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Hair as a source of forensic evidence in murder investigations

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Abstract

Obtaining palynological and other botanical evidence from murder victims is becoming part of routine mortuary protocol in the United Kingdom. Forensic pathologists are often keen to cooperate in the collection of classes of material that have, in the past, been considered to be of little importance in criminal investigation. Work over the last eight years has demonstrated the great value in scrutinising cadavers for the presence of plant material and/or soil stains. Macroscopic plant remains and palynomorphs (pollen, spores and other microscopic entities) retrieved from skin and hair have allowed the differentiation of murder scenes from places of eventual deposition. Furthermore, although the opportunity has not yet presented itself, obtaining palynological evidence from the hair of suspects is feasible. During an offence, the offender might have had physical contact with foliage or the ground. Pollen and spore assemblages picked up by hair during that activity might provide forensic evidence for contact. Brief details of some aspects of case histories are presented to demonstrate the value of sampling cadavers. One case has been through the courts while the other is ongoing and, therefore, cannot be identified.

Keywords: Hair; Skin; Cadaver; Pollen; Palynomorphs; United Kingdom

1. Introduction

Mammalian hair (including wool and fur) is composed of the protein keratin [1]. Each hair arises below the surface of the skin from a root, which is enclosed in a follicle. The shaft of the hair consists of the innermost medulla (only present in thick hairs), a middle layer known as the cortex and the outermost cuticle [2]. The cuticle consists of overlapping scales; as the hair ages, the scales gradually erode and are affected by hair treatments and styling products [3]. Hair exhibits piezo-electricity and pyroelectricity [4] which means that it can attract particulates through electrostatic forces. Pollen and spores can be held on hair and fur for long periods and, in archaeological contexts, for millennia [5]. In the forensic context, pollen and spores may be retained by hair indefinitely, depending on washing frequency (personal observation); and it would seem that, for trapping pollen and spores, untreated hair is as effective as that treated with styling products [6].

Sometimes, the hair of a murder victim is clean and well groomed, but it is often the case that it is matted with body fluids, and coated with dirt, soil and other materials. If the victim is discovered some time after death, the scalp may be detached, and the hair distributed over the ground around the corpse. This is particularly the case where the body has been dumped out of doors, and birds and rodents have access to the body. Hair is good nesting material.

Before, during and after death, a victim's head may pick up palynomorphs from the ground or standing vegetation. The polleniferous surface may be in a place other than where the body was found and, if the palynological evidence has sufficient resolution, a picture of that other place may be gained. This provides investigating officers with valuable intelligence, and can link the cadaver with places related to offenders. Even if a suspect has not been identified, the kind of place revealed by the palynological assemblage can help police to restrict their search area. This saves valuable resources of time and money.

The quality of data required for court presentation differs from that needed for answering preliminary questions where answers are needed urgently. In the two case histories presented in this paper, the role of the palynologist was to help investigators locate some unknown place. If palynology had been needed evidentially later in these investigations, greater stringency in analysis would obviously have been necessary.

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The full data set would have been re-analysed and detailed counts of all, even over-represented taxa, would have been made.

2. Methods

The hair may be in a detached mass, or attached to a scalp. If the cadaver is recent and likely to be viewed by relatives, pathologists and mortuary technicians are often reluctant to remove the hair. In these cases, the head of the victim is supported over the back of the mortuary trolley and treated as though it were in a hairdressing salon. If, however, the corpse is in an advanced state of decomposition, the hair may be cut or plucked from the scalp.

It should be noted that tightly curled, negroid hair is difficult to wet, and it may be necessary to soak it before agitation. If the cadaver is not decomposed and the scalp is firmly attached, this can present considerable difficulties. On one occasion, this was circumvented by dissecting the whole of the facial skin and scalp and removing it like a ''glove puppet''. The hair was then soaked and agitated for a lengthy period. The soft tissue of the head was then replaced so accurately that its prior removal was undetectable.

Methods for extracting palynomorphs from a range of materials and objects have recently been published [7]. However, the techniques described are unnecessarily complicated and likely to yield fewer palynomorphs than in the simple method described here. Furthermore, it would be exceedingly difficult to employ the methods described in [7] when dealing with an intact cadaver.

The electrostatic forces holding pollen and other particulates onto hair are easily discharged by washing in hot, dilute, antimicrobial detergent solution. A non-perfumed, medicated shampoo is excellent for the purpose. It must be remembered that the hair could represent a biohazard since it is often contaminated with decomposing human body fluids and, indeed, still be adhering to a detached, fleshy scalp. The application of an antimicrobial solution, such as a dilute, non-perfumed, medicated shampoo, rids the sample of odour and serves as a disinfectant. But the palynologist must still be aware of the risk of hepatitis and other transmissible diseases.

A small volume of hot detergent solution is placed in an impeccably clean stainless steel bowl. The hair is then immersed, and agitated and rubbed vigorously for several minutes, and the washings saved. The hair is then rinsed with distilled water. The washings and rinsings are combined, mixed thoroughly and centrifuged at 3000 rpm for 5–6 min. The supernatants are discarded into a clean beaker and then into disinfectant before disposal. If the sample is to be subjected only to palynological analysis, it can be acidified with 10% HCl, mixed and centrifuged again. This ensures good preservation of the sample during transport to the laboratory. Acidification should be omitted where mineralogical analysis is also required since low pH can affect mineral solubility. These methods have been tested many times. They have proved to be highly efficient at retrieving the maximum amount of pollen possible from human hair and fur. They have the added advantage that large amounts of material can be processed and consolidated into a single sample.

The centrifuged sample is split into two aliquots (to avoid the risk of accidental loss of the whole sample). The pellet is then subjected to standard palynological processing, and palynomorphs mounted in glycerol jelly [8]. Counting procedures and details of data expression and nomenclature are given by Wiltshire and Black (this volume). As many palynomorphs as possible are counted, even though the law of diminishing returns may be considered to operate in counts above 300. In forensic investigation, it is important that every attempt is made to identify rare taxa by counting as many palynomorphs as is practicable. These may be critical for comparison. No attempt is made to assess the concentration of palynomorphs by the standard method of counting in relation to known numbers of added exotics [6] as this technique is inappropriate for forensic investigation. Where samples are scanned rather than counted, prepared slides are examined at $\times 400$ (and $\times 1000$ magnification where necessary). Contiguous fields in a minimum of 10 equidistantly separated transects are scanned on each slide. Every palynomorph encountered is identified, and subjective estimates of abundance are made according to a four-point scale. Scanning is invariably a preamble to full analysis, but is useful for quick assessment when investigating officers need answers very quickly.

3. Case history 1: Operation Conifer—the murder of Leanne Tiernan

3.1. Background

In August 2001, the body of Leanne Tiernan was found at the edge of an excavated depression in Lindley Wood (Forestry Commission woodland), near Leeds, West Yorkshire. In and around the deposition site, there were extensive areas of acid grassland with *Ulex europaeus* (gorse), *Calluna vulgaris* (common heather), *Erica* spp. (other heathers), *Vaccinium myrtillus* (bilberry), *Pteridium aquilinum* (bracken), and many herbaceous taxa including *Galium saxatile* (cleavers/bedstraw) and *Potentilla* sp. (tormentil). A diverse mixture of native hard wood species had been planted along the adjacent road but the woodland itself was a plantation of alien conifers including *Larix decidua* (larch), alien pines, and members of the families Taxodiaceae and Cupressaceae. Larch trees dominated the deposition site.

The victim was wrapped in a floral bed cover inside plastic bin liners. The plastic bags were secured by a dog collar fastened around her neck. She had been missing since November 2000 but the state of preservation of the body was such that investigators suspected she had been put into some kind of cold store before burial. Thus, the *post mortem* interval was unknown.

In September 2001, I was asked to visit Leeds Infirmary to obtain palynological samples from the nasal passages and the detached scalp of Leanne Tiernan's corpse. It was hoped that botanical proxy indicators from her body and the bed cover might provide evidence of the victim's whereabouts before her burial. At this time, a suspect had not been identified. It was suggested that if a place other than the gravesite, abduction site, and the victim's home could be characterised, it might lead to a location associated with the offender. I was asked to identify that place from the palynological profiles obtained from the victim and the bedcover. To identify the unknown place, it was necessary to evaluate the palynological profiles of comparator samples from victim's grave and its environs, and a number of places with which she was associated. This was essential for elimination purposes.

I visited the place where she was last seen, the woodland where she had been buried, and the garden of her home. I carried out a brief vegetation survey of each place and, for palynological comparison with the hair, obtained soils and vegetation samples from her grave, and the surfaces of all the other places. Routine palynological preparations were made of (a) the comparator (control) soils, (b) the victim's hair and nasal passages and (c) stains from both inside and outside of the bed cover which was wrapped around her body. Investigators were anxious to have information very quickly so slide preparations were rapidly scanned and first impressions given to the police.

The victim's mother reported that her daughter was fastidiously clean, and washed her hair on alternate days. Thus, if her head had contacted a polleniferous surface before, during, or after her death, the possibility of differentiating the critical place was enhanced.

3.2. Findings

Because of the wrappings, the victim's body should have been protected from particulates in the grave, and from the pollen rain at Lindley Wood. But there was a considerable amount of plant debris (mostly conifer leaves) on both the victim's body and in her hair. Police confirmed that, during the *post mortem*, the cadaver had been contaminated by plant material and soil from the outside of the wrappings. This meant that palynomorphs from Lindley Wood were likely to be a component of the palynological profile obtained from her body. To identify some location other than the places where she was known to have contacted, it was considered appropriate to disregard those taxa (both plant and palynomorph) found only at Lindley Wood, the abduction site, and her home. Palynomorph values were expressed as percentages of total counts. Table 1 shows the results for all other taxa for the victim's hair, the bed cover (average of six samples), the victim's garden (average of four samples back and front), the abduction site (average of three samples) and the suspect's garden (average of six samples—see later).

Apart from traces of organic residues, no palynomorphs were obtained from the victim's turbinates. However, it was obvious that the hair had not been washed for a long (though undetermined) period, and that it had been in direct contact with soil and/or vegetation. A rich assemblage was retrieved from the hair. It yielded large numbers of angular and rounded silica grains along with large concentrations of amorphous and

Table 1
Partial data set of percentage results from exhibits and comparator samples (palynological taxa)

Palynological taxa	Common name	Victim's hair washings	Duvet cover (average)	Suspect's garden (average)	Victim's garden		Abduction site (average)
					Front (average)	Back (average)	
Trees, shrubs and climbers							
Populus	Poplar	5.1	3.1	8.1			
Ligustrum	Privet/lilac	3.5	2.0	11.0		4.2	2.0
Alien unidentified	Non-native cultivars	2.8	9.1	2.0	1.0	+	
Rosaceae (*Prunus* cf.)	Plum/damson/sloe/cherry	1.1	0.9	2.1			
Fagus	Beech	1.0	0.3	0.7			
Sambucus	Elder	0.7	+	0.8			
Rosaceae indet	Bramble/hawthorn/rose	0.4	0.3	0.4			
Taxus	Yew	+		+		+	
Eucalyptus	Gum	+					
Herbs							
Chenopodiaceae	Goosefoot family	8.2	5.6	7.5		+	
Urtica	Nettle	3.0	2.6	3.1			
Asteraceae (fenestrate)	Dandelion-like plants	1.0	0.4	2.0	4.8	5.3	3.0
Polygonum aviculare	Knotweed	0.6	+	0.3		+	
Brassicaceae indet	Charlock and others	0.5		0.3		1.0	
Achillea type	Yarrow	0.4		+			
Caryophyllaceae	Chickweed family	0.3	+	0.4			
Alchemilla type	Lady's mantle/parsley piert	+		+			
Brassicaceae (Capsella type)	Shepherd's purse and others	+		+	2.9	+	
Centaurea (cf.)	Knapweed	+	+	+			
Cereal type	Wheat/oats/barley-not rye	+	+	0.4			
Fabaceae (Trifolium type)	Clover and others	+		+			
Fabaceae indet	Pea/bean/gorse family	+	+	+	1.0	+	
Galium type	Cleavers/bedstraws	+	1.2	+			
Potentilla type	Silverweed/tormentil	+					
Solanum indet	Tomato/potato/black nightshade	+		0.4			
Stachys type	Hedge woundwort and others	+					
Ferns							
Dryopteris type	Buckler fern	+	+	+			
Thelypteris	Marsh fern		+				
Mosses							
Sphagnum	Sphagnum moss	+	+	+	5.8	+	
Burnt fragments							
Charred tracheids	Conducting elements of conifers	++	+	+++			
Charred wood vessels	Conducting elements of hard woods	++	++	+++			
Microscopic charcoal	Burnt microscopic fragments	+++	++	++++	+	+	+
Psilate fungal spores (tetrads)	Smooth spores in groups of four	+++	+++	+++	+	+	

Taxa from the deposition site excluded.
Palynological taxa with "+" = <0.3% total pollen and spores.

angular microscopic charcoal fragments, abundant fragments of burnt tracheids and wood vessels, and tetrads of fungal spores. The relative abundances of wood elements and fungal spores were assessed subjectively and shown as '+' in Table 1, with increasing plus signs indicating increased frequency. The large quantity of these microscopic remains led me to believe that the hair had been in contact with soil and wood ash for a considerable (but unknown) period. Such amounts would be unlikely to be accumulated by brief contact.

Considering the neglected and poor nature of the victim's back garden, it was highly unlikely that she would have lain on the ground there, especially at the time of year she was reported missing (November). Even if she had been lying on the lawn for some reason, it is improbable that she would have accumulated such a heavy load of plant debris, soil, palynomorphs and charred fragments. For transference of such a high load of material, her hair would have had to be directly on the ground and/or have contacted vegetation of some kind.

Table 1 shows that the victim's hair and the bed cover were palynologically similar. But these differed considerably from the results obtained from the victim's garden and the abduction site; and the values did not reflect the vegetation found growing either at those places or the deposition site. As already stated, for ease of comparison, most taxa found at the deposition site, including Poaceae (grasses) were not included in Table 1. Only those likely to facilitate recognition of some deposition site *other* than where the body was found were presented.

3.3. Visualisation of the "other place"

From the percentages given in Table 1, it was possible to envisage a neglected, weedy garden (or waste ground close to a garden). The remains of a bonfire where both soft and hard woods had been burnt could also be predicted. To be recorded in the hair, the fire must have been close to the body.

It was thought likely that there would be an overgrown hedge of *Ligustrum* (privet), possibly with *Sambucus* (elder), *Rubus* (brambles), *Crataegus* (hawthorn) and *Prunus* (cherry/plum/sloe) growing very close to the body. Elder, bramble, hawthorn and sloe could have been components of the hedge, as could *Dryopteris* (buckler fern). However, as a garden was envisaged, the *Prunus* type might also have been derived from a cherry or plum tree. *Fagus* (beech) and *Populus* (poplar) were in the catchment and they would probably have been seen from the place where the body lay. The herbaceous plants were interesting and characteristic of broken, disturbed and enriched soils. Apart from Poaceae (grasses—not shown), the assemblage was dominated by Chenopodiaceae (goosefoot family, e.g. orache) and *Urtica* (nettle). The rest of the profile was very mixed and could have been typical of an abandoned garden or waste ground. *Sphagnum* moss was also found but, although it is typical of acidic, boggy moorland, bog peat is often used as a soil improver and is frequently encountered in palynological samples from British gardens.

3.4. Outcomes

Excellent detective work on the part of West Yorkshire Police eventually identified a suspect. When they entered the back garden of his home, officers recognised it from the description they had been given. The garden was small, and typical of those found with semi-detached, three bed-roomed dwellings very common throughout much of northern England. The suspect had been a dog breeder and there were derelict brick-built kennels at the southern and south-eastern boundaries. The remains of a bonfire were spread over an area of ground adjacent to these buildings. This corner of the garden was overhung by mature poplar trees (*Populus* sp.) and a very tall, neglected hedge of privet (*Ligustrum ovalifolium*) and elder (*Sambucus nigra*). There were two mature damson or plum trees (*Prunus domestica*) approximately in the middle of the garden, to the north of the bonfire. The main ground vegetation consisted of grasses (Poaceae), bindweed (*Calystegia sepium*), common orache (*Atriplex patula*), nettle (*Urtica dioica*) and bramble (*Rubus fruticosus* agg.). The remains of a second bonfire were spread over an area on the south-western side of the garden.

I was asked to confirm that the palynological profile from the victim's hair and the bed cover matched the vegetation of the garden. Not only was I able to confirm that this was likely to be the right garden, but could also state with considerable confidence that the victim's hair and the bed cover had contacted the ground close to the dog kennels and bonfire on the southern side of the area.

Six comparator samples were collected from the garden and the *average* percentage of the total count of all samples is given in Table 1. Inter-sample variation in pollen percentages was high but this was to be expected when the local dispersal of many of the plant species was considered. It was obvious that percentages of privet pollen for samples closer to the privet hedge had higher values than those further away. The same was true for plum/damson pollen where the percentages in the samples near to the plum trees were very high for this insect-pollinated plant. The overall palynological profile presented a reasonably faithful record of the plants growing in the suspect's garden. *Ligustrum* (privet), *Prunus* type (plum/damson), *Populus* (poplar), *Urtica* (nettle), *Dryopteris* (buckler fern) and Chenopodiaceae (goosefoot family) were consistently represented. The latter pollen type was derived from the very abundant *A. patula* (common orache), a weed infesting the south-eastern area of the garden. The relative abundance of cereal pollen was also of interest since it was probably derived from herbivore dung (possibly used for fertilising the garden) or, more likely, from straw that had been strewn on the kennel floors. Plants not found in the garden were also represented, but this should be expected, especially of wind-pollinated taxa.

There was close concordance between the palynological profiles from the suspect's garden and the victim's hair and bed cover. As well as pollen and spore taxa, there were similarities between the fungal remains, charred wood elements and microscopic charred fragments. Furthermore, the amount, and wide size range, of microscopic burnt fragments were similar; very large burnt fragments were highly abundant in both the

hair and garden soil samples. This might suggest further that the victim's hair had been in close contact with the wood ash since large fragments would be unlikely to be carried far in the wind.

The close similarity of the palynological results from the southern corner of the suspect's garden, the victim's hair and the bed cover, and the low level of similarity with results from the other sites, suggested that Leanne Tiernan had lain in the garden next to the derelict kennels, with her hair spread into the ash of the bonfire. The suspect confessed to her murder, but, if he had claimed innocence, the palynological results would have been useful to demonstrate a link between the victim and the suspect's garden, and thus provide evidence towards a conviction.

4. Case history 2: the murder of a prostitute

4.1. Background

The offender for this case has not yet been apprehended and it has been necessary to omit any detail that might identify the investigation.

A poor, young, single mother, who made her living through prostitution, was found dead during Easter 2002; her body had been dumped, very close to a minor road, at the edge of some derelict ancient woodland near Norwich in Norfolk. The road was bordered by a mature hedge of *Prunus spinosa* (sloe) with *Lonicera periclymenum* (honeysuckle) on the northern side, and a strip of old, relatively undisturbed woodland on the southern side. The most obvious plant taxa observed during the initial field visit are listed in Table 2. The deposition site was dominated by *Fraxinus excelsior* (ash) and the woodland floor was carpeted with *Mercurialis perennis* (dog's mercury) and *Adoxa moschatellina* (town clock). The verge bordering the woodland was of mixed grasses (Poaceae) with *Anthriscus sylvestris* (cow parsley), *Rumex* spp. (docks), *U. dioica* (nettle) and other herbs (see Table 2).

The immediate place where the body had been dumped was dominated by *R. fruticosus* (bramble) with mixed herbs (including dog's mercury and town clock) growing through the litter and bramble stems. The tree immediately overhanging the deposition site was a mature ash, and a *Euonymus europaeus* (spindle) was growing at the foot of the ash at the "entrance" to the site.

The pathologist considered that the body had lain in the woodland overnight, and investigating officers were keen to know whether the victim had been killed elsewhere before being dumped in the woodland. Furthermore, once they had identified an offender, they wanted to be able to investigate any links between him/her, the deposition site, and any other pertinent place. It was thought that palynology might provide a means for achieving these aims.

At the *post mortem*, the cadaver was examined very carefully for soil and vegetation on her skin and under her nails. Her nasal passages were irrigated, and her hair was washed thoroughly before the *post mortem* examination began, and the washings kept for palynological examination. A series of comparator samples were taken from the road, verge and woodland floor at the deposition site, and sampling was concentrated in those areas most likely to have been contacted by the offender. All samples were subjected to routine palynological processing, and detailed analysis was carried out on the samples from the cadaver. Because of the constraints of time, it was decided to defer detailed analysis of the comparator samples until an offender had been identified. The urgent task was to find the place where the girl had been murdered. This might then lead investigators to one or more suspects.

4.2. Findings

Very few palynomorphs were retrieved from the victim's nasal passages, but, washings from her hair, and mud from her face, yielded large enough counts of pollen and spores for the construction of meaningful palynological profiles. The results are given in Table 2 along with those plant taxa found in the woodland where she was found. Where any taxon achieved a value of $<0.4\%$, it was presented as a plus sign.

Certain palynomorph taxa were so frequent in the samples from the cadaver that it was decided to ignore them in the analysis, and they were not included in the pollen sum. Their relative abundances were given as a series of plus signs in Table 2 (at the base of the table) with increasing plus signs indicating greater relative frequency. These included *Fraxinus* (ash), *Adoxa* (town clock) and *Mercurialis* (dog's mercury). However, there was also a great abundance of Cupressaceae (cypress and allies), *Populus* (poplar), unidentified Taxodiaceae and other conifers not native to Britain. Members of the Cupressaceae, Taxodiaceae, *Populus* and other alien conifers were not observed at the place where the body was found. Rosaceae (cf. *Rubus*—bramble) also achieved high levels (for this taxon); it might have been picked up from the brambles within which the body was dumped. This taxon *was* included in the pollen count.

When combined with other taxa from the deposition site, pollen from plants such as *Adoxa* and *Mercurialis* would provide an excellent marker for the woodland. Furthermore, the high abundance of pollen from these plants meant that anyone walking at the deposition site would have been unable to avoid picking them up on their clothing and footwear. The likelihood of the pollen from these plants being secondarily transferred to a vehicle was also very high since pollen tends to persist in foot well mats, even after thorough cleaning.

4.3. Visualisation of the "other place"

The plants at the deposition site were very abundant in the hair and on the face of the victim. In fact, considering the relatively short time that her body must have lain in the woodland, the values for *Fraxinus*, *Mercurialis* and *Adoxa* were remarkably high. Her body had lain on litter and brambles so most of the pollen was probably derived from the airspora. Experience has shown that it is unusual for airborne pollen to contribute such a large component of the pollen assemblage retrieved from hair and clothing. In spite of the large quantities of pollen from the above plants, there were considerable amounts from plants not observed anywhere near the deposition

Table 2
Percentage results from the cadaver, with lists of taxa found at the deposition site and the fish farm

	English name	PW/7 Hair	MJH/29a Face mud	Trout farm	Deposition site
Trees, shrubs and climbers					
Betula	Birch	31.3	14.2	+	+
Carpinus	Hornbeam	15.0	5.3	+	
Pinus	Pine	12.4	15.5	+	
Salix	Willow	9.4	2.3	+	
Alnus	Alder	4.5	5.1	+	
Ulmus	Elm	3.9	0.4	+	
Quercus	Oak	2.8	7.6	+	+
Corylus	Hazel	2.8	1.1	+	+
Hedera	Ivy	1.7	2.5	+	+
Rosaceae indet	Bramble/hawthorn/rose	0.9	1.5	+	+
Ligustrum	Privet/lilac	0.6	0.6	+	
Rosaceae (*Rubus* cf.)	Bramble	0.4	1.7	+	+
Rosaceae (*Prunus* type)	Sloe/cherry/plum	0.5	0.4	+	
Acer	Sycamore/maple	+	+	+	+
Picea	Spruce		1.5	+	
Lonicera	Honeysuckle		+	+	+
Tamus (cf.)	Black bryony		+	+	
Herbs					
Poaceae	Grasses	3.4	26.3	+	+
Urtica	Nettle	1.5	1.9	+	+
Cereal type	Wheat/oats/barley-not rye	1.3	1.1	+	
Chenopodiaceae	Goosefoot family	1.3	0.4	+	
Apiaceae	Hogweed family	0.9	0.8	+	+
Brassicaceae (Sinapis type)	Charlock and others	0.6	2.5	+	
Aster type	Daisy	0.4	+	+	
Asteraceae (fenestrate)	Dandelion-like plants	+	1.5	+	
Brassicaceae	Rape family	+		+	
Caryophyllaceae	Chickweed family	+		+	
Ranunculus type	Buttercups	+		+	+
Rumex indet	Docks		1.1	+	+
Galium type	Cleavers/bedstraw		0.6	+	+
Fabaceae	Clover family		+	+	
Geum	Wood avens		+		+
Plantago lanceolata	Ribwort plantain		+	+	
Stachys type	Woundwort and allies		+	+	
Ferns					
Monolete indet	Other ferns	0.4		+	
Pteridium	Bracken		0.4		
Plants of wet soils					
Cyperaceae	Sedges	0.4	0.6	+	
Aquatics/emergents					
Sparganium type	Bur-reed/lesser reedmace	0.9	0.6	+	
Elodea (cf.)	Canadian pond weed		0.4	+	
Potamogeton	Pond weed		+	+	
Mosses					
Sphagnum	Sphagnum moss	+			
Not included in count-over-represented taxa					
Adoxa	Town clock	++	++		+
Mercurialis	Dog's mercury	+++++	+++++		+
Cupressaceae	Alien conifers (also juniper)	+++	+++	+	
Fraxinus	Ash	++	++	+	+
Populus (cf.)	Poplar	+++++	+	+	
Taxodiaceae	Alien conifers	++	++	+	

site. Presumably, these would represent the other place or places where her head and face had lain.

The combined assemblage retrieved from the hair and face was dominated by trees and shrubs, although the herbaceous component indicated that there must have been weedy, grassy areas and some ''waste ground'', rough paths and/or unkempt path edges. The assemblage suggested mixed, deciduous woodland but no woodlands were known in this part of East

Anglia where *Betula* (birch), *Carpinus* (hornbeam), *Pinus* (pine), *Salix* (willow) and *Alnus* (alder) were co-dominants, especially when the rest of the assemblage was considered. The profile indicated considerable heterogeneity in the vegetation, with indicators of both acidic and basic soils.

The lifestyle of the victim had to be taken into consideration; she did not have the resources to entertain her clients in other than vehicles and out-door places. It was possible that such a mixed palynological assemblage could have been derived from multiple depositions over a period of time. With this in mind, all the places where she was known to take her clients were visited, and the vegetation at each place was evaluated. At many of the places, there were trees and shrubs that were also recorded from her hair and face, but no place supported the vegetation that matched the whole assemblage. Indeed, even the *combined* assemblages seen at *all* the known sites failed to match the required profile.

It became obvious that, if only one place were involved, it was an area supporting mixed woodland (too mixed to be natural) and rough, weedy and grassy areas. While a mixture of *Betula* (birch), *Pinus* (pine), *Salix* (willow), *Alnus* (alder), *Quercus* (oak), *Corylus* (hazel) and *Hedera* (flowering ivy) could be expected, the inclusion of Cupressaceae (cypress and allies), *Populus* (poplar), *Picea* (spruce), other alien conifers, *Carpinus* (hornbeam), *Ligustrum* (privet), *Prunus* (cherry/sloe), *Acer* (maple/sycamore), *Lonicera* (honeysuckle), *Tamus* (black bryony) and *Pteridium* (bracken), was less likely. The above list includes native, alien, woodland, plantation and even garden plants all combined. Other important elements were the plants characteristic of wet places and open water: Cyperaceae (sedges), *Sparganium* type (bur-reed and lesser reedmace), *Potamogeton* (pondweed) and *Elodea* cf. (Canadian pondweed). It was very difficult indeed to reconcile this mixture of plant taxa if, indeed, only one place were involved.

If a single location were the source of the palynological assemblage, it indicated some kind of estate with ponds. When this was suggested to the police, they immediately recognised that the only place in that part of Norfolk that could conceivably match the picture was a trout farm less than 10 miles from the deposition site, and about 15 miles from Norwich. It was decided that the trout farm and its environs should be evaluated for its palynological potential.

4.4. Outcomes

The area of land occupied by the fish farm and adjacent property supported remarkably rich assemblages of plants of varying ecology. Many of these had been carefully selected and planted (both alien and native species) while others were obviously natural and probably adventive. The entrance to the property led up a path, lined either side by mixtures of native and non-native trees and shrubs. The planted fringe of trees and shrubs on the northern side formed a boundary between grounds of the trout farm and an extensive wheat field. The borders of the path supported mixed grasses and herbs and, towards the house, there was a thick belt of *Populus* (poplar), *Pinus* (pine) and alien conifers. The margins of both lakes supported highly diverse assemblages of aquatic and emergent plants, and the drier areas were rich in grasses, ruderals and meadow species. The owner's house stood very close to the biggest lake and there was a large flowering *Lonicera* (honeysuckle) on the back veranda. This was very close to the muddy banks of the largest lake where swathes of dredged aquatic plants had been dragged and left. The pollen profile obtained from the girl matched what was expected from the vegetation observed at the scene.

The deliberately planted vegetation obscured the nature of the soil to the casual observer, but the distribution of native and adventive plants suggested soils of mixed reaction. Some areas were probably mesic to eutrophic, especially nearer areas of the lakes, but there were certainly more acidic soils in the catchment. The finding, in the pump house, of a packet of pH buffer of 10.7 might indicate a periodic need to raise the pH of the water. This suggests acidic run-off from local soils.

In botanical terms, the visit to the trout farm was a revelation. It was immediately obvious that the richly planted grounds, the areas around the ponds, the weedy grassy areas, the rough paths, and adjacent cereal fields could easily have contributed most of the palynomorph assemblage retrieved from the victim. Nearly all the woody plants, climbers, all the herbaceous pollen taxa, and the aquatics represented on the victim were present at the site (see Table 2). Furthermore, the high frequency of *Populus* (poplar) and alien conifers at the fish farm could explain the high abundance of their pollen in the hair and mud on her face.

Police interviews proved that the victim had, indeed, been a frequent visitor to the trout farm.

The palynological profile suggested that the mud on the girl's face, and much of the pollen in her hair was likely to have been picked up at the back of the owner's house between the honeysuckle plant and the dredgings from the lake. However, the high diversity of palynomorphs suggests that her head had touched the ground in more than one place in the grounds of the trout farm. Natural heterogeneity in the pollen rain means that she was unlikely to have picked up the whole assemblage from the one place behind the owner's house.

No individual has been apprehended for this murder.

5. Conclusion

Hair has proved to be an excellent trapping medium for pollen, spores and other particulates. Washing with hot surfactant solution will retrieve most of the palynomorphs from the hair mass and allow the characterisation of the plants and soils with which it had been in contact. If the palynologist has a good grasp of ecological principles, plant distribution, palynological taphonomy, and an ability to visualise vegetation and landscapes from tables of percentage figures, the discipline can be a useful aid to criminal investigation. Places can be located, and trace evidence can be provided to link people and objects with them. Palynology should be considered at every *post mortem* since palynomorphs can be found in and on the cadaver. The pathologist might be persuaded to delay washing the corpse until appropriate samples can be taken; such samples might provide both spatial and temporal evidence that could prove critical to the case.

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