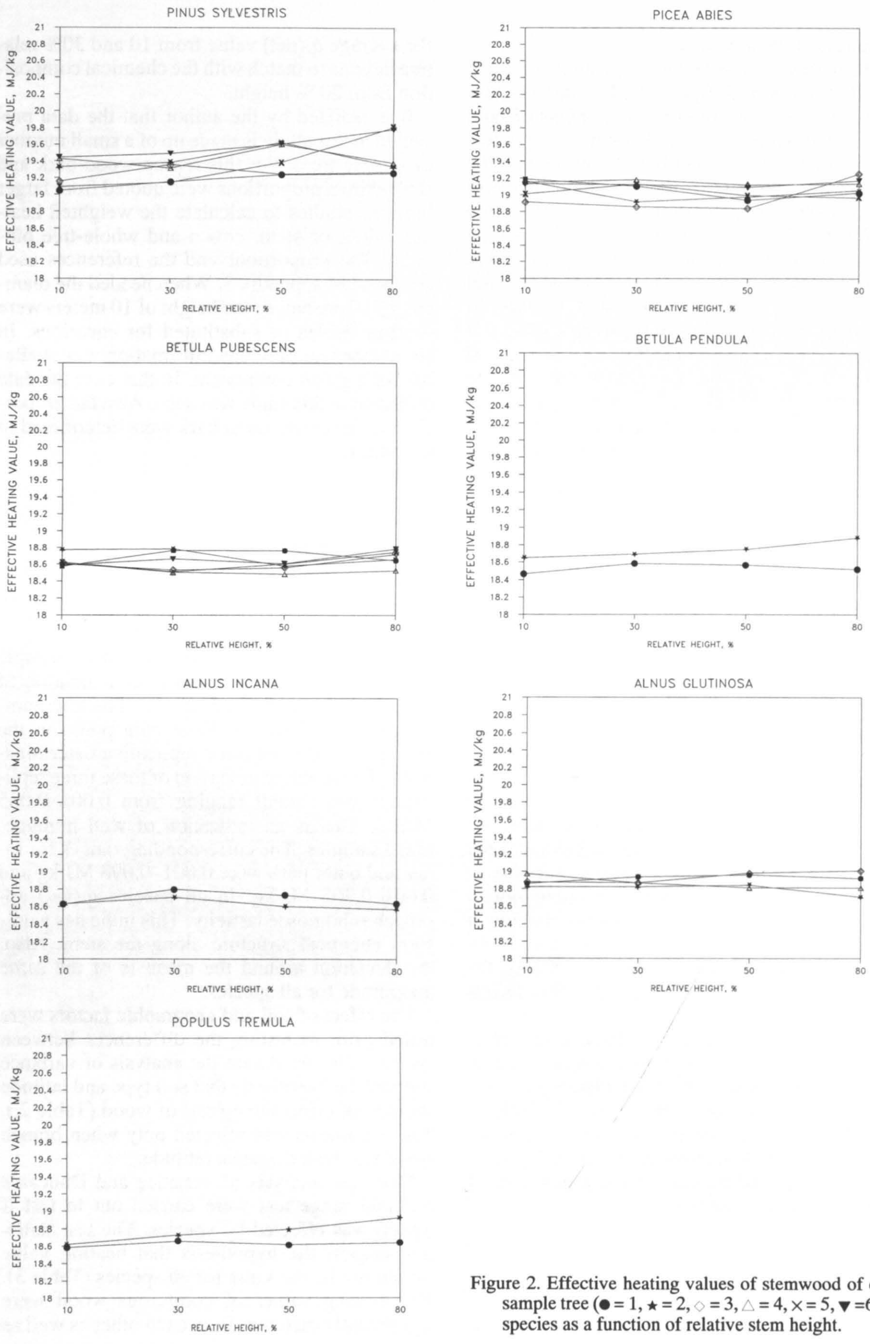


Figure 2. Effective heating values of stemwood of each sample tree (● = 1, ★ = 2, ◇ = 3, △ = 4, × = 5, ▼ = 6) by species as a function of relative stem height.

from all the other species. This can also be seen in Figure 3 which shows the average heating values as a function of stem height. The higher percentage of lignin in coniferous wood explains to a large extent why it has a higher q_v(net) than the wood of broad-leaved species. The two birch species, grey alder and aspen were not shown to be different from each other. Black alder, however, is different from all the other species and has a q_v(net) between the coniferous and other broad-leaved species. Olofsson's (1975) q_v(net) is slightly lower for pine and higher for silver birch.

Branch wood has a higher q_v(net) than stem wood. It increases with decreasing branch diameter. The explanation for this is not so self evident. It is known that in coniferous branches compression wood is formed. It is characterized by increased lignin content. In thicker branches the stresses are greater and hence more compression wood is created, i.e. lignin content is increased (Appendix 1). This means that q_v(net) would decrease with decreasing diameter if we had extractive free wood. However, wood in the smallest branches is richer in extractives than other woody components. This explains why branches <5 mm have a higher q_v(net).

In broad-leaved species the reasoning is more self-evident. The lignin gradient is the opposite to coniferous wood as tension wood is characterized by lack of cell wall lignification. Hence, the extractive content and heating value increase with decreasing branch diameter but to a lesser degree than in conifers. The only exception to the rule is

Table 2. F-ratios for one way analysis of variance with repeated measures for soil type and latitude.

Whole-tree component		Factor Soil type	Latitude
Wood	stem	0.02	0.78
	branches	0.00	10.79*
Inner bark	stem	0.60	74.00***
	branches	0.60	4.58
Outer bark	stem	8.08*	44.70***
	branches	30.74***	36.81***

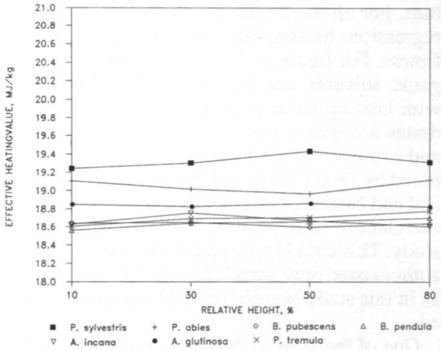


Figure 3. The average effective heating values of stemwood as a function of stem height for all species.

Table 3. The effective heating values (MJ/kg) and test statistics for wood components.

Whole-tree component	Latitude		Pinus sylvestris	Picea abies	Betula pubescens	Species Betula pendula	Alnus incana	Alnus glutinosa	Populus remula	F-ratio
Stem	South		19.308**a**	19.048**b**	18.617**c**	18.611**c**	18.670**c**	18.883**d**	18.668**c**	27.59***
		s=	0.147	0.125	0.100	0.071	0.071	0.077	0.106	
Branches >5 mm	–”–		19.796**a**	19.627**a**	18.672**b**	18.726**b**	18.935**b**	18.725**b**	18.790**b**	18.53***
		s=	0.028	0.142	0.067	0.095	0.121	0.285	0.196	
Branches <5 mm	–”–		20.150**a**	19.793**b**	18.885**c**	18.732**c**	19.035**c**	18.875**c**	18.763**c**	41.01***
		s=	0.263	0.140	0.079	0.030	2.974	0.107	0.017	
Stem	North		19.392**a**	19.083**b**	18.606**c**					33.10***
		s=	0.249	0.071	0.083					
Branches >5 mm	–”–		20.051**a**	19.432**b**	19.011**b**					27.64*
		s=	0.178	0.072	0.046					
Branches <5 mm	–”–		20.839**a**	20.052**b**	19.172**c**					37.14**
		s=	0.188	3.268	0.097					

The mean heating values indicated with the same letter in horizontal direction do not differ from each other at 5% significance level.

aspen. Its chemical composition should suggest a similar trend from large to small branches. On the contrary q_v(net) decreases with decreasing diameter. Why this should be could not be determined on the basis of the available data.

The northern branch specimens possess the same trend in q_v(net) as the southern ones (Table 3). But, the effect of branch diameter is somewhat more pronounced due to the relatively large amounts of extractives soluble to organic solvent. This makes the differences larger in the north. Subsequent reductions are noted in the carbohydrate contents.

The relationship of q_v(net) and chemical compounds can be seen in Figure 4. Here q_v(net) is used as an independent variable and lignin, carbohydrate and extractives as dependent variables. For all three regressions $\beta \neq 0$. Of the three regressions heating value and lignin give the best fitness. For lignin and extractives soluble in organic solvents and hot water the relationship with heating value is positive and for carbohydrates a negative one. The correlation of lignin and extractives with heating value has also been noted by Doat (1977) and White (1987) for tropical and North American species. However, their correlations were better than those given by this study. This could be caused by the fact that these authors used only samples from the stem whereas in this study branch material was also included.

One of the aims of this study was to see if the determination of heating value could be used as a mean to predict the cellulose content of wood. For this reason and inspite of the fact that the number of sample trees per species is small the test statistics concerning the relationship between carbohydrate content and heating value are also reported separately for each species in Table 4. As with the pooled data the relationship is negative for individual species. The test statistics suggest that this method might give a good prediction of cellulose content on coniferous wood. It might be useful to take a more detailed look to this approach to determine the cellulose content.

Table 4. Carbohydrate content of wood (Y) as a function of effective heating value (X).

Species	Regression model	R2	P	n
P. sylvestris	23.054 – 0.053X	0.852	0.001	8
P. abies	22.198 – 0.041X	0.918	0.001	8
B. pubescens	19.759 – 0.014X	0.358	0.117	8
B. pendula	20.055 – 0.021X	0.953	0.024	4
A. incana	$18.826 + 136X^{-6}$	0.000	0.990	4
A. glutinosa	20.387 – 0.025X	0.504	0.290	4
P. tremula	19.119 – 0.006X	0.300	0.452	4

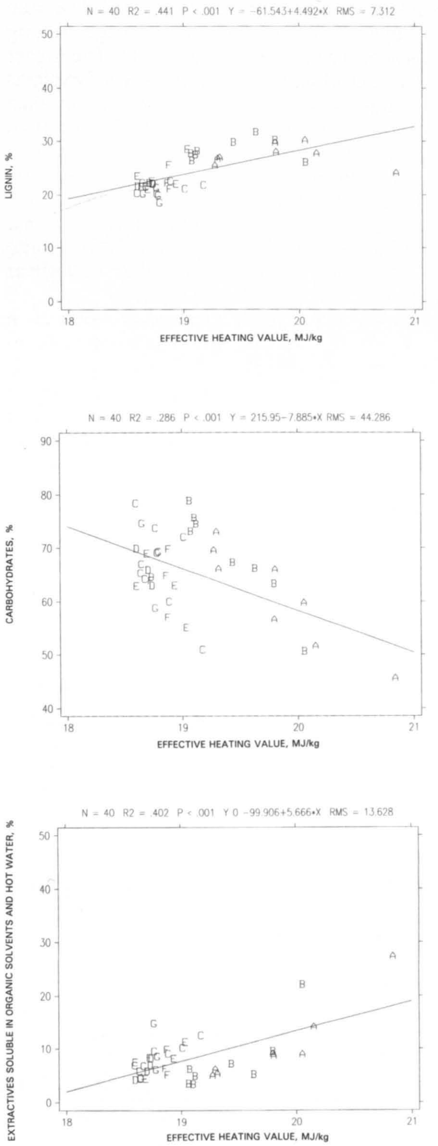


Figure 4. The chemical composition of wood as a function of effective heating value. Tree species A = *P. sylvestris*, B = *P. abies*, C = *B. pubescens*, D = *B. pendula*, E = *A. incana*, F = *A. glutinosa*, G = *P. tremula*.

Table 5. The effective heating values (MJ/kg) and test statistics for inner bark components.

Whole-tree component	Latitude		Species *Pinus sylvestris*	*Picea abies*	*Betula pubescens*	*Betula pendula*	*Alnus incana*	*Alnus glutinosa*	*Populus tremula*	F-ratio
Stem	South		18.758**a**	17.844**b**	18.965**a**	18.846**a**	20.14**c**	19.262**d**	18.049**b**	84.41***
		s=	0.249	0.282	1.457	0.101	0.149	0.107	0.248	
Branches >5 mm	-”-		19.441**a**	18.481**b**	18.985**a**	18.763**ab**	19.491**a**	19.413**a**	17.822**b**	4.61**
		s=	0.282	0.738	0.332	0.161	0.073	0.160	0.146	
Stem	North		19.089**a**	18.828**a**	19.181**a**					0.13
		s=	0.574	0.696	0.084					
Branches >5 mm	-”-		20.379**a**	18.258**b**	18.975**ab**					10.12*
		s=	0.525	0.304	0.036					

The mean heating values indicated with the same letter in horizontal direction do not differ from each other at 5% significance level.

3.1.2 Bark

3.1.2.1 Inner bark

In the forest industry inner and outer bark are handled as one component. In this study, however, bark is divided into inner and outer bark. This is done to provide basic information on the chemical composition and heating value of these two bark components of different physiological origins. Together they make up 10–20 % of the dry stem mass and as much as 60 % of the small branches. On average two thirds of the bark component is inner bark (Appendix 3). In comparison with wood, bark is more complex in chemical structure. It contains compounds that are present in wood in only minor quanties or not at all. Such compounds include fenolic acids and polyestolids which are soluble only in alkaline solvents.

The heating values of individual stems by species are shown as a function of relative stem height in Figure 5. The first observation is that there is more variation in conifers than in broad-leaved species. Second, the trend in broad-leaved species is more linear than in conifers. This nonlinearity is most evident in the northern specimens of pine and spruce. This is also supported by the results of analysis of variance which show latitude to have a significant effect on heating value (Table 2). Hence, Duncan's test was made separately for southern and northern trees. Data from mineral and organic soils was combined.

The test statistics on southern trees supports the hypothesis which assumes that q_v(net) should not be the same in all species. This is illustrated in Figure 6 which shows the range of species to be about 2.4 MJ/kg at any given stem height. This is threefold compared to stemwood indicating a greater variation in chemical structure as well.

Conifers and broad-leaved species are distinctly different in terms of lignin and extractives soluble in organic solvents and hot water. Coniferous inner bark contains low quantities of lignin whereas in broad-leaved species the concentration is three to four fold. The extractive content is higher in conifers but by a smaller margin than lignin in broad-leaved species.

On the basis of information presented above one would expect to find little deviation in heating values within subdivisions. However, we can see from Table 5 that the q_v(net) of southern spruce is considerably lower than that of pine or spruce specimens from northern Finland. Its chemical structure suggests that the reason might be found in the concentration of extractives soluble in organic solvents and hot water. The higher concentration of these extractives in the north increases the heating value. As a result analysis of variance testing does not support the hypothesis of species being different in the north.

The q_v(net) of branch inner bark was determined only on those branches over 5 mm in diameter. There is less variability between species in branch than stem inner bark. One would expect this to reflect a greater degree of homogenity in chemical structure among species. However, no evidence for this was found.

Of the four regressions of Figure 7 carbohydrates and alkali soluble extractives do support

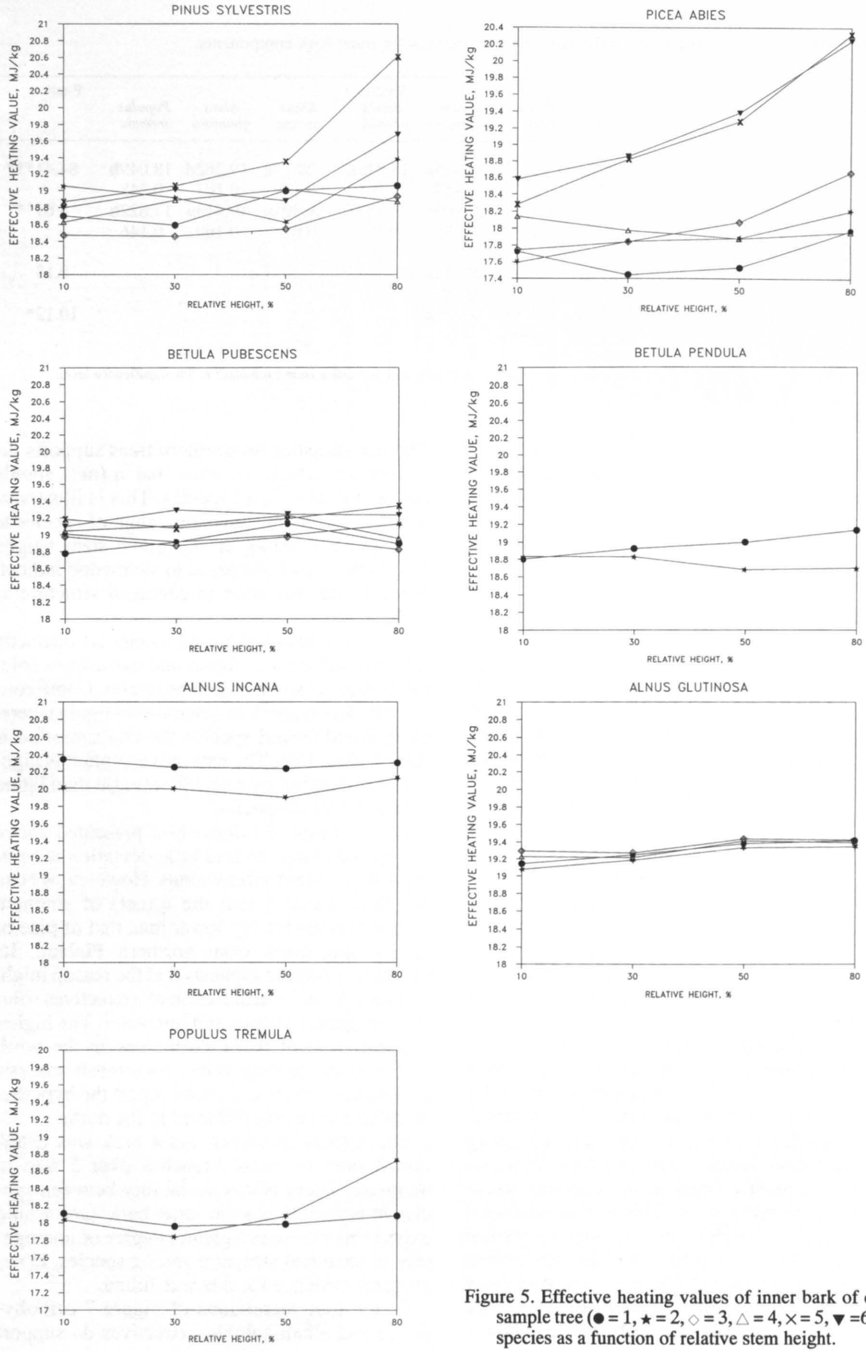


Figure 5. Effective heating values of inner bark of each sample tree (● = 1, ★ = 2, ◇ = 3, △ = 4, × = 5, ▼ = 6) by species as a function of relative stem height.

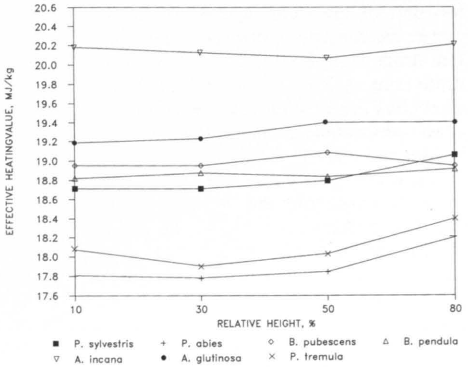


Figure 6. The average effective heating values of stem inner bark as a function of stem height for all species.

the H_0: $ß \neq 0$. Whereas with lignin and extractives soluble in organic solvents and hot water as dependent variables the model did not support the hypothesis.

3.1.2.2 Outer bark

Outer bark is a less important fuel than wood or inner bark when evaluated in terms of quantity. It makes up usually less than 5 % of the stem mass and no more than 10 % of the branch mass. It presents more variability between species in terms of chemical structure and heating value than the other two components. The within species variation of the heating values of outer bark is no greater than with wood but many species show a nonlinear trend along the stem. For the two birch species the trend is a decreasing and for black alder an increasing one. For other spe-

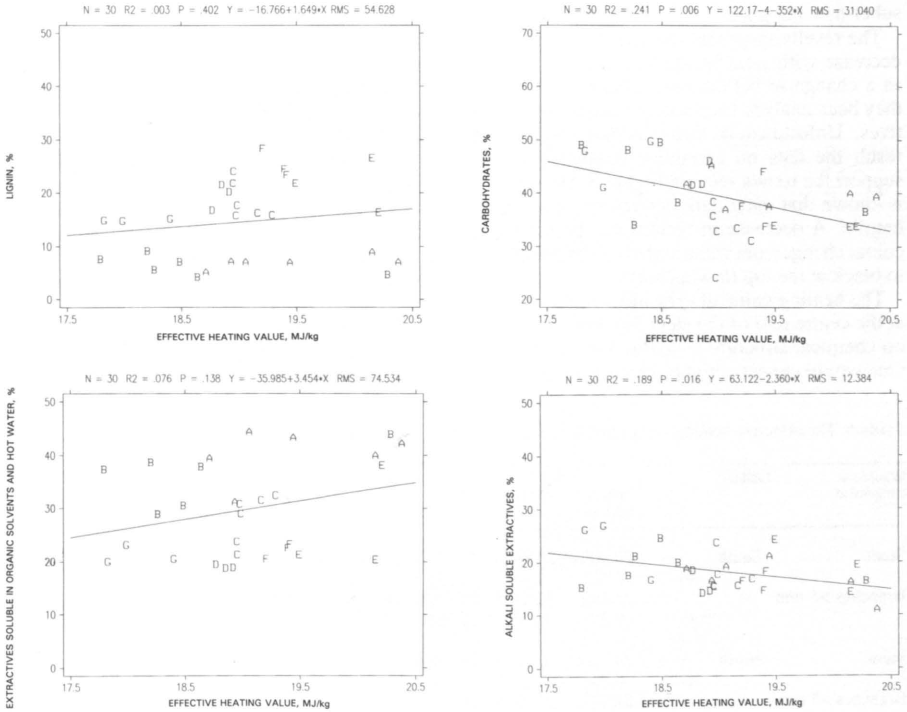


Figure 7. The chemical composition of inner bark as a function of effective heating value. Tree species A = *P. sylvestris*, B = *P. abies*, C = *B. pubescens*, D = *B. pendula*, E = *A. incana*, F = *A. glutinosa*, G = *P. tremula*.

cies the trend is intermediate (Figure 8).

The most noticeable change in q_v(net) is that of black alder. It increases 4 MJ/kg from the base to the top of the tree. This corresponds with an increase in content of alkali soluble extractives from 24.0 % at 20 % relative height to 32.2 % at 80 % height. The respective increase in organic and hot water extractives is from about 14.9 % to 22.2 %. At the same time lignin concentration drops from 32.0 % to 19.6 % (Appendix 1). As the extractives are higher in heating value than lignin the heating value of outer bark increases as the ratio between the two compounds changes in favour of extractives toward the top of the tree.

The outer barks of the two birch species have the highest q_v(net) of all species. This is caused by the high extractive concentration, mainly betulin (soluble in organic solvents) and suberin (alkali soluble). According to Ekman (1983) birch outer bark contains 315 g of triterpenoids per kilogramme of bark and betulinol accounts for 77 % percent of that amount. The amount of suberin is 322 g/kg.

The results show that the q_v(net) of *Betula* sp. decrease with stem height which could be seen as a change in betulin and suberin content had they been analyzed separately from other extractives. Unfortunately this was not done. As a result the data on extractive content does not support the trends seen on Figure 8. However, it is known that outer bark derives its colour from betulin. A decrease in betulin can be seen as a colour change from white at the base (high q_v(net)) to black at the top (low q_v(net)).

The heating value of grey alder seems to peak at the centre part of the stem but there is no data on chemical structure available for that section. One would expect a higher heating value for the top part of the stem because of the increased extractive contents. Correspondingly lignin content drops from 26.0 % to 11.7 % and carbohydrate content from 20 % to 14.2 %. It is most likely that these trends counter balance each other as corresponding changes are not seen in the heating values.

A lesser trend is seen in pine where the heating value increases from the centre of the stem to the top. This reflects the increase in extractives and the decrease in lignin content. Aspen has a similar weak trend which is supported by a slight increase in alkali soluble extractives and a decrease in both lignin and carbohydrates.

It was hypothesised that soil type and latitude do not effect q_v(net). Table 2 shows that data do not support it. On average q_v(net) of pine, spruce and downy birch is lower when trees are growing on organic soils. The fact that latitude is shown to be a significant factor is caused by downy birch as its q_v(net) is almost 3 MJ/kg lower in the northern trees. Unfortunately the data on chemical components does not explain this difference.

Figure 9 shows the average q_v(net) as a function of stem height. The range of heating values is over 12 MJ/kg. This is much higher than with wood and inner bark components. The test statistics of analysis of variance shows species to be a highly significant factor (Table 6).

The heating values of the outer bark of branches over 5 mm in diameter are seen in Table 6. The species are in the same order of magnitude as the stem outer bark. The reasons for the order are the same as with stem outer bark, i.e. high energy alkali soluble, organic and hot water extractives as well as lignin in broad-leaved species overruling low energy carbohydrates. The ratio is the opposite in conifers causing them to

Table 6. The effective heating values (MJ/kg) and test statistics for outer bark components.

Whole-tree component	Latitude		Species							F-ratio
			Pinus sylvestris	*Picea abies*	*Betula pubescens*	*Betula pendula*	*Alnus incana*	*Alnus glutinosa*	*Populus tremula*	
Stem	South		20.309**a**	20.542**a**	31.433**b**	32.045**b**	28.900**d**	23.286**e**	21.202**c**	400.16***
		s=	0.624	0.448	3.035	3.972	3.944	2.537	0.697	
Branches >5 mm	-”-		21.166**a**	20.691**a**	27.580**bc**	28.548**c**	26.758**bd**	25.901**d**	21.886**a**	54.28***
		s=	0.295	0.107	1.025	2.810	0.009	0.615	0.319	
Stem	North		20.933**a**	20.771**a**	28.904**b**					2890.07***
		s=	0.434	0.207	1.024					
Branches >5 mm	-”-		21.947**a**	20.801**b**	26.479**c**					205.72***
		s=	0.359	0.049	0.119					

The means indicated with the same letter in horizontal direction do not differ from each other at 5% significance level.

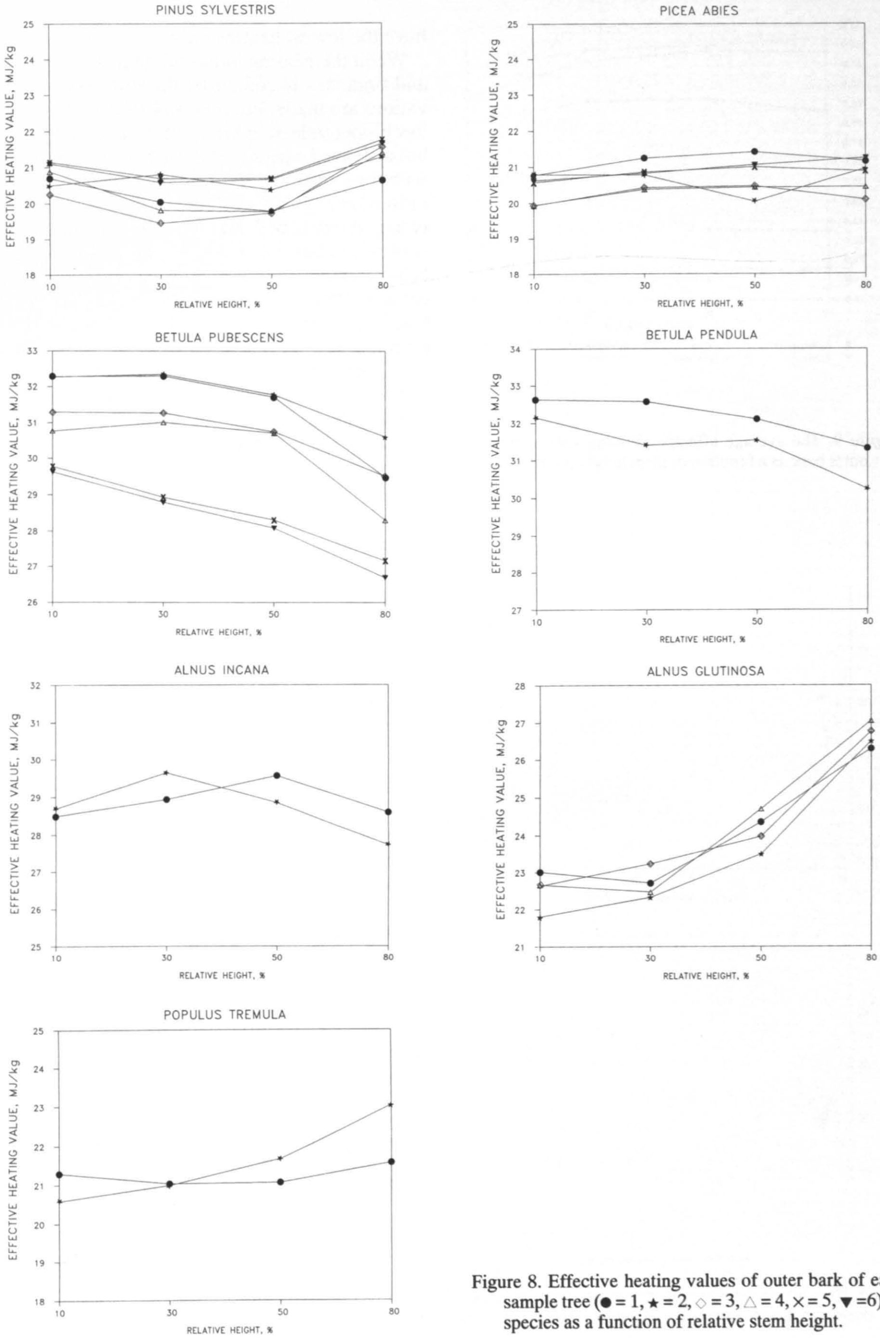


Figure 8. Effective heating values of outer bark of each sample tree (● = 1, ★ = 2, ◇ = 3, △ = 4, × = 5, ▼ =6) by species as a function of relative stem height.

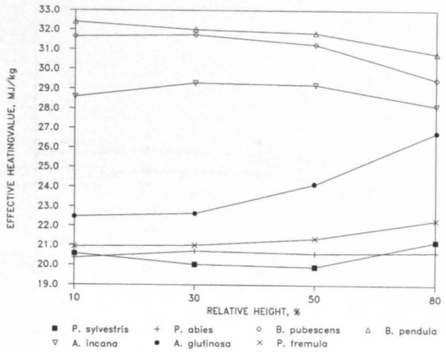


Figure 9. The average effective heating values of stem outer bark as a function of stem height for all species.

have the lowest heating values.

When the heating value of outer bark on stem and branches is compared the following observations are made. For pine and spruce outer bark has higher values in branches than in stems. For broad-leaved species the case is the opposite with the exception of black alder and aspen. The most likely explanation for conifers is the slightly higher extractive content in branch outer bark. It is more difficult to find an explanation for the behaviour in broad-leaved species. However, with birches, grey alder and aspen the amount of extractives soluble in organic solvents and hot water are lower in branches than in stems.

In Figure 10 the chemical components are regressed with heating value. All the regressions support the H_0: $\beta \neq 0$. For lignin and carbohydrates the slope is negative and positive for both categories of extractives.

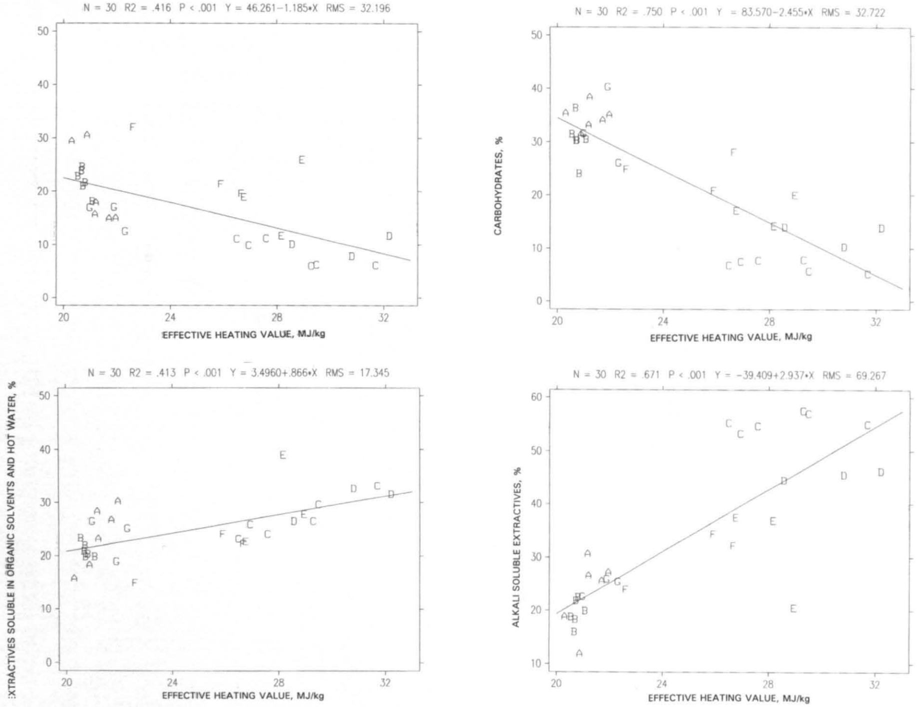


Figure 10. The chemical composition of outer bark as a function of effective heating value. Tree species A = *P. sylvestris*, B = *P. abies*, C = *B.pubescens*, D = *B. pendula*, E = *A. incana*, F = *A. glutinosa*, G = *P. tremula*.

Table 7. The effective heating values (MJ/kg) and test statistics for bark on branches less than 5 mm in diameter.

Latitude		Species *Pinus sylvestris*	*Picea abies*	*Betula pubescens*	*Betula pendula*	*Alnus incana*	*Alnus glutinosa*	*Populus tremula*	F-ratio
South		21.258**ab**	20.273**ac**	21.945**d**	20.815**c**	21.534**b**	21.024**ac**	17.983**e**	39.26***
	s=	0.156	0.287	1.515	0.152	0.255	0.660	0.038	
North		22.082**a**	20.593**a**	20.815**a**	..	..	..	..	4.80
	s=	0.602	0.252	0.068					

The mean heating values indicated with the same letter in horizontal direction do not differ from each other at 5% significance level.

Table 8. The effective heating values (MJ/kg) and test statistics for foliage.

Latitude		Species *Pinus sylvestris*	*Picea abies*	*Betula pubescens*	*Betula pendula*	*Alnus incana*	*Alnus glutinosa*	*Populus tremula*	F-ratio
South		20.950**a**	19.400**cd**	19.550**cd**	19.700**cd**	20.600**ab**	20.100**bc**	19.200**d**	10.00**
	s=	0.127	0.195	0.265	0.088	0.401	0.048	0.322	
North		20.800**a**	19.300**b**	19.350**b**	..	..	..	..	96.78**
	s=	0.118	0.062	0.026					

The mean heating values indicated with the same letter in horizontal direction do not differ from each other at 5% significance level.

3.1.2.3 Bark on small branches

Half of the dry mass of branches <5 mm in diameter is bark. The two bark components were not separated before the calorimetric and chemical analysis because of the small branch diameter. The heating values and test statistics are seen on Table 7. Species are shown to have a significant effect on the heating value which is supportive of the hypothesis.

Heating values are intermediate to those of inner and outer bark of branches over >5 mm in diameter. This is understandable as the bark component is a combination of these two barks and is also supported by the analysis on chemical composition (Appendix 1). This applies to all species except pine. Its q_v(net) is higher than the value of either inner or outer bark values of the larger branches. The only indication why this should be is that carbohydrate content is lower in the <5 mm than in either of the two bark components of >5 mm branches. This should give more room to the high energy compounds.

3.1.3 Foliage

The chemical composition of foliage is rather different in coniferous and broad-leaved trees. The results of the analysis of variance of heating values in Table 8 also suggest differences in chemical composition. Conifers are high in carbohydrates and extractives soluble in organic solvents and hot water. Broad-leaved species on the other hand are higher in lignin and alkali soluble extractives. This would indicate rather similar heating values within both subdivisions. This, however, is not the case. On the contrary the heating values of conifers and broadleaved species do overlap. Why for example pine and spruce have heating values of such a different magnitude can not be concluded on the basis of the chemical data. Olofsson reports a slightly smaller difference as his spruce had a higher q_v(net) than in this study.

The broad-leaved genera are in their own groups in terms of chemical composition. Birches have a higher content of extractives soluble in organic solvents and low lignin content. Alders, which are higher in heating value are lower in these extractives and higher in lignin. It seems that whatever the fraction composition of these extractives is they are lower in heating value than lignin. The genera seem to have similar compositions when concerning alcali soluble extractives and carbohydrates .

Aspen is lowest of all species in heating value. Lignin and carbohydrate content are the same as in other broad-leaved species. However, aspen has the lowest content of extractives soluble in

Table 9. The effective heating values (MJ/kg) of oven dry stem components.

Species	Latitude	Wood	Bark Inner	Bark Outer	All bark	Whole stem
P. sylvestris	south	19.308	18.758	20.309	19.529	19.333
	north	19.392	19.089	20.933	19.981	19.479
P. abies	south	19.048	17.844	20.542	18.803	19.022
	north	19.083	18.828	20.771	19.621	19.161
B. pubescens	south	18.617	18.965	31.433	22.745	19.187
	north	18.606	19.181	28.904	22.545	19.528
B. pendula	south	18.611	18.846	32.045	22.525	19.151
A. incana	south	18.670	20.141	28.900	21.566	19.000
A. glutinosa	south	18.883	19.262	23.286	21.438	19.305
P. tremula	south	18.668	18.049	21.202	18.574	18.652

organic solvents and highest alcali soluble extractive content. The composition of these extractive fractions are species specific but it seems that it is the extractives soluble in organic solvents that increase the heating value among broadleaved species. The reason why this does not apply to spruce has to lie in the differences in the extractive composition.

3.2 The weighted heating values of stem, branch and whole-tree biomass

Stem biomass is composed of wood, inner bark and outer bark. The proportions of these components vary with the relative stem height and age of the tree (Taras 1978, Hakkila et al. 1975). The majority of stem mass is concentrated in the wood proper (Appendix 3). This makes it the single most important component to consider when a heating value for the whole stem is calculated.

Figure 11 shows that in all species and at any given stem height the heating value of outer bark is higher than the heating value of wood or inner bark. Furthermore, the heating value of combined inner and outer bark is higher than that of wood for all species except for aspen and southern sample trees of spruce (Table 9).

Musselman & Hocker (1981) and Singh & Kostecky (1986) found that North American species in genera *Pinus*, *Picea*, *Betula* and *Populus* had higher heating values in bark as well. Olofsson (1975) reports q_v(net) of pine, birch and spruce bark to be higher than of wood as well. His value for spruce bark is higher than what was determined in this study for the specimens either from southern or northern Finland. On the other hand, the heating values of pine, downy and silver birch bark of this study are higher than those given by Olofsson.

The average q_v(net) of stem biomass is the weighted mean of wood and bark values (Table 9). In spite of the large differences in proportions and q_v(net) of tree components the differences between species actually turn out to be very small on whole stem basis. This has also been earlier shown by Olofsson (1975). Although outer bark is higher in heating value than the other two components it makes a lesser contribution to the average heating value of stem biomass than the other two components. This is caused by the small quantity. For example the high qv(net) of the birch bark has relatively little effect on the weighted q_v(net) of stem biomass. This is also supported by Sandala et al. (1981) who report on the heating values of three broad-leaved species from the north eastern United States. It should also be noted that the stems of the northern specimens have a higher heating value than the southern ones. On a whole this is caused by the combined effect of higher component q_v(net) values and higher bark percentage (Appendix. 3). This holds also for the crown material.

The crown is formed by branches including wood, bark and foliage. Biomass studies referenced in appendix 3 show that bark accounts roughly for one third of the branch mass without foliage. This enhances the heating value of crown biomass as the heating value of bark is higher than of wood. A considerable amount of the live crown is made up by foliage. This is especially true in conifer stands (Hakkila 1991). Although the heating values of foliage are reported in Table 10 the values for crown do not include foliage. This is because most often whole-tree chips do contain little foliage as they are lost during

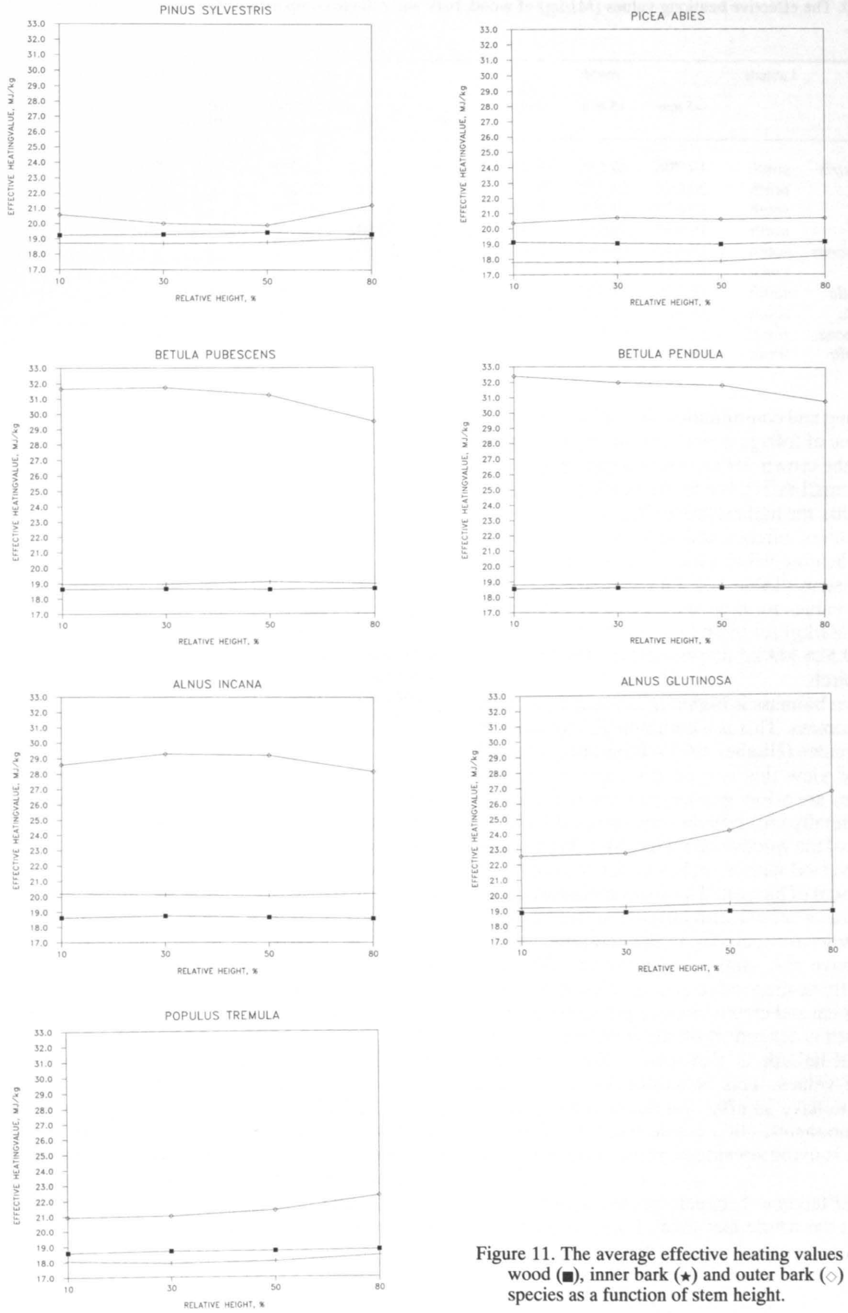


Figure 11. The average effective heating values of stemwood (■), inner bark (★) and outer bark (◇) for each species as a function of stem height.

Table 10. The effective heationg values (MJ/kg) of wood, bark and foliage components of branches over and under 5 mm.

Species	Latitude	Wood			Bark				Foliage	Crown without foliage
		>5 mm	<5 mm	All branch	>5 mm Inner	>5 mm Outer	<5 mm	All bark		
P. sylvestris	south	19.796	20.150	19.970	19.441	21.166	21.258	20.668	20.996	20.234
	north	20.051	20.839	20.473	20.379	21.947	22.082	21.629	20.777	20.873
P. abies	south	19.627	19.793	19.734	18.481	20.691	20.273	19.830	19.224	19.772
	north	19.432	20.052	19.900	18.258	20.801	20.593	20.390	19.298	20.108
B. pubescens	south	18.672	18.885	18.734	18.985	27.580	21.945	22.294	19.766	19.944
	north	19.011	19.172	19.076	18.975	26.479	20.815	21.447	19.372	20.181
B. pendula	south	18.726	18.732	18.728	18.763	28.548	20.235	21.083	19.723	19.526
A. incana	south	18.935	19.035	18.962	19.491	26.758	21.534	21.676	20.571	20.029
A. glutinosa	south	18.725	18.875	18.769	19.413	25.901	21.024	20.383	20.080	19.365
P. tremula	south	18.790	18.763	18.786	17.822	21.886	17.983	18.280	19.180	18.613

seasoning and comminution. In addition the heating value of foliage is not very different from the rest of the crown. Its inclusion would make only a very small difference to the heating value.

Pine has the highest crown heating value. Next come alders, birches and spruce. Aspen has the lowest heating value which is about the same as for the stem (Table 10). Olofsson (1975) gives similar values for pine and spruce but, his value (20.28 MJ/kg) for birch branches is much higher than 19.526 MJ/kg determined in this study for silver birch.

Crown biomass is higher in heating value than stem biomass. This is a common phenomema in many genera (Hughes 1971). From the fuelwood point of view this is a positive aspect because branches are a low quality, low value and most often a totally unacceptable raw material for most sectors of the woodworking industry. When trees are harvested with branches intact not only will the amount of harvested biomass increase but the energy recovery will also increase per unit weight.

A whole-tree includes all the components of a tree above the stump cross-section (Hakkila 1989). Its heating value is somewhat dependent on the stem and crown biomass proportions. This in its turn is dependent on the stand history. The effect of latitude is also seen in the whole-tree heating values. This is natural as it has been shown to have an effect on the heating value of the components. On a whole-tree level this difference is to the advantage of the northern speciment.

Table 11. The effective heating values (MJ/kg) of stem, crown without foliage and whole tree biomass.

Species	Latitude	Stem	Crown	Whole-tree
P. sylvestris	south	19.333	20.234	19.525
	north	19.479	20.873	19.763
P. abies	south	19.022	19.772	19.286
	north	19.161	20.108	19.478
B. pubescens	south	19.187	19.944	19.301
	north	19.528	20.181	19.651
B. pendula	south	19.151	19.526	19.208
A. incana	south	19.000	20.029	19.182
A. glutinosa	south	19.305	19.365	19.314
P. tremula	south	18.652	18.613	18.647

The differences between species, however, are small at the whole-tree level. Pine has the highest and aspen the lowest q_v(net) by a margin of only 5 %. These differences may be so insignificant that they may not effect the pricing of fuelwood when purchased in the form of whole-trees. Even the errors of similar margin may take place in timber scaling, not to speak of the moisture variation within a fuelwood pile which has a much greater effect on the fuelwood value. In addition, it is interesting to see that inspite of the differences in materials and methods between this and Olofsson's study the heating values for pine (19.453 vs.19.59 MJ/kg), spruce (19.146 vs. 19.19 MJ/kg) and silver birch (19.049 vs. 19.04 MJ/kg) are almost the same. For practical purposes, tables of effective heating values of moist wood derived from Table 11 are given separately for southern and northern Finland for fixed moisture contents in Table 12. Those interested in other moisture contents should refer to the Formula [2] in Chapter 23.

Table 12. The effective heating values (MJ/kg) of wood fuel at different moisture contents in southern and northern Finland.

Tree part	Species	Moisture content, % 0	10	20	30	40	50	60
		SOUTHERN FINLAND						
Stem	*P. sylvestris*	19.333	19.061	18.721	18.283	17.700	16.883	15.658
	P. abies	19.022	18.750	18.410	17.972	17.389	16.572	15.347
	B. pubescens	19.187	18.915	18.575	18.137	17.554	16.737	15.512
	B. pendula	19.151	18.879	18.539	18.101	17.518	16.701	15.476
	A. incana	19.000	18.728	18.388	17.950	17.367	16.550	15.325
	A. glutinosa	19.305	19.033	18.693	18.255	17.672	16.855	15.630
	P. tremula	18.652	18.380	18.040	17.602	17.019	16.202	14.977
Crown without foliage	*P. sylvestris*	20.234	19.962	19.622	19.184	18.601	17.784	16.559
	P. abies	19.772	19.500	19.160	18.722	18.139	17.322	16.097
	B. pubescens	19.944	19.672	19.332	18.894	18.311	17.494	16.269
	B. pendula	19.526	19.254	18.914	18.476	17.893	17.076	15.851
	A. incana	20.029	19.757	19.417	18.979	18.396	17.579	16.354
	A. glutinosa	19.365	19.093	18.753	18.315	17.732	16.915	15.690
	P. tremula	18.613	18.341	18.001	17.563	16.980	16.163	14.938
Whole-tree	*P. sylvestris*	19.525	19.253	18.913	18.475	17.892	17.075	15.850
	P. abies	19.286	19.014	18.674	18.236	17.653	16.836	15.611
	B. pubescens	19.301	19.029	18.689	18.251	17.668	16.851	15.626
	B. pendula	19.208	18.936	18.596	18.158	17.575	16.758	15.533
	A. incana	19.182	18.910	18.570	18.132	17.549	16.732	15.507
	A. glutinosa	19.314	19.042	18.702	18.264	17.681	16.864	15.639
	P. tremula	18.647	18.375	18.035	17.597	17.014	16.197	14.972
		NORTHERN FINLAND						
Stem	*P. sylvestris*	19.479	19.207	18.867	18.429	17.846	17.029	15.804
	P. abies	19.161	18.889	18.549	18.111	17.528	16.711	15.486
	B. pubescens	19.528	19.256	18.916	18.478	17.895	17.078	15.853
Crown without foliage	*P. sylvestris*	20.873	20.601	20.261	19.823	18.475	17.658	16.433
	P. abies	20.108	19.836	19.496	19.058	18.548	17.731	16.506
	B. pubescens	20.181	19.909	19.569	19.131	18.548	17.731	16.506
Whole-tree	*P. sylvestris*	19.763	19.491	19.151	18.713	18.130	17.313	16.088
	P. abies	19.478	19.206	18.866	18.428	17.845	17.028	15.803
	B. pubescens	19.651	19.379	19.039	18.601	18.018	17.201	15.976

4 Conclusions

Species were found to have a significant effect on the heating value of wood, bark and foliage components. The heating value of wood is highest in the conifers. But, the heating value of the combined inner and outer bark is higher in the broad-leaved species. On the whole the combined bark has a higher heating value than wood. The heating value of crown material is higher than that of the stem. This means that those parts of the tree that are not wanted by the forest industry as a raw material, i.e. bark, crown and small whole-trees in general are actually the fuelwood components of a tree with the highest heating values per unit weight. It should be noted, however, that unless some form of integrated harvesting is used the procurement of small trees and crown material may be to costly to carry out. Also, the conventional boilers with grates do require larger facilities when this low density fuel is burned. Fortunately floating bed instalations are invading the markets. They are more expensive to instal, but have the advantage of being much less sensitive to the fuel composition and quality than the conventional boilers. Furthermore, it is important to recognize that the heating value of the stem or whole-tree biomass is very little affected by species. From the user point of view the moisture content and the quantity of fuelwood are much more important factors than the species.

It was hypothesised that there is a relationship between chemical composition heating value. The test statistics from the regression analysis do support the hypothesis of some chemical components being dependent on the effective heating value. The heating value of inner bark does not form good regressions with any of the dependent variables because of the variation in data. The best models for outer bark do result when carbohydrates and alkali soluble extractives are used as dependent variables. With wood the dependence of lignin and extractives soluble in organic solvents and hot water on heating value are stronger than that of carbohydrates on heating value. However, it seems that when regression analysis is focused on individual species rather than on pooled data heating value would give a good estimate of the carbohydrate content for coniferous species. A more detailed work would need to be carried out to find out wether this method could be used to determine carbohydrate contents.

Soil type has only a minor effect on the heating value of the individual components. Contrary to the hypothesis the results do suggest that latitude has a significant effect on most of the components. The results indicate that the heating value of stem, crown and whole-tree material is higher in the northern extent of the growing range than in the southern part of the country.

One of the aims of the study was to give practical information of the heating values to the fuelwood users. This is fulfilled by giving heating values of stem, crown and whole-tree biomass of seven indegenous species at varying moisture contents separately for the southern and northern parts of the country.

References

Ager, A., Rönnberg-Wästljung, A., Thorsén, J. & Sirén, G. 1986. Genetic improvement of willows for energy forestry in Sweden. Swed. Univ. Agric. Sci., Dept. of Ecology and Environmental Res. Sec. of Energy Forestry. Report 43. 47p.

Arola, R.A. 1977. Wood fuels — how do they stack up? In: Energy and the wood products industry: Proc. of a symposium, 1976 Nov. 15–17, Atlanta, GA. Madison, WI: For. Products Res. Soc. 34–45.

Björklund, T. 1984. Tervalepän biomassa. Summary: Biomass of black alder. Metsäntutkimuslaitoksen tiedonantoja 151. 71p.

— & Ferm, A. 1982. Pienikokoisen koivun ja harmaalepän biomassa ja tekniset ominaisuudet. Summary: Biomass and technical properties of small-sized birch and gray alder. Folia Forestalia 500. 37p.

Bureau of Analysed Samples Ltd. 1988. Certificate BCS-CRM No. 190p Bensoic Acid Thermochemical Standard (with Energy of Combustion certified by the University of Mancherster). 1p.

Bowersox, T.W., Blankenhorn, P.R. & Murphey, W.K. 1979. Heat of combustion, ash content, nutrient content and chemical content of Populus hybrids. Wood Science 11(4): 257–261.

Corder, S.E. 1973. Wood and bark as fuel. Res. Bull. 14. Corvallis, OR: Oregon State Univ., School of Forestry. 28 p.

Doat, J. 1977. Le pouvoir calorifique des bois tropicaux. Bois et Forets des Tropiques 172: 33–47.

Ekman, R. 1983. The suberin monomers and triterpenoids from the outer bark of Betula verrucosa Ehrh. Holzforschung 37: 205–211.

Energiakatsaus. 1992. KTM/Energiaosasto. No. 2. 40 p.

Fredrikson, H. & Rutegård, G. 1985. Lagring av småved och bränsleflis i binge. Summary: Storage of chunk wood and fuel chips in bins. Swed. Univ. Agric. Sci., Dept. of Forest Products. Research Notes No 151. 32p.

Fuwape, J.A. 1989. Gross heat of combustion of Gmelina (Gmelina arborea (Roxb)) Chemical Components. Biomass 19: 281–287.

Hakkila, P. 1967. Vaihtelumalleja kuoren painosta ja painoprosentista. Summary: Variation patterns of bark weight and bark percentage by weight. Communicationes Instituti Forestalis Fenniae 62(5). 37p.

— 1968. Geographical variation of some properties of pine and spruce pulpwood in Finland. Seloste: Eräitten mänty- ja kuusipaperipuun ominaisuuksien maantieteellinen vaihtelu Suomessa. Communicationes Instituti Forestalis Fenniae 66(8). 60p.

— 1970. Basic density, bark percentage and dry matter content of grey alder (Alnus incana). Seloste: Harmaalepän puuaineen tiheys, kuoriprosentti ja kuiva-ainesisältö. Communicationes Instituti Forestalis Fenniae 71(6). 27p.

— 1978. Pienpuun korjuu polttoaineeksi. Summary: Harvesting small-sized wood for fuel. Folia Forestalia 342. 38 p.

— 1989. Utilization of residual forest biomass. Springer Series in Wood Science. Springer-Verlag. 568 p.

— 1991. Hakkuupoistuman latvusmassa. Summary: Crown mass of trees at the harvesting phase. Folia Forestalia. 773. 24p.

— (ed.) 1992. Metsäenergia. Metsäntutkimuslaitoksen tiedonantoja 422. 51p.

— , Kalaja, H. & Mäkelä, M. 1975. Kokopuunkäyttö pienpuuongelman ratkaisuna. Summary: Full-tree utilization as a solution to the problem of small-sized trees. Folia For. 240. 78p.

Harris, R.A. 1984. Fuel values of stems and branches in white oak, yellow poplar, and sweetgum. Forest Products Journal 34(3): 25–26.

— 1985. Fuel values of stems and branches in post oak and red maple. Forest Products Journal 35(4): 43–44.

Howard, E.T. 1973. Heat of combustion of various southern pine materials. Wood Science 5(3): 194–197.

Howard, J.O. 1988. Energy values for whole trees and crowns of selected species. USDA For. Serv., Research Note PNW-RN-480. 6 p.

Hughes, M.K. 1971. Seasonal calorific values from a deciduous woodland in England. Ecology 52: 923–926.

Koch, P. 1985. Utilization of hardwoods growing on southern pine sites: the raw material. U.S. Dept. Agr. For. Serv., Agr. Handbook 605. 1418 p.

Kollman, F. 1951. Technologie des Holzes und der Holzwerkstoffe I. Springer Verlag. 1050 p.

Kärkkäinen, M. 1980. Haapakokopuiden tekniset ominaisuudet. Summary: Technical properties of aspen whole trees. Manuscript at University of Helsinki, Department of forest technology.

Murphey, W.K. & Masters, K.R. 1978. Gross heat of combustion of northern red oak (Quercus rubra L.) chemical components. Wood Science 10(3): 139–141.

Musselman, K. & Hocker, Jr., H.W. 1981. Caloric values of eight New Hampshire forest tree species. Canadian Journal of Forest Research 11: 409–412.

Neenan, M. & Steinbeck, K. 1979. Caloric values for young sprouts of nine hardwood species. Forest Science 25(3): 455–461.

Olofsson, L. 1975. Värmevärden för olika delar av tall, gran och björk. Summary: Heating values for different parts of pine, spruce and birch. Dept. of Operational Efficiency. Research Notes 90. 39 p.

Report of the technical panel on fuelwood and charcoal on its second session. A/CONF. 100/PC/34, 25 February 1981.

Sandala, M.G., Blankenhorn, P.R. & Kline, D.E. 1981. Thermal analysis of white oak, northern red oak, and black cherry bark chemical components. Wood Science 13(3): 157–165.

Sastry, C.B.R. & Anderson, H.W. 1980. Clonal variation in gross heat of combustion of juvenile Populus hybrids. Canadian Journal Forest Research 10: 245–249.

Simola, P. 1977. Pienikokoisen lehtipuuston biomassa. Summary: The biomass of small-sized hardwood trees. Folia Forestalia 302. 16p.

Singh, T. & Kostecky, M.M. 1986. Calorific value variations in components of 10 Canadian tree species. Canadian Journal of Forest Research 16: 1378–1381.

Stringer, J.W. & Carpenter, S.B. 1986. Energy yield of black locust biomass fuel. Forest Science 32(4): 1049–1057.

Taras, M.A. 1978. Biomass of southern pines and their product yields. In: McMillin, C.W. (ed.). Complete tree utilization of southern pine. Forest Products Research Society Madison, 15–23.

Thörnqvist, T. 1985. Trädbränslekvalitet — vad är det? (Wood fuel quality — what is it?) Sveriges Lantbruksuniv. SIMS Uppsatser 14, 18 p.

Virtanen, P. 1963. Fuel properties of barking refuse from Finnish tree species. Pap. Puu 45: 313–330.

Voipio, R. & Laakso, T. 1992. Pienikokoisten puiden maanpäällisen biomassan kemiallinen koostumus. Summary: Chemical composition of the above ground biomass of small-sized trees. Folia Forestalia 789. 22p.

Wang, S., Huffman, J.B. & Littell, R.C. 1981. Characterization of Melaleuca biomass as a fuel for direct combustion. Wood Science 13(4): 216–219.

White, R.H. 1987. Effect of lignin content and extractives on the higher heating value of wood. Wood and Fiber Science 19(4): 446–452.

Zobel, B.J. & van Buijtenen, J.P. 1989. Wood variation Its causes and control. Springer Series in Wood Science. Springer-Verlag. 363p.

Total of 45 references

Appendix 1. The chemical composition of biomass components by species. The trees from the northern latitude are indicated with an asterisk (*).

A. The lignin content.

Tree species	Stem						Branches > 5mm			Branches < 5mm		
	20% height			80% height								
	Wood	Inner bark	Outer bark	Wood	Inner bark	Outer bark	Wood	Inner bark	Outer bark	Wood	All bark	Foliage
P. sylvestris	25,5	5,3	29,5	27,0	7,2	17,9	29,7	7,1	15,7	27,8	10,5	9,8
	26,8*	7,3*	30,6*	28,0*	9,0*	14,9*	30,2*	7,2*	15,0*	24,2*	16,7*	11,9*
P. abies	27,8	7,7	22,9	28,2	9,2	23,9	31,7	7,2	24,7	30,2	18,7	11,5
	27,5*	4,3*	21,0*	26,4*	4,8*	18,1*	29,8*	5,7*	21,7*	26,1*	22,3*	10,5*
B. pubescens	22,2	24,2	6,2	21,5	21,9	6,3	21,5	17,7	11,2	22,5	14,1	14,6
	20,3*	16,3*	6,1*	20,2*	15,9*	9,0*	21,1*	15,8*	11,1*	21,8*	12,0*	..
B. pendula	21,9	21,6	11,7	22,7	20,2	7,9	21,9	16,8	10,1	22,8	14,5	18,5
A. incana	23,0	26,7	26,0	22,4	16,4	11,7	23,8	21,9	18,9	26,5	19,0	21,5
A. glutinosa	24,8	28,4	32,0	25,2	24,6	19,6	25,9	23,5	21,4	27,5	22,0	25,0
P. tremula	20,1	14,8	16,9	19,8	15,2	12,5	18,4	14,9	17,0	21,2	17,5	18,6

B. The carbohydrate content.

Tree species	Stem						Branches > 5mm			Branches <5mm		
	20% height			80% height								
	Wood	Inner bark	Outer bark	Wood	Inner bark	Outer bark	Wood	Inner bark	Outer bark	Wood	All bark	Foliage
P. sylvestris	69,6	41,8	35,4	66,1	37,0	38,4	56,6	37,6	33,2	51,6	31,1	37,4
	73,0*	45,4*	31,4*	66,0*	40,0*	34,1*	59,8*	39,4*	35,1*	45,6*	33,0	39,3*
P. abies	78,9	49,1	31,5	74,5	48,2	36,3	66,2	49,6	30,3	63,3	36,5	31,7
	75,7*	38,3*	30,3*	73,1*	36,6*	30,5*	67,3*	34,1*	24,1*	50,6*	26 3	39,3*
B. pubescens	67,0	38,4	5,3	65,3	35,8	5,8	64,2	32,9	7,8	60,0	23,4	20,1
	78,4*	33,5*	7,9*	73,7*	31,1*	7,6*	72,0*	24,2*	6,9*	50,9*	19,2	..
B. pendula	69,9	41,8	13,9	65,9	46,2	10,3	64,6	41,6	14,0	63,0	26,0	22,3
A. incana	69,0	33,8	20,0	62,6	33,9	14,2	63,0	34,0	17,1	55,0	28,3	20,4
A. glutinosa	69,8	37,6	24,9	64,8	44,2	28,1	63,9	33,8	20,9	57,0	25,9	23,8
P. tremula	74,6	41,1	31,6	69,1	49,8	26,1	69,3	48,0	40,3	58,8	38,5	24,8

C. The content of extractives soluble in organic solvents and hot water.

Tree species	Stem						Branches > 5mm			Branches < 5mm		
	20% height			80% height								
	Wood	Inner bark	Outer bark	Wood	Inner bark	Outer bark	Wood	Inner bark	Outer bark	Wood	All bark	Foliage
P. sylvestris	5,0	39,5	15,9	5,4	44,4	23,3	9,1	43,3	28,4	14,1	38,2	40,6
	6,2*	37,7*	23,4*	8,7*	44,7*	32,1*	9,0*	49,3*	35,9*	27,4*	40,6*	41,7*
P. abies	3,5	37,4	23,4	4,9	38,7	20,9	5,2	30,5	22,0	9,6	26,4	43,3
	3,4*	45,1*	26,2*	6,2*	52,1*	25,3*	7,2*	37,3*	25,5*	22,1*	33,0*	47,9*
B. pubescens	4,4	21,3	33,2	5,8	23,7	29,6	6,8	29,0	24,1	9,1	23,9	32,5
	6,9*	37,5*	28,8*	9,6*	39,8*	28,4*	10,2*	38,0*	25,1*	12,5*	35,3*	..
B. pendula	4,2	18,8	31,6	5,8	18,9	32,7	7,0	19,5	26,5	8,2	20,5	33,4
A. incana	4,4	20,4	27,8	7,5	38,2	39,0	8,2	21,3	22,7	11,3	22,5	28,3
A. glutinosa	5,1	20,5	14,9	6,2	22,4	22,2	8,3	23,5	24,1	9,8	21,1	27,6
P. tremula	4,5	23,1	26,5	6,1	20,5	25,2	8,6	20,0	19,0	14,8	19,5	25,4

D. The content of the alkali soluble extractives.

Tree species	Stem				Branches > 5mm		Branches < 5mm	
	20% height		80% height					
	Inner bark	Outer bark	Inner bark	Outer bark	Inner bark	Outer bark	All bark	Foliage
P. sylvestris	18,8	18,9	19,2	26,7	21,1	30,7	24,4	17,7
	16,5*	12,0*	16,2*	25,7*	11,0*	27,3*	20,3*	15,1*
P. abies	15,2	18,8	17,6	16,0	24,5	18,3	19,7	13,0
	20,0*	21,8*	16,4*	19,9*	21,2*	22,6*	21,7*	11,1*
B. pubescens	15,3	55,0	15,5	57,0	17,7	54,7	36,6	25,6
	15,6*	57,6*	14,5*	53,3*	19,5*	55,3*	36,9*	..
B. pendula	14,1	46,3	14,5	45,6	18,5	44,6	33,0	23,9
A. incana	14,2	20,5	19,5	36,9	24,1	37,5	29,9	25,2
A. glutinosa	16,4	24,0	14,5	32,2	18,2	34,4	29,9	22,8
P. tremula	26,9	22,6	16,7	25,5	26,1	26,0	22,5	28,1

Appendix 2. The elemental composition of tree components by species**Appendix 1.** The chemical composition of biomass components by species. The trees from the northern latitude are indicated with an asterisk (*)..

Species	Wood			Inner bark		Outer bark		Bark	Foliage
	Stem	Branches > 5mm	Branches < 5mm	Stem	Branches > 5mm	Stem	Branches > 5mm	Branches > 5mm	
Carbon									
P. sylvestris	52.34	53.53	50.87	50.83	52.33	55.75	56.35	54.99	54.20
P. abies	52.43	53.36	50.37	49.70	50.20	55.56	56.10	54.02	51.30
B. pubescens	50.97	50.97	48.39	52.20	52.49	72.64	68.37	57.82	49.12
B. pendula	47.43	48.67	48.05	48.00	48.60	66.71	64.34	50.24	48.68
A. incana	49.09	48.21	49.17	49.67	48.34	64.09	60.58	51.53	49.75
A. glutinosa	46.64	47.90	48.45	50.29	50.09	58.52	62.06	53.97	50.95
P. tremula	46.21	46.84	50.23	48.95	47.81	52.71	52.94	48.05	48.23
Hydrogen									
P. sylvestris	6.09	6.03	5.23	6.17	6.36	5.68	6.12	6.70	6.82
P. abies	5.86	5.61	5.14	5.59	5.62	5.85	5.77	5.95	6.28
B. pubescens	5.86	5.80	5.15	5.79	6.10	9.37	8.43	6.55	6.13
B. pendula	5.22	5.25	5.18	5.10	5.01	9.41	8.40	5.33	6.08
A. incana	5.77	5.16	5.71	6.15	5.94	8.59	7.66	6.48	6.22
A. glutinosa	5.01	5.84	5.89	5.77	5.57	6.37	7.56	6.23	5.90
P. tremula	4.98	5.09	5.98	5.74	5.73	6.42	6.18	5.77	5.95
Nitrogen									
P. sylvestris	0.08	0.10	0.19	0.48	0.55	0.15	0.38	0.68	0.88
P. abies	0.01	0.03	0.14	0.47	0.52	0.33	0.43	0.74	0.79
B. pubescens	0.12	0.18	0.28	0.63	0.86	0.28	0.47	1.20	1.73
B. pendula	0.07	0.18	0.28	0.33	0.65	0.79	0.59	0.74	1.59
A. incana	0.44	0.59	0.83	1.49	1.74	1.28	1.23	1.72	2.79
A. glutinosa	0.20	0.46	0.62	1.06	1.26	1.15	1.06	1.33	2.22
P. tremula	0.15	0.29	0.61	0.84	1.30	0.59	0.88	1.00	2.50

Appendix 3. The stem, crown and whole-tree composition by species. The division of stem and branch biomass into wood and bark, and the division of whole-tree into crown and stem are based on referenced biomass studies.

A. Stem composition.

Species	Latitude	Bark division*)		Stem division		Literature source
		Inner	Outer	Wood	Bark	
		%		%		
P. sylvestris	south	50.5	49.5	88.9	11.1	1)
	north	54.7	45.3	85.2	14.8	*)
P. abies	south	64.7	35.3	87.9	12.1	1)
	north	60.0	40.0	85.5	14.5	*)
B. pubescens	south	69.4	30.6	86.2	13.8	1)
	north	65.0	35.0	76.6	23.4	*)
B. pendula	south	72.5	27.5	86.2	13.8	1)
A. incana	south	84.0	16.0	88.6	11.4	2)
A. glutinosa	south	45.8	54.2	83.5	16.5	3)
P. tremula	south	83.2	16.8	83.5	16.5	4)

1) Hakkila 1967
3) Björklund 1984
2) Hakkila 1970
4) Kärkkäinen 1980
*) data collected in this study

B. Crown composition

Species	Latitude	Branches > 5 mm*)				Branches*) < 5 mm		Total branch		Literature source
		Bark, %		Branch						
		Inner	Outer	Wood	Bark	Wood	Bark	Wood	Bark	
P. sylvestris	south	61.5	38.5	69.6	30.4	43.6	56.4	62.9	37.1	1)
	north	53.6	46.4	64.6	35.4	33.6	66.4	65.4	34.6	1)
P. abies	south	75.5	24.5	72.7	27.3	50.1	49.9	60.4	39.6	1)
	north	40.9	59.1	65.3	34.7	37.3	62.7	57.5	42.5	1)
B. pubescens	south	59.7	40.3	77.9	22.1	67.7	32.3	66.1	33.9	2)
	north	61.4	38.6	59.6	40.4	44.3	55.7	54.9	45.1	*)
B. pendula	south	73.2	26.8	73.9	26.1	54.4	45.6	66.1	33.9	2)
A. incana	south	69.2	30.8	71.1	28.9	52.1	47.9	60.7	39.3	2)
A. glutinosa	south	71.7	28.3	64.7	35.3	48.9	51.1	63.1	36.9	3)
P. tremula	south	87.4	12.6	70.7	29.3	39.1	60.9	65.9	34.1	*)

1) Hakkila 1991
3) Björklund 1984
2) Björklund & Ferm 1982
*) data collected in this study

C. Whole-tree composition.

Species	Latitude	Branches*)		Whole-tree		Literature source
		>5 mm	<5 mm	Crown	Stem	
P. sylvestris	south	50.8	49.2	21.3	78.7	1)
	north	46.4	53.6	20.4	79.6	1)
P. abies	south	35.4	64.6	35.2	64.8	1)
	north	24.4	75.6	33.5	66.5	1)
B. pubescens	south	69.4	30.6	15.1	84.9	1)
	north	59.8	40.2	18.9	81.1	1)
B. pendula	south	73.7	26.3	15.1	84.9	1)
A. incana	south	72.8	27.2	17.7	82.3	2)
A. glutinosa	south	70.7	29.3	15.8	84.2	3)
P. tremula	south	84.8	15.2	11.6	88.4	4)

1) Hakkila 1991
2) Simola 1977
3) Björklund 1984
4) Kärkkäinen 1980
*) data collected in this stydy

Instructions to authors — Ohjeita kirjoittajille

Submission of manuscripts

Manuscripts should be sent to the editors of the Society of Forestry as three full, completely finished copies, including copies of all figures and tables. Original material should not be sent at this stage.

The editor-in-chief will forward the manuscript to referees for examination. The author must take into account any revision suggested by the referees or the editorial board. Revision should be made within a year from the return of the manuscript. If the author finds the suggested changes unacceptable, he can inform the editor-in-chief of his differing opinion, so that the matter may be reconsidered if necessary.

Decision whether to publish the manuscript will be made by the editorial board within three months after the editors have received the revised manuscript.

Following final acceptance, no fundamental changes may be made to manuscript without the permission of the editor-in-chief. Major changes will necessitate a new submission for acceptance.

The author is responsible for the scientific content and linguistic standard of the manuscript. The author may not have the manuscript published elsewhere without the permission of the publishers of Acta Forestalia Fennica. The series accepts only manuscripts that have not earlier been published.

The author should forward the final manuscript and original figures to the editors within two months from acceptance. The text is best submitted on a floppy disc, together with a printout. The covering letter must clearly state that the manuscript is the final version, ready for printing.

Form and style

For matters of form and style, authors are referred to the full instructions available from the editors.

Käsikirjoitusten hyväksyminen

Metsäntutkimuslaitoksesta lähtöisin olevien käsikirjoitusten hyväksymismenettelystä on ohjeet Metsäntutkimuslaitoksen julkaisuohjesäännössä.

Muista käsikirjoituksista lähetetään Suomen Metsätieteellisen Seuran toimitukselle kolme täydellistä, viimeisteltyä kopiota, joihin sisältyvät myös kopiot kaikista kuvista ja taulukoista. Originaaliaineistoa ei tässä vaiheessa lähetetä.

Vastaava toimittaja lähettää käsikirjoituksen valitsemilleen ennakkotarkastajille. Tekijän on otettava huomioon ennakkotarkastajien ja toimituskunnan korjausesitykset. Korjaukset on tehtävä vuoden kuluessa siitä, kun käsikirjoitus on palautettu tekijälle. Jos tekijä ei voi hyväksyä korjausesityksiä, hänen on ilmoitettava eriävä mielipiteensä vastaavalle toimittajalle tai toimituskunnalle, joka tarvittaessa ottaa asian uudelleen käsittelyyn.

Acta Forestalia Fennican toimituskunta päättää kirjoituksen julkaisemisesta ennakkotarkastajien lausuntojen ja muiden ilmenneiden seikkojen perusteella. Päätös tehdään kolmen kuukauden kuluessa siitä, kun käsikirjoituksen lopullinen korjattu versio on saapunut toimitukselle.

Hyväksymisen jälkeen käsikirjoitukseen ei saa tehdä olennaisia muutoksia ilman vastaavan toimittajan lupaa. Suuret muutokset edellyttävät uutta hyväksymistä.

Tekijä vastaa kirjoituksen tieteellisestä asiasisällöstä ja kieliasusta. Tekijä ei saa julkaista kirjoitusta muualla ilman Acta Forestalia Fennican julkaisijoiden suostumusta. Acta Forestalia Fennicaan hyväksytään vain aiemmin julkaisemattomia kirjoituksia.

Tekijän tulee antaa lopullinen käsikirjoitus ja kuvaoriginaalit toimitukselle kahden kuukauden kuluessa hyväksymispäätöksestä. Käsikirjoituksen saatteesta pitää selvästi ilmetä, että käsikirjoitus on lopullinen, painoon tarkoitettu kappale. Teksti otetaan mieluiten vastaan mikrotietokoneen levykkeellä, jonka lisäksi tarvitaan paperituloste.

Käsikirjoitusten ulkoasu

Käsikirjoituksen asun tulee noudattaa sarjan kirjoitusohjeita, joita saa toimituksesta.

ACTA FORESTALIA FENNICA

232 **Valsta, Lauri.** An optimization model for Norway spruce management based on individual-tree growth models. Tiivistelmä: Kuusikon käsittelyn optimointi puittaisiin kasvumalleihin pohjautuen.

233 **Ovaskainen, Ville.** Forest taxation, timber supply, and economic efficiency. Seloste: Metsäverotus, puun tarjonta ja taloudellinen tehokkuus.

234 **Hämäläinen, Jouko & Kuula, Markku.** An integrated planning model for a farm with an adjoining woodlot. Tiivistelmä: Metsää omistavan maatilan kombinoitu suunnittelumalli.

235 **Nikinmaa, Eero.** Analyses of the growth of Scots pine: matching structure with function. Seloste: Analyysi männyn kasvusta; rakenteen sopeutumista aineenvaihduntaan.

1993

236 **Nurmi, Juha.** Heating values of the above ground biomass of small-sized trees. Tiivistelmä: Pienikokoisten puiden maanpäällisen biomassan lämpöarvot.

237 **Luomajoki, Alpo.** Climatic adaptation of Scots pine (*Pinus sylvestris* L.) in Finland based on male flowering phenology. Seloste: Männyn sopeutuminen Suomen ilmastoon hedekukkimisaikojen valossa.

238 **Mäkinen, Pekka.** Puutavaran kuljetusyritysten menestymisen strategiat. Summary: Strategies used by timber truck transport companies to ensure business success.

ISBN 951-40-1280-1
ISSN 0001-5636

Acta Forestalia Fennica 236 – Nurmi