METSÄNTUTKIMUSLAITOKSEN JULKAISUJA

COMMUNICATIONES
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MEDDELANDEN FRÅN SKOGSFORSKNINGSINSTITUTET I FINLAND
MITTEILUNGEN DER FORSTLICHEN FORSCHUNGSANSTALT IN FINNLAND
PUBLICATIONS OF THE FINNISH FOREST RESEARCH INSTITUTE
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METSÄNTUTKIMUSLAITOS
Metsätietotekniikan osasto

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KOIVUTUKKIPUIDEN KUUTIOIMIS-MENETELMÄ

JUHANI NOUSIAINEN, JUHA PURANEN JA PAAVO TIIHONEN

DEUTSCHES REFERAT

EINE KUBIERUNGSMETHODE FÜR BIRKENBLOCHHOLZ

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ALKUSANAT

Koivutukkipuiden kuutioimismenetelmää koskeneet tutkimukset aloitettiin metsäntutkimuslaitoksessa allekirjoittaneen Tiihosen johdolla jo 1950-luvulla. Tehtävää vaikeuttivat aikaisemmin käytetty mittayksikkö, erilaiset apteeraustavat ja keskittyminen yksinomaan puutavaralajitaulukoiden laadintaan. Ratkaisuun päästiin vasta vuoden 1972 alussa uuden mittayksikön, kiintokuutiometrin käyttöönoton ansiosta. Osoittautui, että menetelmää saatettiin soveltaa mm. leimikoiden pystymittauksissa. Laajamittainen toiminta edellytti ATK-laskentaa. Käytännön mittaus- ja laskentatehtäviä silmällä pitäen katsottiin aiheelliseksi muodostaa allekirjoittaneista koostunut työryhmä, jonka toiminnan tuloksena on äskettäin valmistunut tämä tutkimusselostus.

Tutkimuksen kenttä- ja laskentatöihin on osallistunut useita metsäntutkimuslaitoksen metsänarvioimisen tutkimusosaston palveluksessa olevia henkilöitä. Aineiston keruussa on saatu arvokasta tukea erityisesti Koivukeskukselta ja Oy Wilh. Schauman Ab:n metsäosastolta. Valtion tietokonekeskuksen Oulun aluekeskuksen henkilökunta on suorittanut suurta kärsivällisyyttä edellyttäneen työn.

Tutkimuksen käsikirjoituksen ovat lukeneet professorit Kullervo Kuusela ja Yrjö Vuokila. Julkaisun saksankielisen selostuksen ovat kääntäneet rouva Marianne Kahanpää ja fil. maisteri Yrjö Sihvo.

Esitämme kunnioittavasti kiitokset saamastamme monipuolisesta tuesta.

Helsinki, heinäkuu 1973

Juhani Nousiainen *Juha Puranen* *Paavo Tiihonen*

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JOHDANTO

Uuden mittausjärjestelmän käyttöönotto muutti tunnetusti myös pystypuiden kuutioimisperusteita. Leimikoiden pystymittauksissa sovellettu kuutioimismenetelmä oli kokonaan uusittava. Pystymittausten yleistyminen korosti lisäksi uusimisen kiireellisyyttä. Puutavaran mittaussääntö (163/69) edellytti metsäntutkimuslaitokselta uusien puutavaralajitaulukoiden valmistamista. Uusien mittausperusteiden ja menetelmien selvittely katsottiin niin tärkeäksi tehtäväksi, että myös puun myyjiä ja ostajia sekä metsäntutkimuslaitosta edustavista henkilöistä koostuva, kuutioimisperusteiden yhdenmukaistamista v. 1970 käsitellyt työryhmä päätti jatkaa toimintaansa keväällä 1971. Työryhmän toiminnan tuloksena valmistui kesäkuussa 1972 kiintokuutiometrin käyttöön perustuva, lähinnä leimikoiden pystymittauksiin tarkoitettu mutta samalla yleensä pystypuiden kuutiointiin soveltuva menetelmä (Nousiainen et al. 1972). Sitä on jo nyt sovellettu varsin suuressa määrin käytännön mittauksissa.

Uuteen kuutioimismenetelmään sisällytettiin myös koivutukkipuita koskeva osamenetelmä. Toimintamahdollisuudet jäivät kuitenkin havupuihin verrattuna huomattavasti vähäisemmiksi. Koivutukkipuiden kuutioimistaulukoiden laadinnassa ei löydetty tyydyttävää ratkaisua. Jouduttiin rajoittumaan vain ATK-laskentaan, joka merkitsi kyllä olennaista etua. Tätä osamenetelmää koskevien, tähän mennessä suoritettujen tarkistuslaskelmien tulokset ovat lisäksi varsin myönteisiä. Katsottiin, että laskelmia olisi pikaisesti jatkettava.

Leimikoiden pystymittausten jatkuva lisääntyminen syyskaudella 1972 kiirehti osaltaan koivutukkipuiden kuutioimismenetelmän täydentämistä. Todettiin, että käytännön mittauksia saatettiin usein yksinkertaistaa, jos myös koivutukkipuut voitiin sisällyttää pystymittauksen piiriin samanlaisin mittausperustein kuin havupuutkin. Täydennyksen suorittamista korosti edelleen se seikka, että Maanmittaushallitus ja Keskusmetsälautakunta Tapio päättivät kesällä 1972 ryhtyä käyttämään laadittua kuutioimismenetelmää.

Koivun tukkipuutaulukoiden laadintamahdollisuuksia koskevia tutkimuksia jatkettiin metsäntutkimuslaitoksen metsänarvioimisen tutkimusosastossa kesä—syyskaudella 1972. Lokakuussa 1972 päädyttiin ratkaisuun, joka tarjosi perustan käytännön tarvetta vastaavien tukkipuutaulukoiden

laadinnalle. Koivutukkipuiden kuutioimismenetelmän täydentämistä päätettiin jatkaa koko laajuudessaan. Aiheen monitahoisuuden vuoksi katsottiin aiheelliseksi muodostaa kirjoittajista koostuva työryhmä, jossa Nousiainen ja Puranen keskittyivät erityisesti ATK-laskennan toteuttamiseen ja Tiihonen vuorostaan kuutioimismenetelmän perusteita ja käyttöä koskeviin kysymyksiin.

Tutkimustehtävää suoritettaessa ilmeni vähäistä tarkistuksen ja lisäysten tarvetta eräissä muissakin kuutioimismenetelmän perusteissa. Tehdyn ratkaisun mukaisesti liittyivät tukkipuutaulukoiden ja ATK-laskennan perusteet kiinteästi toisiinsa. Katsottiinkin, että aikaisemmin esitettyjen varsin suppeiden kuvausten (Nousiainen et al.) täydentämisen asemesta oli selvempää laatia uusi, yhtenäinen koivutukkipuiden kuutioimismenetelmää käsittelevä tutkimusselostus. Se esitetään tässä julkaisussa.

AINEISTO

Tutkimuksen aineisto käsittää kaksi osa-aineistoa. Toinen koostuu tarkasteltavan kuutioimismenetelmän keskeisimpinä perusteina olevien I l v e s s a l o n (1947) »Pystypuiden kuutioimistaulukoiden» ja koivun kapenemistaulukoiden (T i i h o n e n 1961 b) koepuuaineistosta, jota jäljempänä kutsutaan tutkimusaineistoksi. Toinen on 13 koepuuerää käsittävä, maan eteläpuoliskon eri osissa sijainneilta käytännön hakkuutyömailta koottu tarkistusaineisto. Tutkimus- ja tarkistusaineisto sisältävät koepuita seuraavasti.

	Koepuiden lukumäärä *Anzahl der Probestämme*
Tutkimusaineisto — *Hauptmaterial*	1 761
Tarkistusaineisto — *Kontrollmaterial*	
v. 1966—67 mitatut koepuut — *in den J. 1966—67 ermessene Probestämme*	1 191
v. 1972 mitatut koepuut — *i. J. 1972 ermessene Probestämme*	2 131
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Koepuiden jakaantumista erotettuihin luokkiin valaistaan jäljempänä kuutioimismenetelmän luotettavuuden tarkastelun yhteydessä.

Jokaisesta tutkimusaineiston koepuusta on tehty seuraavat mittaukset:

— rinnankorkeusläpimitta, jäljempänä lyhennys d,
— pituus (h) ja kapeneminen (d—d6),
— läpimitta 0.5, 2, 4, 6 . . . jne. metrin korkeudelta tyvestä lukien, ja
— mahdollisen kannon korkeus ja läpimitta.

Kaikki läpimitat on mitattu kahdessa toisiaan vastaan kohtisuorassa suunnassa kuoren päältä millimetrin, pituus vuorostaan senttimetrin tarkkuudella.

Tarkistusaineiston koepuiden mittaus on suoritettu pääosiltaan edellä esitetyllä tavalla. Läpimittojen mittausta täydennettiin kuitenkin siten, että jakomiehen jokaisesta rungosta erottama tukkiosa ja 6 cm:n läpimittaan (kuoren alta) asti ulotettu kuitupuuosa voitiin kuutioida erikseen. Lisäksi mitattiin tukkien pituudet ja läpimitat (keskeltä), joskin näitä mittaustietoja on käytetty vain tukkiosan kuutioinnin tarkistukseen.

Läpimittojen ja pituuden mittauksen alkamiskohta on molemmissa osa-aineistoissa sama Ilvessalon (mt.) soveltama puun juurenhaarojen määrittämä alin mahdollinen kaatokorkeus.

Tarkistusaineiston rungot oli apteerattu yleensä puun myyjien ja ostajien järjestöjen (MTK:n metsävaltuuskunnan ja Koivukeskuksen) yhteisesti esittämien ohjeiden mukaisesti. Eräissä koepuuerissä oli sovellettu hieman tavanomaista pienempää minimiläpimittaa. Tästä ei kuitenkaan aiheutunut mitään haittaa, koska kuutioimismenetelmän laadinnassa ei nojauduttu edellä viitatun mukaisesti tukkien mittoihin.

KUUTIOIMISMENETELMÄN YLEISPERUSTEET

Tavoitteena oli menetelmä, jolla voitaisiin jakaa koivun rungon koko kuutiomäärä tukki- ja kuitupuuosan sekä käytön ulkopuolelle jäävän latvan kesken. Kysymystä on tarkasteltu varsin paljon aikaisemmin julkaistujen puutavaralajitaulukoiden (esim. T i i h o n e n 1966 a, 1969 a, 1969 b) laadinnan yhteydessä. Kuutiojalan käyttö tukkiosan mittayksikkönä ja tukkien apteerausperusteiden vaihtelu aiheuttivat kuitenkin sen, ettei onnistuttu kehittämään riittävän yksinkertaista mutta samalla kohtuullisen luotettavaa kuutioimismenetelmää.

Kiintokuutiometrin valinta uudeksi, kaikkien puutavaralajien yhteiseksi mittayksiköksi paransi ratkaisevasti kuutioimismenetelmän valmistamisen mahdollisuuksia. Määrällisten lukujen rinnalla tai asemesta voitiin nojautua suhteellisiin lukuihin. Laadinnassa saatettiin soveltaa jo aikaisemmin hahmoteltuja perusteita ja menetelmiä (A r o 1935; T i i h o n e n 1961 a, 1966 a). Niitä käyttäen määritetään ensin eri puutavaralajien suhteelliset osuudet ja siirrytään niistä sitten vastaaviin määrällisiin lukuihin. Keväällä 1972 tehdyt kokeet osoittivat, että koivutukkipuille voitiin valmistaa mainitunlaisen yleisperusteen mukaisesti ainakin ATK-laskentana suoritettava kuutioimismenetelmä.

Tehdyn ratkaisun mukaisesti uuden kuutioimismenetelmän keskeisinä perusteina ovat I l v e s s a l o n (mt.) »Pystypuiden kuutioimistaulukoiden» yksikkökuutiot ja koivun runkomuotoa kuvaavat kapenemissarjat (T i i h o n e n 1961 b). Aikaisemmin oli jo valmistettu koivun latvan keskimääräiskokoa osoittavat taulukot (T i i h o n e n 1972). Ne esitetään myös tässä julkaisussa (taulukko 1). Ns. peruskuutiomääränä on yhdenmukaisesti havutukkipuiden kuutioimismenetelmän kanssa (ks. N o u s i a i n e n et al.) rungon käyttöosan kuutio (käyttöpuu), joka saadaan vähentämällä I l v e s s a l o n taulukoiden yksikkökuutiosta taulukon 1 mukainen latvaosa. Rungon käyttöosan kuutio jaetaan sitten tukki- ja kuitupuun kesken vastaavien %-osuuksien mukaisesti. Määrittäminen edellyttää neljännen tunnuksen käyttöönottoa varsinaisten kuutioimistunnusten, rinnankorkeusläpimitan, pituuden ja kapenemisen rinnalla. Tämä neljäs tunnus on tukkiosan pituus.

Kuutioimismenetelmään sisällytetään kuten havutukkipuillakin k a k s i v a i h t o e h t o i s t a l a s k e n t a m e n e t e l m ä ä: numeeriset tau-

Taulukko 1. Koivujen keskimääräinen latvaosuus (kuorineen).
Tabelle 1. Durchschnittlicher Zopfanteil der Birke (mit Rinde).

Pituusluokka, m *Höhenklasse, m*	d-luokka, cm — *d-Klasse, cm*																			
	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45+
	dm³ kuorineen/runko — *dm³ mit Rinde/Stamm*																			
5	7	6	6																	
6	8	7	7	6																
7	9	8	8	7																
8	10	8	8	7	6															
9	11	9	8	7	6	6														
10	12	9	8	7	7	6	5	4												
11	13	10	8	7	7	6	5	4	4	4										
12	14	11	9	7	7	6	5	4	4	4	4	4								
13	16	13	9	8	7	6	5	4	4	4	4	4	4	4						
14	17	14	10	8	7	6	5	4	4	4	4	4	4	4	4	4				
15	17	15	11	9	8	6	5	4	4	4	4	4	4	4	4	4	4	4		
16		16	12	10	8	6	5	4	4	4	4	4	4	4	4	4	4	4	4	4
17		16	12	10	8	6	5	4	4	4	4	4	4	4	4	4	4	4	4	4
18			13	11	9	7	5	4	4	4	4	4	4	4	4	4	4	4	4	4
19				12	9	7	5	4	4	4	4	4	4	4	4	4	4	4	4	4
20					9	7	5	4	4	4	4	4	4	4	4	4	4	4	4	4
21					9	7	5	4	4	4	4	4	4	4	4	4	4	4	4	4
22						7	5	4	4	4	4	4	4	4	4	4	4	4	4	4
23						7	5	4	4	4	4	4	4	4	4	4	4	4	4	4
24							5	4	4	4	4	4	4	4	4	4	4	4	4	4
25							5	4	4	4	4	4	4	4	4	4	4	4	4	4
26							5	4	4	4	4	4	4	4	4	4	4	4	4	4
27								4	4	4	4	4	4	4	4	4	4	4	4	4
28								4	4	4	4	4	4	4	4	4	4	4	4	4
29									4	4	4	4	4	4	4	4	4	4	4	4
30+									4	4	4	4	4	4	4	4	4	4	4	4

lukot eli tukkipuutaulukot ja ATK-laskentamenetelmä. Molemmilla vaihtoehdoilla päästään käytännöllisesti katsoen samoihin tuloksiin. Tukkipuutaulukoiden käyttöön liittyvä inter- ja ekstrapolointi saattaa aiheuttaa vähäisiä eroja ATK-laskennan tuloksiin verrattuna.

Tarvittaessa voidaan erottaa kaksi alaluokkaa, normaalit ja poikkeukselliset tukkipuut. Molempien laskentaperusteet ovat kuitenkin samat.

Kuutioimismenetelmän mittayksikkönä on kuorellinen todellinen kiintokuutiometri.

MENETELMÄN ATK-SOVELLUTUS

Yleistä

Koivutukkipuiden ATK-laskentamenetelmän kehittäminen perustettiin olettamukseen, ettei yksinomaan tavanomaisilla kuutioimistunnuksilla (d, d—d6 ja pituus) vielä voida määrittää eri puutavaralajien usein suurestikin vaihtelevia suhteellisia ja määrällisiä osuuksia. Neljännen tunnuksen tarve oli ilmeinen ja metsäntutkimuslaitoksessa suoritettujen tutkimusten pohjalta päädyttiin tukkiosan päättymiskorkeuden eli tukkiosan pituuden käyttöön. Miltei vastaavanlaista laskentaperustetta on aikaisemmin käytetty poikkeuksellisten havutukkipuiden kuutioimismenetelmässä (N o u s i a i n e n et al. 1972), missä tukki- ja kuitupuun rajakohtien määrittämisellä pyritään osoittamaan se osa tai osat rungosta, josta tukkeja yleensä voidaan valmistaa. Tukkipuun mitat ja laatuvaatimukset täyttävistä rungonosista voidaan havupuilla useinkin käyttää vain osa tukeiksi, muun osan siirtyessä kuitupuuksi. Koivutukkipuilla tukkiosan pituus sen sijaan ilmaisee päättymiskorkeuden eli pituuden, johon asti runko kokonaisuudessaan luetaan tukkipuuksi. Koivutukkipuiden mittausohjeiden mukaisesti (M T K : n m e t s ä v a l t u u s k u n n a n . . . ; V a n e r i k o i v u j e n . . .) ja käytännöllisistä syistä oli tukkiosan pituuden määrittämisessä syytä soveltaa sopivaa luokitusta.

Neljännen tunnuksen valinnan jälkeen voitiin kuutioimismenetelmän laadintaa jatkaa, kuten edellä yleisperusteissa on lyhyesti todettu, A r o n (1935) ja T i i h o s e n (1961 a) tutkimusten mukaisesti selvittämällä ensin eri puutavaralajien suhteelliset osuudet ja siirtymällä niistä sitten vastaaviin määrällisiin osuuksiin. Näin päädyttiin varsinaiseen laskentamenetelmään. Sen keskeisimmiksi perusteiksi tulivat I l v e s s a l o n (1947) »Pystypuiden kuutioimistaulukot» ja T i i h o s e n (1961 b) laatimat, koivun runkomuotoa kuvaavat kapenemissarjat. Menetelmän käyttökelpoisuutta tutkittiin ensin kapenemistaulukoiden koepuuaineiston perusteella. Lisäksi kerättiin erillinen tarkistusaineisto (ks. s. 7).

Mainittuihin perusteisiin nojautuen tapahtui ATK-laskennan tekninen suunnittelu ja valmistaminen valtion tietokonekeskuksen Oulun aluekeskuksen ja metsäntutkimuslaitoksen metsänarvioimisen tutkimusosaston yhteistyönä kevät—syyskaudella 1972.

Laskennan lähtötiedot

Koivutukkipuiden ATK-laskennan edellyttämät tiedot kootaan samanlaisille lomakkeille kuin havupuiden mittauksessa. Runkolukusarja kootaan siten puidenluvun yhteydessä ao. lomakkeille. Rinnankorkeusläpimittojen mittaus tapahtuu kuten jäljempänä tarkasteltavia tukkipuutaulukoita käytettäessä tavanomaiseen tapaan 2 cm:n tasaavin luokin.

Koepuutiedot merkitään samoin kenttätöiden yhteydessä koepuulomakkeelle. Läpimittojen (d ja d6) ja puun koko pituuden lisäksi merkitään lomakkeeseen tukkiosan pituus. Rungon tyviosaan rajoittuvan, 7—8 m:n korkeuteen asti ulottuvan tukkiosan pituus ilmaistaan koivutukkien mittausperusteiden mukaisesti 3 dm:n kerrannaisina (31, 34, 37 . . . jne.). Tukkiosan pituuden ylittäessä mainitun korkeuden tunnus ilmaistaan 0.5 m:n tasaavin luokin, luokkakeskusten ollessa täysiä ja puolia metrejä.

Tietokonekäsittelyä varten tiedot lävistetään reikäkorteille, joilta ne siirretään tarkistuksia suorittavalla ohjelmalla magneettilevymuistille. Ennen varsinaisten kuutioimisohjelmien ajoa aineisto lajitellaan perusrekisteriksi.

Tietokonelaskennan logiikka

Tarkasteltava ATK-laskenta sisältää seuraavat toiminnot.

1. Ilvessalon »Pystypuiden kuutioimistaulukoista» haetaan rungon kuutioimistunnusten, rinnankorkeusläpimitan, pituuden ja kapenemisen (jäljempänä merkinnät d, h ja d—d6) mukainen kuorellinen yksikkökuutio, josta vähennetään taulukon 1 mukainen käytön ulkopuolelle keskimäärin jäävä latvaosa. Tulokseksi saadaan rungon käyttöosan kuutio kuorellisina todellisina kiintokuutiometreinä. Laskenta jatkuu seuraavasti.

2. Rungon kuutioimistunnuksilla (d, h ja d—d6) haetaan kapenemistaulukoista koivun runkomuotoa kuvaava prosenttisarja, johon lisätään 0.5 metrin korkeuden läpimittaa vastaava %-luku, 109.

3. Lasketaan prosenttilukuja vastaavat määrälliset, kuorelliset läpimitat millimetrin tarkkuudella. Tuloksiin tehdään ns. d6-korjaus, jolla tarkoitetaan kapenemistaulukoiden sisältämien, 2 cm:n luokin ilmaistujen runkoviivojen täsmentämistä seuraavasti:

— tyvestä lukien 2—6 m:n välillä kaavan

$$\frac{100 - Pi}{100 - P6} \cdot de$$ mukaan, ja

— 7+ m:n mittakorkeuksilla kaavan

$$\frac{Pi}{P6} \cdot de$$ mukaan.

Pi = prosenttiluku i-metrin korkeudella
P6 = » 6 » »
de = kohdassa 2 lasketun d6 ja mitatun d6 erotus millimetreinä.

4. Täsmennettyjä läpimittoja käyttäen lasketaan rungon käyttöosan todellinen kuutiomäärä (k-m³ kuorineen) 6 cm:n latvaläpimittaan (kuoren alta) saakka. Tuloksesta käytetään lyhennystä Vt.

5. Edellisessä käytettyjen läpimittojen ja ko. koepuulle määritetyn tukkiosan pituuden mukaisesti lasketaan vastaavasti tukkiosan kuutiomäärä vt todellisina kiintokuutiometreinä.

6. Kuitupuuosa Lt saadaan todellisina kiintokuutiometreinä kaavalla:

$$Lt = Vt - vt$$

7. Kohdissa 5 ja 6 esitetyt, kapenemissarjan perusteella lasketut tukki- ja kuitupuuosat tarkistetaan kertomalla ne osamäärällä V/Vt. Tässä V on kohdassa 1 Ilvessalon taulukoita käyttäen saatu rungon käyttöosan tilavuus ja Vt kohdassa 4 kapenemissarjan mukaisesti laskettu vastaava kuutiomäärä. Esitetynlaisen tarkistuksen jälkeen tukki- ja kuitupuuosien summa on täysin sama kuin Ilvessalon taulukoiden pohjalta määritetty rungon käyttöosan tilavuus V.

Tulostus

Tutkimuksen yhteydessä suoritetuissa laskelmissa sovellettiin aikaisemmin käytettyä tulostustapaa (ks. Nousiainen et al. 1972, s. 30). Tulostuslistan yläosasta nähdään tällöin mm. koivutukkipuiden runkolukusarja ja d-luokittaiset yksikkökuutiot, alaosasta taasen seuraavat tulostukset.

A = runkolajin nimi lyhennettynä
B = runkolajin koodi
D = tukkiosan kokonaiskuutiomäärä
E = tukkiosan kuutiomäärä keskimäärin runkoa kohden
K = kuitupuun kokonaiskuutiomäärä

Sovellettua tulostustapaa on tarvittaessa muokattava vastaisten tehtävien mukaisesti.

Toistuvasti mainiten kuutiomäärät ilmaistaan todellisina kiintokuutiometreinä.

TUKKIPUUTAULUKOT

Laadintaperusteet

Koivun tukkipuutaulukoiden ns. peruskuutiomääränä on edellä mainitun mukaisesti rungon käyttöosan kuutio, joka koostuu tukki- ja kuitupuuosasta. Todettiin, että tiettyyn d-, pituus- ja kapenemisluokkaan kuuluvan rungon tukkiosan ja siten myös kuitupuuosan tilavuus (k-m³/runko) saattaa vaihdella suurestikin. Harkittiin kahta vaihtoehtoista esitystapaa. Jokaiselle luokalle esitetään kuten havutukkipuiden taulukoissakin vain yksi tukki- ja kuitupuuosaa osoittava lukupari. Toinen vaihtoehto edellytti useiden tukki- ja kuitupuuosia ilmaisevien lukuparien määrittämistä. Samassa d-, pituus- ja kapenemisluokassa erotettaisiin siis vaihteleva määrä tukkiosan pituuden mukaisia luokkia. Tavallaan kolmantena vaihtoehtona tutkittiin kahden sellaisen lukusarjan esittämismahdollisuutta, joista toinen kuvaa tukkiosan ja toinen rungon koko käyttöosan yksikkökuutioita. Todettiin, että kaksi viimeksi mainittua olivat ensimmäistä vaihtoehtoa edullisemmat.

Luokkien perusteita ja lukumäärää koskevissa selvityksissä kiinnitettiin ensin huomiota seuraavasta asetelmasta nähtävään, A r o n (1935, s. 81) esittämien tutkimustulosten perusteella saatuun lukusarjaan, joka osoittaa, kuinka monta prosenttia koivun rungon käyttöosan kuutiomäärästä keskimäärin jää esitettyjen suhteellisten pituuksien alapuolelle.

Suhteellinen pituus tyvestä lukien, % *Relative Länge vom Zuschnitt aus gerechnet, %*								
10	20	30	40	50	60	70	80	90
Pituusprosenttia vastaava osuus rungon käyttöosasta, % *Dem Längenprozent entsprechender Anteil am Nutzteil des Stammes, %*								
20	40	52	71	82	89	93	97	99

N i s u l a (1967 a) on laskenut vastaavanlaisia prosenttisarjoja T i i h o s e n (1962) laatimien, rinnankorkeusläpimittaan ja pituuteen perustuvien kapenemissarjojen perusteella. Tulokset ovat varsin yhdenmukaiset A r o n (mt.) keskimääräissarjojen kanssa. Tarkastelua jatkettiin tämän tutkimuksen aineiston avulla laskemalla pätkittäisellä kuutioinnilla rungon tyvestä lukien 3, 5, 7, 9 m jne. aina 2 m:n välein suurenevia runkopituuksia vastaavia kuutiomääriä. Määrällisiä tuloksia esitetään jäljempänä kuutioimis-

menetelmän luotettavuuden tarkastelun yhteydessä. Tässä rajoitutaan vain edellisessä asetelmassa esitetynlaisiin suhteellisiin osuuksiin. Laskentatavasta johtuen tulosten ryhmittely on tapahtunut suhteellisten pituuksien asemesta rungon todellisten osapituuksien mukaisesti. Ryhmittelytavasta riippuen samaan luokkaan sisältyy erivahvuisia, eripituisia tai erimuotoisia runkoja. Tulosten esittelyssä rajoitutaan vain seuraavasta asetelmasta nähtäviin, tutkimus- ja tarkistusaineiston kaikki koepuut yhdistäen saatuihin keskimääräistuloksiin.

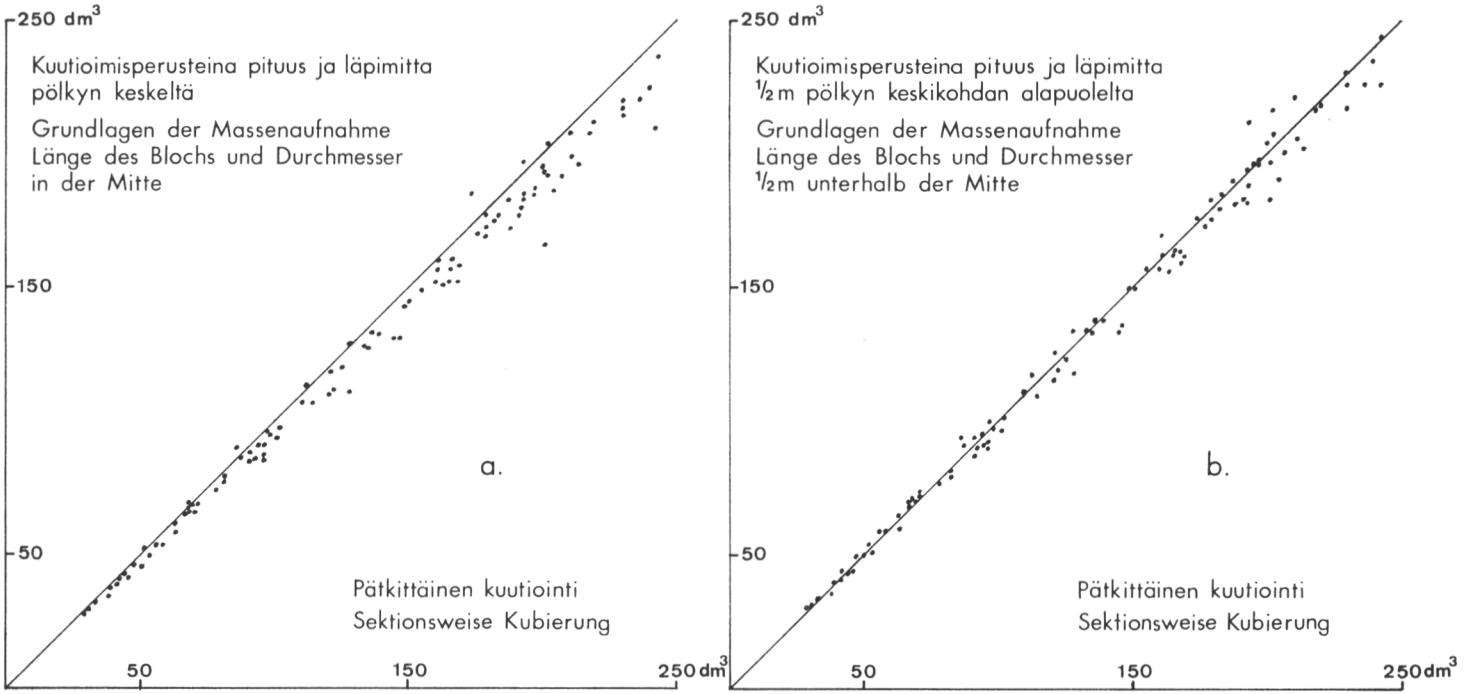
Aineisto *Material*	Etäisyys tyvestä, m *Entfernung vom Zuschnitt, m*					
	5	7	9	11	13	15
	Osuus kuutiomäärästä keskimäärin, % *Durchschnittsanteil an der Kubikmasse, %*					
Tutkimusaineisto — *Hauptmaterial*	44.9	58.7	70.6	80.6	88.2	93.7
Tarkistusaineisto — *Kontrollmaterial*	46.3	60.6	71.6	81.6	89.2	94.4

Suhteellista kuutiomääräosuutta ilmaisevien tulosten mukaan koivutukkipuiden tyviosa käsittää varsin huomattavan osuuden rungon koko kuutiomäärästä. Tyvestä 8—10 m:n korkeuteen ulottuva osa on rungon koko kuutiomäärästä n. 65—75 %, tukkiosasta vieläkin enemmän.

Tyviosan suurehko osuus koko tukkiosan kuutiomäärästä antoi aiheen jatkaa tukkiosan pituuden mittauksen mahdollisuuksien tarkastelua. Todettiin, että 6 m:n läpimitan määrittämisessä käytettävällä 5 m:n tangolla voidaan mitata ainakin 7 m:n korkeus vielä hyvin tarkasti. Silmävaraisesti arvioiden tai pidentämällä tankoa esim. metrin pituisella kevyellä lasikuitukepillä on mahdollista päästä aina 8—10 metriin. Tukkiosan pituuden mittaukseen liittyvät virheet saatetaan siis rajoittaa varsin vähäisiksi.

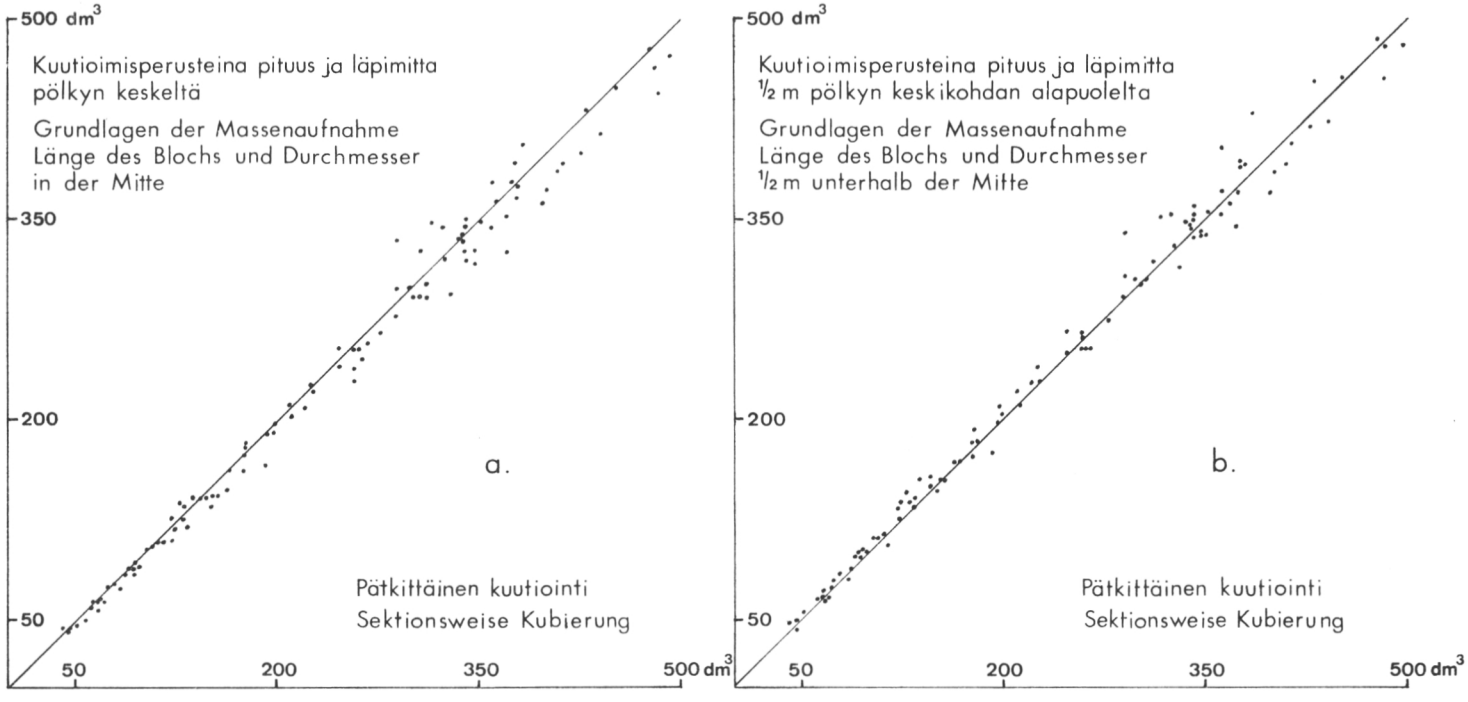
Rungon tyviosaan rajoittuvasta lyhyehköstä tukkiosasta (tukista) voidaan mitata pituuden lisäksi myös läpimitta, jolloin kuutiointi olisi mahdollista suorittaa pituus × läpimitta-periaatteen mukaisesti. Tätä kuutioimistapaa on tutkinut mm. T i i h o n e n leimikon pystymittausta käsittelevien ohjeiden laadinnan yhteydessä (K u r o n e n . . . 1970). Tuloksia havainnollistavat kuvissa 1 ja 2 esitetyt kaksi esimerkkiä. Selvitysten yhdistelmänä todettiin, että yli 15 m pitkiä tukkiosia lukuunottamatta läpimitta oli mitattava noin 0.5 m kuutioitavan tyviosan puolivälin alapuolelta. Täsmälleen puolivälistä mitatun läpimitan mukaisesti kuutioiden päädytään siis lievään aliarviointiin. Vastaavaan tulokseen on vaneritukkien osalta päätynyt myös N i s u l a (1967 b).

Tyviosan kuutioimismahdollisuudet liittyivät myös laadittavien kuutioimistaulukoiden luokkien lukumäärää koskeneeseen tarkasteluun. Katsottiin, että taulukoihin oli sisällytettävä erityisesti 8—10 m:n ylittäviä tukkiosan pituuksia vastaavia yksikkökuutioita. Kuitupuuosan määrittämisen tarve, läpimitan mittauskohtaan liittyvä vähäinen epävarmuus ja käytännölliset



Kuva 1. Esimerkki pätkittäisen sekä pölkyn pituuden ja sen a) keskikohdalta tai b) ½ m keskikohdan alapuolelta mitatun läpimitan mukaisen kuutioinnin riippuvuudesta. — Koivu, tyvestä lukien 5 m pölkky.

Abb. 1. Beispiel von der Korrelation zwischen der sektionsweise Kubierung und der auf der Länge und dem Durchmesser des Blochs fussenden Massenaufnahme a) Durchmesser in der Mitte des Blochs gemessen, b) Durchmesser ½ m unterhalb der Mitte des Blochs gemessen. — Birke, Wurzelbloch 5 m.



Kuva 2. Esimerkki pätkittäisen sekä pölkyn pituuden ja sen a) keskikohdalta tai b) ½ m keskikohdan alapuolelta mitatun läpimitan mukaisen kuutioinnin riippuvuudesta. — Koivu, tyvestä lukien 12 m pölkky.

Abb. 2. Beispiel von der Korrelation zwischen der sektionsweise Kubierung und der auf der Länge und dem Durchmesser des Blochs fussenden Massenaufnahme a) Durchmesser in der Mitte des Blochs gemessen, b) Durchmesser ½ m unterhalb der Mitte des Blochs gemessen. — Birke, Wurzelbloch 12 m.

näkökohdat korostivat toisaalta sitä, että tyviosan pituuden ja läpimitan mukaista kuutiointia olisi vältettävä mahdollisuuksien mukaan. Siten myös pienille d-luokille oli aiheellista muodostaa tukkiosan pituusluokkia, vaikka tukkiosan pituus niillä usein alittaakin edellä esitetyn 8—10 m:n rajan. Koska esitettyä pituuden ja läpimitan mukaista kuutiointia kuitenkin ilmeisesti tarvitaan ainakin laajamittaisessa toiminnassa, katsottiin aiheelliseksi laskea taulukosta 2 ilmenevät, varsinaisiin taulukkoihin liittyvät yksikkökuutioiden sarjat. Laadittua erillistaulukkoa voidaan tarpeen mukaan täydentää tai supistaa.

Toisena luokitusta koskevana tarkastelukohteena olivat tarkistusaineiston perusteella d-, pituus- ja kapenemisluokittain lasketut, tukkiosan keskimääräistä pituutta osoittavat lukusarjat. Pyrittiin myös hahmottelemaan kuva tukkiosan pituuden vaihtelusta ja maksimiarvoista. Ilmeni, että tukkiosan pituus on pitkissä, hyvälaatuisissakin puissa yleensä alle 20 m.

Lopuksi kiinnitettiin huomiota taulukoiden esittämistapaan. Jo kahden tukkiosaa ilmaisevan pituusluokan muodostaminen johtaa esim. havutukkipuiden taulukkoihin verrattuna huomattavasti laajempiin taulukkoihin. Koivutukkipuiden taulukoissa tulee näet jokaiseen luokkaan kaksi yksikkökuutiota, joko tukki- ja kuitupuuosa tai tukkiosa ja rungon koko käyttöosa. Kovin monien tukkiosan pituusluokkien esittäminen ei ollut siis käytännöllisistä syistä perusteltua.

Suoritettujen tarkastelujen yhdistelmänä päätettiin muodostaa d-, pituus- ja kapenemisluokittain kolme tukkiosan pituusluokkaa, joiden väli on 2 m. Todettiin, että tällaisen luokituksen pohjalta suoritettu inter- ja ekstrapolointi on ainakin 1—2 m:iin asti kohtuullisen luotettavaa. Muodostetut kolme luokkaa peittävät siis tukkiosan pituuden vaihtelualuetta ainakin kuuden metrin pituudelta.

Taulukko 2. Lyhyiden tukkiosien kuutioimistaulukko.
Tabelle 2. Massentafeln für Bäume mit kurzen Blochholzanteilen.

Tukkiosan pituus, m *Länge des Blochholz-anteiles*	Läpimitta kuoren päältä, cm — *Durchmesser mit Rinde, cm*											
	17	19	21	23	25	27	29	31	33	35	37	39
	k-m³ kuorineen — *Fm. mit Rinde*											
3.5	0.079	0.099	0.121	0.145	0.172	0.201	0.231	0.264	0.299	0.337	0.376	0.418
4.0	.091	.114	.138	.166	.196	.229	.264	.302	.342	.385	.430	.478
4.5	.102	.128	.156	.187	.221	.258	.297	.340	.385	.433	.484	.538
5.0	.114	.142	.173	.208	.246	.286	.330	.378	.428	.481	.538	.598
5.5	.125	.156	.190	.228	.270	.315	.364	.415	.470	.529	.591	.657
6.0	.136	.170	.208	.249	.295	.344	.397	.453	.513	.577	.645	.717
6.5	.148	.185	.225	.270	.319	.372	.430	.491	.556	.625	.699	.777
7.0	.159	.199	.242	.290	.344	.401	.463	.528	.598	.673	.752	.836
7.5	.170	.213	.260	.311	.368	.430	.496	.566	.641	.722	.806	.896
8.0	.182	.227	.277	.332	.393	.458	.529	.604	.684	.770	.860	.956

Viimeisenä tarkastelukohteena oli kuitupuuosuus. Selvintä oli esittää se jokaiselle luokalle erikseen. Edellä tehdyn ratkaisun mukaisesti jokaisesta sovelletun d-, pituus- ja kapenemisluokituksen mukaisesta rungon käyttöosan kuutiosta erotetaan kolme erisuurta tukkiosan kuutiota. Kutakin tukkiosaa vastaava kuitupuuosa voitiin ilmaista erikseen. Toisena vaihtoehtona oli esittää kolmen kuitupuuosuuden asemesta vain yksi luku, nimittäin ko. luokan rungon koko käyttöosan kuutio. Taulukon yksikkökuutioiden lukumäärää voitaisiin siten huomattavasti pienentää. Inter- ja ekstrapolointi rajoittuisi samalla vain tukkiosaan. Koko käyttöosaa ilmaisevia yksikkökuutioita voidaan käyttää myös muissa kuutioimistehtävissä. Päädyttiin jälkimmäiseen ratkaisuun, jonka mukaisesti luokittain esitetään koko käyttöosan kuutio ja siitä erotetut kolme tukkiosan yksikkökuutiota.

Luokittaiset tukkiosat määritettiin ATK-laskennalla. Yksikkökuutioiden sarjoja tutkittiin vielä graafisesti. Tarkastelun perusteella poistettiin eräiden vierekkäisten sarjojen välillä ilmenneet vähäiset epäsäännöllisyydet. Tukkiosan pituutta ilmaisevien luokkien määrää supistettiin lopuksi vähäisessä määrin muutamissa erotetuissa d- ja kapenemisluokissa.

Lopulliset koivun tukkipuutaulukot on liitetty julkaisun loppuun.

Taulukoiden rakenne ja käyttö

Laadituista taulukoista ilmenee sovelletun luokituksen mukaisten runkojen keskimääräinen tukkiosa ja koko käyttöosa kuorellisina (todellisina) kiintokuutiometreinä. Kuitupuuosa saadaan vähentämällä koko käyttöpuun määrästä tukkiosa. Tukkiosan määrittämisessä nojaudutaan puun myyjien ja ostajien järjestöjen yhteisesti esittämiin ohjeisiin (M T K : n m e t s ä v a l t u u s k u n n a n . . .). Taulukoilla kuutioitavien koivujen on täytettävä seuraavat minimirungon vaatimukset:

— pienin d-luokka 19 cm (18—20 cm), ja

— rungosta saadaan vähintään 340 × 17 cm:n kokoinen tukki (läpimitta latvasta kuoren päältä kapeimmalta puolen), josta ainakin 1.5 m on II, muilta osin III laatuluokkaa.

M i n i m i t u k k i on 310 × 17 cm (läpimitta keskeltä kuoren päältä).

Kuitupuuosa ulottuu 6 cm minimiläpimittaan (kuoren alta) saakka. Todettakoon, että minimiläpimitan mahdollinen suurentaminen 7 cm:iin kuoren päältä pienentäisi kuitupuuosaa aivan vähäisessä määrin. Muutoksella ei kuitenkaan ole koivutukkipuiden osalta taloudellista merkitystä.

Taulukoiden luokitus on seuraava:

— r i n n a n k o r k e u s l ä p i m i t t a (d-) l u o k a t: 19—45 cm,

2 cm:n tasaava luokitus,

— pituusluokat: 15—27 m, metrin tasaavin luokin,

— kapenemisluokat (d—d6): 2—9 cm, senttimetrin tasaavin luokin, ja

— tukkiosan pituusluokat: pääosiltaan kolme tyvestä lukien määritettyä pituutta, joiden väli on 2 m, vähäisessä määrin on erotettu vain 1—2 luokkaa.

Läpimittojen ja pituuden mittauksen lähtökohta on Ilvessalon (mt.) kuutioimistaulukoissaan soveltama puun juurenhaarojen määrittämä alin mahdollinen kaatokorkeus (ks. Ilvessalo 1965, s. 56, kuva 37).

Edellä on kuvattu lyhyesti varsinaisten tukkipuutaulukoiden rakenne. Lisäksi on laadittu suppea erillistaulukko (taulukko 2), jota voidaan käyttää rungon tyvestä saatavan tukkiosan kuutiointiin silloin kun ko. tukkiosaa ei voida määrittää taulukoista edes ekstrapoloinnilla. Tätä erillistaulukkoa joudutaan siis käyttämään lähinnä rungon tyvestä saatavien lyhyiden tukkien kuutiointiin. Tukkiosan (tukin) pituuden lisäksi on mitattava läpimitta noin 0.5 m pituuden puolivälin alapuolelta kuoren päältä 2 cm:n tasaavin luokin. Taulukot on laadittu suurehkojen runkomäärien kuutiointia varten. Ne on edelleen tarkoitettu maan eteläpuoliskon terveiden tukkipuukoivujen kuutiointiin. Vikaisuuksien vaikutus on otettava erikseen huomioon. Niiden arvioimisen mahdollisuuksia tarkastellaan suppeasti jäljempänä.

Taulukoiden käyttö edellyttää edellä esitettyjen neljän tunnuksen (d, pituus, d—d6 ja tukkiosan pituus) määrittämistä kuutioitavista rungoista. Määrittäminen olisi suoritettava mittauksiin perustuen, d-luokka yleensä kaikista rungoista, muut tunnukset sopivasti valituista koepuista. Rinnankorkeusläpimitta mitataan eteen sattuvalta puolelta, puidenluvussa 2 cm:n, koepuiden mittauksessa lisäksi kuten d6 senttimetrin tasaavin luokin. Pituus mitataan metrin, tukkiosuus 0.5 metrin tasaavin luokin, jälkimmäisen luokkakeskusten ollessa täysiä ja puolia metrejä. Rungon tyviosaan rajoittuvan lyhyehkön tukkiosan pituus voidaan ilmaista, kuten ATK-laskentaa käytettäessä, myös 3 dm:n kerrannaisina (31, 34, 37 . . . jne.).

Jos taulukot eivät sisällä kuutioitavan rungon tunnusten mukaista luokkaa, voidaan nojautua inter- tai ekstrapolointiin, joka on edullisinta suorittaa graafisesti. Taulukoiden vastaista käyttöä ajatellen on syytä kirjoittaa inter- ja ekstrapoloinnilla saadut tulokset taulukkoihin ao. luokkien kohdalle. Lyhyehkö, tyviosaan rajoittuva tukkiosa saatetaan kuutioida myös taulukon 2 mukaisesti. Kuitupuuosa määritetään tällöin hakemalla ensin varsinaisista taulukoista, tarvittaessa Ilvessalon kuutioimistaulukoista, ko. rungon koko käyttöosa ja vähentämällä siitä taulukosta 2 saatu tukkiosa. Erillistaulukon käyttö on siten ilmeisesti hieman vaivalloista.

KUUTIOIMISMENETELMÄN LUOTETTAVUUDESTA

Tunnusten mittaamisesta

Neljännen tunnuksen käyttöönotto antoi osaltaan aiheen kiinnittää huomiota myös mittausten käytännölliseen suorittamiseen ja siinä mahdollisesti syntyviin mittausvirheisiin. Mittausten suoritustapaa tarkastellaan erikseen jäljempänä. Seuraavassa käsitellään lyhyesti mittausvirheitä.

Läpimittojen mittausta on tutkittu erityisesti viime aikoina hyvin runsaasti. Metsäntutkimuslaitoksen metsänarvioimisen tutkimusosastossa kokeita ja vertailuja on suoritettu sekä valtakunnan metsien inventoinnin että pystypuiden mittausta käsittelevien tutkimusten yhteydessä. Tuloksia on kuitenkin julkaistu verraten vähän (esim. Vuokila 1960; Tiihonen 1966 b, 1970). Leimikoiden pystymittauksen yhteydessä on tehty sekä mittaajien koulutuksessa että käytännön mittaustoiminnassa hyvin paljon vertailevia kokeita. Käytettävissä olevien tietojen mukaan eri tahoilla saadut tulokset ovat varsin yhdenmukaiset. Näyttää ilmeiseltä, että koulutetuilla mittaajilla jää läpimittojen mittauksessa syntyvä virhe yleisesti ± 1 cm:iin. Yksittäisiä 2—3 cm:n »kömmähdyksiä» on kyllä todettu, mutta niiden merkitys käytännön mittaustuloksiin jäänee varsin vähäiseksi. Molempien läpimittojen (d ja d6) mittauksessa on kuitenkin vakuuttavasti ilmennyt koulutuksen välttämättömyys. Läpimittojen samoin kuin muidenkin tunnusten mittausvirheiden arvostelussa onkin aina otettava huomioon mittaajien taito ja mittausolosuhteet. Todettakoon vielä, että koivutukkipuilla oksat eivät yleensä vaikeuta läpimittojen mittausta. Haitallista puuston ylitiheyttä tuskin ilmenee. Mittausolosuhteet ovat siten tukkipuukoivikoissa ainakin läpimittojen osalta usein edullisemmat kuin havupuilla, kuuseen verrattuna yleensä huomattavasti edullisemmat.

Pituustunnusten mittauksen tarkastelussa lienee yleensä rajoituttu vain puun koko pituuteen, edelleen useimmiten havupuihin (esim. Tiihonen 1970). Tulosten mukaan on mittauksissa yleisesti onnistuttu hyvin. Toisaalta on ilmestynyt eräitä yllättäviä piirteitä. Seuraava lukusarja valaisee erään havupuiden pituuden mittausta koskeneen kokeen tuloksia. Mittaukset suoritettiin Padasjoella keväällä 1972. Kokeeseen sisältyi 25 koepuuta. Mittaajina oli 10 valtakunnan metsien inventoinnin ryhmänjohtajaa, joten mittausten lukumäärä oli yhteensä 250. Useimmat olivat tottuneita mit-

taajia. Pituudet mitattiin »Suunto»-pituusmittarilla metrin tasaavin luokin. Mittauskohtien etäisyydet puun tyvestä määritettiin mittanauhalla. Koemittausten jälkeen puut kaadettiin ja karsittiin,jonka jälkeen kunkin koepuun pituus mitattiin senttimetrin tarkkuudella. Pituudet vaihtelivat 14—27 m:iin.

Ero todelliseen pituuteen verrattuna, m *Unterschied in bezug auf die wirkliche Länge, m*								
—4	—3	—2	—1	±0	+1	+2	+3	+4
Erojen lukumäärä luokittain *Anzahl der Unterschiede nach Klassen*								
1	1	2	49	164	31	—	1	1

Tulossarjan mukaan pääosa mittauksissa ilmenneistä eroista jää ±1 metriin. Aliarviointi on ollut hieman yleisempää kuin yliarviointi. Yleiskuva on ilmeisesti varsin myönteinen ja hyvin yhdenmukainen aikaisemmin suoritettujen vastaavanlaisten kokeiden tulosten kanssa (esim. Tiihonen 1970). Toisaalta havaitaan muutamia yksittäisiä suuria eroja. Ne ovat saattaneet aiheutua siitä, että pituus on luettu väärin, tähtäys tyveen on unohtunut, on tehty laskuvirhe jne. Pituus on voitu lukea myös pituusmittarista väärältä asteikolta. Viimeksi mainittuun virhemahdollisuuteen on etenkin peruskoulutuksessa kiinnitettävä erityistä huomiota.

Esitetty havupuiden tulossarja luonnehtinee ainakin verraten terävälatvaisten koivujen pituuden mittauksen tarkkuutta. Tarkasteltavaan tutkimukseen sisällytettiin myös koivujen pituuden mittausta koskenut koe. Mittauspaikka oli jälleen Padasjoki. Koepuita oli kaikkiaan 50. Koko pituuden lisäksi jokaisesta rungosta määritettiin kaksi tukkiosan pituutta. Viimeksi mainittujen päättymiskorkeuksia osoittivat runkoon tehdyt maalimerkit, jotka sijaitsivat n. 10—15 m:n korkeudella ja 2—3 m:n etäisyydellä toisistaan. Merkit, jotka tehtiin tikkaita, 5 m:n tankoa ja maalivasaraa apuna käyttäen, luonnehtivat siten yleisimpiä pituusmittarilla määritettäviä tukkiosan pituuksia. Kuten edellä on todettu, voidaan tukkiosan pituus määrittää 8—10 m:iin asti d6:n mittauksessa käytettävän kaulaimen varrella. Kahta erisuurta tukkiosan pituutta luonnehtivan merkin käyttö johtui yksinomaan siitä, että näin menetellen saatiin samoista koepuista kaksinkertainen määrä havaintoja.

Kokeeseen osallistui yhdeksän mittaajaa, joista kolme toimii Enso-Gutzeit Osakeyhtiön metsäosaston leimikoiden pystymittauksissa. Muut olivat valtakunnan metsien inventoinnin ryhmänjohtajia ja mittausapulaisia. Kaikki olivat tehtävään hyvin perehtyneitä, joskin muutamat olivat mitanneet pituuksia käytännössä verraten vähän. Kaikki mittaukset tehtiin 0.5 m:n tasaavaa luokitusta soveltaen. Koe tapahtui muutoin samalla tavalla

kuin edellä tarkasteltu havupuita koskenut koe. Kaikki pituudet mitattiin siis lopuksi kaadetuista rungoista senttimetrin tarkkuudella.

Kokeen suoritus jäi syksyyn, jolloin koivut ovat lehdettömiä. Mittausaikana vallitsi kaunis, aurinkoinen sää. Voitiin kuitenkin otaksua, että lehdettömyys lisäsi tai ainakin suurensi jossain määrin puun koko pituuden mittauksessa syntyneitä eroja. Tulokset nähdään taulukosta 3.

Taulukko 3. Koivun pituuden mittausta koskeneen kokeen tulokset. Padasjoki 1972.
Tabelle 3. Ergebnisse der Probe über die Höhenmessung bei Birke, Padasjoki 1972.

Mittaaja *Person Nr.*	Ero todelliseen pituuteen verrattuna, m — *Differenz gegenüber der wirklichen Länge, m*											
	−2.5	−2.0	−1.5	−1.0	−0.5	±0	+0.5	+1.0	+1.5	+2.0	+2.5	+3.0
	Erojen lukumäärä luokittain — *Klassenweise Anzahl der Differenzen*											
1				2	9	14	12	9	4			
2					2	10	15	12	9		2	
3					7	11	15	12	2	3		
4			1	2	10	14	16	5	2			
5						10	15	15	6	2	1	1
6	1			4	6	15	13	7	2	2		
7			3	7	5	16	7	7	3	2		
8	1			4	6	15	6	11	5	2		
9				2	8	21	10	5	3	1		
Kaikki — *Ganze Testgruppe*	2	—	4	21	53	126	109	83	36	12	3	1
Kaikki — *Ganze Testgruppe*, %	0.4	—	0.9	4.7	11.8	28.0	24.2	18.4	8.0	2.7	0.7	0.2

Taulukko 4. Koivun tukkiosan pituuden mittausta koskeneen kokeen tuloksia. Tukkiosan pituus 12—15 m.
Tabelle 4. Ergebnisse der Probe über die Längenmessung des Blochholzanteils an Birke. Länge des Blochholzanteils 12—15 m.

Mittaaja *Person Nr.*	Ero todelliseen pituuteen verrattuna, m — *Differenz gegenüber der wirklichen Länge, m*										
	−3.5	−3.0	−2.5	−2.0	−1.5	−1.0	−0.5	±0	+0.5	+1.0	+1.5
	Erojen lukumäärä luokittain — *Klassenweise Anzahl der Differenzen*										
1							16	30	4		
2							4	20	23	3	
3							3	19	23	5	
4							16	24	9	1	
5							3	34	12	1	
6						1	12	29	8		
7	1				2	5	8	27	6		1
8						2	14	25	7	2	
9							9	33	8		
Kaikki — *Ganze Testgruppe*	1	—	—	—	2	8	85	241	100	12	1
Kaikki — *Ganze Testgruppe*, %	0.2	—	—	—	0.4	1.8	18.9	53.6	22.2	2.7	0.2

Taulukko 5. Koivun tukkiosan pituuden mittausta koskeneen kokeen tuloksia. Tukkiosan pituus 10—13 m.

Tabelle 5. Ergebnisse der Probe über die Längenmessung des Blochholzanteils an Birke. Länge des Blochholzanteils 10—13 m.

Mittaaja *Person Nr.*	Ero todelliseen pituuteen verrattuna, m — *Differenz gegenüber der wirklichen Länge, m*									
	—3.0	—2.5	—2.0	—1.5	—1.0	—0.5	±0	+0.5	+1.0	+1.5
	Erojen lukumäärä luokittain — *Klassenweise Anzahl der Differenzen*									
1						9	31	9	1	
2						3	23	22	2	
3						3	25	20	2	
4					2	4	27	12	4	1
5							31	18	1	
6						13	25	12		
7	1					6	23	20		
8					1	11	24	14		
9						4	29	17		
Kaikki — *Ganze Testgruppe*	1	—	—	—	3	53	238	144	10	1
Kaikki — *Ganze Testgruppe*, %	0.2	—	—	—	0.7	11.8	52.9	32.0	2.2	0.2

Yli metrin eroja on selvästi enemmän kuin edellä esitetyssä havupuiden tulossarjassa. Muutama suuri ero johtunee jälleen pituuden lukemisesta väärältä asteikolta.

Tukkiosan päättymiskorkeutta luonnehtivien merkkien mukaisten pituuksien mittauksessa syntyneet erot on koottu taulukkoihin 4 ja 5. Ensin esitetään pitempien, n. 12—15 m:n tukkiosien mittausten tulokset (taulukko 4).

Kaikkien mittaajien tuloksia voitaneen pitää varsin hyvinä. Muutamilla mittaajilla ilmenee lievää yliarviointia. Vain yhdessä mittauksessa on päädytty todella suureen 3.5 m:n eroon. Kaikki erot yhdistäen saatu tulossarja osoittaa, että vain runsaat 5 % eroista ylittää ±0.5 m:n luokan (±0.75 m).

Lyhyempien, (n. 10—13 m) alemman merkin mukaisten tukkiosan pituuksien mittauksessa päädyttiin taulukosta 5 nähtäviin eroihin.

Tulossarjat lähenevät edellisiä tuloksia. Lievää yliarviointia esiintyy nyt hieman enemmän. Vajaat 4 % kaikista eroista ylittää ±0.5 m:n luokan.

Koivujen pituutta koskeneiden mittausten ja tarkastelujen yhdistelmänä voitaneen todeta, että koulutetut, huolelliset mittaajat voivat ilmeisesti määrittää ainakin tukkiosan pituuden vähintään kohtuullisella tarkkuudella. Näin lienee huomattavalta osalta myös koko pituuden laita. Kokeissa todetut erot ja virhemahdollisuudet sekä koemittausten vähäinen määrä korostavat kuitenkin yhdessä kokeiden jatkamisen tärkeyttä.

Taulukko 6. Pätkittäisellä kuutioinnilla ja Ilvessalon (1947) »Pystypuiden kuutioimistaulukoilla» saatujen tulosten vertailua.

Tabelle 6. Vergleiche zwischen den durch sektionsweise Kubierung und die »Massentafeln für stehende Bäume» von Ilvessalo (1947) erhaltenen Resultaten.

Aineisto *Material*	Koepuiden lukumäärä *Anzahl der Probestämme*	Pätkittäinen kuutiointi *Sektionsweise Kubierung*	Ilvessalon (1947) taulukot *Nach den Tabellen von Ilvessalo (1947)*
Tutkimusaineisto — *Hauptmaterial*	1 761	1 059.8	1 065.8
Tarkistusaineisto — *Kontrollmaterial*			
Koepuuerä — *Probestammpartie* 1	660	295.1	295.9
» — » 2	531	296.0	297.0
» — » 3	173	99.6	99.0
» — » 4	168	104.1	104.9
» — » 5	173	97.6	96.3
» — » 6	116	47.3	48.4
» — » 7	90	39.2	39.6
» — » 8	37	25.5	25.8
» — » 9	244	126.1	126.6
» — » 10	278	129.5	128.8
» — » 11	433	243.0	243.5
» — » 12	249	116.3	117.6
» — » 13	170	80.8	82.4
Yhteensä — *Insgesamt*	3 322	1 700.1	1 705.8

Tarkistuslaskelmien tuloksia

Tarkistuslaskelmat sisältävät neljänlaisia vertailuja. Ensin tarkasteltiin koko rungon kuutiomäärää luonnehtivien Ilvessalon (mt.) kuutioimistaulukoiden tarkkuutta. Aihetta on tutkittu viimeksi kuitu- ja tukkipuiden uuden kuutioimismenetelmän (Nousiainen et al.) laadinnan yhteydessä. Tulokset antoivat aiheen otaksua, että taulukoiden sisältämät koivun yksikkökuutiot kuvaavat hyvin koko rungon kuutiomäärää. Mainitun tutkimuksen valmistumisen jälkeen täydennettiin tarkistusaineistoa vielä kahdeksalla koepuuerällä, jotka sisälsivät kaikkiaan 1 485 koepuuta. Taulukossa 6 esitetään tähän mennessä mitattujen koepuuerien tulokset.

Taulukon tulossarjaan sisällytettyjen uusien koepuuerien (erät 6—13) tulokset vahvistavat aikaisemmin muiden koepuuerien perusteella tehtyä päätelmää siitä, että Ilvessalon taulukoilla saadaan myös tukkipuukoivujen kuutioinnissa erinomaisia tuloksia. Tukkipuukoivujen yksikkökuutioihin ei myöskään ole aiheellista tehdä kannon koon mahdollisesta pienentymisestä aiheutuvaa lisäystä.

Todettakoon, että taulukon 6 tulosten osoittama selvä yhdenmukaisuus ilmeni myös d-, pituus- ja kapenemisluokittain tehdyissä vertailuissa.

Rungon koko kuutiomäärän lisäksi tarkasteltiin tukki- ja kuitupuuosia. Tehtiin kolmenlaisia vertailuja. Ensin tutkittiin lähinnä kuutioimismenetelmän laadintatapaa ja perusteita suorittamalla vertailuja, joissa rungon

Taulukko 7. Esimerkkejä kuutioimismenetelmän ATK-laskennalla ja pätkittäisellä kuutioinnilla saaduista, tukkiosaa kuvaavista tuloksista. — Tutkimusaineisto.

Tabelle 7. Beispiele für die Resultate für den Blochholzanteil durch 1) EDV der Massenermittlungsmethode und 2) sektionsweise Kubierung. — Hauptmaterial.

Menetelmä — *Methode*	Tukkiosan pituus, m *Länge des Blochholzanteils, m*			
	5	9	11	13
	k-m³ kuorineen *Fm. mit Rinde*			
1. Kuutioimismenetelmän ATK-laskenta — *EDV der Massenermittlungsmethode*	474.6	746.6	851.8	933.6
2. Pätkittäinen kuutiointi — *Sektionsweise Kubierung*	474.3	747.4	853.4	935.3

Taulukko 8. Esimerkkejä kuutioimismenetelmän ATK-laskennalla (1) ja pätkittäisellä kuutioinnilla (2) saaduista, tukkiosaa kuvaavista tuloksista d-luokittain. — Tutkimusaineisto.

Tabelle 8. Beispiele für die d-klassenweisen Resultate für den Blochholzanteil durch 1) EDV der Massenermittlungsmethode und 2) sektionsweise Kubierung. — Hauptmaterial.

d-luokka, cm *d-Klasse, cm*	Koepuiden lukumäärä *Anzahl der Probestämme*	Tukkiosan pituus, m — *Länge des Blochholzanteils, m*							
		5		9		11		13	
		Menetelmä [1]) — *Methode* [1])							
		1	2	1	2	1	2	1	2
		k-m³ kuorineen — *Fm. mit Rinde*							
19	52	7.0	7.1	10.9	11.0	12.2	12.4	13.2	13.4
23	312	60.9	61.2	95.9	96.6	109.0	110.0	118.8	120.0
27	290	76.9	76.6	121.3	121.0	138.6	138.4	152.1	151.8
31	147	50.6	50.4	79.4	79.3	90.6	90.5	99.2	99.3
35	59	25.2	25.3	39.2	39.5	44.9	45.2	49.5	49.9

[1]) Menetelmät: 1 = kuutioimismenetelmän ATK-laskenta, 2 = pätkittäinen kuutiointi.
Es bedeuten: 1 = EDV der Massenermittlungsmethode, 2 = sektionsweise Kubierung.

tyvestä lukien täysien parittomien metrien mukaisesti laskettuja, pätkittäisen kuutioinnin (1—2 m:n pölkyt) tuloksia verrattiin vastaaviin alustavalla kuutioimismenetelmällä (ATK-laskennalla) saatuihin tuloksiin. Tarkastellut tukkiosaa kuvaavat pituudet olivat 5, 7, 9, 11, 13, 15 ja 17 m. Parittomien metrien valinta johtui yksinomaan siitä, että koepuiden läpimitat oli mitattu tyveä lukuun ottamatta parillisin metrein. Taulukoissa 7 ja 8 valaistaan ensin tutkimusaineiston avulla suoritettujen vertailujen tuloksia. Taulukoiden supistamista silmällä pitäen rajoitutaan vain muutamien esimerkeiksi valittujen tulossarjojen esittelyyn. Toistettakoon, että tutkimusaineisto käsittää kaikkiaan 1 761 koepuuta.

Taulukon 7 tulokset osoittavat, että ATK-laskenta on johtanut kaikilla tarkastelluilla tukkiosan pituuksilla käytännöllisesti katsoen pätkittäisen kuutioinnin mukaisiin tuloksiin. Yhdenmukaisuus ilmenee miltei yhtä selvänä myös taulukon 8 tuloksista. Vielä 15 ja 17 m:n pituuksia vastaavat

Taulukko 9. Esimerkkejä kuutioimismenetelmän ATK-laskennalla (1) ja pätkittäisellä kuutioinnilla (2) saaduista, tukkiosaa kuvaavista tuloksista. — Tarkistusaineiston koepuuerät.

Tabelle 9. Beispiele von den Resultaten für den Blochholzanteil durch 1) EDV der Massenermittlungsmethode und 2) sektionsweise Kubierung. — Kontrollmaterial.

Koepuuerä *Probestammpartie*	Menetelmä [1] *Methode* [1]	Tukkiosan pituus, m *Länge des Blochholzanteils, m*			
		9	11	15	17
		k-m³ kuorineen — *Fm. mit Rinde*			
1	1	221.1	249.5	282.9	289.6
	2	223.0	250.9	283.8	290.6
2	1	207.7	237.5	277.0	287.2
	2	206.1	236.0	275.3	285.5
3	1	66.2	76.2	90.4	94.7
	2	66.2	76.3	91.1	95.4
4	1	71.5	82.0	96.6	100.5
	2	72.1	82.8	97.2	100.9
5	1	66.8	76.4	89.4	92.9
	2	67.4	77.2	90.8	94.3
6	1	34.9	39.7	45.9	47.3
	2	35.2	39.7	45.4	46.6
7	1	27.7	31.7	37.0	38.4
	2	27.7	31.6	36.9	38.3
8	1	16.6	19.1	23.0	24.2
	2	16.7	19.2	23.0	24.1
9	1	89.1	101.6	118.3	122.5
	2	90.4	103.0	119.0	123.0
10	1	91.0	103.9	120.9	125.3
	2	92.0	105.0	122.3	126.6
11	1	173.5	197.9	229.5	237.5
	2	175.8	200.2	231.3	238.4
12	1	83.7	95.4	110.7	114.4
	2	84.5	95.9	110.6	114.0
13	1	58.5	66.6	77.1	79.7
	2	59.0	67.0	76.8	79.2

[1] Menetelmät: 1 = kuutioimismenetelmän ATK-laskenta, 2 = pätkittäinen kuutiointi.
Es bedeuten: 1 = EDV der Massenermittlungsmethode, 2 = sektionsweise Kubierung.

samoin kuin pituus- ja kapenemisluokittain lasketut tulosparit vahvistavat taulukon 7 osoittamaa kuvaa. Viitaten edellä todettuun koko rungon kuutiomäärää osoittavien Ilvessalon taulukoiden yksikkökuutioiden luotettavuuteen voitaneen päätellä, että kapenemissarjat muodostavat osaltaan myös varsin luotettavan kuutioimisperusteen. ATK-laskentana toteutetun kuutioimismenetelmän valmistamisessa on taulukoiden 7 ja 8 tulosten mukaan onnistuttu siis erittäin hyvin.

Taulukoissa 7 ja 8 esitetty vertailu tehtiin myös erikseen kaikilla tarkistusaineiston koepuuerillä. Tulosten esittelyssä rajoitutaan vain taulukosta 9 nähtäviin, kaikki d-, pituus- ja kapenemisluokat yhdistäen saatuihin tulossarjoihin. Havaitaan, että eri menetelmillä saadut tulokset ovat nytkin hyvin samansuuruiset. Kokonaisuudessaan vertailussa on päädytty erittäin yhdenmukaisiin tuloksiin.

Taulukko 10. Kuutioimismenetelmällä ja pätkittäisellä kuutioinnilla apteerauksen mukaisesti saadut tukki- ja kuitupuun kuutiomäärät. — Tarkistusaineisto.

Tabelle 10. Die mit Hilfe des Massenermittlungsverfahrens und der sektionsweisen Kubierung nach Ablängung erhaltenen Massenbeträge. — Kontrollmaterial.

Koepuuerä *Probestammpartie*	Koepuiden lukumäärä *Anzahl der Probestämme*	Tukkipuu — *Blochholz*			Kuitupuu — *Faserholz*	
		Pätkittäinen kuutiointi *Sektionsweise Kubierung*	ATK-lask., tarkka pit. *EDV. exakte Länge*	ATK-lask., 0.5 m luokitus *EDV. auf 0.5 m ausgleichende Klassifizierung*	Pätkittäinen kuutiointi *Sektionsweise Kubierung*	ATK-lask., tarkka pit. *EDV. exakte Länge*
		k-m³ kuorineen — *Fm. mit Rinde*				
1	660	215.0	210.2	210.0	77.7	80.1
2	531	220.5	219.0	219.1	75.6	74.9
3	173	72.2	72.0	72.0	26.7	26.3
4	168	74.2	73.5	73.5	29.2	30.7
5	173	59.7	58.9	58.8	37.0	36.7
6	116	34.4	34.1	34.1	12.5	13.9
7	90	27.2	27.2	27.2	11.7	11.9
8	37	21.8	21.8	21.8	3.6	3.8
9	244	107.0	105.6	105.6	18.3	20.0
10	278	102.5	101.0	101.1	26.1	26.6
11	433	203.5	201.0	201.0	38.0	40.7
12	249	91.1	90.3	90.3	24.4	26.3
13	170	64.0	63.6	63.6	16.2	18.1
Yhteensä — *Insgesamt*	3 322	1 293.1	1 278.2	1 278.1	397.0	410.0

Kolmannessa vertailuvaiheessa, joka tapahtui yksinomaan tarkistusaineiston avulla, verrattiin laaditun kuutioimismenetelmän ATK-laskennalla saatavia tukki- ja kuitupuun määriä vastaaviin pätkittäisen kuutioinnin tuloksiin. Kaikissa laskentavaiheissa nojauduttiin samoihin, ko. hakkuutyömaiden jakomiesten määrittämiin tukkiosan pituuksiin, jotka samalla osoittivat myös kuitupuuosan alkamiskohdat. Kuutioimismenetelmällä laskettiin tulokset edellä esitettyjen perusteiden mukaisesti 0.5 metrin tasaavin tukkiosan pituusluokin ja lisäksi tarkan pituuden mukaisesti. Taulukosta 10 nähdään ensin eri menetelmillä saadut koepuuerittäiset tukki- ja kuitupuun kokonaismäärät. Taulukkoon on toistuvasti otettu jo aikaisemmin (s. 25) esitetyt koepuiden lukumäärät.

Kuutioimismenetelmällä saadut koepuuerittäiset tulokset ovat vähintään tyydyttäviä. Keskimääräispiirteenä ilmenee lievä tukkiosan aliarviointi ja määrällisesti likimäärin samansuuruinen kuitupuuosuuden yliarviointi. Ottamalla huomioon vanerikoivuissa varsin yleisesti esiintyvät pienet mutta usein vaikeasti havaittavat viat voitaneen katsoa, että tulosten osoittama tukkiosan lievä aliarvioimisen mahdollisuus ei ole haitallinen piirre. Kuutioimismenetelmällä saadut molemmat tukkiosaa ilmaisevat tulossarjat ovat miltei samat. Tukkiosan pituuden mittaus 0.5 m:n tasaavin luokin näyttää siis olevan myös tulosten laskennan kannalta hyvin perusteltua.

Taulukko 11. Kuutioimismenetelmällä ja pätkittäisellä kuutioinnilla saadut tukki- ja kuitupuun kuutiomäärät d-luokittain. — Tarkistusaineisto.

Tabelle 11. Die mit Hilfe des Massenermittlungsverfahrens und der sektionsweisen Kubierung erhaltenen Massenbeträge in den verschiedenen d-klassen. — Kontrollmaterial.

d-luokka, cm *d-Klasse, cm*	Koepuiden lukumäärä *Anzahl der Probestämme*	Tukkipuu — *Blochholz*			Kuitupuu — *Faserholz*	
		Pätkittäinen kuutiointi *Sektionsweise Kubierung*	ATK-lask., tarkka pit. *EDV. exakte Länge*	ATK-lask., 0.5 m luokitus *EDV. auf 0.5 m ausgleichende Klassifizierung*	Pätkittäinen kuutiointi *Sektionsweise Kubierung*	ATK-lask., tarkka pit. *EDV. exakte Länge*
		k-m³ kuorineen — *Fm. mit Rinde*				
19	174	28.7	28.2	28.2	19.5	20.2
21	562	127.0	124.1	124.1	63.3	64.7
23	746	223.2	219.7	219.5	84.6	87.6
25	722	277.4	274.0	274.0	83.4	85.8
27	478	224.4	221.9	221.8	56.8	58.7
29	336	189.7	188.5	188.5	43.3	45.0
31	149	96.9	97.0	97.1	20.8	21.7
33	94	70.0	69.3	69.5	15.8	16.1
35	40	35.1	35.0	34.9	6.6	7.3
37	19	18.5	18.3	18.3	2.5	2.7
39	2	2.2	2.2	2.2	0.2	0.2
Yhteensä — *Insgesamt*	3 322	1 293.1	1 278.2	1 278.1	397.0	410.0

Taulukosta 11 nähdään tukki- ja kuitupuun kuutiomäärät d-luokittain. Taulukon supistamista silmällä pitäen on rajoituttu kaikki koepuuerät yhdistäen saatuihin tuloksiin. Tarkastelu antanee aiheen todeta, että kuutioimismenetelmällä on saatu myös d-luokittain varsin hyviä tuloksia.

Viimeisenä tarkastelukohteena olivat laadituilla tukkipuutaulukoilla saadut tulokset. Todettakoon, että edellä taulukoissa 10 ja 11 esitetyt, 0.5 m:n luokitusta soveltaen saadut tulokset luonnehtivat ATK-laskennan ohella osittain myös tukkipuutaulukoiden luotettavuutta. Voitiin kuitenkin otaksua, ettei käsinlaskentana tapahtuva taulukoiden avulla suoritettu, varsin paljon inter- ja ekstrapolointia sisältävä kuutiointi johtaisi yhtä tarkkoihin tuloksiin.

Tukkipuutaulukoiden luotettavuutta koskeneiden vertailujen tuloksista esitetään esimerkkejä taulukoissa 12 ja 13. On rajoituttu vain tukkiosaa koskeviin tuloksiin, edelleen v. 1972 mitattuihin tarkistusaineiston koepuueriin (3—13). Havaitaan, että sekä koepuuerittäin (taulukko 12) että d-luokittain on päädytty varsin yhdenmukaisiin tulossarjoihin. Vastaavanlainen yhdenmukaisuus ilmeni myös pituus- ja kapenemisluokittain ryhmitetyistä tuloksista. Tulossarjojen ja I l v e s s a l o n kuutioimistaulukoiden luotettavuuden pohjalta saatetaan päätellä, että tukkipuutaulukoilla saadaan myös kuitupuun osalta varsin hyviä tuloksia. Laadittuja koivun tukkipuutaulukoita voitaneen siten suositella käytettäviksi erilaisissa käytännön mittaus-

Taulukko 12. Esimerkkejä koivun tukkipuutaulukoilla ja pätkittäisellä kuutioinnilla saaduista, tukkiosaa koskevista tuloksista. — Tarkistusaineiston koepuuerät 3—13.

Tabelle 12. Beispiele für die den Birkenblochholztabellen entnommenen und bei der sektionsweisen Kubierung erhaltenen Resultate über den Blochholzanteil. — Probestammpartien 3—13 aus dem kontrollmaterial.

Koepuuerä *Probestammpartie*	Koepuiden lukumäärä *Anzahl der Probestämme*	Pätkittäinen kuutiointi *Sektionsweise Kubierung*	Tukkipuutaulukot *Blochholztabellen*
		k-m³ kuorineen — *Fm. mit Rinde*	
3	173	72.3	71.9
4	168	73.3	73.8
5	173	59.3	59.3
6	101	31.6	31.8
7	90	27.2	27.0
8	37	22.1	21.7
9	209	102.1	100.7
10	242	95.9	95.7
11	433	201.0	202.7
12	188	79.2	77.9
13	156	62.3	61.7
Yhteensä — *Insgesamt*	1 970	826.3	824.2

Taulukko 13. Esimerkkejä koivun tukkipuutaulukoilla ja pätkittäisellä kuutioinnilla saaduista, tukkiosaa koskevista tuloksista d-luokittain. — Tarkistusaineiston koepuuerät 3—13.

Tabelle 13. Beispiele für die den Birkenblochholztabellen entnommenen und bei der sektionsweisen Kubierung erhaltenen d-Klassenweisen Resultate über den Blochholzanteil. — Probestammpartien 3—13 aus dem Kontrollmaterial.

d-luokka, cm *d-Klasse, cm*	Koepuiden lukumäärä *Anzahl der Probestämme*	Pätkittäinen kuutiointi *Sektionsweise Kubierung*	Tukkipuutaulukot *Blochholztabellen*
		k-m³ kuorineen — *Fm. mit Rinde*	
19	23	3.7	3.8
21	296	67.0	67.7
23	442	132.0	133.0
25	476	188.4	188.3
27	304	149.1	147.9
29	227	133.6	130.9
31	96	65.0	64.5
33	60	44.5	45.2
35	30	26.5	26.5
37	14	14.3	14.2
39	2	2.2	2.2
Yhteensä — *Insgesamt*	1 970	826.3	824.2

tehtävissä, myös leimikon pystymittauksissa. Edellä viitatun mukaisesti taulukoiden käytössä tarvittavaan inter- ja ekstrapolointiin on kuitenkin kiinnitettävä riittävästi huomiota. Graafinen tarkastelu on varmaankin usein perusteltua.

Mittausten suorittamisesta

Edellä suppeasti tarkasteltujen kuutioimistunnusten mittausten luotettavuuden tutkimisen yhteydessä ei ilmennyt mitään aihetta poiketa totunnaisista läpimittojen mittaustavoista. Näin oli myös koko pituuden mittauksen laita. Neljännen tunnuksen, tukkiosan pituuden mittaus tulisi suorittaa, ehkä tavanomaisista tavoista poiketen, mahdollisuuksien mukaan d6:n mittauksessa käytettävällä tangolla. Tukkiosasta huomattavan osuuden käsittävän rungon tyviosan pituuden mittaukseen on siis syytä kiinnittää erityistä huomiota. Tukkiosan pituuden ylittäessä 8—10 m mitataan tukkiosa pituusmittarilla kuten koko pituuskin.

Mahdollisten vikaisuuksien tarkastelu liittyy kiinteästi tukkiosan pituuden määrittämiseen. Tarkastelun perusteella voidaan päätellä, onko ko. koivutukkipuu normaali vai poikkeuksellinen tukkipuu. Töiden joustavaa suorittamista ja eri osapuolten välisten mahdollisten mielipide-erojen välttämistä silmällä pitäen suositetaan etenkin suurien ja arvokkaiden sekä runsaasti vikaisuuksia sisältävien leimikoiden koepuut mitattavaksi seuraavasti.

Ostajan ja myyjän edustajat seuraavat tai mieluummin osallistuvat kiinteästi mittauksiin. Tukkiosan pituus pyritään ratkaisemaan molempia osapuolia tyydyttävällä tavalla puu puulta.

Tukkiosan pituuden mittaukseen sisällytetään vikaisuuksien arvostelu. Objektiivisesti arvostellen pyritään molempien osapuolten kannalta oikeaan ratkaisuun. Jos vikaisuutta on runsaasti, saattaa arvostelu pystypuista olla vaivalloista ja epävarmaa. Tällöin määritetään tukkiosuus niin, että siihen sisältyvät myös otaksutut mutta pituudeltaan epävarmat vikaiset rungonosat. Tarkastelua jatketaan kaadon jälkeen mittaamalla edellä mainitulla tavalla arvioidusta tukkiosasta pölkytyksessä erotetut, hukka- tai kuitupuuksi luettavat pölkyt pituus × läpimitta-periaatteen mukaisesti. Tukkiosaa pienennetään sitten mittaustulosten mukaisella kuutiomäärällä. Jos on syytä otaksua, että tukkiosan pituuden ja vikaisten rungonosien määrittäminen muodostuu kaadetuista rungoista erilaiseksi kuin pystypuista, voidaan pystypuihin tehdä sopivia merkintöjä, esim. tukkiosan pituus metreinä hieman lukumerkin yläpuolelle jne.

Todettakoon, että edellä esitetynlaista tukkiosan pituuden arviointia on tutkinut ja suosittanut käytettäväksi erityisesti metsäteknikko Antero Kuronen (Kml. Tapio).

Vikaisuuksien arvostelu saatetaan tehdä myös puidenluvun yhteydessä. Ilmeistä on, että koivutukkipuiden pystymittauksissa tarvitaan ostajan ja myyjän yhteistoimintaa huomattavasti enemmän kuin havupuiden mittauksissa.

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MTJ = Metsäntutkimuslaitoksen julkaisuja
FF = Folia Forestalia

EINE KUBIERUNGSMETHODE FÜR BIRKENBLOCHHOLZ

Deutsches referat

Zur einleitung

Die Arbeit an einem Massenermittlungsverfahren für Birkenblochholz wurde an der Forstlichen Forschungsanstalt in Finnland schon in den 1950er Jahren aufgenommen. Erschwert wurde diese Aufgabe durch die Verschiedenheit der Ablängungsprinzipien beim Birkenblochholz und die bis vor kurzem angewandte Masseinheit, nämlich Kubikfuss. Erst Anfang 1972 wurde die Entscheidung getroffen, eine neue Masseinheit, das Festmeter mit Rinde einzuführen. Es erwies sich als gerechtfertigt, die neuausgearbeitete Methode dem Massenermittlungsverfahren anzufügen, das u.a. zur Massenaufnahme beim stehenden, zum Hieb ausgezeichneten Holz verwendet wird.

Die Aufarbeitung dieser Methode für die Ansprüche der forstlichen Praxis wurde einer Arbeitsgruppe übergeben, die aus den Unterzeichneten bestand. Als Resultat dieser Gruppenarbeit kam der vorliegende Bericht heraus.

Das Material der Untersuchung

Das Material setzt sich aus zwei Teilmaterialien zusammen: 1) das eine besteht aus den Probestämmen der »Massentafeln für stehende Bäume» von Ilvessalo (1947), der wichtigsten Unterlage dieser Untersuchung, und der »Ausbauchungstafeln der Birke» von Tiihonen (1961 b); dieses Teilmaterial wird in der Publikation als Untersuchungsmaterial bezeichnet. 2) das Kontrollmaterial, das 13 Probestammpartien umfasst. Die Mengen des Materials sind auf S. 7 angeführt. Die Verteilung des Materials auf die angewandten Klassen wird im Zusammenhang mit der Besprechung der Zuverlässigkeit der Resultate dargelegt. Bei jedem Probestamm sind die Kubierungsmerkmale — Brusthöhendurchmesser, Länge und Ausbauchung — aufgenommen. Für das Kontrollmaterial wurde noch ein viertes Merkmal, die Länge des Blochholzanteils, herangezogen. Weiter wurden an jedem Stamm die Durchmesser auf 0.5 m, 2 m, 4 m, 6 m usw. für die sektionsweise Kubierung gemessen. Bei der Bestimmung des Blochholzanteils wurden die üblichen Grundlagen der Ablängung befolgt.

Die allgemeinen Grundlagen der Kubierungsmethode

Das Ziel war eine Methode, nach der die Gesamtmasse eines Birkenstamms in Bloch- und Faserholz sowie den zurückbleibenden Zopfteil eingeteilt werden kann. Zu diesem Zweck wurden die von Aro (1935) und Tiihonen (1961 a, 1966 a) publizierten Richtlinien befolgt. Dabei werden die Anteile der verschiedenen Holzsortimente in Prozent von der Kubikmasse des Nutzteils bei einem Stamm bestimmt, um erst hierüber

auf die entsprechenden absoluten Zahlenwerte zu kommen. Für die Arbeit werden, wie schon erwähnt, die Einheitsmassenwerte bei Ilvessalo, die die Gesamtmasse des Stammes aufzeigen, die Ausbauchungsreihen bei Tiihonen (1961 b), die die Schaftform bei der Birke beschreiben, und die Durchschnittszahlen (Tabelle 1 *loco*), die die Grösse des zurückbleibenden Zopfteils angeben, zu Hilfe genommen. Zur Festsetzung des Grenzpunktes zwischen den Blochholz- und Faserholzanteilen wird ein zusätzliches Merkmal — die Länge des Blochholzanteils — herangezogen. In der Methode sind, wie beim Nadelholz, zwei rechnerische Alternativen inbegriffen: 1) die numerischen Tabellen oder Blochholztafeln und 2) die EDV. Diese zwei Alternativen führen zu praktisch übereinstimmenden Resultaten.

Die an die Methode angepasste EDV

Die wichtigsten Grundlagen sind bereits oben dargelegt. Programmiert auf diese Argumente wurde die EDV in Zusammenarbeit zwischen dem Staatlichen EDV-Dienst/Bezirksbüro in Oulu und der Forstlichen Forschungsanstalt/Abt. Abschätzung ausgeführt.

In der Veröffentlichung werden die Ausgangsdaten der EDV, das Sammeln derselben, die benutzten Vordrücke und die Behandlung der Daten beschrieben. Im Kapitel über die Logik der EDV wird der Vorgang ausführlich besprochen.

Die Blochholztafeln

Auch die Blochholztabellen sind aufgrund von vier Merkmalen aufgestellt. In der Publikation wird die Wahl der Grundlagen und der Anzahl der Klassen kurz behandelt. Es wird u.a. geprüft, wieviel die Kubikmasse der verschiedenen Stammsektionen, vom Wurzelende her, in Prozent von der Gesamtmasse des Stammes bzw. von der Masse des Nutzteils ausmacht (Zusammenstellung auf S. 14). Es wird festgestellt, dass mit Hilfe des Schaftes der zur Messung der Ausbauchung benutzten Kluppe — Länge 5 m — die Länge des Blochholzanteils mindestens bis zu 7 m Höhe exakt gemessen werden kann, und ziemlich genau noch bis zu 8—10 m Höhe. Kurze Wurzelblöcher konnten auch nach dem Prinzip »Länge × Durchmesser» kubiert werden. Der Durchmesser musste bei ungefähr 0.5 m unterhalb der Mitte des Blochholzanteils gemessen werden. Für solche Massenbestimmung wurde eine Tabelle für sich ausgearbeitet (Tab. 2). Zum Schluss wurde die Struktur der Tafeln beachtet, wobei zu bemerken war, dass sehr dichte Abstufung zu unbequemen Tafeln führt.

Es wurde vereinbart, drei Blochholzlängenklassen mit einem Abstand von je 2 m durch die d-, Höhen- und Ausbauchungsklassen zu bilden. Es ergab sich, dass die aufgrund dieser Klassifizierung ausgeführte Inter- und Extrapolierung noch bis zu mindestens 1—2 m ziemlich zuverlässig war. Die drei Klassen decken also zumindest 6 m von der Variationsbreite der Länge des Blochholzanteils. Für jede Klasse sind zwei Einheitsmassenwerte angegeben: der Blochholzanteil und der ganze Nutzteil des Stammes. Auf diese Weise kann die erforderliche Inter- und Extrapolation lediglich auf den Blochholzanteil beschränkt werden. Um den Anteil an Faserholz zu erhalten, muss die Kubikmasse des Blochholzanteils von dem Gesamtnutzteil abgezogen werden.

Die klassenweisen Blochholzanteile wurden mit Hilfe der EDV bestimmt, und die Reihen der Einheitsmassenwerte graphisch analysiert. Zum Schluss wurde die Anzahl der Blochholzlängenklassen in einigen gesonderten Klassen reduziert. Die Blochholztafeln stehen am Schluss der vorliegenden Veröffentlichung.

Zur Zuverlässigkeit der Methode

Die Zuverlässigkeit der Methode wurde in zwei Richtungen geprüft. Erstens wurde den bei der Erhebung der Kubierungsmerkmale möglicherweise entstehenden Messfehlern nachgegangen. Hinsichtlich Brusthöhendurchmesser, Länge und Ausbauchung stützten wir uns in der Hauptsache auf die Ergebnisse früherer Untersuchungen. Teste über die Messung der Höhe bei Birke wurden noch im Herbst 1972 gemacht. In der Publikation sind Resultate von Versuchen über die Höhenmessung bei Nadelholz und Birke (Zusammenstellung S. 22 und Tab. 3, S. 23) aufgeführt. Besondere Aufmerksamkeit wurde der Messung des neuen Kubierungmerkmals — der Länge des Blochholzanteils, zugewandt. Resultate der im Herbst 1972 ausgeführten Teste sind in Tab. 4 und 5, S. 23—24 zusammengestellt. Man sieht, dass eine ordentlich ausgebildete Mannschaft imstande ist, die Länge des Blochholzanteils an einem Stamm zumindest befriedigend genau zu bestimmen. Dies dürfte im allgemeinen auch für die Messung der ganzen Baumhöhe zutreffen, es wird aber doch gerechtfertigt sein, auch noch in der nächsten Feldsaison vergleichende Teste zu machen.

Zweitens wurde die Zuverlässigkeit durch Kontrollberechnungen geprüft, wobei viererlei Vergleiche angestellt wurden. Da die Massentafeln von Ilvessalo von grundlegender Bedeutung für die hier besprochene Methode sind, gingen wir folgerichtig auf die Prüfung der Zuverlässigkeit dieser Tafeln zurück. Tab. 6 zeigt die Resultate in verschiedenen Probestammpartien. Sie bestätigen erneut die schon aufgrund früherer Proben gewonnene Auffassung, dass die Tafeln von Ilvessalo auch bei der Kubierung von Birkenblochholz ausgezeichnete Resultate liefern. Die klare Übereinstimmung in den Ergebnissen der Tab. 6 tritt auch bei den nach d-, h- und Ausbauchungsklassen angestellten Vergleichen hervor.

Die Resultate bezüglich der Blochholz- und Faserholzanteile wurden mit Hilfe von drei Testreihen nachgeprüft. Zuerst wurden die Ausarbeitung und die Grundlagen der Kubierungsmethode untersucht, wozu Vergleiche ausgeführt wurden, die sich 1) auf die Resultate der sektionsweisen Kubierung — Sektionen auf unpaarigen Vollmetern vom Wurzelende her — und 2) auf die entsprechenden, mit der vorläufigen Methode erzielten Resultate bezogen. Dass unpaarige Zahlen für die Aushaltung gewählt wurden, geht auf die Bezeichnung der d-Klassen zurück. Die Ergebnisse sind in den Tabellen 7 bis 9 dargestellt. Es zeigte sich, dass die Methode zu recht guten Resultaten führt.

Bei den Vergleichen wurden ferner die Blochholz- und Faserholzanteile an den Stämmen, die nach der üblichen Forstpraxis abgelängt waren, anhand der aufgestellten Kubierungsmethode (EDV) ausgerechnet. Was die Länge des Blochholzanteils betrifft, so wurde sowohl die exakte Länge als eine ausgeglichene (Abstufung zu 0.5 m) Länge herangezogen. Die Ergebnisse sind aus den Tabellen 10 und 11 ersichtlich. Es hat sich erwiesen, dass der Blochholzanteil durchschnittlich etwas unter- und der Faserholzanteil entsprechend etwa gleichviel überschätzt wird. Mit Rücksicht auf die bei der Sperrholzbirke häufigen leichten Fehler wirkt sich dieser Umstand nicht nachteilig aus. Die Resultate dürfen also mindestens als befriedigend gelten.

Zuletzt wurden die mit den Blochholztafeln erhaltenen Resultate geprüft, von denen einige Beispiele aus den Tabellen 12 und 13 ersichtlich sind. Mit den Tabellen ergaben sich z.T. grössere Differenzen als mit der EDV. Hieran ist u.a. die mit den Gebrauch der Tafeln verknüpfte Inter- und Extrapolation schuld. Aufgrund der Vergleiche lässt sich jedoch sagen, dass die veröffentlichten Blochholztafeln für Birke insbesondere für ungefähre Massenbestimmungen brauchbar sind, ferner auch zum Vergleich neben der EDV, und sogar auch als eigentliche Kubierungsgrundlage, wenn Möglichkeiten für EDV nicht gegeben sind. Besonders im letzteren Fall sollte die Inter- und Extrapolierung graphisch ausgeführt werden.

KOIVUN TUKKIPUUTAULUKOT
BLOCHHOLZMASSENTAFELN FÜR BIRKE

Luokitus:

Rinnankorkeusläpimitta (d-) luokat: 19—45 cm, 2 cm:n tasaava luokitus.
Pituusluokat: 15—27 m, metrin tasaavin luokin.
Kapenemisluokat (d—d6): 2—9 cm, senttimetrin luokkavälein, tasaava luokitus.
Tukkiosan pituusluokat: pääosiltaan kolme tyvestä lukien määritettyä pituutta, joiden väli on 2 m.

Klassifizierung:

Brusthöhendurchmesser (d-)klassen: 19—45 cm, ausgleichende Klassifizierung.
Höhenklassen: 15—27 m, Stufenweite 1 m, ausgleichende Klassifizierung.
Ausbauchungsklassen (d—d6): 2—9 cm, Stufenweite 1 cm, ausgleichende Klassifizierung.
Blochholzlängenklassen: Zum grössten Teil drei Klassen mit einem Abstand von je 2 m.

TUKKIPUUTAULUKOT — *Blochholzmassentafeln* Koivu — *Birke*

Pituusluokka, m *Höhenklasse, m*	Tukkiosan pituus, m *Länge des Blochholzanteils, m*	d-luokka, cm — *d-Klasse, cm*									
		19		21		23		25		27	
		Tukkiosa (1) ja rungon koko käyttöosa (2), k-m³ kuorineen/runko *Blochholzanteil (1) und der ganze Nutzteil des Stammes (2), Fm. mit Rinde/Stamm*									
		1	2	1	2	1	2	1	2	1	2
	3	0.083		0.101		0.122		0.142		0.165	
15	5	.131	0.229	.160		.192		.226		.262	
	7			.213	0.282	.256	0.340	.301	0.402	.350	0.470
	3	.084		.101		.122		.143		.165	
16	5	.131	.241	.161		.192		.226		.263	
	7			.213	.296	.256	.356	.301	.421	.352	.492
	5	.131	.252	.163		.193		.228		.266	
17	7			.215	.310	.259		.303		.355	
	9					.305	.373	.361	.442	.421	.516
	5	.132	.264	.165		.197		.231		.269	
18	7			.220	.325	.262		.309		.361	
	9					.314	.391	.372	.463	.433	.540
	5	.136	.276	.165		.200		.236		.272	
19	7			.222	.339	.267		.314		.366	
	9					.321	.409	.381	.485	.442	.566
	5	.137	.288	.168		.203		.237		.275	
20	7			.222		.269		.317		.369	
	9			.273	.354	.326	.428	.386	.507	.451	.593
	5	.138	.300	.168		.203		.238		.277	
21	7			.222		.270		.319		.372	
	9			.274	.369	.329	.447	.388	.529	.454	.619
22	7			.223		.271		.320		.375	
	9			.274	.384	.330		.390		.458	
	11					.379	.466	.448	.552	.527	.646
23	7			.224		.271		.321		.377	
	9			.274	.400	.331		.392		.460	
	11					.383	.485	.453	.576	.530	.675
	7			.224		.272		.322		.378	
24	9			.275	.415	.332		.394		.461	
	11					.386	.504	.457	.601	.536	.704
	9			.275	.431	.333		.396		.463	
25	11					.387	.523	.461		.538	.733
	13							.519	.625		
	9					.334		.400		.468	
26	11					.391	.543	.466		.545	.762
	13							.524	.650		
	9							.404		.474	
27	11					.393	.563	.470		.554	.792
	13							.532	.674		

KAPENEMISLUOKKA, 2 cm — *Ausbauchungsklasse, 2 cm*

Pituusluokka, m *Höhenklasse, m*	Tukkiosan pituus, m *Länge des Blochholzanteils, m*	d-luokka, cm — *d-Klasse, cm*											
		29		31		33		35		37		39	
		Tukkiosa (1) ja rungon koko käyttöosa (2), k-m³ kuorineen/runko *Blochholzanteil (1) und der ganze Nutzteil des Stammes (2), Fm. mit Rinde/Stamm*											
		1	2	1	2	1	2	1	2	1	2	1	2
	5	0.303		0.344		0.392		0.443		0.502		0.564	
15	7	.407		.463		.527		.598		.676		.761	
	9	.481	0.544	.549	0.622	.625	0.708	.710	0.805	.804	0.913	.904	1.026
	5	.303		.346		.393		.445		.503		.565	
16	7	.409		.465		.528		.600		.679		.762	
	9	.485	.570	.556	.654	.632	.745	.716	.847	.810	.960	.911	1.076
	7	.411		.471		.532		.602		.685		.765	
17	9	.486		.562		.641		.725		.818		.918	
	11	.545	.597	.627	.686	.714	.782	.809	.888	.916	1.006	1.026	1.126
	7	.415		.478		.543		.612		.695		.770	
18	9	.500		.575		.655		.741		.838		.929	
	11	.562	.625	.647	.719	.737	.821	.835	.929	.948	1.056	1.050	1.176
	7	.421		.486		.550		.620		.702		.776	
19	9	.512		.588		.669		.758		.852		.945	
	11	.575	.655	.665	.753	.758	.859	.858	.972	.967	1.096	1.071	1.216
	7	.427		.489		.556		.628		.704		.780	
20	9	.521		.595		.680		.768		.858		.956	
	11	.590	.686	.680	.788	.775	.898	.876	1.016	.979	1.136	1.088	1.266
	9	.526		.602		.685		.773		.865		.962	
21	11	.600		.689		.785		.884		.989		1.100	
	13	.658	.717	.753	.822	.858	.937	.966	1.056	1.084	1.186	1.203	1.316
	9	.532		.608		.690		.776		.867		.970	
22	11	.610		.698		.794		.891		.995		1.110	
	13	.671	.748	.768	.857	.870	.976	.981	1.096	1.097	1.226	1.222	1.376
	9	.534		.612		.695		.778		.870		.974	
23	11	.614		.700		.797		.893		.998		1.118	
	13	.679	.781	.777	.894	.882	1.016	.990	1.136	1.106	1.276	1.235	1.426
	11	.619		.706		.800		.898		1.004		1.125	
24	13	.691		.789		.894		1.003		1.121		1.253	
	15	.746	.815	.850	.931	.966	1.056	1.084	1.186	1.211	1.326	1.330	1.476
	11	.623		.710		.803		.904		1.008		1.131	
25	13	.699		.796		.905		1.015		1.129		1.270	
	15	.759	.849	.865	.969	.979	1.096	1.102	1.236	1.227	1.376	1.357	1.536
	11	.631		.717		.806		.915		1.015		1.140	
26	13	.710		.807		.916		1.031		1.150		1.275	
	15	.776	.884	.882	1.006	1.003	1.146	1.126	1.286	1.257	1.436	1.392	1.596
	13	.724		.820		.928		1.045		1.174		1.310	
27	15	.792	.919	.901		1.021		1.149		1.287		1.436	
	17			.980	1.046	1.095	1.186	1.230	1.336	1.376	1.496	1.526	1.656

TUKKIPUUTAULUKOT

Koivu

Pituus-luokka, m	Tukkiosan pituus, m	d-luokka, cm									
		19		21		23		25		27	
		Tukkiosa (1) ja rungon koko käyttöosa (2), k-m³ kuorineen/runko									
		1	2	1	2	1	2	1	2	1	2
	3	0.082	0.214	0.100		0.120		0.141		0.164	
15	5			.155	0.266	.187		.220		.256	
	7					.246	0.323	.290	0.384	.338	0.450
	3	.083	.225	.101		.121		.142		.165	
16	5			.157	.278	.188		.222		.258	
	7					.247	.337	.292	.401	.341	.470
	3	.084	.235	.102		.121		.142		.165	
17	5			.158	.291	.188		.222		.259	
	7					.247	.352	.293	.419	.342	.492
	3	.084	.245	.102		.122		.143		.166	
18	5			.158		.189		.224		.260	
	7			.207	.304	.249	.368	.295	.439	.345	.515
	5			.159		.191		.227		.264	
19	7			.208	.317	.251		.299		.350	
	9					.302	.385	.361	.459	.423	.538
	5			.159		.193		.228		.266	
20	7			.209	.330	.254		.302		.353	
	9					.305	.402	.364	.479	.428	.562
	5			.159		.195		.229		.269	
21	7			.210	.343	.256		.304		.358	
	9					.309	.419	.368	.499	.434	.586
	5			.160		.196		.231		.270	
22	7			.211	.356	.257		.306		.359	
	9					.311	.436	.371	.520	.438	.612
	7			.212	.370	.258		.308		.360	
23	9					.312	.453	.373		.441	
	11							.430	.542	.507	.638
	7			.213	.384	.259		.310		.363	
24	9					.315	.470	.377		.444	
	11							.436	.564	.513	.664
	7			.214	.398	.260		.311		.364	
25	9					.317	.487	.380		.447	
	11							.440	.586	.519	.690
	7					.260		.312		.365	
26	9					.318	.504	.382		.448	
	11							.443	.608	.523	.716
	9							.384		.451	
27	11							.447		.525	
	13							.501	.630	.589	.743

KAPENEMISLUOKKA, 3 cm

Pituus-luokka, m	Tukkiosan pituus, m	d-luokka, cm											
		29		31		33		35		37		39	
		Tukkiosa (1) ja rungon koko käyttöosa (2), k-m³ kuorineen/runko											
		1	2	1	2	1	2	1	2	1	2	1	2
	5	0.297		0.338		0.385		0.437		0.496		0.561	
15	7	.393		.449		.512		.582		.655		.749	
	9	.463	0.523	.531	0.600	.605	0.684	.690	0.780	.784	0.889	.887	1.006
	5	.298		.342		.388		.440		.500		.563	
16	7	.395		.455		.516		.590		.660		.750	
	9	.470	.547	.538	.630	.615	.719	.700	.819	.793	.930	.898	1.046
	5	.299		.343		.388		.442		.502		.565	
17	7	.397		.456		.520		.591		.663		.750	
	9	.474	.572	.544	.660	.623	.754	.705	.857	.798	.971	.901	1.096
	7	.400		.460		.525		.594		.669		.750	
18	9	.482		.553		.630		.714		.809		.905	
	11	.538	.598	.621	.690	.709	.790	.805	.897	.912	1.016	1.018	1.136
	7	.405		.467		.533		.602		.676		.753	
19	9	.490		.565		.645		.730		.822		.916	
	11	.555	.626	.639	.722	.731	.826	.828	.936	.932	1.056	1.038	1.176
	7	.412		.477		.545		.613		.689		.765	
20	9	.500		.581		.663		.750		.841		.935	
	11	.568	.654	.659	.754	.750	.862	.852	.976	.955	1.096	1.068	1.226
	7	.419		.485		.552		.620		.695		.775	
21	9	.508		.589		.670		.759		.847		.943	
	11	.577	.682	.671	.786	.765	.898	.865	1.016	.967	1.136	1.083	1.276
	9	.511		.593		.672		.762		.850		.944	
22	11	.587		.678		.771		.871		.976		1.094	
	13	.644	.712	.743	.818	.848	.934	.958	1.056	1.070	1.186	1.199	1.326
	9	.513		.594		.673		.762		.850		.945	
23	11	.592		.683		.776		.876		.982		1.096	
	13	.651	.742	.751	.852	.856	.970	.966	1.096	1.085	1.226	1.205	1.366
	9	.516		.596		.674		.762		.850		.945	
24	11	.598		.688		.780		.880		.987		1.099	
	13	.663	.772	.760	.886	.866	1.006	.978	1.136	1.094	1.276	1.218	1.416
	9	.519		.596		.675		.762		.850		.945	
25	11	.602		.691		.781		.884		.989		1.100	
	13	.670	.803	.768	.922	.870	1.046	.986	1.186	1.101	1.326	1.227	1.476
	11	.603		.692		.783		.890		.990		1.102	
26	13	.676		.775		.878		.997		1.109		1.237	
	15	.735	.835	.843	.958	.955	1.086	1.086	1.236	1.208	1.376	1.348	1.536
	13	.686		.788		.889		1.006		1.124		1.249	
27	15	.750	.867	.861		.972		1.100		1.230		1.366	
	17			.917	.996	1.036	1.126	1.173	1.276	1.311	1.426	1.456	1.586

TUKKIPUUTAULUKOT

Koivu

Pituus-luokka, m	Tukkiosan pituus, m	d-luokka, cm									
		21		23		25		27		29	
		Tukkiosa (1) ja rungon koko käyttöosa (2), k-m³ kuorineen/runko									
		1	2	1	2	1	2	1	2	1	2
	5	0.151	0.249	0.184		0.217		0.254		0.294	
15	7			.238	0.305	.282	0.365	.331		.384	
	9							.383	.430	.450	0.501
	5	.152	.260	.185		.218		.254		.295	
16	7			.238	.318	.284	.381	.333		.385	
	9							.388	.449	.456	.524
	5	.153	.271	.185		.219		.255		.296	
17	7			.239	.332	.285		.335		.386	
	9					.333	.398	.393	.469	.461	.548
	5	.154	.283	.186		.221		.256		.298	
18	7			.240	.347	.287		.337		.389	
	9					.337	.416	.399	.490	.466	.572
	5	.155	.294	.187		.223		.259		.300	
19	7			.242	.361	.290		.340		.394	
	9					.346	.434	.407	.511	.474	.597
	5	.155	.306	.188		.223		.261		.303	
20	7			.245	.376	.292		.342		.398	
	9					.349	.452	.411	.533	.483	.623
	5	.155	.318	.189		.224		.263		.307	
21	7			.246	.391	.293		.345		.402	
	9					.351	.470	.416	.556	.490	.649
	7			.247		.294		.346		.405	
22	9			.295	.407	.354	.489	.418		.492	
	11							.480	.579	.562	.676
	7			.247		.295		.348		.407	
23	9			.297	.422	.356		.420		.493	
	11					.407	.508	.485	.602	.567	.703
	7			.248		.296		.350		.410	
24	9			.298	.436	.359		.424		.495	
	11					.411	.528	.489	.626	.571	.731
	9			.299	.451	.360		.426		.496	
25	11					.415	.547	.493	.649	.574	
	13									.636	.759
	9			.300	.466	.361		.428		.498	
26	11					.417	.567	.495	.673	.576	
	13									.643	.788
	9					.362		.429		.499	
27	11					.420	.587	.497	.698	.580	
	13									.650	.817

KAPENEMISLUOKKA, 4 cm

Pituus-luokka, m	Tukkiosan pituus, m	d-luokka, cm									
		31		33		35		37		39	
		Tukkiosa (1) ja rungon koko käyttöosa (2), k-m³ kuorineen/runko									
		1	2	1	2	1	2	1	2	1	2
	5	0.336		0.381		0.434		0.491		0.555	
15	7	.441		.502		.572		.646		.731	
	9	.515	0.577	.588	0.660	.671	0.755	.764	0.859	.864	0.969
	5	.338		.383		.437		.496		.556	
16	7	.444		.507		.577		.650		.733	
	9	.522	.605	.599	.693	.681	.791	.773	.899	.872	1.016
	5	.340		.384		.439		.498		.556	
17	7	.446		.511		.581		.654		.735	
	9	.529	.633	.605	.726	.691	.827	.781	.939	.877	1.056
	7	.449		.515		.584		.657		.737	
18	9	.536	.662	.613		.699		.789		.883	
	11			.684	.760	.778	.864	.880	.979	.985	1.096
	7	.454		.520		.588		.661		.740	
19	9	.546	.691	.626		.709		.798		.891	
	11			.704	.793	.799	.901	.901	1.016	1.007	1.136
	7	.462		.527		.594		.670		.745	
20	9	.557	.721	.639		.722		.814		.905	
	11			.723	.826	.820	.938	.923	1.056	1.027	1.176
	7	.467		.533		.600		.675		.751	
21	9	.563	.750	.647		.729		.822		.915	
	11			.735	.859	.832	.976	.935	1.096	1.045	1.226
	9	.567		.650		.731		.824		.918	
22	11	.648	.780	.742		.836		.944		1.053	
	13			.811	.893	.921	1.016	1.031	1.136	1.155	1.276
	9	.569		.650		.732		.826		.920	
23	11	.653	.811	.746		.840		.948		1.057	
	13			.817	.926	.926	1.046	1.037	1.176	1.162	1.316
	9	.570		.651		.734		.828		.920	
24	11	.657	.842	.748		.845		.950		1.062	
	13			.825	.960	.937	1.086	1.048	1.226	1.171	1.366
	11	.661		.750		.848		.951		1.065	
25	13	.732	.875	.831		.943		1.057		1.178	
	15			.898	.996	1.016	1.126	1.142	1.266	1.275	1.416
	11	.663		.751		.852		.953		1.069	
26	13	.738	.909	.840		.953		1.065		1.185	
	15			.913	1.036	1.036	1.176	1.158	1.316	1.289	1.466
	11	.665		.753		.858		.957		1.070	
27	13	.749	.943	.853		.964		1.081		1.200	
	15			.931	1.076	1.053	1.216	1.180	1.366	1.318	1.526

TUKKIPUUTAULUKOT

Koivu

Pituus-luokka, m	Tukkiosan pituus, m	d-luokka, cm									
		21		23		25		27		29	
		Tukkiosa (1) ja rungon koko käyttöosa (2), k-m³ kuorineen/runko									
		1	2	1	2	1	2	1	2	1	2
	5	0.149	0.233	0.182	0.287	0.215		0.250		0.291	
15	7					.275	0.346	.325	0.410	.378	
	9									.443	0.479
	5	.150	.243	.183	.299	.216		.251		.291	
16	7					.278	.361	.327	.427	.380	
	9									.449	.500
	5	.151	.253	.183	.312	.217		.252		.292	
17	7					.280	.376	.328		.381	
	9							.385	.446	.453	.522
	5	.152	.263	.184	.325	.217		.253		.293	
18	7					.281	.392	.329		.383	
	9							.387	.465	.457	.544
	5	.152	.273	.184		.218		.255		.295	
19	7			.232	.338	.282	.408	.330		.386	
	9							.389	.484	.463	.568
	5	.153	.283	.185		.219		.256		.296	
20	7			.234	.351	.282		.331		.388	
	9					.334	.424	.392	.504	.470	.592
	5	.153	.293	.186		.220		.257		.297	
21	7			.236	.364	.283		.332		.390	
	9					.336	.440	.396	.524	.475	.616
	5			.186		.220		.258		.298	
22	7			.237	.377	.284		.334		.392	
	9					.338	.457	.400	.545	.478	.641
	7			.237	.390	.285		.335		.393	
23	9					.341	.474	.403		.480	
	11							.460	.566	.542	.665
	7			.237	.403	.285		.336		.394	
24	9					.342	.492	.405		.481	
	11							.462	.588	.545	.690
	7			.238	.416	.286		.338		.395	
25	9					.344	.509	.407		.482	
	11							.468	.609	.547	.716
26	9					.344		.408		.483	
	11					.395	.527	.470		.550	
	13							.521	.630	.616	.742
27	9					.345		.408		.483	
	11					.397	.544	.472		.555	
	13							.527	.651	.625	.767

KAPENEMISLUOKKA, 5 cm

Pituus-luokka, m	Tukkiosan pituus, m	d-luokka, cm											
		31		33		35		37		39		41	
		Tukkiosa (1) ja rungon koko käyttöosa (2), k-m³ kuorineen/runko											
		1	2	1	2	1	2	1	2	1	2	1	2
	5	0.334		0.380		0.431		0.488		0.550		0.618	
15	7	.434		.495		.564		.640		.722		.815	
	9	.504	0.553	.576	0.634	.657	0.723	.747	0.824	.846	0.934	.944	1.044
	5	.335		.381		.434		.493		.551		.621	
16	7	.437		.500		.569		.643		.723		.818	
	9	.513	.579	.588	.665	.668	.759	.760	.864	.854	.976	.962	1.091
	5	.335		.381		.436		.495		.552		.621	
17	7	.440		.504		.572		.645		.723		.818	
	9	.519	.606	.595	.696	.677	.794	.768	.902	.861	1.016	.969	1.131
	5	.345		.382		.439		.498		.554		.623	
18	7	.442		.506		.574		.646		.724		.818	
	9	.523	.632	.600	.728	.687	.828	.775	.939	.866	1.056	.972	1.176
	7	.444		.509		.578		.648		.726		.818	
19	9	.529		.609		.693		.778		.870		.974	
	11	.593	.660	.681	.759	.772	.863	.873	.976	.980	1.096	1.086	1.216
	7	.446		.512		.580		.650		.727		.818	
20	9	.536		.616		.699		.781		.875		.975	
	11	.625	.687	.694	.790	.788	.898	.881	1.006	.994	1.136	1.102	1.261
	7	.448		.515		.582		.652		.728		.818	
21	9	.540		.622		.703		.785		.879		.978	
	11	.614	.714	.706	.821	.799	.932	.892	1.046	1.006	1.176	1.118	1.311
	9	.545		.625		.706		.790		.883		.980	
22	11	.620		.713		.807		.905		1.012		1.126	
	13	.677	.742	.779	.852	.883	.967	.991	1.086	1.108	1.216	1.235	1.356
	9	.549		.627		.709		.792		.885		.984	
23	11	.626		.719		.813		.914		1.018		1.133	
	13	.688	.770	.788	.883	.897	1.006	1.005	1.126	1.120	1.256	1.247	1.401
	9	.551		.629		.712		.795		.887		.987	
24	11	.630		.722		.818		.918		1.023		1.139	
	13	.696	.799	.796	.915	.905	1.036	1.014	1.166	1.131	1.306	1.258	1.456
	9	.553		.630		.713		.797		.888		.990	
25	11	.633		.724		.820		.921		1.025		1.142	
	13	.703	.829	.803	.949	.910	1.076	1.021	1.206	1.138	1.346	1.269	1.511
	11	.636		.726		.823		.923		1.027		1.144	
26	13	.709		.810		.916		1.030		1.144		1.278	
	15	.767	.860	.874	.982	.993	1.116	1.116	1.256	1.239	1.396	1.385	1.561
	11	.641		.728		.825		.926		1.030		1.148	
27	13	.717		.815		.928		1.038		1.155		1.285	
	15	.780	.891	.889	1.016	1.008	1.156	1.130	1.296	1.260	1.446	1.407	1.616

TUKKIPUUTAULUKOT

Koivu

Pituus-luokka, m	Tukkiosan pituus, m	d-luokka, cm									
		23		25		27		29		31	
		Tukkiosa (1) ja rungon koko käyttöosa (2), k-m³ kuorineen/runko									
		1	2	1	2	1	2	1	2	1	2
	3	0.120		0.141		0.165		0.191		0.218	
15	5	.177	0.270	.211		.246		.287		.332	
	7			.266	0.327	.315	0.390	.368	0.459	.426	0.532
	3	.120		.142		.166		.193		.222	
16	5	.179	.280	.212		.247		.288		.332	
	7			.269	.340	.317	.406	.371	.479	.429	.557
	5	.180	.291	.213		.248		.288		.332	
17	7			.270	.354	.318	.423	.373		.430	
	9							.436	.500	.505	.581
	5	.181	.303	.214		.249		.289		.333	
18	7			.270	.368	.318	.440	.375		.432	
	9							.438	.520	.510	.605
	5	.181	.314	.214		.250		.290		.333	
19	7			.270	.382	.318		.375		.433	
	9					.372	.458	.440	.541	.513	.630
	5			.214		.250		.291		.334	
20	7			.270	.397	.319		.376		.434	
	9					.375	.476	.443	.563	.517	.656
	5			.214		.250		.293		.334	
21	7			.271	.411	.320		.377		.435	
	9					.377	.493	.447	.585	.520	.681
	7			.271	.426	.320		.378		.436	
22	9					.380	.511	.450		.522	
	11							.510	.606	.592	.705
	7			.271		.321		.379		.437	
23	9			.320	.441	.382		.452		.525	
	11					.434	.530	.514	.628	.595	.730
	7			.271		.321		.379		.438	
24	9			.321	.456	.383		.453		.526	
	11					.436	.549	.516	.649	.598	.756
	7			.272		.322		.379		.439	
25	9			.322	.471	.384		.453		.526	
	11					.438	.567	.518	.671	.601	.783
	9			.323	.486	.384		.453		.526	
26	11					.440	.585	.519		.603	
	13							.575	.693	.670	.810
	9			.323	.500	.385		.453		.526	
27	11					.442	.603	.520		.605	
	13							.582	.715	.677	.836

KAPENEMISLUOKKA, 6 cm

Pituus-luokka, m	Tukkiosan pituus, m	d-luokka, cm											
		33		35		37		39		41		43	
		Tukkiosa (1) ja rungon koko käyttöosa (2), k-m³ kuorineen/runko											
		1	2	1	2	1	2	1	2	1	2	1	2
	5	0.376		0.428		0.483		0.542		0.602		0.667	
15	7	.485		.553		.627		.705		.786		.865	
	9	.558	0.609	.638	0.697	.723	0.792	.816	0.894	.909	0.996	1.012	1.106
	5	.377		.430		.487		.545		.606		.671	
16	7	.490		.558		.631		.709		.788		.867	
	9	.562	.637	.649	.728	.735	.827	.827	.931	.920	1.041	1.025	1.156
	5	.378		.431		.491		.547		.608		.673	
17	7	.493		.560		.633		.710		.789		.869	
	9	.575	.666	.657	.760	.745	.863	.835	.969	.931	1.081	1.033	1.201
	5	.378		.432		.492		.547		.610		.673	
18	7	.495		.562		.634		.711		.790		.870	
	9	.583	.696	.662	.793	.750	.899	.841	1.006	.936	1.126	1.039	1.251
	7	.496		.563		.635		.711		.790		.870	
19	9	.588		.667		.753		.843		.939		1.041	
	11	.653	.726	.742	.826	.838	.934	.937	1.046	1.044	1.166	1.155	1.291
	7	.498		.564		.635		.711		.790		.870	
20	9	.593		.674		.756		.846		.944		1.043	
	11	.666	.755	.758	.860	.851	.968	.953	1.086	1.065	1.216	1.175	1.341
	7	.500		.566		.636		.711		.790		.870	
21	9	.597		.678		.762		.850		.948		1.047	
	11	.677	.784	.769	.893	.866	1.006	.965	1.126	1.078	1.256	1.189	1.386
	9	.600		.680		.768		.853		.951		1.051	
22	11	.683		.776		.876		.975		1.086		1.201	
	13	.744	.812	.847	.925	.956	1.046	1.065	1.166	1.187	1.301	1.315	1.441
	9	.602		.682		.770		.856		.952		1.053	
23	11	.688		.781		.880		.981		1.093		1.209	
	13	.754	.840	.856	.956	.968	1.086	1.077	1.206	1.201	1.346	1.329	1.491
	9	.605		.685		.771		.859		.953		1.055	
24	11	.690		.785		.885		.986		1.097		1.218	
	13	.759	.868	.866	.988	.976	1.116	1.089	1.246	1.212	1.396	1.347	1.551
	11	.691		.787		.885		.990		1.100		1.220	
25	13	.763		.871		.979		1.097		1.221		1.355	
	15	.821	.898	.937	1.026	1.053	1.156	1.182	1.296	1.317	1.446	1.462	1.606
	11	.692		.789		.885		.993		1.103		1.223	
26	13	.769		.877		.984		1.107		1.227		1.363	
	15	.831	.930	.950	1.066	1.065	1.196	1.198	1.346	1.330	1.496	1.475	1.661
	11	.694		.790		.886		.995		1.105		1.225	
27	13	.775		.883		.995		1.114		1.235		1.374	
	15	.843	.962	.959	1.096	1.080	1.236	1.211	1.386	1.349	1.546	1.496	1.716

TUKKIPUUTAULUKOT

Koivu

Pituus-luokka, m	Tukkiosan pituus, m	d-luokka, cm							
		27		29		31		33	
		Tukkiosa (1) ja rungon koko käyttöosa (2), k-m³ kuorineen/runko							
		1	2	1	2	1	2	1	2
	5	0.242		0.283		0.326		0.370	
15	7	.302	0.369	.356	0.438	.413		.471	
	9					.470	0.510	.538	0.585
	5	.242		.283		.326		.370	
16	7	.303	.384	.358	.456	.415		.473	
	9					.478	.532	.547	.612
	5	.243		.283		.326		.371	
17	7	.303	.400	.359	.474	.415		.475	
	9					.482	.555	.553	.639
	5	.243		.283		.326		.371	
18	7	.304	.416	.359	.493	.415		.476	
	9					.485	.577	.557	.666
	5	.243		.283		.326		.372	
19	7	.305	.432	.359	.512	.415		.477	
	9					.487	.600	.561	.693
	5	.243		.284		.326		.373	
20	7	.306	.448	.359	.532	.416		.478	
	9					.490	.623	.566	.720
	5	.244		.285		.327		.374	
21	7	.307	.464	.360	.552	.417		.480	
	9					.494	.645	.570	.746
	5	.244		.286		.328		.374	
22	7	.307		.361		.418		.480	
	9	.360	.479	.430	.571	.497	.667	.571	.771
	5	.244		.286		.328		.374	
23	7	.307		.362		.419		.480	
	9	.360	.495	.430	.589	.499	.689	.572	.796
	7	.307		.362		.419		.480	
24	9	.360	.511	.430		.499		.572	
	11			.483	.608	.562	.711	.648	.821
	7	.307		.362		.420		.480	
25	9	.360		.430		.500		.572	
	11	.408	.526	.485	.627	.565	.734	.650	.847
	9	.360		.430		.500		.572	
26	11	.410	.541	.488		.568		.654	
	13			.540	.646	.630	.757	.725	.874
	9	.360		.430		.500		.572	
27	11	.411	.556	.489		.572		.657	
	13			.543	.664	.636	.781	.733	.902

KAPENEMISLUOKKA, 7 cm

Pituus-luokka, m	Tukkiosan pituus, m	d-luokka, cm											
		35		37		39		41		43		45	
		Tukkiosa (1) ja rungon koko käyttöosa (2), k-m³ kuorineen/runko											
		1	2	1	2	1	2	1	2	1	2	1	2
	5	0.420		0.476		0.534		0.590		0.653		0.715	
15	7	.537		.610		.680		.760		.840		.925	
	9	.616	0.670	.701	0.764	.792	0.864	.883	0.966	.978	1.066	1.077	1.176
	5	.422		.478		.535		.590		.654		.716	
16	7	.540		.612		.681		.760		.840		.925	
	9	.626	.701	.711	.798	.802	.900	.892	1.004	.985	1.111	1.086	1.226
	5	.424		.481		.535		.590		.656		.717	
17	7	.541		.612		.682		.760		.840		.925	
	9	.632	.732	.717	.832	.806	.936	.896	1.042	.990	1.156	1.095	1.281
	5	.424		.481		.535		.590		.656		.717	
18	7	.542		.612		.682		.760		.841		.925	
	9	.635	.762	.720	.865	.809	.973	.901	1.086	.995	1.206	1.101	1.331
	7	.542		.612		.682		.760		.841		.925	
19	9	.640		.724		.813		.904		1.000		1.104	
	11	.710	.792	.803	.897	.899	1.006	1.005	1.126	1.111	1.246	1.226	1.376
	7	.543		.612		.682		.760		.842		.925	
20	9	.646		.727		.816		.907		1.005		1.106	
	11	.725	.823	.817	.929	.918	1.046	1.022	1.166	1.130	1.291	1.247	1.426
	7	.544		.612		.683		.761		.843		.925	
21	9	.650		.730		.820		.912		1.010		1.110	
	11	.736	.853	.826	.961	.929	1.086	1.034	1.206	1.144	1.336	1.260	1.476
	7	.544		.612		.683		.762		.843		.925	
22	9	.651		.732		.822		.917		1.015		1.114	
	11	.740	.882	.831	.996	.935	1.126	1.042	1.251	1.153	1.386	1.268	1.526
	9	.653		.734		.823		.919		1.017		1.115	
23	11	.743		.836		.940		1.048		1.160		1.275	
	13	.815	.911	.917	1.026	1.031	1.156	1.154	1.296	1.277	1.436	1.401	1.576
	9	.653		.736		.823		.920		1.018		1.115	
24	11	.745		.839		.943		1.053		1.164		1.278	
	13	.820	.941	.922	1.066	1.039	1.196	1.163	1.336	1.285	1.481	1.414	1.631
	11	.747		.841		.945		1.056		1.167		1.280	
25	13	.826		.929		1.044		1.168		1.293		1.422	
	15	.885	.970	1.000	1.096	1.126	1.236	1.257	1.381	1.392	1.531	1.532	1.686
	11	.749		.844		.946		1.058		1.169		1.283	
26	13	.833		.938		1.052		1.176		1.304		1.438	
	15	.900	1.006	1.016	1.136	1.140	1.276	1.277	1.431	1.414	1.586	1.559	1.751
	11	.750		.847		.947		1.062		1.173		1.285	
27	13	.839		.945		1.062		1.188		1.319		1.455	
	15	.911	1.036	1.032	1.176	1.154	1.316	1.292	1.476	1.435	1.641	1.583	1.811

TUKKIPUUTAULUKOT

Koivu

Pituus-luokka, m	Tukkiosan pituus, m	d-luokka, cm									
		25		27		29		31		33	
		Tukkiosa (1) ja rungon koko käyttöosa (2), k-m³ kuorineen/runko									
		1	2	1	2	1	2	1	2	1	2
	5	0.196	0.290	0.235		0.275		0.319		0.362	
15	7			.289	0.349	.343	0.418	.399	0.488	.456	0.561
	5	.196	.300	.235		.275		.320		.363	
16	7			.290	.363	.343	.434	.400	.508	.458	.586
	5	.196	.311	.235		.275		.320		.363	
17	7			.291	.377	.343	.450	.400	.529	.459	.611
	5	.196	.321	.235		.275		.320		.363	
18	7			.291	.391	.343	.467	.400	.549	.460	.636
	5	.196	.332	.235		.275		.320		.363	
19	7			.291	.406	.343	.485	.400	.569	.460	.661
	5	.196	.344	.235		.275		.320		.364	
20	7			.292	.420	.344	.502	.401	.590	.460	.685
	5	.196	.355	.235		.276		.320		.364	
21	7			.293	.434	.345		.401		.460	.708
	9					.400	.519	.475	.610		
	5			.235		.276		.320		.364	
22	7			.293	.447	.345		.401		.460	.731
	9					.400	.536	.475	.630		
	5			.235		.276		.320		.364	
23	7			.293		.346		.401		.460	.754
	9			.338	.460	.400	.552	.475	.650		
	5			.235		.276		.320		.364	
24	7			.293		.346		.401		.460	
	9			.338	.473	.401	.568	.475	.669	.540	.776
	7			.293		.346		.401		.460	
25	9			.338	.486	.401		.475		.541	
	11					.455	.583	.534	.688	.616	.799
	7			.293		.346		.401		.460	
26	9			.338	.498	.402		.475		.542	
	11					.456	.599	.535	.707	.620	.822
	9			.338	.510	.402		.475		.543	
27	11					.457	.614	.537		.622	
	13							.596	.727	.690	.846

KAPENEMISLUOKKA, 8 cm

Pituus-luokka, m	Tukkiosan pituus, m	d-luokka, cm											
		35		37		39		41		43		45	
		Tukkiosa (1) ja rungon koko käyttöosa (2), k-m³ kuorineen/runko											
		1	2	1	2	1	2	1	2	1	2	1	2
	5	0.412		0.466		0.524		0.581		0.638		0.702	
15	7	.521		.590		.660		.736		.815		.900	
	9	.594	0.644	.678	0.736	.765	0.833	.854	0.931	.951	1.034	1.047	1.141
	5	.414		.468		.524		.581		.639		.702	
16	7	.523		.590		.660		.738		.815		.900	
	9	.602	.673	.683	.768	.774	.867	.862	.967	.955	1.071	1.051	1.181
	5	.415		.470		.524		.581		.640		.702	
17	7	.524		.590		.661		.739		.815		.900	
	9	.610	.701	.690	.799	.780	.901	.866	1.004	.958	1.111	1.056	1.226
	5	.415		.470		.524		.581		.640		.702	
18	7	.524		.590		.662		.740		.815		.900	
	9	.613	.729	.695	.829	.782	.935	.868	1.042	.960	1.156	1.059	1.276
	7	.524		.590		.662		.740		.815		.900	
19	9	.616		.697		.786		.870		.962		1.062	
	11	.682	.757	.771	.859	.868	.969	.968	1.081	1.070	1.196	1.181	1.321
	7	.524		.591		.663		.740		.815		.900	
20	9	.620		.699		.789		.873		.966		1.068	
	11	.692	.784	.784	.889	.881	1.006	.981	1.116	1.085	1.241	1.202	1.371
	7	.525		.592		.663		.741		.815		.900	
21	9	.623		.703		.791		.876		.970		1.071	
	11	.702	.811	.794	.920	.890	1.036	.995	1.156	1.101	1.281	1.213	1.416
	7	.526		.592		.664		.741		.815		.900	
22	9	.624		.705		.792		.879		.975		1.073	
	11	.706	.838	.800	.951	.894	1.066	1.002	1.201	1.111	1.331	1.223	1.466
	7	.526		.592		.665		.742		.815		.900	
23	9	.625		.707		.792		.881		.978		1.075	
	11	.709	.865	.803	.982	.898	1.106	1.008	1.241	1.117	1.376	1.230	1.516
	9	.626		.708		.792		.883		.980		1.075	
24	11	.710		.805		.900		1.009		1.120		1.235	
	13	.776	.892	.886	1.016	.993	1.136	1.114	1.276	1.238	1.421	1.365	1.571
	9	.626		.708		.792		.884		.980		1.075	
25	11	.710		.805		.900		1.010		1.123		1.240	
	13	.781	.918	.889	1.046	.998	1.176	1.118	1.321	1.243	1.471	1.369	1.621
	11	.710		.806		.901		1.012		1.125		1.241	
26	13	.785		.892		1.003		1.124		1.251		1.381	
	15	.848	.944	.964	1.076	1.089	1.216	1.217	1.361	1.355	1.516	1.496	1.676
	11	.711		.807		.901		1.013		1.128		1.242	
27	13	.790		.895		1.005		1.137		1.264		1.391	
	15	.856	.971	.973	1.106	1.095	1.246	1.234	1.406	1.373	1.566	1.513	1.726

TUKKIPUUTAULUKOT

Koivu

Pituus-luokka, m	Tukkiosan pituus, m	d-luokka, cm									
		25		27		29		31		33	
		Tukkiosa (1) ja rungon koko käyttöosa (2), k-m³ kuorineen/runko									
		1	2	1	2	1	2	1	2	1	2
	3	0.135		0.159		0.187		0.215		0.243	
15	5	.189	0.270	.226	0.329	.265		.310		.356	
	7					.330	0.396	.385	0.466	.443	0.537
	3	.135		.159		.187		.215		.244	
16	5	.189	.280	.226	.341	.265		.310		.356	
	7					.330	.411	.385	.484	.443	.560
	3	.135		.159		.187		.215		.244	
17	5	.189	.289	.226		.265		.310		.356	
	7			.277	.354	.330	.426	.385	.503	.443	.583
	3	.135		.159		.187		.215		.244	
18	5	.189	.299	.227		.266		.310		.356	
	7			.277	.367	.330	.441	.385	.521	.443	.606
	5	.189	.308	.227		.267		.310		.356	
19	7			.278	.380	.330		.385		.443	
	9					.380	.457	.445	.539	.516	.629
	5	.189	.317	.227		.267		.310		.356	
20	7			.278	.392	.330		.385		.444	
	9					.380	.472	.447	.558	.516	.650
	5	.189	.326	.227		.267		.310		.356	
21	7			.278	.403	.330		.386		.444	
	9					.380	.486	.449	.576	.516	.671
	5	.189	.335	.227		.267		.311		.356	
22	7			.278	.414	.330		.386		.444	
	9					.381	.500	.449	.593	.518	.692
	5			.227		.268		.311		.356	
23	7			.279	.425	.331		.386		.444	
	9					.381	.515	.450	.610	.519	.712
	5			.227		.268		.311		.356	
24	7			.279	.435	.331		.386		.444	
	9					.382	.528	.450	.627	.520	.731
	9					.382		.450		.520	
25	11					.426	.540	.503		.585	
	13							.553	.643	.644	.751
	9					.382		.450		.520	
26	11					.426	.552	.503		.585	
	13							.554	.658	.647	.771
	9							.450		.520	
27	11							.503		.586	
	13							.555	.674	.649	.791

KAPENEMISLUOKKA, 9 sm

Pituus-luokka, m	Tukkiosan pituus, m	d-luokka, cm											
		35		37		39		41		43		45	
		Tukkiosa (1) ja rungon koko käyttöosa (2), k-m³ kuorineen/runko											
		1	2	1	2	1	2	1	2	1	2	1	2
	5	0.405		0.455		0.510		0.565		0.625		0.685	
15	7	.505		.575		.645		.718		.790		.870	
	9	.576	0.618	.657	0.707	.744	0.801	.833	0.898	.925	0.996	1.015	1.096
	5	.405		.455		.510		.565		.625		.685	
16	7	.505		.575		.645		.718		.790		.870	
	9	.581	.644	.662	.736	.748	.833	.835	.931	.925	1.033	1.018	1.136
	5	.405		.455		.510		.565		.625		.685	
17	7	.505		.575		.646		.718		.790		.870	
	9	.587	.670	.666	.765	.751	.864	.838	.966	.926	1.071	1.020	1.181
	5	.405		.455		.510		.565		.625		.685	
18	7	.505		.575		.646		.718		.790		.870	
	9	.590	.696	.668	.793	.754	.896	.841	1.002	.927	1.111	1.022	1.226
	7	.505		.575		.646		.718		.790		.870	
19	9	.593		.670		.756		.843		.929		1.023	
	11	.654	.721	.742	.821	.837	.927	.932	1.034	1.032	1.146	1.138	1.266
	7	.506		.575		.646		.718		.790		.870	
20	9	.595		.673		.757		.845		.931		1.026	
	11	.662	.746	.750	.848	.845	.957	.943	1.071	1.044	1.186	1.152	1.311
	7	.506		.575		.646		.718		.790		.870	
21	9	.597		.675		.757		.846		.933		1.029	
	11	.667	.771	.756	.876	.849	.986	.951	1.106	1.052	1.226	1.162	1.356
	7	.506		.575		.646		.718		.790		.870	
22	9	.599		.677		.757		.850		.938		1.034	
	11	.673	.796	.762	.905	.854	1.016	.960	1.146	1.064	1.271	1.173	1.406
	9	.600		.680		.758		.853		.944		1.040	
23	11	.675		.765		.860		.965		1.070		1.182	
	13	.737	.820	.838	.935	.945	1.056	1.061	1.186	1.175	1.316	1.298	1.456
	9	.600		.682		.758		.855		.946		1.044	
24	11	.675		.770		.863		.968		1.075		1.188	
	13	.740	.844	.845	.966	.950	1.086	1.065	1.221	1.183	1.356	1.310	1.501
	9	.600		.682		.759		.856		.948		1.047	
25	11	.675		.770		.864		.970		1.076		1.190	
	13	.741	.867	.849	.996	.953	1.116	1.067	1.256	1.188	1.401	1.314	1.551
	11	.675		.770		.865		.970		1.076		1.192	
26	13	.743		.850		.958		1.075		1.193		1.319	
	15	.802	.891	.914	1.016	1.037	1.156	1.162	1.296	1.290	1.441	1.427	1.596
	11	.675		.770		.865		.970		1.076		1.194	
27	13	.745		.850		.963		1.080		1.200		1.322	
	15	.809	.914	.923	1.046	1.045	1.186	1.171	1.331	1.305	1.486	1.444	1.646

STUDIES ON THE UPTAKE OF FERTILIZER NITROGEN BY SCOTS PINE USING ^{15}N LABELLED UREA

INFLUENCE OF PEAT THICKNESS AND APPLICATION TIME

EERO PAAVILAINEN

SELOSTE:

TUTKIMUKSIA TURPEEN PAKSUUDEN JA LEVITYSAJANKOHDAN VAIKUTUKSESTA MÄNNYN LANNOITETYPEN OTTOON

HELSINKI 1973

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PREFACE

This study represents one part of a series of research projects designed to clarify the basis of nitrogen fertilization of peatland forests. It became possible to carry out this study after Typpi Oy (nowadays Kemira Oy) provided some urea fertilizer containing ^{15}N isotope and also paid for all the necessary analyses. I would like to extend my sincerest thanks to Kemira Oy, and especially to Mr. Veli Tuomikoski, M.Sc., who has taken part in this study from the very beginning and who has supported its implementation in many ways, and to Mr. Jukka Piironen, Division Manager of Kemira Oy. In addition, I would like to thank Mr. Sakari Moisio, M.Sc. for his scrupulous and skilful supervision of the mass spectrometer analyses carried out at Valio's Biochemical Research Institute, and Professors Artturi I. Virtanen and Matti Kreula for their extremely positive attitude towards this research work.

While I have been carrying out this study, I have had to bother almost all the members of the staff at the Forest Research Institute's research station in Parkano and of the Department for Peatland Forestry. The manuscript has been read by Prof. Max. Hagman, Mr. Olavi Halonen, M.Sc., Prof. Olavi Huikari, Mr. Erkki Lipas, Lic.Sc.(For.), Mr. Eino Mälkönen, Lic.Sc.(For.) and Mr. Kimmo Paarlahti, Lic.Sc.(For.). The translation from Finnish into English has been made by Mr. John Derome, B.Sc. I would like to express my thanks to all of them.

Helsinki, July 1973

Eero Paavilainen

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1. INTRODUCTION

When estimating the need of peatland forests for nitrogen fertilization and developing the most suitable fertilization techniques, attention should be given to a number of factors: in particular to

— the site,
— the type of fertilizer and
— the time of fertilizer application.

Tree growth on peat soils is limited by a nitrogen deficiency especially on cottongrass and *Sphagnum fuscum* peatland types which are poor in nutrients. Nitrogen fertilization is in Finland also recommended on moderately fertile sites if it is a question of a fully stocked old drainage area, or if the peat layer is thin (e.g. Huikari and Paavilainen 1972).

The thickness of the peat, as has earlier been shown (Huikari 1973), plays a very significant role in the estimation of the need of peatland forests for nitrogen fertilization. Peatlands with a thin peat layer represent an intermediate stage between peat and mineral soils in which the nitrogen deficiency is probably not quite as great as in forest covered mineral soils. However, there is still very little information available about the amount and mechanism of nitrogen uptake by trees growing on peat soils and about the effect of peat thickness on the utilization of fertilizer nitrogen by trees.

In investigations concerning the suitability of different types of nitrogen fertilizers for use on peatland forests, calcium ammonium saltpeter, montan saltpeter, ammonium sulphate and urea have all given good results (Huikari 1964, 1973, Paavilainen 1972 a). Of these fertilizers, urea deserves special attention because its use involves the lowest costs. In field experiments carried out on both peat soils (Paavilainen 1972 a) and mineral soils (e.g. Brantseg 1970, Möller 1971, Viro 1972), the average effect of urea has remained weaker than for instance that of calcium ammonium saltpeter, even though the results it has given in certain cases on peat soils have been quite good.

Urea is hydrolysed in the soil enzymatically into ammonium carbonate which subsequently dissociates into ammonium (NH_4^+) and carbonate (CO_2^{2-} or HCO_3^-) ions. Unaltered urea can leach through the soil. Nitrogen

volatilization can occur if the pH value of the soil is so high (pH > 6.5) that the nitrogen present as ammonium ions becomes free ammonia. When the uptake, retention and leaching of nitrogen given as urea are mentioned in this study, reference is really made to ammonium ions, because urea is hydrolysed rather quickly in ground covered by vegetation (e.g. Gibson 1930, Roberge & Knowles 1966). Similarly, volatilization of nitrogen refers to volatilization of ammonia.

Volatilization of some of the ammonia produced by the hydrolysis of urea has been suggested as one possible reason for the weaker effect of urea than of calcium ammonium saltpeter. This assumption is based closely on the results of laboratory and field experiments carried out for instance in Sweden and Norway (e.g. Nömmik 1967, Overrein 1968, 1969). In the case of peatlands, it has been stressed that the behaviour of urea in peat is not clearly known and thus further research has been considered necessary (Paavilainen 1972 a).

According to the studies carried out upto now, the time of fertilizer application on deep peat is of small practical significance while the ground is not frozen (Paarlahti 1967, Karsisto 1967, Paavilainen 1969). Application of easily soluble nitrogen fertilizer during wintertime has increased the growth, although it has given clearly weaker results than applications carried out during the growing season (Paavilainen 1969). There is no corresponding information available about peatlands with a thin peat layer, and the effect of the time of application on peat and mineral soils has not been compared.

The aim of this study is to shed some more light on questions that have been dealt with earlier and which form the basis of the nitrogen fertilization of peatland forests. In particular, an attempt is made to investigate how peat thickness and time of fertilizer application affect the uptake of fertilizer nitrogen by Scots pine *(Pinus silvestris* L.).

Urea labelled with ^{15}N isotope has been used in the study. No studies have earlier been carried out in Finland using this isotope technique in connection with forest fertilization, the usefulness of which has been shown by authors in other countries (e.g. Nömmik 1966, Björkman, Lundeberg & Nömmik 1967, Overrein 1967, 1968, 1969, 1970, 1971 a, b, 1972, Nömmik & Popovic 1971, Ivanko 1972).

The following points are investigated in the study:

— the uptake of fertilizer nitrogen, applied as urea, by pines growing on peatlands with a thick peat or a shallow peat layer and on a mineral soil site for comparison,
— the dependence of nitrogen uptake on the time of fertilizer application and the growing season,

— the retention of fertilizer nitrogen by different parts of pine and the ground vegetation,

— the leaching and volatilization of nitrogen given as urea in peat soils.

The author has already published some preliminary results of this study at the 4th International Peat Congress (P a a v i l a i n e n 1972 b).

2. MATERIAL AND METHODS

The field and laboratory experiments were carried out at the Forest Research Institute's research station at Parkano. The research plan involved three separate parts.

1. The purpose of the broadest experiment, i.e. that set up on forest covered soils, was to determine the uptake of ^{15}N urea fertilizer by pine and ground vegetation, and its dependence on the thickness of the peat layer and the time of fertilizer application.
2. In order to supplement the above experiment, an experiment was set up on a *Sphagnum fuscum* open swamp designed to investigate how the nitrogen from the urea fertilizer is retained in the peat when application is carried out on top of a snow cover or on the bare ground. Above all, it was thus used to determine the significance of the time of fertilizer application.
3. The third experiment was carried out in the laboratory and was designed to show whether nitrogen from the urea fertilizer is volatilized from the surface of the peat and how the fertilizer nitrogen leaches through the peat when varying amounts of water are applied onto the peat surface. Thus, attempts were made even in the laboratory experiment to determine the significance of the time of fertilizer application and thus to further supplement the field experiments.

The results were treated in the Peatland Forestry Department of the Forest Research Institute. Variance analysis was used for determining the significance of the various factors making up the experimental results. In order to do this, arc sin transformation was done from the percentage values.

The ^{15}N analyses, which were the basic measurements obtained in the study, were carried out at Valio's Biochemical Research Institute. Other nutrient- and all other soil analyses were carried out by Viljavuuspalvelu Oy. Owing to the great expense of the analyses, it became necessary to reduce the number of samples from that which had been planned when the experiments were originally set up.

21. Experiment on forest covered soils

The experiment which was designed to find out about the uptake of nitrogen from ^{15}N urea fertilizer by pine and ground vegetation was set up at Alkkianvuori (N 62°10′, E 22°45′) situated in the Parkano experimental area of the Forest Research Institute. The area is located about 190 m above sea level. Adjacent thick peated peatland (peat thickness 100—160 cm) and shallow peated peatland (peat thickness 10—30 cm) sites, and for comparison a Vaccinium Type site (= VT, for the Finnish forest site classification see C a j a n d e r 1949), were chosen for the study (Fig. 1).

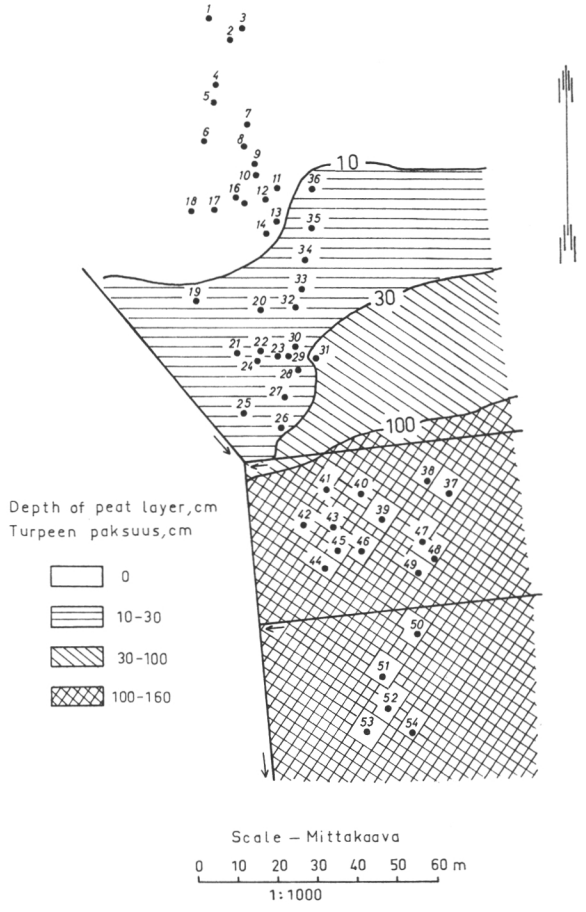


Fig. 1. Location of the sample trees on the experimental area.
Kuva 1. Koepuiden sijainti tutkimusalueella.

The peatland sites closely resembled the sedge pine swamp and shallow sedge pine swamp types (cf. H u i k a r i 1952), although the surface peat was drier than is normal for these types and partly covered by *Carex globularis*. The coverage of some of the most common plant species occuring on these sites are presented below. The values represent average values for the species growing on ten sample plots of 1 m² each.

Plant species	Sedge pine swamp	Shallow sedge pine swamp	VT site
		Coverage, %	
Vaccinium myrtillius	10	25	40
Vaccinium vitis-idaea	3	5	30
Vaccinium uliginosum ...	15	15	—
Calluna vulgaris	2	2	20
Ledum palustre	45	40	—
Betula nana	6	4	—
Pleurozium Schreberi	8	40	80
Sphagnum sp.	90	60	—

Table 1. Results from analyses made on the soils in the experimental areas.
Taulukko 1. Maa-analyysien tuloksia tutkituilla kasvupaikoilla.

Depth, cm *Syvyys, cm*	Volume weight, g/l *Tilavuus-paino, g/l*	Specific gravity, g/cm³ *Ominais-paino, g/cm³*	Organic matter, % *Orgaaninen aines, %*	pH	Ntot. mg/100 g	Ptot. mg/g	Ktot. mg/g	Catot. mg/g
		Sedge pine swamp *Suursararäme*						
0—5	123	1.20	78.7	4.8	1.08	0.55	0.74	0.90
5—10	152	1.30	81.7	4.6	1.28	0.70	0.63	0.87
10—15	230	1.23	82.8	4.5	1.58	0.88	0.48	0.84
15—20	236	1.57	87.2	4.5	1.75	0.93	0.41	0.82
		Shallow sedge pine swamp *Ohutturpeinen suursararäme*						
0—5	189	1.32	76.9	4.7	1.45	0.70	0.70	0.84
5—10	140	1.39	77.1	5.0	1.17	0.63	0.66	0.91
10—15	334	1.42	63.8	4.8	1.64	0.97	0.49	0.64
15—20	877	2.57	10.8	4.8	0.21	0.12	0.21	0.06
		Sphagnum fuscum open swamp *Rahkaneva*						
0—5	173	1.35	79.0	4.0	0.98	0.50	0.64	..
5—10	164	1.40	69.0	3.9	0.94	0.70	0.69	..
10—15	190	1.45	80.5	3.9	1.11	0.70	0.48	..
15—20	185	1.39	76.0	3.8	0.88	0.40	0.27	..
		VT site *Puolukkatyypin kangas*						
Humus	304	1.44	56.3	4.3	0.90	0.86	0.52	0.40
Mineral soil *Kivennäismaa*						$P_{HCl\ sol.}$ mg/g	$K_{HCl\ sol.}$ mg/g	$Ca_{HCl\ sol.}$ mg/g
0—5	1 121	2.52	3.8	4.7	0.09	0.13	0.16	0.03
5—10	1 158	2.55	3.3	5.1	0.06	0.59	0.21	0.02
10—15	1 135	2.48	3.3	5.3	0.07	1.25	0.23	0.02
15—20	1 130	2.39	3.4	5.4	0.07	1.26	0.23	0.02

It seems likely that the forementioned peatland sites have earlier been of the VT type, and gradually a part of the area has become paludified and turned into a shallow sedge pine swamp, and as a result of more advanced paludification another part has turned into a deep sedge pine swamp.

The analyses carried out on samples taken from near some of the sample trees, which are discussed later in part a) on page 14, give some idea about the physical properties of the soil, pH values, and nutrient status of the study areas. These analyses showed, that there was a high mineral soil content at a depth of 15—20 cm in the samples taken from the shallow sedge pine swamp and also rather much organic matter (10.8 %) when compared with the mineral soil samples taken from the VT site in which the level of organic matter was only 3.3—3.8 % (Table 1). The volume weight of the peat was slightly greater and the nitrogen and phosphorous level was slightly higher at the surface of the peat (0—5 cm) in the shallow sedge pine swamp than in the deep sedge pine swamp. On the basis of measurements carried out in different parts of the VT site, the thickness of the humus layer was on average 3.1 cm. The soil texture composition of both the VT site and the shallow sedge pine swamp is presented in Table 2.

Table 2. The texture of mineral soil in the experimental areas.
Taulukko 2. Kivennäismaan raekoostumus tutkituilla kasvupaikoilla.

Depth, cm *Syvyys, cm*	Soil texture, % *Raekoostumus, %*								
	Gravel *Sora*		Sand *Hiekka*		Fine sand *Hieta*		Silt *Hiesu*		Clay *Savi*
	(20—6 mm)	(6—2 mm)	(2—0.6 mm)	(0.6—0.2 mm)	(0.2—0.06 mm)	(0.06—0.02 mm)	(0.02—0.006 mm)	(0.006—0.002 mm)	(0.002 mm)
	Shallow sedge pine swamp *Ohutturpeinen suursararäme*								
15—20	5	1	9	21	45	10	5	2	2
	VT site *Puolukkatyypin kangas*								
0—5	4	3	9	26	39	10	5	2	2
5—10	10	2	9	24	34	10	6	2	3
10—15	13	4	10	23	34	8	4	1	3
15—20	11	5	9	31	25	9	5	2	4

Eighteen sample trees were selected at random from each of the three sites for detailed study (Fig. 1). The average dimensions of them were as follows:

	Diam. at breast height, cm	Height, m	Length of the living crown as % of the total height
Sedge pine swamp	11.9	8.0	48
Shallow sedge pine swamp	11.7	9.8	57
VT site	12.0	10.4	55

The mean age of the trees was 70—90 years.

The root studies, discussed later in part b) (p. 14), showed that in the case of the sedge pine swamp, the roots of the sample trees were found in most cases near the surface, but in the VT site they were found much deeper. The average depth of the root systems of pine in the sedge pine swamp was 3.8 cm, 5.6 cm in the shallow sedge pine swamp, and 7.0 in the VT site (Table 3). The depth distribution of the root systems of the ground vegetation did not show a corresponding trend, for they were closest to the surface in the VT site and deepest in the shallow sedge pine swamp. The superficiality of pine root systems in peatlands as compared to mineral soils, has been demonstrated also in several earlier studies (e.g. Kalela 1949, Heikurainen 1955, Paavilainen 1966).

It can also be seen in Table 3 that the total length of pine roots was approximately the same in all the sites studied. The total length of ground vegetation roots was greater in the swamp sites than in the VT site.

Each sample tree was isolated from its surroundings by means of polythene sheeting which extended from the ground surface down to a depth of half a meter (Fig. 2) at a distance of 2 m from the base of the trunk. A total of 20 g of urea fertilizer containing ^{15}N isotope (^{15}N excess 0.9 %) was spread in 0.5 m wide strips at right angles to each other, with the sample tree at the point of intersection, within the area enclosed by the polythene



Fig. 2. Sample tree isolated from its surroundings by polythene sheeting.
Kuva 2. Ympäristöstään muovilla eristetty koepuu.

Table 3. Amount of roots in the various sites studied.
Taulukko 3. Juurten määrä eri kasvupaikoilla.

Depth, cm *Syvyys, cm*	Sedge pine swamp *Suursararäme*			Shallow sedge pine swamp *Ohutturpeinen suursararäme*			VT-site *VT-kangas*			
	Pine roots *Männyn juuria* m/m²	Ground vegetation roots *Pintakaskasvillisuuden juuria* m/m²	Total amount of roots *Juuria yhteensä* m/m²	Pine roots *Männyn juuria* m/m²	Ground vegetation roots *Pintakasvillisuuden juuria* m/m²	Total amount of roots *Juuria yhteensä* m/m²	Depth, cm *Syvyys, cm*	Pine roots *Männyn juuria* m/m²	Ground vegetation roots *Pintakasvillisuuden juuria* m/m²	Total amount of roots *Juuria yhteensä* m/m²
							Humus (0—3.1 cm) Mineral soil *Kivennäismaa*	160.8	534.8	695.6
0—5	271.0	720.7	991.7	179.7	409.6	589.3	0—5	73.1	251.5	324.6
5—10	83.6	331.2	414.8	99.5	459.6	559.1	5—10	43.8	152.8	196.6
10—15	1.6	215.7	217.3	39.7	318.1	357.8	10—15	42.4	135.7	178.1
15—20	1.2	213.4	214.6	6.7	250.4	257.1	15—20	20.0	78.2	98.2
Total — *Yhteensä*	357.4	1 481.0	1 838.4	325.6	1 437.7	1 763.3		340.1	1 153.0	1 493.1
Average depth of root system *Juuriston keskisyvyys* [1])	3.8	7.2	..	5.6	8.9	..		7.0	7.1	..

[1]) Average depth of roots weighted by the length of roots (cf. K a l e l a 1949)
Juurten pituudella punnittu keskisyvyys (vrt. esim. K a l e l a 1949).

sheeting. The total fertilized area around each sample tree thus measured 3.75 m^2. The quantity of fertilizer used was equivalent to 53.3 kg N/ha.

Fertilizer applications were carried out on 18. 12. 1970, 1. 3. 1971, 27. 4. 1971, 19. 5. 1971 and 16. 7. 1971. The sample trees to be fertilized at different times were selected randomly, there being three of them on each site at each time of fertilizer application. In addition, three sample trees were left unfertilized on each site to act as controls.

The uptake of fertilizer nitrogen by the sample trees was studied on the basis of needle analysis. The needle samples were taken from the third branch whorl counted from the top of the tree. Samples were taken from the unfertilized control trees once a month between Jan.—Oct. 1971, and from the fertilized trees also once a month commencing from the time of fertilizer application. The samples taken between Jan.—June comprised needles produced in 1970, and those taken between July—Oct. ones produced in 1971. Initially, the ^{15}N level of 12 sample trees fertilized between Jan.—April and 4 control trees was analysed. After the analyses showed that these samples contained no nitrogen originating from the fertilizer, further analyses were limited to those samples taken between May—Oct. 1971. The total nitrogen content of these samples and the proportion of nitrogen originating from the fertilizer was then determined.

In addition to the earlier mentioned study objects, sample trees fertilized in May and unfertilized control sample trees were selected from each site (sample trees No. 2, 4, 6, 7, 19, 28, 30, 35, 37, 44, 45, 54) and used for further study. The following factors were investigated:

a) The physical properties and the nutrient level of the soil. Two samples were taken from next each sample tree between 10.—20. 10. 1971 (one from each side of the tree in the unfertilized areas situated at a distance of about 1 m from the tree) using the soil sampler developed by Juusela, Kaunisto and Mustonen (1969, p. 9—11). The samples which had a diameter of 19 cm were taken down to a depth of 30 cm. Those taken from peatlands were divided from the surface downwards into 5 cm long sections, and those from the mineral soil site also into 5 cm long sections after the humus layer had been separated away. The results of the analyses carried out on these samples are presented in Tables 1 and 2.

b) The structure of the root systems of the tree stands and the ground vegetation. The samples used in the study were taken from the fertilized areas near to the sample trees using the same technique and at the same time as those in a). The root systems were studied by the quantitative method proposed by Kalela (1949), Heikurainen (1955) and Paavilainen (1966). The length of the roots of the pines and the ground vegetation were studied in the same layers as those in which the analyses concerning the physical properties of the soil and the nutrient level were made.

c) The total nitrogen content and the proportion of ^{15}N fertilizer nitrogen in the total nitrogen of the trunk, bark, and different aged needles in different parts of the tree. The sample trees were felled for this purpose on 19.—20. 10. 1971

and their crowns divided into three parts. Needles produced in 1969, 1970 and 1971 were taken from each third for analysis. Although stem wood and bark samples were taken from five different points along the trunks, only the nitrogen content of samples taken from halfway along the trunk were actually measured.

d) The total nitrogen content and the proportion of ^{15}N fertilizer nitrogen in the total nitrogen of the dwarf shrubs and other plants forming the field layer, and mosses. Samples representative of the fertilized area next to each sample tree were collected for this purpose on 19.—20. 10. 1971. About 20 % of the mosses and 80 % of the dwarf shrubs and other field layer plants growing on the fertilized areas were collected for analysis.

e) The ^{15}N content in the peat (0—20 cm) and roots of the trees and ground vegetation growing on sedge pine swamps. The analyses concerning the root systems were carried out on the samples described in b). Two separate samples were taken from the fertilized area next to each sample tree in the same way as in b) for studies on the peat.

f) Estimation of the biomass of the trees and ground vegetation growing on sedge pine swamp. The stump and rootstock of sample tree No. 54 was dug out of the ground for this investigation. Samples were then taken from the stump, trunk and crown and their dry weight measured by weighing. The values obtained were multiplied by the respective ratios between the measured fresh weights in order to obtain values for the various parts of the tree in question. The dry weight (g/m^2) of the ground vegetation and the fine roots was determined using samples obtained in the forementioned manner. Thus a rough estimate was obtained which could be used to determine the ratio between the biomass of the trees and the ground vegetation.

Figure 3 shows the meteorological conditions prevailing during the study period, and includes the average daily temperature and amount of precipitation for the period Sept. 1970—Oct. 1971. The observations were made at the Alkkia meteorological station of the Parkano research station, situated about 6 km from the experimental area. Some idea of the variations in the thickness of the snow cover can be obtained from the measurements made on a *Spagnum fuscum* open swamp situated 4 km away. The results are presented later on in this paper (p. 33). The snow thickness on the experimental area was also measured and meteorological observations were made whenever fertilizer was applied or needle samples taken.

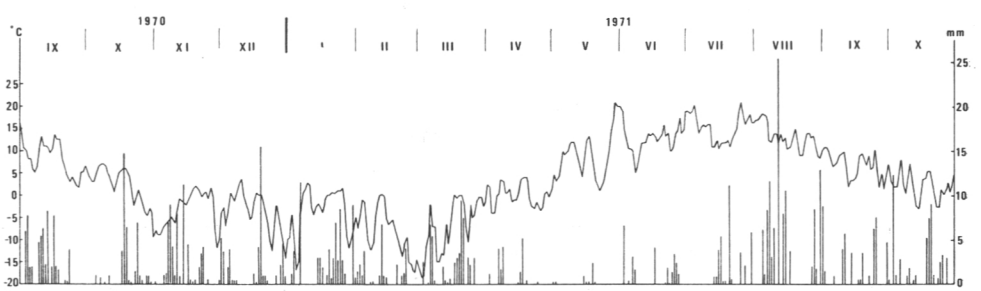


Fig. 3. Air temperature and amount of precipitation recorded at Alkkia meteorological station.
Kuva 3. Ilman lämpötila ja sateen määrä Alkkian säähavaintoasemalla.

22. Experiment on a Sphagnum fuscum open swamp

A comparative field experiment concerning the movement of ^{15}N urea fertilizer was set up on a drained *Sphagnum fuscum* open swamp. The pH value of the peat was clearly lower and the nutrient level also lower in this type of peatland than in the sedge pine swamp (Table 1). Sixty four experimental points were marked out near the ditches on the *Sphagnum fuscum* open swamp (Fig. 4). Circular areas with a diameter of 19 cm (same size as the samples used in the laboratory experiment) situated next to the points, received surface fertilizer applications of 1 g ^{15}N labelled urea. The fertilizer dose was given to three randomly selected points at each application time. Altogether, fertilizer applications were carried out 18 times at weekly intervals between 2. 1.—29. 4. 1971. In addition, ten unfertilized control points were left on the experimental area.

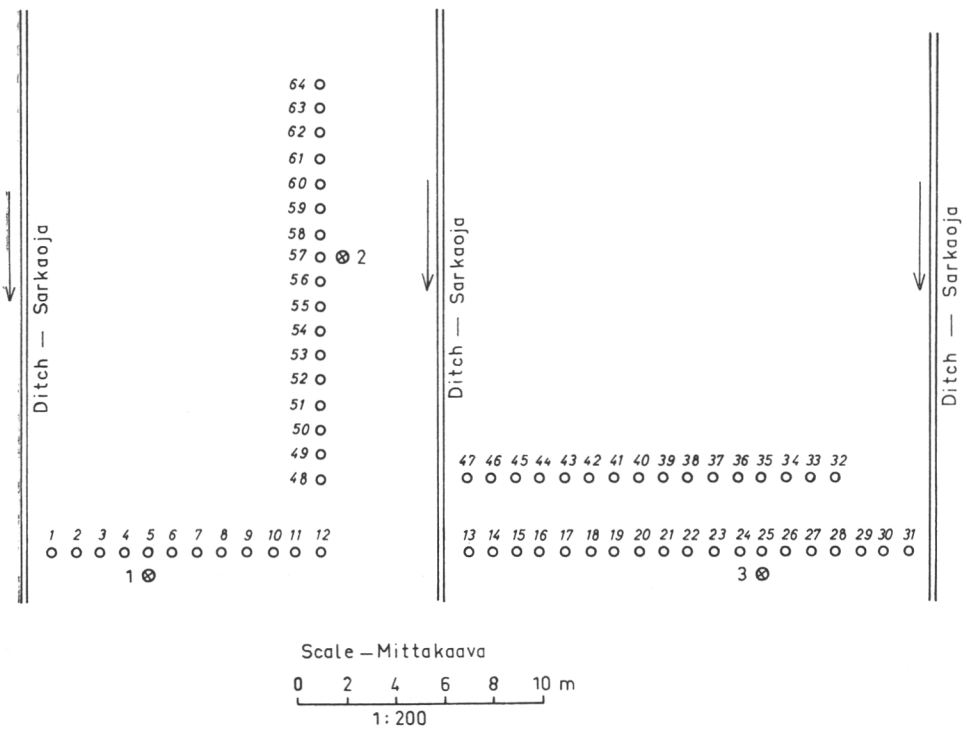


Fig. 4. Fertilized sample points (open circles) and the points where snow depth and water equivalent values were measured (circles containing a cross).

Kuva 4. Lannoitetut koepisteet (avoimet ympyrät) sekä lumen syvyyden ja vesiarvon mittauskohdat (ympyrät, joiden sisällä risti).

The thickness and density of the snow was measured at three observation points on the experimental area during the experiment (Fig. 4). The thickness of the snow layer and the water equivalent values of the snow can be seen in Fig. 9, p. 33.

Soil samples were taken from all the experimental points during 11. 6.—14. 6. 1971. The cross-sectional area of the soil sampler was 4 cm × 5 cm. Sampling was done within the fertilized circle down to a depth of 20 cm from the peat surface and the samples were then divided, after removal of the litter and living moss layer, into 5 cm long sections measured from the peat surface downwards.

As analysis of all the samples was economically impossible, two unfertilized control samples and ten samples from the points fertilized at the following times were analysed: 2. 1., 5. 1., 5. 2., 5. 3., 26. 3., 2. 4., 8. 4., 16. 4., 23. 4. and 29. 4. 1971. Most of these samples had been fertilized at times when changes in the snow cover were greatest.

23. Laboratory experiment

The possible volatilization and downward movement in peat of the nitrogen given as urea was also studied in the laboratory. The experiment was carried out at the Forest Research Institute's Alkkia field station during the period 7. 1.—6. 2. 1971. Samples for this purpose were taken with the forementioned soil sampler developed by J u u s e l a, K a u n i s t o and M u s t o n e n (1969, p. 9—11), which meant that the samples could be placed in plastic tubes (diameter of 190 mm) without disturbing the structure of the soil. The samples were 50 cm long. A container was tightly attached under every plastic tube so that all the water passing out of the samples could be collected.

The samples used in this experiment were taken from the same sedge pine swamp as that used as one of the sites in the forest covered soils experiment. Altogether, there were 54 samples which were divided up on the basis of fertilization and irrigation intensity into the following treatments:

	Irrigation, mm/day				
Fertilization	0	0.5	1	2	4
	No. of samples				
^{15}N labelled urea, 1 g	9	9	9	9	9
No fertilization	9	—	—	—	—

Of the samples that received each treatment combination, 3 were taken for further treatment after 10 days, 3 after 20 days, and 3 after 30 days from the beginning of the experiment. Fertilization, irrigation intensity, and the time at which the samples were removed for further study, were all selected randomly. In order to prevent edge effects, an untreated 1 cm wide strip was left around the edge of the container whenever fertilization or irrigation was carried out.

Before further studies were performed on the samples, they were divided from the surface downwards into 5 cm long sections. When the sample parts were analysed, the ^{15}N content down to a depth of 50 cm was first determined in two of the samples which had received the strongest irrigation intensity (4 mm daily irrigation for 30 days). Analysis of the remaining samples was restricted to the first 15 cm, after it became clear that only a very small amount of the fertilizer nitrogen in the above samples had moved deeper than 15 cm.

The air temperature and relative humidity were measured during the experiment with a thermohygrograph placed at the same level as the upper surface of the experimental containers. The air temperature and relative humidity recorded during the experiment are presented in Fig. 5.

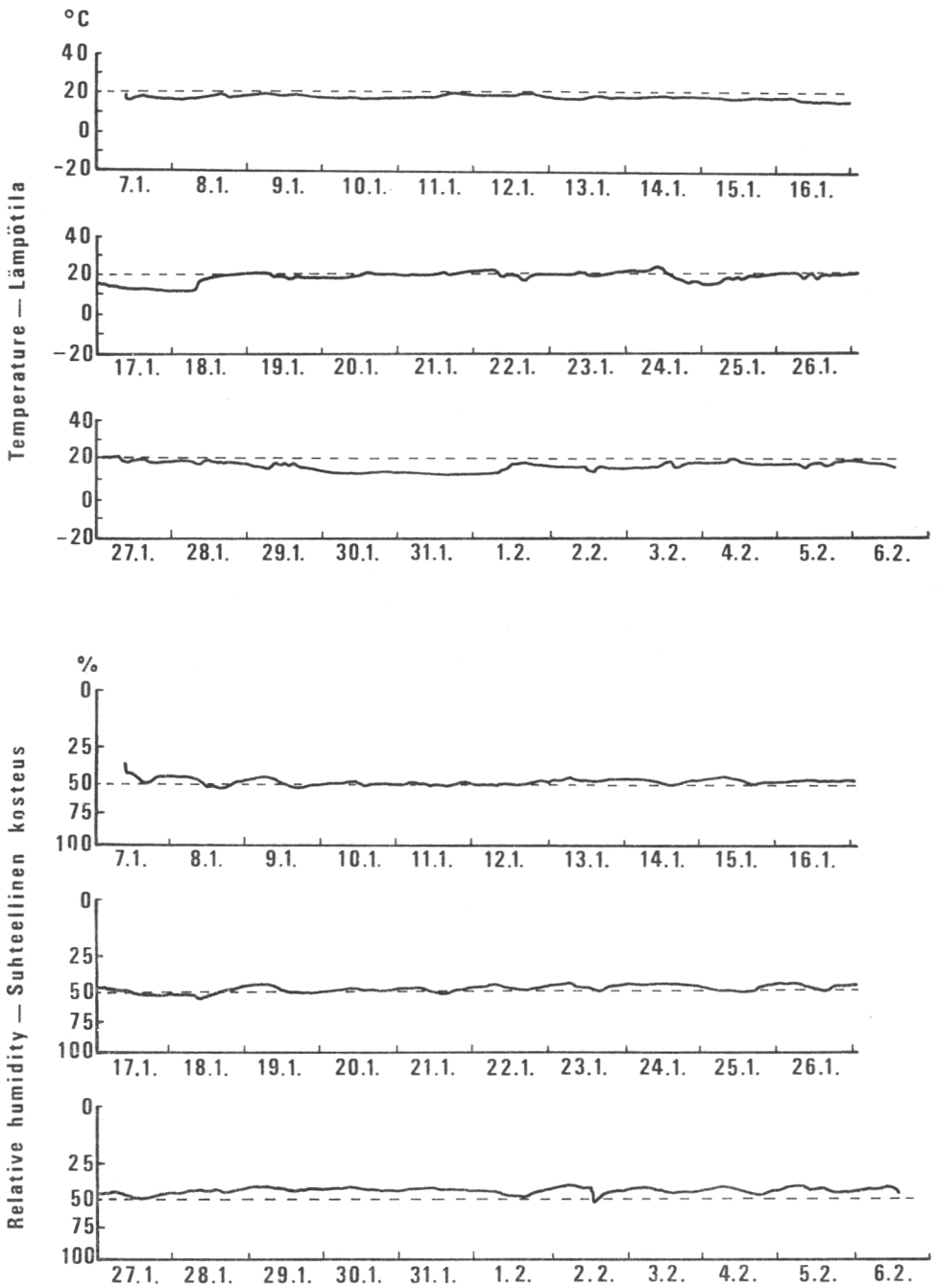


Fig. 5. Air temperature and relative humidity during the laboratory experiment.
Kuva 5. Ilman lämpötila ja suhteellinen kosteus laboratoriokokeessa.

3. RESULTS

31. Uptake of fertilizer nitrogen by pine on the basis of needle analysis

As was earlier mentioned on p. 14, the nitrogen content of needle samples taken at different times were initially determined by spot checkning. As no nitrogen originating from the fertilizer was found in needle samples taken between Jan.—April, the nitrogen content of the needles was determinated only in the samples taken between May—Oct., apart from the ones used for spot checks.

The effect of site, time of fertilizer application, and time of needle collection on the nitrogen content of the needles was found to be statistically significant (Table 4). As the material collection in October consisted of only one time of fertilizer application, a corresponding analysis was not carried out.

The total nitrogen content of the needles is presented in Fig. 6, and the proportion of the total nitrogen originating from the urea on different sites in Fig. 7.

Table 4. Results of the significance tests for the nitrogen content of the pine needles. Samples taken in May-September.

Taulukko 4. Merkitsevyystestien tulokset eri tekijöiden vaikutuksesta männyn neulasten typpipitoisuuteen. Touko-syyskuussa otetut näytteet.

Source of variation *Vaihtelun aiheuttaja*	Total nitrogen content of needles *Neulasten kokonaistyppipitoisuus*	Proportion of N fertilizer in total nitrogen *Lannoitetypen osuus kokonaistypestä*
	F	F
Site — *Kasvupaikka*	7.58***	6.66**
Application time — *Lannoitteen levitysajankohta*	3.47**	3.05*
Time of sampling — *Neulasten ottoaika*	44.47***	40.16***
Application time x site — *Levitysajankohta x kasvupaikka*	—	5.02***

[1]) * = significant at 95 % confidence level
merkitsevä 95 %:n luotettavuudella

** = significant at 99 % confidence level
merkitsevä 99 %:n luotettavuudella

*** = significant at 99.9 % confidence level
merkitsevä 99.9 %:n luotettavuudella

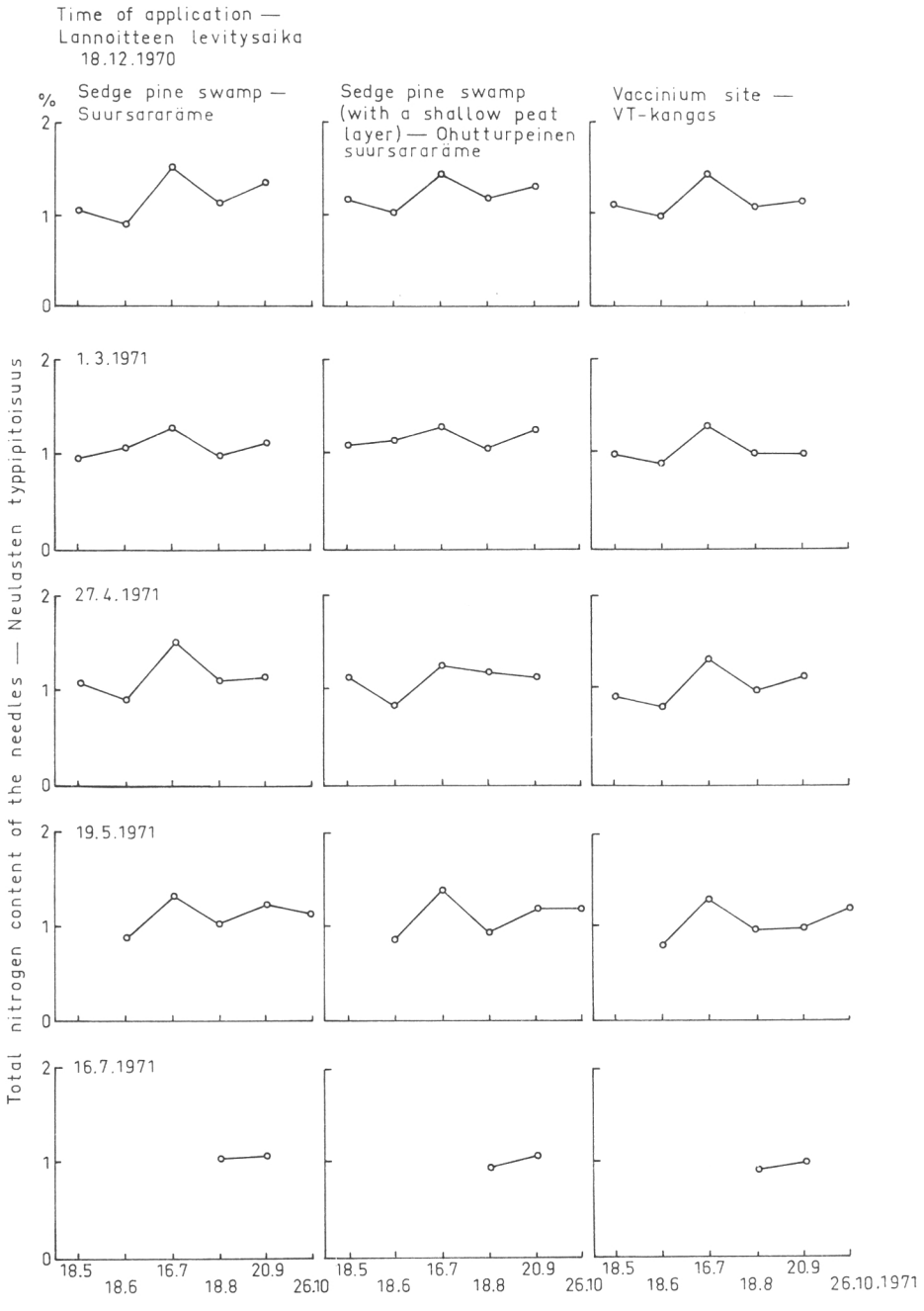


Fig. 6. Total nitrogen content of the pine needles.
Kuva 6. Männyn neulasten kokonaistyppipitoisuus.

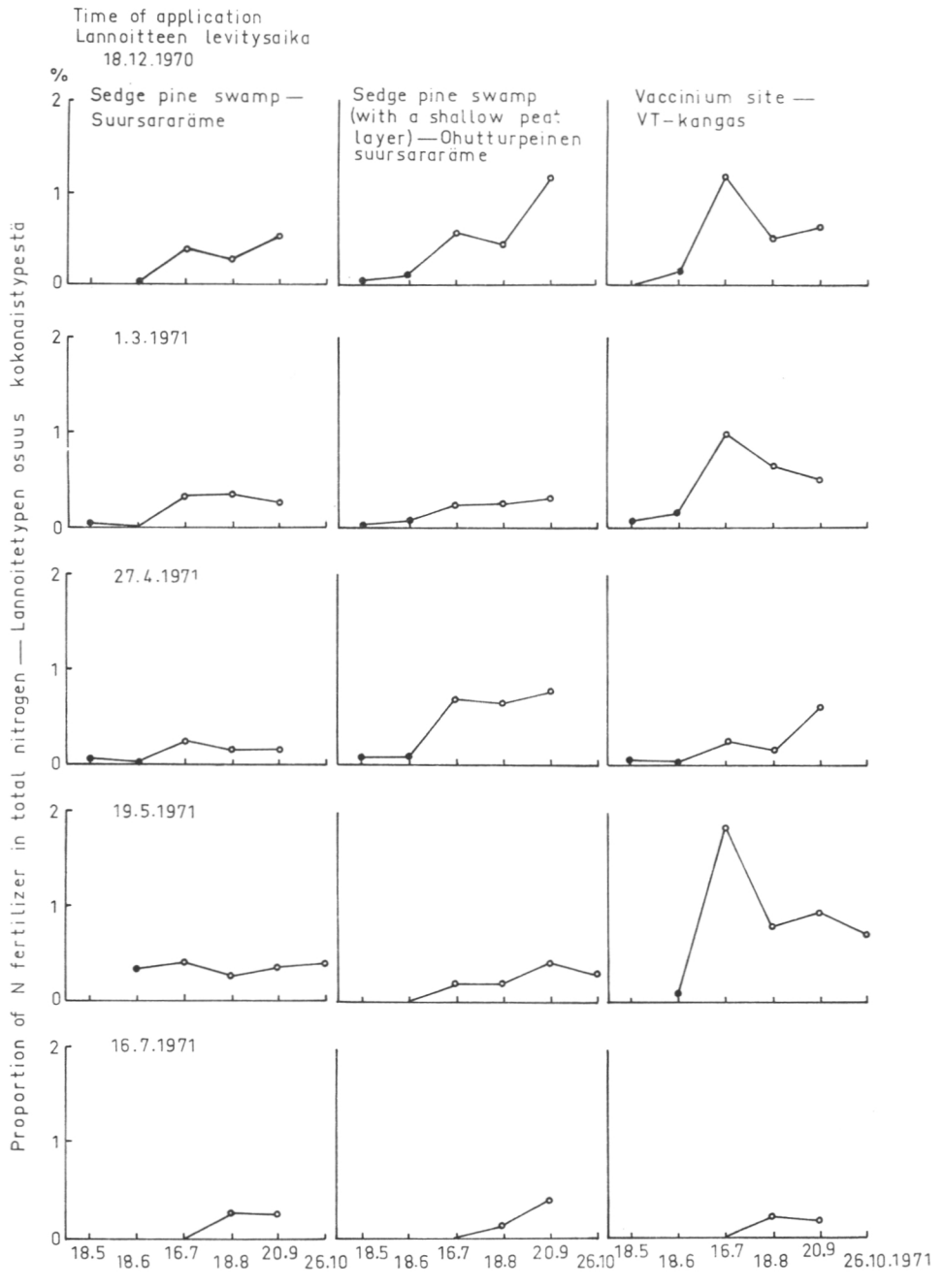


Fig. 7. Proportion of fertilizer nitrogen in the total nitrogen of the pine needles.
Kuva 7. Lannoitetypen osuus männyn neulasten kokonaistypestä.

311. Effect of the site

It can be seen from Fig. 6 that the total nitrogen content of the sample tree needles was greatest on the sedge pine swamp (on average 1.13 %), next highest on the shallow peated sedge pine swamp (1.12 %), and lowest on the VT site (1.04 %). However, the nitrogen content of the needles from the sedge pine swamp was also quite low. Paarlahti, Reinikainen & Veijalainen (1971) for instance, have come to the conclusion that nitrogen should be included in the fertilization of peatlands, if the nitrogen content of the needles is lower than 1.20 %.

The proportion of fertilizer nitrogen in the total nitrogen was highest on the mineral soil site and showed a decreasing trend as the thickness of the peat increased (Fig. 7). The effect of the site on the proportion of fertilizer nitrogen thus had an opposite effect to that which it had on the total nitrogen content of the needles.

The results prove, that the sample trees growing on the peatlands have clearly taken up less fertilizer nitrogen given as urea than those on the mineral soil site and on the thick peated peatland less than on the shallow peated one. The amount of fertilizer nitrogen bound by the needles on the VT site was approx. 2.3 times higher and on the shallow peated sedge pine swamp 1.6 times higher per unit dry weight than on the thick peated sedge pine swamp.

312. Effect of the time of fertilizer application

A total of five different times of fertilization application were used in the study: 18. 12. 1970, 1. 3. 1971, 17. 4. 1971, 19. 5. 1971 and 16. 7. 1971. At the time when fertilizer was applied in Dec. 1970, there was approx. 5 cm of snow on the ground. However, the snow cover was removed and the fertilizer applied to the bare ground. The air temperature was —3 °C. When fertilizer application was carried out in March 1971, there was 30—35 cm of snow on the thick peated sedge pine swamp and 25—30 cm on the other sites used in the study. The air temperature was —15 °C. The snow thickness at the time of fertilizer application in April was approx. 10 cm, and the air temperature was +5 °C. The July fertilization was carried out after quite a long period of low rainfall (cf. Fig. 3), but rain was falling during the actual application. The air temperature was +15 °C.

The time of fertilization application had a significant effect on the total nitrogen content of the needles of the sample trees (cf. Table 4). The nitrogen content of the needles of the sample trees which received fertilizer in July was lower on average than the others. The most likely reason for this is that

needle samples were taken from these sample trees only in August and September, at which time the nitrogen level in needles is usually low.

The time of application clearly affected the extent to which the sample trees took up nitrogen given as urea (Fig. 7). The proportion of fertilizer nitrogen in the total nitrogen of the needles taken from the sample trees which received the urea fertilizer on snowless ground before the start of tree growth was approximately twice the level in the sample trees which received the fertilizer on top of the snow cover. The trees have not been able to take up much nitrogen from the fertilizer given in July during the same year as the fertilization was carried out.

The effect of the time of application was significantly dependent upon the site (cf. Table 4). It can be seen from Fig. 7, that the differences between the various times of application were greater on the mineral soil site than on the peatlands. In addition, the results show that the effect of fertilization in May on the shallow peated sedge pine swamp remained relatively weaker than on the other sites. However, this result may have been caused by other factors, apart from the site properties, because the other application carried out during a snowless period (in Dec. 1970) has also increased the proportion of ^{15}N nitrogen in the total nitrogen of the needles on the shallow peated sedge pine swamp to a similar extent as on the other sites.

As regards applications made on the bare ground, quite as good results have been obtained when application has been done on thawed ground in the spring before tree growth starts, as when it has been done on strongly frozen ground in December. The effect of the time of application was in this case also less on the peatlands than on the mineral soil site.

313. Nitrogen content of the needles at different times during the growing season

After comparing the nitrogen content of the needles at different times (Fig. 6), it becomes clear that the nitrogen content of the needles produced in 1970 was, in the case of the whole material, on average 1.04 % in May and fell to 0.92 % towards the middle of June. The nitrogen content of the new needles produced in 1971 was on average 1.34 % in the middle of July and then clearly decreased until the middle of August to 1.05 %. In September, the total nitrogen content of the needles increased to 1.16 % and further increased in October to 1.20 %. This last result, however, is questionable because the material for October was small. According to several earlier studies, noticeable variations in the nutrient content of the needles do occur throughout the growing season (e.g. White 1954, Tamm 1955, 1968, Hoffmann 1967). For example, the results which Tamm

(1955) obtained show that the nutrient content in the needles was at its greatest late in the autumn and winter, and at its lowest in the beginning of the summer.

The trees have taken up only a small amount of fertilizer nitrogen by the middle of June. The proportion of fertilizer nitrogen in the total nitrogen of the needle samples taken in May was on average 0.01 %, and of those taken in June 0.04 %. The proportion of fertilizer nitrogen in the samples taken in July, which were new needles produced in 1971, was noticeably greater — on average 0.56 % of the total nitrogen. The proportion of fertilizer nitrogen then changed and showed the same trend as the total nitrogen level of the needles, i.e. the level decreased in August and increased again in September.

The proportion of fertilizer nitrogen in the total nitrogen of the needles is smaller in this study than that which for instance Nömmik (1966) and Björkman, Lundeberg & Nömmik (1967) have presented. The proportion of fertilizer nitrogen in the total nitrogen of the needles, according to Nömmik's material (1966), was on average 2.23 % by the end of the first growing season. The corresponding proportion found in this study was less than 1.00 %. The most likely reason for this is the small amount of fertilizer (53.3 kg N/ha) used in this study, and the fact that large trees were studied while Nömmik (1966) used seedlings about 10 years old in his experiments.

The results show that the sample trees have taken up fertilizer nitrogen, given as urea, so slowly that the nitrogen content of the needles can effectively be affected in the year of fertilization if fertilization is carried out before the start of the trees' growing season.

The low ^{15}N content of the samples taken in May and June, as well as the results of analyses carried out on samples taken between Jan.—Apr. (cf. p. 14), show that the sample trees have been able to taken up very little, if any at all, of the fertilizer nitrogen before the start of the growing season.

32. Retention of fertilizer nitrogen by different parts of the tree and ground vegetation

321. Crown of the tree

The total nitrogen content and the proportion of fertilizer nitrogen in the total nitrogen of different aged needles from pines growing on various sites was studied using sample trees (cf. p. 15) felled at the end of October. The analyses concerning the total nitrogen were carried out on samples taken from the upper third of the crown, the middle part of the crown,

Table 5. Nitrogen content of pine needles in different parts of the crown.
Taulukko 5. Männyn neulasten typpipitoisuus latvuksen eri osissa.

Site *Kasvupaikka*	Needles produced in the year *Neulasvuosikerta*					
	1969		1970		1971	
	A	B	A	B	A	B
	Upper part of the crown *Latvuksen ylin osa*					
Sedge pine swamp — *Suursararäme*	1.15	0.21	1.13	0.16	1.18	0.39
Shallow sedge pine swamp — *Ohutturpeinen suursararäme*	1.15	0.20	1.23	0.31	1.21	0.31
VT site — *VT kangas*	1.14	0.50	1.15	0.48	1.21	0.72
	Middle part of the crown *Latvuksen keskiosa*					
Sedge pine swamp — *Suursararäme*	1.18	..	1.21	..	1.23	..
Shallow sedge pine swamp — *Ohutturpeinen suursararäme*	1.34	..	1.41	..	1.38	..
VT site — *VT kangas*	1.29	..	1.37	..	1.34	..
	Lower part of the crown *Latvuksen alin osa*					
Sedge pine swamp — *Suursararäme*	1.26	..	1.32	..	1.33	..
Shallow sedge pine swamp — *Ohutturpeinen suursararäme*	1.31	..	1.34	..	1.38	..
VT site — *VT kangas*	1.27	..	1.28	..	1.28	..

A = Total nitrogen content of needles, % — Neulasten kokonaistyppipitoisuus, %
B = Proportion of N fertilizer in total nitrogen, % — Lannoitetypen osuus kokonaistypestä, %

and the lower third of the crown. The proportion of fertilizer nitrogen was studied on needle samples taken only from the upper third of the crown. The results of the analyses are presented in Table 5, and the statistical significance of the effect of different factors, can be found in the following text table.

Source of variation	Total nitrogen content of the needles	Proportion of fertilizer N in the total nitrogen
	F	F
Part of the crown	8.89***	—
Site	3.00	1.20
Age of the needles	1.31	0.43

The effect of the site on the total nitrogen content of the needles and the proportion of fertilizer nitrogen in the total nitrogen was not statistically significant in this part of the study material. The needle age did not have a significant effect either. The variance analysis did show, however, that the position of the needles in the crown had a significant effect on the total nitrogen content of the needles.

The total nitrogen content of the needles in the top of the crown was smaller on average than in the middle part and in the lower third (Table 5). In the study carried out by Björkman, Lundeberg & Nömmik (1967), the nitrogen content of the needles in the top of the crown was 1.09 %, in the middle part 1.14 %, and in the lowest third 1.16 %.

When estimating the total amount of fertilizer nitrogen retained by the needles, the results of the analyses made on needle samples taken from the top of the crown have been considered to represent the proportion of fertilizer nitrogen. In the case of the branches, the values obtained from the analyses carried out on pine stemwood and bark samples have been considered to represent the proportion of fertilizer nitrogen.

322. Trunk and root system of the tree

It can be seen from the analysis results presented in Table 6, that the nitrogen content of the stemwood of the sample trees was very low (0.04—0.06 %) on all the sites studied. The proportion of fertilizer nitrogen in the total nitrogen of the stemwood was also small, the calculated averages for the different sites varying between 0.21—0.33 %.

The nitrogen content of the bark of the sample trees was on average 0.33—0.44 %, which is noticeably greater than that in the stemwood. The proportion of fertilizer nitrogen in the bark samples was also greater than in the stemwood. These estimations were carried out on samples taken

Table 6. Nitrogen content of stem and root system of pine.
Taulukko 6. Männyn rungon ja juuriston typpipitoisuus.

Site *Kasvupaikka*	Total nitrogen, % *Kokonaistyppi, %*	Proportion of N fertilizer in total nitrogen, % *Lannoitetypen osuus kokonaistypestä, %*
	Stem wood — *Runkopuu*	
Sedge pine swamp — *Suursararäme*	0.05	0.25
Shallow sedge pine swamp — *Ohutturpeinen suursararäme*	0.04	0.21
VT site — *VT kangas*	0.06	0.33
	Bark — *Kuori*	
Sedge pine swamp — *Suursararäme*	0.33	0.43
Shallow sedge pine swamp — *Ohutturpeinen suursararäme*	0.44	0.33
VT site — *VT kangas*	0.42	0.40
	Root system — *Juuristo*	
Sedge pine swamp — *Suursararäme*	0.69	0.64

from halfway along the trunk. A better idea would have been obtained about the nitrogen content of the whole of the trunk, which may vary at different heights (cf. Mälkönen 1970), if samples taken from different heights had been studied. Unfortunately this was not possible.

When Mälkönen (1972) calculated the amount of nutrients removed from stands by harvesting, he found that the nitrogen content of the stemwood was 0.067 % N, and that of the bark was 0.31 %.

There were comparatively clear differences in the nitrogen content of samples taken from different sites, but the effect of the site was not statistically significant (for the total nitrogen in the stemwood $F = 0.56$, and in the bark $F = 4.31$; for the proportion of fertilizer nitrogen in the stemwood $F = 1.49$, in the bark $F = 0.33$).

The nitrogen content of the root systems was determined only for the sample trees growing on the sedge pine swamp. The total nitrogen content of the root systems was on average 0.69 %, and the proportion of fertilizer nitrogen in the total nitrogen was 0.64 %.

323. Ground vegetation

The dwarf shrubs and mosses making up the ground vegetation were examined separately on all the three sites. However, all the roots of the ground vegetation were handled together, and only those from the thick peated sedge pine swamp were subjected to analysis.

The results presented in Table 7 show that the nitrogen content of the dwarf shrubs varied between 1.07—1.30 %. The proportion of fertilizer nitrogen in the total nitrogen was 2.53—3.91 %, which was noticeably greater than that in the pine needles (cf. Fig. 7). The site did not significantly affect the total nitrogen content of the dwarf shrubs ($F = 1.40$) or the proportion of fertilizer nitrogen in the total nitrogen ($F = 0.30$).

The total nitrogen content of the mosses was slightly lower than that of the dwarf shrubs, 0.93—1.04 %. The mosses retained greater amounts of fertilizer nitrogen than the dwarf shrubs, as the proportion of fertilizer nitrogen in the total nitrogen of the mosses was 8.47—11.34 %. The site did not significantly effect the total nitrogen content of the mosses ($F = 4.28$), nor the proportion of fertilizer nitrogen in the total nitrogen ($F = 0.37$).

The total nitrogen content (0.70 %) and the proportion of fertilizer nitrogen in the total nitrogen (0.47 %) of the root systems of the ground vegetation are approximately the same as those of the pine root systems.

Table 7. Nitrogen content of ground vegetation.
Taulukko 7. Pintakasvillisuuden typpipitoisuus.

Site *Kasvupaikka*	Total nitrogen, % *Kokonaistyppi, %*	Proportion of N fertilizer in total nitrogen, % *Lannoitetypen osuus kokonaistypestä, %*
	Dwarf shrubs — *Varvut*	
Sedge pine swamp — *Suursararäme*	1.30	2.53
Shallow sedge pine swamp — *Ohutturpeinen suursararäme*	1.18	3.06
VT site — *VT kangas*	1.07	3.91
	Moss vegetation — *Sammalet*	
Sedge pine swamp — *Suursararäme*	0.93	8.47
Shallow sedge pine swamp — *Ohutturpeinen suursararäme*	1.04	11.02
VT site — *VT kangas*	1.02	11.34
	Root system of ground vegetation *Pintakasvillisuuden juuristot*	
Sedge pine swamp — *Suursararäme*	0.70	0.47

324. Total amount of fertilizer nitrogen retained by the tree and ground vegetation

The dry weight of sample tree No. 54 and the ground vegetation surrounding it were determined (cf. p. 15) in order to study how much nitrogen, given as fertilizer, has been retained by the trees and the ground vegetation. The dry weights for the ground vegetation were calculated on the basis of the area where fertilization was supposed to have affected the nitrogen level of the organic material. Estimation of the effect of fertilization in the case of the mosses was restricted to the 0.5 m wide fertilized strip. The area affected by fertilization in the case of the dwarf shrubs was larger, because it was clear from the root studies that the roots of the dwarf shrubs grew into the fertilized area from quite far outside. As an exact analysis could not be done, it was assumed that the effect area for the dwarf shrubs was 8 m^2. In the case of the root system of the sample tree, the whole area limited by the polythene sheeting was regarded as the affected area. The calculated dry weights can be seen in the following table.

	Dry weight, kg
Pine	
Needles	1.2
Branches	2.9
Trunk	13.3
Stump and thick roots	9.7
Fine roots	1.7

Ground vegetation	
Dwarf shrubs	3.0
Mosses	0.8
Roots	5.0

The total amount of fertilizer nitrogen retained by the sample tree and ground vegetation was calculated using these dry weight values and the results presented earlier concerning the total nitrogen level and the proportion of fertilizer nitrogen in the total nitrogen. The proportion of bark was estimated to be 15 % of the dry weight of the stem, and the stump and thick roots.

Furthermore, it was possible to calculate the organic matter content of the peat and using these results to estimate the amount of fertilizer nitrogen in the ground surrounding the sample tree. The amount of nitrogen in the ground down to a depth of 20 cm was naturally calculated per 0.5 m wide fertilized strip.

The following results were obtained from the above calculations:

	Percentage of the nitrogen given as fertilizer
In the sample tree	2.3
In the ground vegetation	19.4
In the soil (0—20 cm)	44.0
Total	65.7

The amount of fertilizer nitrogen retained by the vegetation and the ground in this study, was found to be slightly smaller than that which has been presented in earlier studies. Björkman, Lundeberg & Nömmik (1967) found that when ammonium sulphate was used, 79.3 % of the nitrogen had become bound during the first growing season, of which 20.8 % was in the vegetation and 58.5 % in the soil. According to Nömmik & Popovic (1971), 87.1 % of the urea nitrogen had been bound by the end of September in the year of fertilization, of which 13.2 % was in the vegetation.

The general trend of the results obtained in this study is quite clear. Trees are obviously able to use only a very small part of the urea given as fertilizer during the first growing season when growing on sedge pine swamps. A noticeably greater part of the urea fertilizer is retained by the ground vegetation or remains in the ground, from where to a certain extent it can become available to the trees. Some of the nitrogen given as urea is probably not retained at all by the trees, ground vegetation or in the peat layer down to a depth of 20 cm. It has not been possible in this experiment to find out whether any of the fertilizer nitrogen has been lost through leaching or volatilization. However, this question is discussed

later on in the study on the basis of the results of an experiment carried out in the laboratory and an experiment set up on a *Sphagnum fuscum* open swamp.

33. Leaching and volatilization of fertilizer nitrogen in peat soils

The leaching and volatilization of urea from the peat surface were studied in the laboratory on samples taken from the experimental area on the sedge pine swamp (cf. p. 17). Urea containing ^{15}N was spread on the surface of the peat samples and different irrigation intensities were then applied. The leaching of urea was also studied in the experiment set up on the *Sphagnum fuscum* open swamp (p. 16).

331. Leaching

The results of the analysis show that even when large amounts of water are given during irrigation, after 30 days the fertilizer nitrogen is still largely retained in the first 5 cm of the peat (Fig. 8). The depth distribution of nitrogen movement has been greater, the more water has been applied into the surface of the experimental containers. However, it has been found that when the strongest irrigation intensity is used, i.e. 4 mm/day, there is very little fertilizer nitrogen deeper than 15 cm.

It can be seen below, that the differences between different peat depths and different irrigation intensities as regards the total nitrogen content and the proportion of fertilizer nitrogen were statistically significant. The interaction between the time elapsed since the start of the experiment and the depth of the sample, and also between the irrigation intensity and sample depth (in the case of the proportion of fertilizer nitrogen) were also significant.

Source of variation	Total nitrogen	Proportion of N fertilizer in the total nitrogen
	F	F
Depth	9.96***	319.65***
Irrigation intensity	3.93**	7.86***
Time elapsed since start of the experiment	0.72	0.91
Irrigation intensity x depth	0.72	2.58*
Time x depth	2.05*	2.30*

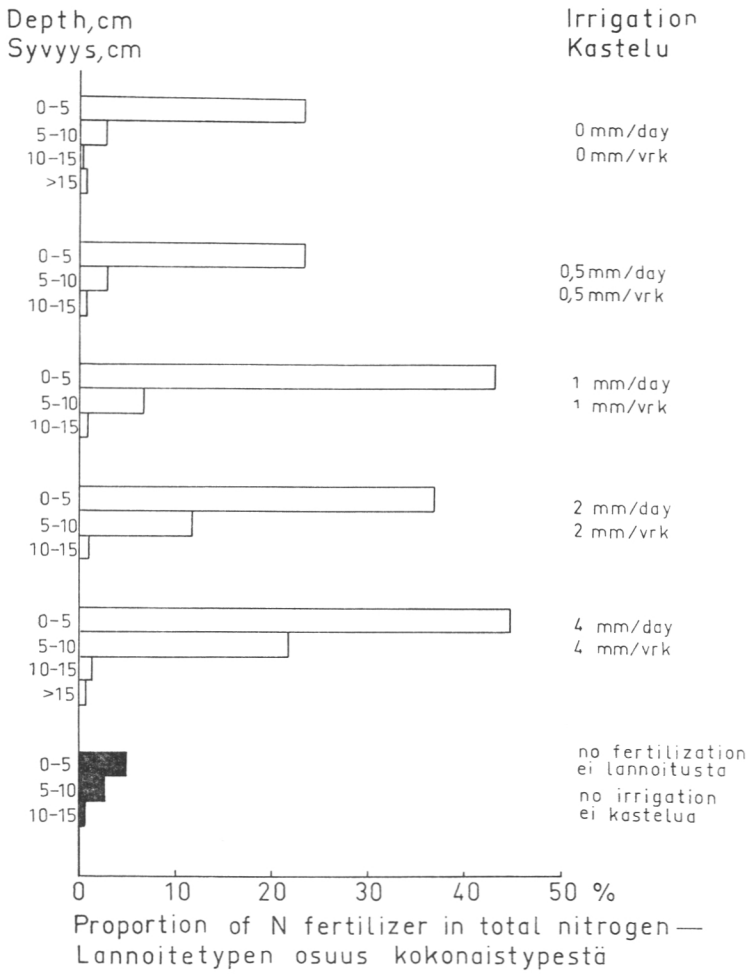


Fig. 8. Proportion of fertilizer nitrogen in the total nitrogen of the samples used in the laboratory experiment (average 10—30 days after the experiment commenced).

Kuva 8. Lannoitetypen osuus kokonaistypestä laboratoriokokeen näytteissä (keskimäärin 10—30 vrk:n kuluttua kokeen aloittamisesta).

The results of the experiment set up on a *Sphagnum fuscum* open swamp also show that the fertilizer nitrogen given as urea is strongly retained by the peat (Table 8). Several months after fertilizer application, most of the fertilizer nitrogen was still in the first 5 cm of the peat and the amount of nitrogen decreased from the surface downwards. However, some of the fertilizer nitrogen may have moved deeper than 20 cm in the peat, but judging by the results of the analyses obviously only very small quantities could be involved.

Table 8. Total nitrogen content of peat and the amount of nitrogen originating from the fertilizer at various depths after application at different times. Experiment on *Sphagnum fuscum* swamp. Analyses are made in 11.—14. 6.

Taulukko 8. Turpeen kokonaistyppipitoisuus ja lannoitteesta peräisin olevan typen määrä eri syvyyksissä annettaessa lannoite eri ajankohtina. Rahkanevan koe. Analyysit on tehty 11.—14. 6.

Depth, cm *Syvyys, cm*	Time of application *Lannoitteen levitysajankohta* 2.1.	15.1.	5.2.	5.3.	26.3.	2.4.	8.4.	16.4.	23.4.	29.4.	Mean *Keskiarvo*
	Total nitrogen, % — *Kokonaistyppi*, %										
0—5	1.00	0.89	0.94	0.89	0.90	1.00	0.87	0.94	0.96	0.94	0.93
5—10.....	0.90	0.92	0.93	0.85	0.83	0.82	0.74	0.98	0.93	0.69	0.86
10—15.....	0.87	0.93	1.02	0.85	0.69	0.87	0.82	0.89	0.81	0.94	0.87
15—20.....	0.82	0.89	0.84	1.00	0.82	0.93	0.78	1.07	0.59	1.18	0.89
Mean *Keskiarvo*	0.89	0.90	0.93	0.89	0.81	0.90	0.80	0.97	0.82	0.93	0.88
	Proportion of N fertilizer in total nitrogen, % — *Lannoitetypen osuus kokonaistypestä*, %										
0—5	0.93	11.92	1.92	1.58	2.72	0.56	1.34	3.37	8.79	8.28	4.14
5—10.....	1.45	1.40	0.60	0.43	0.68	1.94	0.86	0.76	2.07	2.69	1.29
10—15.....	0.48	1.45	0.37	0.85	0.34	0.52	0.58	0.63	0.95	1.22	0.74
15—20.....	0.48	0.75	0.57	0.31	0.52	0.34	0.35	0.29	0.59	0.45	0.47
Mean *Keskiarvo*	0.83	3.88	0.86	0.79	1.06	0.84	0.78	1.26	3.10	3.16	1.66

The time of application also had a clear effect on the retention of fertilizer nitrogen (Fig. 9). When application was carried out on bare ground, noticeably more nitrogen remained in the peat than when it was applied onto a snow cover. The strongest nitrogen retention occurred when application was carried out on frozen ground on 15. 1. 1971.

It can be seen in the following text table that the total nitrogen content in the peat was not significantly dependent on the sample depth or the time of fertilizer application in the experiment set up on the *Sphagnum fuscum*

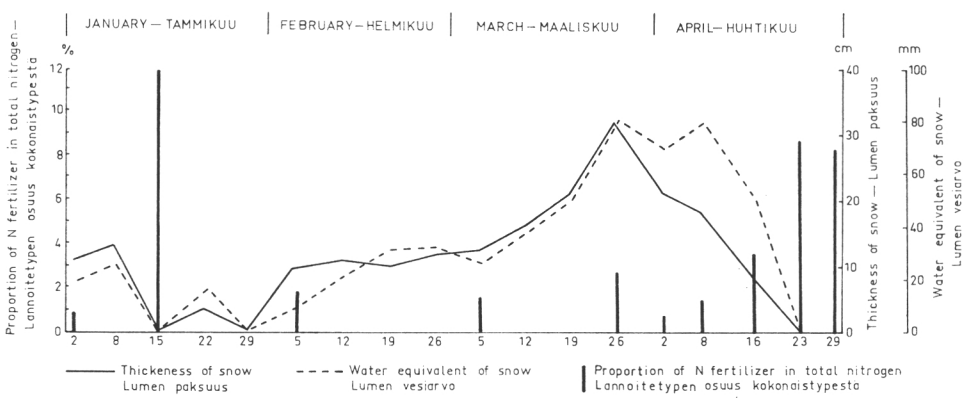


Fig. 9. Snow thickness and water equivalent values, and proportion of fertilizer nitrogen in the total nitrogen of the experiment set up on a *Sphagnum fuscum* open swamp.

Kuva 9. Lumen paksuus ja vesiarvo sekä lannoitetypen osuus kokonaistypestä rahkanevan kokeessa.

open swamp. On the other hand, these factors had a significant effect on the proportion of fertilizer nitrogen. The interaction between the sample depth and the time of application was also significant.

Source of variation	Total nitrogen	Proportion of N fertilizer in the total nitrogen
	F	F
Depth	1.06	33.72***
Time of application	1.18	6.96***
Depth x time of application	0.90	3.03***

332. Volatilization

The laboratory experiment was also designed to find out whether nitrogen given as urea volatilizes from the surface of the peat. The temperature and humidity at the top of the experimental containers were measured during the experiment with a thermohygrograph. The results of these measurements are presented in Fig. 5 (p. 19).

It can be seen from the results presented in Table 9, that when no irrigation at all was carried out, 75.3 % of the nitrogen given by fertilization remained in the sample. The amount of fertilizer nitrogen in the sample increased as the irrigation intensity was increased. In the case of the greatest irrigation intensity, i.e. 4 mm/day, more fertilizer nitrogen was found in the samples than had been given by fertilization. Nitrogen originating from urea fertilizer was also found in the samples which had not received any ^{15}N fertilization at all.

Table 9. Amount of nitrogen originating from the fertilizer at various depths in samples of the laboratory experiment (on an average 10—30 days after beginning the experiment)

Taulukko 9. Lannoitteesta peräisin olevan typen määrä eri syvyyksissä laboratoriokokeen näytteissä (keskimäärin 10—30 vrk:n kuluttua kokeen aloittamisesta).

Depth, cm *Syvyys, cm*	Fertilization with ^{15}N urea and irrigation (mm/day) *Lannoitus ^{15}N-urealla ja kastelu (mm/vrk)*					Without fertilization and irrigation *Ilman lannoitusta ja kastelua*
	0	0.5	1.0	2.0	4.0	
	Fertilizer nitrogen, mg *Lannoitetyppeä, mg*					
0—5	305.8	272.8	324.8	308.1	311.1	33.3
5—10	33.6	41.0	40.1	105.5	187.1	13.2
10—15	7.0	5.6	8.9	13.6	32.3	5.8
Total *Yhteensä*	346.4	319.4	373.8	427.2	530.5	52.3
	Fertilizer nitrogen, % of the amount used — *Lannoitetyppeä, % käytetystä määrästä*					
0—15	75.3	69.4	81.3	92.9	115.3	11.4

These results indicate that in the laboratory experiment, some of the nitrogen given as urea has obviously volatilized from the surface of the peat and collected on the surface of neighbouring sample containers. In the sample containers which had received irrigation intensities varying between 0—2.0 mm/day, there was altogether 3.6 g less fertilizer nitrogen than had been applied, while in the other containers there was altogether 1.1 g more fertilizer nitrogen than had been applied. Volatilization has been strongest when fertilization has been carried out without irrigation, for the nitrogen can only be moved below the surface layer of the peat by irrigation. There has been either a very small volatilization loss or none at all when the samples have been irrigated strongly.

4. DISCUSSION

The results of the study indicate that the thickness of the peat affected the utilization of fertilizer nitrogen by pine. Pines growing on mineral soil clearly took up more of the nitrogen from urea fertilizer labelled with ^{15}N per unit needle dry weight than those growing on peat soil, and more on shallow peated peatland than on thick peated one. The results thus show that the need for nitrogen fertilization has decreased with increasing peat thickness, just as has been presented in recommendations for practical forestry (e.g. Huikari and Paavilainen 1972). The main reason for this is that nitrogen is the nutrient which has the strongest effect on tree growth on the mineral soil in Finnish conditions (Viro 1965), while on the other hand the lack of phosphorus and potassium has the greatest effect on peatlands.

When discussing factors which may possibly have affected the more efficient uptake of fertilizer nitrogen by pines growing on the mineral soil site compared to those growing on the peatlands, attention should also be payed to the root system ratios of both the trees and the ground vegetation. The results showed that there were approximately as many pine roots on all the sites studied, but there were fewer ground vegetation roots on the mineral soil site than on the peatlands. Root system competition with the ground vegetation, which strongly affects the nutrient uptake of trees (cf. e.g. Hesselman 1910, 1917, Aaltonen 1920, 1926, Björkman 1945, Björkman & Lundeberg 1971), has thus been less on the mineral soil site than on the peatlands, in which case the pines have been able to take up nutrients given by fertilization more easily.

The different depth distribution of the root systems on the various sites may also have affected the utilization of fertilizer nitrogen by pine. The pine roots especially on the thick peated peatland were very superficial and although urea is strongly retained by the peat (cf. p. 32), some of the nitrogen may have been leached out of the surface layer where most of the pine roots were situated. On the other hand, it should be mentioned that it has initially been easier for the trees to take up the nitrogen given by fertilization, the more superficial their root systems have been.

Furthermore, it can be assumed that pine is generally able to take up nutrients more efficiently on mineral soil sites than on undrained peatlands, in which for instance the total air space in the peat may be so low that it is one factor disturbing the growth and action of the roots (e.g. Paavilainen 1967, Lähde 1969). The nitrogen given by fertilization might also be bound more strongly by peat than by the humus layer of the mineral soil, thus making it more difficult for the trees to use it.

The time of fertilizer application affected the utilization of urea fertilizer by pine on all sites studied, although the effect was less on the peatlands than on the mineral soil site. The results of the experiment set up on forest covered sites showed that the trees took up less fertilizer nitrogen when application was carried out on the top of a snow cover than when fertilizer was applied onto the bare ground. In addition, the experiment on the *Sphagnum fuscum* open swamp showed that clearly more urea fertilizer was retained in the ground when it was applied on the bare ground than on the top of a snow cover. According to these results, application carried out on the bare ground on peatlands gives better results as far as tree growth is concerned than application on snow, as earlier studies concerning the effect of the time of application also show (Paavilainen 1969).

When attempting to affect the uptake of fertilizer nitrogen by trees during the same growing season, the results obtained in this study show that the fertilizer should be applied before tree growth starts. A corresponding conclusion has also been reached in earlier studies (cf. Viro 1970). As regards the uptake of nitrogen by trees, application carried out on frozen but snowless ground gave as good a result as the application done in the spring. The retention of nitrogen by the peat was in both cases approximately as great.

The results also show that pine has probably not been able to take up fertilizer nitrogen when the ground is frozen, although the uptake of water is to a certain extent possible in frozen peatlands (Huikari & Paarlahti 1967, Leikola & Paavilainen 1972). The effect of nitrogen fertilization given late in the autumn or at the beginning of the winter will thus only become apparent in the following growing season.

There was no significant difference between the uptake of fertilizer nitrogen by dwarf shrubs and mosses on the sites studied. This result is probably influenced by the small number of observations made, as the material in this case consisted of only one time of fertilizer application, yet there were altogether five times of application used in the pine study.

The nitrogen given as urea is quite strongly retained by peat. Even when an irrigation intensity corresponding to very heavy rain was used, only a very small amount of the fertilizer nitrogen leached deeper than 15

cm from the surface of the peat. Several earlier studies have also shown that of the various types of nitrogen fertilizers, particularly the ammonium nitrogen formed from urea by hydrolysis is retained very strongly by the litter and humus layer of forest mineral soils and by peat (e.g. Roberge & Knowles 1966, Overrein 1967, 1968, 1969, 1971 a, b, Nömmik & Popovic 1971, Knowles & Lefebvre 1972, Malcolm 1972, Popovic & Nömmik 1972). On the basis of these results, it seems highly unlikely that nitrogen would pass into the drainage ditches or ground water if urea is correctly applied as a nitrogen fertilizer on peatlands.

The laboratory experiments would indicate that ammonia formed from urea probably can volatilize from peatlands. It is obvious that the hydrolysis of urea takes place quite quickly even in acidic peat (cf. Gibson 1930) and that when urea is applied, the pH value of the soil rises locally so high that volatilization of ammonia becomes possible. It would appear that the danger of volatilization is greatest during dry or low rainfall periods when the initially damp peat dries up (cf. Ernst & Massey 1960, Westman 1973). On the other hand, when the surface of the peatland remains wet, for instance if fertilization is followed by rainy periods, then the loss of nitrogen is probably very small. Many experimental results have been obtained for forest covered mineral soils which show that the ammonia formed from urea has been volatilized (e.g. Nömmik 1967, Overrein 1968, 1969, Hüser 1969, Volk 1970), but results have also been presented which show that volatilization has remained low (e.g. Knowles & Lefebvre 1972, Overrein 1972). In forest covered mineral soils, the weather conditions play quite a decisive role in the volatilization of nitrogen derived from urea (cf. e.g. Viro 1972).

It can be seen from the results that a pine growing on a sedge pine swamp has taken up only 2.3 % of the nitrogen given by fertilization, while the proportion in the ground vegetation was over eight times greater, i.e. 19.4 %. According to earlier studies, the relative proportion of nitrogen taken up by trees has usually been greater. Nömmik (1966) found that 3—9 % of the nitrogen given by fertilization was retained during two growing seasons in the parts above ground of 11—12 years old pine seedlings. According to Björkman, Lundeberg & Nömmik (1967), 7 % of the nitrogen given by fertilization was retained in one growing season by young pine trees, and 2—18 % by the ground vegetation. In mature stands, the utilization of fertilizer nitrogen by trees has been noticeably greater (e.g. Tamm 1963 a, b, Popovic & Burgtorf 1964, Viro 1965). For instance, according to Viro (1965) the trees in spruce stands and VT pine stands took up during five years about 25 % of the nitrogen given by fertilization.

The most important reason for the differences in the results is presumably because a noticeably smaller amount of nitrogen was used in this study, only about 50 kg N/ha, than in earlier studies. The growth reaction of trees growing in peatland pine stands can not be very efficiently affected by such a small amount of nitrogen (P a a v i l a i n e n 1972 a). In practice, a fertilization application of 75—100 kg of nitrogen is recommended for forest covered peatland sites (e.g. H u i k a r i & P a a v i l a i n e n 1972).

The uptake of nitrogen by trees would become noticeably more efficient if competition from the ground vegetation could be eliminated. As the actual destruction of the ground vegetation for the time being has no realistic basis as far as forest economics is concerned, one possibility would be to grow the stands so dense that the amount of ground vegetation would be kept to a minimum. The addition of nutrients through fertilization is likely to make possible the growing of stands denser than would otherwise be possible on the sites in question. Single tree and strip fertilization may be possible on certain sparse pine swamp stands where the trees are small, thus limiting the unnecessary fertilization of the ground vegetation.

This study was a basic investigation in which the ^{15}N isotope technique was used. The method proved to be so useful, that further studies about many of the questions concerning nitrogen fertilization of peatland forests would seem justified.

5. SUMMARY

The following points have been examined in the study:

— the uptake of fertilizer N, applied as urea, by pines growing on peatlands with a thick peat or shallow peat layer and on a VT site for comparison,
— the dependence of nitrogen uptake on the time of fertilizer application and the growing season,
— the retention of fertilizer nitrogen by different parts of pine and the ground vegetation, and
— the leaching and volatilization of nitrogen given as urea in peat.

Urea labelled with ^{15}N isotope has been used in the study. Altogether there were three series of experiments, one of which was carried out on forest covered sites, one on a *Sphagnum fuscum* open swamp, and one in the laboratory. Information concerning the material and methods have been presented in Tables 1—3 and Figs. 1—5.

The results indicate that the thickness of the peat has an effect on the ability of pine to utilize fertilizer nitrogen. Pines growing on the mineral soil site clearly took up more nitrogen per unit needle dry weight than those on peat soils, and on shallow peat more than on thick peat (Table 4, Figs. 6—7).

The time of fertilizer application also affected the extent to which the sample trees were able to take up nitrogen given as urea. The proportion of fertilizer nitrogen in the total nitrogen of those sample trees which received urea fertilizer on snowless ground before growth started, was approximately twice that of the sample trees which received the fertilizer while the ground was covered with snow. The differences between sample trees fertilized at different times were greater on the mineral soil site than on the peatland sites. The nitrogen content of the needles could clearly be affected in the year when fertilization took place, if it was carried out before the onset of tree growth. As the ground was still frozen before the start of the growing season, the trees have probably not been able to take fertilizer nitrogen.

The nitrogen content of needles from different parts of the crown is shown in Table 5, that of the trunk and root system of pine in Table 6, and the nitrogen content of the ground vegetation in Table 7. On the basis of the analysis results and the dry weight determinations, it was calculated that altogether 65.7 % of the fertilizer nitrogen had been retained on the sedge pine swamp. The sample tree retained 2.3 %, and the ground vegetation surrounding the tree 19.4 %. The amount of fertilizer nitrogen taken up by the tree was smaller than the amount reported in earlier studies, but this may be above all due to the small amount of nitrogen used in this study (53.3 kg N/ha).

The results indicated, that if competition from the ground vegetation could be eliminated, the uptake of nitrogen by the trees would become noticeably more effective. One possible way of doing this would be to grow such dense stands that the amount of competing ground vegetation would be kept to a minimum. Single tree and strip fertilization may be possible on certain pine stands on peatlands where the trees are small, thus limiting the unnecessary fertilization of the ground vegetation.

The results of both laboratory and field experiment showed that nitrogen given as urea was quite strongly retained by the peat (Table 8, Figs. 8—9). It is thus obvious that there seems to be no likelihood that nitrogen would pass into the drainage ditches or ground water if urea is correctly applied as a nitrogen fertilizer on peatlands.

The results of the laboratory experiment showed that ammonia formed from urea can volatilize from peat soils (Table 9, Fig. 8). The danger of volatilization seems to be greatest during rainless or low rainfall periods when the initially moist peat dries out. On the other hand, when the surface of the peatland remains wet, for instance if fertilization is followed by rainy periods, then the loss of nitrogen through volatilization is probably very small.

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TUTKIMUKSIA TURPEEN PAKSUUDEN JA LEVITYSAJANKOHDAN VAIKUTUKSESTA MÄNNYN LANNOITETYPEN OTTOON.

SELOSTE

Tutkimuksessa, jonka tarkoituksena on tuoda lisävalaistusta suometsien typpilannoituksen perustana oleviin kysymyksiin, on selvitetty:

— neulasanalyysien avulla männyn lannoitetypen ottoa paksuturpeisella ja ohutturpeisella suolla ja vertailua varten myös kankaalla sekä typen oton riippuvuutta lannoitteen levitysajankohdasta ja kasvukauden ajasta,
— lannoitetypen pidättymistä männyn eri osiin ja pintakasvillisuuteen sekä
— ureana annetun typen huuhtoutumista ja haihtumista turpeessa.

Lannoitteena on käytetty ^{15}N-isotoopilla merkittyä ureaa. Kun Suomessa ei ole aikaisemmin tehty metsänlannoitukseen liittyviä tutkimuksia tätä erittäin käyttökelpoiseksi osoittautunutta isotooppitekniikkaa hyväksi käyttäen, on käsillä oleva julkaisu myös perusselvitys mahdollisia suometsätieteellisiä jatkotutkimuksia varten.

Koesarjoja perustettiin kaikkiaan kolme. Niistä yksi sijaitsi metsässä, yksi rahkanevalla ja yksi tehtiin laboratoriossa. Aineistoa sekä käytettyjä menetelmiä on selostettu sivuilla 8—19 sekä taulukoissa 1—3 ja kuvissa 1—5.

Turpeen paksuus vaikutti männyn lannoitetypen ottoon. Kankaalla puut ottivat samaa neulasten kuiva-ainemäärää kohden selvästi runsaammin typpeä ^{15}N:llä merkitystä urealannoitteesta kuin suolla ja ohutturpeisella suolla enemmän kuin paksuturpeisella (taulukko 4, kuvat 6—7). Neulasten kokonaistyppipitoisuus oli kankaalla alempi kuin turvemaalla. Tulokset viittaavat siihen, että typpilannoituksen tarve vähenee turpeen paksuuden kasvaessa, kuten käytäntöä varten annetuissa suosituksissa on esitettykin. Eräänä tekijänä, joka saattaa vaikuttaa männyn lannoitetypen erilaiseen hyväksikäyttöön kankaalla suohon verrattuna, on suoritettujen mittausten perusteella esitetty puiden ja pintakasvillisuuden juurten määrä ja syvyysjakautuminen näillä kasvupaikoilla.

Levitysajankohta vaikutti myös selvästi siihen, kuinka runsaasti puut ottivat ureana annettua typpeä. Annettaessa urea lumettomalle maalle lannoitetypen osuus neulasten kokonaistypestä muodostui noin kaksinkertaiseksi verrattuna lumelle suoritettuihin levityksiin. Eri levitysajankohtien väliset erot olivat kankaalla jyrkempiä kuin suolla.

Lumettomaan maahan levityksessä saatiin jokseenkin yhtä voimakas vaikutus suoritettaessa levitys joulukuussa maan ollessa lumeton, mutta vahvasti roudassa, taikka keväällä ennen puiden kasvun alkamista. Annettaessa lannoitus heinäkuussa puut ehtivät ottaa varsin vähän lannoitetyppeä lannoitusvuoden aikana.

Männyn neulasten kokonaistyppipitoisuus oli toukokuun puolivälissä koko aineiston mukaan keskimäärin 1.04 % ja aleni kesäkuun puoliväliin mentäessä 0.92 %:iin. Uusien lannoitusvuotena muodostuneiden neulasten pitoisuus oli korkeimmillaan heinäkuussa (1.34 %), aleni tämän jälkeen elokuussa, mutta nousi jälleen

syksyllä. Lannoitetypen osuus neulasten kokonaistypestä oli toukokuun ja kesäkuun näytteissä varsin pieni, vaikka lannoite annettiin ennen kasvukauden alkua. Heinäkuussa lannoitetypen osuus lisääntyi selvästi. Keski- ja loppukesällä neulasten sisältämän lannoitetypen osuuden vaihtelu oli samansuuntainen kuin kokonaistypenkin vaihtelu.

Männyn latvuksen eri osissa kasvaneiden eri-ikäisten neulasten typpipitoisuus on esitetty taulukossa 5, rungon ja juuriston taulukossa 6 sekä pintakasvillisuuden typpipitoisuus taulukossa 7. Analyysitulosten sekä kuivapainomääritysten perusteella laskettiin, että 65.7 % annetusta lannoitetypestä oli pidättynyt suursararämeellä koepuuhun, pintakasvillisuuteen ja maahan. Koepuun osuus lannoitetypestä oli 2.3 % ja pintakasvillisuuden osuus 19.4 %. Puun ottaman lannoitetypen määrä oli pienempi kuin mitä aikaisemmissa tutkimuksissa on yleensä esitetty. Tämä johtunee etenkin käytetyn typpimäärän pienuudesta (53.3 kg/ha N) sekä siitä, että tutkittiin varttuneita puita.

Puiden typen otto tehostuisi huomattavasti, jos voitaisiin eliminoida pintakasvillisuuden kilpailu. Kun pintakasvillisuuden suoranaiseen hävittämiseen ei ainakaan tällä hetkellä ole reaalisia edellytyksiä käytännön metsätaloudessa, on eräänä mahdollisuutena pidettävä puuston kasvattamista niin tiheänä, että pintakasvillisuuden määrä jää vähäiseksi. Ravinteiden lisääminen lannoituksella antaneekin mahdollisuuden kasvattaa puusto tiheämpänä kuin mitä ko. kasvupaikalla muuten tehtäisiin. Harvassa rämepuustossa ja pienten puiden ollessa kysymyksessä olisi kaikesta päätellen aihetta käyttää puukohtaisia ja kaistalannoituksia, jolloin ei turhaan lannoitettaisi pintakasvillisuutta.

Sekä kenttä- että laboratoriokokeen tulokset osoittivat, että ureana annettu typpi pidättyy varsin voimakkaasti turpeeseen (taulukko 8, kuvat 8—9). Kenttäkokeen mukaan typen pidättyminen oli paljaan maan levityksissä huomattavasti voimakkaampaa kuin lumelle levitettäessä. Tämä osoittaa yhdessä jo aikaisemmin esitettyjen koetulosten kanssa, että urean levitystä paljaalle maalle on pidettävä turvemailla metsän kasvatuksen kannalta edullisempana kuin levitystä lumelle.

Laboratoriossa turvealustalla tehty koe osoitti, että erittäin runsasta sadetta vastaava kastelukin sai vain hyvin vähäisen määrän lannoitetypestä huuhtoutumaan 15 cm:ä syvemmälle. Näiden sekä kenttäkokeen tulosten perusteella onkin ilmeistä, että käytettäessä suon typpilannoituksessa ureaa ja suoritettaessa lannoitus teknillisesti oikein, ei ole sanottavaa pelkoa siitä, että typpeä joutuisi ojastoihin tai pohjaveteen.

Laboratoriokokeen perusteella on pidettävä mahdollisena, että ureasta muodostuvaa ammoniakkia voi haihtua turvemaasta (taulukko 9, kuva 8). Haihtumisen vaara näyttäisi olevan suurin sateettomana tai hyvin vähäsateisena aikana alunperin kostean turpeen kuivuessa. Sen sijaan suon pinnan pysyessä märkänä esimerkiksi lannoitusta seuraavan sateen vaikutuksesta typen haihtumishäviö on todennäköisesti varsin pieni.

AN ENERGETIC MODEL LINKING FOREST INDUSTRY AND ECOSYSTEMS

JAMES P. CUNNINGHAM

SELOSTE

METSÄTEOLLISUUDEN JA EKOSYSTEEMIEN VÄLISEN VUOROVAIKUTUKSEN ENERGIAMALLI

RÉSUMÉ

КРАТКОЕ ИЗЛОЖЕНИЕ

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Preface

This report presents the first results of an ongoing project intended to quantify certain relationships between industry and ecosystems. The forest products sector is first described within the frame of the national economy of Finland. A theoretical foundation is developed for synthesizing economic and ecological methods in the study of interactions between human activities and the environment, and these principles are then applied to a model of the wood-using industries. Finally, an account is given of empirical work undertaken to describe and test the correspondence between economic and ecological formulations of industrial production, with particular emphasis on paper manufactures in Finland.

A number of persons in the Forest Research Institute and in other branches of the Finnish government have assisted me during the course of the project. Especially I must acknowledge Professor Lauri Heikinheimo, who seems never to tire in his commitment to maintaining the best possible climate of work for every one under his supervision. Professors Pentti Hakkila and Kullervo Kuusela and Mr. Reino Hjerppe reviewed the manuscript for publication, as did Professor Pentti Malaska. Their comments on fundamental issues of the study were particularly constructive. Mr. Olli Nissilä has repeatedly extended himself to untangle the numerous small problems of a stranger to his land.

Helsinki, August 1973

James P. Cunningham

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1.0 THE STUDY SYSTEM

In Finland the forest-based industries support a major share of the national economy, in 1969 accounting for some 24 % of total industrial output, and 58 % of vital exports (32). In turn, the forest industries are dominated by papermaking, which comprised about 75 % of the output in this sector. As in most other technologically advanced nations, public and private groups in Finland now face certain problems associated with maintaining a desired level of economic growth. Foremost among these is the growing scarcity of raw materials and power sources to support industrial expansion. In the forest industry sector, the MERA program (15) represents a vigorous and comprehensive effort to expand the raw-material base, undertaken by Finnish government and industry with international backing in the form of a World Bank loan. Although the outcome will depend to a large extent on the willingness of private landowners to invest in timber production, the goal is to increase allowable drain by over 50 % from 1973 to 1987, with even greater gains in succeeding periods. A state power company (9) projects power use from all sources also to increase by half in Finland during the next ten years.

In these forest-products industries *there is a close and perhaps unique relation between the raw material and the power for processing it.* Wood in various forms has been heavily used in this country for heating of homes and other buildings and for the generation of industrial power. Basic studies (28, 29) of this utilization have been conducted by the Forest Research Institute. Demands for raw material have encouraged reduction of the proportion of wood which is used as fuel, while increasing power requirements have given birth to technologies such as that of the recovery boiler for generating power from papermaking residues. The tradeoffs between these utilization alternatives for wood are inherent in the material, which now can be rather easily converted into food as well (27). Even in 1969, wood supplied well over half of the fuels used in the paper industry, and more than a quarter of those for the whole industrial system. The earlier significance of this source of power can be inferred from the official industrial

statistics (35): as recently as 1963, all fuels used by industry were converted into equivalent volumes of »piled pine firewood»!

At the same time certain adverse effects upon natural systems, as well as upon the quality of human life, are engendered by the securing and industrial processing of raw materials and power, and by the consumption of the goods and services thus produced. In Finland as elsewhere, it is recognized (23, 32) that the real standard of living is incompletely measured by the goods and services customarily accounted as national income. Certain »discommodities» have to be measured as well, if we are to obtain accurate measures of income and welfare. In the forest industries, these include the aesthetic losses sometimes associated with timber harvesting, as well as pollution of waters and the air. As we proceed, it will be seen that certain features of these apparently disparate costs can be measured in the same way that we measure production.

»— but those are all only symptoms of our rather lavish consumption of energy.»

That remark by my long-time teacher and friend John Duffield, a silviculturist, came as the wry response to a rather diffuse declaration of interest in studying »environmental problems—pollution, population growth, and things like that». The conversation (4) provided a gell for ideas gathered from diverse sources, and later a focus for this study.

In all industrialized countries, economic decisions are made by market mechanisms operating within a framework of governmental requirements and restrictions. Whatever may be the differences in institutional systems, the effectiveness of economic decision making cannot exceed the quality of the information available to planners. To accurately assess the net contribution of the wood processing industry to national income and wealth, we need some common measures for activities as diverse as the planting of trees, the cooking of wood pulp, and the life processes of fresh-water bacteria. This is a large order, and no one approach can be satisfactory by itself.

2.1. Ecology and energy

I propose that we can significantly augment both the scope and the accuracy of useful economic data by borrowing some of the techniques of quantitative ecology. Now, »ecology» has lately become a slogan word inspiring devotion, fear or amusement, depending on the vantage point from which you view the various cross-fires of the current environmental crusade. The association is made almost inevitable by the fact that some of the leading scientists of this discipline are also foremost among the campaigners. This movement is largely motivated by a perceived need for better means of directing a system, the industrial state, judged by many to be out of control in certain important respects. The most evident symptom is the current exponential growth of population and production, with attendant depletion of resources, which seems likely to over-run the carrying

capacity of the terrestrial biosphere within a few decades, or generations at most (14, 19). In the last few years there have been encouraging signs that these systems may be self-regulating: in Finland and in the United States, for example, the rate of population growth has slowed — quite dramatically in the former (34). However, from past experience it is likely that these demographic adjustments are transitory, and in any case it does not necessarily follow that there will be any slackening of the upward pressure on national incomes generated by demands for higher standards of living. It can be disheartening to see to what little effect cautioning voices are raised. Mill's (17) discourse »Of the Stationary State» might as well have been written for our century as his.

Let us consider briefly some features of ecological science, to discharge the emotional content of this term. Although many biologists are raising these warnings that human survival may be endangered, it is paradoxical that in their science the survival of an organism is interesting only with respect to the adaptive information it passes on to the population, and even the disappearance of whole species can often be viewed as ordinary adjustments in a dynamic system. Their approach to behavior is evolutionary: an organism's response to a particular stimulus is conditioned by the sum of successful responses over many generations. Appropriately, the notion that a lower organism acts in a certain way because it *feels a need to do so* is dismissed as teleology. Thus it is not to be expected that the methods of economics will be supplanted by those of ecology in dealing with these problems: the models of the latter contain no provision for deliberate decision-making. However, in its empirical methodology there is much which is useful to the resource economist.

Ecology is a comparatively young science, the term »ecosystem» having been introduced by A. G. Tansley less than 40 years ago (33), although the concept predates his work. It comprises elements of taxonomy, genetics, physiology, population dynamics and community interactions. The study of *bioenergetics* has become a major unifying principle, roughly in the last decade, although there were seminal studies as early as 1922. Engelman (5) gives a thorough review of this development as it relates to terrestrial studies. It has been demonstrated that there are regular relationships between the energy received by organisms, their photosynthesis and/or respiration, and the living matter they embody. Furthermore, these functions can be used to predict the development of communities of different species. Many ecosystems are fully as complex as human societies, and present equally unmanageable complexity if described as natural history. The bioenergetic approach enables the major elements of these systems to

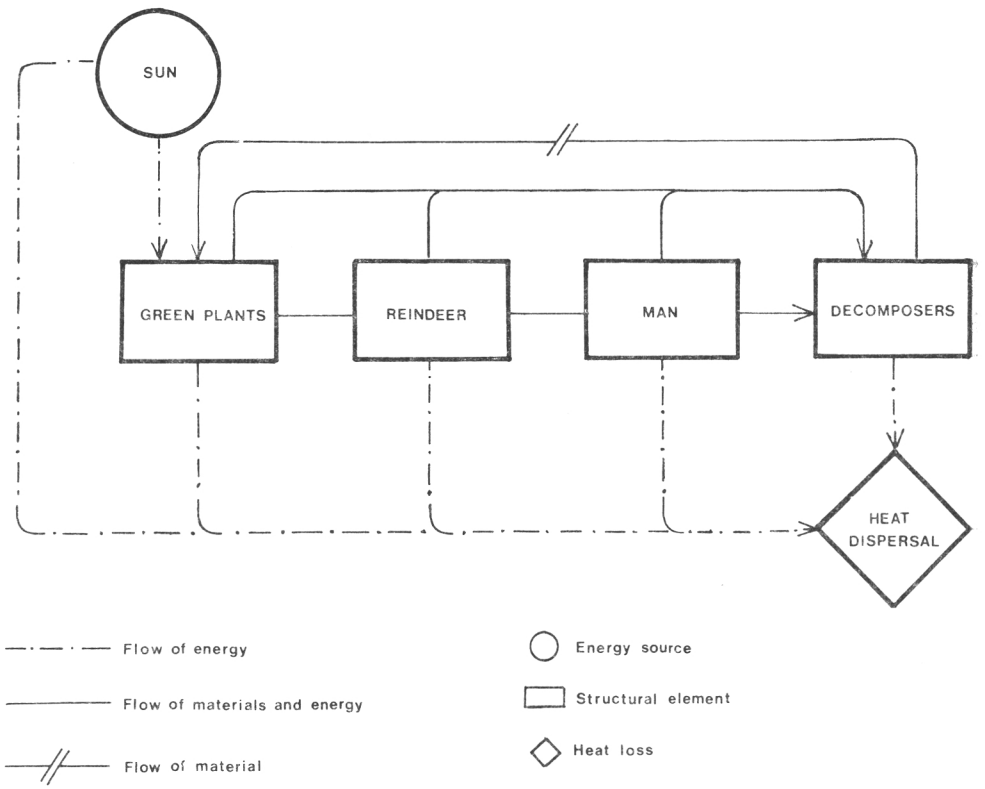


Figure 1. Food chain showing transfers of materials and energy.

This is one of the shortest and simplest food chains in which man participates. In remote parts of Lapland some Samish people still rely almost entirely on the reindeer although most have some contact with industrial societies. In the ecosystem pictured, man is really a part of nature because his numbers and activities are circumscribed by the solar energy captured by plants and concentrated by these animals which both serve as food and provide transportation.

be represented according to principles as simple as the laws of thermodynamics.

Figure 1 presents such a model, of a sort which by now is familiar to most secondary school students. Each element in this system can be represented as a flow or storage of energy. The intensity of sunlight is easily measured. The energy content of fuels and food is gauged by dehydrating and burning them, recording the amount of heat generated. At each transfer of energy from one organism to another, some energy is *lost as heat*, some is used to *perform work*, and some is again *stored as structure*, becoming part of the receiving organism's body. Ultimately all of the energy will be dissipated in heat. We can speak of the efficiency of converting received energy to

biomass, and the ratio of energy flow to biomass is often used to compare different communities of organisms.

Indeed, certain primitive human ecosystems — one may as well say economic systems — have been satisfactorily described in this way. Rappaport (25) details the energy flows and storages in the agriculture practiced by the Tsembaga tribesmen of New Guinea, and concludes that this simple system is »elegant» in that it provides a very large food-energy income to the farmers, compared to the energetic cost of their labor. Kemp (10) has similarly described the hunting activities of Baffin Island eskimos. In contrast to the tropical farmers, their energy sources also include gasoline.

Not all foresters who were trained more than ten years ago are familiar with the language of energy studies, but they are surely conversant with the concepts. The productive potentials of woodland ecosystems are a primary concern of this profession. For every latitude and climate there is a certain amount of solar energy which reaches the earths' surface. The amount of wood which can be harvested from a given area is determined by this sunlight, the efficiency of different trees in converting it to stored chemical energy,* and the work directed by the forester — also an energy input. The main purpose of silviculture is to improve the effectiveness of this energy conversion, and yield studies are measurements of the result.

2.2. Industry and energy

Elementary texts in economics present circular flow models of industry such as Figure 2 a, in which physical transfers between producers and consumers are governed by equivalent flows of money in the opposite direction. Setting aside the payment cycle for the moment, and elaborating slightly on the material flows, we have figure 2 b. The materials lost as industrial pollution and consumer wastes are all potentially recoverable: some are reconcentrated by natural processes, others command sufficiently high market prices to ensure their recovery. Others, such as toxic substances, may have no value for re-use, but containment is mandated to avoid incurring the damage costs of release. Finally, some materials may be allowed

* The process of photosynthesis, common to all green plants. Still imperfectly understood, the reaction can be verbally expressed as: water + carbon dioxide → glucose + oxygen. This conversion is performed by sunlight in the presence of enzymes associated with chlorophyll. Thus plants provide oxygen and food for all other life. The sugar produced in photosynthesis can be metabolized directly, or provide energy and structural components for other kinds of organic compounds. Cellulose, the major constituent of wood and currently the one of greatest economic value, is a long-chain molecule or polymer built of simple sugar monomers. So-called plant nutrients such as nitrogen, phoshorus, and potassium may serve as catalysts and enter the structure of certain molecules, but they are not really food.

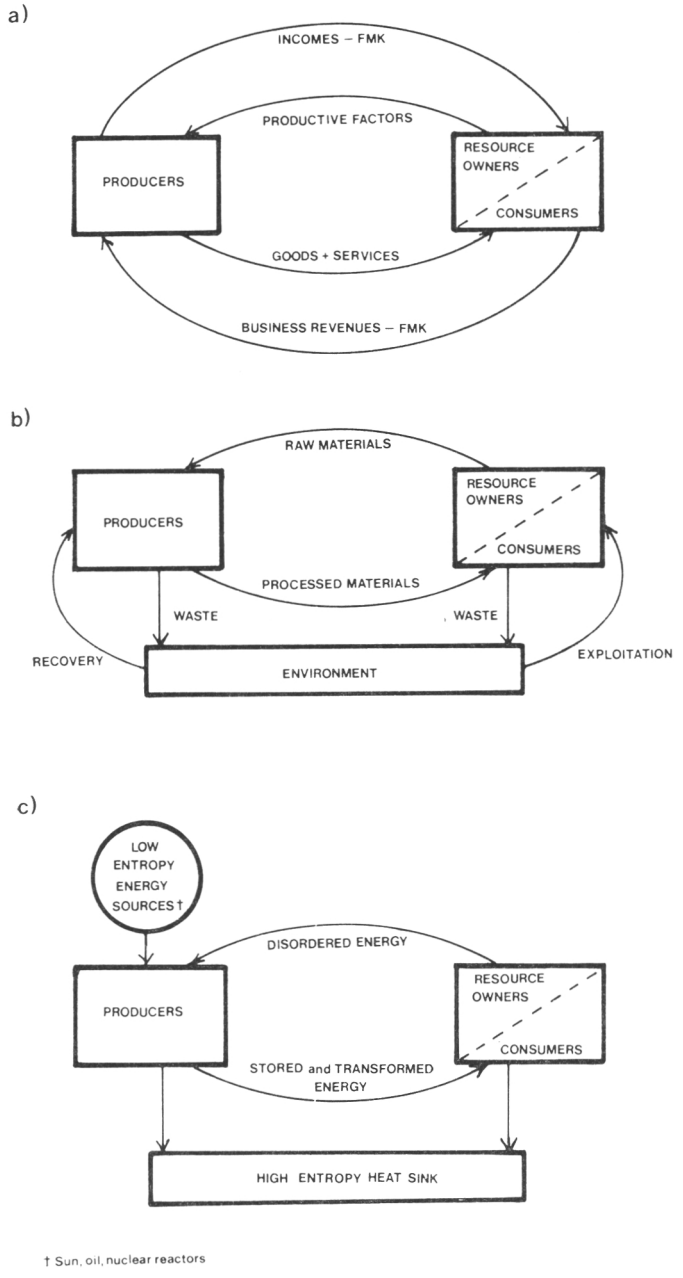


Figure 2. Physical counterparts of the economic process.

The simple circular-flow model economy presented in (a) is modified first to show materials cycles and then energy flows.

to dissipate because they appear to have no further usefulness and no damaging potential. It must be noted that this last category includes many things which have high potential usefulness, but current market conditions are such that alternative sources of supply are less expensive. Palo (23) explores this problem of material loss and recycling with particular reference to the paper industry.

Then there are the corresponding energy flows presented in Figure 2 c. A distinguishing feature is that these flows are *all one-way:* each transfer is accompanied by some loss into heat, often very great, and once lost energy is not recoverable. Georgescu-Roegen (6) builds a case for applying this universal physical *entropy law* to economic activities. As he and Odum point out, all work is by definition an expenditure of energy, and the development of modern industrial society has been due not so much to a sudden flowering of human inventiveness as to the exploitation of fossil fuels — coal, oil, and gas. This view is reinforced by empirical data presented by Cook (2) and by Singer (30). In cross section comparison of several countries, they find linear relationships between energy use and state of economic development, measured as GNP per capita. Along the same lines, A. J. Grayson (7) suggests that

»Energy = g-cm sec^{-1} which is the same as money, as paid to labour for example, or as incorporated in fixed capital».

Similarly, Odum treats money transfer as an information feedback system which stimulates and channels »upstream» energy flows. This is equivalent to the economic notion that the existence of profits guides allocation of resources and expansion of industry in competitive markets. Recalling the three ends of energy flows in natural systems — *work, structure, and heat* — it is clear first of all that these fully apply to industrial activities in their precise physical definitions. Then some parallels with economic concepts become apparent. For example:

Variable costs are equivalent to the work done directly in manufacturing a product

Fixed costs are energetic »overhead» which is used to create and maintain structure, i.e. capital equipment and the human organization

Efficiency can be measured as that fraction of received energy which performs useful work, compared with the proportion of heat lost.

There are four areas of economics which seem particularly likely to benefit by adopting the methodology of energetics:

2.2.1. Growth and development

Practitioners and theorists of economic development are concerned with achieving the preconditions sufficient for a »take-off» into sustained economic growth, usually measured in terms of increase in gross national product. Activities toward this goal are directed to *labor and capital* inputs: on the one hand, education, labor mobilization and entrepreneurial incentives; on the other, creation of infrastructure and attracting investment funds. Employment and investment questions are also foremost in the management of mature industrial economies. Energy requirements have not been ignored in practice, but regarded as a fairly minor item among the inputs required by the labor-capital machine. Energetic formulations have not entered into formal economic growth theory at all, even though they are occasionally used in econometric estimation. The reasons for this neglect are not difficult to find: until recently, the costs of energy from fossil fuels have generally reflected only the expenses of finding, mining, transporting and refining them, perhaps with some royalties to the owners of land where they are found.

The money cost of energy from this source has heretofore been very small, and not at all related to the work potential of the fuel. Energy itself has thus been treated as a virtually free good in economic analysis, its physical importance notwithstanding. Recent events suggest that the time when we could do this is at an end. An OECD document (20) reveals a certain complacency with regard to energy supply among senior national and international officials, even in the mid-sixties. The Energy Committee was then concerned about how certain predicted energy *surpluses* could be absorbed by international markets. In the few years since warnings of an impending »energy crisis» were raised by a few scientists, this concern has gone through the usual wave of popular journalism and now appears as hard reality. Natural gas reserves in the United States (which uses some 35 % of the world's energy) have been depleted to the point that in some parts of that country it is impossible to get new service connections. Shortages of electric power requiring »brownouts» have become chronic. In the spring of 1973, petroleum demands so far outran supplies that many service stations (42) and even municipal transportation systems (3) literally ran out of gas. This short-run shortage could perhaps be viewed as a problem in refinery capacity or even business collusion, but it is taken officially as symptomatic of a long run problem: The government has ordered reductions in its own energy consumption, and established a special agency to deal with energy policy (38, 39). At the same time, the oil-producing nations of the Middle East have begun what is expected to be a massive increase in petroleum

prices (43). Energy use has been thrust into the concern of economic planners, and the theories of economic growth ought to take account of this primacy. A remarkable reflection of the rapid evolution of official thinking is Öllers (41) assumption that

> »The rising prices of fuels are expected to influence not only the structure of energy consumption but also the industrial structure. Scarcity of energy would favour labour intensive production and might even become an obstacle for growth in the future.»

2.2.2. Capital Theory

Capital accumulation, capital/output ratios and capital/labor ratios are major components of economic growth models, but difficulty in measuring this input has presented perhaps the greatest obstacle to empirical implementation of these theories. Problems of obsolescence and of adding unlike items of equipment are particularly intransigent. It is interesting to note that the notion of measuring capital in labor-units enjoys periodic revival in the literature (26), although Solow (31) makes the point that this has a »faintly archaic flavor» and brings us no closer to solving the empirical problem. This approach becomes irrelevant in view of the fact that, in Finland for example, even by a generous estimate the energy contributed by labor to physical work performed is less than one-half of one percent — see Figure 6.

The work of Niitamo (17) presented a fresh approach to the problem, by using some partial power measures — use of electricity and machine capacity — as indicators of the *use of capital*. Although I have added together all of the major sources of energy for industry, this aspect of the present work differs from his not so much in content as in point of view: it now seems more reasonable to treat capital as a *valve* channelling disordered flows of energy to useful purposes, as in Figure 3.

It may indeed be impossible to find a satisfactory common measure for valves of different designs and ages, made of different materials. But it is not quite so difficult, and for many purposes should be more useful, to measure the flow through the valve and the leakage around it.

2.2.3. Technological change

Again in growth models especially, the measurement of technological change presents problems, partially related to capital. There are also formula-

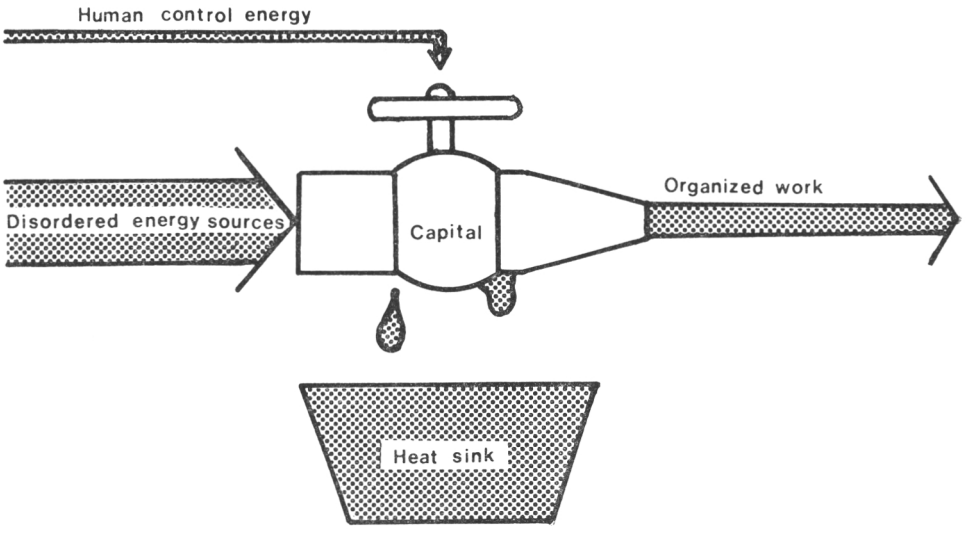


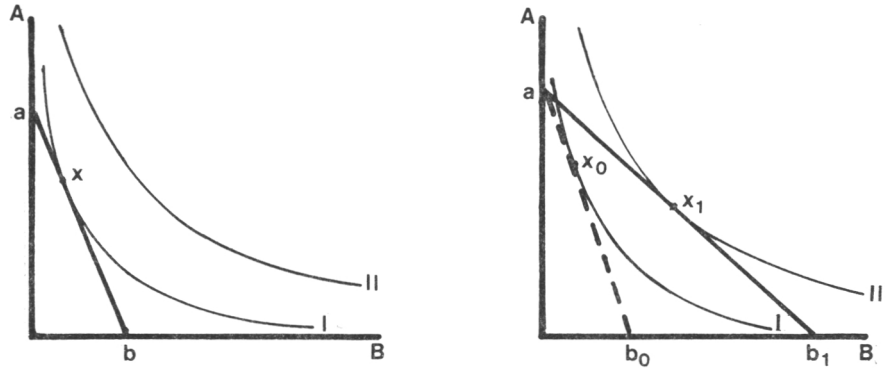
Figure 3. Capital is a valve channeling energy to perform work.

Economic theory has treated labor and capital as the primary, indeed the only inputs for transforming raw materials into useful products. While not wishing to minimize the need of providing for these factors, we can say that such a view does not conform well with the physical reality of industrial processes. Machines stand idle until power is applied, and human energy is scarcely sufficient to operate the controls.

tions for technological change relating to labor, for neutral and for »disembodied» technological change. In each case, however, the effect is of an autonomous force which increases productivity. Various indirect measures have been proposed in econometric studies, but a precise specification of just what technological change *is* remains elusive. A major component of any such definition ought to be *increase in the intensity of energy utilization.*

2.2.4. Cost-benefit analysis

We have seen that if some resource, such as energy, is priced lower than its actual scarcity warrants, then the whole industrial system may expand beyond the limits which can be sustained by the resource base. In the same way, on the micro level if some of the costs of making and using a particular thing are borne by persons other than those who produce and consume it, then that product will be relatively cheaper than it should be and more of it will be made and used than is socially desirable. Figure 4 illustrates an aberration of this kind in production decision analysis following Hicks' (8) principles.



i. Costs fully internalized.

ii. Some costs of input B are external to to the firm.

Figure 4. Effect of externalities on output.

The axes A and B measure quantities of two resources, inputs needed for production. In (i), the line segment *ab* is one of a family of so-called »budget lines», the locus of all maximal combinations of the two inputs which can be purchased for a given amount of money. The slope of this family of line segments is given by the relative prices of the two inputs. The curves I and II are two of a family of curves, each the locus of all minimal combinations of the two inputs which are required to produce a given amount of output. The point of tangency x locates the input combination which will produce the largest output within this budget constraint. In (ii), the line segment ab_0, the curves I and II, and the point of tangency x_0 reproduce the situation in (i), assuming that all costs of production are paid by the firm. However, if someone outside the firm were to pay part of the costs for input B, then all of the input combinations along ab_1 could be obtained for the same cash outlay, and a greater amount of output can be produced at x_1.

This kind of thing is sometimes done deliberately, for example by government subsidy to help an industry expand. At present we are concerned with another case, in which the costs are incurred involuntarily. This is often what happens with industrial pollution: if one factory does not pay to repurify the water it uses, then those downstream who receive the same water must pay more to make it fit to use again. Then they are really paying some of the production costs for the first factory. Of course, these secondary users might be compensated for their losses, perhaps even by transferring the costs back to the firm if government taxes the polluter and uses these revenues to clean up the waters. Indeed, it matters little how these transfers are arranged, so long as all parties are fully compensated. But before com-

pensation can be made the costs must be measured — and in our example these will include some costs which are readily accountable, but other »intangibles» such as loss of enjoyment by those who use the waters for recreation.

These vagrant costs — *externalities* or *spillover effects* — present such a difficult problem in empirical economics because they typically have no readily identifiable money value. However, some of them — such as pollution — can be measured in terms of the energy stress they place upon environmental systems. This has been a common procedure for the watershed manager and the industrial engineer for some years. Counting these energy loads as costs enables us, at the least, to quantify one additional dimension of heretofore unmeasurable environmental costs. Further, this energy accounting provides a unifying element needed for linking the forest industries and ecosystems.

3. AN INTEGRATED INDUSTRY — ECOSYSTEM MODEL

3.1. Physical linkages

In Finland this field is new, though Malaska (12) has called for combining the study of natural and technological systems. A member of the Club of Rome, he is engaged (13) in the energy economy working group of the Bank of Finland. Pulliainen and Seiskari (24) have prepared a popular book on ecology and economics. The works of Palo, previously cited, and Kuusela (11) relate directly to the forest industry. Both present charts of flows and storages of both materials and energy in industry — ecosystem interactions. That of Kuusela is richer in description of the compartments making up the system, while Palo's presentation emphasizes possibilities for augmenting the circular flows of materials through recycling. Such efforts may help to relieve raw-materials shortages, and to ease problems of solid waste disposal.

On the other hand, the decisive limiting factors for economic growth may well prove to be energy sources, as well as the capacity of ecosystems for absorbing the application and dissipation of concentrated streams of energy.

In Figure 5 a we have the forest and lake ecosystems characteristic of the Finnish countryside, viewed as though there were no human component. Biomass production and respiration are limited by the availability of energy from the sun, and they are in dynamic equilibrium. This does not exclude the possibility of some long-term changes taking place, however. The forest may be colonized by new species, old ones may be removed by parasites. In northern climates especially, conditions are frequently such that there is a gradual accumulation of dead organic matter, as explained by Viro (37). The lake may gradually *eutrophy* * as nutrients and organic material

* This enrichment causes increased primary production, typically first in the form of phytoplankton and algae, and increased biomass and respiration of all components of the lake ecosystem. The oxygen content at the bottom may fall to zero due to the activity of bacteria, and growth of rooted vegetation at the shoreline is encouraged. In this way the lake may gradually fill in by accumulation of organic matter and other sediments, and colonization by land plants (40). Shallow lakes with slow circulation — conditions which typify Finnish lakes — are especially susceptible to these changes if sufficient nutrients become available.

are washed into it from the land. However, these processes are so gradual that they may be perceptible only over many hundreds of years.

Figure 5 b introduces the forest industry — let us say a paper mill — as a dynamic element in the system. All of the human activities of the industry are directed to converting and exporting from the forest as much of its primary production as possible. To illustrate how the elements of this system can be quantified, I have calculated the energy value of commercial fellings (16) in 1969. In that year about 35.3 million solid cubic meters of wood were felled. Converting these to approximate piled volumes and using the energy conversion factors for firewood from the Finnish industrial statistics, we find the energy stored in this wood is on the order of 81 million gigacalories or 94 million megawatt-hours. To put this quantity in perspective, it is some 9 % greater than the net energy use of all Finnish industry in that year. It must be recognized that it is usually not possible to *increase* the primary production of the forest, the transformation of sunlight into biomass, although we can contrive to convert a larger proportion of this into usable wood. With forest management operations, we bring in other energy sources to supplement that of the sun. If we are able to take more wood from the managed forest, it is because we direct technological work to perform some activities (regeneration, thinning, selection of superior genotypes) and control others (insects, diseases, fire), all of which drain energy from the unmanaged forest and subtract from the sum of standing-crop biomass produced. In these circumstances the trees are grown partially by the oil which powers our machines, as well as by the sun.

Especially at the mill, there are other consequences of this new input of energy. All of it must be dissipated as heat, and much of this will occur at the mill site. If heated water is discharged into a comparatively small body of water, it may cause changes in the communities of organisms living there. The air will also be warmed in the vicinity of the mill. This may not be important if the plant is isolated, but in industrialized regions can cause measurable changes in the local climate. Often these changes may not be large and they may not be harmful, but they do occur.

Concerning pollution, we will make one restriction: at present we will not consider discharges of toxic chemicals. The combined influences of costs and law can be expected to mandate a high degree of containment and recycling of these, at least in new mills. In paper production, a large share of the potential toxins are valuable chemicals which are customarily recovered for re-use.

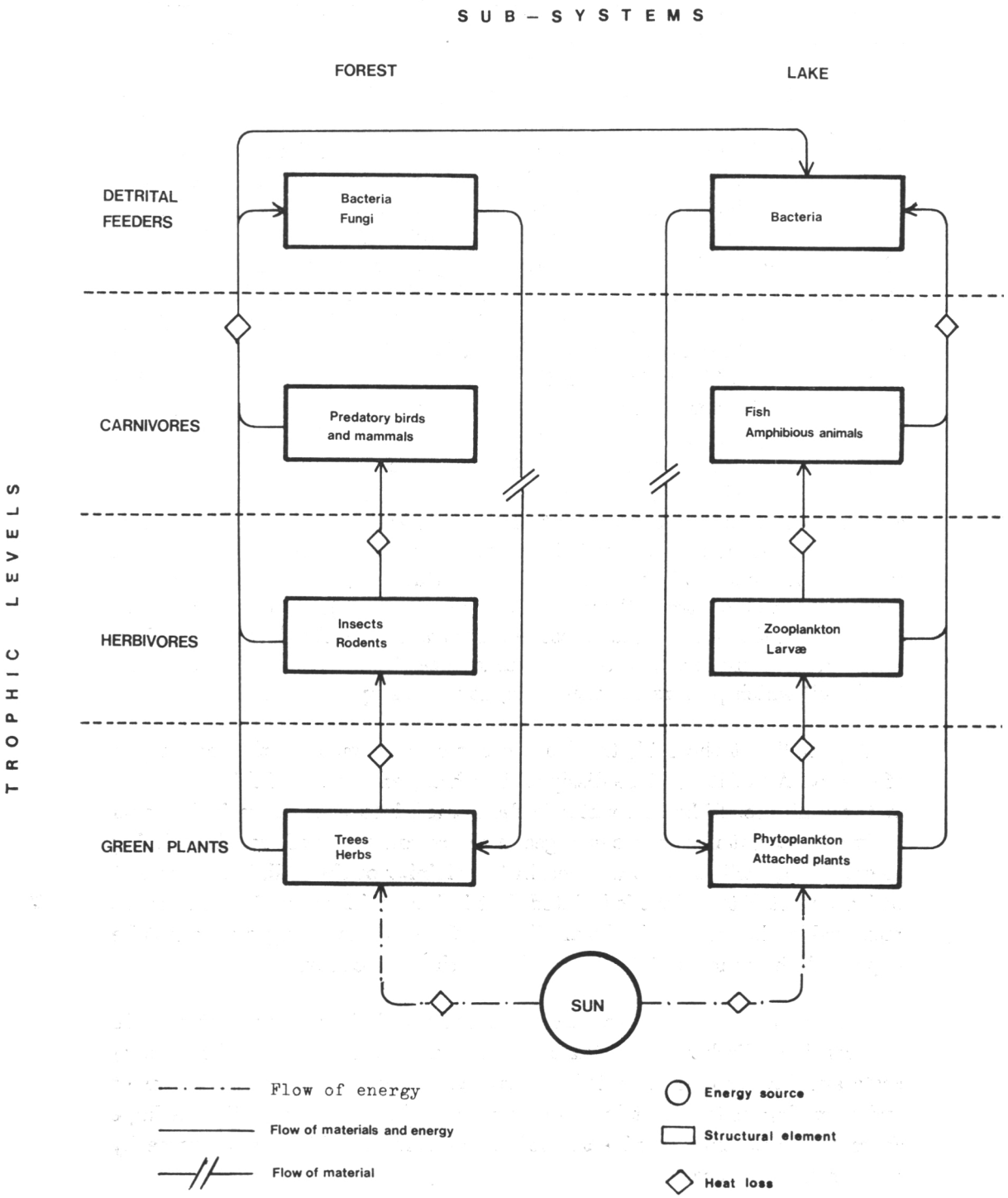


Figure 5a. Forest and lake ecosystems in natural linkage.

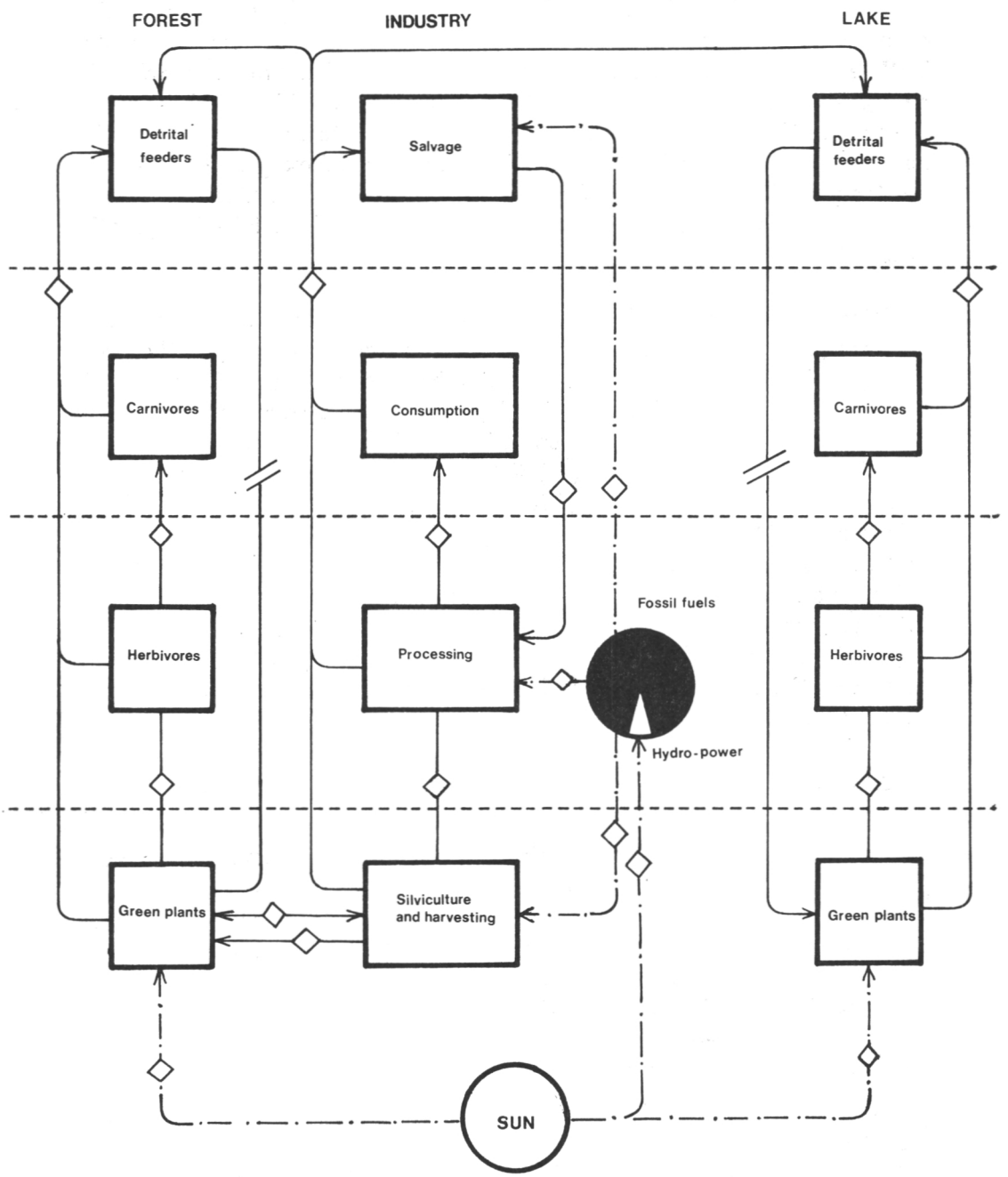


Figure 5b. Forest and lake ecosystems linked with wood-using industry.

In a paper mill which is relatively clean of toxins, there are two major components of water-borne effluent: suspended organic solids and »color» (22). Both exert influences on the water ecosystem which are measurable in energetic terms. The stains, besides being aesthetically objectionable, reduce the penetration of light into the water. This tends to reduce the plant life at lower depths, thereby hastening the depletion of oxygen. The organic matter provides a source of food for aquatic organisms. The effect is to create conditions paralleling those of a naturally eutrophic lake, but greatly intensified.

When the eutrophication process, which might have taken thousands of years (if it occurred at all) is collapsed into a few decades (21) there are clearly visible adverse affects. The water becomes murky and smells foul; fish and other wildlife disappear, leaving only lower organisms; and in some cases there is danger to public health by proliferation of pathogenic micro-organisms. There is evidence (36) that many of Finland's waters are on their way to this condition, with some 15 % of watercourses receiving effluents and 16 % of lakes in an eutrophic state, although the latter figure probably includes some naturally eutrophic waters. The wood processing industry contributes a very large proportion of this pollution, 73 % of the total volume from all sources in the country and 84 % of the *biological oxygen demand.** Table 1, taken from the first Finnish yearbook of environmental statistics, displays the sources of pollutants entering the waters of Finland in 1970.

Table 1. Waste water loading of Settlement and Industry by water courses in Finland in 1970.

	Quantity m^3/day	BOD_5/day	Nitrogen kg/day	Phosphorns kg/day
Settlement	783 000	127 600	21 100	5 680
Foodmanufacturing	398 000	40 000	2 300	880
Manufacturing of chemicals	360 000	2 500	11 500	870
Mining and quarrying	44 000	300	50	5
Manufacturing of metal products	481 000	1 400	100	15
Manufacturing of leather and leather products	5 000	10 000	800	130
Manufacturing of wood and paper products	5 620 000	989 200	11 700	2 170
Manufacturing of textiles	26 000	2 600	150	60
Total	7 717 000	1 173 600	47 700	9 810

* This is expressed as BOD_5, kilograms of oxygen equivalent to 5 days' consumption by micro-organisms in metabolizing the organic pollutants. It is a standard measure in water quality studies and is directly related to the energy content of pollutants.

Viewed as ecosystems, conditions in a managed forest are strikingly similar to those in an eutrophic lake. Biomass production is increased, species diversity is diminished, and stability- as evidenced, for example, by resistance to pathogens — declines also. Of course, the increased production and the elimination of undesired species are deliberate goals in forest management, whereas the same things occur »accidentally» in the lakes. But regardless of intent, it is the influx of an artificial source of concentrated energy which has affected both of these natural systems, and it is not surprising that they respond in similar ways. Indeed, this is a classic pattern followed by communities of organisms which receive large imports of food.

3.2. Practical goals

We are now in a position to phrase the purposes of this project rather precisely in energy terms. Broadly, it is *to provide private and public planners with information which will assist them in increasing the energetic efficiency of the forest products industry.* This could enable them to maintain relatively high levels of output, while reducing the energetic stress which this industry currently places upon land and water ecosystems. This in turn would enable people to enjoy the amenities of cleaner waters and less disturbed woodlands, while reducing the sacrifice of real product necessary to make this possible.

The key to this prospect is the physical interdependence between tree growth, industrial processing, and pollution. Recognition of these linkages is vital to a successful solution. For example: if pollution is simply contained, its disposal may increase the energetic (and monetary) costs of processing, as well as requiring that an even greater stress be placed upon the forests, to increase wood production and hold down the costs of raw materials. However, the wood constituents comprising the pollutants can potentially be used, either by inclusion in products for sale, or as additional sources of power for processing. In the first case, the need for »virgin» raw materials is reduced; in the second, the industry's dependence on external, purchased sources of energy is reduced. Viewed in this light, the aim of this work is industrial cost reduction. If there is a new contribution to be made, it is to improve the information needed to achieve these savings, and to better perceive the similarities between problems which may at first appear quite different.

The energetics of each of these processes — forestry, industry, pollution — are well understood by groups of specialists. What is proposed here is a relatively simple further extension, recognizing and measuring the dynamic linkages among all three elements.

4. EXPLORATORY EMPIRICAL WORK

4.1. Premises

The intent here is to establish some justification for employing the methodology proposed to synthesize economic and ecological studies. Therefore this phase takes in the whole industrial system of Finland, in aggregate and by sectors, although emphasis is placed on the wood-using industries. Broadly stated, the hypothesis to be tested is: *That flow of physical energy determines the generation of monetary value in industry.* However, the inverse proposition, *that economic value guides the flow of energy*, is of much greater interest from the viewpoint of regulating the physical system. We investigate similarities and differences between some economic models, and counterparts constructed for energy variables. Disparities between the results obtained with the two classes of models will be no less interesting than points of agreement, for it is precisely *the area of incompleteness in the monetary value system* which we wish to describe.

Looking only a little beyond the scope of the analysis presented here, it is expected that instances of marked divergence between money and energy costs will serve to identify the existence of some kinds of externalities. Then, tracing the energy flows should help to place the incidence of real costs. Finally, it is to be hoped that planners will thereby be better able to rectify some of the disparities.

4.2. Data

4.2.1. Content

These are the data employed in measuring the variables and estimating the parameters of the models:

L = Man-hours worked per year

Source: Industrial Statistics of Finland

K = Fixed capital of industry, deflated by indices of construction costs and machinery production prices,* in thousands of Finnmarks
Sources: Crude data — Industrial Statistics of Finland. Indices — Statistical Yearbook of Finland

Q = Output taken as value added in manufacturing, the standard definition modified by adding back in the purchase costs of energy consumed in the form of fuels, electricity, steam and hot water; deflated by production price indices; in thousands of Finnmarks
Sources: Crude data — Industrial Statistics of Finland. Indices — Statistical Yearbook of Finland

E = The theory adopted here requires that *the energetic equivalent of value added should be a measure of all work done* in manufacturing a product, including maintenance of the productive system; total energy use in megawatt-hours. As a first approximation, the energy flows added are:

a. Water power — including electric power generated by water turbines, plus power developed by similar engines harnessed directly to machines, the latter quantity estimated by the formula:

$$\frac{\text{wtd}}{\text{wte}} \cdot \text{WE}$$

in which

WE = Electricity generated by water power
wte = Water turbines driving electric generators
wtd = Water turbines driving machines directly

b. Fuels used — primarily wood in various forms, oil, and coal, with several other minor sources including peat.

c. Net electricity used — use minus production, a negative value for the industrial aggregate reflecting supplies to final demand sectors.

d. Net steam and hot water used — use minus production.

e. Human metabolic energy — selection of an appropriate measure here poses certain conceptual problems: should it be only the energy expended in performing productive work? The 24-hour metabolic requirement of the worker? Or perhaps the requirements of his family as well? As a first approximation, a 24-hour metabolic requirement of 3 000 kcal. for an active healthy adult has been divided by 8 working hours, and the result multiplied by the number of man-hours worked per year. In any case, this measure is unlikely to affect significantly the results obtained, since the magnitude is something less than 0.5 % of total energy used.

* The entries in the official statistics are fire-insurance or self-risk values. It seems reasonable to assume that these are closely related to replacement costs; hence the choice of indices.

4.2.2. Availability

There are certain data lacks of a more serious nature, however. More detailed work will require measures of efficiency of conversion of one form of energy to another, and of efficiency of applying energy to perform useful work: in each case, the proportion of the energy which is lost as unuseful heat. To adequately describe the system relationships, we would also need a set of accounts describing intersectoral energy transfers. Such information, perhaps cast in the form of input-output tables, would provide a better measure of total energy costs of producing a good, by adding indirect costs to the direct ones already measured.

In spite of these problems, data are available for Finland from 1954 permitting a rather good aggregate estimate of energy used by industry, although there are still certain inadequacies when individual industries are considered: chief among these is the omission, until 1965, of information on the production and consumption of energy in the form of steam and hot water, a major item for some sectors. Since 1965, the energy data are good enough to warrant cross-sectional analysis for Finland. As might be expected, the measures of labor, capital and output needed for economic models are sufficient throughout the study period.

4.2.3. Classification

Time period: annual data for the 16 years from 1954 to 1969 have been studied.

Industrial sectors: in the analysis of this report, 26 sectors have been recognized, the code numbers * corresponding to those in the Industrial Statistics of Finland:

Finnish Standard Groups No	Activities Included
12	Mining and quarrying
14	Stone quarrying, sorting of gravel and sand
15	Other mineral quarrying
16	Digging and preparation of peat
20	Food manufacturing industries, except beverage industries
21	Beverage industries
22	Tobacco manufactures
23	Manufacture of textiles

* As of 1969, corresponding in most cases to ISIC group numbers.

24 Manufacture of footwear, other wearing apparel and made-up textile goods
25 Manufacture of wood and cork, except manufacture of furniture
26 Manufacture of furniture and fixtures, except manufacture of metal furniture
27 Manufacture of paper and paper products
28 Printing, publishing, and allied industries
29 Manufacture of leather and leather products, except footwear
30 Manufacture of rubber products
31 Manufacture of chemicals and chemical products
32 Manufacture of products of petroleum and asphalt
33 Manufacture of non-metallic mineral products, except products of petroleum and coal
34 Basic metal industries
35 Manufacture of metal products, except machinery and transport equipment
36 Manufacture of machinery, except electrical machinery
37 Manufacture of electrical machinery, apparatus, appliances and supplies
38 Manufacture of transport equipment
39 Miscellaneous manufacturing industries
51 Electricity, gas and steam services
52 Water supply

Further disaggregation of these statistics is possible as well: In the wood processing and paper industries (sectors 25 and 27), of particular interest to us, 27 subsectors are recognized. All of the kinds of information used thus far in this study, except value of fixed capital, are recorded to this degree of detail in the published statistics or can be derived from them by simple transformations. Of course the confidence of estimates declines as smaller sectors are examined, but these will be helpful in tracing system linkages.

Figure 6 describes by source the energy used in the paper and wood processing industries, in comparison with the aggregate of all Finnish industry. It is particularly important to realize that virtually all *domestic energy sources* — hydropower, wood derivatives, even peat — *are solar based and self renewing* in a rather short time. In contrast, almost all foreign sources are mined products of nonrenewable fossil fuels. Hence any policies or programs which may be undertaken to reduce this source of import debits will also have the effect of helping to buffer the Finnish economy from the losses which will attend exhaustion of these resources.

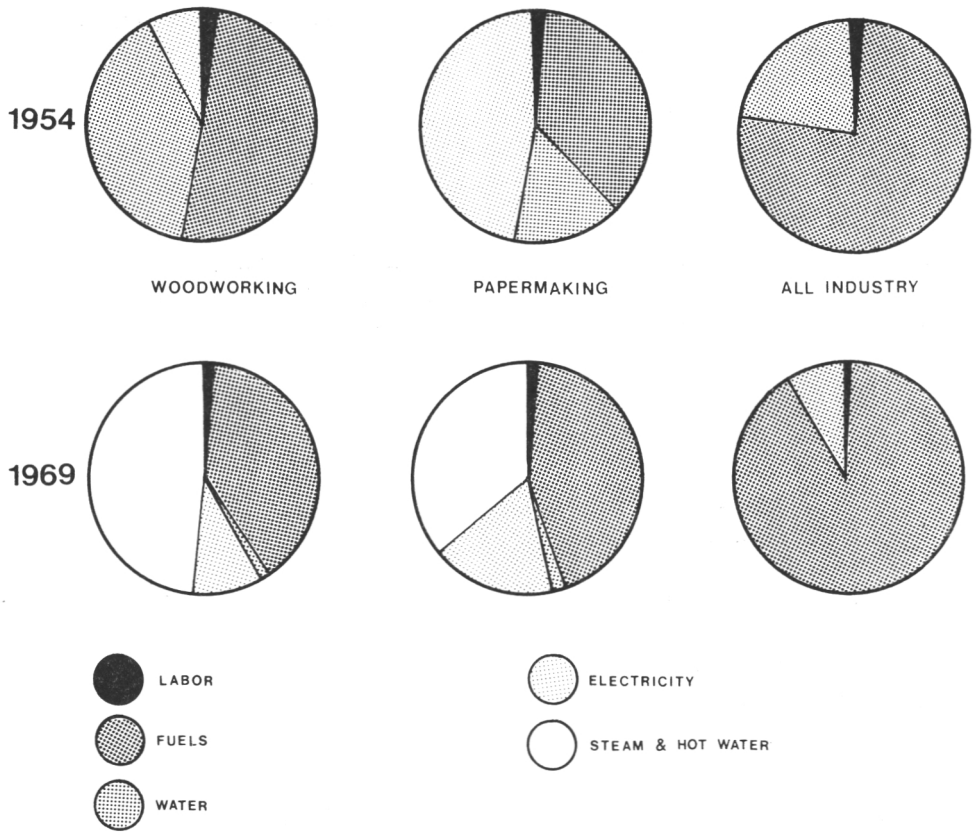


Figure 6a. Energy by physical sources

Human work accounts for very little of the energy expended to produce goods, even in *labor-intensive* industries, and the share is still declining. This need not be true of service sectors. In utilizing wood, some energy savings apparently could be effected by shifting from paper toward mechanical processing. Considering other forest land resources, energy scarcity also favors expansion of recreational services, particularly those generating spending by visitors from abroad.

An obstacle met in preparing this figure points up data needed for structural planning to improve overall energy-output efficiency. Energy from labor, fuels, and water power can be added up straightforwardly with appropriate conversion factors. However, some sectors are powered largely by the *secondary* energy sources of electricity, steam and hot water produced in surplus by other industries. To fully measure the contributions of different primary sources we should add indirect uses, in the manner of preparing input-output tables. We do not as yet have such comprehensive accounts of intersectoral energy transfers.

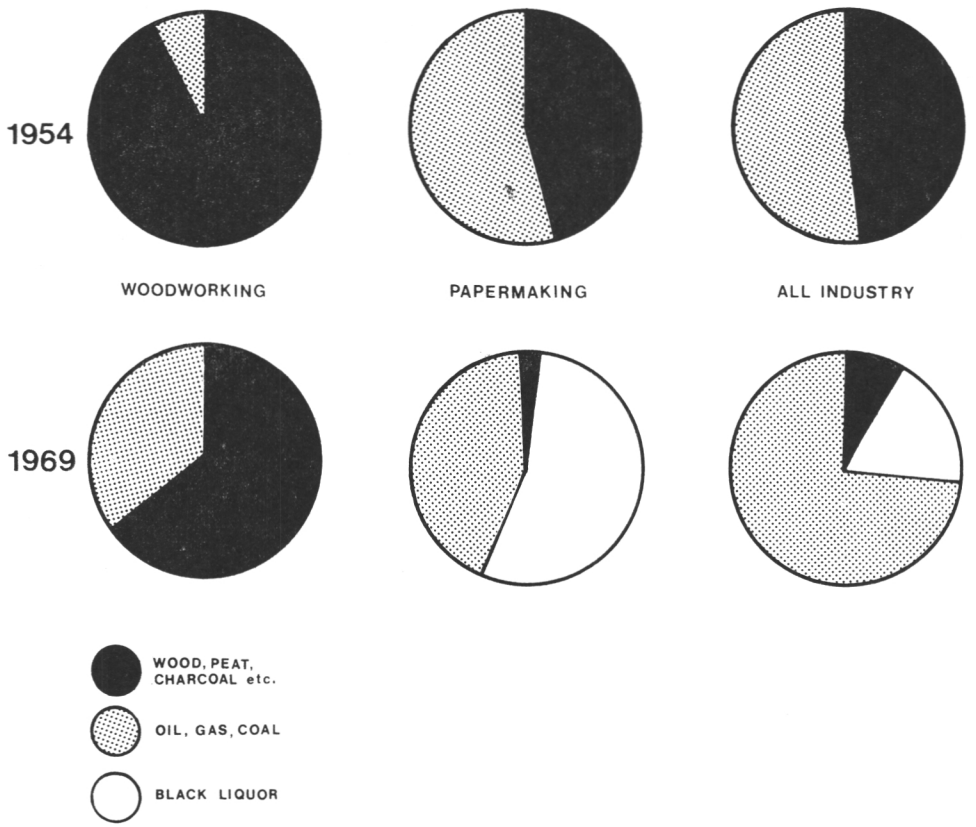


Figure 6b. Energy from fuels by type

Coal supported the early industrial development of most nations and will probably be heavily utilized again as oil supplies dwindle. Because Finland has no domestic resources of coal, in this country a substantial part of the historical place of that fuel was taken by wood. In the early fifties, wood supplied about half of the fuel energy used by all industries, and more than a quarter even in 1969. Finland's reliance on this renewable fuel is certainly unique among nations in comparable stages of development even though the share of wood is currently declining rapidly, particularly in favor of oil. There have been sound technical and economic reasons for the transition, but at this juncture we might question the wisdom of further phasing out wood-based fuels.

For those familiar with the technology of mechanical woodworking, it will not be surprising that waste material still supplies much of the fuel required by these mills. In contrast, burning of solid wood by the paper industry has practically ended but wood derivatives in black liquor have taken up an impressive share of fuel needs.

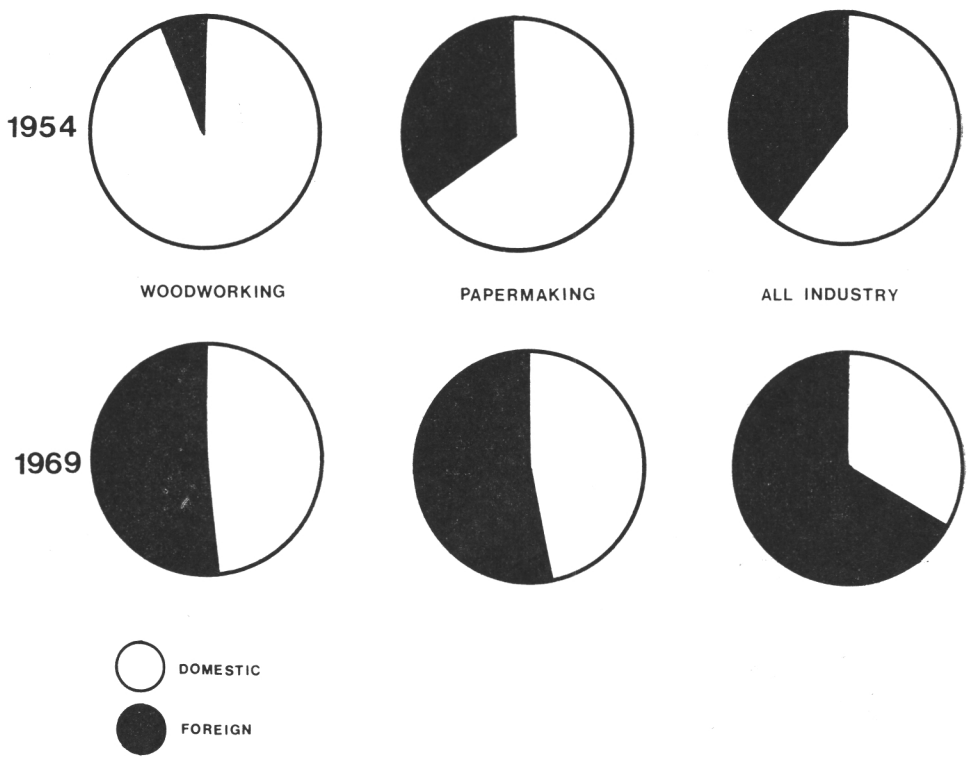


Figure 6c. Energy by place of origin

In 1954 some 60 percent of the energy used by Finnish industry was of domestic origin. By 1969 this fraction had declined to about one-third. Because of changes in technology and in the composition of industry, and in part because of limits on water power potential the substantial economic development of this period depended heavily on expanding consumption of fuels. An accom panying substitution of imported fossil fuels for domestic wood has compounded the effect on trade.

The net result has been a reversal of Finland's earlier position of relative energetic self-sufficiency, and this may prove troublesome if there is a substantial rise in world market prices of fossil fuels. Note that the wood processing industries have lagged behind others in the general swing to dependience on imported energy supplies.

4.3. Analysis

4.3.1 Output-input ratios

Examining the output/energy ratios for different industries in Table 2, we find the paper industry among the lowest of all, second only to petroleum manufactures.

In contrast, the output per man-hour of labor is quite high relative to other sectors. Over all sectors there is an inverse relationship between productivity of labor and of energy, whereas high output/capital ratios tend to be associated with high output/energy ratios. It is worth noting as well the great variation in magnitude of the output/energy ratios. There are two main ways for the national economic planner to use this kind of intersectoral energy use comparison. First, if we should encounter a long period of rising real costs of energy it is clear that those industries with high energy requirements will be at a competitive disadvantage. Some gains in national income can be made by promoting development of less energy-intensive

Table 2. Ratios of output to capital, labor, and energy in Finnish industry, 1969.

Industrial sector	Q/K	Q/L Fmk/Man-hour	Q/E Fmk/Kilowatt-hour
12	0.85	51.38	0.97
14	1.30	20.24	0.37
15	0.31	17.23	0.32
16	0.58	9.45	0.60
20	0.67	23.06	0.35
21	0.55	21.79	0.37
22	0.53	26.86	1.11
23	0.44	9.83	0.35
24	1.69	8.22	1.68
25	*0.70*	*11.79*	*0.21*
26	0.99	8.86	0.55
27	*0.32*	*29.19*	*0.07*
28	1.16	16.68	2.36
29	0.79	4.02	0.34
30	0.54	14.00	0.45
31	0.44	28.41	0.21
32	0.36	90.50	0.04
33	0.49	15.22	0.08
34	0.36	23.55	0.19
35	0.64	12.51	0.59
36	0.73	13.90	0.76
37	0.78	14.97	0.97
38	0.94	12.05	0.63
39	1.02	13.52	0.81
51	0.40	73.29	0.13
52	0.22	62.14	0.63

industries. Of course it is too simplistic to conclude that this is the whole answer: at the national and certainly at the international level, the interdependence of sectors in an industrial *system* has to be evaluated in energetic terms also.

A second, less obvious use for such information has to do with environmental costs such as pollution. Industries with high energy requirements are virtually certain to create intractible pollution problems. This is particularly true if we include thermal pollution in our definition. The fact is that »everything has to go somewhere» and energy used in industry is dissipated into the environment either in the form of pollutants or as heat. A study of industrial energy requirements can thus enable the planner to form a first estimate of the probable pollution costs of alternative development strategies.

4.3.2 Production functions

To examine these relationships in somewhat greater detail, production functions of the Cobb-Douglass form * (1) were compared

1) $Q = m L^{\alpha} K^{\beta}$

or

$\log Q = \log m + \alpha \log L + \beta \log K$

for Q = Industrial output
L = Labor input
K = Capital input
α, β = usually referred to as the »productivities» of labor and capital, respectively
m = constant

with a family of similar functions constructed for inputs defined in energetic terms, the simplest being:

2) $Q = m E^{\lambda}$

or

$\log Q = \log m + \lambda \log E$

Q = Industrial output, defined as above
E = Energy consumed by industry
λ = »productivity» of energy
m = constant

* Strictly defined this class of production functions often has $\alpha + \beta = 1$, so that there are constant returns to scale, but such restriction has been relaxed in this study.

The choice of models was guided by considerations other than convenience. For some years the construction of elegant and sophisticated economic models has gone far ahead of empirical testing of those models. Within this discipline the work of economic theorists has been demonstrated largely by abstract manipulations of the calculus, rather divorced from the efforts of econometricians »thrashing around in multidimensional space.» The existence of this curious gap, although recently narrowing, has meant that policy decisions of firms and governments are often based upon theoretical formulations quite untried beyond the *a priori* reasoning of their makers.

With this background, the present work proposes a certain departure from the customary economic inputs thought to be responsible for production, and this distinction ought to be clearly stated. For wider communication of ideas, the provision of some familiar landmarks to be recognized by nonspecialist readers assumes a value which can be weighed against the pursuit of small increments in correlation. For these reasons I judged it best to employ easily calculated models from the standard toolkit of the policymaker, rather than specialized multivariate formulations of greater complexity.

In addition to the primary data sets previously described, a number of other variables derived from them were tested. These included:

Kt = E/M, M being the engine capacity in kilowatts directly driving machines. This is intended as a partial measure of technology relating to capital.

Lt = E/E_L, E_L being the human metabolic energy. This is intended as a measure of technology relating to labor, and is equivalent to Odum's »labor amphification factor»

H = E/S, S being the energy in steam and hot water produced. This is intended as a crude first approximation of the efficiency of energy use, since S is a portion of energy input which is recovered for a second use before being dissipated.

The models were tested in time series analysis for the aggregate, for the two major wood-using sectors combined, and for the paper industry. Cross-section analysis over all industrial sectors was performed for each of the years 1965 through 1969. Tables 3 and 4 present the correlation matrices of the variables used in time series and in cross-section, respectively. The corresponding data sets are found in Appendix Tables 1 and 2. Only the cross-section for 1969 is reported as the most recent, but results for the other years were quite similar.

Table 3 a. Correlation coefficients from time series analysis of the allindustry aggregates

	Q	L	K	E	Lt	Kt
Q	1.000					
L	.774	1.000				
K	.988	.775	1.000			
E	.981	.779	.983	1.000		
Lt	.972	.680	.975	.987	1.000	
Kt	.173	.353	.234	.122	.064	1.000

Table 3 b. Correlation coefficients from time series analysis of the wood-using industries

	Q	L	K	E	Lt	Kt
Q	1.000					
L	.190	1.000				
K	.967	.212	1.000			
E	.895	.192	.938	1.000		
Lt	.867	—.038	.906	.973	1.000	
Kt	.662	.268	.687	.412	.356	1.000

Table 3 c. Correlation coefficients from time series analysis of the paper industry.

	Q	L	K	E	Lt	Kt
Q	1.000					
L	.126	1.000				
K	.970	.105	1.000			
E	.928	.009	.953	1.000		
Lt	.871	—.078	.888	.975	1.000	
Kt	.568	.164	.630	.386	.232	1.000

Table 4. Correlation coefficients from cross section analysis over industrial sectors, 1969.

	Q	L	K	E	Lt	Kt	H
Q	1.000						
L	.880	1.000					
K	.950	.755	1.000				
E	.870	.684	.920	1.000			
Lt	.245	—.135	.447	.631	1.000		
Kt	—.487	—.307	—.519	—.682	—.599	1.000	
H	.575	—.492	.644	.628	.330	—.617	1.000

Of particular interest in the matrices are the high correlations, encountered in these and in all other analyses performed so far, between *capital stock and energy flow*. This correspondence supports the view that energy can be substituted for capital in economic theory, particularly where comparison of unlike outfits of capital is concerned.

The Cobb-Douglass function for the aggregate time series is

1) $\log Q = .263 + .103 \log L + .850 \log K$

or

$Q = 1.301\, L^{\cdot 103}\, K^{\cdot 850}$

for which $r^2 = .977$

and the best energy function is

2) $\log Q = .133 + .751 \log E$

or

$Q = 1.142\ E^{.751}$

for which $r^2 = .963$

For the combined wood-using industries, the time series Cobb-Douglass function is

1) $\log Q = .977 - .073 \log L + .880 \log K$

or

$Q = 2.656\ L^{-.073}\ K^{.880}$

for which $r^2 = .936$

Now the best energy model has two explaining variables:

3) $\log Q = .142 + .771 \log E + .774 \log Kt$

or

$Q = 1.153\ E^{.771}\ Kt^{.774}$

for which $r^2 = .905$

However, the simplest energy model

2) $\log Q = .313 + .921 \log E$

or

$Q = 1.368\ E^{.921}$

for which $r^2 = .801$

may still be useful for certain purposes.

For the paper industry alone, the Cobb-Douglass function estimated from time series data is

1) $\log Q = .181 - .209 \log L + .971 \log K$

or

$Q = 1.198\ L^{-.209}\ K^{.971}$

for which $r^2 = .942$

Again the best corresponding energy function is

3) $\log Q = .240 + .868 \log E + .646 \log Kt$

or

$Q = 1.292\ E^{.868}\ Kt^{.646}$

for which $r^2 = .913$

but we may also be interested in the simpler

2) $\log Q = .272 + .967 \log E$

or

$$Q = 1.312\, E^{.967}$$

for which $r^2 = .861$

Turning to the 1969 cross-section analysis, the Cobb-Douglas function is

1) $\log Q = .750 + .375 \log L + .626 \log K$

or

$$Q = 2.138\, L^{.375} K^{.626}$$

for which $r^2 = .964$

and the best energy function is

4) $\log Q = .260 + .918 \log E - .529 \log Lt$

or

$$Q = 1.297\, E^{.918} Lt^{-.529}$$

for which $r^2 = .909$

again an improvement over the simple

2) $\log Q = .346 + .672 \log E$

or

$$Q = 1.41\, E^{.672}$$

for which $r^2 = .756$

The confidence limits for the coefficients of variables in all models are presented in Appendix Table 3.

4.4. Interpretation

Compare the performance of the two classes of production functions first in terms of their values for r^2, a measure of the proportion of variation in value added which has been explained by the analysis. For the time series data aggregating all industries, it is clear that the model for only one input, energy, performs as well as that employing labor and capital inputs. This is rather interesting in view of the fact that the wage bill alone, which in fact is largely derived from the labor input by simple multiplicative trans-

formations, accounts for some 40 % of the value added during the study period: Thus there is considerable »built in» correlation between these independent and dependent variables. In contrast, the costs of energy purchased have been about 16 % of value added in manufacturing, and energy prices are by no means directly related to the work input. Looking at individual sectors of industry, it is to be expected that the explanatory power of the two types of models will fall off considerably. However, for the paper industry their performance holds up rather well, perhaps because it is so highly capital- and energy-intensive. Autocorrelation of the residuals was tested but not completely analyzed. For the intermediate level of aggregation combining the woodworking and paper industries, the result is somewhat out of the ordinary: the degree of explanation is slightly less than for paper alone, although the differences are not significant.

This can be attributed largely to the mixed fortunes of the Finnish woodworking industry during the study period. The output — and input use — of this sector has been declining relative to the rest of the industrial system: its real growth has averaged only 4.3 % annually during this time, in contrast to 6.2 % for all industries together and 9.2 % for paper production. This has been due in part to competition for raw materials from the more efficient paper industry, and in part to the relatively slow growth of international demand for worked-wood products. Annual fluctuations have also been greater. In the context of this report, this weakness and instability suggest that prices and output in woodworking have perhaps been more determined by demand conditions in the raw material and product markets, than by inputs of factors of production. In fact, single-sector time series were analyzed for that industry, revealing that coefficients of the variables in both energetic and traditional economic models barely differed significantly from zero.

Cross section analysis is a more rigorous test of the energy-output relationship because of the much greater variability encountered in all features of industry. Some difference does appear, but still models of both classes explain better than 90 % of the variation.

With reference to the slightly lower degree of explanation afforded by some of the energy functions, it should be noted that the energy data used are incomplete, particularly in single-sector time series: for the sake of consistency, the better information available from 1965 forward has been excluded. An interesting feature of the labor-capital time series functions is the apparently small and uncertain influence of labor on changes in production in Finland during this period, evidenced by the range of estimates for the labor coefficients in the linear functions:

Input coefficients, with 95 % confidence

Industry	Labor	Capital
All	.103± .609	.850± .117
Wood-using	—.073± .644	.880± .130
Paper	—.209± .951	.971± .239

This is not so surprising, since the two decades spanned by the data have witnessed rapid industrialization and transformation from an economy which relied heavily on primary industries, and manual labor in many activities. The accompanying rural-to-urban migration, now slowing or even reversed in most western European countries and the United States, is still gathering force in Finland. Under these circumstances, it is reasonable to expect productivity from the acquisition of capital to be high relative to that of labor.

To get an idea of the returns to scale in Finnish industry, look at the sums of the input coefficients for each model. These are .953 for all industry, .807 for wood-using industries and .762 for the paper industry, somewhat less than the unitary value of the standard Cobb-Douglass function. Corresponding coefficients of the simplest energy functions are 0.751, .921 and .861, respectively. These findings are in accord with statements made by the Economic Planning Centre that the »rates of return on capital have been low» (31, p. 169) and that »demand for energy has grown slightly faster in Finland than domestic product.» International comparisons the present author is making among OECD countries are expected to help explain the relation between energy and the productivity of capital.

5. CONCLUSIONS AND PROGRAM OF FURTHER WORK

The dependence of industrial activity on energy sources has been clear enough from an engineering standpoint. The results of this study, although limited in scope and exploratory in nature, support the view that it will be fruitful to incorporate energy measures as explicit variables in certain economic models. More work is needed in this area, to strengthen or refute this assertion. This author intends to continue along this line, developing appropriate theoretical formulations and testing them empirically at each step. Such models also provide framework for the more specific investigation, now going on, of interactions of forest-based industry with the forest and water ecosystems of Finland.

The paper industry in particular is well suited to a project of this kind. It is of considerable economic importance to this country, highly energy--intensive, and its chief raw material is a biological product which has alternative uses as fuel or as structural material (including all end-product uses of wood in which the potential chemical energy stored by the sun is not released: paper, furniture, building materials, and the like). Other considerations are that the dynamics of primary production in temperate forest ecosystems have been rather thoroughly studied and, focusing on the paper industry, the technology of production is fairly standardized and concentrated in a few large establishements. In addition, we have seen that this industry generates most of the water pollution in Finland. Special attention is directed to the proportion of the energetic content of wood which is incorporated in the final product, in relation to that which is utilized as fuel or deposited as waste.

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SELOSTE

Metsäteollisuudella on perinnäisesti ollut tärkeä asema Suomen kansantaloudessa. Se yksin vastaa yhä noin puolesta maan vientituloista. Samanaikaisesti yritykset, valtiovalta ja suuri yleisö Suomessa kohtaavat eräitä ajankohtaisia ongelmia, jotka ovat tyypillisiä kaikille teknisesti kehittyneille maille: (1) Raaka-aineiden ja energian niukkuus rajoittavat metsäteollisuuden tuotoksen kasvua. (2) Eriasteisia ympäristön haittavaikutuksia syntyy jokaisessa tuotannon vaiheessa metsänuudistamisesta metsäteollisuustuotteen lopulliseen käyttöön saakka.

Tämän tutkimuksen keskeisenä tarkoituksena on *sekä teoreettisesti että kokemusperäisen aineiston avulla osoittaa metsäteollisuuden raaka-aineiden, voimantarpeen ja ekologisten vaikutusten keskinäiset dynaamiset riippuvuudet mitattuna energian virtoina ja varantoina.* Näitä teollisuuden ja ekosysteemien välisiä riippuvuuksia voidaan seuraavassa vaiheessa hyödyntää *vertaamalla vaihtoehtoisten taloudellisten toimenpiteiden edullisuutta energiassa mitatuin kustannuksin ja hyödyin.*

Noin kymmenen viime vuoden kuluessa ekologit ovat edistyneet huomattavasti kvantifioimalla monimutkaisia ekosysteemejä energiatutkimuksen keinoin. Toisaalta polttoaineiden välttämättömyys teollisuudelle on luonnollisesti aina tiedostettu, mutta aivan viime vuosiin saakka yleisesti uskottiin, että uusia energialähteitä voitaisiin kehittää riittävästi. Tarkastellessamme tapahtunutta kehitystä voimme todeta nauttineemme jokseenkin pitkään muihin tuotantokustannuksiin verrattuna vakaahintaisesta ja huokeasta energiasta.

Puu- ja paperiteollisuudessa esiintyy eräitä omaperäisiä energiaan liittyviä piirteitä. Ensinnäkin niiden pääraaka-ainetta puuta tuottava *metsä on uudistuva luonnonvara.* Metsän jatkuvan uudistumiskyvyn taustatekijä on sen omintakeinen energiatalous: Metsiä pidetään yhtenä tehokkaimmista nykyisin tunnetuista keinoista auringon energian kahlitsemiseksi, muuntamiseksi ja varastoimiseksi. Puu voidaan sitten jalostaa erilaisiksi tuotteiksi, käyttää polttoaineena tai siitä voidaan valmistaa jopa ravintoa.

Suomella on ehkä ainutlaatuinen asema maailmassa siinä suhteessa, että puuta eri muodoissaan on käytetty suhteellisen paljon lämmitykseen ja voiman lähteenä. Näihin tarkoituksiin puuta käytettiin aikaisemmin pääasiassa polttopuuna. Sittemmin etenkin metsäteollisuuden erilaisten jätteiden poltto on huomattavasti lisääntynyt. Toisaalta tiedetään, että pääosa Suomen vesistöjen jätekuormituksesta on paperiteollisuuden aiheuttamaa. Tämä jätekuormitus voidaan nähdä myös ympäristöä pilaavana energiapurkauksena ja siten hukattuna voimavarana. Kuvassa 5 b (s. 21) on esitetty tällaisen »metsäsysteemin» olennaiset alkiot ja riippuvuudet.

Ekologiassa ja teknologiassa käytetyt mittausmenetelmät ovat tarpeen pyrittäessä kvantifioimaan edellä kuvatun »metsäsysteemin» energiariippuvuuksia. Niiden tunteminen toisi uutta tietoa monia metsäsektorin päätäntätilanteita varten. Kokemusperäisen aineiston käyttö tässä ensimmäisessä tutkimusraportissa on ensi vaiheessa kuvailevaa. Tällöin yksilöidään Suomen teollisuudenalojen energian lähteet ja ver-

rataan eri alojen energiatarvetta. Toisessa vaiheessa rakennetaan teollista toimintaa kuvaavia yksinkertaisia taloudellisia malleja käyttäen myös energiamuuttujia. Lähtien koko teollisuustuotannosta ja 26 teollisuusalasta hahmotellaan viitekehikkoa puu- ja paperiteollisuuden yksityiskohtaisempaa tutkimista varten.

Jalostusarvon suhde energian nettokäyttöön oli 21 penniä kilowattituntia kohden puuteollisuudessa, mikä on hieman korkeampi kuin koko teollisuuden keskiarvo, joka oli 18 p/kWh. Tuotos/energia-suhde massa- ja paperiteollisuudessa oli 7 p/kWh, joka on yksi alhaisimpia kaikista teollisuudenaloista. Tällainen vertaileva tieto saattaa osoittautua hyödylliseksi kokonaistaloudellisessa suunnittelussa.

Cobb-Douglass-tyyppisiä tuotantofunktioita kehitettiin käyttämällä perinteisten työ- ja pääomapanosmuuttujien lisäksi energiamuuttujia. Mallit testattiin Suomen teollisuustilaston antamalla aikasarja- (1954—1969) ja poikkileikkausaineistolla. Saadut tuotantofunktiot selittivät teollisuuden tuotosta jokseenkin hyvin. Energiamuuttujia käyttämällä päästiin työpanos- ja pääomapanosmuuttujia vastaaviin tuloksiin. Jatkotutkimuksissa tulisi erityisesti kiinnittää huomiota tapauksiin, joissa raha- ja energiamitoin saadut arvot poikkeavat olennaisesti toisistaan, koska näin lienee mahdollista yksilöidä puutteellisuuksia rahamittoihin perustuvassa järjestelmässä.

Tämän tapaisessa tutkimuksessa tarpeellinen tietojen saanti aiheuttaa joitakin esteitä, jotka eivät kuitenkaan vaikuta voittamattomilta. Metsien ekosysteemeissä tapahtuvan alkutuotannon dynamiikka on nykyisin jo melko hyvin tutkittu ja ymmärretty. Niin ikään metsien poistuma, hakkuumäärä ja puunkäyttö ovat Suomessa melko hyvin tilastoituja. Ympäristön pilaantumisen energiavaikutusten tunteminen muodostaa heikoimman renkaan tässä ketjussa, mutta tiettyä edistymistä myös tämän aihepiirin tuntemisessa on viime aikoina tapahtunut.

Vuodesta 1965 lähtien sisältyy Suomen teollisuustilastoon melko yksityiskohtainen energian käytön luokittelu päätyypeittäin erikseen kullakin teollisuusalalla. Esimerkiksi puu- ja paperiteollisuudessa koko energian käyttö on tilastoitu 10—27 luokkaan. Kokonaistaloudellisen suunnittelun kannalta kiireellisimmältä tuntuu eri toimialojen välisten energiansiirtojen rekisteröinti ja laatiminen mahdollisesti panos-tuotostaulujen muotoon. Tällainen järjestely helpottaisi riippuvuuksien kuvailua ja mahdollistaisi teollisuuden välillisten ja välittömien energiakustannusten huomioonottamisen.

RÉSUMÉ

L'industrie finlandaise à base de bois soutient une large partie de l'économie nationale et est la source majeure des revenus d'exportation. En même temps les entreprises, le gouvernement et le publique confrontent des problèmes qui sont communs aux pays développés au point de vue de technologie: l'insuffisance en matières premières et sources d'énergie limite la croissance: 2) l'endommagement du milieu à chaque étape, depuis la silviculture jusqu' à la vente du produit final.

Le premier but de cette étude est de démontrer l'interdépendance dynamique de la matière première, les sources d'énergie, et les effets écologiques en termes de flux et dépôts d'énergie. Les relations entre industrie et écosystèmes peuvent être utilisées alors afin de comparer le coût d'énergie et les bénéfices provenant d'activités économiques alternatives. L'écologiste, tentant de mesurer les systèmes complexes biologiques à l'aide d'études d'énergie, a fait des progrès considérables dans cette direction pendant les dix dernières années. Le besoin de combustibles pour l'industrie a été reconnu également, mais il a été assumé jusqu' à récemment que des nouveaux stocks d'énergie pouvaient être développés comme désiré. Il est vrai que nous avons joui d'une longue période de coût stable d'énergie, coût bas en comparaison avec d'autres ressources. Mais il est peu productif d'analyser cette complaisance en rétrospect.

Les industries à base de bois montrent quelques caractéristiques péculières d'énergie. La matière première est renouvellée continuellement. En fait, la forêt est le moyen le plus efficace pour l'accumulation, la transformation, et l'emmagasinage de l'énergie solaire. Le bois peut être employé comme combustible ou bien transformé en nourriture. La Finlande occupe une place unique au monde par son degré de dépendance du bois-jadis sous forme solide et plus récemment par une technologie sophistiquée de récupération de déchets- pour le chauffage et comme générateur d'énergie. Notre milieu est sujet d'une tension énergétique considérable, particulièrement sous forme de pollution d'eau; cette tension peut être considérée comme ressource gaspillée. La figure 5 représente les chaînes essentielles du système.

Les techniques empiriques de l'écologiste et de l'ingénieur fournissent les données nécessaires aux décisions économiques employées dans l'étude de ces chaînes. Le travail empirique présenté ici est en partie descriptif; les sources d'énergie de l'industrie finlandaise y sont identifiées et une comparaison est établie entre les demandes en énergie dans les différents secteurs. Il en a été conclu que le rapport entre production et usage net d'énergie est à peu près. .21 marques finlandaises par kilowattheure pour l'industrie boisière méchanique. Ceci est un peu plus haut que la moyenne de .18 marques par kilowattheure pour l'ensemble des industries, tandis que ce rapport est un des plus bas dans les industries à base de bois et de papier, soit. 07. Des comparaisons pareilles peuvent prouver utiles pour les décisions économiques au niveau national. Afin d'établir un cadre pour une étude plus détaillée des industries forestières, quelques modèles économiques simples d'activité industrielle ont été considéré et ont été formulé en termes énergétiques. Les fonctions de production de la forme Cobb-Douglas

ont été basé sur main-d'oeuvre et capital ainsi que sur variables d'énergie provenant de séries de temps et de données d'une section transversale des industries finlandaises. Les résultats des deux catégories de modèles sont généralement en accord et ils expliquent bien les variations en production. Les différences entre les évaluations monétaires et énergétiques doivent être examinées soigneusement puisqu'elles peuvent servir à identifier des aires incomplètes dans le système monétaire.

Un des obstacles est la nécessité de données, mais il est possible de le surmonter. La dynamique de la production primaire de l'écosystème forestier en zone tempérale est bien connue; les statistiques concernant l'enlèvement et l'usage du bois sont complètes pour la Finlande. Les effets énergétiques de la pollution n'ont pas été étudié en profondeur mais des progrès sont faits dans cette direction. Depuis 1965 la statistique industrielle finlandaise a tenu une comptabilité détaillée de l'usage direct de diverses formes d'énergie secteur industriel. Par exemple toutes les statistiques d'énergie ont été régistré pour au moins 10, et en quelques cas 27, subsecteurs de l'industrie boisière. Au plan national il existe vis-à-vis de la planification économique un besoin urgent pour des données compréhensibles faisant référence aux transfers d'énergie entre secteurs et organisées éventuellement sous forme de tableaux ressources-production. Ceci clarifiera les interdépendances et permettra d'ajouter les coûts directs et indirects d'énergie des industries.

КРАТКОЕ ИЗЛОЖЕНИЕ

Финская деревообрабатывающая и целлюлозно-бумажная промышленность составляют важную часть национальной экономики и являются основными источниками экспортных доходов. В то же время фирмы, правительство и общество в целом стоят перед проблемами, которые приобрели общий характер для всех индустриально развитых стран: с одной стороны, недостаток сырья и лимитирующее вдияние энергетических ресурсов; сдругой стороны, загрязнение окружающей среды на всех стадиях производства от создания древостоев до сбыта готовой продукции.

Основной целью данной работы является выявление динамической взаимозависимости между сырьевыми ресурсами, энергетическими запасами и изменениями экологического характера, показ данной зависимости в форме расхода и накопления энергетического потенциала. Эти связи между промышленностью и экологическими системами можно затем использовать для сравнения энергетических затрат и выгод различных направлений экономической деятельности. В течение приблизительно последних десяти лет экологи добились больших успехов в количественной характеристике биологических систем путем изучения их энергетического баланса. Необходимость получения горючего для промышленности также, естественно, принималось во внимание, но до последнего времени обычно считали, что будут найдены новые неограниченные источники энергии. Хотя ретроспективный анализ такого благодушия едва ли целесообразен, однако следует сказать, что в течение довольно длительного периода энергетические затраты оставались постоянными и более низкими по стравнению с другими издержками производства.

Отрасли промышленности, использующие в качестве сырья древесину, имеют своеобразную энергетическую характеристику. Прежде всего, древесина непрерывно возобновляется; леса из всех известных способов фактически представляют собою наиболее эффективное средство для улавливания, преобразования и накопления солнечной энергии. Древесину в дальнейшем можно перерабатывать в изделия, использовать в качестве горючего или изготовлять пищевые продукты. Финляндия в этом отношении занимает в мире исключительное положение, пожалуй, более чем какая либо другая страна она пользовалась древесиной для отопления и выработки энергии, первоначально в сыром виде, а последнее время в ходе технически достаточно совершенных процессов утилизации отходов основного производства. Значительная энергетическая напряженность, имеющая место в нашей экосистеме, особенно в форме загрязнения водных бассейнов, может, следовательно, рассматриваться как бесполезная растрата энергетических ресурсов. Рисунок 5 б (стр. 21) показывает основные звенья связей в данной системе.

Методика изучения этих связей использует эмпирическую технику экологических и инженерных исследований и имеет целью дать данные для принятия экономических решений. Эмпирическая работа, представленная в этом

первом докладе, носит частично описательный характер, в ней просто указаны источники энергии для промышленности Финляндии, проведено сравнение энергетических потребностей различных секторов промышленности. Было устанавлено, что соотношение между приростом стоимости и потреблением энергии составляет примерно 21 финск. марок на киловаттчас в деревообрабатывающей промышленности, что несколько выше чем в среднем для всей промышленности — 18 фмк/киловаттчас; в то же время соотношение между производством готовой продукции и потреблением энергии в целлюлозно-бумажном производстве является самым низким и равно 0.7. Такая сравнительная информация может оказаться полезной для экономического планирования в масштабе целой страны. С целью получения основы для более детального изучения лесной промышленности были взяты несколько простых моделей промышленной деятельности и перестроены так, чтобы получать результаты в энергетических показателях. Проверены производственные функции Кобб-Дугласа как на материале потребления рабсилы и капитала, так и энергетических переменных с использованием данных для всей финской промышленности с 1954 по 1969 гг. Окончательные данные, полученные от этих двух типов моделей, оказались в общем сходными, позволявшими достаточно хорошо объяснять различия в конечных результатах. При работе по данному методу случаи расхождений в оценке по денежным и энергетическим результатам необходимо тщательно анализировать, так как они часто могут служить для обнаружения неполности денежной системы оценки.

Требования, предъявляемые к исходным данным, представляют определенные трудности, но они не являются непреодолимыми. Динамика первичного производства в лесах умеренной зоны изучена сравнительно хорошо и статистические данные об отпуске леса и использовании лесных ресурсов в Финляндии достаточно полные. Энергетическое влияние загрязнения среды не было основательно документировано, но в настоящее время в этом отношении имеется определенный прогресс. С 1965 года финская промышленная статистика ведет достаточно детальный учет прямого потребления энергии в различных видах по отдельным секторам промышленности. Так, например, в деревообрабатывающей промышленности статистический учет потребления энергии осуществляют по 10 и, в некоторых случаях, по 27 субсекторам. Для генерального экономического планирования в национальном масштабе крайне необходим полный учет передачи энергии от одного сектора к другому, по-видимому, в виде таблиц, показывающих поступление и передачу энергии. Это выявило бы взаимосвязи и позволило бы учитывать прямые и непрямые энергетические затраты в промышленности.

Appendix Table 1 a. Whole industry data indices.

	Q	L	K	E	Lt	Kt
1954	100000	100000	100000	100000	100000	100000
1955	114766	105599	110760	098761	093524	109052
1956	123286	103670	112911	107310	103511	106218
1957	127577	102207	128701	108179	105843	111649
1958	123632	096328	130492	114207	118560	111609
1959	135082	100326	138887	114208	124867	107236
1960	148653	109142	154277	148530	136089	099326
1961	161166	113814	167531	149545	131394	117504
1962	169145	115168	178820	156139	135575	119391
1963	177770	112857	183527	175453	155465	114340
1964	181742	114381	201889	195919	171287	107974
1965	185939	115487	204976	206254	178595	119557
1966	199642	114965	229551	223967	194813	115391
1967	214292	111681	247155	231916	207659	113586
1968	237028	109665	249251	250441	228370	108907
1969	261208	114767	266535	293684	255895	098722

Appendix Table 1 b. Wood-using industries data indices.

	Q	L	K	E	Lt	Kt
1954	100000	100000	100000	100000	100000	100000
1955	121586	103144	109711	094214	091342	114560
1956	120510	091183	113541	094535	103676	118099
1957	143713	090843	126703	099929	110003	119111
1958	147088	093190	130205	102235	109706	122748
1959	150488	096933	138582	108137	111559	122198
1960	177680	110536	157595	113196	102406	130918
1961	190173	112543	179071	131231	116606	145929
1962	187463	108421	197350	130216	120103	152454
1963	203721	107433	195169	133831	124571	163285
1964	210743	107764	213215	162016	150344	143588
1965	212389	106448	233061	222331	208863	112927
1966	217364	100256	250460	172566	172125	157597
1967	229638	093861	262350	179866	191631	152916
1968	289849	095080	265788	179285	188563	153325
1969	320711	099555	288285	238838	239905	126771

Appendix Table 1 c. Paper industry data indices.

	Q	L	K	E	Lt	Kt
1954	100000	100000	100000	100000	100000	100000
1955	137000	107428	111789	111107	103426	098722
1956	147649	106719	118561	119012	111522	096694
1957	172176	109215	133758	126811	116114	095837
1958	175265	106648	137717	127910	119938	103174
1959	176516	111831	147613	135880	121505	103013
1960	206262	122653	171442	138258	112725	114869
1961	228572	132409	198492	162589	122797	131619
1962	233104	132286	221737	164592	124421	135438
1963	256340	131304	216999	171723	130787	143599
1964	266575	133014	237836	206077	154931	127712
1965	269983	132765	263059	295792	222798	096054
1966	280798	129492	285365	227481	175673	164652
1967	297058	123129	298154	239110	194196	130367
1968	375439	123580	302888	240385	194522	129096
1969	409461	126395	328323	323847	256224	105989

Appendix Table 2. 1969 cross section data.

	Q	L	K	E	Lt	Kt	H
12	293880	5720000	345569	303327	11429050	30890	00000
14	18177	898000	14305	49073	11768106	14032	00000
15	30016	1742000	96758	92821	11487748	33108	00000
16	4320	555000	7403	7188	2786047	36519	00000
20	1269335	79774000	1889270	3630693	9808707	06740	26856
21	193869	8897000	352515	529212	12820058	03842	16115
22	57605	2145000	108286	52013	5227437	07548	11820
23	479933	48823000	1093666	1383406	5849744	07580	51340
24	451741	54937000	268019	268953	1055090	07919	07170
25	732404	62135000	1050291	3548532	12308043	08143	17064
26	213976	24158000	215298	390591	3484620	11268	04734
27	2070758	70938000	6253474	27771410	84373113	07826	39142
28	606318	36354000	521916	256643	1521479	11512	00000
29	38803	9649000	48983	113012	2524280	11609	00877
30	124134	8867000	230216	273437	6646500	13252	17186
31	684252	24082000	1555164	3200466	33116753	06564	79300
32	212135	2344000	591018	5041917	463411489	01609	26444
33	447482	29392000	912661	5403214	39618815	03051	00502
34	467554	19851000	1285905	2451050	22610031	09906	31335
35	469240	39662000	775180	837064	4548519	12561	02072
36	942203	67796000	1288458	1241981	3948186	15946	01141
37	412709	27578000	532452	425074	3321929	13536	14549
38	781199	64855000	833477	1247621	4145884	09293	05094
39	232605	17202000	228454	287207	3598183	17409	02462
51	1761623	24037000	4389709	13934121	124936080	02004	223206
52	93584	1506000	433070	147718	21132761	19862	13998

Appendix Table 3. Ranges of coefficient values for independent variables in all models reported, with 95 % confidence.

Data set	*Model*	*Variables*				
		L	K	E	Lt	Kt
Time series						
All industry	1	.103±.609	.850±.117			
	2			.751±.079		
Wood-using industries ..	1	—.073±.644	.880±.130			
	2			.921±.245		
	3			.771±.194		.774±.411
Paper industry	1	—.209±.951	.971±.239			
	2			.967±.207		
	3			.868±.184		.646±.463
Cross section	1	.375±.120	.626±.114			
	2			.672±.156		
	4			.918±.125	—.529±.170	

EPIPHYTOLOGY OF *MELAMPSORA* RUSTS OF SCOTS PINE (*PINUS SYLVESTRIS* L.) AND ASPEN (*POPULUS TREMULA* L.)

TIMO KURKELA

MÄNNYN VERSORUOSTEEN JA HAAVANRUOSTEEN EPIFYTOLOGIA

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PREFACE

Numerous persons helped me during the various stages of this research. The work was initiated in the Finnish Forest Research Institute with the encouragement of Prof. Sakari Saarnijoki and Prof. Risto Sarvas. During the beginning of the work, I received much beneficial advice from Prof. Paavo Juutinen and Mr. Ukko Rummukainen. I have had important discussions concerning the studies with Dr. Allan Klingström of Uppsala University, Sweden, Dr. Veikko Hintikka, Mr. Lalli Laine, and many other colleagues. The encouraging attitudes of these persons, and especially Forest Officers, Mr. Viljo Mattila and Mr. Lauri Rantala, who are working in practical forestry, were decidedly significant in the conduct of the studies.

Mr. Erkki Kaita-aho, Mr. Simo Leinonen, Mrs. Inkeri Erjala, Mrs. Toini Ojala, Mr. Matti Laurila, Mr. Larry Huldén and several other persons assisted me in the field and laboratory work.

The manuscript was read and beneficial criticism given by Dr. Peitsa Mikola, Prof. of Forest Biology, and Dr. Eeva Tapio, Prof. of Plant Pathology, both from the University of Helsinki, and Prof. Paavo Juutinen. Dr. Kim von Weissenberg translated the manuscript, and his wife Joann von Weissenberg revised the English text.

These studies have been included in the research program of the Finnish Forest Research Institute. With a fellowship sponsored by the W. K. Kellogg Foundation (Battle Creek, Mich. U.S.A.) and some financial support from the Society of Forestry in Finland I was able to become acquainted with current research in the corresponding field in the United States and Canada.

I wish to express my sincere thanks to the persons and institutions mentioned above and to all others who have assisted during the course of this study.

Helsinki, October 1973

Timo Kurkela

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INTRODUCTION

The pine twisting rust caused by the fungus *Melampsora pinitorqua* (Braun) Rostr. is economically one of the most important diseases in pine sapling stands in Finland (K a n g a s 1938, K u j a l a 1950). In addition to Europe, at least Asia Minor and the western part of Siberia are included in its range (L o n g o et al. 1970). The main host is Scots pine (*Pinus sylvestris* L.), but the fungus also infects many other pines of the *Diploxylon* group. In order to study the disease in depth, an international working group has been established within IUFRO.

Melampsora larici-tremulae Kleb. causes the needle rust of larch. *M. pinitorqua* and *M. larici-tremulae* can be distinguished from each other only because they develop the aecial states on different hosts, the former on pine shoots, the latter on larch needles. The uredia and telia of both rusts develop on the leaves of aspen. The needle rust of larch is not known to cause any damage of economic importance for forestry.

After the description of the symptoms of the disease (de B a r y 1863) and the life cycle of the pathogen (R o s t r u p 1884), considerable time passed before important publications on the biology of pine twisting rust were published. From the standpoint of epiphytology, the most important of these studies were: S c h a f r a n s k a j a (1940), T r o s c h a n i n (1952), R e g l e r (1957), K l i n g s t r ö m (1963) and L o n g o et al. (1970). These studies have dealt with i.a. infection of pine, the distance to the source of inoculum, germination of teliospores, and the dependence on climatic conditions for infection of pine.

Although the main features of the cycle of the rust are known, there are no other practical methods of control except eradication of aspen from pine sapling stands. This already was recommended by H a r t i g (1885). In order to find new control methods, all possible gaps in our knowledge must be eliminated. Detailed studies of i.a. spore dispersal, process of infection, and the rate of development of the rust on pine and aspen have not been made. The occurrence of the rust in the uredial and telial states especially has received little previous attention.

Pine twisting rust had occurred to some extent on various locations in Finland during the early 1960's. In 1964 severe damage was caused almost

everywhere in the country but especially in the southwestern and western parts, where, subsequently, the Regional Board of Forestry asked for initiation of this study.

This publication reports on the dispersal of the different spore types of *M. pinitorqua* and the subsequent development of rust on the host plants, pine and aspen, in the field conditions. Previously published results by the author (K u r k e l a 1973 a) on the release and germination of basidiospores are discussed in the present report in relation to spore dispersal in nature. Data on *M. larici-tremulae* are also included. This is due partly to the fact that observations on *M. pinitorqua* could not be made every year because of the scarcity of the rust, and partly due to the fact that both rusts are almost identical ecologically; therefore the results could be generalized for both species.

MATERIALS AND METHODS

Description of experimental plots

The development of pine twisting rust was followed on locations where the disease previously had caused considerable damage. The locations of the experimental plots of this study are shown in Fig. 1. The most important part of the study was made in Jauli, Ikaalinen township, (N 61°24′, E 23°26′) the Location 1, where observations were made during 1965—1968. The study area was about 160—180 m above sea level. It had been clear-cut and planted with pine. The sapling stands had been beaten up several times

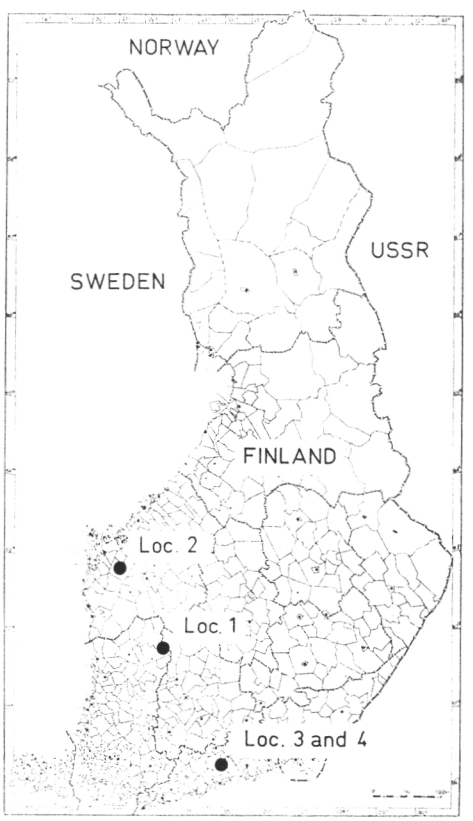


Figure 1. Location of the experiment areas. Ikaalinen, Jauli (N 61°24′, E 23°26′) = Loc. 1. Laihia, Jakkula (N 62°57′, E 22°06′) = Loc. 2. Tuusula, Ruotsinkylä (N 60°38′, E 25°09′) = Loc. 3 and 4.

due to the fail places caused by combined effect of rust and hardwood suckers. At the study site there were 0.5—1 m high pine saplings mixed with some aspen suckers. In 1966 observations were also made in Jakkula, Laihia township, (N 62°57′, E 22°06′) Loc. 2. This area, in a spruce stand, was a North-South clear-cut strip ca. 70 m wide, planted with pine. The pine sapling stand was about 1—2 m high and growing vigorously. The stand was rather densely mixed with aspen suckers.

In 1970 and 1971 the dispersal of *Melampsora* spores was studied in the Ruotsinkylä Experiment Forest of the Finnish Forest Research Institute in Tuusula township (N 60°38′, E 25°09′), Loc. 3. This study area was an opening of 20 m diameter, filled with low (about 0.5 m) aspen suckers, located in a mixed stand of 4—6 m high pine and larch.

In the spring of 1973 the basidiospore dispersal of aspen rust was investigated in the aspen clone bank of the Ruotsinkylä Experiment Forest (Loc. 4). The height of the tallest trees was 6—8 m. When the trees were still without leaves in the spring, insolation, wind, and precipitation could freely affect the fallen leaves on the ground. During the previous summer, the ground vegetation under the trees had been eliminated by using a rototiller.

Measuring of weather factors

The relationship between the pine twisting rust, the aspen rust, and various weather factors were studied by following the dispersal of the pathogen spores, the development of the hosts, and occurrence of the rust on its hosts during various stages of the growing season, and by registering weather factors.

T e m p e r a t u r e a n d h u m i d i t y. The air temperature was measured 2 m above the ground in a standard weather chamber by means of a thermograph or thermohygrograph. The instrument readings were corrected according to a calibrated precision thermometer in the same weather chamber. The temperature was recorded to the nearest 0.1 °C. Calculations of daily mean temperatures were based on graph readings taken at every odd-numbered hour.

The relative humidity of the air was obtained during June—September from a thermohygrograph (hair hygrometer) placed in the weather chamber. The instrument was calibrated prior to and after use in order to detect any measurement errors. For the present investigation the measurement of high relative humidity was the most important. According to A h t i (1972), it is obvious that when the relative humidity approaches 100 %, the hair hygrometer tends to record too low values, the error being on the average larger in summer than in winter.

P r e c i p i t a t i o n a n d d e w. The amount of precipitation was measured by a fluviograph with a clock making a complete revolution in one week. In 1971 and 1973, however, the fluviograph used had a clock making a complete revolution in 24 hours. The amount of water passing through the fluviograph was checked with a graduated cylinder. The precision of measurement was to the nearest 0.1 mm.

In 1971 and 1973 a dew scale was used. The amount of condensed water and the duration of dew were measured. The dew scale also recorded minor precipitation when the amount of water was not sufficient to be recorded by the fluviograph. The precision of the dew scale was to the nearest 0.1 g. The dew scale was also used to measure the total length of the wetness period caused by both precipitation and dew. The cup of the scale was adjusted in such a manner that the water that rained into it could flow out trough the cup bottom. Thus, the recorder always deviated from zero as long as the surface of the cup was wet. With the dew scale it was not always possible to distinguish dew from rain, but this was not necessary. It was only important to measure the time during which free water, precipitated or condensed, occurred on the foliage or on vegetation in general. The dew scale was calibrated once a week with weights of 1 and 5 grammes.

W i n d. Wind velocity recordings from the climatological station in Kuru, Länsi-Aure, of the Meteorological Institute were used for the studies made in Loc. 1, during 1966—1968. The climatological station was located 7 km from the experimental area. The recordings were made three times a day, at 08.00, 14.00, and 20.00. The daily means of these recordings were used in the present study. This is, as such, a very crude estimate of wind velocity, and does not allow a very detailed analysis of the studies of spore flight.

For the 1970 studies the data on wind velocity from the Helsinki Airport (Vantaa township) climatological station of the Meteorological Institute were used. The airport is located 5 km from the study locations Nr. 3 and 4. The recordings at the airport were made at half-hour intervals.

In 1971 and 1973 the wind velocity was measured at the experimental area in Ruotsinkylä (Loc. 4). The sensor was a Lambrecht Nr. 1467G attached to the recorder, Lambrecht Nr. 1487a. The sensitivity of the sensor was 0.6 m/sec. This device was especially useful for measuring the velocity of wind gusts. The maximum velocity for each 10 minute interval was read from the recorder's paper strip. These values were used for calculation of daily and hourly mean velocities.

Measurement of host tree development

G r o w t h o f s h o o t s a n d n e e d l e s i n p i n e a n d l a r c h. The height growth of the pine shoots was measured in order to determine

at what phase of growth infection by the pine twisting rust occurs in nature. Growth was measured in Loc. 1 in 1966—1968 and in Loc. 2 in 1966. In the first measurements a total of 50 saplings were included. From each sapling the growth of the terminal leader and two branches formed during the previous year was measured. In 1967 30 saplings were measured. In 1968 the measurements were continued in the same place as previously; but due to the serious attacks by the rust in the previous summer, only 10 saplings could be included.

The reference point for the measurements was marked on each sapling with an insect needle inserted immediately below the base of the terminal bud. The measurements were made daily at noon. The work was begun in mid-May when the terminal bud had started to elongate. The measurements were made with a sliding caliper. Precision of measurement was to the nearest 0.1 mm. One person made all measurements in Loc. 1, and another made those in Loc. 2.

In connection with shoot measurement, the needle length was also measured. From the growing terminal leaders of pine saplings the lengths of the five uppermost and five lowermost needles were measured in 1967. In 1968 the length of 10 marked needles in each of five trees was measured. The length of larch needles in short shoots was also measured during their development. Measurements were made each day, beginning on the day when the tips of the needles emerged from the fascicle, and ceased when no growth could be detected.

Growth of aspen shoots and leaves. Measurement of the short shoots of aspen commenced before the buds began to expand. The reference point was taken to be the scar of the previous year's leaf at the base of the bud, and the measurements were made from this reference point to the tip of the bud using sliding calipers. During the opening of the bud, measurements had to be discontinued until the tip of the expanding shoot clearly could be detected. At this time the growth measurements of the uppermost leaf commenced. The leaf was measured from its base to the tip. Measurements were continued until no growth could be detected. Some 4—5 groups of suckers were selected for the measurements. From each group four buds were marked for the measurements.

Inoculation of pine shoots with basidiospores

For these experiments 2 year-old nursery-grown transplants were used. The transplants had been lifted from the nursery in the spring and placed in cold storage. The growth of the transplants was slowed down in storage until they were used. The transplants were planted in pots in a greenhouse.

The temperature in the greenhouse varied from 14 to 22°C. The relative humidity was kept at 60—95 % with an air humidifier. Of the potted transplants, the most vigorous ones were selected for the experiment and arranged into groups of ten transplants each. The order of inoculation of the groups was randomized. Since temperature has been found to be a very important factor controlling the annual growth of trees (cf. Sarvas 1965, 1972, Hari et al. 1970), the inoculation interval for the transplants was taken to be 50 degree hours. Calculation of the number of degree hours was commenced when the transplants were potted and transferred to the greenhouse. The number of degree hours was calculated from the mean of the temperature minus five degrees at each odd-numbered hour of the day (cf. Sarvas 1965). The method developed by Moriondo (1961) was used for inoculation. The pine shoots as well as the inner side of a test tube of 25 mm diameter was moistened with a spray of water. The growing shoot was inserted into the test tube deep enough that pieces of aspen leaves, bearing sporulating telia fastened to the inner side of the tube, came level with the tip of the shoot. Before application, the aspen leaves had been incubated at 13 °C for 24 hours. It was extremely difficult to standardize the amount of inoculum, i.e. the number of basidiospres formed by the telia, since the number of telia and their ability to germinate on the aspen leaves varied considerably, which facts have been reported also earlier (Klingström 1972, Kurkela 1973 a). As a source of inoculum three pieces 1 × 3 cm, of aspen leaves were placed inside the test tube. The inoculum was made at 15 °C over a period of 16 hours. Subsequently, the transplants were transferred back to the greenhouse. The experiments were made with two lots of transplants planted at two different times. With the first lot, eight groups of inoculations were made; with the second, only three were made. The smaller number of groups in the second lot was due to the fact that these transplants had been kept in cold storage longer and were, therefore, in such poor condition that a larger proportion of them had to be discarded. In both lots, one group of ten transplants was left as an uninoculated control. The height growth of these transplants was measured each day in order to be able to determine at which phase of growth the inoculation had been made. When the transplants were potted, they had already completed about half of their final height growth.

Trapping of spores and handling of material

In order to monitor spore dispersal, two instruments were used: 1) a pollen sampler developed by Sarvas and Wilska (Sarvas 1952, 1962) and 2) a modified Hirst spore trap (Hirst 1952) manufactured by Burkard Manufacturing Company.

The results obtained by the pollen sampler of Sarvas—Wilska indicated the number of spores trapped per unit of time on a tape surface. The trapping surface was cellophane tape covered with vaseline and wrapped around the clock cylinder of a thermograph. The periphery of the cylinder moved 2 mm/hour. The device was equipped with ball bearings and a wing in such a manner that the opening of the cover was always toward the wind. The opening was conical, tapering off toward the inside. At the point nearest the trapping surface, the opening was 2 mm wide. The amount of air moving through the device was dependent on wind velocity. For each period of time the number of spores was counted on 23 microscopic fields corresponding to a total of 4.5 sq.mm. The vaseline-covered ribbons were examined intact directly under a microscope using phase contrast.

The results obtained by the Hirst spore trap indicate the number of spores per unit of air volume passing through the instrument. Using an adjustable air pump the suction was standardized to 10 litres/hour. Due to variation in temperature and air humidity, the suction of the pump varied. Therefore, the pump had to be adjusted at least once in two days. The instrument had ball bearings so that it turned toward the wind. A tape wrapped around the clock cylinder was covered with vaseline and moved 2 mm/hour. The tape was changed every 6 days. For microscopic examination, the tape was cut into sections corresponding to each day. Each section was mounted in polyvinyl alcohol. The mounting medium used was: 35 g polyvinyl alcohol grade 40—20, 100 ml distilled water, 50 ml glycerol or 40 ml lactic acid, and 2 g phenol. Slide preparation was based on the method presented by Downs (1943). The microscopic examination was made with a × 300 magnification. The numbers of basidiospores, aeciospores and uredospores of *Melampsora* trapped on the tapes were counted. Different species of *Melampsora* were not identified since it is completely impossible for basidiospores and also extremely uncertain when single aecio- or uredospores are examined (cf. p. 49).

The observations on spore dispersal commenced in Loc. 1 at the beginning of June when the growth of the pine shoots had just started and the shoot was still covered by the bud scales. In Loc. 3 and 4, the observations commenced at the beginning of May. The dispersal of spores was related to the climate and the variation in weather factors at the time of spore trapping and to the occurrence of uredia on the aspen leaves.

By using multiple regression analysis, the relationship between some weather factors and the daily numbers of uredospores was investigated. The mathematical data processing was limited to uredospores since their dispersal occurs over a much longer time than that of aeciospores and basidiospores. The following variables were used:

x_1 = number of days since the first uredia were observed in the field,
x_2 = dependent variable, daily mean number of uredospores in the air,
x_3 = number of uredia per day on a unit area of aspen leaves calculated by interpolation of the number of uredia per week,
x_4 = average daily temperature,
x_5 = average daily temperature for the coldest period of the day (21.00—08.00 hours) calculated as the average of six temperature readings taken on odd-numbered hours,
x_6 = average daily temperature for the warmest period of the day (09.00—20.00 hours) calculated as above,
x_7 = average daily wind velocity,
$x_8 = x_3/\log_{10} x_1$,
$x_9 = x_3/x_1$,
$x_{10} = x_3/(x_1)^2$.

The calculations were made according to the stepwise regression analysis by V ä l i a h o (1969). By means of the first and third variable and variables 8—10 formed from the former variables, an attempt was made to remove from the model the effect of the changing number of spores due to the increase in uredia. In addition to the daily mean temperature, the average temperatures of the coldest and warmest periods of the day were also included as variables since it is possible that cold nights may in some way affect the development of the fungus, and since most of the spores are released during the warmest period of the day (cf. p. 28). Wind velocity was included especially because the general effect of wind was of interest and since the number of spores trapped in the two types of traps (Sarvas-Wilska and Hirst) may be dependent on wind velocity.

Investigations on the aecial and uredial states of *Melampsora*

In connection with the daily height measurements of the pines, the number of aecia was also counted. Both sporulating aecia and mere yellow spots were counted.

The number of uredia was determined from pressed samples of aspen leaves. The samples were collected at one-week intervals after the first uredia had been observed and continued until the last week of August. At each collection, three branches were taken from each group of aspen suckers marked for growth measurement. Each branch had to bear at least 10 leaves. The number of uredia was estimated on these 30 leaves. Using a binocular stereomicroscope, the uredia on each of three viewing fields on each leaf were counted (cf. K u r k e l a 1969).

Several investigators have tried to estimate the amount of rust on various species of poplars when assessing their rust resistance (e.g. Schreiner 1959, van der Meiden 1961, Donaubauer 1963). In the paper by Donaubauer (1963) there is also an assessment of the value of previously developed methods. The method used in the present study is surely one of the most elaborate ones for estimating the amount of rust. This method was used since the particular purpose here was to study the development of the pathogen during the growing period, not its effect on the host plant.

In order to determine how far the mycelium spreads in the tissue of the host leaf, the morphology of the diseased leaves was studied. Leaves containing uredia were fixed with a FAA-solution, embedded in paraffin and cut on a microtome. The sections were stained with the method developed by Vagas and Maacz (1960). The size of the infected tissue around the uredia and the distance between the vascular bundles were measured.

RESULTS

Dispersal of basidiospores

The number of airborne basidiospores varied considerably during different years in the Locations 1, 3, and 4. Large numbers of basidiospores were found in the air on rainy days only. The spores were observed in the air 4—6 hours after the beginning of a rain.

In June of 1966, the most important time of spore dispersal and when the pine shoot growth was most intensive, precipitation did not occur in large enough quantities to be registered by the fluviograph (Figure 2). It is possible, of course, that some of the observed maxima of basidiospore dispersal in 1966 occurred due to some local thunder showers. The numbers of basidiospores were quite small, and therefore the results are very unreliable. In the summer of 1966 the same investigations were also carried out in Laihia (Loc. 2), but microscopic studies of the material collected there were not undertaken since no basidiospores were found upon initial examination of the tapes. This lack of basidiospores was apparently due to the fact that only one very small shower of rain occurred during the time of investigation. The shower was not sufficient to cause the telia to germinate and form basidiospores.

The conditions of precipitation in June 1967 were favorable for the formation and dispersal of basidiospores. The number of airborne basidiospores was not very large, however, apparently due to the low air temperature during the periods of rainfall (Figure 3). The average daily temperature during this time was less than 10 °C. The largest number of basidiospores, about 250 spores/sq.cm, was found on June 6.

The crucial importance of rainfall for the dispersal of basidiospores is evident from results obtained in 1968 in Loc. 1 and in 1971 and 1973 in Loc. 3 and 4. The precipitation during May and June of these summers occurred intermittently with very dry days between. The most important maxima of basidiospores occurred during rainy days (Figures 4 and 6). In 1968 the maxima of basidiospores were during June 9 and 24—26. On June 9 the precipitation was 5 mm; on June 24 rain could not be registered, but the day was partly foggy with drizzling rains; and during the two following days, precipitation was several mm. June 27 was rainless, while the precipitation

was great on June 29 and when the capacity of the telia to produce basidiospores apparently was exhausted since, during this time, only about ten basidiospores per cu.m. of air could be counted in spite of the very favorable weather. During the previous rains, the number of spores had been about 1 000/cu.m. The hourly maximum amounts were, of course, much higher (Figure 7), about 3 000 spores/cu.m.

In Loc. 3 and 4 during 1970, 1971 and 1973 the species of *Melampsora* rust investigated was apparently *M. larici-tremulae*. In 1970 basidiospores were observed immediately when the investigations began on May 15 (Figure 5). The whole latter part of May was rainy, and therefore no conclusions can be made about the importance of rainfall for formation and dispersal of basidiospores. After June 10 no more basidiospores could be observed in spite of the rains which occurred after that date. From the results obtained during 1971 and 1973 the crucial importance of rain was quite obvious. During both these years, three distinct maxima of spore dispersal were observed (Figure 6). In the intervals between maxima, very few spores were found. Each maximum dispersal occurred during periods of rainfall. After the third maximum, spores were not detected or else the number was small in spite of favorable rainy weather.

The investigations of 1971 and 1973 were undertaken with considerably more accurate instruments for measurement of wind, rainfall and dew. Consequently, the results obtained from the spore traps could be analyzed in more detail than previously. Figures 8—10 show the hourly numbers of basidiospores during periods of maximum spore dispersal in the summer of 1971. These hourly spore quantities can be related to the amount and duration of rainfall, to dew (i.e. occurrence of free water), and relative humidity. The first maximum of basidiospores occurred on May 22 and 23. At this time spores were airborne some 6 hours after the rainfall began; and the maximum number, about 300—400 spores/cu.m, was reached after 12 hours. After the maximum, the number of spores decreased slowly. Spores were airborne for a total of 1.5 days. Rain or fog persisted continuously for 31 hours. A second maximum of basidiospores occurred on May 28. During the previous morning there was a light rain for about five hours, registered only by the dew scale. As a result of this rain, spores could again be detected about 6 hours after the rain had begun. On the morning of May 28 about 2 mm of rain fell during four hours. Between these two days there was some water in the dew scale continuously and thus the aspen leaves on the ground with their telia did not have any chance to dry out during this time. About four hours after the second rain, large numbers of spores were dispersed into the air. The maximum spore density, 1 300 spores/cu.m, was observed seven hours after the rain began. The spore density decreased rapidly after the maximum, due to rapid drying of the air and ground.

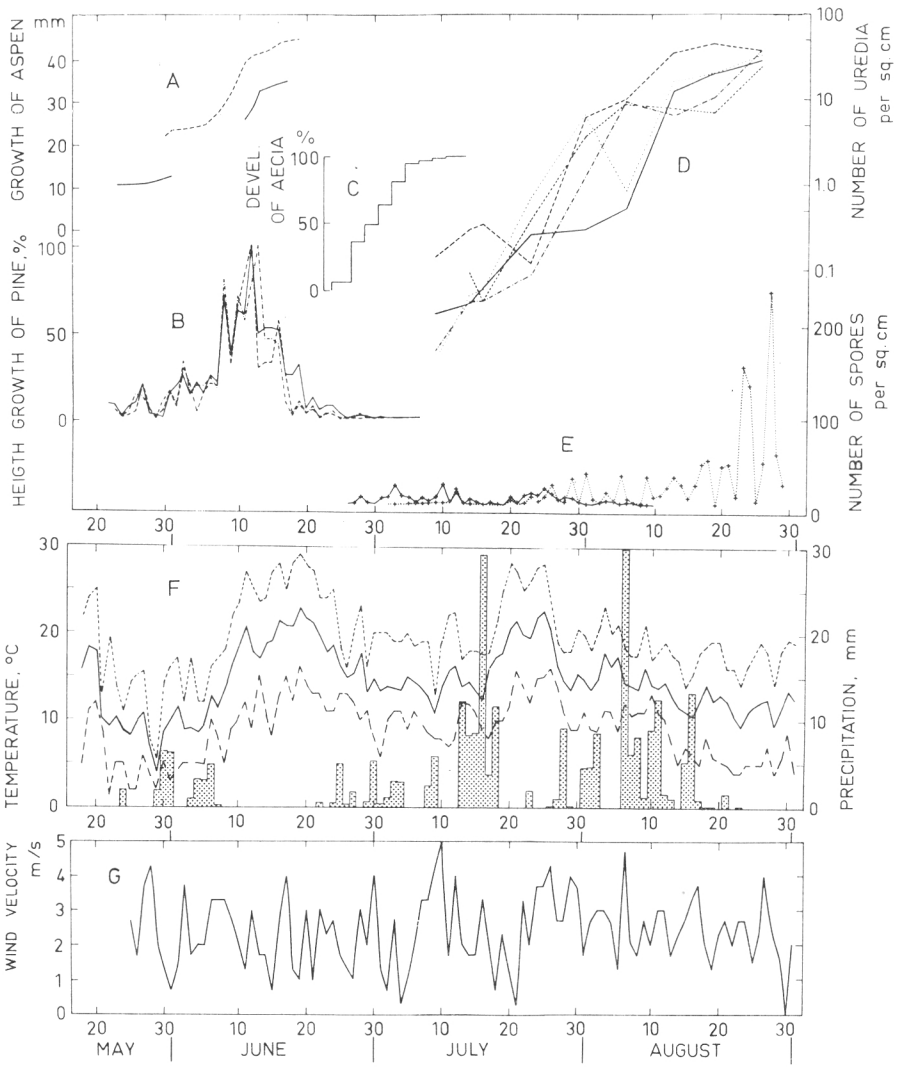


Figure 2. Seasonal development of rust (*Melampsora pinitorqua*) and host trees in relation to some weather factors in Loc. 1 in 1966. A) Cumulative growth (mm) of aspen; lower portion of the solid line indicates the growth of the bud and the upper part, the growth of the short shoot; the dotted line indicates the leaf growth (length of leaf as measured along the central vein). B) The daily height growth of pine as a percentage of total length, the solid line indicates growth of the terminal leader, and the dotted line, growth of the terminals of the previous year's branches. C) Number of mature aecia as a percentage of all aecia. D) Weekly number of uredia per sq.cm leaf surface in five groups of aspen suckers. E) Number of spores per sq.cm. trapped in the spore trap (Sarvas—Wilska), solid line = aeciospores, dotted line = uredospores. F) Daily maximum, average and minimum temperature (°C) and amount of precipitation (mm). G) Wind velocity (m/s), average of observations made at 08.00, 14.00, and 20.00.

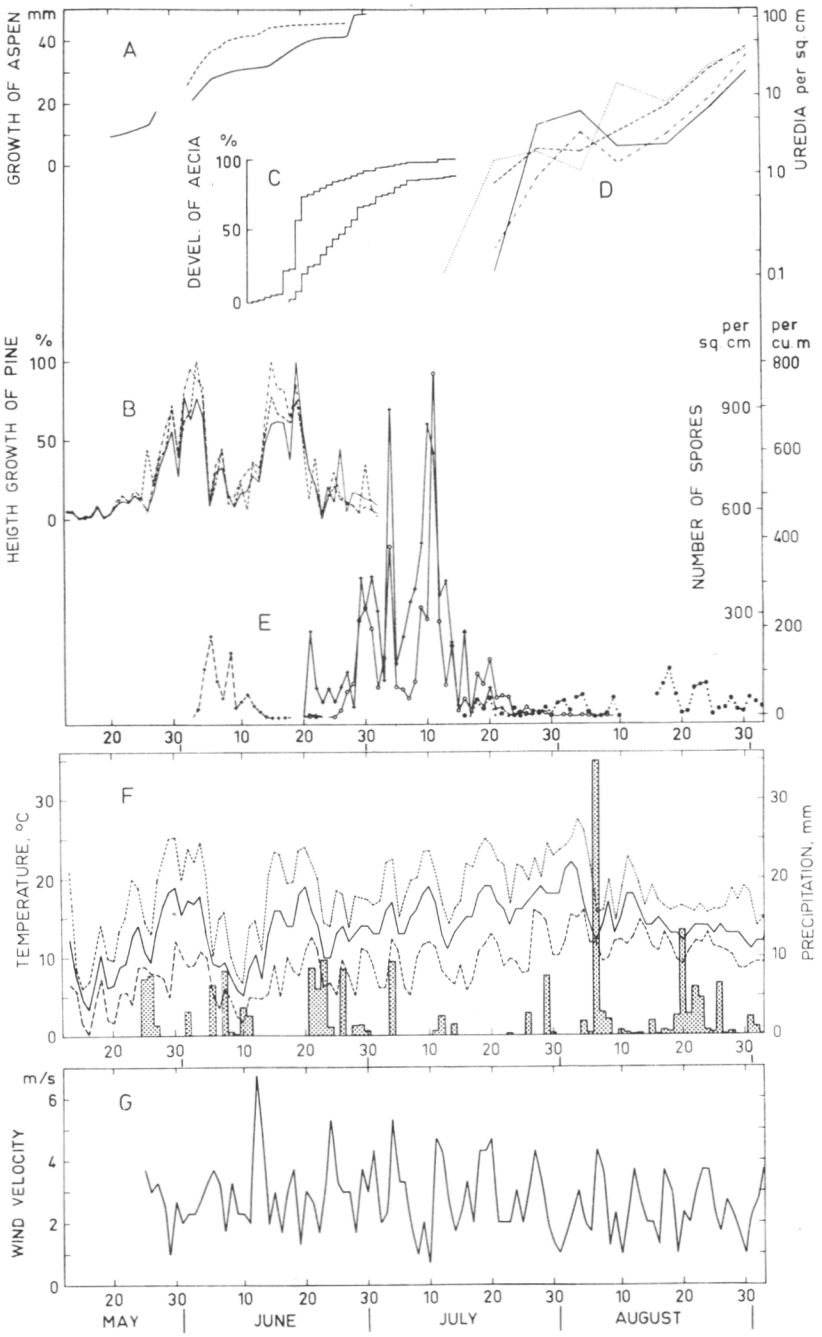


Figure 3. Seasonal development of rust *(Melampsora pinitorqua)* and host trees, Scots pine *(Pinus sylvestris)* and aspen *(Populus tremula)*, in relation to some weather factors in Loc. 1, 1967. A—B) See Figure 2. C) Development of aecia, upper histogram = number of yellow spots, lower histogram = number of mature aecia. D) Weekly number of uredia per sq. cm leaf surface in four groups of aspen suckers. E) Daily numbers of spores, broken line = basidiospores, solid line = aeciospores, dotted line = uredospores. Lines marked with stars indicate results obtained

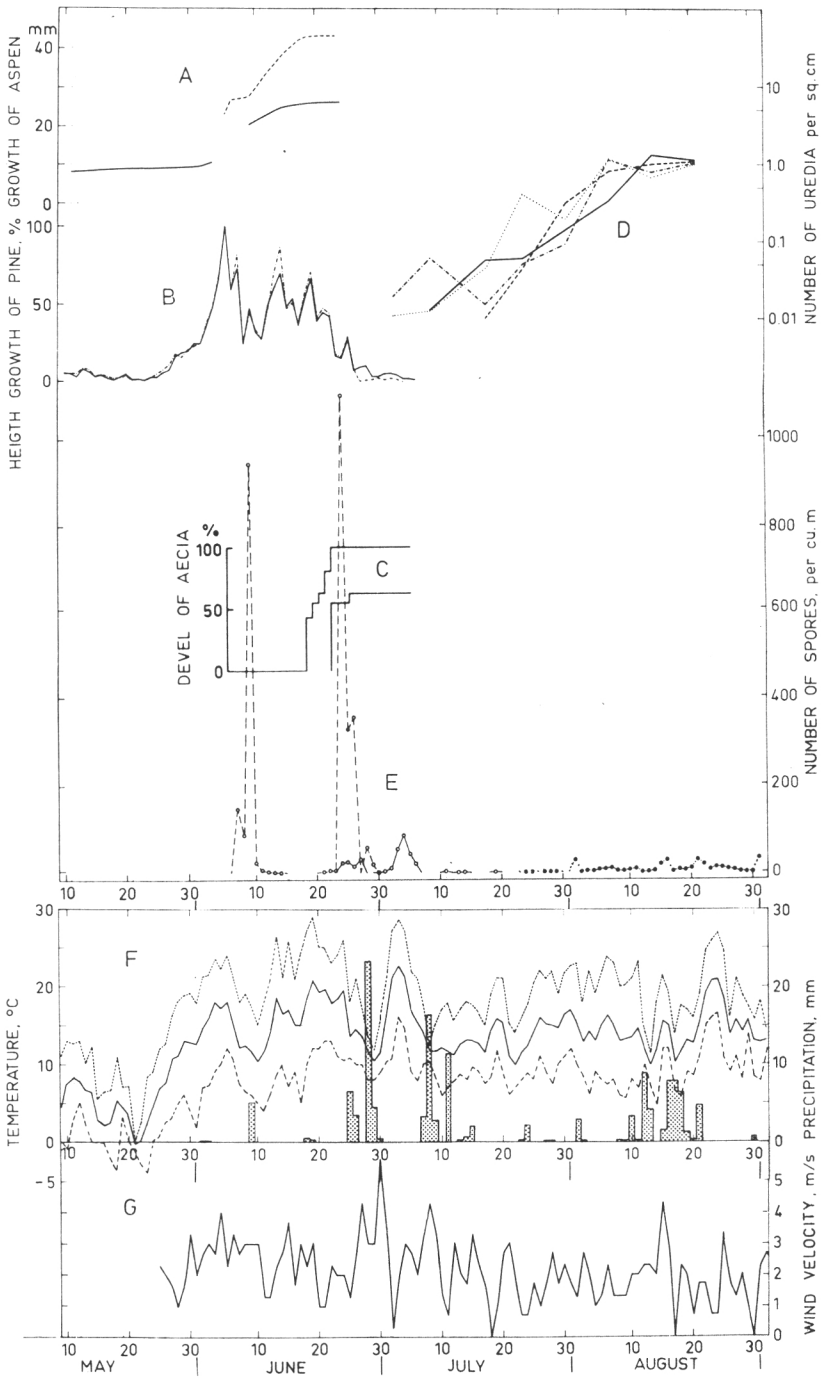


Figure 4. Seasonal development of rust and host trees in relation to some weather factors, Loc. 1, 1968. A—G) As in Figure 3.

with the Sarvas—Wilska pollen trap while lines marked with circles indicate results obtained with the Hirst spore trap. F and G) As in Figure 2.

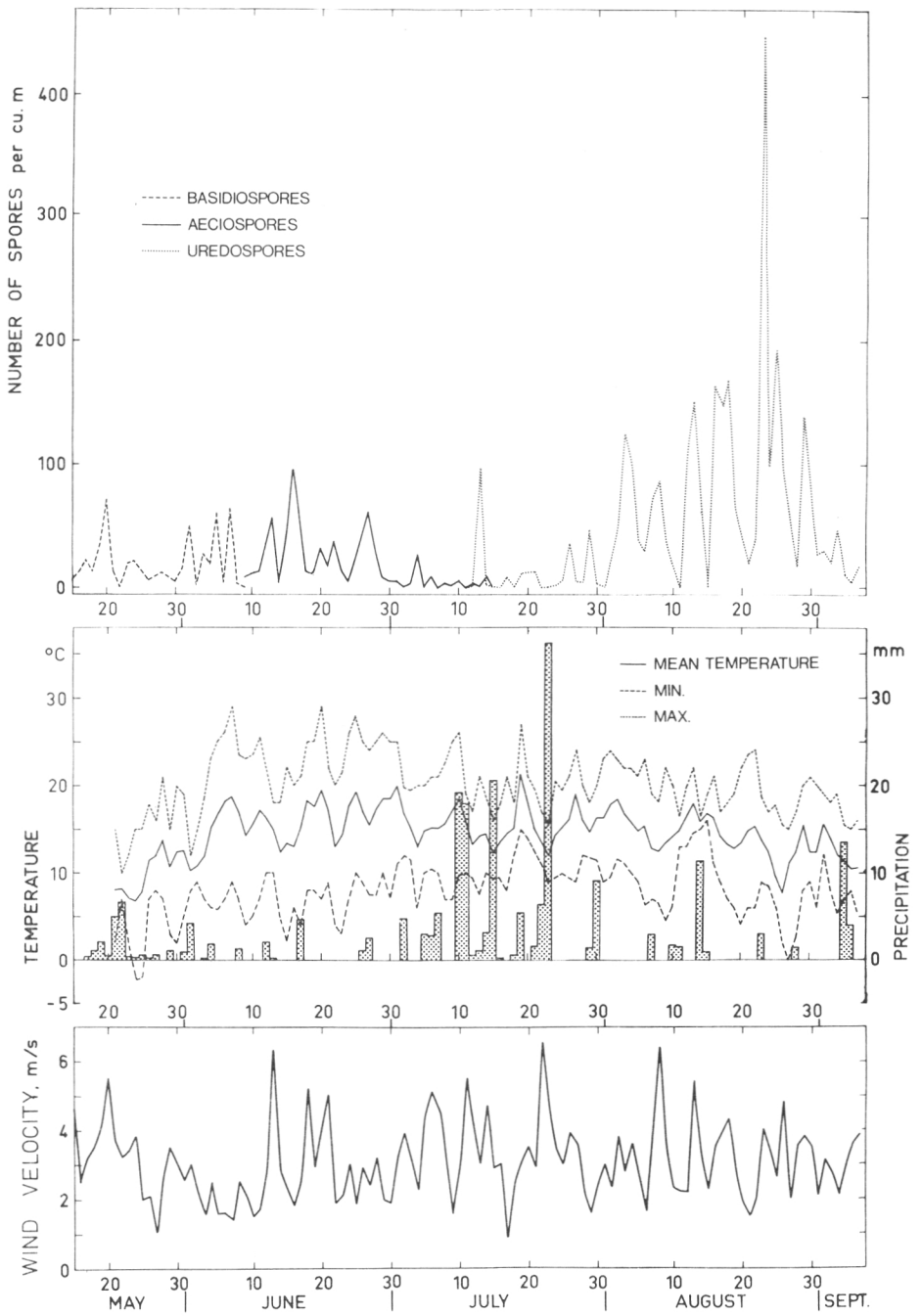


Figure 5. Seasonal spore dispersal of *Melampsora* sp. (mainly *M. larici-tremulae*) in relation to some weather factors in Loc. 3, 1970.

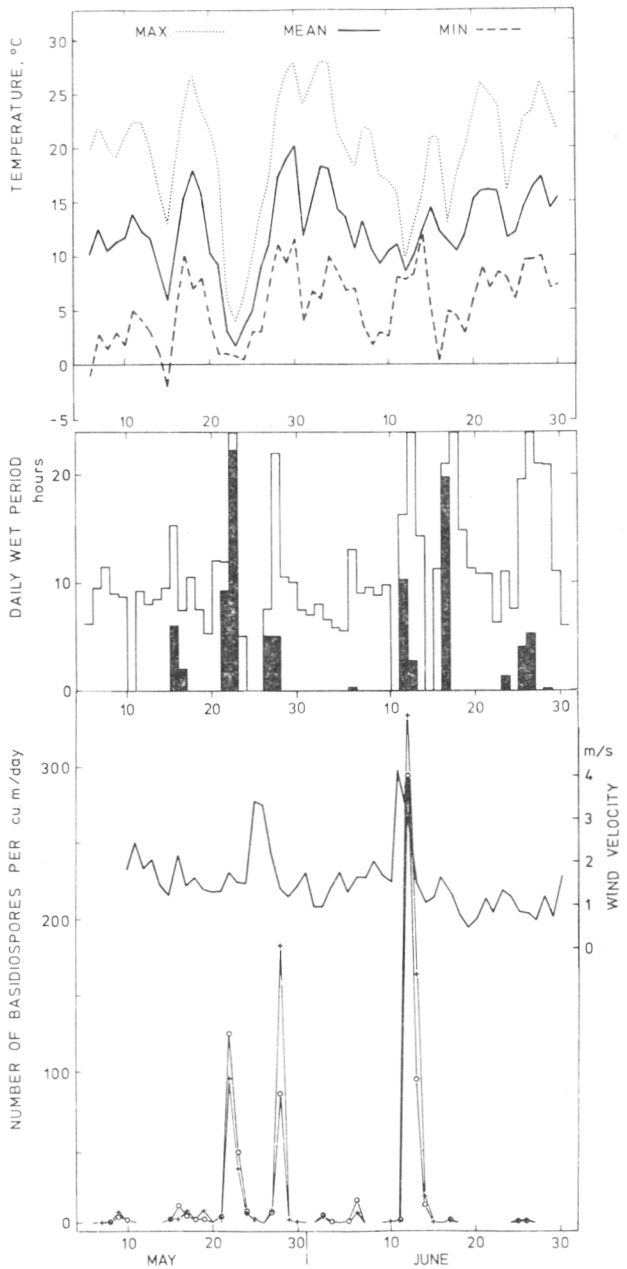


Figure 6. Dispersal of basidiospores of *Melampsora* sp. in relation to some weather factors in Loc. 3, 1971. The spore data were obtained simultaneously with two traps. In the histogram indicating length of daily wet period, the black part indicates duration of rain and the white part, the sum of duration of rain and dew in hours.

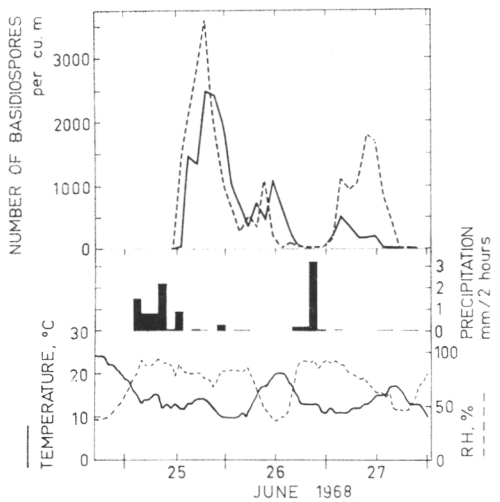


Figure 7. Basidiospore dispersal of *Melampsora pinitorqua* in relation to precipitation, temperature, and relative humidity in Loc. 1, June 25—27, 1968.

The third spore dispersal maximum occurred on June 12 and 13. The first spores were trapped after about 3 hours; after 6 hours the spore density rapidly increased and reached the maximum, ca. 450 spores/cu.m in one trap and over 800 spores/cu.m in the other trap, some 12 hours after the rain began. The almost continuous rain lasted for 41 hours, and considerable numbers of spores occurred in the air for almost two days.

During these three periods of maximum spore occurrence, the capacity of telia to produce spores seemed to be completely exhausted since, after the heavy rain of June 18, only a few spores were trapped.

Results obtained in the spring of 1973 support the conclusions, based on previous years' results, about the most important factors influencing formation and dispersal of basidiospores (Figure 11). In spite of the early spring, the temperatures before the beginning of May were not high enough for formation of spores. During the first days of May, the days became warmer, and after the rain on May 6, the first basidiospores were observed. The second maximum occurred as a result of the rain on May 14. After this, it rained for several consecutive days, and spores seemed to occur less frequently. Apparently, the capacity of telia to produce spores had already decreased considerably. On May 17 a clear maximum of spores was observed, although it was much smaller than the previous ones. The spore maxima on May 6 and 14 were observed 13 and 10 hours after the rains began. During these maxima, the air temperature fluctuated between 5 and 10 degrees.

The presence of water or abundant moisture is crucial for the formation of basidiospores; but, on the other hand, it may be possible that rain inhibits the release of the spores or washes them directly to the ground. In any case,

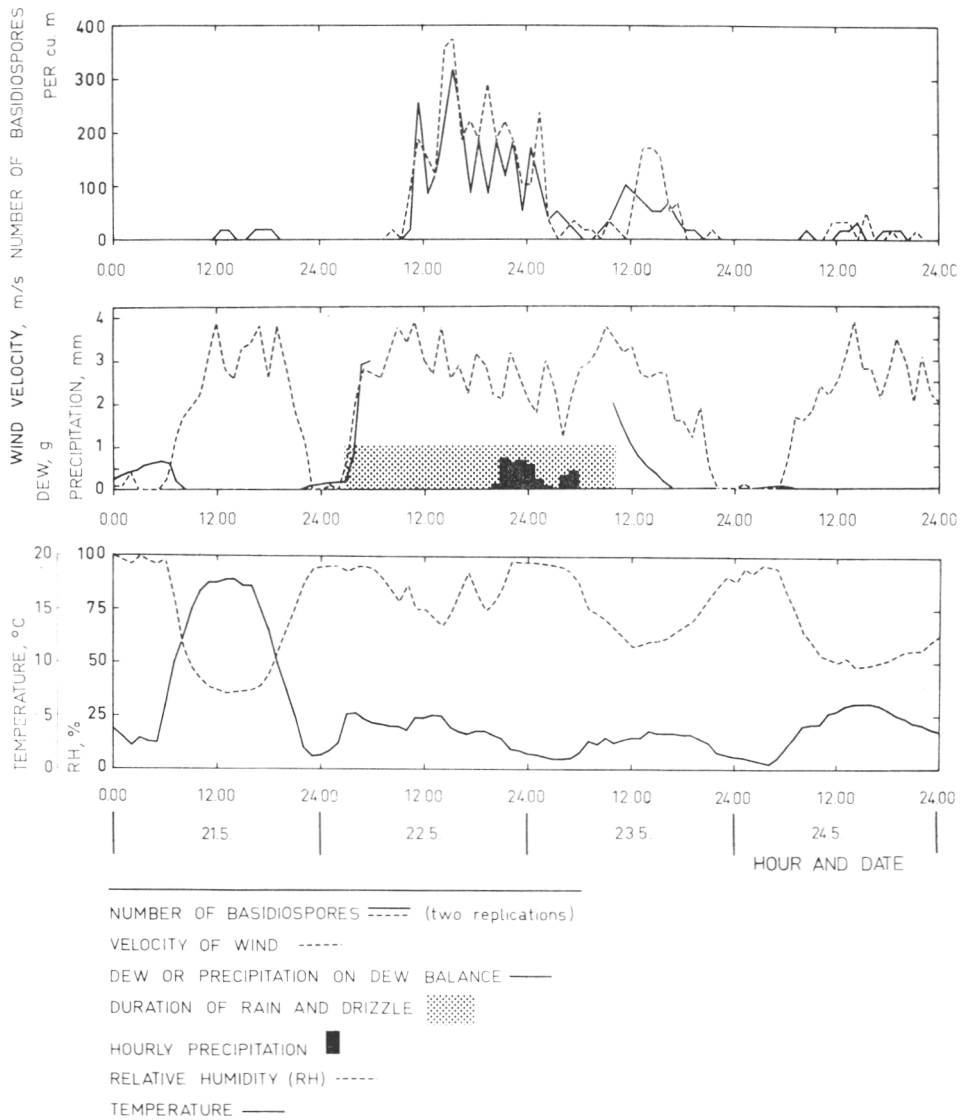


Figure 8. Hourly dispersal of basidiospores (*Meampsora* sp.) in relation to various weather factors in Loc. 3, May 21—24, 1971. The number of basidiospores has been indicated for two replications.

greater numbers of spores have occurred in the air only after rains. The changes in air humidity may have promoted release of the basidiospores.

When the release of spores was at a maximum, the relative humidity of the air was rather high due to the rainy weather. The relative humidity may have varied considerably (100—90 %), however, without appreciably affecting spore density. Apparently, relative humidity, as measured at 2 meters above the ground in a weather chamber, is not a suitable variable

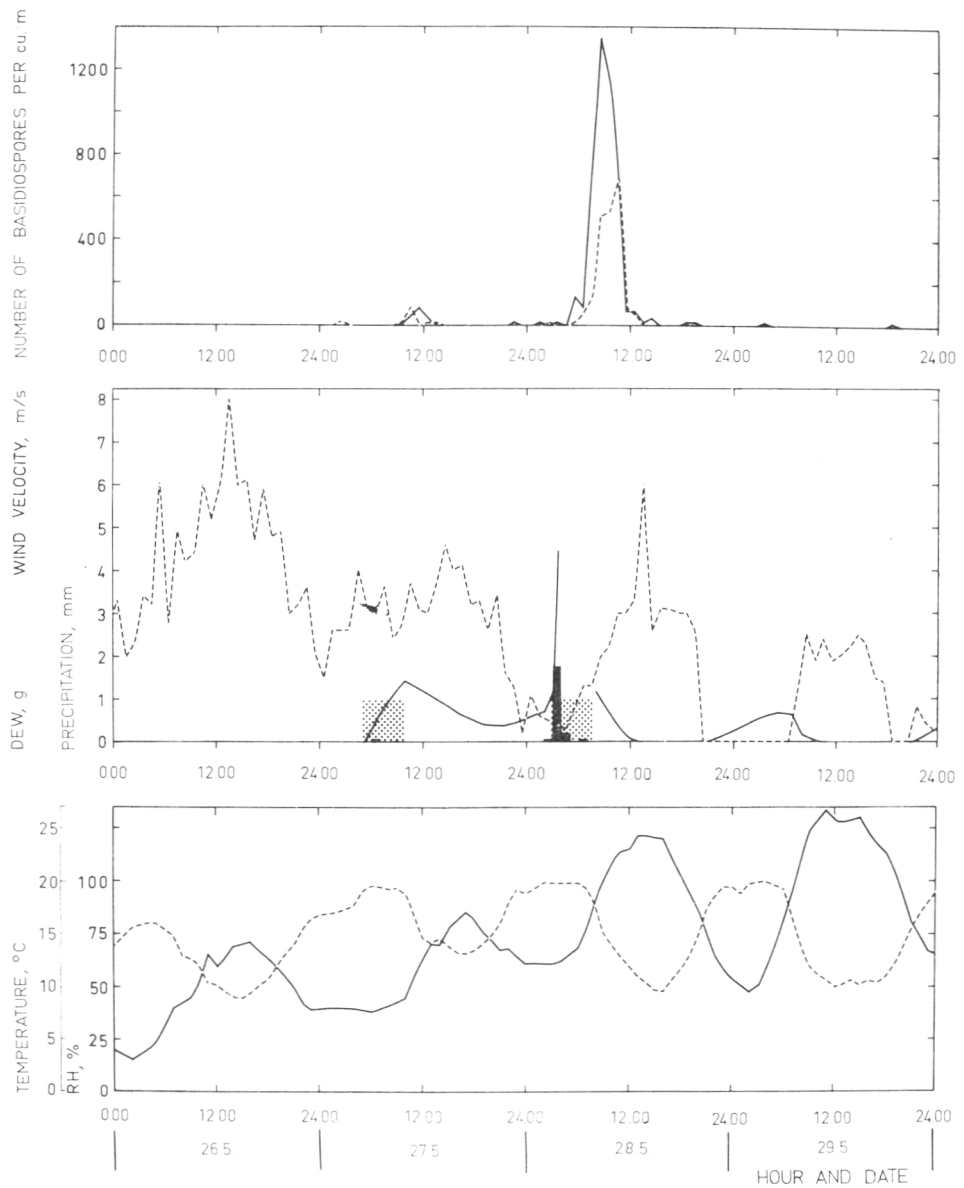


Figure 9. Hourly dispersal of basidiospores (*Melampsora* sp.) in relation to some weather factors in Loc. 3, May 26—29, 1971. For legend see Figure 7.

for explaining formation and release of basidiospores in the ground litter. The same appears to be true for temperature. Although experiments in the laboratory clearly indicated an increase in the rate of spore release (K u r k e l a 1973 a), the same effect of increased temperature could not be observed in the field. In the field considerable numbers of spores could be released even at very low temperatures (less than +5 °C). This was not ex-

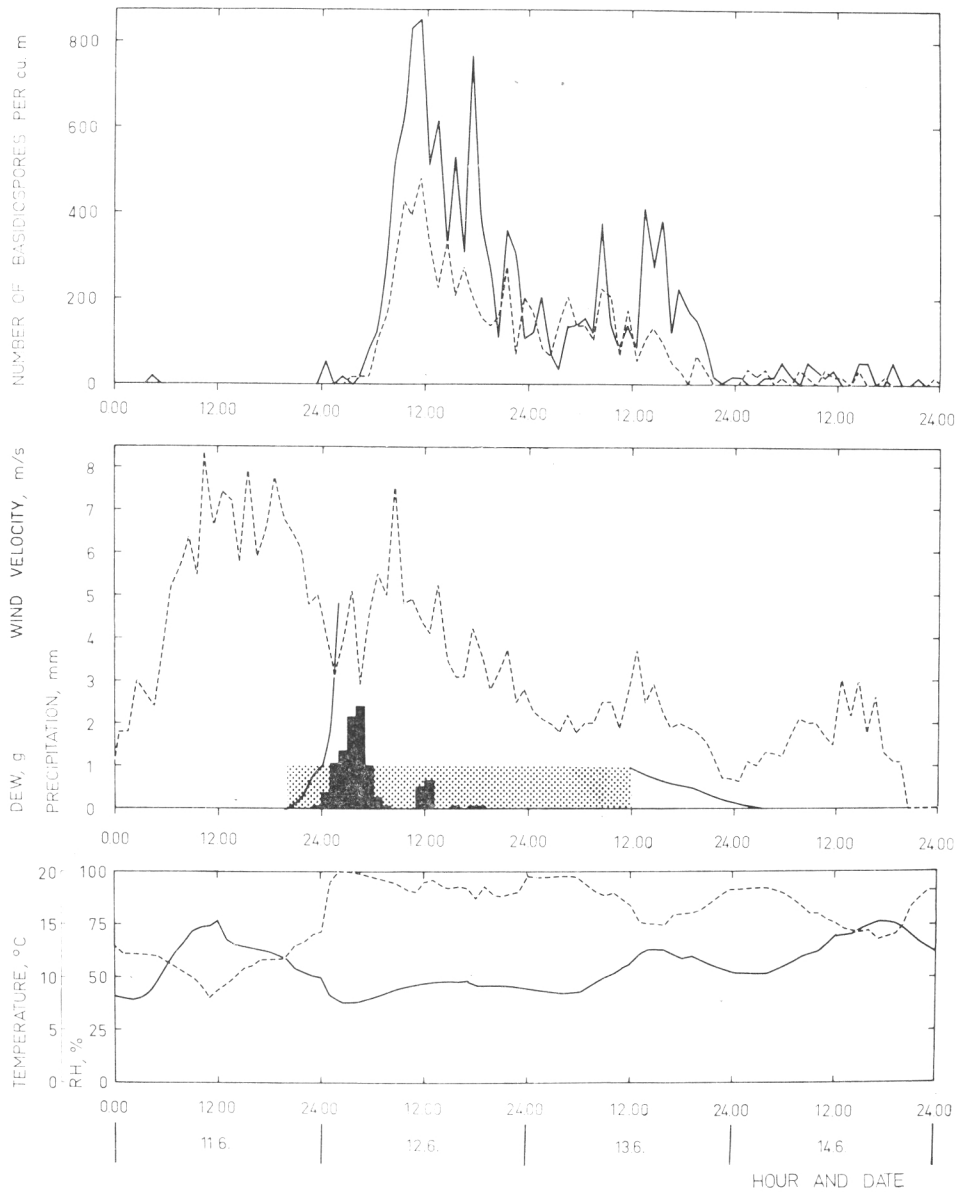


Figure 10. Hourly dispersal of basidiospores (*Melampsora* sp.) in relation to some weather factors in Loc. 3, June 11—14, 1971. For legend see Figure 7.

pected, judging from the results obtained in laboratory experiments. The two results need not be contradictory since the temperature on the ground litter may, sometimes after rains, have been higher than the temperature measured in the weather chamber.

The effect of wind velocity on spore release was even less definite than that of temperature.

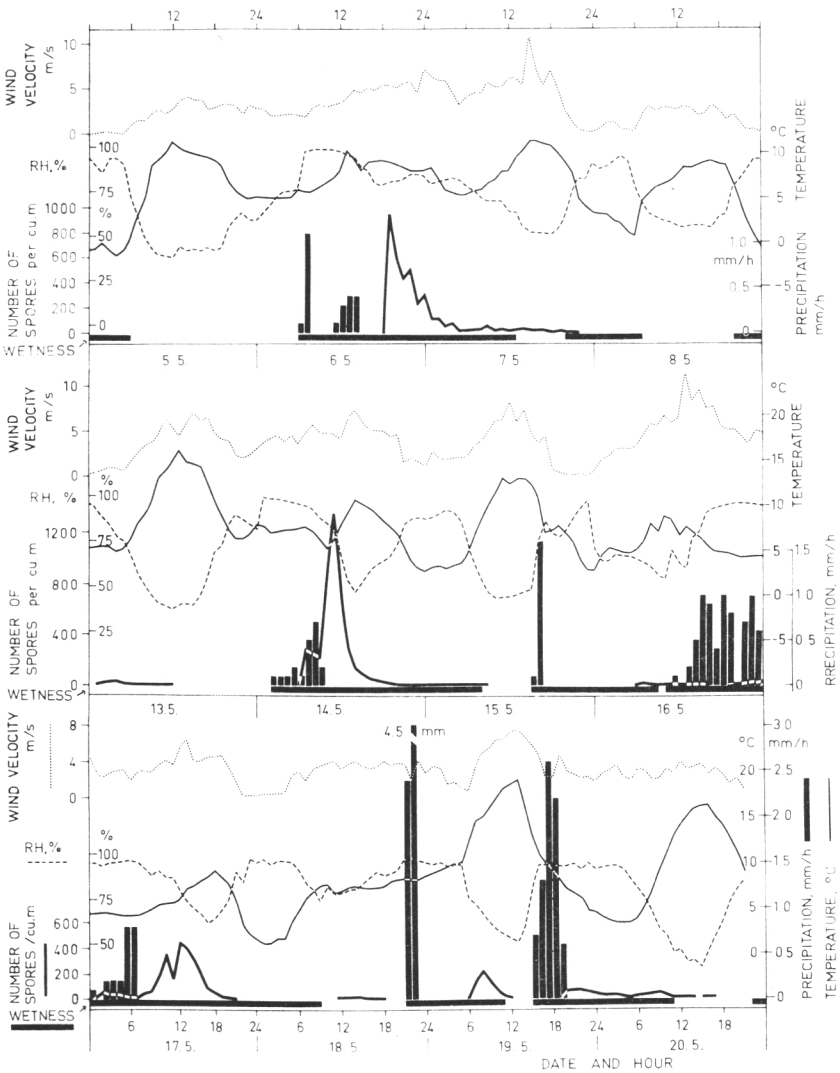


Figure 11. Basidiospore density (spores/cu.m of air) of aspen rust (*Melampsora* sp.), wind velocity (m/s), temperature measured in a weather chamber (°C), relative humidity (RH, %), precipitation (mm/h), and length of wet period caused by rain and dew (h, thick black horizontal line). In Loc. 4 during three four-day periods in May 1973.

Dispersal of aeciospores and uredospores

The number of aeciospores dispersed in the air depended primarily on the extent to which the basidiospores had been able to infect pine shoots or larch needles and, furthermore, on how much the aecia developed after infection. The variation in the numbers of aeciospores from year to year may be

regarded as depended primarily on these two factors. Observations on the shoot and needle development of aecial hosts of *Melampsora* in Loc. 1 showed that larch needles and pine shoots reached a susceptible stage about 15th of May and during the first half of June respectively. Aeciospore dispersal started during the second half of June after the first aecia had developed on pine shoots and lasted 20—30 days.

Inspection of the average daily number of aeciospores (Fig. 2—5) shows, especially in the results of 1967, that during high temperatures the numbers of aeciospores have been greatest. Sudden showers can also rapidly increase the number of spores in the air, as happened on July 4 and 11, 1967 (Fig. 12). Since the thundershowers often were preceded by strong gusts of wind, it was usually impossible to separate the effects of wind and rain. The relative humidity of the air was not included as a variable in the graphs (Fig. 2—5) describing the dispersal of spores and development of the disease during the growing season. If the air humidity in general has any influence on release and dispersal of aeciospores of *Melampsora*, then the correlation is clearly negative. The number of spores fluctuated during different periods of the day (Fig. 13). The spore density of pine twisting rust was at a minimum in the middle of the night, during which time there usually is dew and the

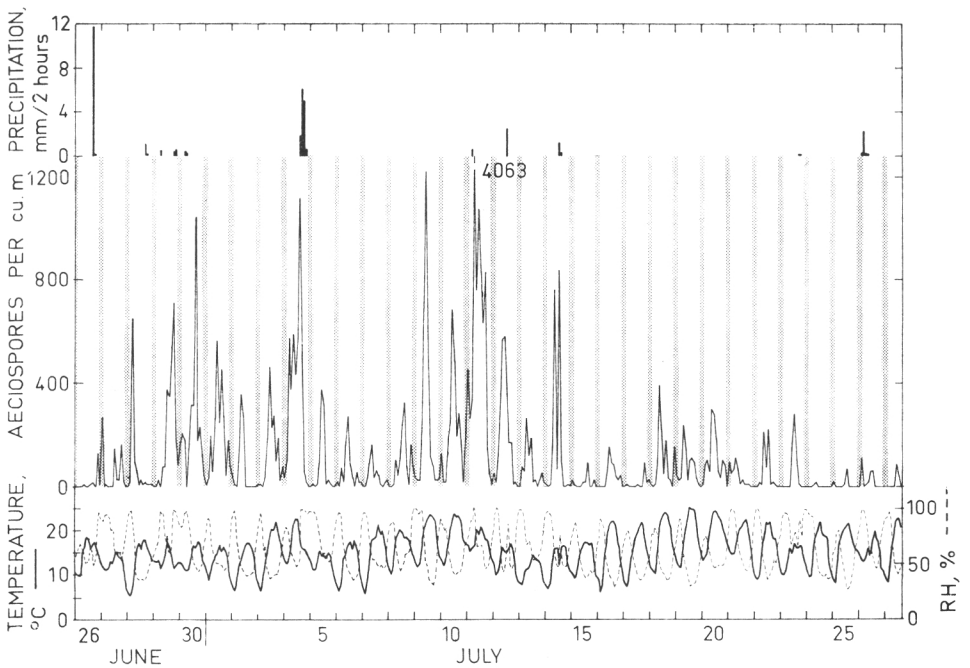


Figure 12. Dispersal of aeciospores of *M. pinitorqua* in the summer of 1967 in Loc. 1 in relation to precipitation, temperature and relative humidity of the air. The shaded areas indicate the time between sunset and sunrise.

air humidity is at a maximum. The number of spores began to increase about 06.00 when the dew started to dry and reached a maximum between 09.00 and 11.00 when the normal dew had completely evaporated. In Tuusula (Loc. 3) the average maximum spore density of the larch rust did not occur until late afternoon at 17.00. The difference between this result and that of Ikaalinen (Loc. 1) may be due to the limited data from Loc. 3, but may also be due to local conditions. In Loc. 1 the aecia of pine twisting rust were located in the tops of 0.5—1.5 m high saplings and thus were exposed immediately to insolation and wind, which dryed the dew rapidly. By contrast, the aecia of the larch rust in Loc. 3 were located on the lower branches of some 6 m high larches which were not reached by continuous insolation.

Dispersal of uredospores commenced in Loc. 1 at the beginning of July and in Loc. 3 at the end of June. The uredospores, similar in this respect to the aeciospores, seem to disperse when dry. Their maximum spore density occurred between 13.00 and 15.00 (Fig. 13). The average maximum of spore density for the whole growing season occurred at 13.00 during 1966 and 1968. On the data from 1967 the variation in spore density was calculated separately for July, August, and September. This was done in order to find out whether the gradual change in various weather components would be accompanied by corresponding changes in the number of uredospores as fall approached. No significant differences between various months were observed. The maximum average spore density for each of the three months occurred at 15.00. The spores were counted at every odd-numbered hour. In Loc. 3 in 1970 the maximum spore density occurred before noon, at 11.00. The minimum density occurred between 24.00 and 06.00. Deviations from the regular pattern of variation were caused by showers accompanied by gusts of wind.

The fact that the daily maximum during the whole dispersal season in Loc. 3 in 1970 occurred at 11.00 is thought to be due to unusually gusty winds and rain showers. On August 23 an exceptionally high spore density occurred. It can be explained only by the coincidence of a very strong wind and a rain shower. The rain, however, could not be registered on the fluviometer. On this day the spore density exceeded 6 000 spores/cu.m/h (Fig. 14) compared to the general daily maximum which was seldom more than 1 000 spores/cu.m/h.

Since the diurnal periodicity of dispersal for both aecio- and uredospores was very obvious, it was rather difficult to distinguish the effects of periodic weather factors on numbers of spores in the air. When the effects of various weather components are examined within a 24 hour period, the air temperature, wind and insolation, which was not measured in this connection, appear to be positively correlated, while relative humidity of the air and dew seem

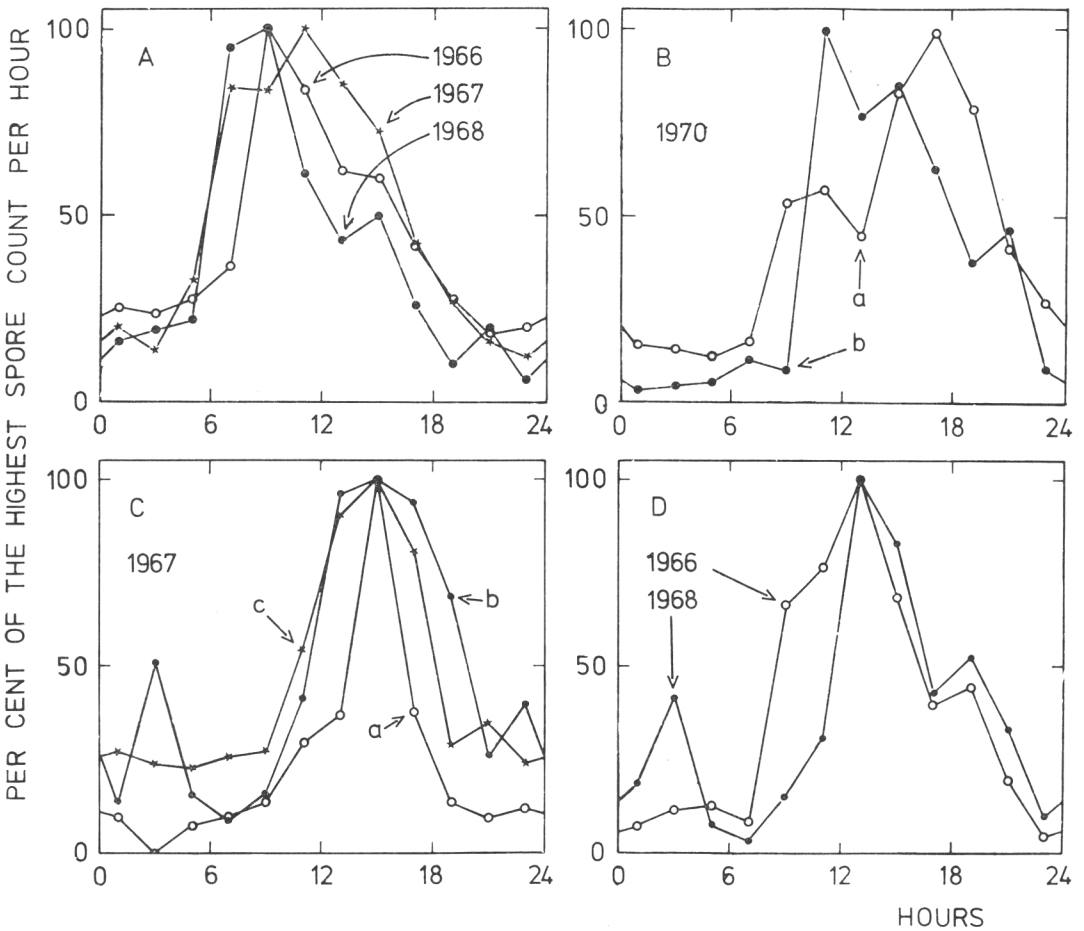


Figure 13. Average daily variation in number of *Melampsora* sp. aecio- and uredospores as a percentage of the highest total count for an hour. A) Diurnal periodicity of aeciospores *(M. pinitorgua)* dispersal in Loc. 1 in 1966—1968. B) Diurnal periodicity of spores *(Melampsora* sp.) in Loc. 3 in 1970, a = aeciospores, b = uredospores. C) Diurnal periodicity of uredospores *(M. pinitorqua)* in Loc. 1 in the summer of 1967, a = July, b = August, c = September. D) Daily average periodicity of uredospores of *M. pinitorqua* in Loc. 1 in 1966 and 1968.

to be negatively correlated with the density of aecio- and uredospores in the air.

Table 1 presents the correlation matrix for the variables used in the regression analysis (except for variable x_{10} which was not statistically significant in any of the models tested). The spore density is most strongly correlated with the number of uredia. This, however, is true only for the data of 1966. For temperature the only significant correlation with the daily spore density was obtained in 1968. In this year the density was positively correlated with the average temperature for the coldest period of the day. To some

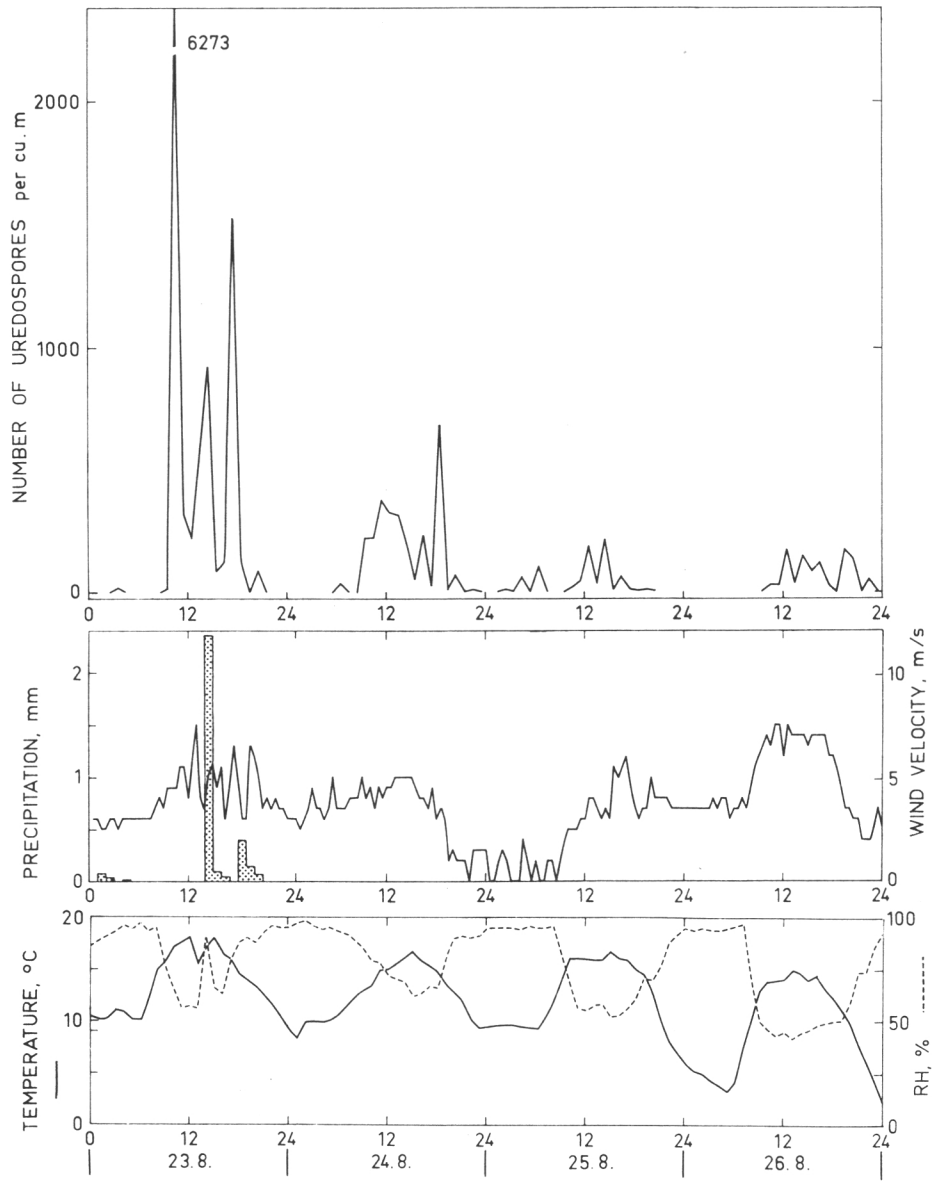


Figure 14. Dispersal of uredospores in relation to rain, wind velocity, air temperature, and relative humidity in Loc. 3, August 23—26, 1970.

extent the density and the temperature appear to be negatively correlated, which simply is due to the fact that, along with the colder weather as fall approached, the number of uredia and uredospores increased logarithmically. A statistically significant correlation between wind and spore density was obtained only in 1968. In addition, the matrix shows the low correlations

Table 1. Correlation coefficients between the number of uredospores trapped, the number of uredia, and some weather factors (for explanations, see pp. 12—13).

	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8
1966	0.546							
x_2 1967	0.424							
1968	0.317							
1966	0.918	0.560						
x_3 1967	0.841	0.249						
1968	0.952	0.296						
1966	—0.336	—0.161	—0.523					
x_4 1967	—0.499	0.041	—0.447					
1968	—0.429	0.293	—0.444					
1966	—0.283	—0.240	—0.498	0.795				
x_5 1967	—0.254	0.201	—0.363	0.786				
1968	—0.171	0.416	—0.280	0.600				
1966	—0.313	—0.111	—0.451	0.957	0.613			
x_6 1967	—0.631	—0.069	—0.466	0.942	0.575			
1968	—0.436	0.180	—0.370	0.912	0.269			
1966	—0.060	0.116	—0.051	—0.124	—0.140	—0.084		
x_7 1967	—0.234	0.130	—0.231	0.126	0.138	0.096		
1968	0.145	0.375	0.111	0.258	0.127	0.215		
1966	0.931	0.566	0.999	—0.521	—0.490	—0.454	—0.041	
x_8 1967	0.849	0.253	0.999	—0.440	—0.352	—0.467	—0.239	
1968	0.937	0.295	0.999	—0.438	—0.291	—0.351	0.111	
1966	0.954	0.578	0.985	—0.521	—0.470	—0.465	0.001	0.970
x_9 1967	0.855	0.249	0.987	—0.405	—0.304	—0.451	—0.270	0.991
1968	0.871	0.284	0.976	—0.409	—0.323	—0.284	0.104	0.986

1966 number of observations 41
1967 number of observations 43
1968 number of observations 29

between the temperature at the coldest period of the day and the other temperature variables. This is due to the fact that the average temperature for the coldest part of the day includes temperature readings before midnight of one day and after midnight (i.e. early morning) of next day.

In the regression analysis, data for each year were analyzed separately. The strongest correlations between spore density (x_2) with other variables were obtained with the following equations:

1966: $y = A+Bx_6+Cx_7+D***x_9$, $r = 0.58$, d.f. $= 37$
1967: $y = A**+B**x_5+Cx_7+D**x_8$, $r = 0.60$, d.f. $= 25$
1968: $y = A*+B***x_1+C*x_6+Dx_7+Ex_9$, $r = 0.55$, d.f. $= 33$

*** = statistically significant, at the 0.1 % level of probability.
** = significant, at the 1 % level of probability.
* = significant, at the 5 % level of probability.

As expected, the variables x_8 and x_9, derived from the number of uredia, best explained the variation in number of spores. In 1966 and 1968 the variables x_9 and x_8, respectively, were statistically significant. In 1967 the

variables derived from the number of uredia were not significant in the regression equations but the variable x_1, the number of days from the first occurrence of uredia, was very significant.

Relatively little can be explained by the temperature variables. During all years the average daily temperature explained less than the average temperature of the coldest or warmest period of the day (x_5 and x_6). In 1967 the factor of variable x_6, and in 1968 the factor of variable x_5 had some significance. When the regression analysis was made for each month, then the significance of variable x_6 was increased in the equation for 1967. This factor became very significant for July—August, and the correlation coefficient for the whole model was 0.70 (d.f. = 22). In July and early August of 1967 the daily average and maximum temperatures were considerably higher than in 1968 (Figures 3 and 4). The high temperatures seem to have increased the formation and release of uredospores. On the other hand, it is possible that the colder nights of 1968, compared to the previous year, would have been a factor limiting the formation of spores. This explanation also has its weakness in that during 1966 the night temperatures at the end of August were even lower, but the number of airborne uredospores reached its maximum (Fig. 2).

At the end of August in 1968 the weather was very warm and no rain occurred. During this time none of the factors for any of the variables reached high statistical significance. The factor of the wind variable provides the best explanation. It was almost significant, and the correlation coefficient of the whole regression equation was 0.73 (d.f. = 10). The data for these 14 days contained, however, only 1 143 uredospores. An analysis of the total data for the different years did not indicate that the effect of wind on numbers of spores would have been statistically significant. It is understandable that the wind had a low correlation. The wind hardly ever (with, perhaps, the exception of the end of August, 1968) was so low that it would have limited the release and dispersal of the spores. On the other hand, the sudden gusts of wind, which were able to release large numbers of spores, usually occurred in connection with thundershowers. Thus the effect of wind was difficult to determine. The wind velocity used in the calculations was the average of the observations per day, which already by definition excludes the possibility of detecting the effect of gusts of wind in the analysis.

The temperature, in a similar situation to that of the wind, was closely related to the rains. As a result of a rain, the temperature usually dropped, and on the other hand, prior to thundershowers, it was usually very warm. The hourly maximum spore densities usually occurred when there first had been warm and sunny weather followed by sudden thundershowers in connection with strong gusts of wind. Long periods of rain or rain during several consecutive days usually caused a definite drop in the numbers of aecio- and

uredospores. This drop may also have been partly due to a drop in the temperature caused by the rain. In order to consider the effect and variation of these short-duration weather components in the regression analysis, the analysis should be based on hourly observations, and the mode of action of each factor should be known in detail.

Twisting rust on pine

Seasonal variation of rust incidence

Tables 2 and 3 indicate the variation in amount of twisting rust in Loc. 1 during 1965—1968. The summer of 1965 was, compared to the previous growing season, more favorable for development of the pine saplings. Aecia of twisting rust occurred on the shoots on an average of 2.2 and 1.5 aecia/dm. During the next year, 1966, there was somewhat more rust per shoot, but the number of aecia per dm was smaller than during the previous year. In 1967 the incidence of rust reached a maximum in Ikaalinen. The amount of rust was about fuorfold compared to the previous year. In 1968 the amount decreased so much that there was not even a tenth of the amount which had been present in 1967. In 1969—1972 no systematic observations were

Table 2. Incidence of pine rwisting rust on the terminal leaders of Scots pine in Loc. 1 during the summers of 1965—1968.

	Year			
	1965	1966	1967	1968
Number of trees surveyed	25	47	30	10
Total length of terminal leaders, dm	77.61	116.50	84.17	18.57
— average length, dm	1.50	2.49	2.81	1.86
Number of aecia				
— total number including yellow spots	94	—[a]	454	11
— aecia matured	55	156	400	6
Number of aecia per terminal leader				
— total number	3.76	—	15.13	1.10
— aecia matured	2.20	3.32	13.33	0.60
Number of aecia per dm				
— total number	2.50	—	5.39	0.59
— aecia matured	1.46	1.34	4.75	0.32
Number of trees				
— with healthy terminal leader	9	—	0	6
— with no matured aecia	12	19	0	6

[a]) — = no record

Table 3. Incidence of pine twisting rust on shoots of one year old branches of Scots pine in Loc. 1 in the summers of 1966—1968.

	Year				
	1966		1967		1968
	Replications				
	I	II	I	II	I
Number of trees	47	47	30	30	10
Total length of shoots, dm	72.99	76.62	55.51	52.92	16.26
— average, dm	1.55	1.63	1.85	1.76	1.63
Number of aecia					
— total number including yellow spots	—[a]	—	157	146	3
— aecia matured	32	36	135	131	1
Number of aecia per shoot					
— total	—	—	5.23	4.87	0.30
— matured	0.68	0.77	4.50	4.37	0.10
Number of aecia per dm					
— total	—	—	2.83	2.76	0.18
— matured	0.44	0.47	2.43	2.48	0.06
Number of healthy shoots	—	—	2	4	8
— with no matured aecia	32	31	4	4	9

[a]) — = no record

made on the incidence of rust. In the fall of 1969 and 1970 the pine saplings on the experimental plots in Loc. 1 were examined, but no symptoms of rust could be detected. Also, during the following years, no serious epiphytotics occurred, but some rust was observed in various parts of the country.

The annual variation in rust incidence was best explained by the occurrence of rains during the growth of the pine shoots. Figures 2—4 show the daily height growth of the pine in Loc. 1 during 1966—1968. At the beginning of growth, before 10—30 % of the total height had been reached, the shoots were still covered with the fascicle scales. These scales seemed to completely prevent rust infection. Only when the surface of the shoots had been exposed were they susceptible to infection by the basidiospores. In the experiments conducted in the greenhouse the pines became resistant only when height growth was almost completed. Consequently, the pine shoots were susceptible to rust for some 20 days, between June 5—25. The amount of twisting rust was strongly correlated with the rains occurring during these days. During 1964 and 1967 the most important rains in June occurred at a time favorable for rust, causing a very heavy epiphytotic. During 1965, 1966, and 1968 the rains during pine shoot growth were not very heavy, but they were heavy enough to result in formation of basidiospores and a medium to light infection of the pine shoots. June of 1969 was

not particularly lacking in rain, but the rains seem to have occurred when the shoots were not susceptible to infection. The next year, 1970, no rains occurred during the critical period, thus causing the pine twisting rust to disappear from most of Finland. Information about the rains during different years and months are available in the Meteorological Yearbook of the Finnish Meteorological Institute (Finnish Meteorological Office 1965—1967, Finnish Meteorological Institute 1968—1970, 1972). In 1966 rain was not registered at all during the time of most intensive growth of pine. The rains during June 3—7 were too light to allow the spread of pine twisting rust. At this time the pine shoots were still protected by the scales of the fascicles. The fact that infection did not take place during these rains can be deduced also from the observation that the first aecia did not occur until June 25. On June 14 and 16 some small thundershowers may have occurred (Finnish Meteorological Office 1966). These, however, were not registered on the fluviometer, at the study area but they could have caused some infection of the pine shoots, which probably resulted in the aecia observed on June 25. Some infection also may have occurred later, e.g. on June 22 when a 0.5 mm rain was registered. The spore counts obtained in 1966 from the Sarvas—Wilska pollen trap were too inaccurate for determining the probable time of infection.

The severe epiphytotic of 1967 was a result of a perfect coincidence of pine shoot growth and rain. It rained on June 1, but the pine shoots could not yet be infected. After this, it was warm for a couple of days when the daily shoot growth almost reached its maximum. On June 5 an almost continuous period of rain began and lasted for seven days. For a long time the average temperature was below 10 °C. The low temperature caused an almost complete cessation of the pine shoot growth (Figure 3). Since the pine shoots remained susceptible to infection for a long time, the infection was unusually intensive even if the temperature was considerably below the optimum for development of the pathogen (cf. K u r k e l a 1973 a). The first aecia were observed on June 19. If the first infections are assumed to have occurred on June 6, then it had taken 14 days for the aecia to develop. The cold weather could, of course, have slowed their development. No new infections resulted from the rains which started on June 21 since basidiospores were observed in the air at this time.

As was stated in the report on dispersal of basidiospores, two rains, which resulted in the formation of basidiospores and fascilitated infection, occurred in 1968 during the shoot growth of the pines. The first of these rains (5 mm) was on June 9—10. Enough moisture for infection occurred, however, during a relatively short period, resulting in a fairly light infection of the pine shoots (Figure 4, Table 2 and 3). The first observations on aecia formation were made on June 19, and on June 23 mature aecia were found.

On June 18 and 19 small showers, which did not result in measurable numbers of basidiospores, occurred. The rain on June 25 and 26 resulted in intensive formation of basidiospores, but new aecia were not formed. Apparently, the pine shoots had already developed resistance against infection.

Effect of wind on the positions of aecia on pine shoots

The position of aecia on the different sides of the pine shoot was clearly dependent on the wind direction at the time of basidiospore dispersal. Since the rust mycelium is limited to the immediate vicinity of the aecia, the positions of the aecia indicate the directions from which the basidiospores have arrived. Figure 15 indicates the relative proportions of aecia positions on the pine shoots in Loc. 1 in 1965 and 1966. The proportions were calculated on the basis of 500 observations. The predominating directions of basidiospore arrival in Loc. 1 in 1965, as well as in Parkano about 30 km away,

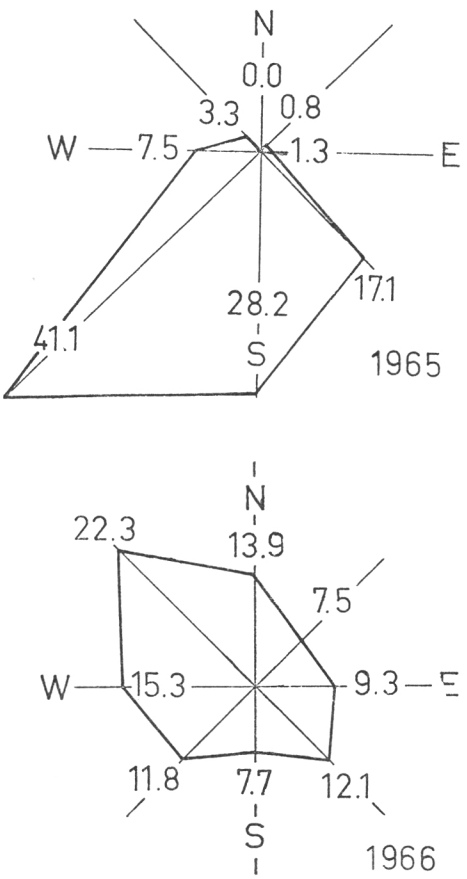


Figure 15. Number of aecia on different sides of pine shoots in percentage of total number, in Loc. 1 in the summers of 1965 and 1966.

were southwest and south. In Parkano some aecia also were located on the northern side of the shoots. The low pressure systems bringing rain to Finland usually arrive from the southwest. During the summer of 1966, at the same location as previously described in Loc. 1, most of the basidiospores had arrived from directions between west and north. During this summer the rains at the time of shoot infection were not caused by low pressure systems. The spores were formed and dispersed only during or after small thundershowers. On the locations examined, aspen leaves bearing telia were found all around the experimental plots. The occurrence of more aecia on some sides of the pine shoots than on others is an indirect indication of how crucially important weather factors of very short duration may be for infection. If such a strict dependence would not exist the aecia would probably be more evenly distributed around the pine shoots. In connection with investigations of this kind, it would be important to register wind direction, but there were no possibilities for such registration during this work.

Growth stage and rust resistance of pine

The infection of pine shoots with basidiospores of *Melampsora pinitorqua* during the pine growth phase resulted in the formation of aecia on the shoots. A relatively large number of aecia also developed on growing needles. When 99.9 % of the shoot growth was completed, aecia were formed only on needles. Inoculations performed later when no shoot growth was observed resulted only in a few yellow spots. These spots were aecial primordia but never did complete their development. In the earlier sets of inoculation the

Table 4. Inoculation of pine saplings with basidiospores of *Melampsora pinitorqua*.

Shoot length, % of final length	Time from planting to inoculation	Number of aecia develped on saplings[a]		Time required for opening of the first aecia, days
		Shoots	Needles	
57.1	0	38	0	11
58.0	0	67	1	11
71.5	3	42	13	11
71.7	4	2	5	14
87.1	6	15	35	12
95.5	9	11	23	12
95.5	14	10	5	11
98.8	14	11	35	13
99.91	18	—[b]	14	13
100	22	0	—	—
100	26	0	0	—

[a]) Every set consisted of 10 seedlings
[b]) Yellow spots only

yellow spots could be detected on the shoots 2—4 days before the aecia opened. Before opening, the yellow spot was surrounded by droplets of liquid with pycnidia forming pycniospores; i.e. fertilizing sporidia (cf. G ä u m a n n 1964). The opening of the aecia occurred 11—14 days after inoculation. The results of these experiments are presented in Table 4.

Correlation between rust incidence, shoot length, and height of pines

Since the basidiospores of a rust fungus land at random on different surfaces, the longer the shoot is, the higher the probability of infection. The correlation between the shoot length and the number of aecia developed on it was studied using the data of 1967. The correlations of shoot length with numbers of aecia (i.e. the number of mature aecia only and counts of aecia which included mature ones and yellow spots) were low ($r = 0.43$ and 0.48) for the data which included terminal leaders. For data on terminals of branches the corresponding correlations were $r = 0.61$ and 0.64, respectively. The combined data resulted in a correlation of 0.75 and 0.77. The highest

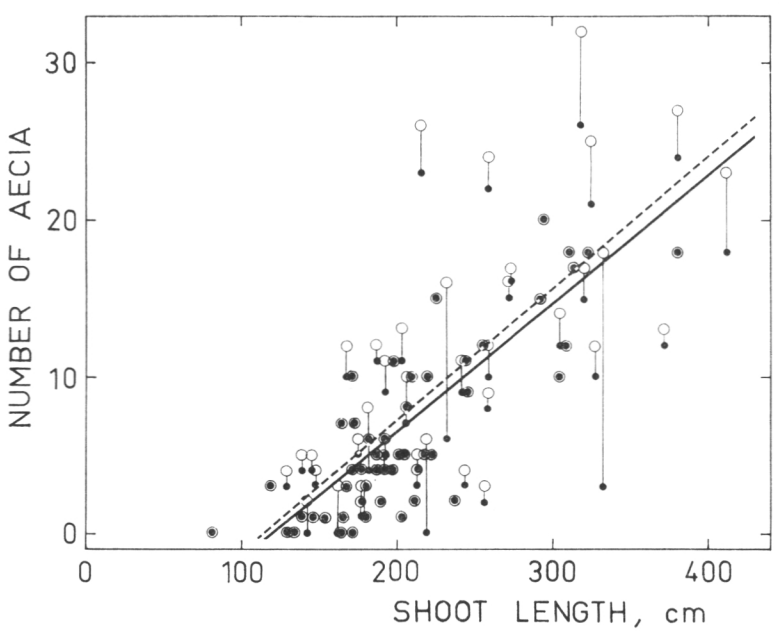


Figure 16. Relationship between shoot length and number of aecia on pine shoots in the summer of 1967. The rings indicate number of yellow spots, and the black dots indicate the number of mature aecia on the shoot. The line connects observations from one shoot. The thick solid line is the regression of number of aecia on shoot length, and the broken line is the regression of number of yellow spots on shoot length.

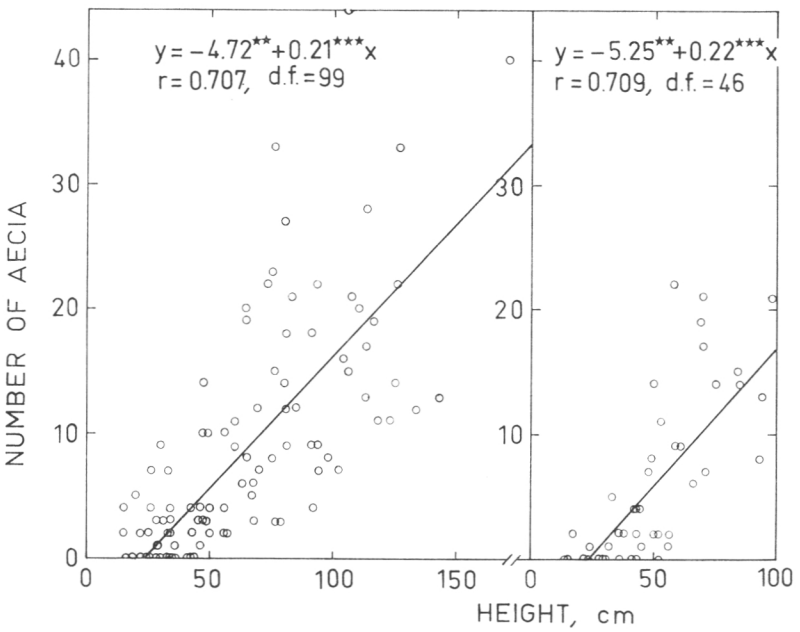


Figure 17. The regression of number of aecia on the two uppermost whorls of branches and the terminal leader on pine sapling height, in Loc. 1 in 1964.

correlation for the combined data was obtained for the regression model $y = A*** + B***x$. Figure 16 indicates the relationship between shoot length and number of aecia. Consequently, on the branch terminals the number of aecia seems to be more dependent on length than on stem terminals. The stem terminals were about three times more susceptible than the branch terminals.

In 1965 on some 25×25 m large plots in Loc. 1 the number of aecia formed during the previous summer was counted on the main shoot and branches of the previous year as well as on the shoots of the one year old branches. When the saplings were less than 1.5 m high, the number of aecia was linearly correlated with the size of the sapling. Figure 17 presents the results from two plots. This linear relationship was more irregular if no aspen occurred on the plot or in its immediate vicinity.

Interaction of the development of pine and rust

The rust seemed to reduce the growth of the pine shoots to some extent. In the 1966 and 1967 data, the shoots, which later became severely infected, started growth slightly more vigorously compared to those remaining healthy or less infected. After the establishment of the fungus daily relative

growth in the infected shoots was less than that in the healthy shoots. For this comparison the relative growth was used, obtained by dividing one day's growth by total length measured the previous day. Even if the difference in average growth caused by the rust seemed clear, no correlation was found between rust severity (number of aecia/dm) and growth of individual trees. Length measurements of severely infected shoots were difficult and more inaccurate due to the twisted shoots as compared to the healthy ones. Since the number of saplings on the experimental areas did not change significantly during 1967 and 1968, the number of aecia per tree could be regarded as an index of the number of aecia in the area (Tables 2 and 3). Since during both years the method of spore trapping was the same, the measured spore densities are comparable. In 1967 the total number of aeciospores was 5 523, and in 1968, 443 spores were trapped. Even though there were ten times more spores in 1967 than in 1968, the number of spores per aecium seems to have been only half the number found in 1968. This difference may have been due partly to the effect of weather factors. It is also possible that in 1967 the aecia may have been too close to each other to get enough nutrients from the shoots for spore production. The sparsely distributed aecia also seem to cause relatively more severe damage than those which are densely distributed. This may be deduced from the fact that the local effect of only one aecium may be sufficient to kill the shoot above the point of infection.

During the severe rust years of 1964 and 1967 in Loc. 1, almost all the terminal leaders of pine were killed on the experimental area as well as elsewhere in western Finland where pine sapling stands with plenty of aspen suckers were found. During other years the damage was less severe.

As a result of the severe rust year of 1967, about 50 % of the pine terminals were dead by August 17. This is thought to be a direct result of the action of the pathogen. During the following winter, the terminals continued to die off so that next spring about 90 % of the terminal leader and branch terminals had died. Death during the winter was often connected with the effects of various weather factors. Many of the shoots infected by the rust in the summer were too weak to endure the strain caused by winter snows. Some shoots which were still alive in the fall died during the winter and spring. The most common reason for death seemed to have been the resin flow and impregnation of the rust-caused wound, resulting in blockage of the phloem connections. It is also possible that the needles on the infected shoots were not resistant enough to desiccation in the winter.

The kind of damage that developed depended quite strongly on the phase of shoot growth at which infection occurred and aecia developed. Early infection resulted in death of the shoot already during the growing season. In some mild cases the shoots were only bent. Infection occurring late during

shoot growth usually did not result in twisting or immediate death of the shoots but resulted in wounds healing by the end of the summer. The wounded places, however, seemed to be very susceptible to breaking by snow in the winter.

The recovery of the pines after rust damage and replacement of the dead shoots were very much dependent on the severity of the attacks. A mild infection does not always cause death of the terminal leader. Even if the leader dies, some of the healthy shoots on the current whorl may already partly replace the leader in the same summer. All the shoots at the top of a sapling may die as a result of severe infection. In such a case the terminal may be replaced by a lower branch or by a shoot developed from the bud of a short shoot (Figure 18). In this case two or three growing seasons may pass before the sapling reaches the height to which it would have developed during the year of the rust, had it not been infected.



Figure 18. The top of a pine sapling severely damaged by pine twisting rust. As a result of the intensive infection, all shoots have died. During the growing season following the year of damage, shoots have grown out of the short shoot to replace the leader.

Incidence of rust on aspen leaves

When aeciospores were released from the aecia of *M. pinitorqua* on the pine shoots, the aspen leaves already were fully developed.

In the pine sapling stands or in their vicinity the first uredia were observed on aspen leaves in Loc. 1 at the beginning of July. The primary infection of the leaves seemed to have been caused by the aeciospores developed on

pines growing on the experimental plots. Uredia were not observed on aspen leaves before the maturation of aecia but were found only 10—20 days after the aeciospores had started to disperse. Consequently, it is obvious that the rust did not overwinter in the uredial stage. Neither could remote dispersal of uredospores have caused the primary infection of the aspen leaves since the first uredospores were trapped at the same time as the first uredia were observed. When aspen leaves were inoculated during rainy weather with aeciospores obtained from the pine shoots, the uredia developed in 10—14 days. On the other hand, it has to be noted that, depending on weather conditions, *M. rostrupii* Wagner (cf. p. 49) and *M. larici-tremulae* may have been able to cause the uredial state on the aspen 15—30 days earlier than *M. pinitorqua*, since these two species of rust compared to *M. pinitorqua* develop their aecial state earlier.

The number of uredia initially increased geometrically (Figures 2—4) due to infection by the ever-increasing number of uredospores. In both 1966 and 1967 the number of uredia of the aspen leaves at the end of August had reached approximately the same level, about 30—50 uredia/sq.cm. In 1968 the number of uredia was considerably smaller compared to previous years, about 1 uredium/sq. cm. The summer of 1968 was relatively cool and rainy, thus inhibiting the continuous multiplication of the uredial stage on the aspen leaves. According to the observations, aspen rust occurred rather sparsely in the fall of 1968 all over the western and northern parts of Finland. During the following three years (1969—1971), aspen rust was very sparse. It was found only in a narrow zone along the southern coast and sporadically in the vicinity of larch stands. Most likely, the rust observed then in the southern parts of the country was *Melampsora larici-tremulae* or *M. rostrupii*, since the aecial stage of these species was not uncommon during these years, but pine twisting rust could hardly be found at all.

In the fall at the end of the growing season the telia of *Melampsora* developed. Their number was 2—5 times greater than that of the uredia.

The mycelium around the uredium was limited to the yellow leaf area surrounding it. The yellow color of the area was due to the fact that the chloroplasts had disappeared from the cells affected by the mycelium (Figure 19). The veins of the leaves limited the spread of the mycelium in the tissue (Figures 19 and 20). To some extent, the mycelium seemed able to bypass the thinner veins. The distance between veins thicker than 50 % of the leaf thickness varied from 0.36—1.23 mm and averaged 0.7 mm. Consequently, the mycelium which developed from one basidiospore could infect the tissue on an area of 0.4—1.2 sq.mm. From this it can be concluded further that on an area of 1 sq.cm there are about 100—200 areas, delineated by the veins, which can be infected independently by a single spore. Usually all these areas are not infected.

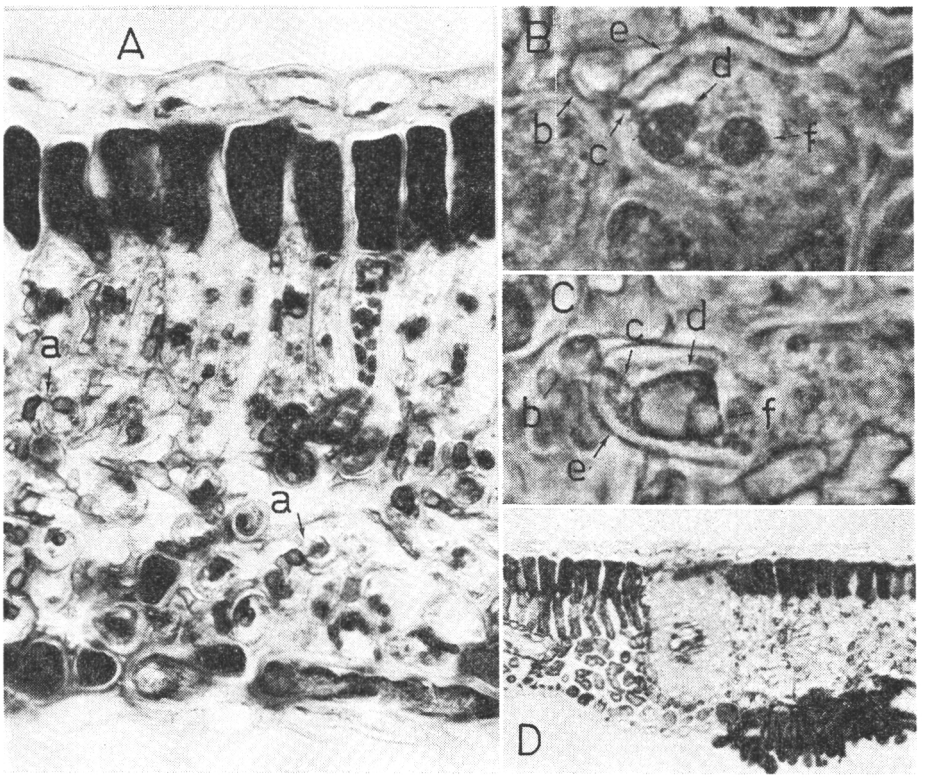


Figure 19. Microscopic sections from aspen leaves infected by the rust. A) Abundant intercellular mycelia in an infected leaf, a) haustorium connected by a thin neck to a mother cell outside the host cell. B and C) Magnifications of the haustorium, b) the mother cell of the haustorium, c) the haustorial neck, d) haustorium, e) wall of host cell, and f) nucleus. D) Cross section of an aspen leaf with a *Melampsora* uredium on the lower surface. The chloroplasts have disappeared from the leaf next to the uredium. In the center of the picture is a vein which has inhibited growth of the mycelium. Healthy tissue to the left of the vein. A) × 300. B and C) × 800. D) × 80.

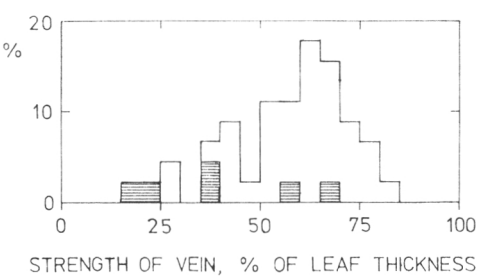


Figure 20. Distribution of the aspen leaf veins of various thicknesses. The thickness of the vein expressed as percentage of the leaf thickness. The shaded areas indicate the number of veins of each thickness class which ones the mycelium had passed.

There was abundant intercellular mycelium in the infected tissue. At places in the tips of the mycelium there were intensively-stained cells which proved to be mother cells of haustoria. In the same host cell there could even be several haustoria, which were connected to the mother cells by a narrow neck (Figure 19). The haustoria appeared to be similar to those studied by Longo and Naldini (1972) and with those of the rust *M. lini* (Ehrenb.) Lév. described by Littlefield (1972).

DISCUSSION

Dispersal of basidiospores and infection of pine

The dispersal of the basidiospores of *Melampsora pinitorqua* was studied during June of three consecutive years: 1966, 1967, and 1968. The study was begun when the buds were still covered with scales, and consequently, the shoots were unsusceptible to infection. Basidiospore dispersal may have occured already before the study began. The maximum spore densities and total numbers of spores were extremely varied during different years. Comparison of the average numbers of spores for different years is complicated by the fact that during 1966 and 1967 the spore counts were obtained with the Sarvas—Wilska pollen sampler, while during later years the counts were obtained with the Hirst spore trap. Since the basidiospores do not have any characteristic features except for the rounded shape, size and a faint, rapidly fading yellow color, their identification was fairly inaccurate on the vaseline-covered, cellophane plates from which one could not make ordinary microscopic slides. During microscopic examination the count might easily have included other particles resembling the spores. This apparently happened in the examination of the material from 1966. When counting spores in 1967 the work was done more critically. Then again, some of the spores may have been uncounted. The numbers of spores counted in 1966 and 1967 were approximately the same, but when considering the abovementioned counting difficulties, it is very probable that the number of spores in 1967 was really much larger at the time when pine was susceptible.

The slight effect of air temperature on the airborne basidiospores concurs with the results of laboratory experiments (K u r k e l a 1973 a), according to which the formation and release of basidiospores occurs over a wide temperature range. According to present knowledge, the basidiospores are actively released (K l e b a h n 1904, D i e t e l 1912, P r i n c e 1943, S a v i l e 1965). and in addition, the spores are so minute ($\varnothing$ 6—10 μ) that even the lightest air current may move them. Therefore, the correlation between wind velocity recorded on an anemometer and the spore density may be mere coincidence. It may be speculated that the vertical air currents, created when the air becomes warmer, are of importance for dispersal of basidiospores since they are formed on aspen leaves lying on the ground

and the basidia are not capable of actively ejecting them very far into the air. The obtained results are not in conflict with such a hypothesis; but, on the other hand, neither can it be proven.

The dispersal of rust basidiospores has been found generally to occur during high relative humidity of the air. In more southern latitudes, where more dew is formed during the night, a diurnal periodicity may be observed with the maximum around midnight (Carter and Banyer 1964, van Arsdel 1967, Snow and Froelich 1968, Pady and Kramer 1971). Even in areas favorable to dew condensation, the formation and dispersal of basidiospores appears to be most intensive when rains have prolonged the moist period (Hirt 1942, Snow and Froelich 1968). In general, the dispersal of basidiospores occurs most intensively, or even exclusively, during nights when there is dew (Hirst 1953, Gregory and Stedman 1958, Sreeramulu 1959, 1963, Wood and Schmidt 1966, Shanmuganathan and Arulpragasam 1966, de Groot 1968). All basidiospores are not, however, dispersed when moist; but, for instance, a reduction in relative humidity may cause release of the spores (McCracken 1972).

Sylvén (1918) already found that the incidence of pine twisting rust was crucially dependent on the rains in May and June. Also, the observations made by Klingström (1963) indicated the importance of rains for spore formation. The germination of telia of *Melampsora* seems to be controlled by an internal rhythm regulated by various weather factors. This results in germination of the telia simultaneously with the height growth of the pine shoots (Klingström 1963, Longo et al. 1970). In the present study the number of airborne basidiospores was reduced to insignificant amounts after mid-June. Exceptional weather may cause irregularities in the germination rhythm of the telia. Regler (1957) found that telia of *Melampsora* may, as an exception, germinate in the fall, which reduces the possibilities for an increase in rust the next spring. Rains have been found to have a crucial influence on formation of basidiospores and the infection caused by several species of *Cronartium* (Hirt 1942, van Arsdel et al. 1956, van Arsdel 1967, Nighswander and Patton 1965, Snow and Froelich 1968, Snow et al. 1968). By means of weather forecasting and by following the development of the telia, it is possible to predict the risk of infection by *Cronartium fusiforme* with a 2—3 day interim (Davis and Snow 1971). For some species of *Gymnosporangium* rains may not be of the same importance as for *Melampsora* and *Cronartium*. The telia of *Gymnosporangium* are often surrounded by a very moist, gelatin-like matrix. Thus, dew during the night may be enough for formation of the spores. This is indicated by the diurnal pattern of release with a maximum at midnight observed by Pady and Kramer (1971). The basidiospores

of *Gymnosporangium* can cause infection on host plants even at considerable distances, such as 10—12 km (MacLachlan 1935) and even as much as 23 km (Parmelee 1968), apparently because the spores can be formed during a comparatively short, moist period but possibly also because of their relatively good survival capacity. The basidiospores of *Melampsora* and *Cronartium* appear to die rather easily if the relative humidity of the air decreases below the saturation point (Schafranskaja 1940, Hirt 1942, Nighswander and Patton 1965). Obviously the pine twisting rust cannot spread very far from the source of inoculation, the aspen suckers, due to low survival of basidiospores (Rennerfelt 1954, Schafranskaja 1940, Troschanin 1952, Kardell 1962, Durrieu 1967). The dispersal distance in each case is very much dependent on local conditions. Even during very favorable conditions, rust cannot occur more than 200—250 m from aspen suckers (Schafranskaja 1940, Troschanin 1952).

Dispersal of aeciospores and uredospores

Aeciospores. Dispersal of rust aeciospores has not been studied very extensively (Pady 1971 a). To my knowledge not a single study has been published about the dispersal of the aeciospores of *Melampsora*. Kramer et al. (1968) found in their studies a distinct diurnal pattern for the dispersal of aeciospores of *Uromyces psoralea* Peck and *Puccinia andropogonis* Schw. with a maximum during the night when high relative humidity occurred. Furthermore, they found that the aeciospores of *Phragmidium speciosum* (Fr.) Cooke did not disperse according to a diurnal pattern. The aeciospores of this fungus were released immediately when it rained, regardless of the time of day. Pady et al. (1968, 1969) studied the release of *Gymnosporangium* sp. aeciospores and found that for some species most aeciospores were released in the morning between 06.00 and 08.00 or, for some other species, generally in the daytime during dry periods. In the aecia of *Gymnosporangium* there is a mechanism which keeps them closed during moist weather (Pady et al. 1968). Experiments conducted in dew chambers indicated that the release of spores occurred immendiately at the end of the dew period regardless of the light conditions (Pady et al. 1969). The aeciospores of *Cronartium* species are released according to a diurnal pattern (Powell 1972, Peterson 1973). Powell (1972) showed that the aeciospores of *C. comandrae* Pk. were dispersed mainly in dry weather with the diurnal maximum around noon. Sudden rains may increase the spore density, but during continuous rains only a few spores are released into the

air (Powell 1972). The rhythm of dispersal of the aeciospores of *C. comandrae* is very similar to the one observed in the present study for *M. pinitorqua*.

Uredospores. Dispersal of rust uredospores has been investigated much more than that of aeciospores. This is mainly due to the fact that the rusts of cereals are dispersed specifically by uredospores. In general, uredospores have been found to disperse according to a diurnal rhythm with the maximum spore density shortly after noon (Hirst 1953, Sreeramulu 1959, Pady et al. 1965, Kramer and Pady 1966). The uredospore dispersal of *Melampsora* appears to follow the same diurnal rhythm as other rust species. Pady (1971 b) reported that in greenhouse experiments the uredospores of *Melampsora euphorbiae* (Schub.) Cast. and *M. lini* (Pers.) Lev. were more often released during daylight hours. In these experiments the spore density usually had been at a maximum at noon or slightly before noon. Taris (1966, 1968) studied the uredospore dispersal of *Melampsora* species on poplars grown in a nursery. The uredospore density in the air reached maximum in the afternoon. Few spores were dispersed if the temperature was below 10 °C, relative humidity above 80 % or wind velocity less than 1 m/sec. A rain which occurred during the study period increased the spore density markedly. Taris (1966) considered this to be due to the mechanical effect of the rain and wind in releasing the spores.

Factors affecting diurnal periodicity of spore dispersal

The diurnal periodicity of spore release may be a result of one or more weather factors. Several weather factors, including light, total radiation, temperature, relative humidity of the air, dew and wind, vary according to a diurnal periodicity. The rainfall does not usually follow a diurnal pattern in Finnish conditions. Since all weather factors are dependent on one another in one way or the other, it is very difficult on the basis of field observations to determine whether one or several factors crucially influence the diurnal periodicity of release and dispersal of the spores. Several scientists have tried to investigate this problem in different conditions ranging from field conditions to microenvironments created in carefully controlled laboratories. The factors controlling periodicity vary according to the species of fungus.

Temperature seems to be positively correlated with spore formation (Jarvis 1962 a, Smith 1966, Cole and Fernandes 1970, Hammett and Manners 1971), at least when the temperature fluctuates mainly below optimum. For many fungi with dry spores the optimum temperature for spore formation is probably about 20 °C, perhaps

even slightly above. On the other hand, the critical temperature above optimum which completely inhibits spore formation may be rather high (e.g. 27 °C for *Alternaria solani*, Waggoner and Horsfall 1969). Wind (Zoberi 1961, Smith 1966, Hammett and Manners 1971) and raindrops (collison with leaves) (Davies 1959, Gregory et al. 1959, Hirst 1961, Bock 1962, Jarvis 1962 b, Hirst and Stedman 1963, Hammett and Manners 1971) are forces releasing the spores. Diurnally varying light often stimulates formation or release of spores (Yarwood 1936, Smith 1966, Cole and Fernandes 1970). Humidity may enhance formation of spores (Jarvis 1962 a) for some fungi, but on the other hand, it may slow down their release (Zoberi 1961, Smith 1966, Hammett and Manners 1971, Powell 1972). A rapid increase in the density of airborne dry spores is usually caused by the initiation of rain (Sreeramulu 1962, Taris 1966, Mills 1967, Hammett and Manners 1971). With the continuing rain the air is rapidly washed free of spores (Hirst 1953, Ludlam 1967, Chamberlain 1967). Structures of the mycelia which form the spores may be destroyed by the rain, causing the spore density to remain low for some time after the rain (Yarwood 1937, Sreeramulu 1964, Waggoner and Horsfall 1969).

Limitations in identifying the spores of *Melampsora* species

Literature on the morphology of spores

The rusts of aspen leaves are collectively known as *Melampsora populnea* (Pers.) Karst., which can be subdivided into several races or species according to the host on which the aecial state occurs (cf. Liro 1908, Hylander et al. 1953). These fungi cannot be distinguished by morphological characteristics. The aecial states of the following aspen rusts have been found in Finland (Hylander et al. 1953):

Melampsora larici-tremulae Kleb. on *Larix*,
M. magnusiana Wagner on *Chelidonium* and *Corydalis*,
M. pinitorqua Rostr. on *Pinus*,
M. rostrupii Wagner on *Mercurialis*.

Obviously, one has to be critical in considering the causal agents of pine twisting rust, *M. pinitorqua*, and the needle rust of larch, *M. larici-tremulae*, as different species. At the time, the separation of the two species was done on the basis of results obtained from inoculation experiments (Rostrup 1884, Klebahn 1897 a, b, 1899, Liro 1906). According to some

studies (L o n g o et al. 1970), *M. pinitorqua* also can infect larch. The rusts of pine and larch can probably occur on aspen leaves as mixed populations. Thus, using the same telial material, it is possible to get aecia to form regardless of which aecial host is used. On the other hand, the aecia of *Melampsora* which occur on larch may belong to species with aspen as alternate host or to species in which the uredial and telial states occur on different species of *Salix*. The name *M. larici* Hartig (cf. G ä u m a n n 1959) has been used as the collective name for these larch rusts. According to Z i l l e r (1959), the lateral walls of the aeciospores of aspen rust generally are expanded inward, whereas the walls of the aeciospores of rusts on *Salix* generally are expanded in the other apex. This special feature of the aeciospore walls has not been studied systematically on the aspen rusts occurring in Finland.

The aeciospores of *Melampsora* can be distinguished from the uredospores on the basis of differences in their surface structure. The surface of the aeciospores is finely verruculose and the uredospores have fairly large spines about 2 μ apart (cf. G ä u m a n n 1959, W i l s o n and H e n d e r s o n 1966). This is particularly clear on scanning electron micrographs (A r t h a u d 1972). According to the literature, the aecio- and uredospores of aspen rusts are of the same size (cf. G ä u m a n n 1959). For all these rusts the uredospores have been reported to be somewhat more oblong than the aeciospores. The size of the aeciospores has been reported as 13—20 μ × 12—17 μ and of the uredospores, 15—27 μ × 10—18 μ. There are very few descriptions of the rust basidiospores in the literature, including the species of *Melampsora*. This is apparently due to the minute differences between them. According to K l i n g s t r ö m (1963), the basidiospores of *M. pinitorqua* are round and measure 5—8 μ in diameter. The figures compiled in G ä u m a n n's (1959) book show basidiospores of *Puccinia* and *Uro-*

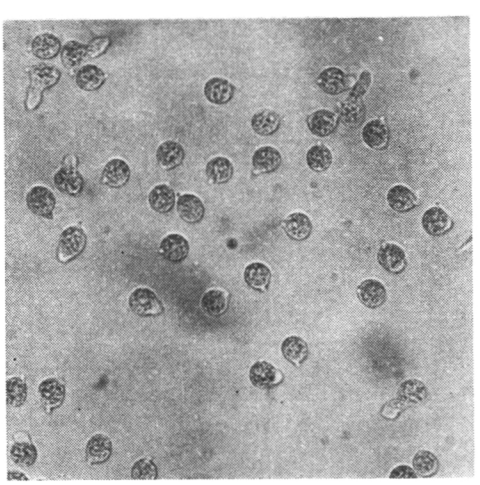


Figure 21. *Melampsora pinitorqua* basidiospores which have been released naturally and deposited on a microscope slide. Some of the spores have an emerging germ tube. × 450.

myces rusts as allantoid in clear contrast to the round ones of *Melampsora*. Some species of rust (e.g. *Melampsoridium betulinum* (Pers.) Kleb.) may have basidiospores of the same size and shape as *Melampsora*, while the basidiospores of e.g. *Thekopsora areolata* (Fr.) Magn. are clearly smaller, about 3 μ (G ä u m a n n 1959). The basidiospores of *Melampsoridium betulium* (S a p p i n - T r o u f f y 1896) and many species of *Cronartium* (H i r t 1935, K a i s 1963, K r e b i l l 1972) may form secondary sporidia during germination. There do not appear to be any such reports on *Melampsora* in the literature. Figure 20 shows basidiospores of *Melampsora* deposited on glass. Some already have germinated during a release period of one half hour.

Measurements of spores

In order to achieve more accurate identification of spores in examinations of spore trap material, the size distribution of some spore samples of *Melampsora* were measured. Aeciospore from the following species were measured: *M. pinitorqua* on *Pinus sylvestris* L., *M. larici-tremulae* on *Larix sibirica* Lebed., and *M. rostrupii* on *Mercurialis perennis* L. For measurements of uredospores, samples representing *M. pinitorqua* were collected from aspen suckers in a pine sapling stand where twisting rust had occurred abundantly during the same growing season and where hosts for other aecial states were not found in the immediate vicinity. The samples of *M. larici-tremulae* were made on fresh specimens. At least 200 spores per sample of both aecio- and uredospores were measured. The basidiospores of *M. pinitorqua* were obtained in the laboratory from germinating telia depositing their spores directly on microscope slides. The inoculation of pine transplants were made with the same telial material. Five hundred basidiospores were measured. The optics used were $\times 400$. The results of the spore measurements are presented in Table 5. The spore size distributions of the studied species of *Melampsora* were almost identical. Consequently, size measurements are not suitable for identifying individual species. The results corroborate data in the literature, even though the aeciospores of different species appear to be somewhat more rounded and the uredospores somewhat more elongated compared with previous reports. The average diameter of the basidiospores was 7—7.5 μ with extremes of 5.5 and 9.5 μ. When fresh, the basidiospores were yellow but when stored at room temperature this color was lost in about a month. In connection with the measurements, the wall thickness was also observed in order to determine whether this characteristic, reported by Z i l l e r (1959), was suitable for distinguishing the spores of aspen and *Salix* rusts from each other. The observations indicated that the differences in wall thickness varied, depending on the position of the spore. Consequently, this

Table 5. Reults of measurements of aecio-, uredo-, and basidiospores of some *Melampsora* species.

Rust species	Spore form	Dimension	Size class μ 9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	Total
			% frequency																				
M. pinitorqua	I[a]	Length						4.0	9.0	9.5	11.0	17.0	18.5	18.0	7.0	5.0	0.5	0.5					100
M. larici-tremulae	I	»		0.5	0.5	1.0	1.5	2.5	9.5	11.0	21.0	15.5	18.0	11.5	4.0	2.0	1.0	0.5					100
M. rostrupii	I	»			0.5		0.5	5.5	3.0	7.0	23.0	24.0	21.0	11.5	1.5	1.0	1.0			0.5			100
M. pinitorqua	I	Width				0.5	4.0	10.5	9.5	12.5	19.0	18.0	18.0	6.0	1.0	0.5							100
M. larici-tremulae	I	»	1.0		2.0	4.5	15.0	19.0	19.0	15.5	10.5	5.5	5.5	1.5	1.0								100
M. rostrupii	I	»			1.0	8.0	15.5	21.5	20.5	16.0	11.0	3.5	1.5	1.0	0.5								100
M. pinitorqua	II[b]	Length							0.5	3.5	3.0	10.1	20.1	20.6	19.1	10.1	7.5	2.0	1.0	2.0		0.5	100
» »	II	»							0.9	1.0	2.8	10.3	15.1	16.4	22.5	13.6	8.0	5.6	1.9	1.4	0.5		100
M. larici-tremulae	II	»							0.9	1.4	6.4	13.3	17.0	24.8	20.6	10.6	1.4	1.8	0.9	0.9			100
» »	II	»									0.4	1.7	8.0	17.2	18.5	19.3	16.4	11.8	4.6	1.3	0.4	0.4	100
M. pinitorqua	II	Width				2.9	5.3	17.4	31.9	31.8	9.7	1.0											100
» »	II	»			1.0	3.9	13.0	14.0	18.3	17.9	19.3	10.2	1.4	1.0									100
M. larici-tremulae	II	»		0.9	2.4	6.5	9.3	15.8	22.3	18.6	15.4	6.5	2.3										100
» »	II	»				1.4	11.5	15.1	21.5	21.6	17.0	9.6	1.4	0.9									100
			Size class, μ																				
			5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5												
			% frequency																				
M. pinitorqua	IV[c]	Diam.	1.4	5.4	14.0	21.6	25.4	17.2	8.4	5.0	1.6												100

[a]) I = aeciospores
[b]) II = uredospores
[c]) IV = basidiospores

characteristic can be used only when examining a large number of spores of the same origin (e.g. when identifying aecia developed on the needles of larch).

Characteristics which determine rust incidence in pine stands

The incidence of rust on the aspen leaves, the germination capacity of the telia, and the weather conditions influencing the pathogen are, of course, the most important properties controlling the infection of the pine shoots in a stand; but the infection also is partly dependent on the structure of the pine sapling stand and the resistance of the pines. Klingström (1969) and v. Weissenberg (1973) isolated from shoots of *Pinus silvestris* L. and *P. taeda* L. some substances that inhibited germination of basidiospores of *M. pinitorqua* and *Cronartium fusiforme* Hedge & Hunt ex Cumm. These substances may, in one way or the other, be related to rust resistance. According to many investigators (Eklundh-Ehrenberg 1963, Schütt 1964, Illy 1966, Kardell 1966, Klingström 1969), the tallest or most vigorously growing saplings commonly have been more intensively infected by the rust. Sylven (1917) and Klingström (1963) observed that the rust occurred more frequently on the terminal leader than on the shoots of the current whorl. This was also observed in the present study. Also, Karu (1937) found that smaller saplings, which often are protected by grass or the branches or larger saplings, were less commonly infected than larger saplings. According to Nabatov (1968), a dense cover of grass will protect the pine saplings from infection by basidiospores of *M. pinitorqua*. The uneven soil surface and the ground cover absorb airbone spores, resulting in a more rapid reduction of spore density with increased distance to the source of inoculum among ground cover than above it (Waggoner 1965). It is, of course, natural that there may even be considerable genetic variation in resistance; and, on the other hand, the terminal leaders are clearly more susceptible to the rust than are the leaders of the branches. The more frequent infection of larger saplings may be partly due to a more favorable environment for trapping infective spores.

Interaction of pine and rust

The capacity of one aecium of twisting rust to produce spores appears to decrease with increasing density of aecia on the shoot. In studying inoculated seedlings of wheat and oats, it has been noted that where large numbers of competing mycelia are crowded in a leaf, the pustules formed are

minute and produce few spores (Allen 1923 a). Allen (1923 a) also found that a sparse infection causes greater damage to the host than does the same number of basidiospores infecting the host in closer proximity to each other. The damage caused by the twisting rust is not directly dependent on the number of lesions of infection, since even one aecium alone may be lethal if the infection occurs in an early enough stage of growth. The later the infection occurs, the larger the number of primordial aecia that do not complete their development. When the growth of the shoot is completed, the tissue of the shoot surface appears to grow strong enough not to allow the late-developing aecia to burst open. Moriondo (1954) has found such unopened aecia.

In both the present study and in the experiments by Longo and Naldini (Longo et al. 1970) the development of aecia took 11—14 days from the time of inoculation. Regler (1957) and Moriondo (1961) reported that the development of the aecia took 16 days.

Rust on aspen leaves

The development of aspen rust in the Finnish conditions seems to start when the aeciospores infect the aspen leaves. The overwintering of the uredial state as mycelium may sometimes, however, be possible (Klebahn 1938, Kujala 1950, Regler 1957, Moriondo 1961, Ge et al. 1964). Uredospores may also overwinter in suitable conditions (Chiba and Zinno 1960). The factors influencing the amount of aspen rust are the number of aeciospores infecting the aspen, conditions of rain and temperature when these spores are dispersed and, in addition, the weather in July—August when the uredial state reproduces. The fructification period of the uredial state was found to be 10—14 days when the inoculation was done with aeciospores (cf. Hartig 1885). The same experiment has not been done with uredospores. In the experiments done by Toole (1967) the development of uredia took four days from the time the leaves of *Populus deltoides* Marsh. were inoculated with uredospores of *Melampsora medusae* Thüm. In nature the deposition of a uredospore on a susceptible surface does not invariably result in infection, but often several days may pass and many spores may die before the weather is suitable for infection. Therefore, the reproduction of the disease in nature is much slower than expected on the basis of the fructification or generation cycle.

The summers of 1966 and 1967 with their regularly occurring rains were relatively favorable for the increase of aspen rust. The summer of 1968 was unfavorable for rust development. On the experimental area of Ikaalinen the number of aecia was small, and rainless weather dominated when these

spores and the uredospores were dispersed. The increase in the rust population was much slower than during the previous summers.

When the increase is measured by the changes in the total number of uredia, it seems most likely that the progress of the epiphytotic is relatively faster at the beginning of the growing season than at the end. During the progress of the epiphytotic, an ever-increasing portion of the uredia lose their spore-producing capacity when the nutrients of the substrates are becoming utilized or due to secondary fungi or bacteria. When the growing season is suitable for development of *Cladosporium*, this fungus may rapidly infect the newly-developed uredia, apparently inhibiting their spore-producing capacity; and consequently, the number of spore-producing uredia remains small (K u r k e l a 1973 b). Rainy weather permanently reduces the germination of uredospores formed by the uredia, apparently due to secondary infections (B i e r 1965). The same kind of a situation is also observed with *Cronartium comandrae* (P o w e l l 1971), in which case the main secondary colonizing organism in rust galls was *Cladosporium gallicola* Sutton (S u t t o n 1973). Z a d o k s (1961) also reports that cereal rust epiphytotics in rainy seasons usually are not very severe.

The reproductive capacity of the fungus is considerably reduced if the mycelium in the tissue of the host cannot expand and form new uredia without new uredial infection (cf. M a n n e r s 1971).

Since the network of vascular bundles, which prevent expansion of rust mycelia, is rather dense, it is hardly possible that one infection could result in several uredia. Consequently, the emergence of secondary uredia around the primary uredium probably requires new infections. This view is supported by the observation that the secondary uredia always occur completely at random around the primary uredium, and not in concentric rings around it, which would be the case if the expansion of the mycelium was not limited (A l l e n 1923 b, 1928).

Possibilities for control of pine twisting rust

The obtained results indicate that the main factors influencing the incidence of pine twisting rust are: 1) the number of overwintering telia on aspen leaves from the previous year, 2) precipitation and duration of rainfall during height growth of pine and 3) the timing of the telial germination activity during pine growth. When these conditions are favorable for rust development, the pines are infected.

Eradication of the aspen, the host of the uredial and aecial states of *M. pinitorqua*, from the pine sapling stands has been considered the most reliable means of controlling pine twisting rust (H a r t i g 1885, L i e s e 1923,

Böhner 1952). Nowadays the eradication of the aspen is achieved best with chemical methods (Rennerfelt 1954, Bärring 1965, Rummukainen 1969 a, b).

The chemical control of rust on aspen suckers probably is technically feasible today (cf. Aerts 1963, Froiland and Littlefield 1972), but for economic reasons, it cannot be done; and, on the other hand, control of the aspen rust would promote growth of the suckers which would hinder the growth of pine saplings.

Assuming that the aspen, at least to some extent, has the same beneficial effect on the soil as the birch (cf. Mikola 1954) and keeping in mind the value of aspen from the standpoint of game management, the aspen should not be totally eradicated, but its growth should be suitably limited. The growth inhibition caused by the rust (cf. FAO 1958, Lilja 1973) may be considered an advantage. This advantage offered by the rust could be used by spreading in aspen sucker stands a rust which does not have pine as its aecial host. The most suitable rust for this purpose would be the larch rust, *M. larici-tremulae*. It would remain on the area if some larch were planted as mixture in the pine stand. The spread of larch rust to the aspen leaves may already begin about half a month earlier than *M. pinitorqua* (p. 42). This time difference for the start of the epiphytotic may be crucial in establishing the desired proportions of the two rusts in the pathogen population. Assuming that the spore-producing capacity per pustule of each species is the same and that formation of new pustules is not possible in previously infected tissue, the proportion of the two rust species will remain as it was when the aeciospores of the later-arriving rust caused its primary infection. At the end of this rust epiphytotic, when new susceptible leaf tissue is no longer formed, the amount of infected tissue will crucially limit the development of new pustules. If, for example, 50 % of the leaf surface is infected, which may be possible at the end of July if the epidemic started at the beginning of June, only half of the spores deposited on the leaf surface can cause infection. If the number of aeciospores of the two rust species is the same when causing the primary infection and the one rust starts to spread one month earlier than the other and if the amount of rust increases tenfold in one month, the ratio between the two species is 10 : 1. The maximum number of telial pustules (all palisade parenchyma tissue is infected) on an aspen leaf is about 200 pustules/sq.cm, of which pustules of twisting rust, considering a mixed population of *M. larici-tremulae* and *M. pinitorqua*, would be only slightly more than 20 pustules/sq.cm. Since during years of abundant rust, the number of telial pustules of *M. pinitorqua* was on an average not more than 120—150 pustules/sq.cm, the number of telia of twisting rust would be even less than 20 pustules/sq.cm. The drawback of this rust control measure, i.e. using a mixed rust population, is that its

effectiveness cannot be measured unless the quantitative identification of the different rusts is possible. So far, no reliable method has been found for this purpose. The determination of the amount of rust in the field does not reveal the effectiveness of the method. The rust can spread over experimental plots located close to each other. Plots located far a way from each other cannot be compared since the differences in the local conditions may greatly influence the amount of rust and the development rate of the epiphytotic. There are a few investigations on the negative effect of a primary infection on the secondary infection. A strong local infection may reduce the intensity of a later, secondary infection by the same species *(Uromyces phaseoli)* (Y a r w o o d 1954). Inoculation with avirulent races of the rust may later reduce the intensity of a virulent race of the same species *(M. lini)* (L i t t l e f i e l d 1967). Two different pathogenic species may prevent each other's development on the host plant (J o h n s t o n and H u f f m a n 1958) in the same way as the growth of a non-pathogenic species on the leaves of its host (Y a r w o o d 1956).

Another rust control method may be worth developing: the spread of a secondary parasite or saprophyte in the rustsusceptible aspen sucker or pine sapling stand. B i e r (1965) found that some common saprophytes living on the leaves of black cottonwood reduced the rust on them. Infection of the uredial pustules of aspen rust by *Ramularia* (M a g n a n i 1971), and the *Cladosporium* fungi (K u r k e l a 1973 b) may considerably reduce the dispersal of uredospores. In the Soviet Union V a s i l j e v et al. (1970) obtained promising results in controlling twisting rust with preparations of some bacteria.

CONCLUSIONS

The conclusions subsequently presented are based mainly on results obtained from the present study but also on results published elsewhere by the author (K u r k e l a 1973 a, b).

1. The formation of basidiospores occurs only under the influence of rain. The dew does not provide enough moisture for basidiospore formation, and the duration of dew during the night is not long enough. The dispersal of basidiospores commonly begins 4—6 hours after the rain starts. Air humidity does not seem to play an important role in the formation and dispersal of spores if there is free water in the leaf litter. A reduction in air humidity also causes the leaf litter to dry and spore production to stop, resulting in a rapid decrease in the number of airborne spores.

2. Increased air temperature increases the formation of spores and results in early commencement of spore release and larger spore density in the air during maximum dispersal in periods of high temperature. The formation and thus, also the dispersal of the basidiospores occurs over a wide temperature range +5 to +25 °C. The spore formation is at a maximum between 12—22 °C.

3. Wind does not have a crucial influence on the number of airborne spores. The spores are dispersed by the wind, resulting in their deposition on pine shoots according to wind direction.

4. The dispersal of basidiospores may occur in the spring, during May and June, in 2—4 separate periods of rain after which airborne spores are not observed regardless of favorable weather conditions.

5. The formation of aecia on the pine shoots or larch needles is a result of infection caused by basidiospores dispersed during rainy weather. A long rainy period leads to more severe infection.

6. The aecia are formed on the pine shoots within 10—14 days after infection.

7. The infection of the shoots can occur only when the surface of the shoots has been exposed between the fascicle scales. The shoots become resistant when shoot elongation has ceased. In greenhouse conditions with high relative air humidity needles also may be infected.

8. The aeciospores are dispersed when the aecia are mature, beginning at the end of June and continuing through mid-July.

9. There is a clear diurnal rhythm in the dispersal of aeciospores, which most likely is a joint result of all the weather factors following a diurnal rhythm (temperature, relative air humidity, dew, wind, radiation etc.).

10. The formation of aeciospores appears to be at a maximum during high temperature. A high relative air humidity may slow down the release of aeciospores.

11. The number of airborne aeciospores begins to increase from its nightly minimum in the morning at about 06.00, reaching a maximum in the morning or at noon during dry weather. The drop to a minimum is slower than the increase to maximum.

12. A beginning rain is in strong positive correlation with airborne spore density. A maximum may be reached any time of the day as the result of a sudden strong shower, e.g. a thundershower, since it effectively releases spores.

13. As a result of infection caused by the aeciospores on the lower surface of aspen leaves, the uredia develop within 8—14 days. The uredospores cause the multiplication of the rust on the aspen leaves with an initial logarithmic increase. When the dispersal of the aeciospores begins, most of the aspen leaves have already grown to full size.

14. The number of uredia reaches a maximum at the end of August when there may be 40—50 uredia/sq.cm during a year of abundant rust. The telia are developed in August—September and exceed the number of uredia by about 3 times.

15. The production of spores in the uredia may often be reduced by hyperparasites in the uredia or by secondary parasites spreading into the tissue through the uredia.

16. The veins of the leaf inhibit the growth of the rust mycelium in the leaf. The mycelium often stops at the veins. Due to the small size of the areas delineated by the veins, several uredia cannot develop from one infection.

17. The rust mycelium in the leaf tissue is intercellular. Throughout the mycelium are mother cells of haustoria. From the mother cell thin hyphae penetrate the walls of the host cells, and haustoria are formed in the tips of the hyphae.

18. The dispersal of uredospores follows the same pattern as that of the aeciospores. The maximum for airborne uredospores is at the end of August.

19. The damage caused to the pine shoots by the rust infection depends on its severity and time of occurrence. An infection occurring late in the shoot

expansion period usually causes only a rapidly healing scar, while an early infection causes the shoot to bend severely and finally die.

20. The amount of both aspen rust and pine twisting rust varies greatly from year to year. Dry weather unfavorable to rust development during any phase of the cycle may endanger the annual cycle. The *Melampsora* fungus is most sensitive to damage in its telial or basidial stage. If in the spring rain does not occur at a suitable time, basidiospores may not be formed. The basidiospores cannot cause infection unless the host plant is in the proper phase of growth or if the weather rapidly becomes dry when the basidiospores have been formed. Another sensitive phase occurs when the aeciospores are dispersed to the aspen leaves. If it is continuously dry at this time, the aspen leaves are not infected and the cycle is interrupted.

SUMMARY

The dispersal of different spores of *Melampsora pinitorqua* and *M. laricitremulae* (causal agents of pine twisting rust and larch needle rust) was studied using mainly the Hirst spore trap. The growth of pine shoots and development of rust on them was followed by daily observations. Pine shoots also were inoculated artificially.

The development of rust on the aspen leaves was followed by counting the number of pustules on leaf samples which were collected weekly. Also, the growth of aspen shoots and leaves was measured daily.

The basidiospores of *Melampsora* dispersed in the spring during May and June. Dispersal took place under moist weather conditions, starting 4—6 hours after the beginning of a rain, and reaching maximum after some ten hours of rain. When the rainy weather continued for a longer time, infection of pine shoots took place. Those shoots which had terminated their growth were resistant to the rust. The development of aecia on the pine shoots took place within 10—14 days. The aeciospores dispersed in the period June—July, and thereafter the uredial state was formed on the leaves of aspen. The numbers of aeciospores and uredospores in the air usually reached maximum around noon. These spores are both of a type which are distributed dry. High temperature stimulated development of the rust and spore formation. Wind gusts and rain showers occurring during a warm spell may suddenly swell the numbers of these spores at an extremely high rate. Considerable variations could be observed in the occurrence of both pine twisting rust and aspen rust from year to year; this was mainly due to the weather conditions.

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MÄNNYN VERSORUOSTEEN JA HAAVANRUOSTEEN EPIFYTOLOGIA

Melampsora pinitorqua on männyn versoruosteen aiheuttaja. *M. larici-tremulae* aiheuttaa lehtikuusen neulasruosteen. Mainituilla isäntäkasveilla nämä ruostesienet esiintyvät helmi-itiöasteisina. Molempien kesä- ja talvi-itiöaste kehittyy haavan lehdillä. *M. pinitorqua*n ja *M. larici-tremulae*n eri itiömuotojen leviämistä ilmassa tutkittiin käyttäen pääasiassa Hirst-itiöpyydystä. Männynversojen kasvua ja ruosteen kehitystä niillä seurattiin päivittäisin havainnoin. Ruosteen kehitykseensä vaatiman ajan määrittämiseksi tehtiin myös keinollisia saastutuksia. Ruosteen kehitystä haavan lehdillä seurattiin viikon väliajoin tehdyin havainnoin sekä mittaamalla haavan versojen ja lehtien kasvua päivittäin. Ruosteiden eri asteiden kehityksessä ja runsaudessa esiintynyttä vaihtelua verrattiin eri säätekijäin vaihteluihin.

*Melampsora*n basidiosporit levisivät keväällä touko—kesäkuussa. Leviäminen tapahtui kostealla säällä alkaen 4—6 tunnin kuluttua sateen alkamisesta ja saavutti maksiminsa n. 10 tunnin kuluttua. Kostean sään jatkuessa edelleen yhtäjaksoisesti tapahtui männynversojen saastuminen. Kasvunsa päättäneet versot olivat ruosteenkestäviä. Helmi-itiöpesäkkeiden kehitys männynversoissa tapahtui 10—14 päivän kuluessa. Helmi-itiöt levisivät kesä—heinäkuussa, minkä seurauksena tapahtui kesäitiöasteen muodostuminen haavan lehdille. Helmi- ja kesäitiöiden määrä ilmassa oli yleensä runsaimmillaan keskipäivän aikaan. Nämä molemmat ovat ns. kuivana leviäviä itiöitä. Korkea lämpötila edisti ruosteen kehitystä ja itiöiden muodostusta. Lämpimällä säällä sattuneet tuulenpuuskat ja sadekuurot voivat äkillisesti nostaa näiden itiöiden määrät ilmassa erittäin suuriksi. Sekä männyn versoruosteen että haavanruosteen runsaus vaihteli eri vuosina hyvin paljon lähinnä sääsuhteista johtuen.

KENTTÄVARASTOINNIN SUORITUSTAVAN VAIKUTUS KUUSEN TAIMIEN ALKUKEHITYKSEEN

OLAVI HUURI

SUMMARY:

THE EFFECT OF FIELD STORAGE METHODS ON INITIAL DEVELOPMENT OF PLANTED SPRUCE

HELSINKI 1973

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ALKULAUSE

Pyrittäessä selvittämään männyn ja kuusen istutukseen liittyvien eri työvaiheiden merkitystä istutuksen kokonaistulokselle tahdottiin Metsäntutkimuslaitoksen metsänhoidon osaston 1960-luvulla aloittamissa koesarjoissa tutkia myös taimien kenttävarastoinnin erilaisten suoritustapavaihtoehtojen vaikutusta taimien alkukehitykseen maastossa. Siinä tarkoituksessa perustettiin männyn ja kuusen taimien kenttävarastointia koskevia esikokeita Hartolaan vuosina 1964—1966. Tässä julkaisussa selostetaan kokeiden tuloksia kuusentaimien varastoinnin osalta.

Työhön ovat kirjoittajan ohella osallistuneet rouva Aili Heikkonen ja metsätyömies Esa Sarikka viikosta toiseen toistuneiden istutusten suorittajina, vaimoni Leena Huuri kokeiden mittaajana ja aineiston käsittelijänä sekä herra Olli Virta tulosten laskijana, testaajana sekä tämän julkaisun kuvien piirtäjänä. Neiti Riitta Kantola on kärsivällisesti ja huolellisesti suorittanut käsikirjoituksen puhtaaksikirjoitustyön. Metsänhoitaja Kullervo Etholén on suomentanut venäjänkielisen lähdekirjallisuuden ja tohtori Kim. v. Weissenberg on kääntänyt englanniksi julkaisun lyhennelmän ja kuvatekstit. Tohtori Matti Leikolan ohjaus ja kritiikki on erittäin hyödyllisenä ollut käytettävissä julkaisun koko kirjoitusvaiheen ajan. Hänen ohellaan ovat käsikirjoitukseen tutustuneet professorit Olavi Huikari, Risto Sarvas ja Paavo Yli-Vakkuri, tohtori Veikko Hintikka sekä maisteri Ukko Rummukainen varteenotettuja parannusehdotuksia tehden.

Myös monet käytännön metsänviljelytyötä johtavat metsäammattimiehet ovat tutkimussarjan eri työvaiheissa antaneet kirjoittajalle arvokasta apua niin uusia ideoita kirvoittavina keskustelijoina kuin rohkaisijoina ja kriitikkoinakin sekä myös käytännön tukea antaen. Heistä mainittakoon tässä yhteydessä ennen kaikkea metsäneuvos Oiva Lyytinen, metsäteknikko Toivo Martikainen ja metsänhoitaja Mauno Uusitalo.

Suomen Luonnonvarain Tutkimussäätiö ja Tiuran Säätiö ovat tukeneet taloudellisesti tutkimusten sarjaa, josta nyt julkaistava tutkielma muodostaa yhden osan.

Kirjoittaja tahtoo kohdistaa parhaan kiitoksensa kaikille yllämainituille työtovereilleen ja auttajilleen.

Helsingissä lokakuussa 1973

Olavi Huuri

SISÄLLYSLUETTELO

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1. JOHDANTO

'Taimia tai vesoja ei saa niiden noston jälkeen jättää pitkäksi aikaa maassa virumaan, sillä silloin ne kadottavat ilman, tuulen ja auringon vaikutuksesta helposti nesteensä. Parasta olisi, jos ne voitaisiin istuttaa samana päivänä, jona ne on nostettukin. Mutta jos ne pitää kuljettaa kauemmaksi tai niitä ei voida heti istuttaa ja ne joutuvat olemaan muutamia päiviä ylhäällä maasta, voidaan ne kietoa olkiin tai sammaliin, tai mikäli on mahdollista upottaa niiden juuret viileään veteen, mikä on erikoiseksi hyödyksi ja estää nesteiden ja kosteuden pakenemisen.

Muutamat panevat nostetut vesat yhdeksi yöksi vesikuoppaan, mikä ei ole vahingoksi. Muutamilla puutarhanhoitajilla on myös tapana pystyttää nostetut vesat multaan ja peittää sillä niiden juuret ja sen jälkeen tilaisuuden tullen istuttaa vesat vähin erin' (käännös saksankielestä).

Näin esittelee ohjeita taimien varastoinnista varhaisin tunnettu pelkästään metsätaloutta esittelevä teos »Sylvicultura oeconomica» (v. Carlowitz 1713) kuudennentoista kapittelinsa 16. pykälässä. Noina aikoina ei taimien varastointi tullut kovin usein kysymykseen istutusten vähäisyyden takia sekä siitä syystä, että tuolloin istutuksiin käytetyt taimet pääasiassa nostettiin luontaisten taimistojen tiheimmistä kohdista juuripaakuissaan ja siirrettiin harvempiin, täydennystä kaipaaviin taimiston kohtiin viime hetkeen saakka alkuperäisellä kasvupaikallaan kehittyneinä.

Paljasjuuristen taimien käytön yleistyessä 1800-luvun jälkipuoliskolla ja myös taimien kuljetusmahdollisuuksien lisääntyessä rautatieverkoston 1850-luvulla tapahtuneen voimakkaan kehityksen mukana (Hesmer 1950) jouduttiin taimia varastoimaan niin taimitarhoilla, kuljetusvälineissä kuin istutuspaikoillakin entistä yleisemmin.

Mielenkiintoista on havaita, että tällöin itse taimien suojaamistavat pysyivät edelleen jotakuinkin samanlaisina kuin mitkä jo v. Carlowitz oli esittänyt (Cotta ja Berg 1856, Burckhardt 1893, Heyer 1893, Gayer 1898 ja Reuss 1907). Juurten suojana käytettiin yleisesti märkää sammalta ja tavallisimmin suositeltu taimien varastointitapa istutuspaikalla oli valeistutus. Mm. Cotta ja Berg (1856) korostavat niiden huolellisen käytön tärkeyttä 'Maasta nostettujen taimien juuret on suojattava aurinkoa ja tuulta vastaan sammalilla tai muilla sopivilla peiteaineilla.

Kun taimet saapuvat istutuspaikalle eikä niitä heti voida istuttaa, ne on välittömästi ja huolellisesti sijoitettava valeistutukseen. Nämä ovat kaksi tärkeätä sääntöä, joita vastaan käytännössä näkee usein rikottavan' (käännös saksankielestä em. teoksen sivulta 322).

Myös meidän oloissamme on valeistutus ollut suositelluin välittömästi istutuspaikalla suoritettavan varastoinnin muoto (esim. Blomqvist 1898, Paavonen 1915, Hannikainen 1919, Ahola 1930, Borg 1948, Ahola 1949, Kauttu 1965, Lehto ja Simolinna 1966 sekä Antola ja Lehto 1969). Useimmat mainituista ohjeiden esittäjistä ovat kuitenkin suositelleet taimien väliaikaista varastointia myös erilaisissa kellareissa, mikäli niitä on ollut käytettävissä riittävän lähellä istutuspaikkaa. Taimet on meillä tavallisesti neuvottu valeistuttamaan varjoisaan metsämaastoon kaivettuun ojaan, johon taiminiput asetetaan vieri viereen juuret tiiviisti irtomaalla peittäen. Mikäli kuivuus tai helle uhkaavat taimia, on niput peitettävä esim. kuusenhavuilla. Valeistutusvakoa on myös kasteltava tarpeen mukaan (Paavonen 1915, Hannikainen 1919, Antola ja Lehto 1969). Jotta maan kosteus olisi jo itsestään taattu, on sopiva valeistutuspaikka yleisesti etsitty kostealta maaperältä, esim. suon laidalta. Kehitys on johtanut myös siihen, että taimien juuret on ruvettu upottamaan maastossa keväisin helposti löytyviin vesikuoppiin tai pikku puroihin pelkän veden peittoon. Tästä varastointitavasta aiheutuvana haittana on kuitenkin esitetty mm. se, että hienot maahiukkaset tällöin huuhtoutuvat veden mukana ja niiden juurille antama suoja vähenee (Yli-Vakkuri 1961).

Taiminippujen avovedessä säilyttämistä on esim. Blekingen läänissä Ruotsissa suositeltu jopa niin hyvänä varastointitapana, että sen käyttöä on pidetty eräänä selityksenä sikäläisten kuusenistutusten erityisen hyvälle onnistumiselle (Ståål 1964). Vuodesta 1953 alkaen kuusen taimet on siellä varastoitu heti autokuljetuksen päätyttyä juoksevaan tai seisovaan veteen, jossa niitä on säilytetty jopa kahdeksan viikkoa istutustuloksen heikentymättä. Suomessa on mm. Yli-Vakkuri käsitellyt tätä kysymystä (esim. 1961). Hän päätyy kuitenkin suosittelemaan vain lyhytaikaista juurten vedessä pitämistä. Hänen havaintojensa mukaan lyhytaikainen juurten liottaminen lisää taimien elinvoimaa erityisesti sellaisissa tapauksissa, että ne ovat kärsineet lievästä vesivajauksesta. Tähän käsitykseen on päätynyt myös Räsänen (1970).

Laajimpia tutkimuksia taimien pakkauksesta ja kuljetuksesta sekä niiden erilaisten suoritustapojen vaikutuksista on meillä suorittanut Yli-Vakkuri (1957). Tätä työtä on viime vuosina laajennettu koskemaan myös kentällä tapahtuvaa välivarastointia, mm. valeistutusta sekä kellarivarastointia (Räsänen ym. 1970 sekä Räsänen 1970). Viimeksimainitut tutkimukset on kuitenkin suoritettu pelkästään männyn taimia käyttäen.

Tämän tutkimuksen tarkoituksena on vertailla muutamia kuusentaimien varastointitapoja, jotka olivat yleisesti käytössä Etelä-Suomessa tutkimuksen suorittamisaikana. Kirjoittajan oma käytännön kokemus sekä neuvottelut metsänviljelytyötä kentällä ohjaavien ammattimiesten kanssa antoivat varastointitapojen valinnalle pohjaa. Tutkimuksella pyrittiin selvittämään, miten pitkälle kesään kullakin varastointitavalla voitaisiin siirtää istutuksen ajankohtaa ilman että istutustulos liiaksi huononisi. Kokeet rajoitettiin koskemaan vain avomaalla kasvatettuja, koulittuja kuusen taimia. Kokeita perustettiin vain yhdelle eteläsuomalaiselle paikkakunnalle, Hartolaan, jossa koesarjoja kuitenkin istutettiin kahden vuoden, 1964 ja 1966, olosuhteissa. Koealueiden maaperä oli kuusenistutuksessa yleisimmin kyseeseen tulevaa ravinnerikasta kangasmaata.

2. TUTKIMUSAINEISTO JA -MENETELMÄ

21. Käytetyt taimet

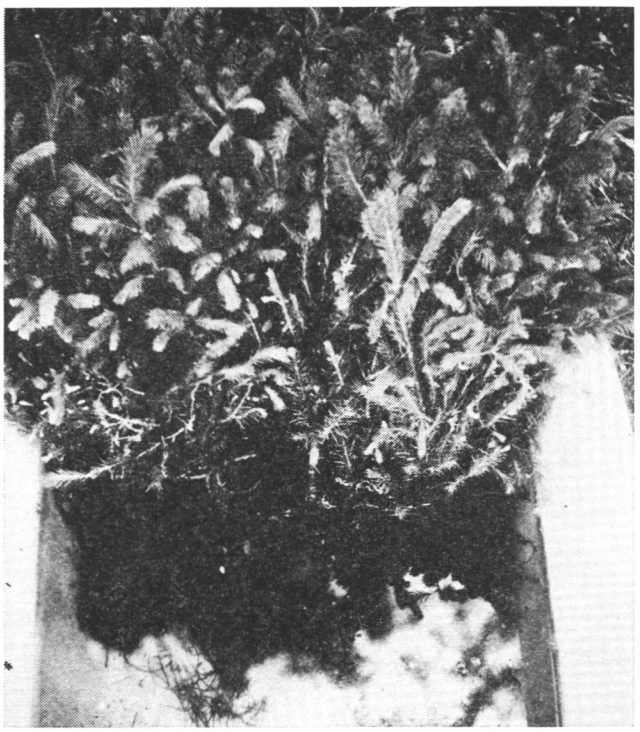
Koska kuusentaimista kokonaan avomaalla kasvatetut, 2A+2A-lajiset taimet (Raulo ja Hinttala 1972) olivat kokeen suorittamisaikana laajassa metsänviljelytyössä yleisimmin käytettyjä, kohdistettiin varastointikokeet pelkästään niihin. Taimet hankittiin vuoden 1964 koetta (koe A) varten eräältä yksityiseltä, lähellä koealuetta sijaitsevalta taimitarhalta ja vuoden 1966 uusintakokeeseen (koe B) Itä-Hämeen piirimetsälautakunnan Hartolassa sijaitsevalta taimitarhalta. Taimet oli kasvatettu paikallisesta siemenestä. Ennen taimien nostoa taimipenkistä rajoitettiin ne arpomalla määräytyneet kohdat, joihin taimet jätettiin toistaiseksi koskemattomina kasvamaan (vrt. sivu 9, varastointitapa 5). Noston jälkeen ennen toisiin käsittelyeriin arpomista taimet pyrittiin valikoimalla saamaan saman kokeen puitteissa pituudeltaan ja tanakkuudeltaan mahdollisimman yhdenmukaisiksi. Niistä eroteltiin pois kokonaiserän keskikokoa selvästi pienemmät ja myös suuremmat taimet sekä ulkoasultaan poikkeavat, sairaat ja mekaanisesti vahingoittuneet taimet. Taimipenkissä varastoitujen taimien (5) osalta valinta tehtiin kuitenkin vasta kunkin istutuserän noston jälkeen. Työn kaikkien vaiheiden aikana taimet suojattiin mahdollisimman hyvin häiriötekijöiltä. Esim. lajittelut suoritettiin aina kellarin kosteudessa.

22. Varastot ja varastointiajat

Seuraavia varastoinnin suoritustapoja kokeiltiin:

1. Varastointi talouskellarissa. Taimet sijoitettiin tiheään asentoon — kuitenkin niput löyhennettyinä — puulaatikkoon, jonka pohja oli peitetty märillä rahkasammalilla. Laatikon reunojen ja taimien väliin sekä muihinkin taimiväleihin tungettiin sammalta. Sammalien kosteutta tarkkailtiin ja niitä kasteltiin aika-ajoin kaivovedellä. Laatikko sijoitettiin tavalliseen maalaistalon talouskellariin, jonka lämpötilaa ja ilman kosteutta seurattiin piirturilla. Lämpötila vaihteli seitsemän ja kahdentoista asteen välillä ja ilman suhteellinen kosteus välillä 85 %—88 %.

2. Varastointi valeistutuksessa. Taimien valeistutusta varten kaivettiin oja syvämultaiseen Pteris-kasvuston peittämään kohtaan yli-ikäisen rauduskoivikon varjoon. Taimien juuret peitettiin ojaan paikalta otetulla kuohkealla, runsaasti humuksensekaisella moreenimaalla. Taimet jäivät hiukan kaltevaan asentoon



Kuva 1. B-kokeen taimia valokuvattuina 4. 7. 1966 vesisammiossa. Taimet ovat olleet 28 vuorokautta kaivoveteen varastoituina.

Figure 1. Transplants of experiment B photographed on July 4 1966 immersed in a tub of water. The transplants have been stored in well water for 28 days.

suoriin ja tiheisiin riveihin. Valeistutuskohta oli varjoinen, joten taimia ei peitetty. Varastointikohdan multaa kasteltiin kaivovedellä silloin tällöin kuivimpina aikoina.

3. Varastointi ojavedessä. Taimet painettiin löyhennetyissä nipuissa juurenniskaa myöten veden peittoon istutusalueen lähellä hitaasti virtaavan pienen joen rantaan. Uppoamisen estämiseksi niput kiinnitettiin puukehykseen, jonka varassa ne saattoivat kellua oikeassa syvyydessä, vaikka vesi varastoinnin aikana odottamatta olisi noussutkin. Veden lämpötilaa ei mitattu. Hitaasti virtaava vesi kuljetti mukanaan hiukan mutaa, jota varastoinnin aikana tarttui myös taimien juuriin. Myös veden pieneliöstö pääsi vapaasti vaikuttamaan taiminippujen juuristoihin. Taimet olivat rantapensaikon varjossa, mutta muuten peittämättöminä.

4. Varastointi kaivovedessä. Löyhennetyt taiminipu seisoivat kaivovedellä täytetyssä matalassa sammiossa juurenniskaa myöten veden peittäminä (kuva 1). Sammion vesi vaihdettiin kerran viikossa. Sammio oli sijoitettu koivikon varjostamaan paikkaan. Muulla tavoin taimia ei suojattu auringonpaisteelta.

5. Varastointi taimipenkissä. Taimet saivat istutushetkeen saakka kasvaa alkuperäisissä paikoissaan taimipenkissä sen jälkeen kun kaikkiin muihin käsittelyihin käytettävät taimet oli niille sattumanvaraisesti määräytyneistä penkkien kohdista jo nostettu.

Kokeen perust.vuosi ja tunnus *Year of planting and symbol of experiment*	Varastoinnin suoritustapa ja sen numero *Method of storage and its number*	Taimien varastoinnin (—), noston ja varastoinnin (+), istutuksen (●) sekä noston ja istutuksen (◖) ajankohdat *Time of storage (—), lifting and storage (+), planting (●) and lifting and planting (◖)*
		Toukokuu — *May*: 16 18 20 22 24 26 28 30 · Kesäkuu — *June*: 1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 · Heinäkuu — *July*: 1 3 5 7 9 11 13
1964 A	1. Kellari — *Cellar*	+ 26 · ● 9 14 · ● 25 29 · ● 3 41
	2. Valeistutus — *Heeling-in* ...	+ 26 · ● 9 14 · ● 25 29 · ● 3 41
	3. Ojavesi — *Ditch water*	+ 26 · ● 9 14 · ● 25 29 · ● 3 41
	5. Taimipenkki — *Nursery bed*	◖ 26 0 · ◖ 9 14 · ◖ 25 29 · ◖ 3 41
1966 B	1. Kellari — *Cellar*	+ · ● 7 20 · ● 13 27 · ● 19 34 · ● 25 41 · ● 31 48 · ● 55
	2. Valeistutus — *Heeling-in* ...	+ } 20 vrk:n esivarastointi kellarissa *20 days preceding storage in cellar* { — · ● 13 7 · ● 19 14 · ● 25 21 · ● 31 28 · ● 35
	3. Ojavesi — *Ditch water*	+ } { — · ● 13 7 · ● 19 14 · ● 25 21 · ● 31 28 · ● 35
	4. Kaivovesi — *Well water* ...	+ } { — · ● 13 7 · ● 19 14 · ● 25 21 · ● 31 28 · ● 35
	5. Taimipenkki — *Nursery bed*	◖ 7 20 · ◖ 13 27 · ◖ 19 34 · ◖ 25 41 · ◖ 31 48 · ◖ 55

Kuva 2. Eri tavoin varastoitujen taimien noston, varastoonpanon ja istutuksen ajankohdat sekä erilaisten varastointien kestoajat. Istutusmerkkien takana olevat numerot ilmoittavat varastointiaikojen pituudet vuorokausina.

Figure 2. Time of lifting, storage, and planting, and the duration of storage of transplants. The numbers following the respective signs indicate the length of storage in days.

Kaikki edellä esitetyt varastoinnin suoritustavat olivat kokeen perustamisen aikana metsänviljelyn kenttätyössä realistisiksi katsottavia toimintavaihtoehtoja istutuksen ajankohtaa lykättäessä. Koejärjestelyssä niitä erilaisine kestoaikoineen voitaneen myös pitää erilaisina käsittelyinä, vaikka joissakin vaihtoehdoissa (5) ei taimia ennen istutusta käsin kosketeltukaan.

Vuonna 1964 perustetussa kokeessa A taimet nostettiin taimitarhasta 26. 5. (kuva 2) ja ne sijoitettiin arvotuin käsittelyerin välittömästi kellariin (suoritustapa 1), valeistutukseen (2) ja ojaveteen (3). Suoritustavalla 5 (taimipenkki) varastoitavat taimet jäivät kuitenkin edelleen kasvamaan paikoilleen. Eripituiset varastointiajat kellarissa, valeistutuksessa ja ojavedessä olivat siten A-kokeessa 14 vrk., 29 vrk. ja 41 vrk. (kuva 2).

Kokeessa B, jolla haluttiin varmistaa A-kokeella saatuja tuloksia, taimet nostettiin varastointeja 1—4 varten 17. 5. 1966 (kuva 2). Ennen varsinaisen varastointikokeen aloittamista pyrittiin taimia kuitenkin käytännön olosuhteita mukaillen heikentämään pitämällä niitä esivarastoinnissa edellä kuvatussa talouskellarissa 20 vuorokauden ajan. Tämän jälkeen sijoitettiin arvotut taimierät varastointeihin 2—4 kellarivarastoinnin jatkuessa kuitenkin käsittelyerän 1 (kellari) osalta sellaisenaan ja taimipenkissä varastoitavien taimien (5) kasvaessa edelleen alkuperäisillä paikoillaan. Tässä kokeessa olivat varastointiajat siten: kellarissa 20 vrk., 27 vrk., 34 vrk., 41 vrk., 48 vrk. ja 55 vrk. sekä valeistutuksessa, ojavedessä ja kaivovedessä esivarastoinnin jälkeen 7 vrk., 14 vrk., 21 vrk., 28 vrk. ja 35 vrk. (kuva 2) sekä taimipenkissä muiden taimierien noston jälkeen 20 vrk., 27 vrk., 34 vrk., 41 vrk., 48 vrk. ja 55 vrk.

23. Testisarjat ja niiden perustaminen

Kokeen tuloksia ei käytännöllisistä syistä voitu mitata fysiologisia määrityksiä tai mittauksia käyttäen. Siitä syystä jäi ainoaksi keinoksi testata varastoinnin vaikutuksia istuttamalla taimet heti varastointien päättyessä ja seuraamalla niiden kehitystä istutuksen jälkeen. Oletettiin, että eri ajankohtina suoritettujen istutusten tulokset kuvastavat niitä taimiin kohdistuneita yhteisvaikutuksia, jotka aiheutuvat varastoinnin suoritustavasta, varastoinnin kestosta ja itse istutuspaikan olosuhteissa kesän edistyessä tapahtuneista muutoksista. Koko tämä vaikuttajakompleksi kulkeekin ehjänä kokonaisuutena mukana myös käytännön metsänviljelytyössä istutuksen ajankohtaa syystä tai toisesta lykättäessä. Koska nyt suoritetuissa kokeissa istutuspaikan olosuhteet olivat saman kokeen kaikille taimierille samat ja vain varaston laatu ja varastointiaika vaihtelivat, kuvastanee tutkimuksen tulos varastoinnin erilaisten suoritustapojen vaikutusta taimien elinvoimaan eri ajankohtina suoritetun istutuksen jälkeen. Tässä mielessä antaa koe myös kuvan kunkin suoritustavan käyttökelpoisuudesta metsänviljelyssä.

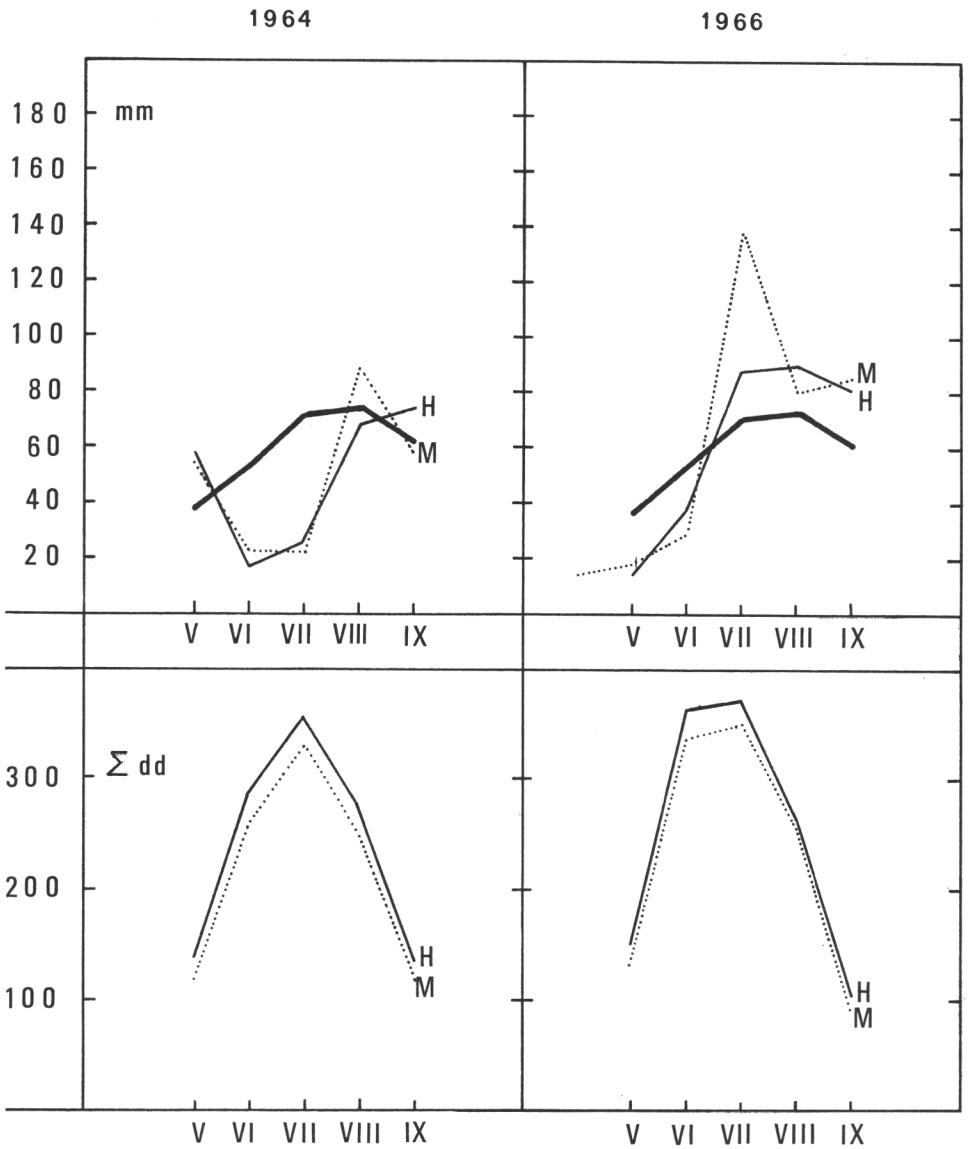


Kuva 3. A-kokeen testialuetta viisi kasvukautta istutuksen jälkeen.
Figure 3. Test area of experiment A five years after planting.

Sen vuoksi kaikki kokeessa olleet taimet istutettiin heti varastointien päättyessä testisarjoihin erikseen A- ja B-kokeiden osalta. Istutukset testisarjassa A suoritettiin ajankohtina 26. 5., 9. 6., 24. 6. ja 6. 7. 1964. B-testisarjassa taas olivat istutusten ajankohdat 6. 6., 13. 6., 20. 6., 27. 6., 4. 7. ja 11. 7. 1966 (kuva 2).

Molemmat testisarjat istutettiin rehevälle käenkaali—mustikkatyypin kasvupaikalle tiheähkön leppäverhopuuston suojaan (kuva 3) noin 600 metrin etäisyydelle toisistaan. Paikan maantieteellinen pituus on 25°58′ ja leveys 61°29′. Kummankin alueen maaperä on hiesusavea, jota peittää paksuhko mineraalimaansekainen humuskerros. Istutuskokeet järjestettiin arvottujen lohkojen periaatteen mukaisesti. Eri varastointikäsittelyt esiintyivät A-kokeessa kahtena ja B-kokeessa viitenä viiden taimen suuruisena toistoruutuna. Kussakin ruudussa yksi taimi sijoitettiin keskelle ja muut noin puolentoista metrin etäisyydelle siitä, lähelle ruudun kulmia. Testisarjojen yhteinen ruutuluku on 176 ja taimien kokonaismäärä 880.

Molemmissa kokeissa käytettiin kuusentaimien istutuksen nykyisin yleisintä suoritustapaa, ns. kuopan laitaan istutusta SFJ-kourukuokalla (esim. Huuri 1972). Kummassakin testisarjassa pyrittiin myös siihen, että sama henkilö olisi suorittanut istutukset läpi koko kokeen. A-kokeen verhopuusto on säilytetty miltei alkuperäisenä (kuva 3), mutta B-kokeen päältä sitä on harvennettu kahteen otteeseen. Molempien koealueitten rehevälle maaperälle kehittynyttä pitkää ja tiheätä ruohostoa ja heinästöä on



Kuva 4. Kesäkuukausien sadesummat (mm) ja lämpösummat (degree days, d.d.) Heinolan (H) ja Mikkelin (M) sääasemilla vuosina 1964 ja 1966. Sadesummien kohdalla paksu viiva kuvaa vuosien 1931—1960 keskiarvoa. (Ilmatieteellinen Keskuslaitos 1965 ja 1967)

Figure 4. The rain sums (mm) and temperaure sums (degree days, d.d.) during the summer months at Heinola (H) and Mikkeli (M) climate stations in 1964 and 1965. The heavy line for rain sums indicates the mean of 1931—1960. (Finnish Meteorological Office 1965 and 1967)

torjuttu vain polkemalla sitä maahan taimien ympärillä syksyisin suoritettujen inventointien yhteydessä. Heinästö on vaikuttanut taimien pituuskehitykseen häiritsevästi, mutta ei ole voinut merkittävästi vaikuttaa niiden kuolleisuuteen, mikäli taimet ovat olleet istutettaessa hyväkuntoisia.

Kokeiden suorittamisvuodet 1964 ja 1966 olivat keskinkertaista tuntuvasti lämpimämmät (kuva 4). Näin oli asian laita erityisesti vuoden 1966 kohdalla. Myös kosteusolot olivat vuonna 1966 keskimääräistä suotuisammat heinäkuusta kesän loppuun saakka. Sen sijaan vuosi 1964 oli sangen niukkasateinen etenkin kesä—heinäkuun osalta.

24. Mittaukset ja havainnot

Testisarjat on istutuksen jälkeen inventoitu syksyisin miltei vuosittain. Päähuomio on kiinnitetty taimien elossaoloon, kuntoon ja pituuskehitykseen. Jokaisen kokeeseen istutetun taimen osalta määriteltiin sen kunto inventointihetkellä seuraavaa luokitusta käyttäen:

a. Vahvat, rehevät taimet, jotka vetävät vertoja vastaavissa oloissa kasvaneille, samanikäisille, terveille luonnontaimille.

b. Normaalikuntoiset istutustaimet. Nämä eivät alkuvuosina ole vastaavissa oloissa kasvaneiden luonnontaimien veroisia, mutta näyttävät todennäköisesti selviävän istutuksen niille aiheuttamista rasituksista ja saavuttavan muutaman juromisvuoden jälkeen luonnontaimille vertoja vetävän rehevyyden ja kasvun.

c. Lievästi kärsineet taimet, joissa heikentymisen merkkeinä näkyy esim. neulaston harvuutta tai kellertävää väriä, varren hentoutta tai ohimeneviltä tuntuvia muita heikkouden merkkejä.

d. Pahoin kärsineet, lähes kuolemaisillaan olevat taimet, joiden maanpäällisissä osissa on kuitenkin heikoimmissakin tapauksissa todettavissa vielä tuoreutta ja ainakin joissakin neulasissa myös vihreätä tai keltaista väriä. Parhaassakin tapauksessa tällaiset taimet ovat erittäin heikkoja ja vain harvoin toipumiskykyisiä.

e. Kuolleet taimet, joiden maanpäälliset osat ovat ruskettuneet ja kuivuneet.

Päärangan viimeinen vuosiverso mitattiin kaikilla inventointikerroilla jokaisesta elossaolevasta taimesta puolen senttimetrin tarkkuudella. Myös alkuperäiset taimitarhapituudet mitattiin ensimmäisellä inventointikerralla jokaisesta istutetusta taimesta. Tätä varten etsittiin juurenniska, josta lähtien pituus mitattiin taimitarhavaiheen latvasilmun tyveen. Käytännöllisistä syistä tämän katsottiin sijaitsevan latvaan silmujen suojaksi muodostuneen neulaskiehkuran alkamiskohdassa. Mittausta silmujen kärkeen ei käytetty, koska silmun pituus saattoi vaihdella sen kasvuvaiheesta riippuen. Tiheän neulaskiehkuran tyvi sen sijaan oli miltei aina selvästi todettavissa ja sen paikka jää myös rungolle näkyviin moniksi vuosiksi. Vuosiversojen pituus voitiin saada mitatuksi myöhemminkin vanhoja oksakiehkuroita hyväksi käyttäen. Kiehkuroitten välimatkat mitattiin tässä tapauksessa oksien yläpinnasta toisen oksakiehkuran oksien yläpintaan.



Kuva 5. A-kokeen taimia valokuvattuina 9. 6. 1964. Vasemmanpuoleiset taimet ovat olleet 14 vuorokautta kellarissa ja oikeanpuoleiset taimet 14 vuorokautta valeistutuksessa varastoituina.
Figure 5. Transplants of experiment A photographed on June 6, 1964. Transplants to the left have been in the cellar for 14 days and those to the right have been heeled-in for 14 days.

Varsinaisten inventointimittausten ja -havaintojen lisäksi tehtiin eri istutuskertojen yhteydessä havaintoja myös sillä kertaa istutettavien ja aikaisemmin istutettujen taimien kunnosta. Näistä havainnoista on mainintoja esitetty kappaleessa 31. tutkimusten tuloksia selostettaessa. Myös lukuisin värivalokuvin pyrittiin tallettamaan tietoa eri varastoista ja taimien ulkonäöstä varastoinnin eri vaiheissa. Niistä valmistettuja ovat esim. kuvat 1 ja 5.

25. Tulosten laskenta

Koska kuhunkin ruutuun oli istutettu vain viisi tainta, olisi laskennassa ollut saatavissa ruutujen sisäisestä vaihtelusta vain 20 %:n ryhmiin jakautunut karkea kuva. Tästä syystä tuloksia ei käsitelty taimikohtaisina, vaan aluksi laskettiin ruuduittaiset keskiarvot ja niiden avulla edelleen eri käsittelyille keskiarvot sekä näille luotettavuusrajat 95 %:n todennäköisyydellä. Laskenta suoritettiin kummallekin testisarjalle erikseen, koska olosuhteet niissä poikkesivat toisistaan B-kokeessa varsinaisia varastointikäsittelyjä edeltäneen kellarivarastoinnin takia.

3. TUTKIMUKSEN TULOKSET

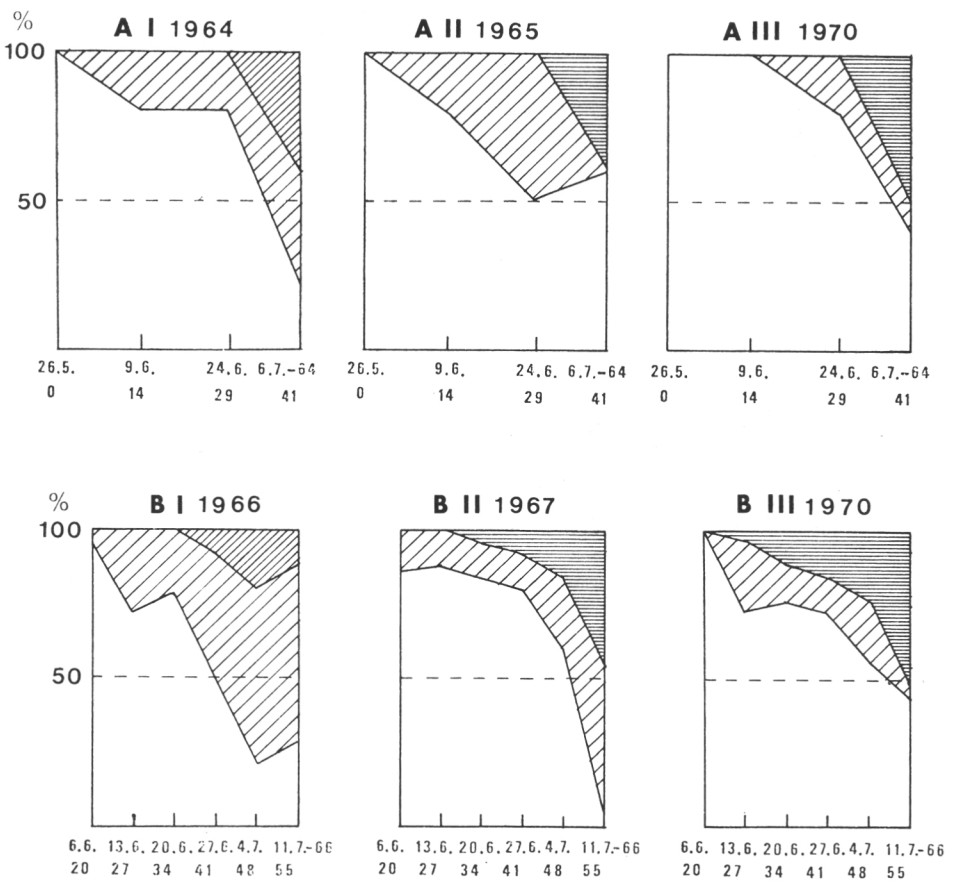
31. Varastoinnin suoritustavan vaikutus taimien eloonjäämiseen ja kuntoon

311. Varastointi talouskellarissa

Varastoinnin tämän suoritustavan vaikutukset taimien kuntoon ja kuolleisuuteen nähdään kuvassa 6. Kappaleessa 24. esitetyn kuntoluokituksen mukaisesti on siinä erilaisin varjostuksin (vrt. kuvan merkkiselitys) esitetty, millaisiin taimien kuntoryhmiin pitkittynyt kellarivarastointi on sijoittanut taimet istutuskesän syksynä (osakuvat I), seuraavan vuoden syksynä (osakuvat II) ja syksyllä 1970 (osakuvat III). Tähän vuoteen mennessä ovat A-kokeen taimet kehittyneet seitsemän ja B-kokeen viisi kasvukautta maastossa.

Kuvasta nähdään A-kokeen osalta, että talouskellari on neljän viikon ajan sangen luotettava taimivarasto. Näin pitkään varastoidut ja kesäkuun lopulla, jopa juhannuksen tienoilla, istutetut taimet näyttävät kaikki jääneen henkiin, joskin heikkokuntoisuutta ilmenee kahden ensimmäisen kasvukauden aikana yli viidesosalla taimista. Kun varastointiaika on pidentynyt kuudeksi viikoksi, taimet alkavat kuitenkin heikentyä niin suuressa määrin, että kuolleisuus A-kokeessa jo toisena kesänä nousee lähes 40 %:iin ja seitsemän vuoden päästä se on 41 vrk. kellarissa varastoitujen taimien keskuudessa noussut jo 50 %:iin.

Hyvin samanlainen on kehitys ollut myös kahta vuotta myöhemmin perustetussa kokeessa B. Vasta neljän viikon varastoinnin jälkeen alkaa ilmetä kuolleisuutta, ja kahdeksan viikon kellarivarastointi on johtanut jo 50 %:n ylittävään kuolleisuuteen. Mielenkiintoinen havainto taimien sitkeähenkisyydestä on tehtävissä ensimmäisen ja toisen syksyn tuloksia vertaamalla. Ensimmäisen kasvukauden lopulla (kuva 6, osakuva B I) ei kuolleisuutta vielä ilmene lainkaan. Tällöin pahoin kärsineiksi luokitellut taimet ovat kuitenkin seuraavan vuoden inventointiin mennessä kaikki kuolleet (osakuva B II). Lievästi kärsivien taimien määrä on vuosien mittaan vähentynyt toipumisen kautta. Kuitenkaan tämä ryhmä ei ole kokonaan hävinnyt kummastakaan testisarjasta, vaikka kaikkein heikoimmat taimet ovatkin inventointihavaintojen mukaan vuosien mittaan kuolleet.



a ja b, normaalikuntoiset ja niitä rehevämmät taimet

a and b, transplants of normal and exellent condition

c, lievästi kärsineet taimet

c, slightly suffering transplants

d, kuolemaisillaan olevat taimet

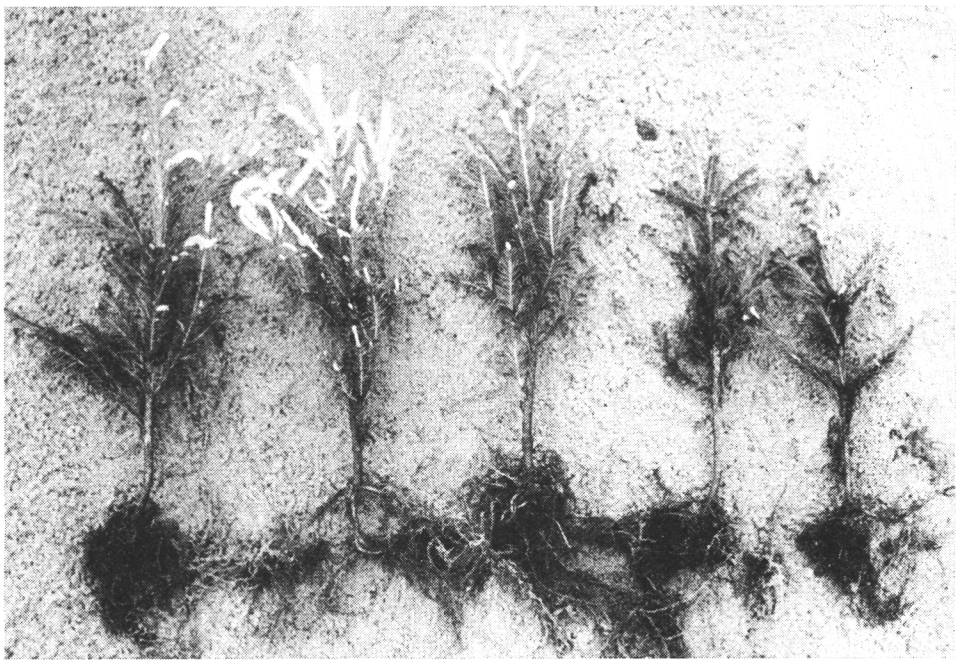
d, transplants about to die

e, kuolleet taimet

e, dead transplants

Kuva 6. Kellarissa varastoitujen kuusentaimien kunto ja kuolleisuus testisarjassa A vuosina 1964, 1965 ja 1970 sekä testisarjassa B vuosina 1966, 1967 ja 1970. Vaaka-akselilla istutuksen ajankohta ja varastoinnin pituus vuorokausina. Pystyakselilla taimien jakautuminen kuntoluokkiin inventointivuotena, joka on merkitty kuvaruudun yläpuolelle.

Figure 6. The condition and mortality of spruce transplants stored in cellar in test series A in 1964, 1965, and 1970, and in test series B in 1964, 1967, and 1970. Abscissa = the date of planting and the duration of storage in days, ordinate = the distribution of the transplants into condition classes in the year of survey, indicated above the frame.



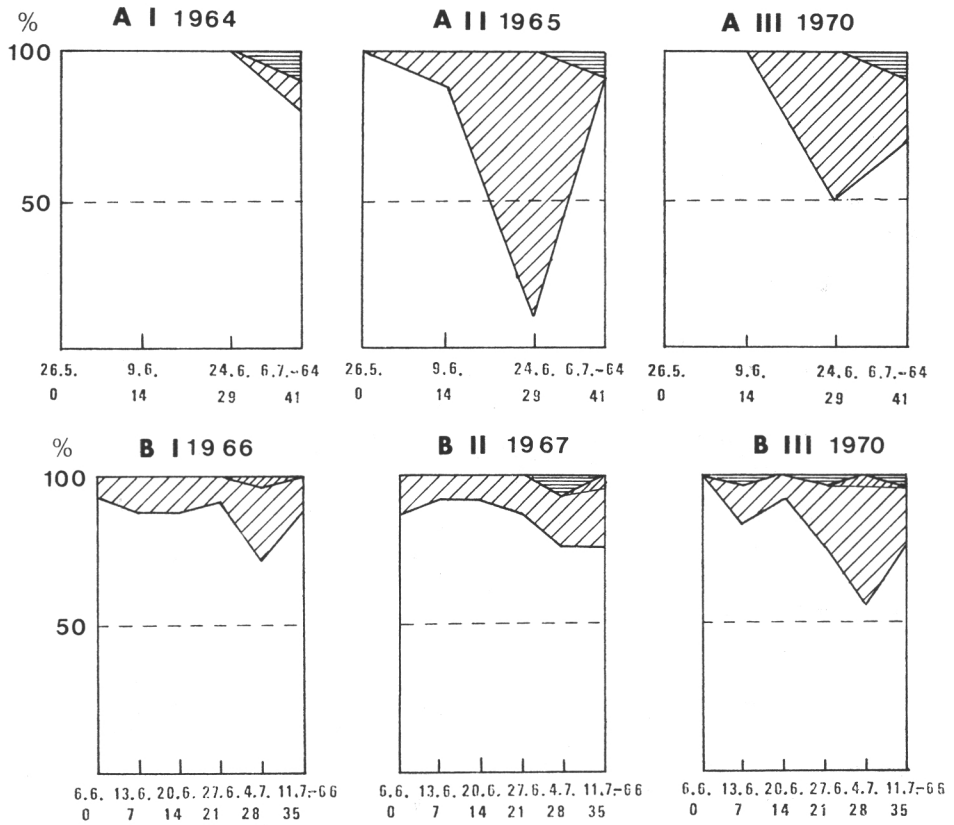
Kuva 7. Talouskellarissa 48 vuorokauden ajan varastoituja B-kokeen taimia valokuvattuina 4. 7. 1966.

Figure 7. Transplants of experiment B stored 48 days in a cellar. Photograph July 4, 1966.

Pitkittyneen kellarivarastoinnin vaikutuksia taimiin valaisevat myös kuvat 5 ja 7 sekä istutusten yhteydessä tehdyt muistiinpanot:

Kokeen tunnus	Kellari-varastoinnin pituus	Taimia koskevat havainnot
Koe A	14 vrk.	Uudet versot n. 1 cm. Kellertävän vihreitä (kuva 5).
»	29 »	Versot vaaleankeltaisia, 4—5 cm. Juurissa hometta.
»	41 »	Versot keltaisia, heikkoja. Juurissa ja tyvissä hometta.
Koe B	20 vrk.	Silmut 0—1 cm. Kellertäviä. Juuret tuoreita, muutamia pitkiä kasvukärkiä.
»	27 »	Versot 1—3 cm. Vaaleankeltaisia. Juurissa runsaasti kasvukärkiä.
»	34 »	Versot vaal.kelt., 1—3 cm. Juuret tuoreet. Runsaasti kasvukärkiä.
»	48 »	Kalpean keltaiset uudet versot kasvaneet jopa 5 cm:n pituisiksi. Juuret märkiä. Niissä ei hometta mutta kylläkin lievää hajua.

Pitkittynyt kellarivarastointi johti uusien kasvainten kellastumiseen sekä juurien heikkenemiseen homeiden takia ja taimien juurtumiskyvyn heikkenemiseen epäilemättä myös siten, että ravinnevarastot ehtyivät yhteyttämis-



Kuva 8. Valeistutuksessa varastoitujen kuusentaimien kunto ja kuolleisuus testisarjassa A vuosina 1964, 1965 ja 1970 sekä testisarjassa B vuosina 1966, 1967 ja 1970. Merkinnät samat kuin kuvassa 6.

Figure 8. The condition and mortality in 1964, 1965, and 1970 in test series A, and in 1966, 1967, and 1970 in test series B of heeled-in spruce transplants. Legend as in Figure 6.

mahdollisuuksien puuttuessa sekä hengityksen ja muiden elintoimintojen kuluttaessa niitä puolilämpimässä kellarissa. A- ja B-kokeiden välille ei näytä kehittyneen silminnähtäviä eroja tuloksissa. Tämä onkin ymmärrettävää, koska B-kokeessa taimien heikentämiseen tähtäävä käsittely oli kellarivarastointia kuten A-kokeessakin.

312. Varastointi valeistutuksessa

Valeistutuksessa varastoinnin antamia tuloksia esittää kuva 8, joka on laadittu samalla tavoin kuin kuva 6. Voidaan nähdä, että taimien säilyttäminen ulkoilmassa ja niiden juurien peittäminen maahan on taimien kunnon kannalta tuntuvasti suotuisampi varastointimuoto kuin varastointi kellarin pimeydessä ja kosteudessa. Tämä voidaan nähdä myös kuvasta 5.



Kuva 9. Valeistutuksessa 28 vuorokauden ajan varastoituja B-kokeen taimia. Tällaisten taimien eloonjääminen istutuksen jälkeen oli sangen hyvä, vaikka tiheästä varastointiasennosta johtuen alimpien oksien uudet neulaset olivatkin kehittyneet väriltään keltaisiksi. Valok. 4. 7. 1966.

Figure 9. Transplants of experiment B heeled-in for 28 days. Survival of such transplants after planting was rather high in spite of the needles of the lower branches having turned yellow due to density of storage. Photograph July 4, 1966.

Kuolleisuutta alkaa esiintyä A-kokeessa vasta, kun taimet ovat olleet valeistutuksessa runsaasti yli kuukauden ja ne on istutettu niin vaikeana ajankohtana kuin heinäkuun alussa. Kuolleisuus ei tästäkään huolimatta lainkaan lisäänny seitsemän seuraavan kasvukauden aikana, vaikka lievää kärsineisyyttä ilmeneekin taimissa jatkuvasti. Se ei luultavasti kuitenkaan johdu varastoinnista eikä istutuksen ajankohdasta, vaan tiheästä verhopuustosta, joka on jatkuvasti varjostanut A-kokeen taimia.

Myös kaksi vuotta myöhemmin perustetun B-kokeen taimet kehittyvät miltei samoin kuin A-kokeenkin. Taimien kunto, ehkä lievemmän varjostuksen takia, on kuitenkin nyt kauttaaltaan hieman parempi. Kuolleisuutta

alkaa nytkin esiintyä vähäisessä määrässä vasta varastointiajan lähetessä neljää viikkoa.

Ne havainnot, jotka eri istutuskerroilla valeistutuksessa olleista taimista tehtiin, toivat näkyviin valeistutuksen haitoista mm. taimien tiheän varastointiasennon, minkä johdosta ryhmien sisälle jääneiden taimien uudet versot kellastuivat (kuva 9).

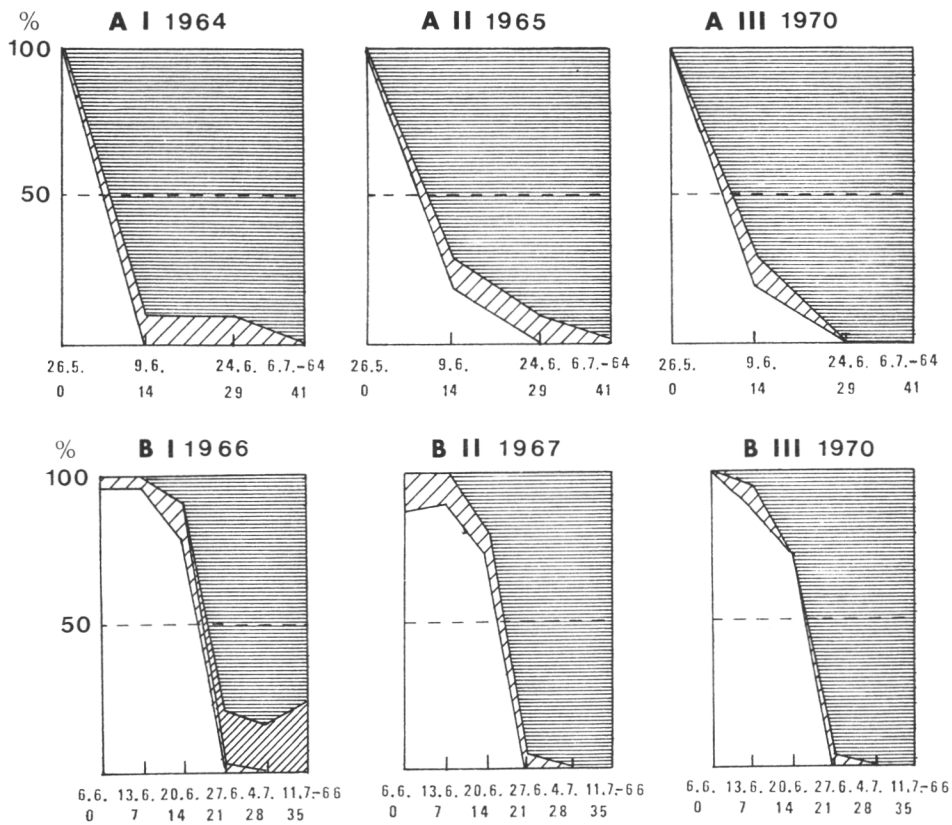
Vertailtaessa heikentämättömillä A-kokeen taimilla saatuja tuloksia 20 vrk:n kellarivarastoinnilla heikennettyjen B-kokeen taimien antamiin ei johdonmukaisia eroja voida havaita. Taimien kunnon heikentämiseen tähtäävän esivarastoinnin vaikutus lienee ollut liian lyhytaikainen.

313. Varastointi ojavedessä

Kuva 10, joka esittää ojavedessä varastoinnin vaikutuksia taimiin, näyttää jyrkästi huonompaa tulosta kuin edellä tarkastellut.

Kehitys kokeessa A varastointiaikojen 0 vrk. ja 14 vrk. välillä ei kuitenkaan todellisuudessa kulje aivan niin suoraviivaisesti kuin osakuvien 10 A I—III interpoloidut kuvaajat esittävät. Sen sijaan on varmaa, että kahden viikon pituinen varastointi on jo ensimmäiseen syksyyn mennessä ruskettanut lähes 90 % taimista niin, että ne on arvioitu kuolleiksi. Pitempi, 29 vuorokauden varastointi on ollut tulokseltaan tätä vielä hieman huonompi ja 41 vuorokauden varastoinnissa ovat taimet kärsineet niin pahoin, että ne jo ensimmäisen maastokasvukauden loppuun mennessä ovat kaikki kuolleet. Seuraavan kasvukauden syksynä kuitenkin todettiin, että osa 14 vuorokautta varastossa olleista, kuolleiksi luokitelluista taimista olikin toipunut ja osoittautunut tässä inventoinnissa eläviksi taimiksi. Kahta viikkoa pitempään varastoidut taimet sen sijaan olivat säilyneet siinä kuntoluokassa, mihin ne oli sijoitettu jo edellisen syksyn inventoinnissa. Seitsemännen kasvukauden loppuun mennessä nämä taimet olivat jo kaikki kuolleet.

Kahta vuotta myöhemmin perustetussa B-kokeessa olivat varastointiaikojen erot puolta lyhyemmät, vain yhden viikon pituiset. Tämä järjestely salli kuolleisuuden muutoksien piirtyä yksityiskohdiltaan tarkempina ja osoittaa selvemmin, miten pitkään taimia voidaan varastoida ojavedessä. Nytkin on taimille tuhoisia seurauksia alkanut näkyä varastoinnin ylittäessä kahden viikon ajan. Kolmen viikon varastointi johti jo ensimmäisen kesän loppuun mennessä siihen, että miltei kaikki taimet olivat kuolemaisillaan pääosan kuuluessa jo kuolleitten ryhmään. Tämä tilanne on varmistunut seuraavan kasvukauden aikana, jonka jälkeen aivan valtaosa yli kolme viikkoa ojavedessä varastoiduista taimista on kuollut. Lyhyet varastointiajat ovat nyt mielenkiintoiset, koska ne osoittavat kuusentaimien kestävän tällaista varastointimuotoa noin 7 vuorokauden ajan melko vähäisin vaurioin



Kuva 10. Ojavedessä varastoitujen kuusentaimien kunto ja kuolleisuus testisarjassa A vuosina 1964, 1965 ja 1970 sekä testisarjassa B vuosina 1966, 1967 ja 1970. Merkinnät samat kuin kuvassa 6.

Figure 10. The condition and mortality in 1964, 1965, and 1970 in test series A, and in 1966, 1967, and 1970 in test series B of spruce transplants stored in ditch water. Legend as in Figure 6.

Tällöin istutetut taimet ovat nimittäin säilyneet elossa siksi hyvin, että kuolleisuutta esiintyy myöhemminkin sangen vähän, alle 10 %.

Eri istutuskerroilla tehdyt havainnot kertovat taimissa istutushetkellä näkyvistä varastointivaurioista mm. seuraavaa:

Kokeen tunnus	Ojavesi-varastoinnin pituus	Taimia koskevat havainnot
Koe A	14 vrk.	Uudet versot n. 1 cm, epätasaisesti venyneitä, vihreitä.
»	29 »	Versot 2—3 cm pitkiä. Hyvin erilaisissa vaiheissa kehityksessään. Taimet jokseenkin huonokuntoisia. (Edellisellä kerralla istutetuista taimista on tehty merkintä: Yli puolet taimista heikossa kunnossa. Latvat kellertävän ruskeita. Heikkokuntoiset taimet eivät ole ollenkaan kasvaneet. Osa taimista jo täydellisesti ruskettuneita. Osalla tyviosassaan tuoreita oksia).



Kuva 11. Ojavedessä 28 vuorokauden ajan varastoituja B-kokeen taimia. Tällaiset taimet kuolivat miltei kaikki jo istutuskesän aikana. Varastoinnin aikana kasvaneet uudet versot jäivät riippuviksi ja ruskettuneiksi. Juuret ja taimien tyvet mustuivat. Valok. 4. 7. 1966.

Figure 11. Transplants of experiment B stored in ditch water for 28 days. Almost all such seedlings died during the first growing season. The shoots which expanded during storage remained drooping and brown. The roots and the base of the stem turned black. Photograph July 4 1966.

Koe A	41 vrk.	Kaikki taimet huonossa kunnossa. Usein latva ja koko taimikin mustunut, joskus lähes kokonaan vihreä. Versot 2—4 cm, usein uudet versot ruskeat.
Koe B	7 vrk.	Verso 2—3 cm, vaal.vihreä. Juuret tuoreita, mustahkoja.
»	14 »	Ojavesitaimilla versot lyhyimmät. Juurissa kasvupisteitä.
»	28 »	Ojataimet surkeassa kunnossa. Uusista versoista vain latvat vihreät, nekin lerpallaan. Alempien oksien päät ruskettuneet ja jopa homehtuneet. Juurissa paha haju, kiiltävä pintakalvo (kuva 11).

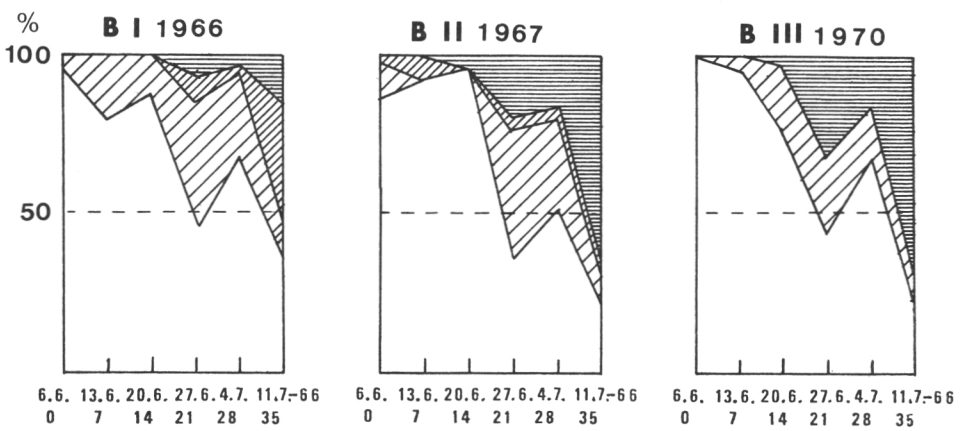
Luonnossa tavattavat allikot ja virtaavan veden uomat voivat paljonkin vaihdella veden laadun suhteen. Nyt kokeillussa tapauksessa saattoi mudan hiljainen liikkuminen ja takertuminen taimien alaosan peitoksi aiheuttaa osan kuolleisuudesta.

Taimien heikentäminen esivarastoinnilla B-sarjassa ei nytkään ole aiheuttanut tuloksiin näkyvää eroa. Näyttää jopa siltä kuin B-sarjan taimet olisivat

kestäneet varastointia ojavedessä hieman paremmin kuin täysikuntoisina varastoidut A-sarjan taimet. Kokeet on kuitenkin tehty eri vuosien erilaisissa olosuhteissa ja tämä huonontaa vertailumahdollisuuksia.

314. Varastointi kaivovedessä

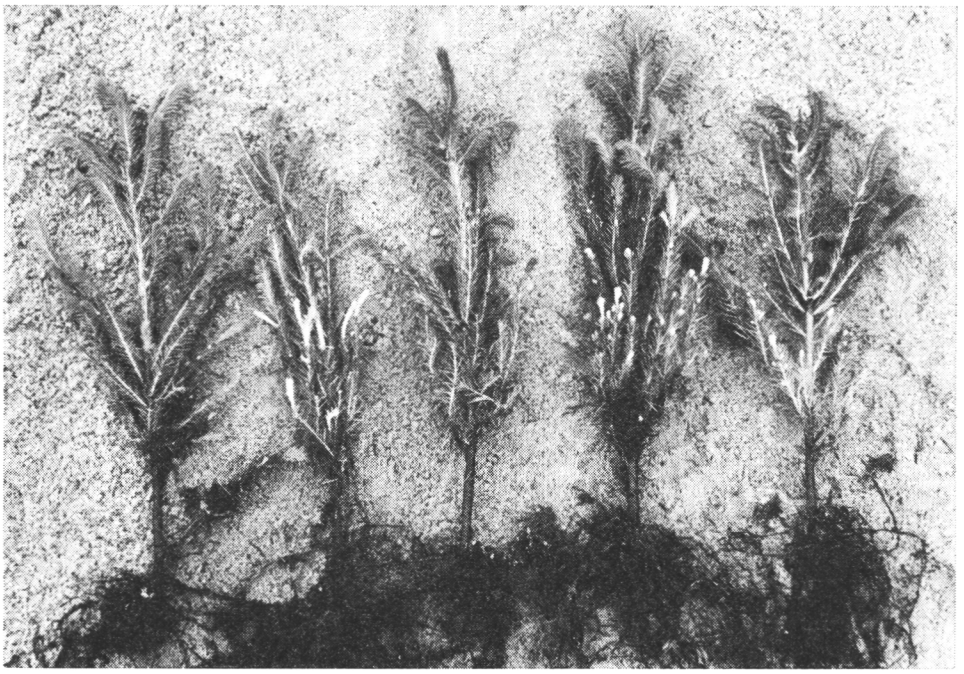
Tätä varastoinnin suoritustapaa kokeiltiin vain vuonna 1966 perustetussa B-kokeessa. Ojavedessä varastoimisen huonojen tulosten alustavasti selvittyä haluttiin kokeilla, oliko sen aiheuttaman suuren taimikuolleisuuden syynä juurten tukehtuminen veden hapettomiin oloihin, vai jokin ojaveteen liittyvä epäpuhtaus tms. Varastoinnin tässä suoritustavassa kokeiltiin puhdasta kaivovettä, joka vaihdettiin uuteen kaivosta otettuun vesierään kerran viikossa. Tämän kokeen tulos esitetään kuvassa 12.



Kuva 12. Kaivovedessä varastoitujen kuusentaimien kunto ja kuolleisuus testisarjassa B vuosina 1966, 1967 ja 1970. Merkinnät samat kuin kuvassa 5.

Figure 12. The condition and mortality in 1966, 1967, and 1970 in test series B of spruce transplants stored in well water. Legend as in Figure 6.

Taimien kuolleisuus on nyt selvästi vähäisempää kuin varastoitaessa ojaveteen. Kuitenkin kuolleisuutta alkaa esiintyä jo ensimmäisen kasvukauden aikana taimilla, joiden varastoinnin pituus ylittää kahden viikon ajan. Ensimmäisen kasvukauden syksynä on myös kuolemaisillaan olevien taimien määrä merkittävän suuri kolmeviikkoisessa ja sitä kauemmin kestävässä varastoinnissa. Kuolemaisillaan olevien taimien määrä ylittää jopa 50 % viiden viikon varastoinnissa ja näistä taimista kuolee yli puolet toisen kasvukauden aikana. Kuolleisuus ei kuitenkaan enää seuraavina kasvukausina lisäänny.



Kuva 13. Kaivovedessä 28 vuorokauden ajan varastoituja B-kokeen taimia, joiden alaoksien uudet versot ovat kellastuneet tiheästä varastointiasennosta johtuen ja juuret sekä taimien tyvet mustuneet veden vaikutuksesta. Valok. 4. 7. 1966.

Figure 13. Transplants of experiment B stored for 28 days in well water. The new shoots of the lower branches have turned yellow due to the dense storage, and the roots and the base of the stems have turned black because of the effect of the water. Photograph July 4, 1966.

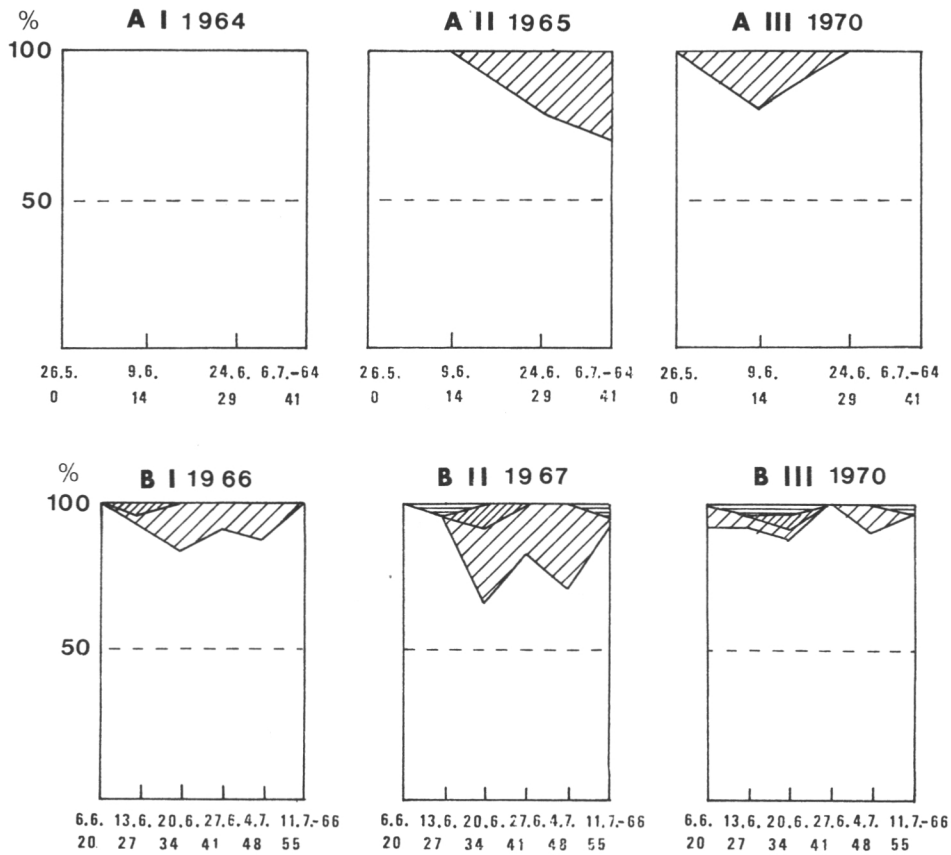
Seuraavia havaintoja on tehty kaivovedessä varastoitujen taimien kunnosta:

Kokeen tunnus	Kaivovesi-varastoinnin pituus	Taimia koskevat havainnot
Koe B	7 vrk.	Versot n. 1—3 cm, vaalean vihreitä, juuret hyväkuntoisia, niissä runsaasti kasvupisteitä.
»	28 »	Kaivovesitaimet selvästi ojataimia parempia, joskin juurissa hajua jonkin verran. Nippujen sisässä keltaisia versoja, valonpuutteesta johtuen. Valossa kehittyneet versot vihreitä ja voimakkaita.

Käsityksen viimemainittujen taimien ulkonäöstä antaa myös kuva 13.

315. Varastointi taimipenkissä

Eräs muoto lähellä istutuspaikkaa suoritettavaa taimien varastointia on koulintataimitarhojen perustaminen korkeintaan tunnin automatkan päähän istutuspaikoista ja taimien jakeleminen istutusaloille pienin päiväerin tiheätä

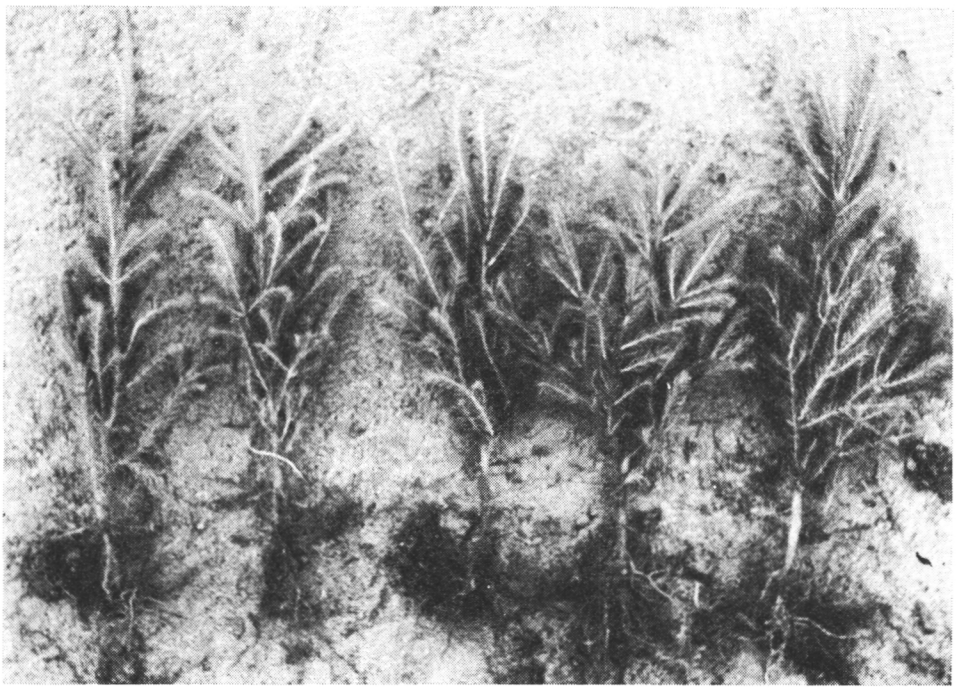


Kuva 14. Taimipenkissä varastoitujen kuusentaimien kunto ja kuolleisuus testisarjassa A vuosina 1964, 1965 ja 1970 sekä testisarjassa B vuosina 1966, 1967 ja 1970. Merkinnät samat kuin kuvassa 6.

Figure 14. The condition and mortality in 1964, 1965, and 1970 in test series A, and in 1966, 1967, and 1970 in test series B of spruce transplants stored in the nursery bed. Legend as in Figure 6.

metsätieverkkoa hyväksikäyttäen. Tällaista taimien korkeintaan tunnin pituista kuljetusta ja varastointia tutkittiin vuonna 1966 kokeessa B (kuva 14, B I—III). Taimien aivan välitöntä siirtämistä istutusalan lähellä olevasta koulintataimitarhasta istutukseen taas käytettiin vuoden 1964 A-kokeessa (kuva 14, A I—III).

Viimemainitusta osakuvasta ilmenee, että varjoiselle kuusen uudistusalalle hyväkuntoisina istutetut A-kokeen taimet ovat selvinneet keskikesänkin lämpiminä ajankohtina suoritetuista istutuksista aivan ilman taimitappiota. Ensimmäisen kasvukauden lopulla on kaikki aikavälillä 26. 5.—6. 7. istutetut taimet luokiteltu normaalikuntoisiksi tai niitä rehevämmiksi. Tällöin ei taimissa ole näkynyt lieviäkään kärsimisen merkkejä. Kun kärsi-



Kuva 15. B-kokeen taimia, jotka ovat istutushetkeen 4. 7. 1966 saakka saaneet rauhassa kasvaa taimipenkissään. Tällaiset taimet jäivät eloon ja kehittyivät maastossa istutuksen jälkeen odottamattoman hyvin, vaikka istutushetkellä niiden uudet versot olivatkin jo kehittyneet pitkiksi ja pehmeiksi.

Figure 15. Transplants of experiment B. The seedlings have developed intact until time of planting on July 4, 1966. Such seedlings survived and developed in the field unexpectedly well in spite of the fact that their expanding shoots were already long and succulent.

neisyyttä alkaa ilmetä seuraavana kasvukautena, esiintyy sitä vain sellaisissa taimierissä, jotka on istutettu juhannuksen tienoilla ja heinäkuun alkupäivinä, jolloin uudet versot olivat kehittyneet täysimittaisiksi, mutta olivat vielä puutumattomina voimakkaasti haihduttavia.

Myöskin vuonna 1966 perustetun B-kokeen osalta (kuva 14, B I—III) voidaan tehdä samantapainen havainto. Ensimmäisen kasvukauden aikana ei taimia ole kuollut lainkaan. Toisen kasvukauden aikana (osakuva B II) ilmenee kuolleisuutta erittäin vähän, joskin taimien lievää kärsineisyyttä esiintyy runsaanpuoleisesti. Viidennen kasvukauden loppuun mennessä on huonokuntoisten taimien osuus kuitenkin huomattavasti vähentynyt. Taimet ovat nyt miltei kaikki normaalikuntoisia ja kuolleisuus niiden joukossa on edelleen pysynyt aivan vähäisenä. Käsityksen heinäkuun alussa istutettujen taimien ulkonäöstä antaa kuva 15. Kuvan esittämässä kasvuvaiheessa olevat kuusentaimet jäivät kaikki eloon erittäin vaikeana pidetystä istutusajankohdasta huolimatta.

316. Varastojen vertailua

Pyrittäessä vertailemaan kokeiltuja varastoja toisiinsa on niiden käyttökelpoisuuden mitaksi tässä valittu sen ajan pituus, jonka varastointi saa vaikuttaa taimiin ilman, että taimien kuolleisuus seuraavien viiden kasvukauden aikana ylittää 10 %:n rajan.

Tämän mukaan sijoittuivat nyt tutkitut varastot seuraavan asetelman mukaiseen järjestykseen parhaimmasta huonoimpaan luetellen:

Varasto	Varastointiaika, jonka jälkeen taimien kuolleisuus ylittää 10 %
1. Taimipenkki	Edellämainittua varastointiajan vaarallista ylärajaa ei kokeessa lainkaan kohdattu
2. Valeistutus	Varastoinnin vaaraton kestoaika n. 5—6 viikkoa
3. Kellari	Vaaraton kestoaika korkeintaan 4 viikkoa
4. Kaivovesi	Vaaraton kestoaika korkeintaan 2 viikkoa
5. Ojavesi	Vaaraton kestoaika korkeintaan 1 viikko

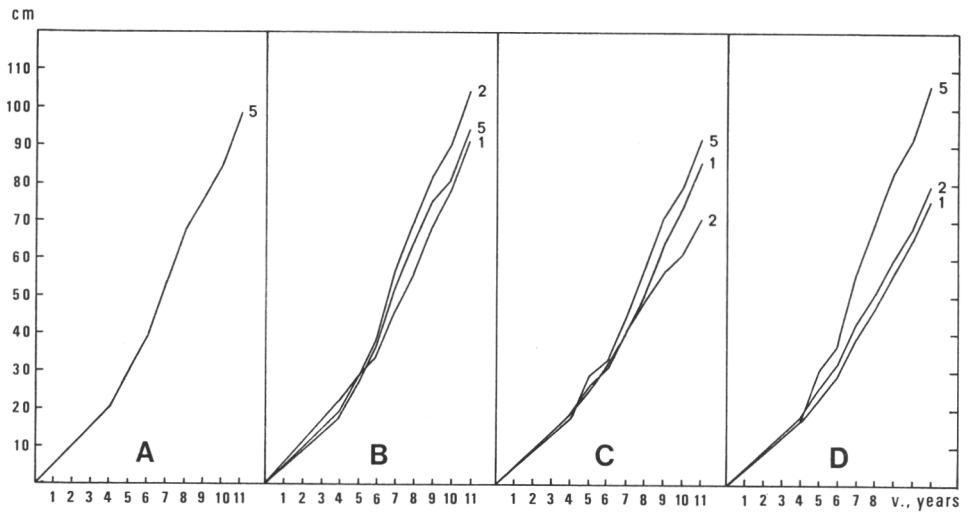
Kokeessa A erottui varastointi ojavedessä (3) jo 9. 6. suoritetusta istutuksesta alkaen tilastollisesti merkitsevästi toisista käsittelyistä niitä heikompana. B-kokeessa taas oli ojavarastoinnin huonommuus 95 %:n todennäköisyydellä merkitsevä muihin varastoinnin suoritustapoihin nähden istutuksissa 27. 6., 4. 7. ja 11. 7. Myös kellarivarastointi jää muita huonommaksi lähes merkitsevästi 4. 7. suoritetussa istutuksessa ja merkitsevästi 11. 7. suoritetussa istutuksessa. Puhtaassa vedessä varastointi on merkitsevästi muita varastointitapoja heikompi istutuksessa 11. 7. Pisimmässä varastoinnin kestossa ja molemmissa kokeissa erottuvat muista tilastollisesti merkitsevästi parhaiksi ne varastoinnit, joissa taimet saivat olla luonnonmukaisimmissa olosuhteissa, versot auringonpaisteessa ja vapaasti liikkuvassa ilmassa sekä juuret mullan peitossa.

32. Varastoinnin suoritustavan vaikutus taimien kokonaispituuteen ja vuotuiseen pituuskasvuun

Paitsi taimien eloonjääminen, on metsänviljelyn tulokselle tärkeä myöskin taimien kasvu, ennen kaikkea taimien päärangan pituuskehitys. Tämän havainnollistamiseksi A-kokeen osalta on piirretty kuva 16, jossa eri pituisten varastointien tulokset on koottu yhtenäiseksi sarjaksi.

Kuvasta voidaan tehdä seuraavat havainnot:

— Lepikon varjostamalla kasvupaikalla (kuva 3) ovat nopeimmin kehittyneet A-kokeen taimet saavuttaneet vasta noin metrin keskimääräisen pituuden, vaikka istutuksesta on kulunut jo seitsemän kasvukautta ja taimet ovat viimeisessä mittauksessa olleet kylvöstä lukien 11 vuoden ikäisiä.

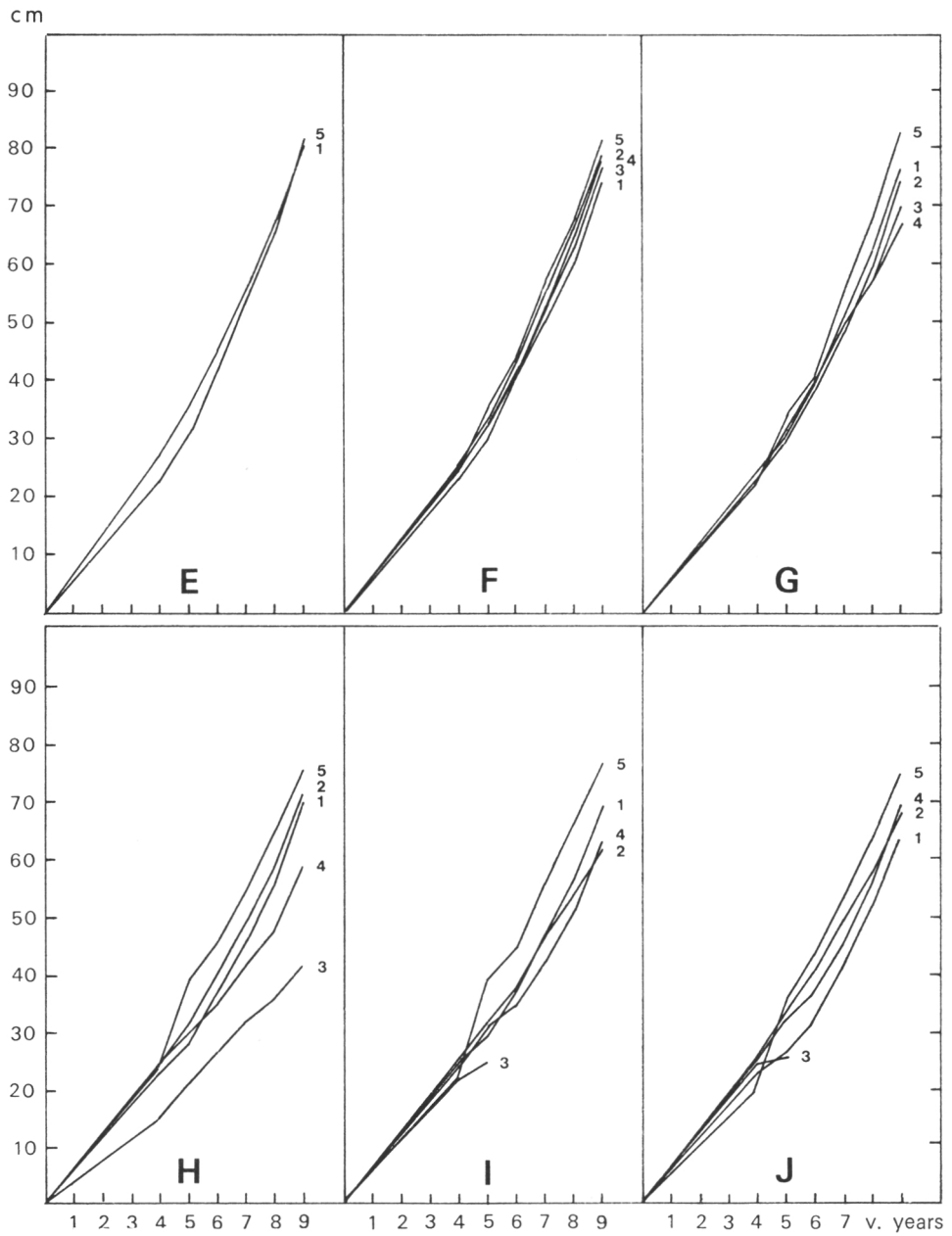


Kuva 16. Eri tavoin varastoitujen (1—5) ja eri aikoina istutettujen (A—D) kuusentaimien pituuskehitys A-kokeessa. Vaaka-akselilla taimien ikä kylvöstä lukien ja pystyakselilla taimien pituus.
Varastoinnin suoritustavat: 1 = kellari, 2 = valeistutus, 5 = taimipenkki.
Istutuspäivämäärät v. 1964: A = 26. 5., B = 9. 6., C = 24. 6., D = 6. 7.
Varastointiaikojen pituudet: Katso kuva 2.

Figure 16. Stem height of spruce transplants stored by different methods and planted in different times (experiment A).
Abscissa = age of transplants from sowing, ordinate = height of transplants.
Methods of storage: 1 = cellar, 2 = heeling-in, 5 = nursery bed.
Dates of planting: A = May 26, B = June 9, C = June 24, D = July 6.
Duration of storage: See Figure 2.

— Parhaiten elossa pysyneet taimet (kuvat 8 ja 14), jotka oli varastoitu taimipenkissä (5) tai valeistutuksessa (2), ovat saavuttaneet yleensä myös suurimman keskipituuden. Suoraan taimipenkistä istutettujen taimien pituus näyttää olevan sitä suurempi mitä myöhemmin kasvukauden aikana taimet on istutettu. Niinpä heinäkuun istutuksessa (osakuva D) taimitarhataimien (5) pituus näyttää selvästi suuremmalta kuin kesäkuun alussa (osakuva B) ja juhannuksen aikoina suoritetuissa istutuksissa (osakuva C). Valeistutuksessa olleet taimet jäävät kasvussaan jälkeen taimipenkissä varastoiduista varastointiajan pidetessä (osakuvat C ja D) vaikkakin 9. 6. istutetuilla valeistutustaimilla näyttää kasvu olleen erittäin voimakasta. Kellarivarastoinnista eloonjääneiden taimien kasvu heikkenee varastointiajan pidentyessä ja ne näyttävät olevan kokeen lopussa taimitarhataimista selvästi jäljessä.

— Ojavedessä varastoidut taimet kuolivat jo ensimmäisten kasvukausien aikana niin vähälukuisiksi, että niistä ei voitu tehdä luotettavia pituusmittauksia. Muutamien tehtyjen havaintojen perusteella taimet ovat olleet kokeen koko kehitysajan muiden käsittelyryhmien taimista kasvussaan selvästi jäljessä.



Kuva 17. Eri tavoin varastoitujen (1—5) ja eri aikoina istutettujen (E—J) kuusentaimien pituuskehitys B-kokeessa. Vaaka-akselilla taimien ikä kylvöstä lukien ja pystyakselilla taimien pituus.
Varastoinnin suoritustavat: 1 = kellari, 2 = valeistutus, 3 = ojavesi, 4 = kaivovesi ja 5 = taimipenkki.
Istutuspäivämäärät v. 1966: E = 6. 6., F = 13. 6., G = 20. 6., H = 27. 6., I = 4. 7., J = 11. 7.
Varastointiaikojen pituudet: Katso kuva 2.

Figure 17. Stem height of spruce transplants stored by different methods and planted in defferent times (experiment B). Abscissa = age of transplants from sowing, ordinate = height of transplants.
Methods of storage: 1 = cellar, 2 = heeling-in, 3 = ditch water, 4 = well water.
Dates of planting: E = June 6, F = June 13, G = June 20, H = June 27, I = July 4, J = July 11.
Duration of storage: See Figure 2.

Kuva 17 taas esittää B-kokeen taimien vastaavaa pituuskehitystä. Myös nämä taimet ovat kasvaneet verrattain tiheän verhopuuston alla ja vahvan vadelmikon sekä heinästön ahdistamina. Nähdään, että niiden pituuskehitys onkin ollut nopeudeltaan jotakuinkin samanlainen kuin A-kokeen taimien. Osakuvista E—J voidaan B-kokeen taimista tehdä seuraavat eri varastointikäsittelyjä koskevat havainnot:

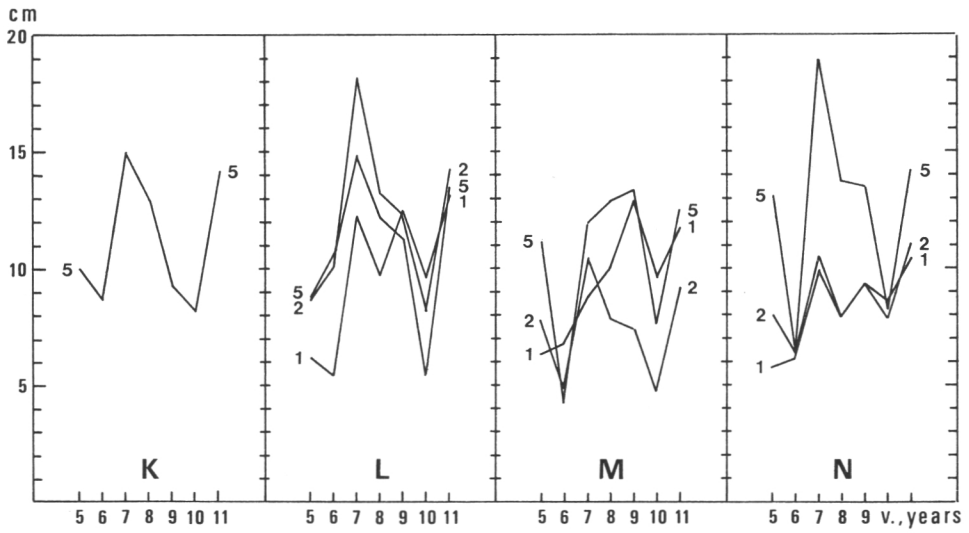
— Nytkin ovat suoraan taimitarhapenkistä istutetut taimet (5) kehittyneet vuoteen 1970 mennessä pitemmiksi kuin muilla suoritustavoilla varastoidut taimet. Näidenkin taimien kokonaispituus alenee kuitenkin hitaasti ajankohdan muuttuessa istutukselle epäsuotuisammaksi. Valeistutuksessa varastoidut taimet (2) eivät varastointikauden lopussa jää paljonkaan jälkeen edellisistä ja myös varastoinnin alussa ne ovat taimitarhataimien kanssa samantasoisia. Pitkittynyt kellarivarastointi (1) jättää myös taimien pituuskehityksen em. kahdella varastointitavalla saavutettua heikommaksi, vaikka huonommuus ei ole niin suuri kuin eloonjäämisen kohdalla. Taimet, jotka on varastoitu kaivovedessä, ovat edellisiä lyhyempiä, mutta vielä paljon huonompi on pituuskehitys ollut ojavedessä varastoiduilla (3) taimilla. Kaksi luonnonmukaisinta varastointitapaa, varastointi valeistutuksessa ja varastointi taimipenkissä, näyttävät siis olevan myös pituuskehityksen kannalta taimille suotuisimmat.

Lopuksi on mielenkiintoista tarkastella kuvien 18 ja 19 avulla, ovatko varastoinnin erilaiset suoritustavat vaikuttaneet taimien vuotuisen pituuskasvun määrään tai rytmiin. Tällöin on otettava huomioon, että voimakas heinittyminen on molemmilla koealoilla häirinnyt taimien säännöllistä pituuskehitystä. Muutamia havaintoja voidaan kuitenkin tehdä. A-kokeen osalta nähdään kuvasta 18:

— Ensimmäisen maastokasvukauden verrattain hyvän pituuskehityksen jälkeen seuraa miltei kaikissa käsittelyryhmissä toisena kasvukautena pituuskasvun lyhytaikainen tyrehtyminen. Tämä johtunee siitä, että ensimmäisen kesän kasvun tapahduttua pääasiassa taimitarhalla varastoituneiden ravinteiden turvin ovat toisena kasvukautena siirron aiheuttamat vaikeudet jyrkimmillään. Kasvun hidastuminen on selvin pitkien varastointien jälkeen istutetuilla taimilla.

— Jo kolmantena kasvukautena kuvaajat kääntyvät kuitenkin nousuun, joka todennäköisesti varjostusten ja heinittymisen vuoksi taas nopeasti kehittyy heittelehtiväksi kasvunopeuden vaihteluksi. Vaihtelut ovat voimakkaimmat osakuvassa L, joka esittää kasvua lyhyen, 14 vrk:n varastointiajan jälkeen istutetuilla taimilla.

— Kasvun vaihdellessa jyrkästi näyttävät taimitarhalla varastoidut taimet pysyttelevän muita käsittelyryhmiä hieman edellä niin kasvusaavutuksissa kuin vaihtelun jyrkkyydessäkin. Osakuvissa M ja N havaittava taimitarhalla varastoitujen (5) taimien kasvun näennäisesti jyrkkä hidastuminen



Kuva 18. Eri tavoin varastoitujen (1—5) ja eri aikoina istutettujen (K—N) kuusentaimien vuotuisen pituuskasvun vaihtelut A-kokeessa. Vaaka-akselilla taimien ikä kylvöstä lukien ja pystyakselilla latvakasvaimen pituus.

Varastoinnin suoritustavat: 1 = kellari, 2 = valeistutus, 5 = taimipenkki.
Istutuspäivämäärät v. 1964: K = 26. 5., L = 9. 6., M = 24. 6. ja N = 6. 7.
Varastointiaikojen pituudet: Katso kuva 2.

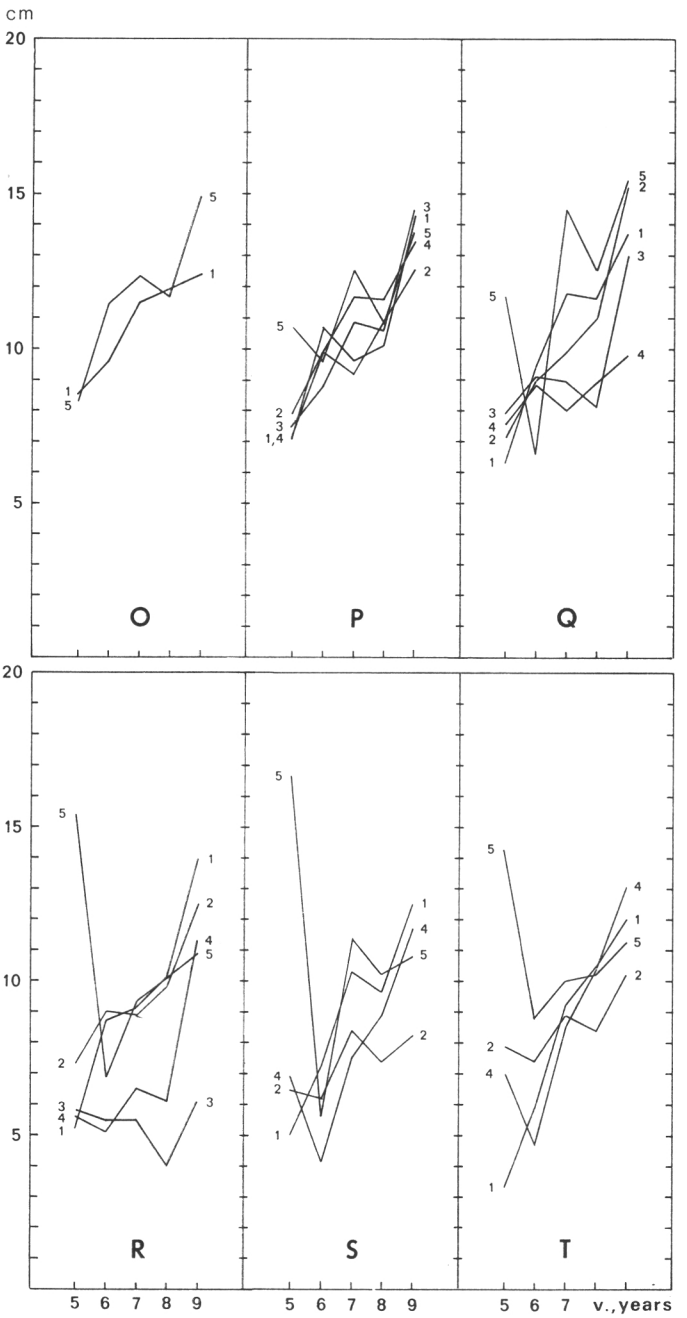
Figure 18. Annual height increment of spruce transplants stored by different methods and planted in different times (experiment A). Abscissa = age of transplants from sowing, ordinate = length of the annual shoot.

Methods of storage: 1 = cellar, 2 = heeling-in, 5 = nursery bed.
Dates of planting: K = May 26, L = June 9, M = June 24, N = July 6.
Duration of storage: See Figure 2.

viidennen ja kuudennen kasvukauden välillä johtunee pääosaltaan siitä, että viidentenä kasvukautena kesäkuun lopun ja heinäkuun alun istutuksessa näiden taimien latvaverso on ennättänyt kasvaa erittäin pitkäksi jo taimitarhalla. Todennäköistä on, että tämä kasvu tuntuu taimitarhalle varastoitujen taimien kokonaispituudessakin monta vuotta istutuksen jälkeen ja se voikin olla eräänä selityksenä näiden taimien muita ryhmiä suurempaan pituuteen vielä 5—7 vuoden kuluttua istutuksesta. Toisena, joskin ehkä vähäisempänä syynä tähän tuloksen on kuitenkin myös näiden taimien omaama, jatkuvastikin verrattain hyvä kasvukyky.

B-kokeen osalta voidaan kuvasta 19 tehdä seuraavat havainnot:

— Nyt ei pituuskehityksen tyrehtymistä ole tapahtunut istutusta seuraavana kasvukautena lainkaan siinä määrin kuin kokeessa A. Vain varastoinnin suoritustavoissa 3 (ojavesi) ja 4 (kaivovesi) näkyy osakuvista R—T pitkän varastoinnin vaikutus aluksi myös taimien kasvun tyrehtymisenä. Taimipenkissä varastoiduilla taimilla (5) on kasvun väheneminen jyrkkä ja



Varastoinnin suoritustavat:
1 = kellari, 2 = valeistutus, 3 = ojavesi, 4 = kaivovesi ja 5 = taimipenkki.

Istutuspäivämäärät v. 1966:
O = 6. 6., P = 13. 6., Q = 20. 6., R = 27. 6., S = 4. 7. ja T = 11. 7.

Varastointiaikojen pituudet:
Katso kuva 2.

Methods of storage:
1 = cellar, 2 = heeling-in, 3 = ditch water, 4 = well water, 5 = nursery bed.

Dates of planting:
O = June 6, P = June 13, Q = June 20, R = June 27, S = July 4, T = July 11.

Duration of storage:
See Figure 2.

Kuva 19. Eri tavoin varastoitujen (1—5) ja eri aikoina istutettujen (O—T) kuusentaimien vuotuinen pituuskasvu B-kokeessa. Vaaka-akselilla taimien ikä kylvöstä lukien ja pystyakselilla latvakasvaimen pituus.

Figure 19. Annual height increment of spruce transplants stored by different methods and planted in different times (Experiment B). Abscissa = age of transplants from sowing, ordinate = length of the annual shoot.

johtunee jälleen siitä, että myöhäisissä kesäistutuksissa (osakuvat Q—T) taimien latvakasvain on ennen istutusta taimitarhan suotuisissa olosuhteissa saavuttanut huomattavan suuren 13—17 cm:n pituuden. Ero on luonnollisesti suuri, kun näiden taimien pituuskasvu toisena maastokasvukautena putoaa toisten käsittelyryhmien kasvun tasolle, 4—9 cm:iin. Vuotuisen kasvun tämän jälkeen tasaisesti parantuessa tapahtuu kehitys kaikkien käsittelyryhmien eloonjääneillä taimilla kuitenkin hyvin yhdenmukaisesti taimitarhalla varastoitujen taimien (5) enää erottumatta toisten joukosta.

4. TULOSTEN TARKASTELUA

Nyt suoritettu tutkimus on tuonut esiin taimien fysiologisen kunnon ensiarvoisen merkityksen istutuksen onnistumiselle. Tähän seikkaan on meillä kiinnittänyt huomiota ehkä eniten Yli-Vakkuri (1957, 1961) selvittäessään taimien suojelua noston ja istutuksen välisenä aikana. Metsänviljelyn suoritusketjun tässä osavaiheessa voikin piillä eräitä niistä syistä, jotka aiheuttavat epäonnistumisia viljelyssä, mutta joita on myöhemmin vaikea havaita ja osoittaa todellisiksi syiksi.

Itse istutustyö suoritettiin tämän tutkimuksen kaikkien taimierien kohdalla mahdollisimman hyvin ja taimet hoidettiin myös mitä suurimmalla huolella työn kaikissa vaiheissa. Siitä huolimatta kuolivat vahvat, koulitut kuusentaimet miltei kaikki toisen kasvukauden loppuun mennessä esim. kahta viikkoa pitemmän ojavedessä varastoinnin ja sitä erittäin suotuisana kevätkesän ajankohtana seuranneen istutuksen jälkeen.

Näyttää siis siltä, että paljon pelätty taimien ja niiden juurien kuivuminen ei ilmeisesti olekaan ainoa käytännön varastoinneissa taimien fysiologista kuntoa heikentävä tekijä. Taimien kunnon heikkenemiseen voivat johtaa myös aivan päinvastaisetkin olosuhteet, liiallinen kosteus ja sen mukanaan tuomat vaarat, mm. kosteassa lämmössä viihtyvä, taimia heikentävä mikroflora. Edelleen taimia heikentävät myös varastointipaikasta tai taimien tiheästä asennosta johtuva valaistuksen tai ilmanvaihdon riittämättömyys.

Luonnollista myös on, että pitkä varastointi puolilämpimissä olosuhteissa ja pimeässä kuluttaa taimien vararavinnevarastoja ja siten heikentää niiden juurtumiskykyä, jonka on todettu riippuvan mm. taimiin varastoituneiden tärkkelyksen ja sokereiden runsaudesta (esim. Curtis ja Clark 1950, Kramer ja Kozlowski 1960 sekä Jones 1967). Milloin taimet varastoidaan valaistukseltaan riittämättömissä, mutta lämpötilaltaan taimen elintoiminnat, mm. hengityksen käynnistävissä olosuhteissa, jollaiset vallitsevat esim. talouskellareissa, on luonnollista, että taimet ajan pitkään menettävät istutuskelpoisuuttaan. Kuitenkin vasta taimien eri osien ravinnepitoisuuksien toistuvat mittaukset voisivat selvästi kartoittaa näiden tekijöiden täyden merkityksen.

Vesivarastoinneissa 3 ja 4 taimien latvaosat olivat koko varastointiajan ulkoilman luonnonmukaisissa olosuhteissa auringonsäteilyn ja ilmavirtojen vaikutuksen alaisina. Kuitenkin juuri nämä varastointimuodot olivat kaikista nyt kokeilluista kuusentaimille tuhoisimmat. Tämä johtunee eräästä seikasta, jonka tärkeyden herkkiin havaintoihin kyenneet metsämiehet ovat jo aikaisin intuitiivisesti havainneet — juurten hapentarpeesta. Jo sangen varhain (esim. v. Carlowitz 1713 ja Manteuffel 1874) on viitattu siihen, että tiivisrakenteinen maaperä vaatii juurten sijoittamista istutuksessa aivan maan pintakerroksiin. Juurten hapentarve on ollut jo kauan myös tutkijoiden tiedossa ja sen merkitystä on korostettu mm. metsäpuiden fysiologiaa tutkivien tiedemiesten keskuudessa. Esim. puiden juurten vedenotolle on aerobisten olosuhteiden todettu olevan tärkeänä edellytyksenä (Kramer ja Kozlowski 1960 ja Kozlowski 1964). Orlovin (1966) suorittamissa kuusentaimien vesityskokeissa juurien kasvu päättyi jo muutamia tunteja vesityksen alkamisesta, kun vedessä olevan hapen varasto oli käytetty loppuun. Jo kolmipäiväinen vesitys aiheutti melkein kaikkien kuusen kasvujuurien kuolemisen. Tämän tiedon pohjalta voidaan ymmärtää, miten tuhoisia pitkälliset vedessä varastoinnit taimille tässä kokeessa olivat ja miten suuria taimitappioita tällaiset varastointitavat käytännön työssä huomaamatta ovat ehkä aiheuttaneet.

Näyttää myös siltä, että mikäli kuusentaimet ovat aktiivivaiheessaan (Sarvas 1972) eivätkä lepotilassaan, jolloin niitä voidaan varastoida pitkiäkin aikoja koneellisesti jäähdytetyissä kylmävarastoissa, ei auta kovinkaan paljoa se, että niiden elintoimintoja pyritään pitämään mahdollisimman hitaina. Parempia tuloksia saadaan, jos taimien annetaan olla varastoinnin aikana mahdollisimman luonnonmukaisissa olosuhteissa ja niiden elintoimintojen annetaan tapahtua vapaina ja voimakkaina. Hyvä ilmanvaihto ja auringon säteily taimien oksistoissa sekä juurien luonnolliset elinolosuhteet riittävän kosteassa, kuohkeassa ja ilmavassa maassa varastoinnin aikana näyttävät takaavan taimien parhaan kehityksen myös keskellä kesää suoritetun istutuksen jälkeen.

Hyvin samantapaiseen tulokseen päätyi myös Arnborg (1959) kokeillessaan männyntaimien fysiologisen kunnon merkitystä niiden taimitarhakoulinnan onnistumiselle. Loppupäätelmissään hän kehoittaa antamaan taimien seistä alkuperäisessä penkissään viivästyneeseenkin koulintaan saakka. Männyntaimien erikoisominaisuudet sekä männyn istutuksessa yleensä kyseeseen tulevien uudistusalojen karuus, aukeus ja kuivuus aiheuttavat kuitenkin sen, että taimitarhaolosuhteissa saadut tulokset eivät ole ilman muuta sovellettavissa männyntaimien maastoistutuksiin. Sen sijaan kuusen istutusajankohdan vaikutusta kokeiltaessa on pohjoismaisissa oloissa saatu useallakin eri taholla siihen viittaavia tuloksia, että paljasjuuristen kuusentaimien istuttaminen suoraan taimipenkistä onnistuu kasvukauden kaikkina ajankohtina (esim. Heikinheimo 1941, Mork 1950, Huss 1958 ja Brekken 1965).

5. TUTKIMUKSEN PÄÄTULOKSET

— Jos kuusentaimien varastoinnin suoritustavan käyttökelpoisuuden mitaksi valitaan sen ajan pituus, jonka varastointi saa vaikuttaa taimiin ilman että niiden kuolleisuus istutusta seuraavien viiden kasvukauden aikana ylittää 10 %:n rajan, sijoittuvat nyt kokeillut taimien varastointitavat seuraavaan järjestykseen parhaasta huonoimpaan luetellen:

Varasto	Varastointiaika, jonka jälkeen taimien kuolleisuus ylittää 10 %
1. Taimipenkki	Edellämainittua varastointiajan vaarallista ylärajaa ei kokeessa lainkaan kohdattu
2. Valeistutus	Varastoinnin vaaraton kestoaika n. 5—6 viikkoa
3. Kellari	Vaaraton kestoaika korkeintaan 4 viikkoa
4. Kaivovesi	Vaaraton kestoaika korkeintaan 2 viikkoa
5. Ojavesi	Vaaraton kestoaika korkeintaan 1 viikko

— Luonnonmukaisimmat varastointitavat, varastointi taimipenkissä ja valeistutuksessa, joissa taimien latvat saivat olla vapaasti auringonsäteilyn, ulkoilman lämmön ja ilmavirtojen vaikutuksen alaisina sekä juuret mullan peittäminä, osoittautuivat parhaiksi kuusen taimien ollessa kyseessä.

— Ehdottomasti huonoimmiksi taas osoittautuivat varastointitavat, joissa taimien juuret olivat yhtämittaisesti pelkän veden peittäminä.

— Taimien varastointi juuret jatkuvasti luonnonveden peitossa oli niin tuhoisa varastoinnin suoritustapa, että se jo kolmen viikon pituisena aiheutti valtaosalle taimia kuoleman joko ensimmäisen tai toisen kenttäkasvukauden aikana.

— Taimien turmeltumisen merkkeinä kehittyivät näkyviin liian pitkäksi venytetyssä kellarivarastoinnissa uusien versojen kellastuminen ja juurien sekä taimien tyvioksien homehtuminen. Liian pitkässä vesivarastoinnissa taas juuret mustuivat ja aluksi hyvin kasvaneet taimien latvat veltostuivat ja lopulta ruskettuivat. Valeistutuksen haittoina todettiin taimien tiheästä asennosta johtuva alaoksien kellastuminen kellarivarastoinnin tapaan sekä valeistutusmaan huomaamaton kuivuminen hellepäivien aikana.

— Kuusentaimien istuttaminen suoraan taimipenkistä pitkin kesää verhopuuston alle taas onnistui kaikkina kokeessa kyseeseen tulevina kasvukauden vaikeimpinakin aikoina niin hyvin, että se vakavasti viittaa mahdollisuuteen istuttaa Etelä-Suomen järvialueella kuusta paljain juurin läpi koko kasvukauden verhopuuston suojaan.

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7. SUMMARY

The Effect of Field Storage Methods on Initial Development of Planted Spruce

In the 1960's the Finnish Forest Research Institute investigated, by means of several field experiments, the importance of the various steps in planting operations to the overall reforestation results. In connection with this project it was also desirable to investigate the effect of the most common methods of intermediate storage close to the planting area on the initial development of the planted transplants. Therefore, a few field experiments for spruce and pine were established at Hartola in 1964—1966. The results for spruce will be reported here.

The spruce experiments were conducted during two years in two locations. Both test areas are situated on fertile *Oxalis-Myrtillus* site types covered with a dense alder nurse crop (Figure 5). The plots are located about 600 meters apart in the Kalho village of the Hartola parish (N 61°29′, E 25°58′). The soil is even fine sand and clay covered with a thick layer of mineral soil mixed with abundant humus. The experimental design was single randomized blocks. The treatments, which were combinations of storage method and planting time, were randomized on the blocks of the test areas. The transplants used were 2/2 Norway spruce *(Picea abies* (L.) Karst.), commonly used at that time. Time of lifting, storage, and planting are presented in Figure 2. Each plot had 5 transplants, and the whole experiment contained two test areas, two years, 4—5 methods of storage, 4—6 times of planting, 176 plots, and a total of 880 transplants.

Temperature and rain sums during the year of planting for the two nearest climate stations in Mikkeli and Heinola are presented in Figure 4.

The methods of storage were as follows:

1. S t o r a g e i n a c e l l a r. This was a common method of storage in the Finnish countryside during the time at which the experiment was performed. The opened bundles of transplants were stacked compactly into wooden boxes with the roots covered with wet moss. The boxes were kept at about 10° C and 85 % relative humidity in the almost complete darkness of the cellar.
2. S t o r e d a s h e e l e d - i n t r a n s p l a n t s, according to well-known and international practice.
3. S t o r e d i n t h e w a t e r o f a d i t c h. Storage of transplants in the spring in a water-filled hole or ditch was becoming increasingly common at the time when the experiment was carried out, and therefore, the method was included in order to gain guidelines for field work.
4. S t o r a g e i n w e l l w a t e r. As a comparison with the previous method, the roots of the transplants were submerged in a tub of well water which was changed once a week.
5. S t o r a g e i n t h e n u r s e r y b e d. The transplants remained intact in the original nursery bed until time of planting.

The transplants were planted at the edge of a planting hole made into the center patch with a planting hoe (SFI-hoe). In order to investigate the effect of each storage method in more detail, the planting was carried out at various times throughout the whole planting season. In addition to Figure 2, the times of planting and also the lengths of the storage times have been presented *i.a.* in Figures 6, 8, 10, 12, and 14. Data on survival and condition have been presented in the same figures. The appearance of transplants stored by different methods is indicated by photographs in Figures 1, 5, 7, 9, 11, 13, and 15. Development of total height and annual variation in height growth are presented in Figures 16, 17, 18, and 19.

The main results of the study were:

— Provided that the quality of a storage method is defined in terms of the length of time in storage causing no more than 10 % mortality of planted transplants within the five first growing seasons, the tested field storage methods are ranked (best to poorest) as follows:

1. The seedlings grow intact in the nursery beds until planted: The above-mentioned time limit was not achieved during the experiment.
2. Storage as heeled-in and well-irrigated transplants: Duration without detrimental effects 5—6 weeks.
3. Storage in cellar: Duration without detrimental effects, maximum 4 weeks.
4. Storage in clean well water: Roots continuously covered by water. Duration without detrimental effects, maximum 2 weeks.
5. The same but the roots in ditch water: Duration without detrimental effects, maximum 1 week.

— The most natural methods of storage, in the nursery bed and heeled-in, where the tops of the transplants were freely exposed to insolation, air temperatures and movements, and the roots were covered by soil, proved the best methods for spruce transplants.

— The poorest methods proved to be those where the roots were continuously covered by water. Storing the transplants continuously in natural water was such a detrimental storage method that already after three weeks the majority of the transplants died during the first or second growing season.

— Storage in an ordinary country cellar preserved the spruce transplants in good condition for planting-out during those four weeks for which storing normally may occur in spring spruce planting.

— Signs of impaired condition developed during too long storage in the cellar as yellowing of new shoots and mould on the roots and basal branches. Too long storage in water, on the other hand, caused blackening of roots; the initially rapidly-growing shoots wilted and finally turned brown. Negative effects of heeling-in occurred as yellowing of the lower branches (as in cellar storage) due to density of transplants and unobserved drying out of the soil during hot days.

— On a site under a nurse crop planting-out of spruce transplants lifted directly from the nursery bed was so successful, during even the most difficult periods of the growing season, that it strongly indicates the possibility of planting bare-rooted spruce transplants under nurse crop during the whole growing season in the inland of southern Finland.

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UNEQUAL PROBABILITY SAMPLING BY DBH CUMULATOR

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Seloste

KOEPUIDEN VALINTA KUUTIOMÄÄRÄN SUMMAAJALLA

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PREFACE

The purpose of the paper is to describe with the aid of a theoretical review and some practical applications the usage of statistics for the problem of sample tree selection. In addition to a general sampling theory the paper deals with the systematic sampling from the cumulated measures of size for which a special device has been developed.

I am greatly indebted to the Finnish Forestry Society for providing me with a grant to help the development of an original idea to the level of a practice prototype. At the suggestion of Professor K u l l e r v o K u u s e l a my study was included in the working program of the Department. The manuscript was revised by Kullervo Kuusela and Professor H a n n u V ä l i a h o. In addition, the manuscript was read by or the topics discussed with Mr. E r k k i M i k k o l a, Lic. Phil., Mr. S a k a r i S a l m i n e n, M.F., and Dr. R i s t o S e p p ä l ä. The translation into English was made by Mr. Y r j ö S i h v o, M. A. The English text was checked by Mr. J o h n D e r o m e, B.Sc. I owe sincere thanks to all these persons

Helsinki in October 1973

Jouko Laasasenaho

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1. INTRODUCTION

In forestry, both practical and scientific, one must often have recourse to some method of sampling. Forest estimation for different purposes is usually performed by means of a multiphased sampling method. In Finland more timber is nowadays being sold on-the-stum as a result of a computer system (the so-called PMP-scheme) which was developed for mensuration of standing trees and for calculation of wages. The selection of sample trees in this system is an important phase in the work. There are two phases in stand measuring: counting of trees (preparation of a list-of-units) and measuring of sample trees. When counting the trees, the DBH of every tree which satisfies a prescribed size qualification is recorded (1 or 2-cm. interval). As tem-diameter distribution is thus obtained. Generally this list is made up by tree species and by timber assortments (saw-timber, pulp wood, etc.).

The choice of sample trees takes place either in conjunction with the counting of the trees or else after it. In the former case, the selection is most often made by means of systematic sampling. The sampling interval varies according to the stem-diameter distribution. Visits to sample trees may occur either during the preparation of the list-of-units of after it. In the latter case, the selection of sample trees is ordinarily made with the aid of a relascope from observation points located at regular intervals.

The selection of sample trees is a theoretical sampling problem. Overall instructions cannot be given, because we have no previous knowledge about, for instance, the range of variance in the characteristics to be considered.

Many applications have been derived in the U.S.A. (S c h r e u d e r, S e d r a n s k, W a r e & H a m i l t o n 1971) from the sample tree selection method which was presented by G r o s e n b a u g h (1965) — probability proportional to prediction (the 3 P-sampling). In Finland this approach has also given working models based on differing principles (S e p p ä l ä 1971; L a a s a s e n a h o 1971).

When looking for an adequate sample tree selection method it is very important to bear in one's mind the background theory. In the next section, before the technique of sampling with the Cumulator is presented, some points of sampling theory are touched upon to illustrate which factors influence the accuracy of the results when using the technique generally used in Finland.

2. SAMPLING THEORY

Obtaining a certain precision as to the information about the total volume within a stand which is marked for cutting may be set as target for a sampling. Since we have a stem-diameter distribution and we are interested in the results by DBH-intervals, the DBH-classification forms a stratification in the frame of which the sampling can be carried out.

Under practical conditions in Finland, the diameters at breast height and at 6 m.-height (to the nearest cm) and tree height (to the nearest m) of the sample trees are measured. Subsequently the volume for the tree can be obtained either from the Tables of Ilvessalo (1947) or by equations. This volume however, is not accurate — the relative standard error of the prediction is about 5 per cent. If this error can be assumed to be fortuitous and to vary by single trees, which assumption might not always hold true, the »table error» which is herewith introduced can approximately be controlled by means of the number of sample trees.

The mean error formula shows that the relative »table error» in the mean of the sample trees amounts to

$$\delta_{\bar{x}} = \frac{5}{\sqrt{n}} \%, \text{ where} \tag{2.1}$$

n = number of sample trees.

The variance of the total volume stratified into DBH-classes is obtained from the formula:

$$V(\hat{Y}_{st}) = \sum_{h=1}^{L} N_h (N_h - n_h) \frac{S_h^2}{n_h}, \text{ where} \tag{2.2}$$

N_h = number of trees in DBH-class h
n_h = number of sample trees in DBH-class h
S_h = standard deviation of volume in DBH-class h
L = number of DBH-classes

If the costs per sample tree are supposed to be a constant, although this is not always true under all conditions, we get as sampling amounts for the different DBH-classes according to the optimal allocation (C o c h r a n 1963, p. 97)

$$n_h = n \frac{N_h S_h}{\sum_{h=1}^{L} N_h S_h} \tag{2.3}$$

The variance in the volumes analyzed by DBH-classes increases steeply as the diameters become greater. The variance in volume on a Finnish pine sample plot has been tested and found to approximate the mean volumes of the corresponding DBH-grades when using the 1-cm. classification and working with 1 cu.dm. as a unit. As a matter of fact, the proportion variance/mean volume within a DBH-interval can be expected to be somewhat constant. On the basis of this knowledge a prediction can be made as to the proportional distribution of sample trees into the different DBH-classes.

The directions which have been given for practical purposes about the number of sample trees needed to attain a certain precision are far from being exact. Using a rule-of-thumb is sometimes not efficient enough. By means of the observations and formulae which have been presented above the number of sample trees required for certain cases can be approximated.

The accuracy of the volume is also dependent upon the range of DBH-intervals. The wider the classes, the larger the variance within each class. The effect of classification upon the variance within the classes can be described, for instance, as follows. Suppose the volume equation $f(D)$ which is based on the DBH only is known. For instance, the equation which has been used for spruce in the present paper (3.1) p. 11. The accurate volume of the tree j with a diameter D is

$$V_j = f(D) + \varepsilon_j \tag{2.4}$$

On postulating that inside each class $E\varepsilon_j = 0$, both ε_j and $f(D)$ are independent, the variance for the class is obtained from the formula

$$\begin{aligned} D^2(V) &= D^2 f + D^2 \varepsilon \\ &= Ef^2 - (Ef)^2 + E\varepsilon^2, \text{ where} \end{aligned} \tag{2.5}$$

E is short for expectation; f stands for $f(D)$

The influence of the interval range upon the variance can be computed precisely enough by barring the factor $E\varepsilon^2$. The differences of variance with different class width appear, in particular, to hold true.

Table 1. Dependence of the variance and the displacement in expectation of the mean upon the interval width with a postulated rectangular distribution

Taulukko 1. *Varianssin ja keskiarvon odotusarvon siirtymän riippuvuus luokkavälin laajuudesta tasajakaumaoletuksella*

D	$f(D)$	D^2f, dm³ with the class width of *luokkavälillä*			$E(f)$—$f(D)$, dm³ with the class width of *luokkavälillä*	
		1 cm	2 cm	difference *ero*	1 cm	2 cm
3	1.48	0.15	0.62	0.47	0.03	0.13
5	5.91	0.85	3.48	2.63	0.05	0.19
7	14.72	2.68	10.88	8.20	0.06	0.24
9	29.06	6.29	25.44	19.15	0.07	0.27
11	49.94	12.35	49.91	37.56	0.08	0.31
13	78.27	21.57	87.07	65.51	0.09	0.34
15	114.85	34.59	139.59	105.00	0.09	0.37
17	160.38	52.03	209.88	157.85	0.10	0.40
19	215.48	74.39	300.01	225.62	0.10	0.42
21	280.64	102.08	411.63	309.55	0.11	0.44
23	356.30	135.39	545.87	410.48	0.11	0.45
25	442.77	174.46	703.29	528.83	0.11	0.46
27	540.29	219.25	883.83	664.58	0.11	0.46
29	649.00	269.62	1 086.79	817.17	0.12	0.47
31	768.96	325.25	1 310.84	985.59	0.12	0.46
33	900.11	385.59	1 554.03	1 168.45	0.12	0.46
35	1 042.35	450.05	1 813.70	1 363.66	0.11	0.45
37	1 195.45	517.81	2 086.86	1 569.05	0.11	0.44
39	1 359.13	587.98	2 369.64	1 781.66	0.10	0.42
41	1 533.00	659.66	2 658.37	1 998.72	0.10	0.41
43	1 716.64	731.72	2 948.47	2 216.75	0.09	0.38
45	1 909.50	801.81	3 225.37	2 432.56	0.09	0.36

In Table 1 the dependence of the variance upon the width of the interval has been calculated by means of equation (3.1) with 1 and 2-cm. intervals by postulating a rectangular distribution in each class. In addition, the Table shows the displacement of $E(f)$ in comparison with the value of (3.1) at the centre of the class interval with the same arguments (interval width and rectangular distribution).

It can be seen from the values of $f(D)$ in Table how quickly the volume increases with an increasing DBH. Classification could perhaps be left out alltogether in order to obtain a better understanding of its significance as to the accuracy of the results. If the class width 1 cm is replaced by the 2-cm. grading, then the variance becomes quadruple. Of course, no immediate information can be obtained from these figures which would show how the final results are affected by the DBH-classification.

If we can assume the total variance with the 1-cm. interval to be equal in each DBH-class to the value of $f(D)$ for the same class — as it actually

proved to be in a test carried out by the author — the total variance with the 2-cm. interval would be, in the case of the DBH-classes running over saw-timber size, more than doubled as compared to the 1-cm. interval. One can see from the formula on p. 6 that the variance in total volume is 2-fold. This emphasizes the significance of classification. For stems of greater size the effect of the DBH-classification is greatest. Accordingly, it would be desirable to use the 1-cm. classification for saw-timber sized trees — their unit volume being greater — if the 2-cm. classification has been applied to the pulp-wood size. Moreover, the need for a narrower grading is emphasized by the fact that the saw-timber section of a stem may change very quickly as the DBH is increasing.

In order to calculate the volume using equations, the displacement of the mean can be eliminated by measuring the DBH of the sample trees to 1 mm. and the tree heights to the nearest dm.

3. SAMPLING BY DBH CUMULATOR

31. Finnish experiments of the 3-P sampling

In a colloquy concerning sampling arranged by the Department of Forest Mensuration and Management, University of Helsinki, in 1969, the author suggested that ratio and regression estimators could be used for volume calculation in the sample plots. The accuracy of the results on variable sample sizes has since been analyzed by means of computer simulations to which was applied different calculation and sample tree selection methods. Among other things, simple random sampling was compared to a random sampling from the cumulated sum of the basal areas without replacement. The results obtained in the latter manner were found to be more accurate when applying variable calculation methods. This theme was continued by Messrs. K i l k k i and P a k k a n e n who tested the accuracy of a sampling by DBH arranged in an optimal manner — the results for each DBH-class being calculated on the basis of the sample trees which belonged to this class. Such a sampling was found to give about the same accuracy as the one described above, although the results were not in all respects comparable. For practical reasons, however, the colloquy decided on systematic sampling by DBH for sample tree selection.

The theme was re-actualized in 1971, when S e p p ä l ä presented a method for applying the 3-P sampling using a random number generator.

On the intuition gained from these trials, the author designed a volume cumulator (Section 33) with which the sampling takes place as a systematic sampling from the cumulated sum of the volumes. This method of sampling has proved to be more efficient than, e.g., the 3-P sampling which takes place by trees (S c h r e u d e r, S e d r a n s k, W a r e & H a m i l t o n 1971). The absence of an apparatus simple enough for field use has prevented it from being applied in practice.

32. The principle behind the sampling

With the volume Cumulator, sampling is made as a systematic sampling on the basis of the cumulated sum of the estimated volumes of the trees.

The size of the tree (X_i), which in this case means the volume in dm^3, is estimated with the aid of the DBH. The estimation may be done, for instance, by means of the function calculated for spruce (L a a s a s e n a h o & S e v o l a 1971):

$$\ln X_i = -2.59385 + 2.71757 \ln D - 0.000097 D^2, \tag{3.1}$$

where D is in cm.

The sample is taken without replacement and the probability for each stem becoming a sample tree is proportional to the volume estamate X_i of the tree.

The sampling procedure will be as follows (cf. S c h r e u d e r, S e d r a n s k, W a r e & H a m i l t o n 1971, p. 105).

1. The sampling interval (in volume) is fixed: it is generally greater than any value of X_i.

2. A random number s is chosen so that $0 < s \leq L$. The coice of sampling units is then based on the number series $s + hL$, where $h = 0, 1, 2, \ldots,$ $(n - 1)$. The number of sample trees is then $n = X/L$, $(X = \Sigma X_i)$. There is no need for X to be known in advance.

3. Within a stand, the DBH is measured at every tree so as to obtain X_i. The trees are measured systematically. At the same time, the sum $T_j = \sum_{i=1}^{j} X_i$ $(T_o = o)$ is calculated.

4. A tree j is taken as a sample tree if, and only if, some of the numbers $s + hL$ falls between the numbers T_{j-1} and T_j (T_{j-1} exclusive, T_j inclusive).

In this manner all trees are measured. If for some tree $X_i < L$, it is measured as a sample tree but it is disregarded in the cumulation. This kind of trees form a stratum of their own.

33. The principle of the Cumulator

The sample selector for sample trees consists of two circular plates pivoted one on the other (Fig. 1). The underlying piece is larger and its circumference is scaled for reading the DBH-based volume. When measuring a stand the counting-of-trees is started from any corner of the stand and progresses systematically from that point. The DBH of every tree is measured and in accordance with the scale on the lower plate the upper disc is turned clockwise as fas as is indicated by a DBH gauge. The plate can easily be rotated with the point of a pencil. There is an arrow on the upper circle to mark a sample tree. If the arrow, before the upper disc is rotated, falls

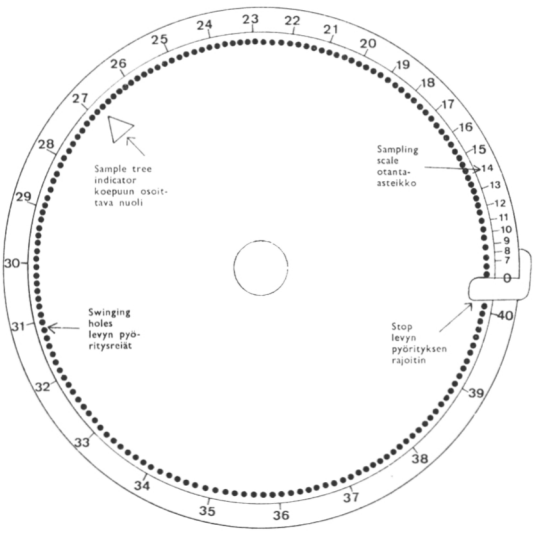


Fig. 1. A DBH cumulator
Kuva 1. Kuutiomäärän summaaja

between the cipher-point and the point which marks the DBH on the lower plate, the tree is taken as a sample tree. The scaled plate is provided with a stop at the cipher-point so as to stop the rotation movement. When starting the samplingprocess the position of the upper disc may be fortuitous (selection of the number s) and accordingly the first sample tree is not determined. In order to fix the sampling density (the sampling interval L) there should be several scales. In addition, the upper plate could be provided with more than one arrow at regular intervals in order to meet the different sampling densities. The arrows could be of different colour and design.

By changing the mechanism of the apparatus, a lottery device for 3-P sampling is obtained, which works on the same principle. This possibility, however, will not be discussed here.

34. Information provided by the Cumulator

In accordance with the principle of the Cumulator a full rotation of the scale corresponds to a certain volume L which can be varied. Hence, on the basis of the sample trees (n) an estimate is obtained for the volume of the stand.

$$\hat{V} = n \times L \tag{34.1}$$

As a volume which is based solely on the diameters is in question the estimate is not very reliable. The relative standard error of the prediction which was obtained by means of the spruce equation described above was about 18 per cent for the material used in the calculation of the function. Within one and the same stand the dispersion is not that wide, and anyway the result can be quite erroneous. The reliability of the estimate can be ameliorated with the aid of information concerning the mean ratio DBH/tree height in the stand. Moreover, there are differences between tree species as regards the volumes analyzed by the DBH. For this reason, a table has been constructed which gives a correction coefficient on the basis of the mean tree (DBH and height) of a stand. The relative standard error of the prediction obtained by means of the following volume equation for pine based on the DBH and height is about 6.7 per cent:

$$V = 0.0785398\, D^2 H\,(-0.111667 - 0.372075/\ln D - 2.77401/H + 2.33018 /\ln H + 0.092927\, H/D)$$

Using this equation we are able to get the following table of correction factors as compared to the volumes (X) given by the equation described which was based exclusively on the DBH.

D, cm	Tree height, m — *Puun pituus, m*								
	6	8	10	12	14	16	18	20	22
7	0.96	1.21	1.48						
9	0.81	1.01	1.22	1.44					
11	0.71	0.87	1.05	1.24	1.43				
13	0.64	0.78	0.93	1.09	1.25	1.42			
15		0.71	0.84	0.98	1.13	1.27	1.42		
17		0.65	0.77	0.90	1.03	1.16	1.29	1.43	
19		0.61	0.72	0.83	0.95	1.07	1.19	1.31	1.44
21		0.57	0.67	0.78	0.89	1.00	1.11	1.22	1.33
23			0.64	0.73	0.83	0.94	1.04	1.13	1.25
25			0.60	0.70	0.79	0.89	0.98	1.08	1.18

This corrected volume obtained above was found to deviate from the actual volume only by a few per cents in the case of some sample plots. On estimating the volume, a better distribution of sample trees may be obtained if the scale of the Cumulator would be applied to the basal area corresponding to the DBH. However, in the stands to be sold on-the-stump the question is usually about the total value of the stand, in which the variance is liable to increase even more quickly than in the volume when the DBH is increasing. In addition, the unit volume value for largesized trees can be even double as compared to the unit volume of small trees. Sampling according to volume is hence better.

Sampling based on the value of the stem would also be interesting, for this would give some idea about the approximate market value of the forest immediately after the counting-of-trees. On the other hand, it is feasible to check the calculations by means of the volume estimate in order to eliminate greater errors because the volume data in any case are being included. The basal area of the forest cannot offer a similar advantage, although it could be determined rather precisely.

4. CALCULATION OF RESULTS

Some estimates can be computed for the whole population using only the sample tree data. The sampling interval is marked with L as above. Thus the selection probability p_i for the tree i is the ratio of its estimated volume (X_i) to L or

$$p_i = \frac{X_i}{L} \tag{4.1}$$

For total volume Y of the population we get the estimator (cf. S c h r e u d e r et al. p. 106)

$$Y = L \sum_{i=1}^{n} \frac{V_i}{X_i}, \text{ where} \tag{4.2}$$

V_i = the volume of the sample tree i which can be obtained from the table or by using an equation.

L/X_i or $1/p_i$ can presupposed to represent the number of trees counted in a full rotation of the plate, or the number-of-stems for the whole population is approximately

$$N' = \sum_{i=1}^{n} \frac{L}{X_i} = L \sum_{i=1}^{n} \frac{1}{X_i} \tag{4.3}$$

The nearer N' is to the true value N of the number-of-stems, the better is the mean volume that we get by means of the sample trees alone:

$$\overline{V} = \frac{\sum_{i=1}^{n} \frac{L}{X_i} \cdot V_i}{\sum_{i=1}^{n} \frac{L}{X_i}} \simeq \frac{n}{\sum_{i=1}^{n} \frac{1}{X_i}} \tag{4.4}$$

When it is a question of systematic sampling, any exact value for the variance cannot be calculated. The true variances in the total volume can

be approximated from the formula, provided that the sampling proportions are small (cf. Schreuder et al. p. 106)

$$V(Y') = \sum_{i=1}^{N} z_i \left(\frac{V_i}{z_i} - Y \right)^2 / n, \tag{4.5}$$

where $z_i = X_i/X$

Y = the true volume

The estimator for that variance is

$$V(Y') = \left\{ \sum_{i=1}^{n} (V_i/z_i)^2 - \left(\sum_{i=1}^{n} V_i/z_i \right)^2 / n \right\} / n\,(n-1) \tag{4.6}$$

In connection with the sampling method described above this formula generally gives too great variances compared to the actual variance.

In so far as the stem-diameter distribution is known, the results can be checked by making the calculations by DBH-classes. Thus the results for each DBH-class are obtained with the aid of the sample trees which fall into the DBH-class in question.

By using the formulae for regression estimators, the information involved in the sample trees can be more efficiently exploited, and there is no need to attach too much attention to the distribution of the sample trees into the different DBH-classes. The formulae for ratio and regression estimates will not be touched upon here.

5. CONCLUSIONS

Selection of sample trees is one of the most important work phases in the estimation of standing trees. This becomes clear if we realise that the visits to sample trees take more than one half of the working time. If the selection of sample trees is arranged in an optimal way, the same accuracy can be attained with a considerably smaller number of sample trees and with lower costs. The sample tree selection method which has been described above has some properties to recommend its usage. As we have seen it distributes the sample trees along the series of numbers of trees in a correct ratio to the variance in volume of the series. Furthermore, on the basis of the numbers of sample trees a fairly good estimate is obtained for the total volume of the population. In addition, the sample trees are evenly distributed througout the different parts of the population. This capacity is quite important if we think that stem form is liable to vary to some extent even within a stand. With the Cumulator the choice of sample trees can be done quickly and easily. However, in order to remove a possibility for subjective selection which goes with such a systematic sampling, the trees ought to be measured completely systematically.

If regression estimators are used for calculating the results, the sample tree data can be more efficiently utilized, and by this means the necessary number of sample trees can also be reduced. The calculations should always be accompanied by an analysis of the reliability of the characteristics used. In this way the results would be more versatile.

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SELOSTE

Käytännön- ja tutkimustehtäviä varten suoritetaan kasvavan puuston mittauksia runsaasti. Erityisesti metsän myyminen pystyleimikkoina on nopeasti lisääntynyt pystymittaus- ja palkanlaskenta- eli PMP-tietokonesysteemin ansiosta. Tällaisissa metsänarviointitehtävissä koepuiden valinta muodostaa tärkeän työn osan. Tässä tutkimuksessa käsitellään yleisen, tehtävään liittyvän otantateorian lisäksi kirjoittajan kehittämällä summaajalla tapahtuvaa koepuiden valintamenettelyä.

Vaikka koepuiden valinta on selvä teoreettinen otantaongelma, on tarkkojen otantaohjeiden antaminen kussakin erillistapauksessa vaikeaa, koska esim. leimikon runkoluvusta ja kiinnostuksen kohteena olevien tunnusten vaihteluiden suuruudesta ei ole tietoa etukäteen. Koepuiden kuutiomäärää ei saada tarkasti kolmen tunnuksen (D, $D6$ ja H) avulla, vaan »taulukkovirheeksi» jää puuta kohti noin 5 %. »Taulukkovirheen» suuruus useampien koepuiden tapauksessa voidaan laskea kaavan (2.1), s. 6, avulla. Läpimittaluokkiin ositetun kokonaiskuutiomäärän varianssi saadaan kaavasta (2.2), s. 6. Optimaalisen kiintiöinnin mukaiset otosmäärät läpimittaluokittain, mikäli mittauskustannukset puuta kohden oletetaan vakioksi, saadaan kaavalla (2.3).

Kuutiomäärien läpimittaluokittaiset hajonnat kasvavat jyrkästi läpimitan kasvaessa. Varianssin ja keskikuution suhde kussakin läpimittaluokassa on likimain vakio. Läpimittaluokituksen laajuuden vaikutusta luokan varianssiin voitiin tutkia kaavan (2.5), s. 7, avulla. Taulukosta 1, s. 8, ilmenee tämä luokkavälin laajuuden vaikutus varianssiin käytettäessä 1 cm:n tai 2 cm:n luokitusta. Taulukon arvot on laskettu tasajakaumaoletuksella. Taulukon arvoista nähdään, että 2 cm:n luokituksesta aiheutuva varianssi 1 cm:n luokitukseen verrattuna on noin nelinkertainen ja edelleen voitiin päätellä, että kokonaiskuutiomäärän varianssi tulee noin kaksinkertaiseksi.

Koska kuutiomäärän varianssi kasvaa suhteessa kuutiomäärään on 3-P otanta, jossa otanta tapahtuu suhteessa puun ennustettuun kokoon, tehokas otantamuoto. Kuvassa 1, s. 12, näkyvällä laitteella otanta tapahtuu systemaattisena otantana runkojen kuutiomäärien kumuloidusta summasta. Rungon tilavuutta estimoidaan rinnankorkeusläpimittaan perustuvan yhtälön (3.1) avulla. Kunkin rungon todennäköisyys tulla koepuuksi on suhteessa rungon estimoituun tilavuuteen.

Koepuiden valintalaitteen muodostaa kaksi päällekkäistä pyöreää levyä (kuva 1), joista alimmainen on suurempi ja sen ulkokehällä on läpimittaan perustuva kuutiomääräasteikko. Tämän asteikon mukaisesti päällimmäistä levyä pyöräytetään luetun läpimitan verran. Mikäli tässä levyssä oleva koepuuta osoittava nuoli ohittaa asteikon 0-kohdan puu tulee koepuuksi.

Summaajan yksi kierros edustaa tiettyä kuutiomäärää L, jota voidaan vaihdella. Täten koepuiden lukumäärän (n) perusteella saadaan kuutiomäärälle estimaatti yhtälöllä (34.1), s. 12. Tätä estimaattia voidaan tarkentaa metsikön keskimääräisen läpimitta-pituus suhteen avulla. Tällaiset pituuskorjauskerrointaulukot on laadittu puulajeittain. Pelkkien koepuutietojen avulla voidaan laskea eräitä estimaatteja populaa-

tiolle. Yhtälön (4.2), s. 15 avulla saadaan kokonaiskuutiomäärä ja estimaattori sen varianssille kaavalla (4.6) s. 16.

Tällä koepuiden valintamenetelmällä on eräitä tärkeitä ominaisuuksia, jotka puoltavat sen käyttöä. Se jakaa koepuut runkolukusarjalle oikeassa suhteessa sillä olevan kuutiomäärän varianssiin nähden. Koepuut jakaantuvat kuutiomäärän suhteen tasaisesti eri osiin leimikkoa. Edelleen jo koepuiden lukumäärän perusteella saadaan melko hyvä estimaatti kokonaiskuutiomäärälle. Koepuiden valinta tapahtuu nopeasti ja helposti kumulaattoria käytettäessä.

ON THE PROPERTIES OF LARCH WOOD IN FINLAND

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LYHENNELMÄ

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PREFACE

The Department of Forest Technology, Finnish Forest Research Institute, began in autumn 1969 to study the wood properties of domestic tree species not hitherto investigated and of exotics that thrive in Finnish conditions. The study was conducted chiefly with reference to the needs of the pulp and paper industry. The first investigations concerned *Alnus incana* and *Pinus contorta*. This part reports mainly on *Larix sibirica*, with minor emphasis on *Larix europaea*, *Larix leptolepis* and *Larix dahurica*. The next to be studied will be some *Picea* and *Abies* species.

The present study was conducted by the Finnish Forest Research Institute. Close cooperation was maintained throughout the work with the Finnish Pulp and Paper Research Institute which, using the same sample trees, performed experiments in pulping, bleaching and paper making. The results have appeared earlier in separate publications (Nikki 1971, Palenius 1971, Saukkonen 1971, Hakkila, Nikki and Palenius 1972, Saukkonen and Arvela 1973).

A Finnish-Soviet Symposium on the »Use of Larch as Raw Material for Pulp and Paper Industry» was arranged in Leningrad November 15—19, 1971, as a part of the scientific-technical cooperation between the Soviet Union and Finland. The papers given in the symposium have been of great value in writing the present report. Especially the practical experience of the Soviet experts in the utilization of larch wood turned out to be most useful for the Finnish research programme.

The material was collected from the forests of the Finnish Forest Research Institute and the National Board of Forestry in summer 1970 by Mr. Simo Jaaranen and Mr. Jaska Kosamo. Mr. Reino Saarnio and Mr. Teuvo Hinttala gave valuable assistance in selecting the sample plots.

Most of the laboratory and typing work was done by Mrs. Marja Eloranta, Mrs. Taija Havanto, Mrs. Kaarina Koskinen, Miss Aira Päivöke, Mrs. Aune Rytkönen, Miss Pirjo Salonen, Miss Raija Siekkinen and Miss Maaret Turunen. The manuscript was translated into English by Mr. L. A. Keyworth and Miss Päivikki Ojansuu.

The authors extend their best thanks to all those participating in the study.

Helsinki, August 1973.

Pentti Hakkila *Arja Winter*

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1. INTRODUCTION

The larch has done fairly well in cultivation experiments with exotics in Finnish conditions. The best results have been achieved with Siberian larch the natural range of which extends almost to Finland's eastern border (Fig. 1). The European larch grows equally fast, but its stem form and resistance to some natural calamities are poorer. Positive results have been obtained also in plantations of Dahurian and Japanese larch. In contrast, North American larch species seem to do poorly in Finland (A. F. Tigerstedt 1922, Sarvas 1964, P. M. A. Tigerstedt 1970).

Great hopes are placed in the long term on hybrids between the species and their improvement is already in progress. However, the best possibilities are offered so far by Siberian larch and almost all the present-day cultivations are in fact of this tree species. The total area of Siberian larch stands established in Finland is 3 000—4 000 hectares.

Siberian larch thrives in a diversity of sites. Its yield in terms of volume is slightly higher than that of Scots pine and Norway spruce in the best

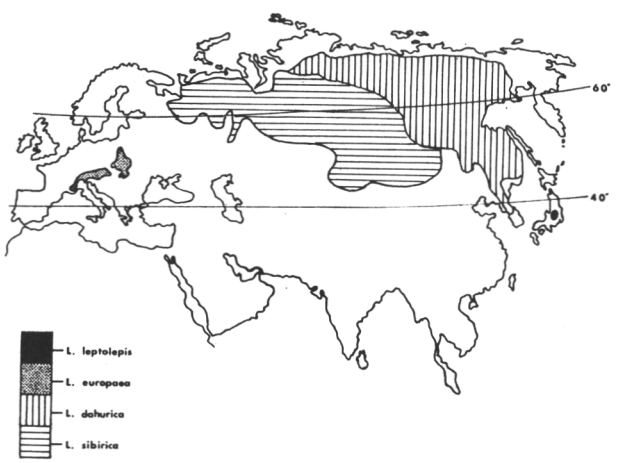


Figure 1. The natural range of Siberian, European, Dahurian and Japanese larch.

Kuva 1. Siperian, Euroopan, Dahurian ja Japanin lehtikuusen luontainen levinneisyysalue.

soils and comes up to the level of domestic softwoods even in mediocre sites. Larch has, moreover, a special characteristic in which it is far superior to the domestic species. The height and diameter growth of individual trees is exceptionally fast — true, at the expense of the number of stems (Fig. 2). Certain dimensions may be achieved even in half the time required by pine and spruce. If it is desired in Finland to grow large timber trees quickly for certain special purposes, this is best achieved with Siberian larch (V u o k i l a 1960 a and b, 1971).

Cultivation of larch can be motivated by growth and yield considerations at least on fertile sites. However, the prejudices that attach to the technical properties of larch wood constitute an obstacle. It is difficult to find markets even for the larch wood offered for sale in Finland today as industry is accustomed to rely on domestic tree species. But it is known that larch has many valuable uses within its natural range of growth in the USSR, Central Europe and North America. It is very suitable for instance for lumber, pitprops, poles, piles and log cabins, and because of its resistance



Figure 2. An 80-year old stand of Siberian larch at Punkaharju in South Finland. (Photo by Reino Saarnio).

Kuva 2. Siperian lehtikuusimetsikkö Punkaharjulla 80 vuoden iässä. (Kuvannut Reino Saarnio).

to decay it is recommended especially for structures exposed to humidity variations (cf. Hakkila 1961).

The pulp industry will be the major wood user in Finland in the future. Large-scale cultivation of foreign tree species, too, thus makes it absolutely essential that the species meets also the demands made by this branch of industry. Above all, the need of raw material for sulphate pulp will increase.

When a tree species is moved outside its natural range its technical properties may change. It is consequently impossible to assess the suitability of Finnish-grown larch for pulp production solely on the strength of foreign experience. Domestic studies are also necessary. For instance, the broad experience gained in the USSR of the utilisation of Siberian larch as industrial raw material relates to old virgin forests, whereas in Finland it is plantations that are at issue.

In summer 1970, therefore, the Finnish Forest Research Institute in cooperation with the Finnish Pulp and Paper Research Institute began a study of the suitability of Finnish larch wood as raw material for sulphate



Figure 3. A 34-year old stand of Siberian larch at Kivalo in North Finland. (Photo by Reino Saarnio).

Kuva 3. Iältään 34-vuotias Siperian lehtikuusimetsikkö Kivalossa Pohjois-Suomessa. (Kuvannut Reino Saarnio).

pulp. The Finnish Forest Research Institute undertook to study the following wood properties important for the pulp industry:

— Percentage of bark
— Percentage of heartwood
— Percentage of knotwood
— Basic density of wood
— Percentage of acetone extractives
— Percentage of hot water extractives

The main material consisted of Siberian larch. Special attention was paid to northern sample stands as Siberian larch thrives also in North Finland (cf. Turtiainen 1969) (Fig. 3). As regards the other larch species, it was sought to clarify only the average characteristics in South-Finnish plantations.

The study keeps in the main to the guidelines applied by the authors in their corresponding work on lodgepole pine (cf. Hakkila and Panhelainen 1970). When the results of these two studies are compared later no mention is made on the whole of the lodgepole pine study in the references.

2. METHODS

From each of the 400 sample trees 5 cm thick discs were taken from the butt cross-section up to the top at intervals of 2 m. In trees the height of which was not more than 12 m, the interval was 1 m only. The discs were measured in the laboratory for diameter without bark, diameter of heartwood, area of knotwood on both sides, green volume without bark, dry weight of wood and dry weight of bark. On the basis of the laboratory measurements, the following factors were calculated for each disc. The stem means were calculated by weighting the disc measurements by the disc diameter and the bolt length.

— Percentage of bark by dry weight
— Percentage of heartwood by green volume
— Percentage of knotwood by green volume
— Basic density of unextracted wood
(dry weight divided by green volume, kg/cu.m)

In addition, a saw dust sample of about 200 grams when green was collected from each tree from randomly selected heights. The sample was taken by a chain saw adjusted for the sampling procedure. To keep the saw dust clean from oil the chain was lubricated extremely sparingly. After lubrication the saw was first used for cutting the discs. The dust sample was automatically collected in a plastic bag (Fig. 4) and always consisted of dust from several complete cross-cuts so that the sapwood and the heartwood were represented in the right ratio. The dust was used to measure the content of acetone and hot water soluble extractives. The method recommended by the Scandinavian Pulp, Paper and Board Testing Committee for the dichlorinemethan extractives was applied here for the acetone extractives (SCAN-C7: 62).

From each tree a 40 cm long bolt was taken from the 25 per cent height. The bolts were used for the sulphate pulping experiments by the Finnish Pulp and Paper Research Institute.

The principal statistical method employed was regression analysis. It was applied to explain the within-stem variation of percentage of bark, percentage of heartwood, basic density and percentage of acetone and hot water



Figure 4. Collecting a saw dust sample by chain saw.
Kuva 4. Purunäytteen keruu moottorisahalla.

soluble extractives. The longitudinal variation in the stem in the percentage of knotwood was described solely by means of averages calculated at different heights. Regression analysis was also used to explain the between-stem and between-stand variations.

Another statistical method applied was analysis of covariance. It was used to test the significance of the differences of the wood properties of larch species in southern Finland and, on the other hand, the differences of the properties of Siberian larch in southern and northern Finland. The effect of age was taken into consideration as a regression variable.

The significance levels used in the tests were 95, 99 and 99.9 per cent. The asterisk after the test quantity denotes that the result is significant with 5 per cent risk. Two and three asterisks signify correspondingly a 1 and 0.1 per cent risk.

The statistical treatment of the material was performed mainly in the UNIVAC 1108 computer of the State Computer Centre. Some of the stepwise, selective analyses of regression were done on the GE-600 computer of Oy Nokia Elektroniikka Ab through the terminal station of the Finnish Forest Research Institute.

3. MATERIAL

The material was collected in summer 1970. In the south the trees were obtained from the research forests of the Finnish Forest Research Institute and in the north from the forests of the National Board of Forestry. The total material comprised 40 plantations, of which seven were in North Finland (Fig. 5).

The bulk of the material, 29 stands, grew Siberian larch (*Larix sibirica* Ledeb.). The country of origin of all the trees was the USSR. The seed of several stands had been collected from the famous Raivola larch plantation on the Karelian Isthmus. The seed had probably been brought to Raivola originally from the Archangel district (Ilvessalo 1923, Heikinheimo 1927).

In addition to Siberian larch the material included three European larch stands (*Larix europaea* DC. or *Larix decidua* Mill.), six Dahurian larch stands (*Larix dahurica* Turcz. or *Larix Gmelini* (Rupr.) Litv.) and two Japanese

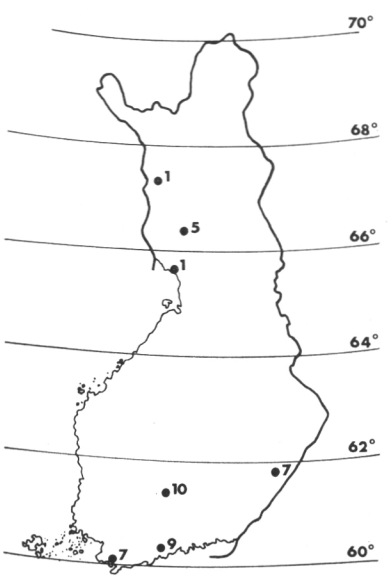


Figure 5. Location and number of sample stands.
Kuva 5. Koemetsiköitten sijainti ja lukumäärä eri paikkakunnilla.

larch stands (*Larix leptolepis* (Sieb. et Zucc.) Gord.). The European larch derived from Germany, the Dahurian from Japan or Korea, and the Japanese larch from Japan. The sample stands of all these species were in southern Finland.

Table 1. Research material
Taulukko 1. Tutkimusaineisto

Stand *Metsikkö*	Seed source *Siemenen alkuperä*	Location *Sijainti*	Latitude *Leveysaste*	Site type *Metsätyyppi*	Age, years *Ikä, vuotta*	Dbh, cm $D_{1,3}$, *cm*	Height, m *Pituus, m*	Volume, l *Tilavuus, l*	Crown proportion *Latvussuhde* %
	Larix sibirica								
1	Soviet Union	Bromarv	59° 59″	OMT	42	19	16	167	48
2	Soviet Union	Bromarv	59° 59″	OMT	41	17	15	116	48
3	Soviet Union	Ruotsinkylä	60° 21″	VT, MT	28	14	12	68	75
4	Soviet Union	Ruotsinkylä	60° 21″	VT, MT	28	11	10	43	73
5	Soviet Union	Ruotsinkylä	60° 21″	MT	27	15	13	95	63
6	Soviet Union	Ruotsinkylä	60° 21″	MT	40	14	15	100	42
7	Soviet Union	Ruotsinkylä	60° 21″	MT, OMT	28	14	12	70	53
8	Soviet Union	Ruotsinkylä	60° 21″	MT, OMT	42	17	16	150	54
9	Soviet Union	Vesijako	61° 26″	MT, OMT	45	18	19	205	43
10	Soviet Union	Vesijako	61° 26″	MT	45	14	14	94	65
11	Soviet Union	Vesijako	61° 26″	OMT	45	19	20	251	42
12	Soviet Union	Vesijako	61° 26″	OMT	62	28	24	579	43
13	Soviet Union	Vesijako	61° 26″	OMT	84	33	24	768	41
14	Soviet Union	Vesijako	61° 26″	OMT	88	28	22	555	61
15	Soviet Union	Vesijako	61° 26″	OMT	88	33	27	924	52
16	Soviet Union	Vesijako	61° 26″	OMT	88	23	23	484	49
17	Soviet Union	Vesijako	61° 26″	OMT	83	33	28	955	50
18	Soviet Union	Vesijako	61° 26″	MT	45	19	18	198	55
19	Soviet Union	Punkaharju	61° 49″	OMT	27	17	15	139	52
20	Soviet Union	Punkaharju	61° 49″	MT	93	34	23	820	73
21	Soviet Union	Punkaharju	61° 49″	OMT	40	20	18	207	42
22	Soviet Union	Punkaharju	61° 49″	OMT, OT	45	29	26	684	35
23	Soviet Union	Simo	65° 37″	EVT	61	23	14	240	67
24	Soviet Union	Rovaniemi	66° 22″	HMT	60	12	10	49	55
25	Soviet Union	Rovaniemi	66° 22″	HMT	42	17	12	105	86
26	Soviet Union	Rovaniemi	66° 22″	HMT	45	14	13	85	65
27	Soviet Union	Rovaniemi	66° 22″	HMT	42	13	12	59	69
28	Soviet Union	Rovaniemi	66° 22″	HMT	26	9	7	21	62
29	Soviet Union	Kolari	67° 12″	EMT	37	11	9	35	72
	Larix europaea								
30	Unknown	Ruotsinkylä	60° 21″	MT	19	11	8	34	82
31	Germany	Ruotsinkylä	60° 21″	OMT	44	17	16	175	61
32	Germany	Punkaharju	61° 49″	MT, OMT	43	27	21	441	54
	Larix leptolepis								
33	Japan	Bromarv	59° 59″	OMT	42	19	17	188	44
34	Japan	Bromarv	59° 59″	OMT	41	27	20	482	52
	Larix dahurica								
35	Japan	Bromarv	59° 59″	OMT	44	18	16	135	60
36	Korea	Bromarv	59° 59″	OMT	44	17	14	138	70
37	Korea	Bromarv	59° 59″	OMT	43	17	15	145	54
38	Japan	Ruotsinkylä	60° 21″	OMT	44	16	16	144	45
39	Korea	Punkaharju	61° 49″	MT, OMT	44	23	21	343	51
40	Japan	Punkaharju	61° 49″	OMT	44	22	22	358	47

Most of southern plantations were on fertile soil in an *Oxalis-Myrtillus* site (OMT). There were also several sample stands on *Myrtillus* site (MT). The majority of the northern stands were on *Hylocomium-Myrtillus* site (HMT). These were typical spruce sites. No peatlands were included in the material.

The sample stands were pure even-aged larch stands established by planting. The age of the plantations ranged from 19 to 93 years. The mean age of the total material was 49 years.

Ten sample trees that represented different size classes were felled from each stand. The total of sample trees was thus 400. About 4 500 discs were sawn from the sample trees. In addition, a saw dust sample was taken from each tree, making 400 samples in all.

Table 1 gives information in the average size of the trees in different sample plots. The smallest trees in the material were the 19-year-old European larches growing in sample plot 30 in Ruotsinkylä; their mean diameter at breast height above bark was 11 cm, height 8 m and volume 34 litres. The largest trees came from sample plot 17 in an 83-year-old Siberian larch stand at Vesijako; their mean diameter at breast height was 33 cm, height 28 m and volume 955 litres.

4. RESULTS

41. Percentage of bark

Contrary to common practice, the proportion of bark was calculated on the dry weight basis in this study. The dry weight of bark was compared with the combined dry weight of bark and wood.

$$\text{Percentage of bark} = \frac{100 \cdot \text{Dry weight of bark}}{\text{Total dry weight of bark and wood}}$$

411. Variation within the stem of Siberian larch

The longitudinal variation of bark percentage is illustrated by a regression equation in which the relative sampling height is the independent variable. Tree height as a separate variable improves the equation as bark percentage depends also on the size of the tree.

	R^2	$s_{y \cdot x}$, %
$y = 21.1 - 0.204x_1 - 0.237x_2 + 0.00434x_1^2 - 0.00420x_1x_2$	0.776	2.7

y = Percentage of bark at a certain height
x_1 = Relative height in the stem, %
x_2 = Stem height, m

The bark percentage of Siberian larch is relatively high on the butt of the tree (Fig. 6). The proportion of bark decreases from the butt to the 1/3 height of the stem. After that the percentage of bark begins to grow again and reaches at the 2/3 height of the stem the same level as on the butt of the tree (Fig. 7).

It is possible to estimate the average bark percentage of the stem on the above basis from a sample taken at a certain height. For example, the bark percentage in the investigation material at breast height was 0.8 per cent units lower than in the whole stem on average. The following equation can be used.

	R^2	$s_{y \cdot x}$, %
$y = 2.21 + 0.902x_1$	0.882	1.3

y = Average percentage of bark in a stem
x_1 = Percentage of bark at breast height



Figure 6. Rough bark at the butt of a Siberian larch stem.
Kuva 6. Rosokaarnaa Siperian lehtikuusen tyvellä.

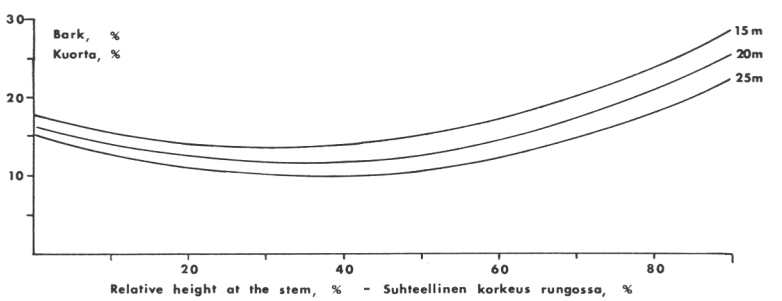


Figure 7. The longitudinal variation of bark percentage in 15-, 20- and 25-metre Siberian larch stems.
Kuva 7. Siperian lehtikuusen kuoriprosentin vaihtelu puun pituussuunnassa 15-, 20- ja 25-metrisissä rungoissa.

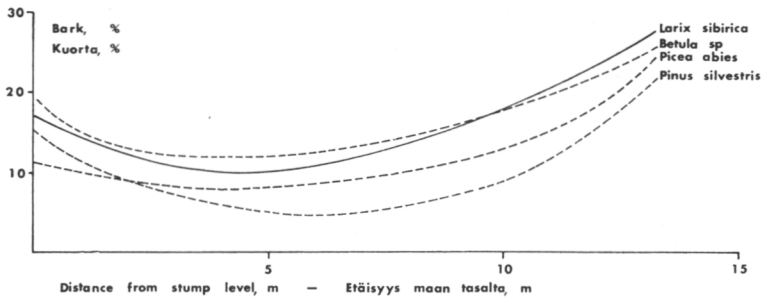


Figure 8. The longitudinal variation of bark percentage of 15-metre Siberian larch stem compared with domestic pine, spruce and birch.
Kuva 8. Siperian lehtikuusen kuoriprosentin vaihtelu puun pituussuunnassa 15-metrisessä rungossa mäntyyn, kuuseen ja koivuun verrattuna.

The bark percentage of Siberian larch is higher than that of Scots pine and Norway spruce in all parts of the stem, but slightly lower than the bark percentage of birch (cf. Hakkila 1967). The bark percentage is high compared with plantation-grown lodgepole pine. The variation pattern of bark percentage of Siberian larch in the longitudinal direction of the stem resembles spruce greatly, with the difference that the larch bark percentage is 4—5 per cent units higher at all heights (Fig. 8).

412. Variation between stems of Siberian larch

The average percentage of bark in the sample trees was 15.5 for Siberian larch. The standard deviation between stems was 3.7 per cent units which was 24 per cent of the mean.

Stem-to-stem variation is explained best by variables that illustrate the tree size, especially tree height. When one independent variable is considered to suffice, the following equation gives the highest degree of determination.

	R^2	$s_{y \cdot x}$, %
$y = 7.9 + 101/x_1$	0.661	2.0

y = Average percentage of bark in a stem
x_1 = Stem height, m

The proportion of bark is thus reduced sharply when a tree grows. To mention an example, according to the equation the percentage of bark in a 10-m high tree is with 95 per cent confidence 18.0 ± 3.9, but correspondingly only 12.9 ± 3.9 in a 20-m tree.

Tree height, m	10	15	20	25	30
Average percentage of bark	18.0	14.6	12.9	11.9	11.3

Among several different external tree characteristics or their combinations, breast height diameter divided by age, in other words the variable that indicates the diameter growth of a tree, improves the former equation best. The faster the tree has grown the smaller is the percentage of bark.

	R^2	$s_{y \cdot x}$, %
$y = 10.8 + 93/x_1 - 5.6x_2/x_3$	0.701	1.9

y = Average percentage of bark in a stem
x_1 = Stem height, m
x_2 = Breast height diameter, cm
x_3 = Age, years

The average percentage of bark in Siberian larch is relatively high compared with domestic tree species. The average stem size in South Finland was 349 litres and bark percentage 14.0. The following observations on the dry weight percentage of bark of domestic tree species are reported by way of comparison (H a k k i l a 1967 and 1970): Scots pine 8.0 (mean volume 166 litres), Norway spruce 10.0 (138 litres), birch 14.8 (148 litres), grey alder 13.0 (23 litres) and plantation-grown lodgepole pine 9.5 (116 litres).

413. Variation between stands of Siberian larch

Stem-to-stem variation of bark percentage is partly the result of variation between stands. On the other hand, stand-to-stand variation is due partly to the differences between the south and the north. Variance analysis shows that geographical variation, too, is statistically significant at a very low risk level.

Source of variation	SS	d.f.	MS	F
Between south and north	1 349	1	1 349	35.50***
Between stands	1 018	27	38	9.50**
Within stand + analytical error	1 079	261	4	
Total	3 446	289		

The differences between stands are caused primarily by the differences in tree size, as can be concluded from the preceding chapter. The differences between south and north are also partly of the same origin. As the growth rate is always slower in North than in South Finland it is not meaningful to compare trees of the same size. On the other hand, it is appropriate to take the effect of age on the bark percentage in a stand into consideration.

	R^2
$y = 17.9 - 0.054x_1$	0.35

y = Average percentage of bark in a stand
x_1 = Age, years

The bark percentage of Siberian larch thus decreases with increasing age. For instance, the percentage of bark in a 20-year-old stand is 16.8 ± 5.2, against only 13.7 ± 5.2 in a 80-year-old stand. A more correct result can be attained, therefore, if the above-mentioned analysis of variance is substituted by analysis of covariance in which the age is also included as a regression variable.

Source of variation	d.f.	Sums of squares and products			Deviations from regression			
		Σx^2	Σxy	Σy^2	$\Sigma y^2 - \frac{(\Sigma xy)^2}{\Sigma x^2}$	d.f.	MS	F
Geographical	1	3 181	—2 071	1 349	—	—	—	
Between stands	27	124 049	—6 673	1 018	659	26	25	6.25*
Within stand + error	261	—	—	1 079	1 079	261	4	
Total	289	127 230	—8 744	3 446	2 845	288	—	
The difference to test the corrected means of south and north .	—	—	—	—	1 107	1	1 107	44.28***

Analysis of coveriance shows the differences between south and north to be significant also after the effect of age on the results has been eliminated. The end results are therefore corrected by the regression coefficient of the age variable, that is —0.054 ($F_{1,26} = 14.36$***), which gives the mean bark percentage for South and North Finland in a 50-year-old stand.

	South	North
Age of sample trees, years	53	45
Bark percentage of sample trees	14.0	19.0
Bark percentage at the age od 50 years	14.1	18.7

The bark percentage of Siberian larch is thus considerably higher at a certain age in the north than in the south. It is largely differences in the size of the trees that is at issue. Siberian larch resembles Norway spruce in this respect (cf. Rikkonen 1971).

414. Variation between larch species

In comparing larch species the effect of age on the results must be eliminated. On the other hand, stem size need not be considered for size differences are to a great extent the consequence of the growth rate characteristic of the species. Only the South-Finnish material is included in the following analysis.

Source of variation	d.f.	Sums of squares and products			Deviations from regression			
		Σx^2	Σxy	Σy^2	$\Sigma y^2 - \frac{(\Sigma xy)^2}{\Sigma x^2}$	d.f.	MS	F
Between species	3	10 918	158	142	—	—	—	
Between stands	29	118 835	—7 295	1 307	859	28	31	10.33***
Between stems + error	297	—	—	955	955	297	3	
Total	329	129 753	—7 137	2 404	2 011	328	—	
The difference to test the corrected means of species	—	—	—	—	197	3	66	2.13

The regression coefficient of age is —0.061 ($F_{1,28} = 14.45$***) for the material from South Finland. In Siberian and European larch the proportion of bark seems to be higher than in Dahurian and Japanese larch. The differences are not statistically significant, however.

	Larch			
	Siberian	European	Dahurian	Japanese
Age of sample trees, years	53	35	44	42
Bark percentage of sample trees	14.0	15.0	12.7	12.7
Bark percentage at the age of 50 years	14.2	14.2	12.4	12.3

42. Percentage of heartwood

The percentage of heartwood refers to the proportion of heartwood in the total volume of barkless wood. Heartwood was separated from sapwood solely by its darker colour (Fig. 9).

$$\text{Percentage of heartwood} = \frac{100 \cdot \text{Volume of green heartwood}}{\text{Total volume of green wood}}$$

421. Variation within the stem of Siberian larch

The variation of the percentage of heartwood in the longitudinal direction of the stem is explained best by an equation in which the sampling height and tree height are concurrently the independent variables. More than three-fourths of the disc-to-disc variation can be explained.

	R^2	$s_{y \cdot x}$, %
$y = 26.0 - 0.375x_1 + 1.97x_2 - 0.00240x_1^2$	0.779	10.7

y = Percentage of heartwood at a certain height
x_1 = Relative height in the stem, %
x_2 = Stem height, m

The percentage of heartwood in Siberian larch is greatest at the butt of the stem and then decreases evenly towards the top of the tree. There is more heartwood in all parts of the stem of large than of small trees (Fig. 10).

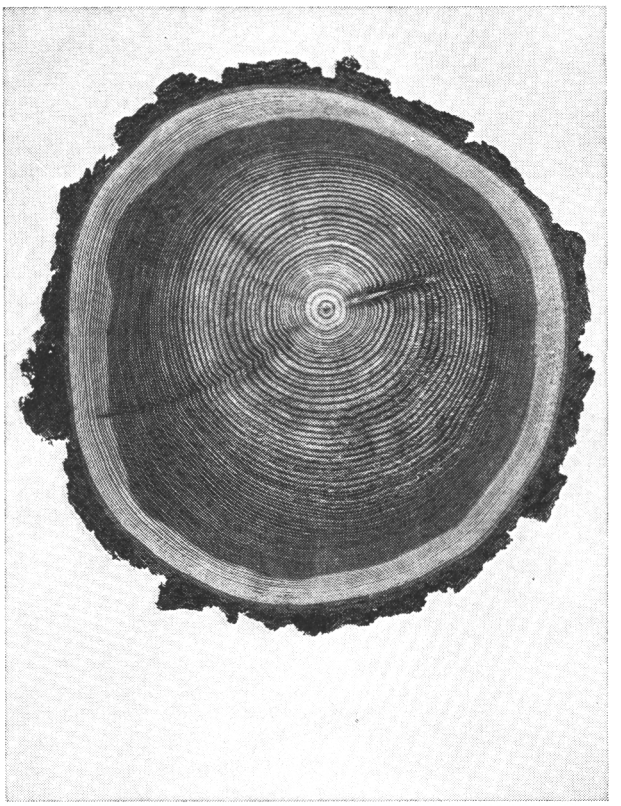


Figure 9. Heartwood formation in Siberian larch.
Kuva 9. Siperian lehtikuusen sydänpuumuodostuma.

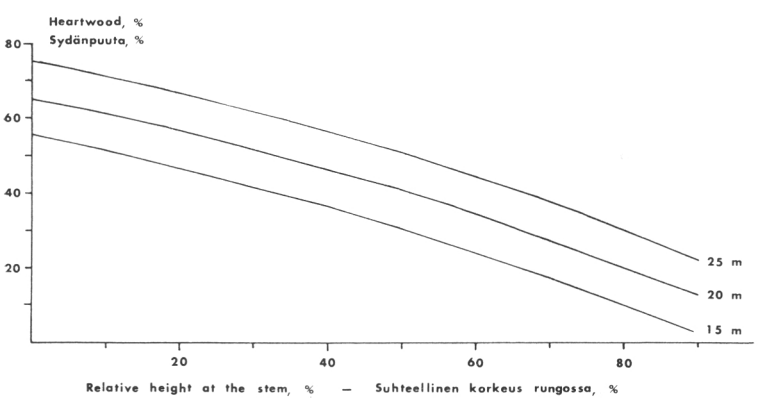


Figure 10. The longitudinal variation of the percentage of heartwood in 15-, 20- and 25-metre Siberian larch stems.
Kuva 10. Siperian lehtikuusen sydänpuuprosentin vaihtelu puun pituussuunnassa 15-, 20- ja 25- metrisessä rungossa.

The variation pattern of the percentage of heartwood in the longitudi nal direction of the Siberian larch stem is different from that of Scots pine and lodgepole pine. In these two pine species the proportion of heartwood grows at first from the butt towards the top and does not begin to diminish until a relative height of 10—30 per cent (cf. Lappi-Seppälä 1952, Uusvaara 1973).

The average percentage of heartwood in a stem can be estimated from a sample taken at breast height. The accuracy of the method is appreciable.

	R^2	$s_{y \cdot x}$, %
$y = 0.858x_1$	0.929	3.5

y = Average percentage of heartwood in a stem
x_1 = Percentage of heartwood at breast height

422. Variation between stems of Siberian larch

The average percentage of heartwood in a Siberian larch stem was 47.8 and its standard deviation was 13.3 per cent units. Of the external tree characteristics, diameter measured at 6 m height explains the variation of heartwood percentage best. A higher degree of determination is achieved by means of an equation in which diameter at breast height and age are concurrently the independent variables.

	R^2	$s_{y \cdot x}$, %
$y = 27.1 + 1.35x_1$	0.539	9.6
$y = 58.4 - 1\,365/x_2 + 51.1x_3/x_2$	0.635	8.5

y = Percentage of heartwood in a stem
x_1 = Diameter at 6 m height, cm
x_2 = Age, years
x_3 = Diameter at breast height, cm

The proportion of heartwood increases with age. On the other hand, there seems to be more heartwood the faster the tree has reached a certain size.

	Dbh, cm		
Age, years	10	20	30
	Heartwood, %		
20	16	41	
40	37	50	
60		53	61
80		54	61

An example may be mentioned by way of comparison of the effect of age on the percentage of heartwood in Siberian larch in the USSR (Khutorschikov and Zorina 1971). The proportion of heartwood appears to have been greater than at the same age in the present study.

Age of sample trees, years	27	54	71	110	149	188
Percentage of heartwood	54	67	71	75	82	86

423. Variation between stands of Siberian larch

It is again possible to distinguish two components from the variation between stands, i.e. stand-to-stand variation and geographical variation. The differences between stands are higly significant.

Source of variation	d.f.	SS	MS	F
Between south and north	1	3 616	3 616	2.31
Between stands	27	42 309	1 567	28.49***
Between stems + error	261	14 248	55	
Total	289	60 173	208	

The age of the stand is an important source of variation. As was shown already by analysis of stem-to-stem variation the percentage of heartwood increases sharply with age.

	R^2
$y = 23.4 + 0.460x_1$	0.620

y = Percentage of heartwood in a stand
x_1 = Age, years

Variance analysis did not establish the differences in the heartwood percentage between South and North Finland to be significant. In analysis of covariance the age differences of the stands may also be considered but the difference proves even then to be insignificant statistically ($F_{1,26} = 1.77$). Average percentages of heartwood corrected by the regression coefficient of age, 0.46 ($F_{1,26} = 42.35$***), are as follows.

	South	North
Average age of sample trees	53	45
Percentage of heartwood in sample trees	48.7	40.5
Percentage of heartwood at the age of 50 years	47.8	43.2

424. Variation between larch species

Analysis of variance based on the South-Finnish material shows again that the variation between stands is statistically highly significant. In contrast, no significant differences are observed between the species.

Source of variation	d.f.	SS	MS	F
Between species	3	5 371	1 790	1.17
Between stands	29	44 415	1 532	31.27***
Between stems + error	297	16 029	49	
Total	329	65 815		

The age variable is again in a decisive position. The coefficient of regression for age, 0.475 ($F_{1,28} = 42.62$***), given by covariance analysis may

be used to correct the heartwood percentage of all tree species to correspond to an age of 50 years. Significant differences ($F_{1,28} = 3.37$*) are then noted between the species. The percentage of heartwood in Japanese larch appears to be higher than that of other species.

	Larch			
	Siberian	European	Dahurian	Japanese
Average age of sample trees	53	35	44	42
Percentage of heartwood in sample trees	48.7	39.1	52.4	58.3
Percentage of heartwood at the age of 50 years	46.9	45.5	54 6	61.6

43. Percentage of knotwood

The percentage of knotwood indicates the proportion of actual knotwood in the total volume of the stem. The anatomically exceptional adjacent wood is not included. It should be noted that the basic density of knotwood is higher than that of defect-free stemwood and that the knotwood volume percentage is therefore always lower than the weight percentage.

$$\text{Percentage of knotwood} = \frac{100 \cdot \text{Volume of green knots}}{\text{Total volume of green stemwood}}$$

431. Variation within the stem of Siberian larch

Siberian larch is characterised by a large number of branches of rather thin diameter in the earlier stages of its development (Fig. 2). Some of the branches are later self-pruned, but the number of small knots within the stem remains great. The proportion of knot-free discs was smaller in this material than earlier in lodgepole pine.

Relative stem height, %	Siberian larch	Lodgepole pine
	Percentage of knot-free discs	
1	52	50
10—30	41	64
40—60	43	62
70—90	63	75

The number of branches is greatest in the lower parts of the tree. However, the butt-end branches die young and are self-pruned rapidly, so the volume percentage of knotwood is always smallest in the butt end of the stem. Branches are longlived higher up in the crown and grow thicker (cf. U u s v a a r a 1973).

The longitudinal variation in the percentage of knotwood in Siberian larch can be seen in Fig. 11 which is based on 3 000 disc measurements and smoothed by eye. Regression analysis and other statistical methods were not applied because of the mode of collection of the material.

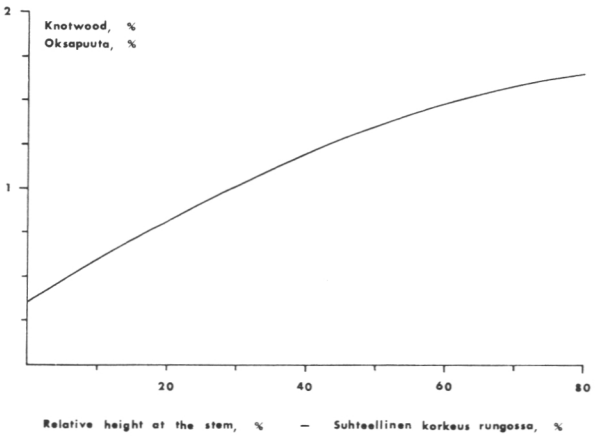


Figure 11. The longitudinal variation of the percentage of knotwood in Siberian larch.
Kuva 11. Siperian lehtikuusen oksapuuprosentin vaihtelu rungon pituussuunnassa.

The percentage of knotwood in Siberian larch at the age of 50 years is equal to that in lodgepole pine at different stem heights. Knotwood seems to be a little more plentiful at least in the central parts of the stem compared with pine and spruce (cf. N y l i n d e r 1959).

	Relative stem height, %			
	1	30	60	90
	Percentage of knotwood			
Plantation-grown Scots pine	0.3	0.6	1.3	1.8
Plantation-grown Norway spruce	0.4	0.6	1.3	2.2
Plantation-grown lodgepole pine	0.4	0.9	1.4	2.0
Plantation-grown Siberian larch	0.3	1.0	1.5	1.8

432. Variation between stems of Siberian larch

The average knotwood percentage of Siberian larch in the total material was 0.96. The variation observed in the sample trees was due largely to an analytical error, for 10—15 randomly selected discs are not enough to establish the percentage of knotwood in an individual tree. However, the effect of the growth rate on the proportion of knotwood is significant.

	R^2	$s_{y \cdot x}$, %
$y = 0.21 + 1.82 x_1/x_2$	0.091	0.74

y = Average percentage of knotwood in a stem
x_1 = Breast height diameter, cm
x_2 = Age, years

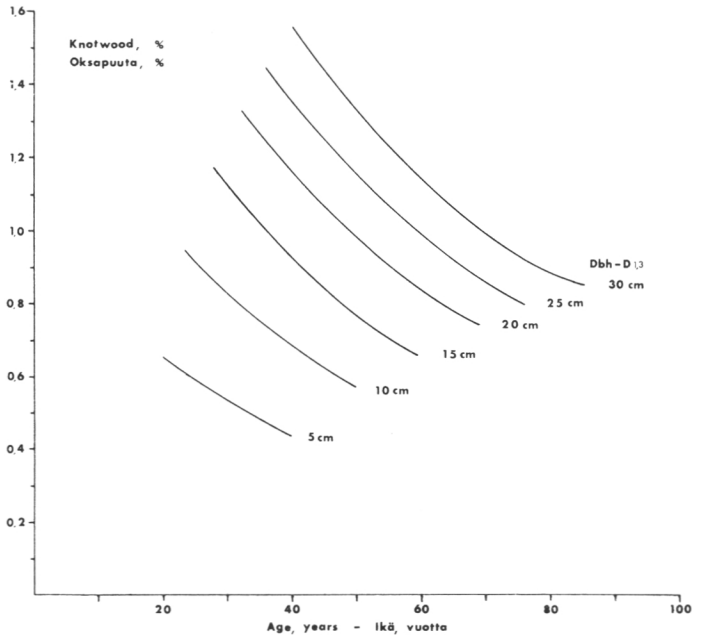


Figure 12. Average percentage of knotwood in a Siberia larch stem as a function of breast height diameter and age.
Kuva 12. Rungon keskimääräinen oksapuuprosentti Siperian lehtikuusessa puun iän ja rinnankorkeusläpimitan funktiona.

The value of the confidence symbols of the equation is small owing to the investigation method. However, Fig. 12 can be drawn to illustrate the interaction of tree size and age on the percentage of knotwood.

433. Variation between stands of Siberian larch

A part of the stem-to-stem variation in the percentage of knotwood can be separated into stand-to-stand variation. Due to the mode of collecting the material, the standard deviation is again increased by analytical error. It is therefore possible to explain only a small part of the variation between stands. Of the individual variables, stand age explains the variation best.

	R^2
$y = 1.30 - 0.0067x_1$	0.150

y = Average percentage of knotwood in a stand
x_1 = Age, years

The proportion of knotwood decreases with the ageing of the stand. For instance, the percentage of knotwood is still 1.17 in a 20-year-old stand,

but only 0.76 in an 80-year-old stand. The age differences in the materials for South and North Finland must thus be considered in the study of geographical variation. It is again possible to use analysis of coveriance in which the age of the stand is the regression variable.

Source of variation	d.f.	Sums of squares and products			Deviation from regression			
		Σx^2	Σxy	Σy^2	$\Sigma y^2 - \frac{(\Sigma xy)^2}{\Sigma x^2}$	d.f.	MS	F
Geographical	1	3 182	163	8	—	—	—	
Between stands	27	124 049	—836	39	33.5	26	1.29	2.76***
Between stems+error	261	—	—	122	121.6	261	0.47	
Total	289	127 230	—673	169	165.5	288	—	
Difference to test the corrected means of south and north ..	—	—	—	—	10.4	1	10.4	8.08**

The materials for South and North Finland are corrected to comparable age by means of the regression coefficient —0.007 ($F_{1,26} = 4.38$*). There is significantly less knotwood in the north, due at least partly to slow tree growth there.

	South	North
Age of sample trees, years	53	45
Percentage of knotwood of sample trees	1.05	0.66
Percentage of knotwood at the age of 50 years	1.07	0.62

434. Variation between larch species

The comparison between larch species is again confined to South Finland. Age differences are taken into consideration in the analysis of covariance in which age is the regression variable.

Source of variation	d.f.	Sums of squares and products			Deviation from regression			
		Σx_z	Σxy	Σy^2	$\Sigma y^2 - \frac{(\Sigma xy)^2}{\Sigma x^2}$	d.f.	MS	F
Between species	3	10 919	— 45	6.1	—	—	—	
Between stands	29	118 835	— 997	61.3	52.9	28	1.89	4.09***
Between stadns+error	297	—	—	137.3	137.3	297	0.46	
Total	329	129 754	—1 042	204.7	196.3	328	—	
The difference to test the means of species .	—	—	—	—	6.1	3	2.04	1.08

The regression coefficient for the age of the stand is —0.008 ($F_{1,28} = 4.43$*). The proportion of knotwood seems to be considerably smaller in Japanese larch than in the other species. However, an attitude of reserve

must be adopted to the difference for the material comprised only 20 Japanese larches. The differences are not statistically significant.

	Larch			
	Siberian	European	Dahurian	Japanese
Age of sample trees	53	35	44	42
Percentage of knotwood in sample trees	1.05	1.31	1.07	0.60
Percentage of knotwood at the age of 50 years	1.08	1.20	1.03	0.54

44. Basic density

The basic density indicates here the dry weight of unextracted wood in kilograms per solid cubic metre of green wood. Unless otherwise stated, the analyses of the within-stem variation represent knot-free wood. The stem and stand means, on the other hand, include the effect of knots.

$$\text{Basic density} = \frac{\text{Dry weight, kg}}{\text{Green volume, cu.m}}$$

441. Variation within the stem of Siberian larch

The structure of Siberian larch is characterised by an abrupt transition from spring- to summerwood (Fig. 13). The wood density of such tree species decreases fairly sharply from the butt of the stem towards the top. The difference between the butt and the top of the merchantable part in defect-free wood is 15 per cent (Fig. 14). When the effect of knots is taken into account the difference diminishes somewhat.

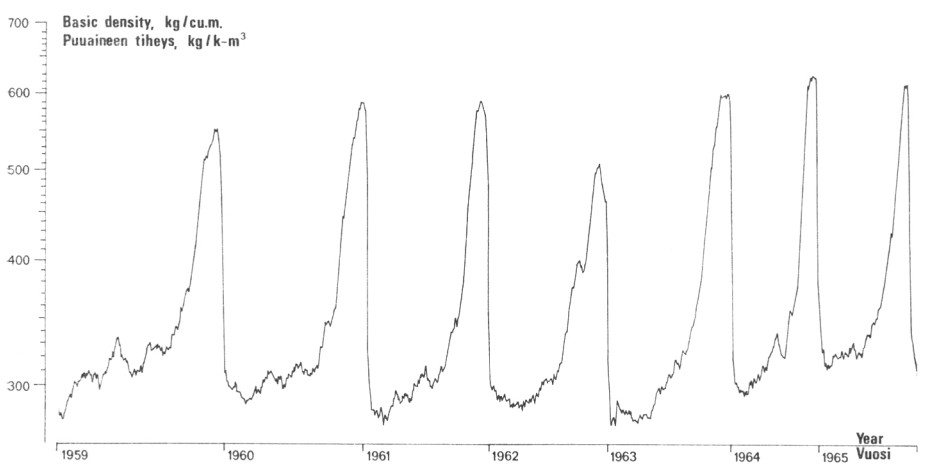


Figure 13. An example of the radial variation in basic density of Siberian larch, based on microdensitometric analysis of a radiograph.

Kuva 13. Esimerkki Siperian lehtikuusen säteensuuntaisesta puuaineen tiheyden vaihtelusta mikrodensitometrillä tulkitun röntgenkuvan pohjalta.

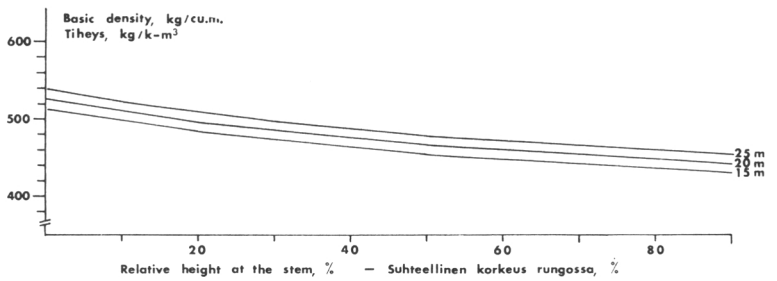


Figure 14. The longitudinal variation in basic density of defect-free wood in 15-, 20- and 25-metre Siberian larch stems.

Kuva 14. Siperian lehtikuusen virheettömän puuaineen tiheyden vaihtelu puun pituussuunnassa 15-, 20- ja 25-metrisessä rungossa.

The density of knotwood is always greater than the density of stemwood. Two equations are therefore presented for the longitudinal variation of wood density. The first represents solely defect-free wood while the other includes also the effect of knots.

	R^2	$s_{y \cdot x}$, kg/cu.m
$y_1 = 302.6 + 17\,687/(x_1 + 100) + 2.386x_2$	0.397	39.6
$y_2 = 317.5 + 15\,664/(x_1 + 100) + 2.663x_2$	0.300	43.2

y_1 = Basic density of defect-free wood at a certain height, kg/cu.m
y_2 = Basic density of wood at a certain height, including the effect of knots, kg/cu.m
x_1 = Relative height in the stem, %
x_2 = Stem height, m

Stem height and the sampling height explain 30 per cent of the variation of the wood density in the disc material. If the random variation caused by knots is omitted and only defect-free wood is considered, the degree of determination rises to 40 per cent. The effect of knots on the density of a 20-m Siberian larch stem can be seen in the following figures. The effect is greatest in the upper parts of the stem.

Relative height in the stem, %	Defect-free wood	All wood	Effect of knots	
	Basic density, kg/cu.m		Kg/cu.m	%
1	525.4	525.8	0.4	0.1
10	511.1	513.1	2.0	0.4
30	486.4	491.2	4.8	1.0
50	468.2	475.1	6.9	1.5
70	454.3	462.8	8.5	1.9
90	443.4	453.1	9.7	2.2

The density of Siberian larch is distinctly greater in all parts of the stem than the density of domestic softwoods. The density is lower than in birch,

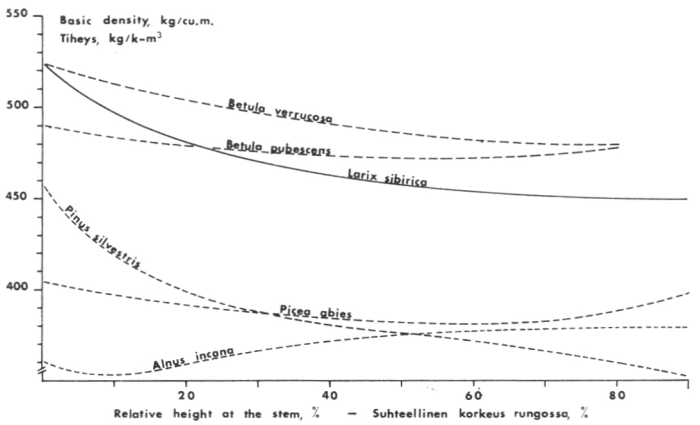


Figure 15. The longitudinal variation in basic density of Siberian larch compared with some domestic species.

Kuva 15. Siperian lehtikuusen puuaineen tiheyden vaihtelu rungon pituussuunnassa eräisiin kotimaisiin puulajeihin verrattuna.

however, except for the butt. The longitudinal variation pattern resembles Scots pine most, though there is a considerable difference in level (Fig. 15).

The investigation work can be speeded up if the average basic of the whole tree can be estimated from a single specimen. It is often simplest in practice to take an increment core sample from a living tree at breast height. The average density at breast height is 4 per cent more than in the tree as a whole. The error can be corrected with the regression equation.

	R^2	$s_{y \cdot x}$, kg/cu.m
$y = 62.4 + 0.837 x_1$	0.878	14.7

y = Average basic density of a stem, kg/cu.m
x_1 = Basic density at breast height, kg/cu.m

A sample taken at breast height explains 88 per cent of the variation of average tree density. An accuracy of $\pm$ 29 kg/solid cu.m is achieved with 95 per cent confidence.

442. Variation between stems of Siberian larch

The stem-to-stem standard deviation of basic density is 40.4 kg/cu.m. Tree age explains the variation best.

	R^2	$s_{y \cdot x}$, kg/cu.m
$y = 539.4 - 2\,057/x_1$	0.182	36.5

y = Average basic density of a stem, kg/cu.m
x_1 = Age, years

The effect of age on average stem density is considerable. To mention an example, the density of Siberian larch at the age of 30 years is 471 kg/solid cu.m, but by 80 years it has already risen to 513 kg/cu.m. The degree of determination is poor, however, for density is influenced also by the growth rate (cf. E d l u n d 1966), genetic factors and other considerations.

In the following table the density of Siberian larch, some other domestic tree species and plantation-grown lodgepole pine is compared. The range and standard deviation are generally greater in naturally regenerated stands than in plantations.

Species	Mean age years	Basic density, kg/cu.m Average	s	Range	s, %
Pinus silvestris, naturally regenerated [1]	68	409	33	311—521	8.0
Pinus silvestris, plantation-grown [2]	42	395	28	..	7.1
Picea abies, naturally regenerated [1]	78	387	30	308—482	7.8
Picea abies, plantation-grown [3] ...	43	352	21	..	6.0
Betula verrucosa, naturally regenerated [1]	57	497	31	407—571	6.3
Betula pubescens, naturally regenerated [1]	54	482	29	397—561	6.1
Alnus incana, naturally regenerated [4]	23	361	22	281—412	6.2
Pinus contorta, plantation-grown [5].	40	433	24	370—495	5.5
Larix sibirica, plantation-grown ...	53	492	40	351—600	8.1

References: [1]) H a k k i l a 1966; [2]) U u u s v a a r a 1973; [3]) H a k k i l a and U u u s v a a r a 1968; [4]) H a k k i l a 1970; [5]) H a k k i l a and P a n h e l a i n e n 1970.

The wood density of Siberian larch is thus appreciably higher than that of other softwoods growing in Finland. In agreement with earlier Russian investigation results, the density of larch wood approaches and sometimes even exceeds the density of birch (G u g n i n, P e r m i n o v, B u y n i t s k a y a and A b a k i n a 1971).

443. Variation between stands of Siberian larch

The stand-to-stand variation in density of Siberian larch is highly significant statistically. On the other hand, the differences between south and north are not significant.

Stand-to-stand variation is explained primarily by the age of the stand. However, it is possible to explain only a fourth of the variation.

	R^2
$y = 455.5 + 0.767x_1$	0.257

y = Average basic density of a stand, kg/cu.m
x_1 = Mean age, years

Nor are the differences between South and North Finland significant in covariance analysis which takes into account the age differences of the material ($F_{1,26} = 0.58$). Corrected by the regression coefficient of age, 0.70 ($F_{1,26} = 8.49^{**}$), the values for the south and the north at the age of 50 years are as follows:

	South	North
Average age of sample trees	53	45
Basic density of sample trees	494	485
Basic density at the age of 50 years	492	490

Edlund (1966) found in Sweden that when the ring width remains unchanged the density of Siberian larch decreases from the south northwards and similarly when altitude from sea level grows. According to the present study deceleration of growth seems to compensate for this tendency so that density is in point of fact the same at a certain age in spite of the geographical location of the stand.

444. Variation between larch species

The comparison of larch species is again confined to South Finland. The most reliable result is given by analysis of covariance in which age is the regression variable.

Source of variation	d.f.	Sums of squares and products			Deviations from regression			
		Σx^2	Σxy	Σy^2	$\Sigma y^2 - \frac{(\Sigma xy)^2}{\Sigma x^2}$	d.f.	MS	F
Between species	3	10 919	8 325	115 619	—	—	—	
Between stands	29	118 823	91 132	271 411	201 524	28	7 198	8.69***
Between stems + error	297	—	—	245 864	245 864	297	828	
Total	329	129 754	99 457	623 894	556 659	328	—	
The difference to test the means of species	—	—	—	—	109 271	3	36 424	5.06**

Different larch species at the age of 50 years can be compared after the means have been corrected by the regression coefficient of age 0.767 ($F_{1,28} = 9.71^{**}$). The density of Dahurian larch seems to be higher than that of other species, whereas the density of Japanese larch is distinctly the smallest. Edlund (1966) found that the basic density of Siberian larch was higher than that of European, Japanese or American larch (*Larix occidentalis*).

	Larch			
	Siberian	European	Dahurian	Japanese
Average age of sample trees	53	35	44	42
Basic density of sample trees	494	476	518	435
Basic density at the age of 50 years	491	486	522	440

45. Content of extractives

The extractive content was measured in two ways. Hot water and acetone were used as solvents and both determinations were made from different samples. Hot water extraction separates from the dust samples mainly arabinogalactan and dihydroquercetin, while acetone extraction results in the separation of phenols, resin and a small amount of dihydroquercetin (Bobrov, Mutovina and Tyukavkina 1971). The extractive content is given in weight per cent.

$$\text{Percentage of extractives} = \frac{100 \cdot \text{Dry weight of soluble matter}}{\text{Dry weight of unextracted wood}}$$

Because of laboratory capacity, the content of extractives was determined from only one sample per tree. It was therefore not possible to apply the same statistical methods as to other wood properties.

451. Acetone extractives

The average content of acetone-soluble extractives in saw dust samples was 2.04 per cent. The standard deviation between samples was 0.87 per cent. The variation can be broken down into the following components.

Source of variation	d.f.	SS	MS	F
Sampling height	13	603 407	46 416	$F_{13,293} = 10.53^{***}$
Larch species	3	446 812	148 937	$F_{3,293} = 33.77^{***}$
Height class	3	59 496	19 832	$F_{3,293} = 4.50^{**}$
Interactions	78	494 887	6 345	$F_{78,293} = 1.44^{*}$
Stem-to-stem + error	293	1 309 674	4 410	
Total	394			

When the effect of tree size is eliminated partly, the standard deviation between stems in the investigation material is 0.66 per cent. However, geographical variation and analytical error are included in this, so the true stem-to-stem variation is smaller. The content of acetone-soluble extractives is greater for larch than spruce in South-Finnish conditions, but smaller than in pine (cf. Hakkila 1968).

	Acetone extractives %
Scots pine pulpwood	3.4
Norway spruce pulpwood	1.5
Plantation-grown lodgepole pine	1.2
Plantation-grown Siberian larch	2.0

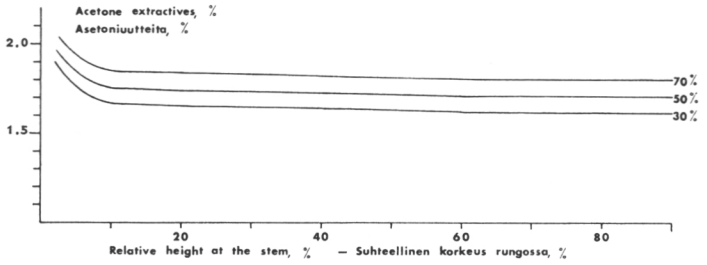


Figure 16. The longitudinal variation of the amount of acetone extractives in Siberian larch when the average percentage of heartwood in the stem is 30, 50 or 70 per cent.

Kuva 16. Asetoniin liukenevien uuteaineitten määrän vaihtelu Siperian lehtikuusessa puun pituussuunnassa, kun puun keskimääräinen sydänpuuprosentti on 30, 50 tai 70.

The content of acetone-soluble extractives decreased from the butt towards the top. It is a fourth smaller at the top of the merchantable part than at stump height. However, the random variation is considerable.

	R^2	$s_{y \cdot x}$, %
$y = 1.84 + 0.68/x_1$	0.207	0.77

y = Percentage of acetone extractives at a certain height
x_1 = Relative height at the stem, %

The degree of determination is increased greatly when the percentage of heartwood in the stem is included as a second independent variable. When the heartwood content increases the amount of extractives also increases (Fig. 16).

	R^2	$s_{y \cdot x}$, %
$y = 1.49 + 0.60/x_1 + 0.0044x_2$	0.393	0.68

y = Percentage of acetone extractives at a certain height
x_1 = Relative height at the stem, %
x_2 = Percentage of heart wood in the stem

452. Hot water extractives

The saw dust samples contained an average of 9.32 per cent of extractives soluble in hot water; this is considerably more than in any domestic tree species. According to Russian studies, the percentage of hot water-soluble extractives was 2—3 for Scots pine and only 1 for Norway spruce (Kosaya 1971, Gugnin, Permikov, Buynitskaya and Abikina 1971). The comparable figures in a domestic study were 5.8 per cent for Scots pine and 4.3 per cent for Norway spruce (Nevalainen and Hosia 1969).

The standard deviation between samples was 3.24 per cent. The variation was broken down into components in variance analysis, and then the sampling height, the larch species and the height of the tree all proved to be statistically significant as sources of variation. On the other hand, interactions were not significant.

Source of variation	d.f.	SS	MS	F
Sampling height	13	80 450	6 188	$F_{13,293} = 7.25^{***}$
Larch species	3	10 320	3 440	$F_{3,293} = 4.03^{**}$
Height class	3	11 774	3 925	$F_{3,293} = 4.60^{**}$
Interactions	78	60 027	770	$F_{78,293} = 0.90$
Stem-to-stem + error	293	253 620	854	
Total	394			

Deviation between stems in which geographical variation and analytical error are again included is still 2.92 per cent when the effect of the height class (4 classes) has been eliminated. A part of the unexplained variation may be combined here with the variation in the percentage of heartwood, for the content of hot water extractives in heartwood is many times that in sapwood. The following examples illustrate Siberian larch.

Research material	Heartwood Hot water extractives, %	Sapwood	Reference
Natural forests, Irkutsk	16.4	2.2	Khutorschikov et al. 1971
Natural forests, Irkutsk	12.9	5.0	Gugnin et al. 1971
Natural forests, Krosnoyarsk ...	11.2	2.7	Gugnin et al. 1971
Plantation-grown, Sweden	16.8	2.4	Edlund 1966
Plantation-grown, Finland	11.5	5.2	Nevalainen et al. 1969

The longitudinal variation pattern of the extractives content in the stem follows the changes in the percentage of heartwood. The extractives content decreases from the butt towards the top. The degree of determination of the equation improves again when the average heartwood percentage of wood is taken into consideration (Fig. 17). The variable that represents tree size also increases the reliability of the equation, but still leaves considerable unexplained variation.

	R^2	$s_{y \cdot x}$, %
$y = 11.56 - 0.83 \log x_1$	0.162	2.96
$y = 8.43 - 0.50 \log x_1 + 0.048 x_2$	0.229	2.83
$y = 8.18 + 0.072 x_1 - 0.97 \log x_1 + 0.118 x_2 - 0.218 x_3$	0.354	2.62

y = Percentage of hot water extractives at a certain height
x_1 = Relative height at the stem, %
x_2 = Percentage of heartwood in the stem
x_3 = Tree height, m

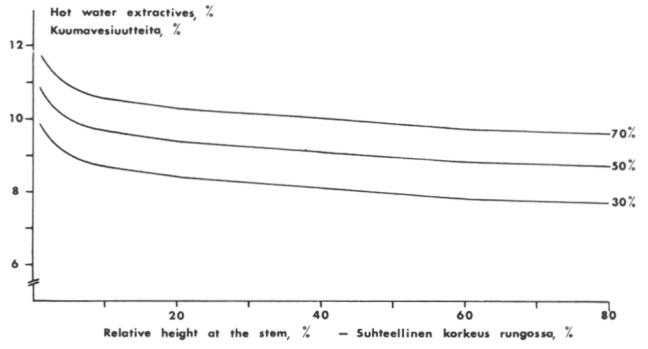


Figure 17. The longitudinal variation of the amount of hot water-soluble extractives in Siberian larch when the average percentage of heartwood in the stem s 30, 50 or 70 per cent.

Kuva 17. Kuumaan veteen liukenevien uuteaineitten määrän vaihtelu Siperian lehtikuusessa puun pituussuunnassa, kun puun keskimääräinen sydänpuuprosentti on 30, 50 tai 70.

A special characteristic of larch wood is the exceptionally high content of water-soluble extractives. The main substance is arabinogalactan. Some Soviet investigation results for the average content of hot water extractives in larch wood are given here.

Species	Amount of hot water extractives in wood, %	Reference
Siberian larch	12—14	Khutorschikov et al. 1971
»	10—12	Chochieva et al. 1971
»	12—14	Korenevsky et al. 1971
»	12—14	Gugnin et al. 1971
Dahurian larch	9	Kosaya 1971

The growing stock in these studies was older than that of the present work. The extractives content is therefore greater in every case than for Finnish plantations.

5. DISCUSSION

The technical properties of larch wood and domestic softwoods differ in many respects. This causes difficulties when timber is used on an industrial scale, but the special characteristics of the wood also have certain advantages provided that they are properly exploited.

Differences between tree species in southern Finnish conditions are presented in Table 2. It should be noted that for pine and spruce the question involves pulpwood made from naturally regenerated forests, while lodgepole pine represents 40-year and Siberian larch 50-year-old plantations. Larch seems to contain a good deal of bark, heartwood and water-soluble extractives compared with other tree species, and its basic density is exceptionally high. According to some earlier studies, the fibre is perhaps slightly shorter than in pine but the difference is not great (F l a m m and B e l l a k 1957, E d l u n d 1966, K h u t o r s c h i k o v and Z o r i n a 1971.)

Table 2. Average properties of Siberian larch at the age of 50 years in southern Finland compared with plantation-grown lodgepole pine, Scots pine pulpwood and Norway spruce pulpwood

Taulukko 2. Siperian lehtikuusipuun keskimääräisiä ominaisuuksia 50 vuoden iällä Etelä-Suomessa verrattuina Murrayn männyn viljelmiin sekä mänty- ja kuusipaperipuuhun

Property *Ominaisuus*	Siperian larch *Siperian lehtikuusi*	Lodgepole pine *Murrayn mänty*	Scots pine *Mänty*	Norway spruce *Kuusi*
Bark, % — *Kuorta*, %	14	10	11 [1]	12 [1]
Heartwood, % — *Sydänpuuta*, %	48	18	20 [1]	25 [1]
Knotwood, % — *Oksapuuta*, %	1.1	1.0	0.7 [2]	0.7 [2]
Basic density, kg/cu.m — *Tiheys, kg/k-m*^{3}	492	433	405 [3]	385 [3]
Acetone extractives, % — *Asetoniuutteita*, %	2.0	1.2	3.3 [3]	1.5 [3]
Hot water extractives, % — *Kuumavesiuutteita*, %	9	..	3 [4]	1 [4]

References: [1]) Unpublished material at the Department of Forest Technology, Finnish Forest Research Institute; [2]) N y l i n d e r 1959; [3]) H a k k i l a 1968; [4]) K o s a y a 1971.

As the physical structure and chemical composition of Siberian larch and domestic softwoods differ, it behaves somewhat differently in the pulp and paper making process. The practical experience of the Soviet pulp and paper industry is limited to old virgin forests. In addition, exhaustive laboratory experiments have been conducted in Sweden and more recently especially in Finland for which the wood material has been collected from plantations.

Larch wood, unlike Scots pine and Norway spruce, contains a large amount of water-soluble extractives consisting mainly of polysacharide-arabinogalactan. This hampers the processing into pulp, making especially sulphite cooking difficult. Moreover, its high wood density makes it necessary to ensure that the chip particles are of even size. Some of the problems observed in the sulphite cooking of larch are due to the following reasons (K o r e n e v s k y and N e p e n i n 1971).

— High wood density impairs impregnation with the cooking solution and favours secondary processes developing inside the chip.
— The resins hamper impregnation.
— The water-soluble substances, mainly arabinogalactan, cause premature loss of sulphite acid stability, resulting in failure to complete the cooking process.
— Subtances of a phenolic nature also hamper the impregnation and delay the process of sulphonation, because phenols participate in the condensation reactions with wood lignin.

Certain difficulties are thus encountered in the sulphite cooking of larch wood. The best results are achieved in the bisulphite or two-stage process, but even then the pulp yield is lower than for pine and spruce (E d l u n d 1966, N e v a l a i n e n and H o s i a 1969, K o r e n e v s k y and N e p e n i n 1971, S a u k k o n e n 1971). The difference in yield is as much as 5—7 per cent units (S a u k k o n e n 1971). Larch is clearly more suitable for the production of sulphate pulp.

The most obvious differences from Scots pine and Norway spruce sulphate pulps are higher consumption of alkali, lower yield, lower brightness, poorer tensile and burst strengths and distinctly superior tear strength. Larch pulp thus represents a new type of sulphate pulp in Finnish conditions, one that is highly reminiscent of the southern pine kraft pulps in the United States (N e v a l a i n e n and H o s i a 1969). The tear strength exceeds that of pine pulp in southern Finland by one third. Unlike pine, the strength properties are the same even in the north (Saukkonen 1971).

The yield of sulphate pulp from Siberian larch is 2 per cent units lower than that from Scots pine (K o s a y a 1971, S a u k k o n e n 1971, H a k k i l a, N i k k i and P a l e n i u s 1972). Due to its high density, however, larch is superior to the domestic softwoods as regards the consumption of wood. While the average consumption of Scots pine wood at kappa number 35 is 4.7 solid cubic metres per a ton of pulp (moisture content 10 %),

the consumption of larch wood is 4.1 solid cubic metres only (Hakkila, Nikki and Palenius 1972). The difference is thus 0.6 solid cubic metres or 13 per cent.

In bleaching the only noteworthy difference from the sulphate pulp of pine results from the higher content of extractives in larch wood. This necessitates a stronger alkali stage (Nikki 1971.)

Larch pulp is eminently suitable as raw material for paper qualities that require tear strength. Sack paper is an example. Larch pulp can be used also for high-quality printing papers by bleaching and mixing it with short-fibred hardwoods (Hosia 1971.) As regards the strength of newsprint, a 15 per cent addition of larch sulphate pulp equals a 20 per cent addition of pine sulphate pulp. Raising the proportion of mechanical pulp, on the other hand, improves the optical properties of newsprint (Saukkonen and Arvela 1973).

6. SUMMARY

Larch thrives relatively well in Finnish conditions. In experimental plantations the best results have been achieved with Siberian larch which has a natural range reaching in the west close to the eastern border of Finland (Fig. 1).

Before large-scale cultivation of an exotic is attempted, its suitability as industrial raw material must be known. To this end a study was begun in summer 1970 by the Finnish Forest Research Institute in cooperation with the Finnish Pulp and Paper Reseacrh Institute. Its aim was to examine the suitability of Finnish-grown larch wood as a raw material for sulphate pulp production. This paper concentrates on some wood properties that were studied by the Finnish Forest Research Institute.

The investigation material comprised 40 plantations, seven of them in North Finland (Fig. 5). The main part of the material, 29 stands, grew Siberian larch (*Larix sibirica*). In addition, there were three European larch (*Larix europaea*), six Dahurian larch (*Larix dahurica*) and two Japanese larch (*Larix leptolepis*) stands in South Finland. The total number of sample trees felled was 400, 10 from each stand (Table 1). The mean age of the trees was 49 years.

The percentage of bark by dry weight, the percentage of heartwood and knotwood by volume and the basic density of wood were determined from 5 cm thick discs which were sawn from the butt cross-section up to the top at intervals of 1 or 2 metres. In addition, the content of acetone- and hot water-soluble extractives was determined from the saw dust sample taken at a random height (Fig. 4). There were in all 4 500 discs and 400 saw dust samples.

The percentage of bark in Siberian larch is relatively high, 15.5 on average. The deviation between stems was 3.7 per cent units. The proportion of bark decreased from the butt to 1/3 height of the stem and then began to increase again towards the top (Figs. 7 and 8).

The tree size explained best the variation in bark percentage. As the tree grew, the proportion of bark decreased. Further, the faster the growth, the smaller was the proportion of bark. The bark percentage was considerably higher in North than South Finland. External characteristics explained 70

per cent of the stem-to-stem variation and 35 per cent of the stand-to-stand variation. No significant differences were seen between the larch species.

The percentage of heartwood is highest at the butt of the stem and then diminishes evenly towards the tree top. Heartwood was most plentiful in large-sized trees (Fig. 10).

The average heartwood percentage of the Siberian larch stem was fairly high, 47.8, and its deviation was 13.3 per cent units. External characteristics explained 64 per cent of the stem-to-stem and 62 per cent of the stand-to-stand variation. Diameter and age gave the best explanation. The proportion of heartwood grew with age. On the other hand, heartwood seemed to be the more abundant the faster the tree grew. No significant difference was established between South and North Finland. The percentage of heartwood in Japanese larch appeared to be higher than in the other larch species.

The proportion of knotwood grew from the butt towards the top. It was 0.3 per cent at the butt of a Siberian larch stem, 1.8 per cent at its top (Fig. 11). The average percentage of knotwood was 1.0.

Young and fast-growing trees contained the most knotwood (Fig. 12). The lower percentage of knotwood in North Finnish trees at a certain age is probably partly due to their slow growth. The differences between the larch species were not significant.

The basic density decreased relatively sharply from the butt of the stem towards the top. The difference between the butt and the top of the merchantable part of the stem was 15 per cent in defect-free wood (Fig. 14). When the effect of knots was taken into consideration, the difference decreased slightly.

The average basic density of Siberian larch, 492 kg/cu.m, was considerably higher than that of domestic softwoods (Fig. 15). It was possible to explain only a little of the stem-to-stem variation, 40.4 kg/cu.m, by means of external charcteristics. The best single variable, age, explained 18 per cent of the stem-to-stem variation and 26 per cent of the variation between stands. No significant difference was established between South and North Finland. The density of Dahurian larch was higher and the density of Japanese larch was distinctly smaller than that of the other larches.

The proportion of acetone-soluble extractives averaged 2.0 per cent. The deviation between the samples was 0.9 per cent. The acetone-soluble extractives content was smaller in South Finnish conditions for larch than for pine, but greater than for spruce. The extractives content diminished from the butt towards the top (Fig. 16).

Hot water-soluble extractives averaged 9.3 per cent, which is considerably more than in any domestic tree species. The variation between samples was 3.2 per cent. The longitudinal variation in the amount of hot water extractives in the stem followed the changes in the percentage of heartwood.

The quantity of extractives thus decreased from the butt towards the top (Fig. 17).

The technical properties of larchwood differ from domestic softwoods in many respects (Table 2). Larchwood therefore behaves slightly differently from the conventional raw material used in the production of pulp and paper in Finland. Water-soluble extractives cause difficulties especially in the sulphite process. The bisulphite or two-stage processes give the best result.

In Finnish condistions, larchwood is above all a raw material of sulphate pulp. Characteristics of larch compared with pine are high consumption of alkali, lower yield, lower brightness, poorer tensile and burst strength, but distinctly superior tear strength.

The yield of sulphate pulp in the cooking experiments conducted by the Finnish Pulp and Paper Research Institute was 2 per cent units lower from Siberian larch than from pine. However, larch was better as regards wood consumption because of its high basic density. The consumption of larchwood was only 4.1 solid cu.m. per ton of chemical pulp (moisture content 10 per cent), 0.6 solid cu.m less than the consumption of pine.

Sulphate pulp made of larch is eminently suitable as a raw material for paper qualities that require a high tear strength. The experiments at the Finnish Pulp and Paper Research Institute also disclosed that when larch sulphate pulp is substituted for pine sulphate pulp in newsprint, the relative proportion of pulp can be raised. The optical properties of the newsprint are improved at the same time.

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SUOMESSA KASVATETUN LEHTIKUUSIPUUN OMINAISUUKSISTA

Lyhennelmä

Lehtikuusi menestyy Suomen oloissa verraten hyvin. Parhaat tulokset on saavutettu Siperian lehtikuusella, jonka luontainen levinneisyysalue etenee lännessä lähelle Suomen itärajaa (kuva 1).

Ennen kuin ulkomaista puulajia voidaan ryhtyä viljelemään käytännön mittakaavassa, sen soveltuvuus teollisuuden raaka-aineeksi on tunnettava. Tästä syystä pantiin kesällä 1970 Metsäntutkimuslaitoksen ja Oy Keskuslaboratorio Ab:n yhteistyönä alulle tutkimus, jonka tavoitteena on selvittää suomalaisen lehtikuusipuun soveltuvuus sulfaattimassan raaka-aineeksi. Käsillä olevassa julkaisussa keskitytään eräisiin puuaineen ominaisuuksiin, joiden tutkiminen on ollut Metsäntutkimuslaitoksen tehtävänä.

Tutkimusaineisto sisälsi 40 istutusmetsikköä, joista 7 sijaitsi Pohjois-Suomessa (kuva 5). Aineiston pääosa, 29 metsikköä, oli Siperian lehtikuusta (*Larix sibirica*). Lisäksi aineisto sisälsi 3 Euroopan lehtikuusen (*Larix europaea*), 6 Dahurian lehtikuusen (*Larix dahurica*) ja 2 Japanin lehtikuusen (*Larix leptolepis*) metsikköä Etelä-Suomessa. Yhteensä kaadettiin 400 koepuuta, 10 kustakin metsiköstä (taulukko 1). Puitten keski-ikä oli 49 vuotta.

Kuoren kuivapainoprosentti, sydänpuun ja oksapuun tilavuusprosentti sekä puuaineen tiheys määritettiin 5 cm:n paksuisista kiekoista, joita sahattiin tyvileikkauksesta lähtien latvaan saakka puun pituudesta riippuen 1 tai 2 metrin välein. Lisäksi määritettiin asetoniin ja kuumaan veteen liukenevien uutteitten määrä satunnaiselta korkeudelta otetusta purunäytteestä (kuva 4). Kiekkoja oli kaikkiaan 4 500 ja purunäytteitä 400 kappaletta.

Siperian lehtikuusen kuoriprosentti on 50 vuoden iässä korkea, keskimäärin 15.5. Kuoren osuus laskee tyveltä rungon 1/3-korkeudelle ja alkaa sen jälkeen jälleen kasvaa latvaa kohti (kuvat 7 ja 8).

Kuoriprosentin vaihtelua selittävät parhaiten puun kokoa kuvaavat muuttujat. Puun kasvaessa kuoren osuus vähenee. Edelleen, mitä nopeammin puu kasvaa, sitä pienempi on kuoren osuus. Kuoriprosentti on Pohjois-Suomessa huomattavasti korkeampi kuin etelässä. Ulkoiset tunnukset selittävät runkojen välisestä vaihtelusta 70 %. Lehtikuusilajien välillä ei todettu merkitseviä eroja.

Sydänpuuprosentti on suurin rungon tyvessä ja pienenee tasaisesti puun latvaa kohti. Siperian lehtikuusessa keskimääräinen sydänpuuprosentti on 50 vuoden iässä 48.

Ulkoiset tunnukset selittivät runkojen välisestä vaihtelusta 64 %. Iän ja puun koon mukana (kuva 10) sydänpuun osuus lisääntyy. Sydänpuuta näyttää olevan myös sitä enemmän, mitä nopeammin puu kasvaa. Etelä- ja Pohjois-Suomen välillä ei havaittu merkitsevää eroa. Japanin lehtikuusen sydänpuuprosentti näytti olevan korkeampi kuin muiden lehtikuusilajien.

Oksapuun osuus kasvaa rungossa latvaa kohti. Siperian lehtikuusirungon tyvessä se oli 0.3, latvassa 1.8 ja keskimäärin 1.0 % (kuva 11).

Oksapuuta oli eniten nuorissa ja hyväkasvuisissa puissa (kuva 12). Pohjois-Suomen puiden alhaisempi oksapuuprosentti tietyssä iässä aiheutunee osittain puiden hitaasta kasvusta. Lehtikuusilajien väliset erot eivät osoittautuneet merkitseviksi.

Puuaineen tiheys alenee rungon tyvestä latvaa kohti. Ero tyven ja käyttöosan latvan välillä on virheettömässä puuaineessa 15 % (kuva 14). Kun oksien vaikutus otetaan huomioon, ero pienenee.

Siperian lehtikuusen puuaineen tiheys, 50 vuoden iällä 492 kg/k-m^3, on huomattavasti korkeampi kuin kotimaisten havupuiden (kuva 15). Runkojen välisestä hajonnasta, 40 kg/k-m^3, voitiin ulkoisten tunnusten avulla selittää vain vähän. Paras yksittäinen muuttuja, ikä, selitti 18 % runkojen välisestä vaihtelusta. Etelä- ja Pohjois-Suomen välillä ei todettu merkitsevää eroa. Dahurian lehtikuusen tiheys osoittautui muita korkeammaksi, Japanin lehtikuusen taas selvästi muita pienemmäksi.

Asetoniin liukenevien uuteaineiden osuus oli keskimäärin 2.0 %. Se on pienempi kuin männyllä mutta suurempi kuin kuusella. Uuteaineiden määrä vähenee tyvestä latvaa kohti (kuva 16).

Kuumaan veteen liukenevia uuteaineita oli keskimäärin 9.3 % eli huomattavasti enemmän kuin missään kotimaisessa puulajissa. Rungon pituussuuntainen vaihtelu myötäilee sydänpuuprosentin muutoksia. Uuteaineiden määrä pienenee siten latvaa kohti (kuva 17).

Lehtikuusipuun tekniset ominaisuudet poikkeavat monessa suhteessa kotimaisista havupuista (taulukko 2). Tästä syystä lehtikuusi käyttäytyy massaa ja paperia valmistettaessa jossain määrin erilailla kuin Suomen massateollisuuden tavanomainen raaka-aine. Vesiliukoiset uuteaineet aiheuttavat vaikeuksia erityisesti sulfiittiprosessissa, jossa parhaisiin tuloksiin johtavat bisulfiitti- ja kaksivaihemenetelmät.

Lehtikuusipuu on Suomen oloissa ennen kaikkea sulfaattimassan raaka-aine. Mäntyyn verrattuna ovat lehtikuuselle ominaisia suuri alkalin kulutus, alhaisempi saanto, huonompi vaaleus, pienempi veto- ja puhkaisulujuus mutta oleellisesti parempi repäisylujuus.

Keskuslaboratorion keittokokeissa sulfaattimassan saanto oli Siperian lehtikuusella 2 prosenttiyksikköä alhaisempi kuin männyllä. Korkean puuaineen tiheyden vuoksi lehtikuusi on kuitenkin kotimaisia havupuita edullisempi puun kulutuksen kannalta. Lehtikuusipuun kulutus oli vain 4.1 kiintokuutiometriä sellutonnia (kosteuspitoisuus 10 %) kohti, mikä on 0.6 kiintokuutiometriä vähemmän kuin männyllä.

Lehtikuusisulfaattimassa soveltuu erinomaisesti korkeata repäisylujuutta vaativien paperien raaka-aineeksi. Keskuslaboratorion kokeissa todettiin myös, että kun mäntysellu korvataan sanomalehtipaperissa lehtikuusisellulla, voidaan hiokkeen suhteellista osuutta nostaa. Samalla sanomalehtipaperin optiset ominaisuudet paranevat.