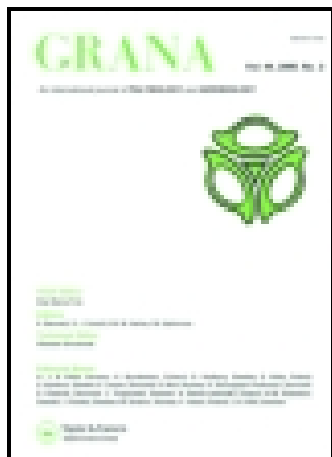




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Frequency and abundance of pollen taxa in crime case samples from the United Kingdom

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Frequency and abundance of pollen taxa in crime case samples from the United Kingdom

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Abstract

The frequency and abundance of pollen taxa in samples from crime cases in which forensic palynology had been employed, was investigated by collating pre-existing data. Fifteen cases from England and Northern Ireland that represented a range of habitats and exhibit types were selected and a total of 199 samples were included in the analysis. Control samples were considered separately to those from exhibits. The latter contained a wider range of taxa and were more likely to contain pollen from planted ornamentals such as *Cedrus*, *Ligustrum*, *Juglans* and *Platanus*. Pollen of the Poaceae family occurred in 100% of samples and in the greatest mean abundance (25.65%) and the wind-pollinated taxa of *Pinus*, *Betula*, *Quercus*, *Alnus*, *Fraxinus*, *Corylus* and *Urticaceae* also occurred with very high frequency (> 80%). Most taxa had a mean abundance of < 6% but several were higher. Maximum abundance was also studied, varying greatly from the mean in some taxa, notably *Castanea sativa*, *Plantago lanceolata*-type, *Pteridium aquilinum* and *Quercus*. Not all taxa that occurred frequently were wind-pollinated: some members of the insect-pollinated families of the Apiaceae, Asteraceae, Brassicaceae, Ericaceae and Rosaceae, as well as *Hedera helix* and *Sambucus*, were quite frequently found, sometimes in relatively high maximum abundance. The results demonstrate that pollen from certain plants repeatedly occur in both control and exhibit samples. This information can assist with the evaluation of pollen profiles in crime cases.

Keywords: *forensic palynology, insect-pollinated, wind-pollinated*

Analysis of pollen (and other palynomorphs such as fungal spores, algae and diatoms) in samples is occasionally employed as a forensic tool to search for links in crime cases and the rationale and processes for its use have been described by various authors (Miller Coyle 2005; Wiltshire 2009; Adams-Groom 2012; Sandiford 2012). Typically, control samples will be collected from scene or alibi locations and exhibit samples such as footwear, clothing, digging implements and vehicles, although pollen can be found on virtually everything. In the majority of cases, control samples come from soil or humic material, while exhibit samples tend to be from soil-based accumulations or washings from exposed surfaces. Items can also gather pollen through direct contact with flowers or from impaction or settlement out of the air since the grains generally stick very well to most surfaces (Wiltshire 2009). The palynologist will usually find a suite of pollen types in a sample, termed a pollen

profile or pollen assemblage, and may then need to determine similarities with comparator samples. There are many factors that make this a complex task. One of these is the comprehension of the frequency and abundance with which any particular pollen type is likely to occur in a sample, since this enables an understanding of its value within a profile from an exhibit.

In the United Kingdom (UK), there are many plants that are widespread and some of these produce abundant pollen, which is then dispersed by the wind. Other plants produce pollen that is destined to be moved between flowers by biotic vectors such as insects, bats and birds. These plants tend to produce less pollen and, in many cases, it never reaches the ambient air-stream and may only reach the soil in small amounts. It is these rarer types that typically lend more credence to the uniqueness of a certain pollen profile, although unusually high abundance of more frequent types may also contribute to this.

Since the pattern of deposition of pollen into the environment is in constant flux, it is not possible to create a lasting contemporary database of pollen profiles from across the country. Indeed, such a project would be extremely time-consuming. There are no articles available that look at the relative percentage frequencies of occurrence of pollen types in surface soil samples from the UK but there are some sources of information that currently give general indications. Wiltshire (2009) discusses sources of information regarding pollen in surface soils that are available to the forensic palynologist. The UK network of pollen sites provides information about wind-pollinated taxa that are commonly found in the air during their flowering season (Emberlin et al. 1999; Corden et al. 2000) and pollen calendars are available online. Poaceae, Urticaceae, *Betula* and *Quercus* pollen occur most abundantly in the air of the UK. Some of this pollen will, of course, be deposited on the ground and become incorporated into the soil along with other more localised types, where it will be subject to various actions of movement and decay by weathering, mould and soil fauna. As for the frequency of types occurring specifically in soil, there are limited references to modern surface soils and no databases allied to forensic palynological analysis exist. The POLLANDCAL (Pollen Landuse Calibrations) initiative collects soil pollen samples, including surface data, from habitats of particular interest to palaeo-palynologists and the data is available online: (<http://www.europeanpollen-database.net/data/>). For data specifically from crime cases in the UK, little information is available in the public domain. However, soil pollen profiles from two crime cases were described by Wiltshire (2006), who presented data from victim hair samples collected in Leeds, West Yorkshire, and from near Norwich in Norfolk, while Brown et al. (2002) presented data from a vehicle and woodland in Leicestershire. Experimental research presenting soil pollen profiles from six sites in the East Midlands was undertaken by Riding et al. (2007).

This study examined the frequency of occurrence and abundance with which different pollen types occur in samples examined by the author, which had been collected from crime scenes and exhibits across a range of cases from locations in England and Northern Ireland, with the aim of providing a point of reference of direct relevance to forensic palynologists.

Material and methods

Case samples

Fifteen cases where forensic palynological assessment had been employed and numerically quantified were selected for this study, encompassing 83

control samples and 116 exhibit samples. The control samples were representative of the locations that suspects may have accessed or been in the vicinity of, such as a crime scene, and are usually taken for comparative purposes. The exhibit samples have derived from items seized in relation to each crime, e.g. footwear belonging to a suspect that may have been worn at the crime scene. This paper does not look at direct comparisons between controls and exhibits for each case but is rather a collection of samples that have been examined for trends in the frequency with which pollen taxa appear generally. The samples were collected in England and Northern Ireland and details on the general locations, habitats and exhibit types can be viewed in Table I. The control samples came from a wide area of England and Northern Ireland and included a broad range of different habitats, while the exhibit samples encompassed items that are typically assessed for palynological evidence, such as footwear, digging implements and vehicles. It should be noted that some of the case samples were related because they were obtained from the same crime scene area and had a very high degree of similarity. For this reason, it was not necessary to include all control samples from each case in the analysis. Control samples had been obtained by scraping soil or humic material from the top few millimetres of the surface at scenes, except where a grave was present, in which case samples were taken from soil layers, from where the body had lain and from mixed spoil. Exhibit samples were obtained by scraping or washing the items or occasionally by tape-lifts. In all cases, pollen data had been collected by separating the pollen from the rest of the sample material using standard palynological extraction processes outlined in e.g. Brown (2008) and Moore et al. (1991). Pollen identification was done using bright-field microscopy and a minimum of 300 pollen grains per sample had been obtained where possible, usually many more, although some exhibits contained fewer. All counts had been transformed into percentages.

Assessment of frequency and abundance of pollen types

The total number of occurrences per taxon, for all the controls and all the exhibit samples, was calculated and the sums converted to percentages. The pollen types were then ranked according to their frequency of occurrence. Pollen abundance percentages from the control and exhibit samples were collated, totalled for each taxon, and the mean, standard deviation from the mean and maximum abundance were calculated.

Controls were collated separately to the exhibits since the former came from known locations, whereas the latter could contain pollen from an unknown number of habitats and may have been subjected to wear or exposure that removed or acquired particles. Only pollen, fern and *Sphagnum* moss spores were included in this particular study, although other palynomorphs are sometimes analysed in forensic cases where deemed evidentially important, particularly fungal spores (Hawksworth & Wiltshire 2011). A few types were only recorded as being present so it was not possible to calculate figures for abundance. Taxa which only occurred once across either all the controls or exhibits were excluded from the analysis since there were many of these. Although such types can be considered as infrequent, it is important to note that the presence of rarer types can be of great significance in crime cases, particularly if there is a suite of them occurring together.

Results

Three taxa were very frequently found in most samples of either type (Tables II, III), and also in relatively high mean abundance of > 10%, and these were Poaceae (100% of all samples), *Pinus* (97.6% and 84.5%) and *Betula* (90.4% and 97.4%). Poaceae was by far the most abundant type with a mean abundance of up to 25.65% and maximum abundance recorded at 85%. *Alnus*, *Quercus*, Urticaceae, *Fraxinus* and *Corylus* were all found very frequently (> 80%) on the exhibits but at a lower mean abundance of < 6%, while in the controls, *Alnus*, *Quercus*

and Urticaceae occurred very frequently (> 80%) but also at a lower mean abundance of < 5%. All of these taxa are wind-pollinated trees or grasses.

Three types were found frequently (60–79%), but usually occurred in moderate to low abundance (< 5%) with an occasionally high maximum abundance: Amaranthaceae (wind-pollinated herbs), *Plantago lanceolata*-types (wind-pollinated herbs) and Asteraceae (insect-pollinated herbs).

Twenty-one types were found moderately frequently (30–59%) in either the controls, the exhibits or both, including *Castanea sativa* Mill. and Cupressaceae (wind-pollinated trees), Rosaceae and *Salix* (insect/wind-pollinated trees), herbs such as *Rumex* and *Artemisia* (wind-pollinated), *Sphagnum* (wind-dispersed moss) and *Hedera helix* L. (insect-pollinated climber). Abundance in this group was more variable with some types occasionally occurring at high maximum abundance levels, notably *Castanea sativa*, Ericaceae (insect-pollinated), *Pteridium aquilinum* (L.) Kuhn (wind-dispersed fern) and *Hedera helix*.

Thirty-two types were found at lower frequencies (< 30%) and generally these always occurred at low abundance too. Sixteen of these are wind-pollinated or wind-dispersed and the remainder insect-pollinated or amphiphilous (wind and insect combined). A few types occurred with greater frequency in the controls than on the exhibits and *vice versa*, e.g. *Sphagnum* was found in 25.9% of exhibit samples compared to 51.8% of controls.

Of the pollen taxa included in this research, 88 occurred altogether in the samples, 68 in the controls and 85 in the exhibits (excluding those that only occurred once). Sixty-five taxa were found in both

Table I. Case samples: location, habitat type for controls, exhibit types and number of samples selected for the analysis.

Location (region or county)	Habitats of controls	Number of controls	Exhibit types	Number of exhibits
Buckinghamshire	Mixed woodland	2	Hair	1
Cambridgeshire	Pine woodland; heathland	11	Footwear; nasal; hair; shovels	27
Hampshire	Birch woodland	2	Footwear	4
Hampshire	Farm	2	Vehicle; shovels	12
Herefordshire	N/A	—	Vehicle; footwear	7
N. Ireland	Suburban areas	4	Duvet; footwear	3
N. Ireland	Pine wood; acid heath	10	Footwear	11
London	Urban/suburban	—	Pollen filter	1
E. London	Allotment	2	Duvet	1
S. London & Kent	Grassland; pond; copse; orchard; verges	8	Footwear; vehicle	8
W. London	Suburban garden	2	Clothing	1
Norfolk	Arable; track verge; woodland	7	Vehicle; clothing	10
Somerset	Verge; hedge; arable	6	Vehicle	8
Staffordshire	Suburban garden: wooded border	1	Clothing; footwear	3
S. Yorkshire	Mixed woodland; suburban gardens; grassland; track verge	26	Spades; vehicles	19
Total samples		83		116

Note: N/A, not available.

and are compared in Figure 1, where it can be seen that the majority of types (57%) were more likely to occur on exhibits than in controls, as would be expected since exhibits may have been exposed to multiple habitats and airstreams, whereas control samples usually represent one location or habitat. Moreover, planted ornamental types such as *Cedrus*, *Ligustrum*, *Juglans* and *Platanus* tended to occur more frequently on exhibits than in controls, possibly because these plants are usually present in areas where footwear and vehicles are more likely to pass near or through, such as parkland and suburban areas.

Discussion

The results demonstrate that many taxa appear repeatedly in samples from controls and exhibits across a range of habitats and also that the majority of taxa occur at relatively low mean abundance. This latter point may be helpful to palynologists because finding a taxon in much higher abundance could suggest that it has a higher value in a particular pollen profile. However, caution should be exercised with the types that are most commonly found, namely Poaceae, *Pinus*, *Betula*, *Quercus*, *Alnus* and *Urticaceae*, since these are also common in the ambient airstream. There are a number of reasons why some types are more likely to occur in samples than others. These can be summarised as: pollination strategy; pollen morphology (size, weight, shape, ornamentation); pollen settling velocity; plant pollen production levels; plant frequency and distribution; plant height; source–distance relationship and flowering season. In this particular study, an additional reason may be some bias towards certain habitats where some of these taxa happened to occur very frequently.

Pollination strategy, morphology and settling velocity

The most frequently occurring types in this study are typically from common wind-pollinated or wind-dispersed plants with high pollen production and small, lightweight grains. Grasses (Poaceae) are extremely common with approximately 160 native or naturalised species adapted to suit most habitats across the UK (Hubbard 1984). They extend their anthers on long, lightly attached filaments, which vibrate on the slightest breeze allowing the pollen to be readily dispersed. Moreover, their pollen grains are rather smooth, rounded and most have a relatively slow settling velocity, although the very large grain of

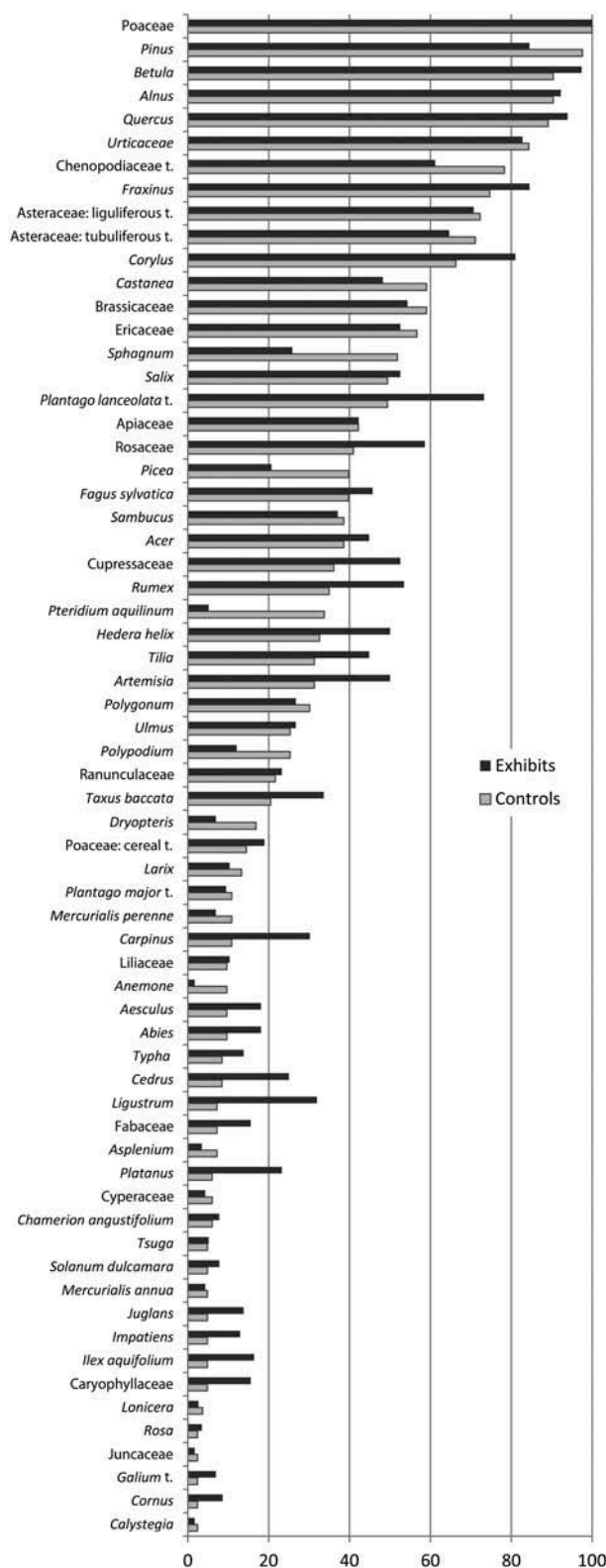


Figure 1. Comparison of frequency of occurrence of taxa found in controls and exhibits (%).

Table II. Frequency, mean abundance, standard deviation (SD) from the mean abundance and maximum abundance of pollen taxa found in control samples (all data in percentages).

Taxon	Frequency	Abundance ($\bar{x}$)	SD	Maximum abundance
Poaceae	100.0	24.5	18.5	85.0
<i>Pinus</i>	97.6	16.1	13.3	57.8
<i>Alnus</i>	90.4	3.3	4.2	27.9
<i>Betula</i>	90.4	10.3	14.4	65.8
<i>Quercus</i>	89.2	4.4	9.6	64.4
Urticaceae	84.3	4.9	6.0	30.8
Amaranthaceae	78.3	1.6	2.4	18.0
<i>Fraxinus</i>	74.7	2.8	3.7	16.2
Asteraceae: liguliferous type	72.3	3.4	4.3	22.7
Asteraceae: tubuliferous type	71.1	1.1	1.1	7.1
<i>Corylus</i>	66.3	2.8	3.9	18.6
<i>Castanea sativa</i>	59.0	4.1	10.3	52.8
Brassicaceae	59.0	2.6	4.9	31.2
Ericaceae	56.6	7.9	10.8	44.7
<i>Sphagnum</i>	51.8	2.2	4.7	22.3
<i>Salix</i>	49.4	2.3	6.1	37.4
<i>Plantago lanceolata</i> type	49.4	2.8	11.1	68.2
Apiaceae	42.2	1.8	2.7	13.7
Rosaceae	41.0	1.2	1.1	5.7
<i>Fagus sylvatica</i>	39.8	2.9	5.3	27.5
<i>Picea</i>	39.8	1.0	1.8	8.9
<i>Acer</i>	38.6	2.6	4.4	20.4
<i>Sambucus</i>	38.6	0.9	1.3	7.0
Cupressaceae	36.1	2.2	3.5	14.0
<i>Rumex</i>	34.9	1.0	1.4	7.1
<i>Pteridium aquilinum</i>	33.7	15.8	16.4	66.7
<i>Hedera helix</i>	32.5	6.5	13.1	42.3
<i>Tilia</i>	31.3	1.0	1.3	4.8
<i>Artemisia</i>	31.3	1.3	2.1	7.7
<i>Polygonum</i>	30.1	1.8	2.4	7.5
<i>Ulmus</i>	25.3	0.5	0.4	1.5
<i>Polypodium</i>	25.3	0.6	0.3	1.3
Ranunculaceae	21.7	0.5	0.4	1.7
<i>Taxus baccata</i>	20.5	1.6	2.2	7.7
<i>Dryopteris</i>	16.9	1.6	2.0	7.1
Poaceae: cereal type	14.5	1.5	1.0	3.4
<i>Larix</i>	13.3	0.5	0.4	1.1
<i>Carpinus</i>	10.8	0.6	0.6	1.8
<i>Mercurialis perennis</i>	10.8	1.3	1.3	4.3
<i>Plantago major/media</i> type	10.8	1.9	2.7	7.0
<i>Aesculus</i>	9.6	1.5	1.9	4.7
<i>Abies</i>	9.6	0.7	0.6	1.9
<i>Anemone</i>	9.6	0.9	0.7	2.1
Liliaceae	9.6	1.4	1.2	4.4
<i>Cedrus</i>	8.4	0.3	0.2	0.5
<i>Typha</i>	8.4	0.6	0.4	1.0
<i>Ligustrum</i>	7.2	0.2	0.1	0.4
Fabaceae	7.2	1.1	1.5	4.0
<i>Asplenium</i>	7.2	16.9	21.7	52.6
<i>Platanus</i>	6.0	1.2	1.2	3.1
<i>Chamerion</i>	6.0	0.5	0.5	1.4
Cyperaceae	6.0	0.8	0.6	1.6
<i>Juglans</i>	4.8	0.5	0.3	1.0
<i>Tsuga</i>	4.8	0.4	0.4	0.9
<i>Ilex aquifolium</i>	4.8	0.1	0.1	0.2
Caryophyllaceae	4.8	0.8	0.3	1.1
<i>Impatiens</i>	4.8	0.5	0.3	1.0
<i>Mercurialis annua</i>	4.8	0.7	0.5	1.3

(Continued)

Table II. (Continued).

Taxon	Frequency	Abundance ($\bar{x}$)	SD	Maximum abundance
<i>Solanum dulcamara</i>	4.8	0.7	0.6	1.5
<i>Lonicera</i>	3.6	0.3	0.0	0.3
<i>Cornus</i>	2.4	1.4	1.4	2.4
<i>Rosa</i>	2.4	4.1	5.1	7.7
<i>Calystegia</i>	2.4	1.7	1.9	3.0
<i>Convolvulus</i>	2.4	0.6	0.6	1.0
<i>Filipendula</i>	2.4	1.2	0.0	1.2
<i>Galium</i> type	2.4	0.3	0.1	0.4
<i>Myosotis</i>	2.4	24.8	22.1	43.1
Juncaceae	2.4	0.5	0.5	1.0

Zea mays L. has a settling velocity approximately ten times greater than, for example, *Dactylis glomerata* L. (Di Giovanni et al. 1995) and is rarely seen in samples. *Alnus*, *Betula* and *Pinus* are also wind-pollinated and their pollen is light with slow settling velocities (Gregory 1961; Sofiev & Bergmann 2013), while the grains of the latter possess air sacks for enhanced buoyancy. To compare, insect-pollinated taxa tend to be heavier; larger grains have faster settling velocities so any pollen grains that do emit from the flower will quickly sink to the ground below. Since the vast majority of plants across the world are insect-pollinated (Gregory 1961), these taxa are, therefore, under-represented in pollen profiles but can be of significance in evidential terms where they do occur.

Pollen production differences

The amount of pollen produced by plants varies from year to year and regionally due to various factors but estimates have been made for some types (Molina et al. 1996; Bricchi et al. 2000; Broström et al. 2008). For example, Molina et al. (1996) counted and calculated the numbers of flowers and pollen grains of ten wind-pollinated trees. The most productive taxon in their study was *Quercus*, which, for one year and three trees they calculated a range of 116.1×10^8 to 550.9×10^8 pollen grains per metre of crown, while in comparison, they calculated a range of 3.4×10^8 to 6.5×10^8 for *Fuglans*. This is reflected in the present study, where *Quercus* was the fifth most common type found across all samples, while *Fuglans* was the 56th. However, a contributing factor to this comparison is that *Quercus* is a very common native tree whereas *Fuglans* is a non-native tree planted occasionally in parks and gardens. The latter taxon would, therefore, be of greater interest to the forensic palynologist since it produces less pollen and has a more narrow distribution in the UK.

Plant frequency and distribution

The taxa that occurred frequently in the samples are all widespread in the UK, but those found more occasionally tend to have a restricted distribution due to habitat preference. For example, the wind-pollinated plant *Mercurialis perennis* L. (10.8% of controls and 6.9% of exhibits) grows widely but is largely restricted to shaded woodland sites on base rich soils and, similarly, the wind-pollinated *Typha* genus (found in 8.4% of controls and 13.8% of exhibits), grows in aquatic habitats. Conversely, even some insect-pollinated types occurred frequently because they tolerate many habitats. Pollen from members of the large Asteraceae family was found in more than 64% of samples, although mean abundance was generally low at no more than 3.4%. Some members of Asteraceae are very common in the UK, for example *Taraxacum vulgare* Schrank and *Bellis perennis* L. Pollination in this group is mainly by insects, although the pollen can be exposed to the air in liguliferous types and wind dispersal occurs in *Ambrosia* and *Artemisia* (Real 1983). The insect-pollinated *Hedera helix* also occurred quite frequently in the samples (32.5% of controls and 50% of exhibit samples) because it is a very common plant in the UK environment. This taxon was highly prevalent in one of the cases, where the main crime scene was in an ivy covered thicket and 42.3% maximum abundance was recorded in the control samples. *Solanum dulcamara* L. is another insect-pollinated type (Proctor & Yeo 1973) that occurred in the samples (4.8% of controls and 7.8% of exhibit samples). This climber grows in some types of woodland, thickets, hedges and ditches in lowland areas (Preston et al. 2002). Therefore, in evidential terms, it is necessary to consider certain taxa very carefully because this study demonstrates that not all insect-pollinated types are rare or particularly site-specific.

Table III. Frequency, mean abundance, standard deviation (SD) from the mean abundance and maximum abundance of pollen taxa found in exhibit samples (all data in percentages).

Taxon	Frequency	Abundance ($\bar{x}$)	SD	Maximum abundance
Poaceae	100.0	25.65	20.25	84.53
<i>Betula</i>	97.4	12.37	11.46	62.00
<i>Quercus</i>	94.0	8.76	12.85	60.00
<i>Alnus</i>	92.2	5.81	8.67	66.67
<i>Fraxinus</i>	84.5	3.63	4.64	22.00
<i>Pinus</i>	84.5	10.94	13.60	67.93
Urticaceae	82.8	6.14	8.12	42.86
<i>Corylus</i>	81.0	1.76	1.87	8.23
<i>Plantago lanceolata</i> type	73.3	3.32	5.99	33.20
Asteraceae: liguliferous type	70.7	2.35	2.63	12.00
Asteraceae: tubuliferous type	64.7	1.60	1.70	12.00
Amaranthaceae	61.2	2.65	4.10	17.48
Rosaceae	58.6	1.43	1.33	7.14
Brassicaceae	54.3	1.93	2.41	11.90
<i>Rumex</i>	53.4	1.39	1.81	7.94
Cupressaceae	52.6	1.37	1.44	6.48
Ericaceae	52.6	3.59	7.58	41.67
<i>Salix</i>	52.6	1.32	1.45	9.31
<i>Artemisia</i>	50.0	1.70	1.92	7.54
<i>Hedera helix</i>	50.0	4.84	10.44	56.07
<i>Castanea sativa</i>	48.3	4.08	11.34	77.29
<i>Fagus sylvatica</i>	45.7	2.52	4.50	22.71
<i>Acer</i>	44.8	1.54	2.27	13.75
<i>Tilia</i>	44.8	1.28	1.66	7.14
Apiaceae	42.2	0.94	0.99	4.97
<i>Sambucus</i>	37.1	1.76	2.43	11.34
<i>Taxus baccata</i>	33.6	1.10	0.87	3.62
<i>Ligustrum</i>	31.9	1.23	0.81	3.77
<i>Carpinus</i>	30.2	1.63	1.93	7.85
<i>Polygonum</i>	26.7	1.07	1.87	9.24
<i>Ulmus</i>	26.7	0.80	1.31	7.14
<i>Sphagnum</i>	25.9	1.26	1.03	4.28
<i>Cedrus</i>	25.0	1.07	1.25	4.65
<i>Platanus</i>	23.3	1.28	1.73	7.96
Ranunculaceae	23.3	0.77	0.45	1.59
<i>Picea</i>	20.7	1.33	1.91	6.74
Poaceae: cereal type	19.0	2.35	2.24	7.80
<i>Abies</i>	18.1	0.84	0.47	2.11
<i>Aesculus</i>	18.1	1.77	2.30	8.02
<i>Ilex aquifolium</i>	16.4	1.86	3.08	11.29
Caryophyllaceae	15.5	0.82	0.70	2.93
Fabaceae	15.5	0.79	1.19	5.13
<i>Juglans</i>	13.8	0.83	0.78	2.91
<i>Typha</i>	13.8	0.58	0.34	1.18
<i>Impatiens</i>	12.9	0.54	0.58	2.37
<i>Allium</i>	12.1	1.09	0.53	1.95
<i>Eucalyptus</i>	12.1	2.45	4.66	17.00
<i>Polypodium</i>	12.1	0.81	0.75	2.17
Myrtaceae	11.2	0.82	0.60	1.78
<i>Larix</i>	10.3	0.36	0.23	0.79
Liliaceae	10.3	0.80	0.68	2.51
<i>Plantago major/media</i> type	9.5	3.15	5.15	17.00
<i>Cornus</i>	8.6	1.21	1.10	3.80
<i>Buddleia</i>	7.8	0.54	0.36	1.00
<i>Chamerion angustifolium</i>	7.8	0.43	0.35	1.22
<i>Solanum dulcamara</i>	7.8	0.53	0.27	0.98
Cannabaceae	6.9	6.84	10.05	28.55
<i>Dryopteris</i> type	6.9	0.77	0.54	1.28
<i>Galium</i> type	6.9	0.39	0.11	0.58
<i>Mercurialis annua</i>	6.9	11.40	11.65	31.41

(Continued)

Table III. (Continued).

Taxon	Frequency	Abundance ($\bar{x}$)	SD	Maximum abundance
<i>Cistus</i>	6.0	0.49	0.52	1.48
<i>Sequoiadendron giganteum</i>	6.0	0.34	0.13	0.49
Berberidaceae	5.2	0.40	0.26	0.87
<i>Tsuga</i>	5.2	0.67	0.28	1.00
<i>Ambrosia</i>	4.3	0.69	0.61	1.48
Cyperaceae	4.3	0.46	0.12	0.55
<i>Mercurialis perenne</i>	4.3	0.51	0.35	1.10
<i>Solanum</i>	4.3	0.53	0.41	1.00
Campanulaceae	3.4	1.16	0.27	1.47
<i>Asplenium</i>	3.4	0.75		0.75
<i>Populus</i>	3.4	0.45	0.41	0.93
<i>Rosa</i>	3.4	1.00		1.00
<i>Casuarina</i>	2.6	0.34	0.35	0.74
<i>Centaurea</i>	2.6	0.30		0.30
<i>Digitalis</i>	2.6	1.45	0.39	1.72
<i>Lonicera</i>	2.6	0.46	0.24	0.63
<i>Acacia</i>	1.7	0.34	0.07	0.39
<i>Anemone</i>	1.7	0.59	0.11	0.67
<i>Calystegia</i>	1.7	0.09		0.09
Juncaceae	1.7	0.56		0.56
<i>Morus nigra</i>	1.7	0.34	0.44	1.00
<i>Sequoia</i>	1.7	0.18		0.18

Plant height and pollen dispersal

Plant height affects the range of dispersal but can dilute concentrations near to the source (Skjøth et al. 2013). Therefore, tall wind-pollinated trees will tend to spread pollen far and wide, while low-lying plants will have a smaller but more concentrated range, depending on pollination strategy and pollen production levels. However, *Sphagnum* moss is an interesting exception in that this low-lying plant has an ‘air-gun’ mechanism of internal pressure, which forces a cloud of spores into the air up to 15 cm or more, where they can catch air-currents more easily (Ingold 1939). *Sphagnum* moss is largely restricted to wet habitats and damp woodland but is also found in gardens where peat is used and, since it was often found in the case samples, its presence in a profile may not always be of particular significance.

Pollen source–distance relationship

The pollen source–distance relationship varies depending on habitat, plant height, plant pollination strategy and exposure to airstreams. Within a closed tree canopy, for example, estimates from various studies suggest the majority of pollen at any given point is likely to have originated within a range of 20 to 150 m (Bunting et al. 2005). For wind-pollinated taxa in an open location, much greater distances can be traversed under suitable meteorological conditions, as demonstrated by Skjøth et al. (2007). The

calculations of mean, standard deviation from the mean and maximum amounts demonstrate that some types have been found in particularly high abundance when the source is very near. For example, in one murder case, the body had been deposited in woodland containing many *Castanea sativa* trees and crime scene samples contained this pollen in great abundance of up to 52.8%, while the mean for this type, across the 59% of samples it was found in, is only 4.1%.

Pollen variation over time due to seasonality

These cases were sampled at different times of year so the taxa in season are those which could be expected to be more prevalent in samples. A different situation can exist for exhibits, however, since there can be a significant time lag between the date a crime took place and seizure of items such that pollen may have been lost and accumulated during the intervening time period. Fresh pollen landing on surface soil becomes incorporated over time into the top few centimetres of soil, mainly due to the action of earthworms (Davidson et al. 1999). Pollen can also become degraded by fungal, bacterial and oxidation processes (Moore et al. 1991) such that eventually it is no longer identifiable.

Some of the pollen found on the exhibits in this study is likely to have been acquired in other countries since some of the suspects in these cases were

immigrants to the UK. For example, *Ambrosia* was found in some of the samples, but this type grows only very rarely in the UK. It should also be noted that there is inevitably an element of bias towards the locations represented in the selected cases and that some types of habitat may be better represented than others. Only a standardised, methodical sampling of all habitats would be able to give the best overall picture of frequency and abundance of taxa in the UK, particularly for those insect-pollinated taxa which occur infrequently.

Further work of this type could focus more closely on comparing plants observed in a habitat to the taxa that actually come through in samples. For example, some insect-pollinated plants are often observed at a location, but their pollen rarely appears in a sample. In one case, *Hyacinthoides non-scripta* (L.) Chouard ex W. Rothmaler carpeted a woodland, where a body had been buried, but none of the control samples, taken just after the flowering of this taxon, contained it. Conversely, taxa sometimes appear in a sample when there are no nearby sources and it would be interesting to identify and quantify these.

Conclusion

The main findings of this study suggest that several taxa can be expected to occur in the vast majority of samples and that, apart from these particular ones, mean abundance generally occurs at, or below, 6%. Wind-pollinated taxa, particularly from trees and grasses, occurred with the greatest frequency and abundance in the case study samples. Poaceae pollen was the most frequent, occurring in all samples, with *Pinus*, *Betula*, *Quercus*, *Alnus*, Urticaceae, *Fraxinus* and *Corylus* found in over 80%. Although insect-pollinated taxa are generally poorly represented in samples, there are some that occur frequently because the plants are very common and widespread in the environment, notably members of the Asteraceae and Rosaceae families. It can be useful in forensic palynology to be able to distinguish between common types occurring in background concentrations and those amounts that may have greater evidential value. This work will assist palynologists when assessing the relevance and value of certain taxa found in crime case samples. Although these findings are potentially of great use to forensic palynologists, every crime case is different and each pollen assemblage should be carefully considered in its own right.

Disclosure statement

There are no conflicts of interest to disclose.

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