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VARIATION IN STRUCTURE AND SELECTED PROPERTIES OF FINNISH BIRCH WOOD: II. OBSERVATIONS ON THE ANATOMY OF ROOT WOOD

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SELOSTE:

SUOMALAISEN KOIVUPUUN RAKENTEEN JA ERÄIDEN OMINAISUUKSIEN VAIHTELU: II. HAVAINTOJA JUURIPUUN ANATOMIASTA

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The anatomical variation of a lateral root was compared with that of the stem of the same tree at breast height by concentrating on the interrelationships of certain anatomical features and basic density in *Betula pendula* and *B. pubescens*. There was a negative correlation between basic density and vessel frequency in the root of both birch species. Several essential features of the stem such as gelatinous fibres, growth eccentricity, vessels with scalariform perforation plates and pith flecks were found in the roots of both the species. There were many statistically significant differences between the stemwood and root wood of both species.

INTRODUCTION

Most of the research on wood anatomy is concerned with stems and branches because the end uses of these parts of the tree are better understood than those of root wood. However, the present emphasis on whole tree utilization has extended anatomical studies to roots as well. For instance, the root wood of *Pinus sylvestris, Picea abies* and *Betula pendula (B. verrucosa)* has proved to be a suitable raw material for kraft pulping (HAKKILA 1975, HARTLER 1976). Therefore, apart from the identification standpoint, the knowledge of root wood anatomy is essential to explain the properties for rational use of roots.

Little work has been done on root wood from the anatomical point of view since the pioneer study on *Pinus sylvestris* by SANIO (1872). The emphasis in textbooks and studies has been on the silvicultural aspects (E.g. KÖSTLER et al. 1968). Some of the generalised views of the earlier studies which deserve mention here are:

a) Pith is absent in root wood (PATEL 1965, FAYLE 1968).
b) The boundaries between the growth rings are not well defined (PATEL 1965, FAYLE 1968, CUTLER 1976).
c) In diffuse porous species, the vessels are larger in the roots than in the stems (FEGEL 1941, MACDONALD 1960, PATEL 1965, FAYLE 1968).
d) Vessel frequency per unit area is lower in roots than in stems (FEGEL 1941, MACDONALD 1960, PATEL 1965, FAYLE 1968). However, CUTLER (1976) made contradictory observations in some of the samples studied.
e) Gelatinous fibres occur in the roots of many species (JAGELS 1963, PATEL 1964, HÖSTER and LIESE 1966), although the occurrence is not universal.
f) In young plants of *Betula verrucosa* the roots and stems are identical (LEBEDENKO 1959).

The object of the present study was to compare the anatomical variation of two lateral roots with that of the stem of the same trees by concentrating on the interrelationships of certain anatomical features and basic density in two commercial species of Finnish birch, viz: *Betula pendula* Roth and *B. pubescens* Ehrh. Other results were presented in an earlier paper (BHAT 1980 b).

The material was collected by Bhat with the assistance of Mr. A. Wäänänen. The laboratory work and the original manuscript are by Bhat. Kärkkäinen computed the results. The English language was checked by L. A. Keyworth. Aune Rytkönen typed the manuscript. Valuable comments were made by Paavo Kallio and Jyrki Raulo. Bhat wishes to express his gratitude to Prof. Bror-Anton Granvik for providing the facilities to work in the Department of Logging and Utilization of Forest Products, University of Helsinki, and to the Ministry of Education, Finland, for financial support.

MATERIAL AND METHODS

One lateral root and a transverse disc of the stem at breast height were collected from one tree in each of the birch species *Betula pendula* Roth and *B. pubescens* Ehrh. on a natural stand near the Forestry Field Station, University of Helsinki, Hyytiälä. As counted at the base of the trees, their age was 51 and 56 years, respectively. From the roots, transverse discs were cut at three 0,5 m intervals from base to distal end so as to cover the greater range of vertical variation within the roots.

The discs of the roots were marked for upper and lower radii and about 15° wedges were cut from each radius. Owing to the difficulty of localising very narrow growth rings, the distance from the "pith" to the outer margin was noted in making small segments in the wedges radially outwards. In addition, one wedge was cut at a random radius of stem disc where there was no sign of reaction wood.

Forty one root samples and 14 stem samples of *Betula pubescens* were sectioned in transverse, radial and tangential planes with a sliding microtome. The corresponding numbers of root and stem samples of *B. pendula* were 26 and 13. The sections were stained with safranin and mounted in glycerine for microscopic observations. Before sectioning, basic density of the samples was determined on oven dry weight to green volume basis.

For each anatomical feature, 30 measurements were taken from each sample; a total of 2010 measurements for the roots and 810 for the stem were considered for each variable. In addition, the number of growth rings in each sample was counted under the microscope. Simultaneously, the average ring width was noted by measuring under the microscope with the help of an ocular micrometer. Each root sample contained on the average 12 growth rings in *Betula pendula* and 7 in *B. pubescens,* whereas the average number in the stem sample was 5 in both the species.

RESULTS AND DISCUSSION

Growth rings

Growth rings were distinct in all the samples studied of both species. The boundaries between them were no less well defined than those of stem as reported for many species in earlier studies (FAYLE 1968). However, ring width appeared to be a highly variable characteristic in roots because it varied from 0,2 mm to 3,6 mm in *Betula pendula* and from 0,3 to 4,3 mm in *B. pubescens* (see also Table 1). The greater variability of ring width might be partly attributable to the very eccentric diameter growth.

In the material studied here, the ring width increased from the pith to the surface. In studies based on larger materials a decreasing trend has been observed (LAITAKARI 1934).

Vessels

It can be seen from Table 1 that in both species the number of vessels per square mm

Table 1. Averages and standard deviations of the anatomical variables of root and stem wood in *Betula pendula* and *B. pubescens*.
Taulukko 1. Raudus- ja hieskoivun juuri- ja runkopuun anatomisten ominaisuuksien keskiarvot ja standardipoikkeamat.

Tree species *Puulaji*	Anatomical feature *Anatominen ominaisuus*	Lateral root *Vaakasuora juuri*		Stem wood *Runkopuu*		t-value *t-arvo*
		x̄	s	x̄	s	
B. pendula *Rauduskoivu*	Ring width, mm *Vuosiluston paksuus, mm*	0,9	0,8	1,6	0,6	2,8*
	No. of vessels per mm² *Putkiloita mm² kohti*	21,6	4,9	59,3	37,4	5,1***
	Tangential vessel diameter, μm *Tangentiaalinen putkilon läpimitta, μm*	114,6	14,4	82,5	9,6	7,2***
	No. of bars in perforation plate *Aukonvälejä perforaatiolevyssä*	8,6	1,6	13,0	0,6	9,5***
	No. of rays per tangential linear mm *Ydinsäteitä tangentiaalista mm kohti*	10,3	1,1	9,8	1,5	1,2NS
B. pubescens *Hieskoivu*	Ring width, mm *Vuosiluston paksuus, mm*	1,9	1,1	0,9	0,2	3,4**
	No. of vessels per mm² *Putkiloita mm²* kohti	13,3	2,8	48,1	26,2	8,5***
	Tangential vessel diameter, μm *Tangentiaalinen putkilon läpimitta, μm*	93,1	13,3	79,5	10,8	3,5**
	No. of bars in perforation plate *Aukonvälejä perforaatiolevyssä*	12,3	2,5	18,6	1,4	8,9***
	No. of rays per tangential linear mm *Ydinsäteitä tangentiaalista mm kohti*	10,1	1,0	9,3	1,5	2,3*

was considerably less in the root than in the stem. Furthermore, the vessels were larger in the root than in the stem. These results showing a lower frequency and larger diameter of the vessels are in agreement with the generally accepted view (FEGEL 1941, MACDONALD 1960, PATEL 1965, FAYLE 1968).

It is evident from earlier studies that the increase in vessel diameter in the stem is accompanied by a decrease in vessel frequency from the pith to the surface in both birch species (OLLINMAA 1955, BHAT and KÄRKKÄINEN 1980). However, in the *Betula pubescens* root samples studied here the negative correlation between these two features was not significant (Table 2), although there was a small rising trend in vessel diameter with the decrease in vessel frequency from the pith outwards. The correlation was positive and highly significant in *B. pendula* (Table 2). The reason is that there was a clear declining trend in vessel diameter from the pith outwards (Fig. 4). The contrary situation was observed in the stems. Even when the two species were taken together the correlation was positive and significant at the 5 % level. The tendency of vessels to be larger near the ontogenetic centre might be due to the different pattern of the organization in the secondary xylem of roots. For instance, in the root wood of *Populus deltoides* the small intact primary xylem in the centre is surrounded by the secondary xylem with considerably larger vessels (EAMES and MACDANIELS 1947). It remains to be confirmed whether this decreasing trend of vessel diameter from the pith outwards is a universal phenomenon in birch roots.

As regards vertical variation, a small increase was noticed in the size and number of vessels from the base to the distal end of

Table 2. Correlation coefficients of some of the anatomical variables and basic density of root wood in *Betula pendula* (R) and *B. pubescens* (H).
Taulukko 2. Rauduskoivun (R) ja hieskoivun (H) eräiden anatomisten ominaisuuksien ja kuiva-tuoretiheyden keskinäiset korrelaatiot.

	Variable *Muuttuja*	Tree species *Puulaji*	Variable – *Muuttuja* 2	3	4	5	6	7	8
1	Vessel frequency	(R)	.774**	–.647**	–.379	.232	–.821**	–.759**	.284
	Putkiloiden tiheys	(H)	–.043	–.659**	–.306*	.118	–.531**	–.623**	.339*
2	Vessel diameter	(R)		–.526**	–.498**	–.161	–.832**	–.668**	.362
	Putkiloiden läpimitta	(H)		.322*	–.024	–.017	.295	.378*	.159
3	Ring width	(R)			.144	–.239	.562**	.736**	–.440*
	Vuosiluston paksuus	(H)			.320*	.149	.167	.506**	–.348*
4	No. of bars in perforation plate	(R)				–.019	.272	.093	–.289
	Aukonvälejä perforaatio-levyssä	(H)				.237	.304	.210	.107
5	Ray frequency	(R)					.017	–.086	–.027
	Ydinsäteiden tiheys	(H)					–.223	–.008	–.084
6	Basic density	(R)						.821**	–.485**
	Kuiva-tuore-tiheys	(H)						.570**	.028
7	Distance from pith	(R)							–.307
	Etäisyys ytimestä	(H)							–.014
8	Sampling distance from base	(R)							
	Etäisyys puun tyveltä	(H)							

the roots, although only the increase in vessel frequency in *Betula pubescens* was statistically significant.

Table 2 reveals that the negative correlation between vessel frequency and average ring width is highly significant in both the species. This indicates the association of greater number of vessels with narrow growth rings in the root, as OLLINMAA (1955) observed in the stem wood.

It is apparent from the results that there is a distinct negative correlation between vessel frequency and basic density in both species. A similar negative correlation between specific gravity and percentage of vessel area was found in the trunk wood of birch in an earlier study (WALLDÉN 1934). Therefore, it is clear that basic density variation partly depends on the amount of vessels present in the roots, as in the case of the stem. However, the correlation between vessel diameter and basic density was significant only in *Betula pendula*.

Vessel perforation plates

There were distinct scalariform perforation plates in the vessels of the roots. The average number of bars varied relatively little. The averages of 30 counts per sampling point were 7 to 11 in *Betula pendula* and the standard deviations 1 to 2. The corresponding averages for *B. pubescens* were 10 to 15 and the standard deviations were 1 to 4.

One source of variation in *B. pendula* was the vessel diameter. According to Table 2, there was a negative correlation between the number of bars and the vessel diameter.

It can be seen from Table 1 that in both species the number of bars was considerably less in the roots than in the stem. Furthermore, there was a marked difference in the number of bars between the roots of the two species. This suggests a possibility of distinguishing between *Betula pendula* and *B. pubescens* roots. A similar method was proposed by BHAT and KÄRKKÄINEN (1980) for separating the stems of these two species. This feature appears to have a practical identification value because even in the roots observed in the present study there was no significant variation either in the longitudinal or in the radial direction.

Gelatinous fibres

One of the interesting observations of this investigation provides evidence of the occurrence of gelatinous fibres in the root wood of both the species. On the other hand, PATEL (1964) did not find them in the roots of *Betula pendula* within the age of 10–18 years. A possible explanation for the conflicting data is that tension wood might not have begun to form in the early stage. The results showing the presence of gelatinous fibres in the roots also disagree with the statement of ONAKA (1956). According to him, reaction wood does not appear in the root

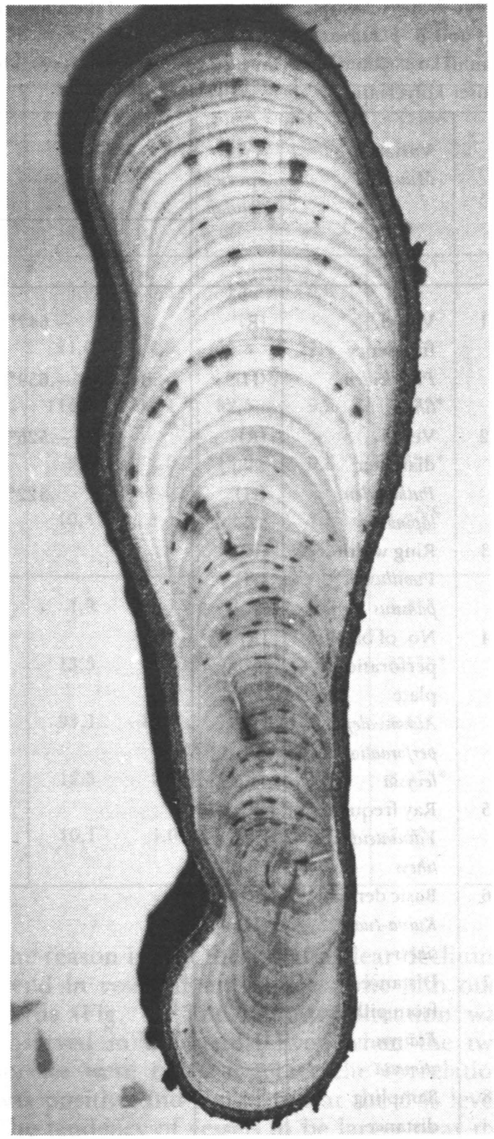

Fig. 1. Transverse disk of *Betula pubescens* root showing eccentric diameter growth and numerous pith flecks.
Kuva 1. Hieskoivun juuren poikkileikkaus, jossa näkyy epäkeskinen kasvu ja lukuisia ruskotäpliä.

(JAGELS 1963). However, the results of the present study support the findings of many authors for the occurrence of gelatinous fibres in the roots of very many species (JAGELS 1963, PATEL 1964, HÖSTER and LIESE 1966).

As regards the position of the occurrence, gelatinous fibres were found on both upper

and lower radii. They were more abundant in the *Betula pubescens* than in the *B. pendula* roots examined. Gelatinous fibres occur as a result of eccentric diameter growth on both radii (Fig. 1). Eccentricity was more pronounced on the upper radius of the proximal end of the lateral roots. The situation might be explained by the accelerated growth of the xylem on the upper radius due to loss of soil caused by rain or other factors (KNY 1908). It was also observed that eccentricity gradually decreased towards the distal end as the roots grew deeper into the soil, a point which LAITAKARI (1934) reported. It was accompanied by a decrease in the amount of gelatinous fibres, although no actual counts were made. As gelatinous fibres and growth eccentricity are the diagnostic features of tension wood (DADSWELL and WARDROP 1949), they confirmed the formation of tension wood in the roots of *Betula pendula* and *B. pubescens*.

Rays

The frequency of rays was a little higher in the roots than in the stem of *Betula pubescens*, and the trend was similar in *B. pendula*. However, the difference was statistically significant only in the former. SÜSS and MÜLLER-STOLL (1973) observed a smaller proportion of rays in the lateral roots than in the tap root of *Platanus acerifolia*.

Pith flecks

Pith flecks were also common in the roots of both species. (Fig. 1). In some cases they were found even in the top part of the roots. The pith flecks were more numerous in the roots than in the stem although their number per unit area was not counted. Furthermore, due to pith flecks several ray abnormalities were observed in the roots of both species, as reported for the stem wood (BHAT 1980 a).

SUMMARY

1) Growth rings were distinct and the boundaries between them were well defined.
2) Vessels were larger in size but less in number in the roots than in the stems.
3) There was a significant negative correlation between vessel frequency and basic density in both birch species.
4) Vessel diameter decreased from the pith outwards in *Betula pendula*, but the trend was not clear in *B. pubescens*.
5) The number of bars in the scalariform perforation plate was smaller compared with stem wood in both the species.
6) Gelatinous fibres and growth eccentricity, the diagnostic features of tension wood, were observed in the roots of both birch species.
7) The frequency of rays was a little higher in the roots than in the stem of *B. pubescens*. The trend was similar in *B. pendula*.
8) Pith flecks were also common in the root wood of both species.
9) Many significant differences were found between the two species in the anatomy of the roots.

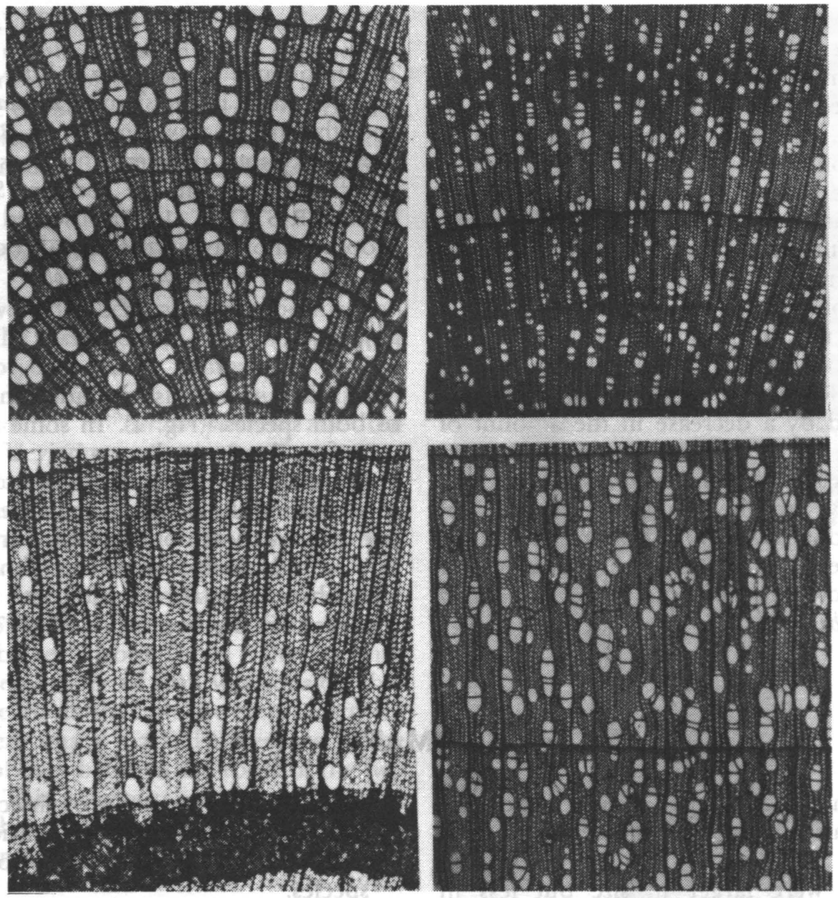

Fig. 2. Transverse sections of roots (on the left) and stems (on the right). The upper figures are *Betula pendula*, the lower *B. pubescens*. The magnification is the same.

Kuva 2. Juurten (vasemmalla) ja runkojen (oikealla) poikkileikkauksia. Ylärivissä on rauduskoivu ja alarivissä hieskoivu. Suurennossuhde on sama.

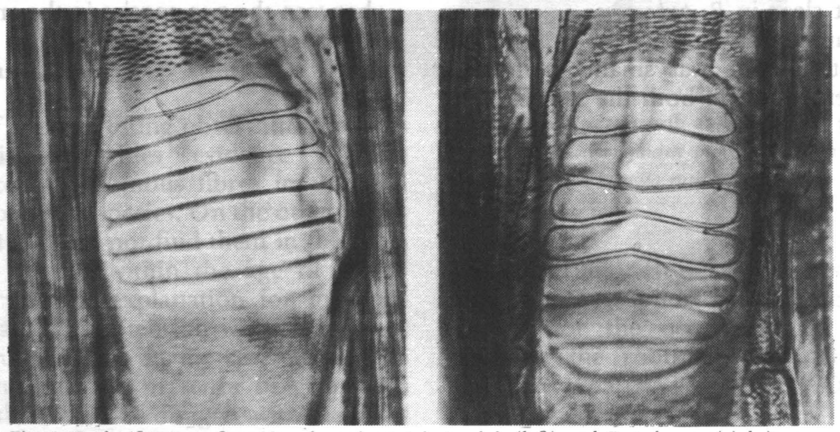

Fig. 3. Scalariform perforation plates in *Betula pendula* (left) and *B. pubescens* (right) roots.

Kuva 3. Rauduskoivun (vasemmalla) ja hieskoivun (oikealla) harvarakoisia perforaatiolevyjä juurissa.

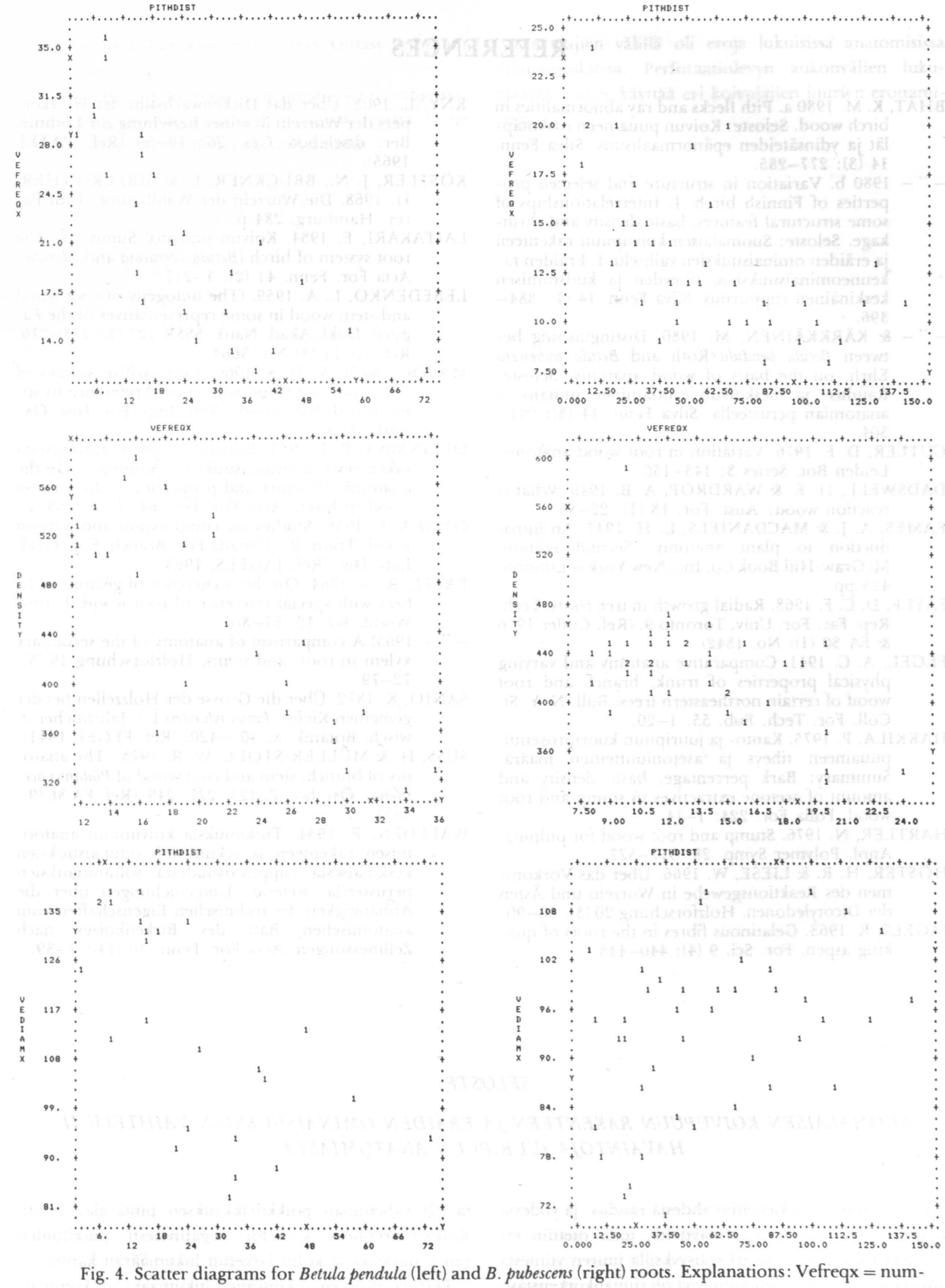

Fig. 4. Scatter diagrams for *Betula pendula* (left) and *B. pubescens* (right) roots. Explanations: Vefreqx = number of vessels per square mm, pithdist = distance from the pith in mm, vediamx = vessel diameter in m, density = basic density in kg/m^3.

Kuva 4. Rauduskoivun (vasemmalla) ja hieskoivun (oikealla) kaksiulotteisia pistediagrammeja juurista. Selitys: Vefreqx = putkiloiden lukumäärä poikkileikkauksen neliömillimetriä kohti, pithdist = etäisyys ytimestä mm, vediamx = putkilon läpimitta m, density = kuiva-tuoretiheys kg/m^3.

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SELOSTE:

SUOMALAISEN KOIVUPUUN RAKENTEEN JA ERÄIDEN OMINAISUUKSIEN VAIHTELU II. HAVAINTOJA JUURIPUUN ANATOMIASTA

Tutkimuksessa tarkasteltiin yhdestä raudus- ja yhdestä hieskoivusta leikattuja juurinäytteitä, joita otettiin eri etäisyyksillä kannosta ja eri etäisyyksillä juuren ytimestä ylös- ja alaspäin. Vertailukohteena oli rinnankorkeustaso samassa rungossa.

Tulosten mukaan vuosilustojen rajat olivat juurissa selvät, joskin havaitsemista vaikeuttaa niiden ohuus. Putkilot olivat juuressa suurempia kuin rungossa, mutta niitä oli vähemmän poikkileikkauksen pinta-alaa kohti. Kuiva-tuoretiheys korreloi negatiivisesti putkiloiden pinta-alayksikköä kohti lasketun lukumäärän kanssa.

Perforaatiolevyn aukonvälien lukumäärä oli kummallakin koivulajilla juuressa selvästi alhaisempi kuin rungossa. Juuren kuiduissa tavattiin usein liivatemainen kerros, joka on tyypillinen vetopuun piirre. Myös erityisesti puun tyven lähellä tavattava kasvun epäkeskisyys ja

juuren poikkileikkauksen epäpyöreys viittasi vetopuun esiintymiseen.

Ydinsäteitä oli juuressa vähemmän kuin rungossa. Ruskotäpliä tavattiin kaukanakin rungon tyveltä, ja ne aiheuttivat epäsäännöllisyyksiä ydinsäteisiin.

Koivulajien välillä oli eroja lukuisissa anatomisissa ominaisuuksissa. Perforaatiolevyn aukonvälien lukumäärää voinee käyttää eri koivulajien juurien erottamiseen.