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RELATIVE POLLEN RAIN AROUND CULTIVATED FIELDS

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HELSINKI—HELSINGFORS
Nov. 1973
Abstract


The extent to which the influence of agriculture is reflected in relative pollen rain is examined for a 27 ha cultivated area surrounded mainly by forest and on one side by bog. The area is situated in the village of Salmi, parish of Vihti, Southern Finland. The method involves the use of recent moss polsters and Tauber traps.

The tree pollen (AP) was seen to be very local in its distribution, reflecting the variations in the dominant tree species. Horizontal transport of this pollen through the forest may thus be said to be minimal. The pollen trap results show the relative proportions of Alnus and Betula to increase as the summer progresses.

The total NAP figure decreases sharply as one moves from the field area into the forest but increases again along the pathways. Outstanding among the NAP species are the dominant Gramineae, Filipendula and Umbelliferae, which in the immediate vicinity of the field area depress the proportions of both the cultivated Cerealia species and the indigenous low-growing weed species which produce very little pollen.

The pollen trap results indicate that the dispersal of Cerealia pollen (Avena, Hordeum and Triticum) is mainly achieved through the agency of man. Its appearance at harvest time instead of at flowering time suggests that the cutting and transporting of the crop serves to disperse Cerealia pollen over the surrounding area. The theory is supported by the appearance of this pollen in the surface samples in agglomerations of several grains. This observation is important in the estimation of the extent of cultivation in earlier cultural periods.

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I. INTRODUCTION

The relationship between pollen rain and present vegetation has been an object of study in both Europe and North America since the early 1940's (Carrol 1943, Gladys 1943, Hansen 1949, Jonassen 1950, Dengler 1955b, Potzger et al. 1956, Goodlett 1960, Potter & Rowley 1960, Mullenders 1962, Heim 1963 etc.). Within Finland research has been concentrated on longdistance transport of tree pollen to treeless areas (Aario 1940, Sarvas 1955), and on pollen production and dispersal rates in trees (Sarvas 1962, 1968, Koski 1970).

The purpose of the present work is to describe with the aid of pollen analyses from moss samples and pollen traps the distribution and proportion of arboreal pollen (AP) and «cultural indicators» in the immediate surroundings of an agricultural area over a period of two years.

Fig. 1. Map showing the site of examination. An open field of some 27 ha, bordered by different kinds of forests and in the north by (Katinhaanansuo) Katinhaanta Bog.

Fig. 2. Map showing the four sampling lines running outwards from the field. Symbols used for cultivation during the summers 1970 and 1971.
The site chosen was an open field of some 27 hectares, bordered principally by forests and in some places by bog, situated in the village of Salmi, parish of Vihti (Fig. 1). This field forms part of the agricultural area whose development has been the subject of earlier work (Vuorela 1972). Among the reasons for selecting this site, in addition to its proximity to Katinhännänsuo (Vuorela 1970), was the absence of public highways or human habitation in the area. There is a narrow cart-track running from a barn in the centre of the field to houses situated at a distance of 1.5 km which is used only by tractors and people on foot during the sowing and harvesting of crops. There is no cattle-rearing in the area, thus no local features appear which could be attributable to the effect of grazing upon the vegetation. The task remains, therefore, to determine the degree to which agriculture and the local vegetation are reflected in the pollen rain of the surrounding area.

The principal crops cultivated in this field area have for many years been *Hordeum* and *Avena*. In 1969 *Triticum* was also grown, but this was restricted to one strip to the east of the barn.

II. MATERIAL AND METHODS

Moss polster and pollen trap samples were collected at 30—100 m intervals along four lines radiating outwards from the field. Three of these lines extend into the forest, the fourth follows the bank of the stream towards Katinhääntä Bog (Fig. 2).

Line I passes through young forest, predominantly pine, crossing the little-used cart-track. Sampling point 1 is situated at the boundary between the field and the forest, points 2 and 3 are in the forest itself and point 4 at the southern edge of the cart-track.

Line II extends from the southern edge of the field into a predominantly deciduous, paludified forest which gradually grades into an impassable bog. A clay bank about 40 m high at the boundary between the field and the forest was taken as sampling point 5; points 6, 7 and 8 are located in thick deciduous forest dominated by *Populus tremula*, and point 9 lies at the transition between deciduous and coniferous forest, in an open marshy area of about 0.5 a in which the ground vegetation consists almost entirely of mosses.

Sampling point 10/III was taken from a section of the field where cultivation ceased about 10 years ago and on which *Pinus* saplings have been planted. From here the line continues into a damp forest with *Picea* dominant, crossing a narrow stream at the junction of field and forest (point 11). Sample 12 was taken from the edge of a path, while point 13 is situated in the spruce forest itself only some 20 m away. Point 14 is located in a drier place on the top of a hill with a sparser covering of *Betula* and *Pinus*, in addition to *Picea*. The difference in height between points 11 and 14 is approx. 20 m, a fact which is evident from their relative humidities and proportions of arboreal species.

Line IV closely follows the bank of the stream which runs from Katinhääntä Bog across the open field area. All the samples except those from point 16 were taken from
The local woody vegetation is chiefly composed of dense stands of *Salix*, although to the east of the stream there are some solitary, struggling *Pinus* and *Betula* specimens. Immediately to the north of point 20 the land has been used by a local peat merchant, and the surface layers have been stripped away.

In addition to the samples taken from along these four lines, analyses were made of moss polsters from three points on the southern border of the field (21, 22, 23). The first two of these are situated on the border with the *Picea* forest and the third on the border with the *Pinus* forest.

The following moss species are represented in the samples: *Bryum* and *Brachythecium* (point 15), *Dicranum* (point 3), *Hylocomium* (points 10, 11 and 23), *Pleurozium* (points 1, 2, 4, 13, 14, 18), *Polytrichum* (points 16, 17 and 20) and *Sphagnum* (points 5, 6, 7, 8, 9, 12, 19, 21, 22). Several writers including Borse (1939), Janssen (1966) and Havinga (1967) uphold the view that those pollen types which perish most easily are preserved best in *Sphagnum* mosses.

Pollen traps were placed at 13 points along the lines described above. These are numbered according to the adjacent moss sampling point, or according to the points between which the trap was situated. They were set level with the surrounding ground vegetation, with the exception of trap 2-3 and trap 5, the former of which was placed on top of a tree stump about 20 cm high, while the latter was located on a clay bank some 40 cm above its surroundings. The cover afforded by fully grown trees was estimated for a ten-metre square around each trap. The nature of the grass cover was described within a radius of 1 m of each trap. These figures for vegetation cover (Table 1) vary throughout the summer, of course, so that the values stated here for the dominant species represent their average incidence (100=total grass cover). Where no exact figure is given the occurrence of the species in question is a matter of an isolated individual or of a small number equivalent to that present in other similarly marked communities.

**Preparation technique**

In order to examine the pollen rain over the longest possible period samples of living mosses were taken from points 1—23 in mid-November 1970, when the soil was already frozen. It should then be possible to consider that the whole range of pollen from the previous flowering season had fallen to the ground at the latest in the autumn rains (Potter & Rowley 1966, Tauber 1967). The size of the sample taken varied depending on the species of moss and the amount available.

The samples were boiled for 5 mins in 10 % KOH, sieved and rinsed. The resultant material was oxidized and preparations mounted using glycerin jelly. Counts were made until either 1000 arboreal pollen grains (AP) or 500 non-arboreal (NAP) had been reached for each slide. The pollen diagram was drawn based on percentages of the total figure (AP+NAP ex. spores).

The pollen traps were placed in position on 15. 4. 1971. Their contents were removed and stored together with the rinsing water and the traps were cleaned and replaced first of all at two month and later at one month intervals, so that the fifth and final sample obtained corresponded to the pollen rain for the period 15th. Sept.—15th. Oct. The samples were sieved and prepared by the KOH method (Fægri & Iversen 1964) and mounted in glycerin jelly. A total of 200 pollen grains per sample was counted and this total figure used as the basis for the diagram.

As a result of some interference with the pollen traps, samples no. 18/IV for August—Sept. and nos. 5/II and 19—20/IV for Sept.—Oct. were lost.
III. POLLEN DISPERSAL AS SEEN FROM MOSS SAMPLES

1. Tree and shrub pollen

A comparison of the AP diagram from present moss samples (Fig. 3) with the proportions of tree species in the vicinity of the sampling points (Fig. 1, Table 1) shows the pollen rain in forested areas to be of an entirely local origin. This nature of the pollen rain is shown in AP relations, where in forested areas changes of arboreal species may be reflected (cf. HANSEN 1949, TSUKADA 1958, HEIM 1963, JANSSEN 1967, ANDERSEN 1967, 1970). It is also seen in the NAP figures, where the steep decline in the proportion of NAP as one moves from open to forested country indicates that the forest acts as an effective pollen filter (JONASSEN 1950, PERSSON 1955, DENGNER 1955, TAUBER 1967). It can be seen from fig. 4 that on entering the forest the proportion of NAP drops within the first 10—20 m. The
principal factors which affect the local nature of the pollen rain are: a) tree species which produce large amounts of pollen (Faegri & Iversen 1964), b) reduced wind strength caused by bio-geographical factors, such as forest canopies of differing ages and heights, a factor especially applicable to the southern Finnish forest types which may form an effective barrier to air currents (cf. Dengler 1955a, b). Such circumstances could not be compared with those in which Tauber (1965, 1967b) obtained values of 0.5—1.5 m/sek. for the air speed operative below tree-top level. Similarly the wind conditions in the area under discussion here differ considerably from those reported in the above-mentioned work, tending to suppress pollen dispersal. The pollen is concentrated to a greater extent amongst the surrounding branches and filters to the ground close to its point of origin (Tauber 1967, Andersen 1970).

distribution in present moss samples.
The local nature of the pollen rain is seen clearly along line II, where the tree species change abruptly from the deciduous forest with *Populus tremula* dominant to a bog with *Pinus*. Due perhaps to the fact that *Populus* pollen is usually badly preserved (ERDTMAN 1931, BORSE 1939, DAVIS & GOODLETT 1960, SANGSTER & DALE 1961, MULLENDERS 1962, HAVINGA 1964, 1967), it is the relative proportion of *Betula* which is outstandingly high in the samples from close to the field area. The subsequent sharp decline in *Betula* values in the forested sectors of line II is due both to the rise of *Pinus* as the dominant tree (Fig. 1) and to the presence of several *Picea* specimens in the immediate vicinity of sampling points 8 and 9. A corresponding local change in the tree species is found at point 14/III, for example.

The absence of closed forest locally along line IV allows a wider area to be considered in studying the dispersal of tree pollen from the forest surrounding the field. Since the direction of the prevailing wind is a significant factor in the dispersal of pollen to different parts of the area (HEIM 1963, ANDERSEN 1970), the various forest types present around the open field differ in their representation in samples from line IV. A certain regularity is observable in the pollen distribution, however, for the AP proportions remain almost unchanged throughout the length of this sAMP-
ling line. In spite of the dominance of *Picea* in the forest situated 300 m away, this pollen type accounts for only 15 % of the total AP (cf. BORSE 1939, GLADYS 1943). REMPE (1937) suggests that the local influence of the pollination of a *Picea* specimen extends up to a distance of 70 m. Beyond this point other factors play a dominant role in pollen dispersion (PERSSON 1955). On the other hand, the pollen production of young *Betula* stands growing on the field left fallow and some young *Pinus* leads to an over-representation of these species along line IV (CARROL 1943, HYDE & WILLIAMS 1944, SCAMONI 1955, POTZGER et al. 1956, TSUKADA 1958, DAVIS & GOODLETT 1960, JANSSEN 1966).

The even distribution of *Alnus* pollen between the forest sampling lines and line IV merits some attention. It is possible that the lightness (SCAMONI 1955) of this pollen type may enable it to be carried to great heights, and its corresponding slow rate of fall may facilitate its dispersal over a wide area. The relatively high proportion of *Alnus* pollen in the samples from the forest areas, where no local specimens are found, might be explained by its gradual descent from the highest air currents to tree-top level (SCAMONI 1955) and its subsequent rapid transport to the ground assisted by rain (MCDONALD 1962, TAUBER 1965, 1967). In this way the horizontal filtering action of the forest would have little opportunity to intercept *Alnus* pollen. A corresponding phenomenon might be the tendency for *Betula* pollen to become concentrated among the branches of conifers (POTZGER et al. 1956). The more far-reaching results obtained from the pollen traps, by means of which the pollen rain may be placed on a time-scale support this theory.

Having put forward some general conclusions on the dispersal of various types, formulated on the basis of the AP contained in recent moss samples, it should be pointed out that such short-term pollen rain figures may be subject to the influence not only of the amount of each pollen type released and its dispersal properties, but also of the climatic conditions prevailing during the flowering season, namely temperature and air humidity (LÜDI & VARESCHI 1936, LÜDI 1937, LEIBUNDGUT & MARCET 1953, SCAMONI 1955).

Only very scattered occurrences of shrub pollen could be noted. Considering the extremely large, dense *Salix* stand immediately adjacent to line IV, this pollen type seems to be grossly underrepresented in samples 15—20/IV (JONASSEN 1950). It constitutes only 1 % of total AP along line IV, the same figure as for line I where it is extremely rare amongst the local vegetation. Since it shows low resistance to oxidation (HAVINGA 1964) and is principally an insect pollinated species (WODEHOUSE 1965), *Salix* cannot
be said to be a reliable or significant indicator (Davis & Goodlett 1960), although for ecological reasons this genus would otherwise be important as an indicator of forest regeneration (Heikinheimo 1915). The greater proportion of Salix pollen found in the traps as compared with the moss polsters indicates that this may partly be a question of its disappearance due to oxidation.

The occurrences of Juniperus pollen at point 1/I and of Rhamnus at point 17/IV may both be considered as local overrepresentation. Juniperus is quite local (see species list, Table 1), and this pollen type does not appear in any other moss samples along line I. In the pollen trap samples its occurrences are more evenly distributed among the sampling points on line I, which may indicate a tendency to decay if subjected to oxidizing conditions (Potter & Rowley 1960).

2. Non-arboreal pollen

The general rapid decline in NAP pollen on entering the forest can be clearly observed in the frequencies of the dominant pollen types, Gramineae, Compositae and Rosaceae (Filipendula) (cf. Jonassen 1950, Andersen 1970). The number of species present similarly decreases at the forest boundary. The filtering property of the forest is very effective in the case of the low-growing field vegetation, whose pollen, at best, is carried only in the lower level air currents.

The proportions of non-arboreal pollen types vary considerably at different points similarly situated with regard to the cultivated area. The proportion of Cerealia pollen, for example, varies according to the ground vegetation of the sampling site concerned from 2 % to 7 % of NAP (Fig. 5), the 2 % figures being those for sites 5/II and 15/IV where the overall proportion of grass pollen is higher than at those sites bordering on coniferous forest. It is evident that, even at the edges of relatively large open fields, Cerealia pollen cannot compete with indigenous NAP, certainly not where the partially or completely self-pollenating species, Avena, Hordeum and Triticum are concerned.

Gramineae pollen can be seen to predominate at points 23,1/I, 5/II and 22, where its proportion is more or less constant around 50—65 % of NAP. At points 21 and 15/IV, however, its position is affected by the large amounts of Filipendula found along the bank of the stream. At the western end of this line Compositae tubuliflorae (excl. Artemisia) are well
represented, in spite of being largely insect pollinated. Lüdi & Vareschi (1936) also draw attention to the higher proportions of this pollen type in the overall non-arboreal pollen rain. Beside these the true weed of cultivation, Chenopodiaceae and the indicator of human activity, Rumex, constitute an almost insignificant part of the NAP count, the former varying around 0—3 % of NAP, the latter around 1—3 (7) % of NAP. The decisive influence on the pollen frequencies at point 1/I is that of the nearby fallow area, while the dominant streambank vegetation serves to reduce the proportions of weeds at points 21 and 15/IV.

The apparent increase in Cerealia pollen as a percentage of NAP further into the forest (on lines I—III) is due to a decrease in the dominant NAP species, especially in Gramineae. The total NAP figure can be seen to fall sharply as one moves away from the open field area (Fig. 4). It was clear during the analysis of the pollen samples that the majority of occurrences of Cerealia both at the edge of the field and further into the forest consisted of agglomerations of several pollen grains rather than of single grains; such agglomerations were counted as equivalent to single-grain occurrences. It could be concluded from this that some of the pollen had been introduced into the samples by a means other than wind dispersal. This impression is supported by the results from the pollen traps presented later.

Fig. 5. The proportions of non-arboreal pollen types at the points bordering the field area.
The poor natural pollination resources of rye are demonstrated in the work of Wolfenbarger (1946) on the pollination of Secale, which even so is the only wind pollinated crop cultivated in Finland. The poor dispersal properties which he mentions may partly be due to the relatively large size of this pollen grain, which may affect its transport in air currents (Wodehouse 1965). Since Hordeum and Triticum are almost exclusively self-pollinating species, natural dispersal of their pollen by wind will obviously be minimal (Heim 1963, Wodehouse 1965).

The proportion of Avena can be seen to increase compared with other Cerealia types as one moves towards the forest along lines I—III (Fig. 6). The reason may be the larger amount of Avena pollen originally released, since it is known to alternate between cross-pollination and self-pollination according to climatic conditions (Valle 1964).

Since in this way not only the distance from cultivated field areas, but also the amount of grass in the local vegetation, the density of the forest, the method of harvesting and the paths and tracks used for this may affect the dispersal of Cerealia pollen, an isolated occurrence of Cerealia need not necessarily indicate the presence of agriculture at that point. Especially in the days of primitive agriculture in woodland clearings, the geographical positioning of the fields varied constantly and the distances over which the harvest was transported tended to be long. Therefore an occurrence of
Cerealia would rather function as an indicator of the practice of agriculture as a source of livelihood within an area defined on a much wider geographical scale.

The differences in the proportions of various NAP types were mostly local ones confined to certain points on the sampling lines (cf. Hesmer 1933, Davis & Goodlett 1960). Several negative factors are involved in their appearance in the pollen figures, the most important being: 1) the reduced force of air currents close to ground level, 2) the small quantity of pollen released and its poor dispersal properties, especially in the case of insect pollinated species, 3) local overrepresentation of some species caused by insects, and 4) the overwhelming overrepresentation of the nearby trees (Davis & Goodlett 1960).

Graminae stands out as the dominant pollen type among the NAP species surrounding the cultivated area along almost every sampling line (Heim 1963). The only exception is line IV where the local Filipendula stand releases a large amount of pollen. The significant role of this species in the stream bank vegetation stands out in a similar manner in the pollen assemblages for points 10/III and 11/III (cf. Andersen 1970). The importance of the occurrence of these dominant pollen types lies in their complete exclusion of the less vigorously pollinating species — not to mention the insect pollinated ones (Table 1) — from the pollen figures unless a very large number of grains is counted. Even in the latter case the proportion of these species within the total NAP remains comparatively insignificant. Examples of this would be the proportions of Cruciferae, Chenopodiaceae and Rumex types within total NAP along the various lines, reading from the field area outwards:

<table>
<thead>
<tr>
<th>Line</th>
<th>Cruciferae</th>
<th>Chenopodiaceae</th>
<th>Rumex</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>1, 1, —, —</td>
<td>3, 11, 10, 6</td>
<td>7, 14, 5, 6</td>
</tr>
<tr>
<td>II</td>
<td>—, —, 3, 3, —</td>
<td>1, 2, 7, 7, 44</td>
<td>3, 1, 3, —, —</td>
</tr>
<tr>
<td>III</td>
<td>+, —, —, —, —</td>
<td>1, 1, 2, 6, 3</td>
<td>2, 2, 4, 3, 15</td>
</tr>
<tr>
<td>IV</td>
<td>—, —, +, +, +, +, 1</td>
<td>0, 1, 2, 2, 1, 1</td>
<td>2, 36, 6, 3, 1, 6</td>
</tr>
</tbody>
</table>

The relatively high percentages of these species for line I are due to the nearby fallow area where the relative proportion of Graminae is less than on the edges of the established field area.

In addition to a percentage increase in the species where the influence of the dominant species is reduced, attention should also be drawn to certain exceptionally high figures for Chenopodiaceae (44 %) and Rumex (36 %) due to entirely local factors. At the sampling points in question,
9/II and 16/IV, the above species do not actually occur in the local vegetation. The role of insects as transporters of pollen is always a possibility to be borne in mind, regardless of whether the species concerned is characteristically wind or insect pollinated, whenever such large amounts of one pollen type are found (SHARMA 1970). It is also possible to find occurrences of insect pollinated species which have been wind dispersed (HYDE & WILLIAMS 1944), even though these may be more local in origin than the wind pollinated species. Examples of this may be the comparatively large amounts of *Filipendula* found at points 5/II and 22 considering its total absence from the local vegetation. The large stands of Filipendula along the bank of the stream, as mentioned above, may be reflected in these samples.

The distribution of pollen between the various NAP types may also be dependent upon the differing powers of resistance of these types to dryness and oxidation. Chenopodiaceae-type pollen is said to preserve especially well (POTTER & ROWLEY 1960, WRIGHT et al. 1967), so that its proportion in surface samples must closely correspond with its proportion in the pollen rain. ERDTMAN (1943) similarly testifies to the durability of Compositae pollen in surface samples, whereas Cyperaceae pollen perishes very easily due to its thin exine. This pollen type is very poorly represented in the present samples, a situation also found by HEIM (1963) and ANDERSEN (1970), for instance.

The rare but evenly distributed occurrences of Labiatae pollen also warrant some comment. Many are cases of *Galeopsis tetrahit*-type pollen, which is a common weed, especially at the outer edges of the field area. The role of this pollen type as a cultural indicator has been noted previously (VUORELA 1972). Other indicators of agriculture appearing in very small numbers in these surface samples are *Urtica*, present at only three sites, *Polygonum amphibium* and *Polygonum viviparum*, each in only one sample, and *Fagopyron* and *Centaurea cyanus*-type similarly in one sample each.

The proportion of *Elytrigia repens* in the Gramineae pollen of the surface samples is very similar to that which prevailed during early agricultural times (VUORELA 1972). The amount of pollen produced by this species is closely comparable to that produced by Cerealia (WODEHOUSE 1965), which may explain its low figures in the diagram.

Compositae tubuliflorae-type can be said to account for about 80—90% of all the Compositae pollen, and a close examination shows *Achillea*-type to be the most frequent at the sampling points nearest to the field area (Fig. 6, Table 1). Further into the forest it has to compete
with *Artemisia* for this position. This supports the theory presented earlier which places *Achillea*-type pollen among the typical species of present-day agricultural areas (Vuorela 1972).

The relative insignificance of the species ordinarily associated with agriculture is somewhat surprising, considering the extent of the agricultural area in question. The low proportion of cultural indicators in surface samples has previously attracted attention, especially in the case of *Artemisia*, Chenopodiaceae, *Rumex* and *Plantago* and even Cerealia-type pollen (Mullenders 1962, Heim 1963). Clearly, such pollen types no longer possess the same significance as they may have had as indicators of past agriculture. Efforts are now made to keep the fields relatively weed-free, and where they have been left fallow for as long as 10 years (as on line III), something much more closely allied to natural meadow vegetation establishes itself in advance of actual forest. On the other side tight bush-vegetation around old fields often prevents Cerealia pollen from spreading to the surroundings. Formerly, when cultivated forest clearings were abandoned many more true weed species occupied them, especially in the first few fallows years. Even so, the weed species typical of such cultivated clearings are extremely difficult to detect, principally because of the local overrepresentation of the surrounding vigorously pollinating trees when the field area is small (Andersen 1970). Since the present results indicate that even in the case of small forest openings and cart-tracks (samples 4/I and 14/III) a slight quantitative and qualitative increase in NAP can be observed (Fig. 3; cf. Jonassen 1950, Heim 1963), it is difficult to determine on the evidence of only a very small percentage of cultural indicators the exact reason for an increase in NAP at any given point.

**IV. POLLEN DISPERSAL AS RECORDED BY POLLEN TRAPS**

Although no attempt was made to calculate absolute pollen frequencies for the pollen traps it was clear that the amount of pollen present in the air currents varied considerably between different seasons of the year. In early summer the 200 grains counted for each sample represent only a tiny fraction of the pollen collected in the trap, whereas in September and October a whole sample might sometimes contain less than 100 grains.

The seasonal variations in the AP/NAP ratio were found to be uniform
Fig. 7. Relative diagram of the recent pollen rain counted in five periods during the summer 1971.
for the different sampling lines, even though local factors such as the type of forest and its distance from the sampling point were reflected in the results from individual traps (Fig. 7). Arboreal pollen predominates until around the latter part of July, though the proportion of NAP increases from 3\% to 36\% at the very beginning of July (Fig. 8). The highest NAP figures are obtained from late summer (July—August 68\%, August—September 61\% of total pollen), by which time the role of the tree pollen, released earlier in the summer, is little more than a secondary one. The wild Gramineae species have been dominating the NAP spectrum from early summer, in August and September other local herb species are producing comparatively large amounts of pollen.

The seasonal variation in the proportions of the various tree species is seen most clearly in the cases of *Pinus* and *Betula* (Fig. 8). The earlier flowering of *Betula* causes its pollen percentage to reach 30\% in the first sampling period, after which it falls steeply when *Pinus* flowers in the following period. The relative decline in the proportion of coniferous pollen at the end of the summer may well result from the tendency of some pollen types, including *Betula* and *Alnus* to accumulate amongst the branches of trees and then be washed to the ground by rain (Potzger et al. 1956). This is supported both by the rise in the proportion of *Alnus* from 2—3\% during its flowering time to 8—9\% in September—October (the corresponding figures for *Betula* being 30\% and 51\%), and also by the low frequency of *Alnus* at point 10/III (Fig. 7) where trees are locally absent. The proportion of *Alnus* in the samples from the shrub and forest vegetation along lines II—IV is extremely high considering its scarce occurrence in the local vegetation.

![Fig. 8. Proportions of Cerealia, Gramineae and NAP / total pollen and different tree pollentypes / AP during the five periods.](image-url)
The discrepancies between the surface samples and the traps in the amounts of *Juniperus* and *Salix* pollen found have been discussed earlier. In the case of the former these results may be compared with corresponding ones obtained in New Mexico (Potter 1957, Potter & Rowley 1960), in which *Juniperus deppeana* was confined to 1—2% of the surface samples in spite of constituting 17% of the pollen rain at the same period. Its vulnerability to oxidation may partly be the reason for its underrepresentation in pollen diagrams.

The isolated, distinct occurrences of *Calluna*, Compositae, Rosaceae and Umbelliferae in the pollen traps results support the theory concerning the local influence of non-arboreal pollen (Heim 1963, Andersen 1970). One important source of discrepancy in pollen trap readings arises from the effect of insects, especially the hairy wasps and bees, which may fall into the traps carrying with them vast amounts of non-arboreal pollen, mainly that of insect pollinated species, but also that of some wind pollinated ones, for example, Gramineae and Cyperaceae (Wodehouse 1965, Sharma 1970). Insects are known to collect the latter in large quantities as food.

The overwhelming proportion of *Succisa* (179%/NAP) in sample 10/III for September—October may be due to a stamen falling into the trap. The relative heaviness of this pollen grain restricts its dispersal properties (Pennington 1963), and it is probable that the source of this pollen is quite local (cf. species list, Table 1).

In a similar way the large amounts of Compositae liguliflorae pollen found in the same trap in July and August may be caused by the local presence of *Hieracium*.

The poor, spasmodic representation of the insect pollinated species in the pollen diagram is clearly seen in the case of site 10/III. In spite of the wide variety of species present locally (Table 1), the greater part of the pollen recorded is accounted for by the above-mentioned dominant pollen types. Even the number of occasional grains does not succeed in raising the overall number of species to a decisively higher figure than that found elsewhere.

Those pollen types which are chiefly wind carried are dispersed more evenly over the surrounding area. Outstanding among these is the pollen of the Gramineae species, whose concentration around the middle of the summer corresponds to the flowering time typical of this group. The proportion of Cerealia pollen is highest in the samples for the late summer, around the latter part of August (Fig. 8). Clearly the scattering of chaff at harvest time and the operation of a combine harvester have some
effect on the distribution of pollen, as indicated by the concentration of Triticum pollen in the moss samples from lines I and II (Fig. 6), the first running close to the cultivated area, the second following the edge of the cart-track.

The proportion of Rumex pollen was found to fluctuate very little throughout the summer, and no clear variations could be observed with increasing distance from the field area. Urtica is also found evenly distributed over the monthly sampling intervals, but in this case more local overrepresentation can be seen. The exceptionally large amount of Urtica in sample 15/IV may originate from local vegetation. The great difference between the frequencies of Urtica in the surface samples and in the pollen traps reflects the ease with which its grains will perish if left exposed to oxidising processes.

In addition to the possible sources of discrepancy in pollen trap analysis mentioned above, it should also be mentioned that numerous needles, broken twigs, tree leaves and other large debris were removed from the traps in the field. The pollen which had fallen or been rinsed from this debris is closely comparable with the pollen which is transported by rains from the branches of trees, even though the role of this secondary pollen rain may in some samples thus be greatly exaggerated. It is clear that with all these possible sources of discrepancy average readings obtained over several flowering seasons will give more representative values of vegetation communities.

V. CONCLUSIONS

In discussing the results of this study on the variation in pollen rain in the vicinity of an agricultural area surrounded by forest the main emphasis was placed on the pollen filtering action of the forest, the resultant local nature of the tree pollen and in the case of NAP the appearance of «cultural indicators» along the sampling lines.

It was deduced that in the forest samples the AP relations follow the variations of the various species in the local vegetation regardless of differences in pollen production, while on the treeless line IV they reflect not only the production but also the differing dispersal properties of the pollen types. In the absence of any local factors no significant variation could be found in the AP proportions along this sampling line.
Alnus and Betula pollen were seen to be concentrated in the pollen trap samples from the late summer. Since this applies only to the traps placed in the forest, it could be thought that the pollen of these species tends to accumulate in the thick branches of trees and be washed down in the early autumn rains.

The extreme local variation in NAP indicates very poor dispersal in air currents. This is especially the case with the lower-growing species. The sharp decline in NAP as one moves from the field area into the forest testifies to the effective filtering action of the vegetation in the Southern Finnish forest type. This phenomenon is clearest in the case of Gramineae pollen which accounts for the majority of the NAP of the agricultural area itself. It is abundant at the edges of the field area and interferes with the representation of other NAP types in the diagram. Some considerable stands of insect pollinated species can also be seen to affect a large area of their surroundings, provided that the air currents succeed in carrying their pollen freely. This is the case at the sampling points around the field area, especially where stands of Filipendula and Umbelliferae are concerned.

Roads, footpaths etc, constitute treeless areas within the forest where NAP pollen is more abundant and where air currents can transport such pollen over long distances. It is true that the NAP figures for the sampling sites by pathways do differ from those for forest sites at comparable distances from the field area both in the total amount of pollen and in the number of species present.

Since the pollen trap samples represent the pollen production of only one month at a time, the results obtained may be affected by quite random factors such as the direction and force of the prevailing wind, temperature and air humidity, and also the flowering times and intensities of different species, which are in turn dependent on these firstmentioned factors. In addition, the flowering rhythm of Picea, for example, which varies greatly from year to year, would require a long period of study in order to obtain reliable results. For these reasons the results presented here are quite local in character and could not be used for comparison with fossil pollen figures (Fagerlind 1952, Kral 1968). Nor, in the absence of any absolute values, could one consider the averages of the monthly proportions as representative of the yearly relative pollen rain.

The pollen trap results show that Gramineae pollen is the dominant NAP group in early and mid-summer, though later in the growing season it is replaced by Compositae and Rosaceae. Perhaps the most important outcome from the pollen trap results is that they support the theory,
formulated in connection with the analysis of the moss samples, concerning the dispersal properties of Cerealia pollen. Attention was aroused by its low frequency even in the immediate vicinity of the agricultural area, which in itself is an indication of the low pollen production of the crop species, here *Avena* and *Hordeum*. However, since it was observed when studying the surface samples that Cerealia pollen very often appeared in agglomerations of several grains even at quite long distances from the field area, these cannot be thought of as being transported by air currents. The pollen trap results suggest that although the flowering time of the crop species, like that of wild Gramineae, occurs in early and mid-summer, Cerealia pollen mostly appears in the pollen rain in the latter part of the summer, in the period 15.VIII—15.X. The co-occurrence of this appearance with the gathering of the harvest may point to man as the transport medium for this pollen type. The rarity of Cerealia in deposits from early cultural ages is easy to interpret against this background, by comparing modern methods of harvesting, with their efficient pollen disperser the combine-harvester, with those used in earlier times. As the fields were quite separate from the dwelling sites in the days of primitive agriculture one might argue that pollen from the chaff would have been scattered along the pathways. Thus single occurrences of Cerealia in particular do not really indicate the presence of agriculture in the immediate vicinity, although they do show the practise of agriculture somewhere in the area. The presence of a large amount of Gramineae pollen in addition to the Cerealia may, however, indicate local agriculture. One may also presume that the fallow and pasturage phases in the cultivation of forest clearings led to a range of true weeds of cultivation which was comparatively greater than is the case in present-day agricultural areas. The species normally designated as "cultural indicators", Chenopodiceae, Cruciferae and *Rumex*, plus others, have their highest percentages on line I, where in the immediate vicinity there is a small area of land which has been left fallow for three years. Elsewhere these species are comparatively insignificant in the recent samples. The pollen types which indicate increasing human interference (Vuorela 1972) are thus to a major extent the outcome of activities other than arable farming, the most important of which may be habitation, transportation and the cultivation of hay for cattle-rearing. As the site for the present investigation was intentionally chosen to be centred around a purely arable area the effect of these factors upon the results obtained is negligible.

The more delicate pollen types (Faegri & Iversen 1964), notably *Juniperus*, Cyperaceae and *Salix* were much better represented in the pollen
traps than in the recent surface samples. This indicates that they may easily perish if left in contact with the air. This should be borne in mind when analysing peat profiles whose accumulation rate may have been particularly slow at times.

Since the moss polsters obviously represent the pollen rain of two, possibly three, years — a fact which is indicated by the appearance in the samples from lines I and II of *Triticum* which was cultivated there the previous year — they may with greater justification be compared with the figure obtained from peat profiles. Here too, however, local factors are seen to affect the results to a very marked extent (Hesmer 1933). Kral (1968) sees a significant difference between recent moss polsters and 1 cm thick surface soil samples. Only in the latter can one assume the influence of random factors to have been reduced.

It should be noted that these pollen-based observations on the influence of agriculture on the vegetation of the surrounding areas cannot be compared with the pollen-analytical observations of past agricultural periods in Finland (Vuorela 1972). In peat and especially in lake sediments the local vegetation does not play such a part as it does in samples from closed forests. Thus variations in the vegetation representing a larger area can be observed. An important reason for the difference may also be the intensification of farming and the associated decline in the weeds of cultivation and also the relative increase in the proportion of coniferous forests as a result of the extension of the agricultural areas.

The disparity between the present results and the recent pollen rain and pollen dispersal figures obtained elsewhere in Northern Europe (Andersen 1967, Tauber 1967b) may be due to the very nature of the forests of Southern Finland both structurally and in terms of the species present. Clearly this forest type with its extremely high pollen productivity and its generally very tight structure from tree-base to crown possesses special pollen dispersal features and requires a great deal more research yet, into both its relative and absolute pollen frequencies.

**Acknowledgements**

The author is grateful to prof. Joakim Donner and dr. Pentti Sorsa for their critical comments on the manuscript. She also wishes to thank her husband for great help in the field work, Mr. and Mrs. Malcolm Hicks for the English translation and Mrs. M. Mayer for drawing the pictures.

Financial aid from Emil Aaltonen Foundation (Emil Aaltonen Säätiö) is gratefully acknowledged.
Table 1. Average proportions of trees and herbs around (Ø 2 m) the sampling points. Wind pollinated types in italics.

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Irniel Vuorela: Relative pollen rain around cultivated fields


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