Forensic Science International 206 (2011) 1–11

Contents lists available at ScienceDirect

Forensic Science International

journal homepage: www.elsevier.com/locate/forsciint

Review article

Forensic mycology: the use of fungi in criminal investigations

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A R T I C L E I N F O

Article history:
Received 27 April 2010
Received in revised form 7 June 2010
Accepted 10 June 2010
Available online 14 July 2010

Keywords:
Clandestine burial
Deposition time
Hallucinogens
Lichens
Palynology
Palynomorph
Poisons
Post-mortem interval
Trace evidence

A B S T R A C T

This is the first overview to be published of the whole field of forensic mycology. It is based on all available information located in the literature, together with 13 examples from recent casework. Background information on fungi is given, and this is followed by an outline of the value, and potentially wide application, of mycology in criminal investigation. Applications include roles in: providing trace evidence; estimating time since death (*post-mortem* interval); ascertaining time of deposition; investigating cause of death, hallucinations, or poisonings; locating buried corpses; and biological warfare. Previous work has been critically evaluated, with particular attention to its evidential value, and suitability for presentation in a court of law. The situations where mycology might assist an investigation are summarised, and issues relating to the further development of the subject are presented. A comprehensive bibliography with 120 citations is provided.

Contents

1. Introduction

Mycology is the study of fungi of all kinds, including blights, moulds, mildews, mushrooms, plant and human pathogens, lichens, rusts and smuts, slime-moulds, truffles, and yeasts. The use of mycological evidence in criminal investigations, and its testing in the courts, i.e. forensic mycology, has until recent years largely been restricted to cases involving poisonous and psychotropic species. However, during the last 3 years we have found various situations in which fungal data can provide critical evidence. The objectives of this review are both critically to consider the published information, and to draw attention to the range of situations where we now know mycological data can be informative – including our personal experience in criminal cases. Applications include roles in: providing trace evidence; estimating

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0379-0738/$ – see front matter
doi:10.1016/j.forsciint.2010.06.012

time since death (*post-mortem* interval); ascertaining time of deposition; investigating cause of death, hallucinations, or poisonings; locating buried corpses; and biological warfare.

2. Background

Fungi have traditionally been studied as a part of botany, but are now known to belong to the same major evolutionary group as animals, and are not included in the plant kingdom. In common with animals, fungi do not manufacture their own food, but obtain nutrients directly from living or dead organisms, or other organic materials.

The fungi were already diverse 600 million years ago, and have continued to diversify to the extent that they are classified into numerous separate groups. About 100,000 species are known worldwide, and around 800 species are currently being named as new to science each year, even from relatively well-researched parts of the world. However, it is now generally accepted that there may well be around 1.5 million fungal species on Earth [1].

As an example of species numbers in a single country, the UK Fungal Records Database (*see* Footnote 9) has around 14,000 species listed, and an additional 40–50 species are added each year. The newly found species include both ones previously recognised in other countries, and ones new to science; the latter even include conspicuous mushrooms (e.g. *Xerocomus chrysonemus* from southern England) as well as more easily overlooked microscopic species (e.g. *Psammina palmata* on wood from East Anglia). The 14,000 figure compares with the about 2100 native flowering plants and ferns in the UK, a total almost unchanged for a century. That there are 6–7 times more native fungi than plants in the UK, means that, potentially, they provide a massive source of additional information for forensic investigations.

The number of fungi present in a single locality is enormous. However, a comprehensive inventory of all the fungi in one place is probably unachievable as many make spore-producing structures only rarely, sometimes decades apart, or require specialist methods to determine their presence. The best documented sites in the UK have yielded 1000–3500 species [2], but even after 30 years of study species continue to be found for the first time in those localities.

Most fungi are associated with particular plants or animals; they may cause disease (pathogens), be beneficial to their hosts (mutualists), have no evident effects (commensals), or live on dead and decaying remains (saprobes). Consequently, distributions are limited by the ranges of the organisms on which they depend. Fungal distribution patterns are not as well-studied as those of plant and many animal groups, but are generally similar in that they have distinct geographical distributions and habitat preferences. However, some mould fungi can be found almost everywhere, especially ones that: (a) spoil foodstuffs; (b) cause the deterioration of manufactured materials; or (c) are involved in decomposition of organic matter in soil.

Fungi are generally dispersed by spores that may be produced either sexually, asexually, or both. These can be diagnostic to species-level in many cases, but in others can only be differentiated to, for example, family or genus. Some are forcibly ejected from the sporophore[1] for a distance of only a few millimeters but, exceptionally, some can achieve 30 cm [3,4]. However, in many cases, dispersal is passive, and spores form slimy or dry masses and are dispersed by outside agencies. Such fungi may never achieve aerial dispersal at all. Many are distributed: (a) on seeds; (b) on plant or wood fragments; (c) by insects; (d) in the faeces of herbivores; (e) by rain-splash; or (f) in water. Where fungi produce dry spores and grow on aerial parts of living plants or trees, rather than on materials on or near the ground, their spores will be more readily caught up in wind currents and can then be distributed more widely, although their concentration in air is normally low. In most cases, fungal spores are rarely dispersed more than 100–200 m horizontally from the source [5]. Nevertheless, spores of certain species that occur abundantly on leaves and bark (e.g. *Alternaria* and *Cladosporium*), can be encountered in large numbers in air samples, particularly in late summer and autumn. In contrast, fungi with more restricted occurrences rarely contribute even 1% of the total air spora[2] [6].

The key reference work in mycology is the current edition of "*Ainsworth & Bisby's Dictionary of the Fungi*" [7]. For more detailed information on biology, physiology, and ecology of fungi, several texts can be recommended [8–15]. For fungal identification, there are 15 books to which we refer frequently [16–30]. These selections are necessarily eclectic, but key works are indicated genus by genus in the "*Dictionary*" [7]. Some additional specialist texts on particular groups are mentioned where they are appropriate in the following sections.

3. Trace evidence

Like other palynomorphs,[3] fungal spores and other remains may be picked up by any object contacting them and are subject to similar taphonomic[4] considerations [31]. Generally, any palyniferous[5] surface will yield palynomorphs, but the main sources in criminal investigations are soils, sediments, vegetation, and plant litter. Unlike plants, fungi (including lichen fungi) can also grow on, for example, stone, brick, tiles, paving stones, wooden objects, leather, plastics, rubber, and textiles [32]. Their spores may thus provide trace evidence in situations where other palynomorphs are scarce or absent. Even fragments of lichens, or fragments of mouldy objects, can become detached and caught up in items that are involved in criminal investigation.

Although there do not appear to be any cases reported in the literature of fungi having been used as trace evidence in criminal cases, we have successfully used them in our own forensic casework[6] and they have greatly augmented palynological[7] data.

To find fungal species during their field surveys, mycologists generally rely on their eyesight, hand lens, and experience of which habitats might prove fruitful. We have, however, found that the methods of sampling vegetation, soils, and forensic exhibits for palynomorphs can yield evidence of species of which are extraordinarily rare. For example, we have encountered the distinctive spores of *Caryospora callicarpa* in preparations made in connection with forensic cases in the UK, although no specimen of the fungus itself has been collected in the country since 1865. This fungus must still be considered rare since it was present in only seven samples out of 1100 examined over a 2-year period, but it is not extinct as might be supposed from field finds [33]. Occurrences of such rare species make them especially valuable as trace evidence.

In an investigation of the murder of a young woman, her body was dumped in a bed of stinging nettles. Nettle (*Urtica dioica*) can support at least 92 fungi, of which about 17 are known only from this plant [23,34]. Spores of two fungi common on dead stinging nettles (e.g. *Periconia* sp., *Torula herbarum*) were found in

[1] Specialised part of the fungal body which produces spores. It may be microscopic as, for example, in *Penicillium* species, or large as in mushrooms.

[2] The air spora consists of organic particulates carried in the air – mostly pollen and plant and fungal spores.

[3] The term "palynomorph" includes pollen of flowering plants and conifers, spores of ferns and mosses, and spores of fungi. Hyphae of fungi and arthropod fragments are also included though not all palynologists consider these as palynomorphs in routine work.

[4] Taphonomy in this context may be considered to be all factors which influence whether a palynomorph will be found at a certain location at a certain time.

[5] Containing, or having a covering of, palynomorphs.

[6] Some of our cases have been anonymised for legal reasons but will be written-up more fully in due course.

[7] Palynology is the study of palynomorphs.