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A year-round outdoor aeromycological study in Waterloo, Ontario, Canada

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The outdoor aeromycota was studied in Waterloo, Ontario, Canada throughout 1992. The dominant outdoor airborne fungal genera and groups recorded on 58 sampling dates were *Cladosporium* (41.0%), unidentified basidiospores (12.1%), unidentified spores (8.5%), *Ganoderma* (7.2%), unidentified ascospores (5.3%), *Leptosphaeria* (5.3%), Coprinaceae (5.0%), hyphal fragments (4.9%), *Aspergillus/Penicillium* (3.8%), *Alternaria* (1.8%), and *Epicoccum* (1.3%). Most common outdoor genera showed distinct diurnal periodicities from May to October, with the exception of *Aspergillus/Penicillium*. Most hyphomycetes displayed daytime peaks, except for *Aspergillus/Penicillium*. Ascospores of *Leptosphaeria* had morning peaks, and basidiospores of *Ganoderma* and Coprinaceae had early morning patterns. Most common outdoor genera, except for *Aspergillus/Penicillium*, also displayed well defined seasonal patterns, with peak periods between May and October.

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Airborne fungi can vary considerably in different geographic areas. There is variation in the taxa recorded, proportions of different taxa, diurnal periodicities, and seasonal periodicities. These variations are determined by a combination of environmental and biological factors, such as those of meteorology, geography, vegetation, human activity, and fungal life cycles (Lyon et al. 1984).

The interactions of discharge mechanisms and variations in meteorological factors produce diurnal fluctuations of airborne fungi. Seasonal periodicities of airborne fungal spores, especially those of plant pathogenic fungi, are often determined by characteristics of vegetation, crop growth cycles and climatic factors (Lacey 1990). The life cycles of fungi and the time and period of spore release relate to both diurnal and seasonal patterns. The life histories of fungi and of their plant hosts contribute most to the seasonal pattern of airborne fungi. Another factor influencing temporal patterns is the duration of spore release. For example, a fruiting body of *Coprinus comatus* (Müll. ex Fr.) Gray releases spores for at most two days, while that of *Ganoderma applanatum* (Pers.) Pat. [*Elfvingia applanata* (Pers.) Karst.] does so for six months (Shao et al. 1984). Many such temporal patterns have been revealed in various studies (Cosentino et al. 1990, Rantio-Lehtimäki et al. 1991, Shaheen 1992). In order to understand the significance of airborne fungi and to predict their occurrence, local diversity, diurnal and seasonal periodicities must be recorded.

In Canada, outdoor aeromycological studies have been conducted in Hamilton, Toronto, Montreal, Ottawa, Winnipeg, Vancouver and in the arctic (Pady 1951, Collins-Williams et al. 1971, Tarlo et al. 1979, Coates et al. unpubl., Comtois unpubl., Hall et al. unpubl.). The airborne mycota and its temporal patterns in the Waterloo area remain unknown. Temporal relationships must be established between exposure to airborne particles and onset of allergic symptoms in patients if we are to be able to any suggest cause-effect relationships (Burge 1986). Since it is believed that airborne fungi can play a significant role in triggering allergic respiratory diseases (Palmas et al. 1989), detailed information, such as a calendar of airborne fungi derived from systematic sampling is necessary to provide a baseline for further research.

The objectives of the study are to define the diurnal and seasonal patterns of airborne fungal spores and to identify the dominant airborne fungal taxa in the Waterloo area.

MATERIALS AND METHODS

Outdoor air sampling was conducted from January to December of 1992 at intervals of five to seven days in Waterloo, Ontario, Canada. Samples were taken on fifty-eight days. On each sampling date, twelve 10-min samples were taken at 2-hr internals with a Samplair-MK1 particle sampler (supplier: Allergenco, 403-7834 Broadway, San Antonio, TX, 78209, USA). The Samplair sampler is 15 × 9 × 12 cm by dimensions and draws air in at the top to collects multiple, discrete samples on 75 × 25 mm slides according to a programmed cycle established by the user. The slide on a stage will be moved forward automatically after each sampling to make samples discrete. The slides used in sampling were coated with a thin layer of a mixture of 90% vaseline and 10% high melting point wax (w/w) and mounted after sampling with polyvinyl lactophenol. There are two timers on the front of the sampler: one controls off-time, the other

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Table I. *Airborne fungal spore abundances in the periods May–October, November–April and the whole year in Waterloo from 696 samples taken on 58 days in 1992.*

Taxa	Year		May–October		November–April	
	Spores m^{-3}	%	Spores m^{-3}	%	Spores m^{-3}	%
Dominant Taxa						
Alternaria	61.6	1.8	138.9	1.9	12.9	1.3
Aspergillus/Penicillium	130.3	3.8	138.6	1.9	125.0	12.4
Unidentified ascospores	185.2	5.3	403.3	5.5	47.7	4.7
Unidentified basidiospores	421.7	12.1	992.3	13.4	62.0	6.2
Cladosporium	1425.3	41.0	3018.2	40.8	421.1	41.2
Coprinaceae	174.3	5.0	443.5	6.0	4.6	0.5
Epicoccum	46.2	1.3	63.5	0.8	35.2	3.5
Ganoderma	248.5	7.2	641.4	8.7	0.8	0.1
Hyphal fragments	171.0	4.9	257.7	3.5	116.3	11.6
Leptosphaeria	182.7	5.3	454.3	6.1	11.5	1.1
Unidentified spores	294.2	8.5	563.2	7.6	124.6	13.4
Minor Taxa						
Agrocybe	<1	<0.1	<1	<0.1	<1	<0.1
Arthrinium	<1	<0.1	<1	<0.1	0.0	0.0
Bipolaris	<1	<0.1	<1	<0.1	0.0	0.0
Bispora	<1	<0.1	<1	<0.1	0.0	0.0
Cercospora	<1	<0.1	<1	<0.1	<1	<0.1
Chaetomium	<1	<0.1	<1	<0.1	0.0	0.0
Curvularia	<1	<0.1	<1	<0.1	0.0	0.0
Cytospora	<1	<0.1	<1	<0.1	<1	<0.1
Drechslera	<1	<0.1	<1	<0.1	0.0	0.0
Fusarium	<1	<0.1	<1	<0.1	<1	<0.1
Inocybe	<1	<0.1	<1	<0.1	<1	<0.1
Monilia	<1	<0.1	<1	<0.1	<1	<0.1
Nigrospora	<1	<0.1	<1	<0.1	0.0	0.0
Oidium	<1	<0.1	<1	<0.1	<1	<0.1
Ophiobolus	<1	<0.1	<1	<0.1	<1	<0.1
Paraphaeosphaeria	<1	<0.1	<1	<0.1	0.0	0.0
Periconia	<1	<0.1	<1	<0.1	<1	<0.1
Peronospora	<1	<0.1	<1	<0.1	0.0	0.0
Pithomyces	<1	<0.1	<1	<0.1	0.0	0.0
Pleospora	<1	<0.1	<1	<0.1	<1	<0.1
Polythrincium	33.6	1.0	86.9	1.2	0.0	0.0
Spegazzinia	<1	<0.1	<1	<0.1	0.0	0.0
Spilocaea	<1	<0.1	<1	<0.1	0.0	0.0
Stemphylium	<1	<0.1	<1	<0.1	0.0	0.0
Torula	<1	<0.1	<1	<0.1	<1	<0.1
Urediniospore (rust fungus)	<1	<0.1	<1	<0.1	<1	<0.1
Venturia	<1	<0.1	<1	<0.1	0.0	0.0
Wallemia	<1	<0.1	<1	<0.1	0.0	0.0
Total Spores	3477.7	100.0	7398.7	100.0	1005.8	100.0

on-time. For the present study, the programmed cycle was as follows: off time 1 h 50 min and on time 10 min. The sampler drew 9 l of air/min (factory calibration). Ten-minute sampling gave an appropriate density of spores for counting and identification. The sampling site was on a two storey buiding near Waterloo Park. Because the roof was inaccessible, sampling was carried out on a balcony. The balcony faced north-west, and was on the external surface of the building. The orifice of sampler on a 1.8 m high rack was 1 m lower than the roof and 1 m away from the external wall of the building. The Samplair sampler is not waterproof, and was therefore protected by a 50 × 50 × 40 cm baffle/cover during sampling. There was 10 cm high opening on the low part of the exhaust outlet side to lead exhaust air out. The top cover was 20 cm above the upper edge of the side cover. The exhaust outlet faced the building, and this effectively reduced wind velocity over the sampling orifice, apparently ensuring that adequate spore numbers were trapped at all sampling times. The prevailing wind was north-west in winter and south-west in Summer in the Kitchener-Waterloo area in 1992.

All fungal spores in the samples were counted and identified under the 40× or 100× objective of a Nikon light microscope equipped with phase contrast optics. The following data were collected and analyzed. (1) spores of eight identified genera: (a) conidia of *Alternaria*, *Aspergillus/Penicillium*, *Cladosporium*, *Epicoccum*, and *Polythrincium*; (b) ascospores of *Leptosphaeria*, (c) basidiospores of Coprinaceae and *Ganoderma*; (2) ascospores of other ascomycetes, and basidiospores of other basidiomycetes which could not be identified to genus; and (3) hyphal fragments, unidentified spores, total fungal spores and total number of genera. Since the spores of *Aspergillus* and *Penicillium* cannot usually be dis-

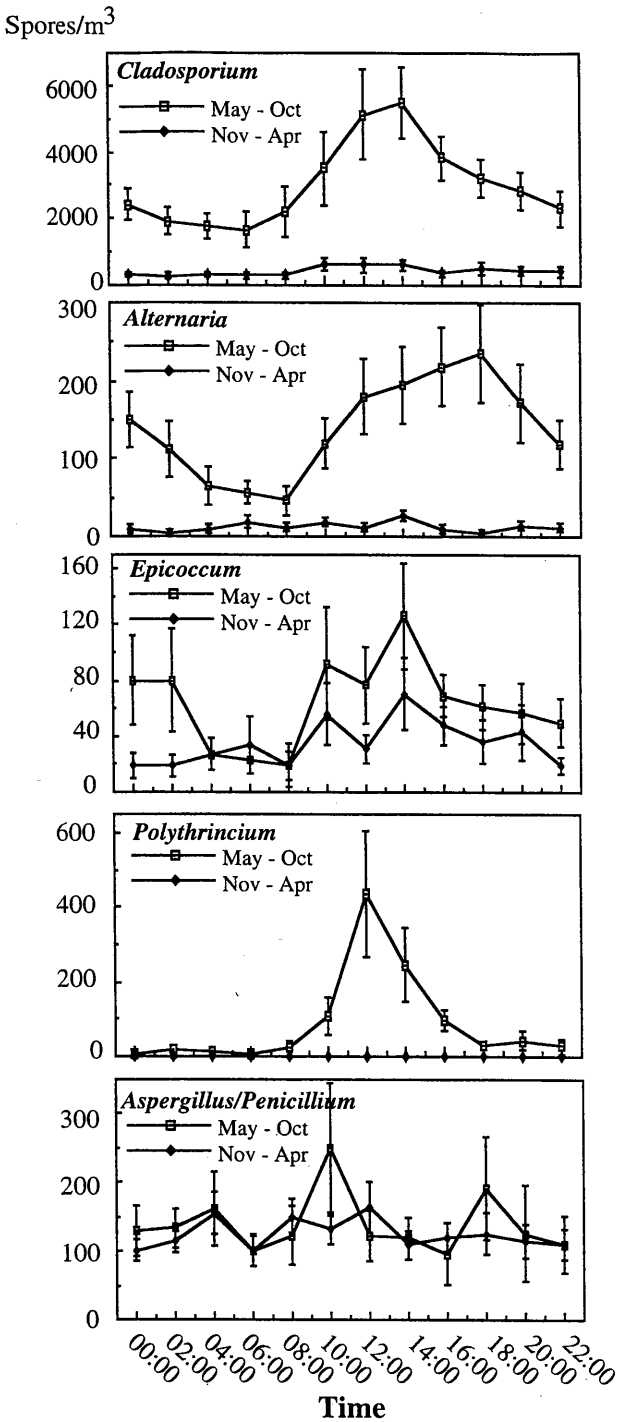

Fig. 1. Diurnal patterns of *Cladosporium*, *Alternaria*, *Epicoccum*, *Polythrincium* and *Aspergillus/Penicillium*.

tinguished under a light microscope, these two genera were recorded as one pooled taxon. It is impossible to identify ballistospores, such as those of *Sporobolomyces* and *Tilletiopsis*, and other yeasts to genus level under light microscopes with confidence. Thus, these spores were included in the category of unidentified spores.

Abundances of airborne fungi during the growing season, the non-growing season and the whole year were determined by their overall concentrations m^{-3} and percentage of total spore counts. The growing season extended from May to October, the non-growing season from November to April.

Means from samples taken at two-hour intervals in a single day were calculated from 29 sampling days of the growing season and the same number of days during the non-growing season. Diurnal and seasonal periodicities in growing and non-growing seasons were determined and compared.

RESULTS

Airborne fungal frequencies

In 1992, the most common airborne fungi overall were *Cladosporium* ($\bar{x}$ = 1425.3 spores m^{-3}, 41.0% of the total count), unidentified basidiospores (421.7 spores m^{-3}, 12.1%), *Ganoderma* (248.5 spores m^{-3}, 7.2%), unidentified ascospores (185.2 spores m^{-3}, 5.3%), *Leptosphaeria* (182.7 spores m^{-3}, 5.3%), Coprinaceae (174.3 spores m^{-3}, 5.0%), *Aspergillus/Penicillium* (130.3 spores m^{-3}, 3.8%), *Alternaria* (61.6 spores m^{-3}, 1.8%), and *Epicoccum* (46.2 spores m^{-3}, 1.3%) (Table I). Hyphal fragments (171.0 pieces m^{-3}, 4.9%) and unidentified spores (294.2 spores m^{-3}, 8.5%), also made up a significant portion of airborne fungal structures. The total airborne spora averaged 3477.7 spores m^{-3}. The common taxa comprised 82.8% of airborne fungi. A wide range of other identified fungal taxa was also recorded, but they made up fewer than 4% of total fungal spores.

In the growing season, the predominant airborne fungal spores were *Cladosporium* (3018.2 spores m^{-3}, 40.8%), unidentified basidiospores (992.3 spores m^{-3}, 13.4%), *Ganoderma* (641.4 spores m^{-3}, 8.7%), *Leptosphaeria* (454.3 spores m^{-3}, 6.1%), Coprinaceae (443.5 spores m^{-3}, 6.0%), unidentified ascospores (403.3 spores m^{-3}, 5.5%), *Alternaria* (138.9 spores m^{-3}, 1.9%), *Aspergillus/Penicillium* (138.6 spores m^{-3}, 1.9%), and *Epicoccum* (63.5 spores m^{-3}, 0.8%) (Table I). Hyphal fragments (257.7 pieces m^{-3}, 3.5%) and unidentified spores (563.2 spores m^{-3}, 7.6%) were also present in significant numbers. The total concentration averaged 7398.7 spores m^{-3}. The common taxa comprised 85.1% of airborne fungal spores. The spores of minor fungal taxa were again diverse, but made up fewer than 4% of the total.

In the non-growing season, the most common airborne fungi were *Cladosporium* (421.1 spores m^{-3}, 41.2%), *Aspergillus/Penicillium* (125.0 spores m^{-3}, 12.4%), unidentified basidiospores (62.0 spores m^{-3}, 6.2%), unidentified ascospores (47.7 spores m^{-3}, 4.7%), *Epicoccum* (35.2 spores m^{-3}, 3.5%), *Alternaria* (12.9 spores m^{-3}, 1.3%), *Leptosphaeria* (11.5 spores m^{-3}, 1.1%), Coprinaceae (4.6 spores m^{-3}, 0.5%), and *Ganoderma* (0.8 spores m^{-3}, 0.1%) in descending order (Table I). Hyphal fragments (116.3 pieces m^{-3}, 11.6%) and unidentified spores (124.6 spores m^{-3}, 13.4%). The spores of common taxa constituted 71.0% of airborne fungal spores. The spores of minor fungal taxa made up 4% of the total. The total fungal spore concentration was 1005.8 spores m^{-3}, only 13.6% of that recorded during the growing season.

The spores of *Cladosporium* was predominant at all times of year. Compared to their numbers during the growing

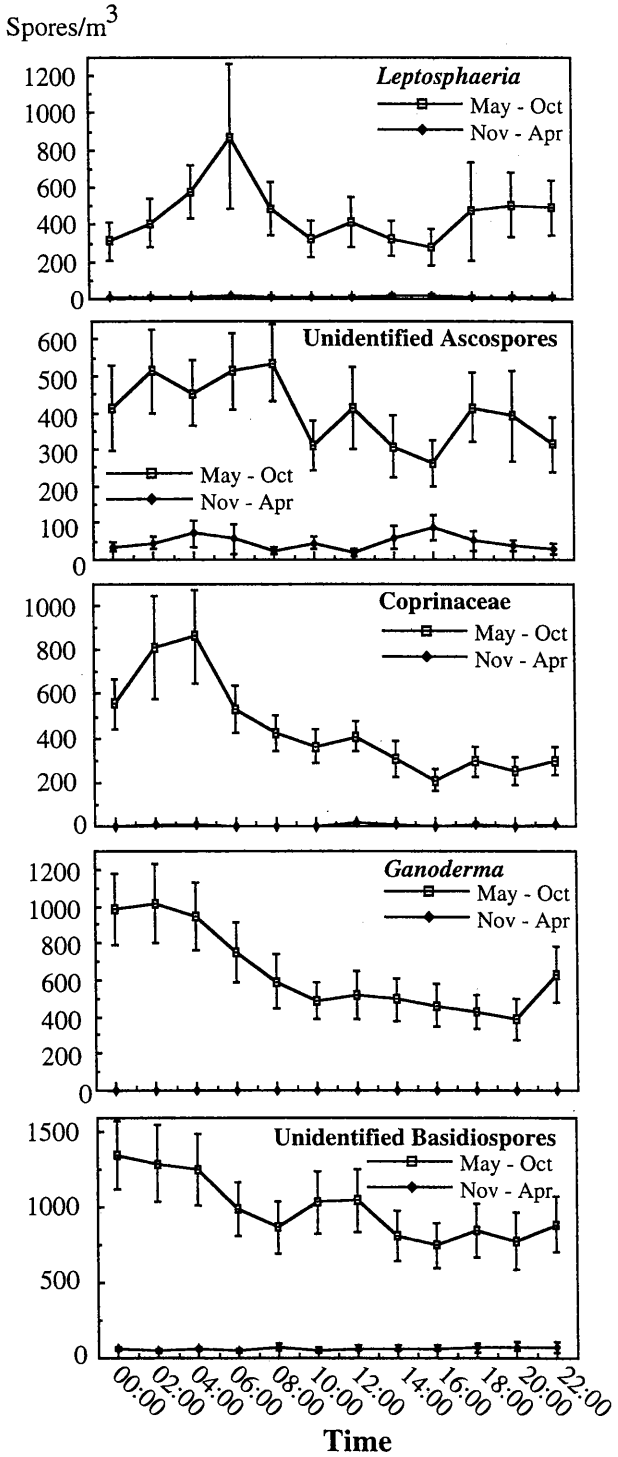

Fig. 2. Diurnal patterns of *Leptosphaeria*, unidentified ascospores, Coprinaceae, *Ganoderma* and unidentified basidiospores.

season. The spores of *Ganoderma*, Coprinaceae, *Leptosphaeria* and unidentified basidiospores decreased by more than 99% in the non-growing season. Interestingly, *Aspergillus/Penicillium*, *Epicoccum* and hyphal fragments did not decline much, though total spores dropped from 7398.7 spores m^{-3} to 1005.8 spores m^{-3} (13.6% of the higher value). Spores of common taxa decreased from 85.1% to 71.0% of the total. *Aspergillus/Penicillium*, which had been the 8th most common spore in the growing season, became the 2nd most common in the non-growing season. The diversity of airborne fungal spores decreased in the non-growing season.

Maximum concentrations of Hyphomycetes recorded by day mean were *Cladosporium* 11722 spores m^{-3} in July, *Alternaria* 519 spores m^{-3} in July, *Aspergillus/Penicillium* 685 spores m^{-3} in September, *Epicoccum* 352 spores m^{-3} in October, and *Polythrincium* 491 spores m^{-3} in September. Those of Ascomycetes were *Leptosphaeria* 1981 spores m^{-3} on a rainy day in August, and unidentified ascospores 1102 spores m^{-3} in July. Those of Basidiomycetes were Coprinaceae 1704 spores m^{-3} in September, *Ganoderma* 2787 spores m^{-3} also in September, and unidentified basidiospores 3231 spores m^{-3} in July. Maximum concentrations of hyphal fragments, unidentified spores and total spores were 1083, 1991 and 22111 spores (pieces) m^{-3} respectively all in September.

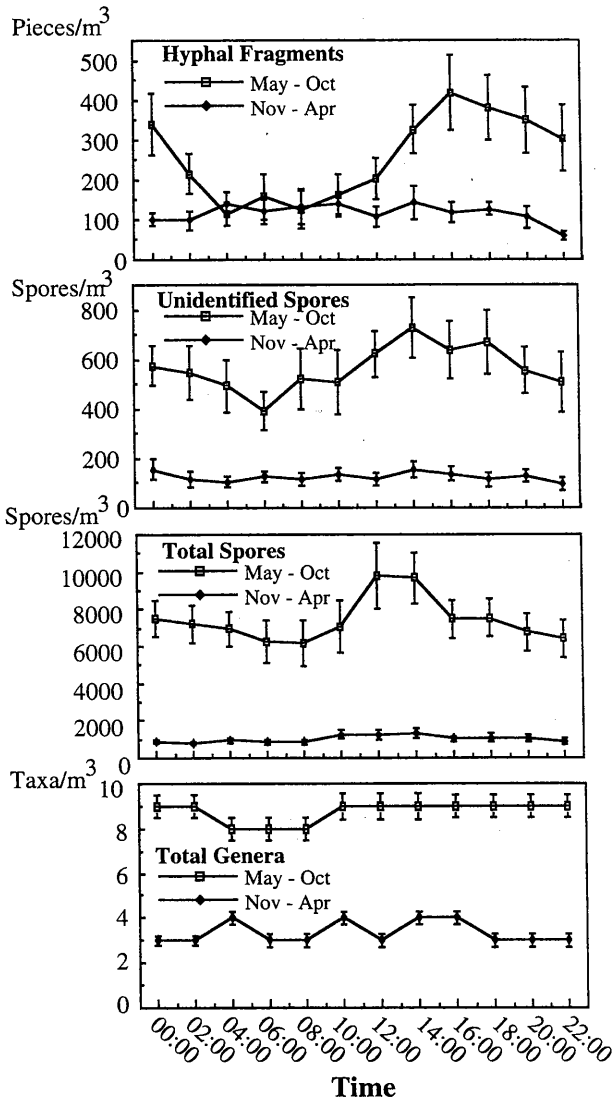

Fig. 3. Diurnal patterns of hyphal fragments, unidentified spores, total spores and genera.

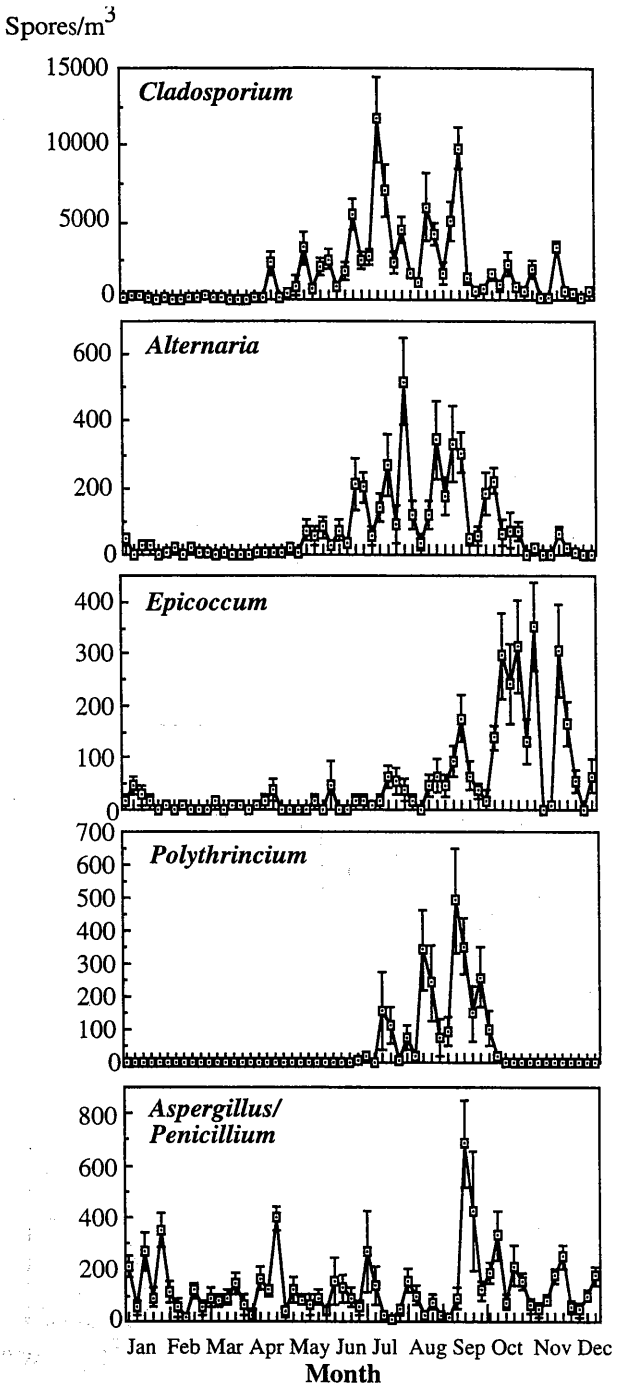

Fig. 4. Seasonal patterns of *Cladosporium*, *Alternaria*, *Epicoccum*, *Polythrincium* and *Aspergillus/Penicillium*.

Diurnal patterns

Growing season (May–October)

The diurnal periodicities of the conidia of different species vary. *Cladosporium* had a midday peak around 14:00 h and lowest values around 06:00 h (Fig. 1). *Epicoccum* also displayed a midday peak pattern, with a major peak period between 10:00 h and 14:00 h, a minor peak around midnight, and lowest numbers from 04:00 h to 08:00 h, although the pattern was not very smooth. *Polythrincium* conidia showed a clear midday peak pattern, with a maximum around 12:00 h and a minimum from 18:00 h to 08:00 h (Fig. 1). *Alternaria* had a late-day peak pattern with a peak from 14:00 h to 18:00 h and lowest numbers around 04:00 h and 08:00 h (Fig. 1). *Aspergillus/Penicillium* did not show a clearly defined pattern, although it had triple peaks.

Ascospores of *Leptosphaeria* exhibited a morning peak pattern, with maxima around 06:00 h and lowest concentration around 00:00 h, even though it had a non-significant minor peak between 18:00 and 22:00 h. Unidentified ascospores showed a non-significant quaternary peak pattern (Fig. 2).

Basidiospores of *Ganoderma* and Coprinaceae shared a similar early morning peak pattern. The differences are that the peak of *Ganoderma* basidiospores was around 02:00 h, the low point around 20:00 h, and the peak of Coprinaceae basidiospores around 04:00 h, the lowest number around 16:00 h (Fig. 2). Unidentified basidiospores also display early morning peak patterns.

Hyphal fragments showed a peak around 16:00 h and a trough around 04:00 h to 08:00 h (Fig. 3). Unidentified fungal spores had an afternoon peak around 14:00 h to 18:00 h and lowest values around 06:00 h (Fig. 3). The diurnal periodicity of total fungal spores displayed a midday peak pattern with the highest spore count around 12:00 h to 14:00 h and the lowest count around 06:00 h to 08:00 h (Fig. 3).

Non-growing season (November–April)

In the non-growing season, the spores of most genera did not show clear diurnal patterns (Fig. 1). Conidia of *Polythrincium* were never found in the non-growing season (Fig. 1). The conidia of *Epicoccum* however still showed a midday peak pattern (Fig. 1). Conidia in the *Aspergillus/Penicillium* category showed multiple peaks with a high spore count around noon, but none of the peaks was well defined (Fig. 1).

Ascospores of *Leptosphaeria* were seldom recorded (Fig. 2). Some unidentified ascospores were found, but no clear diurnal pattern was established. Basidiospores of Coprinaceae and *Ganoderma* were rarely observed. There were some unidentified basidiospores, but the spore counts were very low (Fig. 2), and no diurnal pattern was detected.

Hyphal fragments, unidentified spores, total spores and total number of genera did not display distinct diurnal patterns (Fig. 3).

Total fungal spores recorded in the growing season outnumbered those in the non-growing season significantly by from six to ten times (Fig. 3).

Seasonal patterns in 1992

Conidia of *Polythrincium* had a distinct seasonal occurrence from mid-June to mid-October (Fig. 4). *Alternaria*, *Cla-*

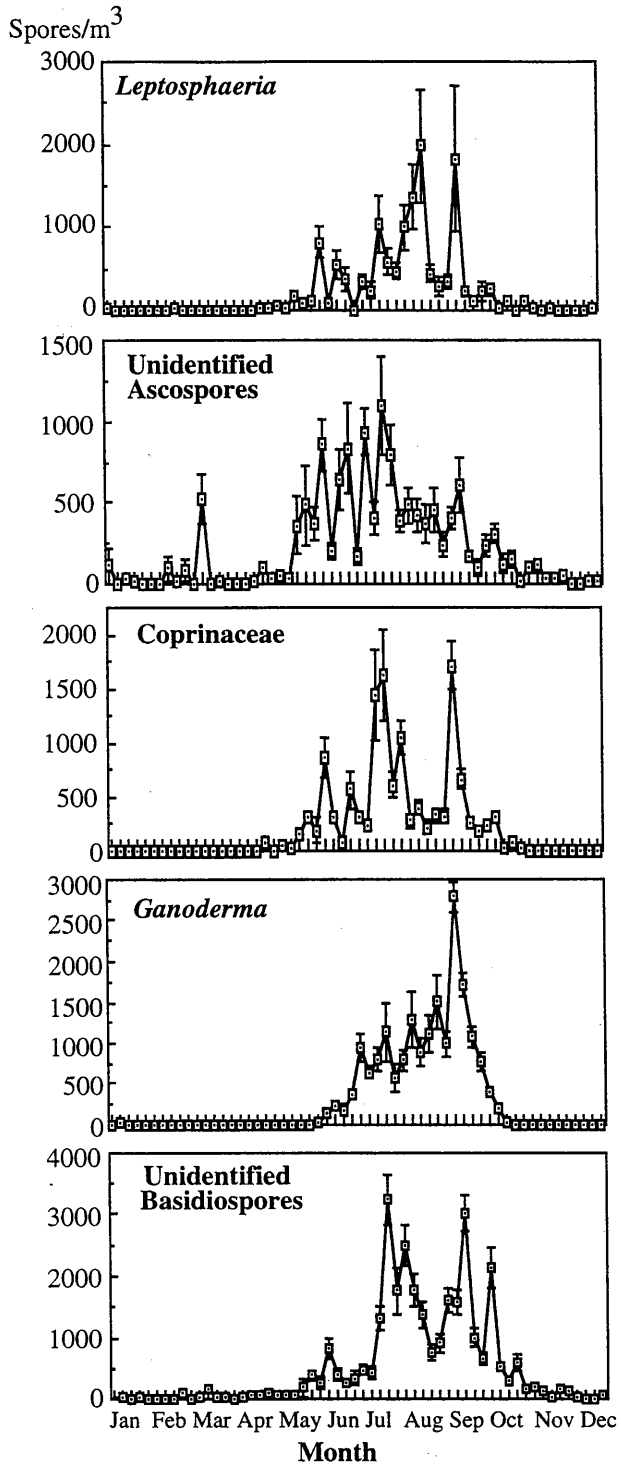

Fig. 5. Seasonal patterns of *Leptosphaeria*, unidentified ascospores, Coprinaceae, *Ganoderma* and unidentified basidiospores.

dosporium and *Epicoccum* conidia were found in all seasons, but mainly in the growing season, except for *Epicoccum* (Fig. 4). *Epicoccum* occurred mainly in fall and early winter (Fig. 4). *Aspergillus/Penicillium* spores did not show a clear seasonal pattern (Fig. 4). Ascospores of *Leptosphaeria* had a well-defined seasonality from mid-April to mid-November (Fig. 5); unidentified ascospores were found in all seasons, but mostly during the growing season. Basidiospores of *Ganoderma*, Coprinaceae and unidentified basidiospores had clear seasonal patterns from early June to mid-October, mid-April to the end of October and May to December respectively (Fig. 5). Hyphal fragments and unidentified fungal spores had no clear seasonal patterns (Fig. 6). Unidentified spores were found at all times of year, but largely during in the growing season. Biodiversity of airborne fungal spores increased in the growing season and decreased in the non-growing season (Fig. 6).

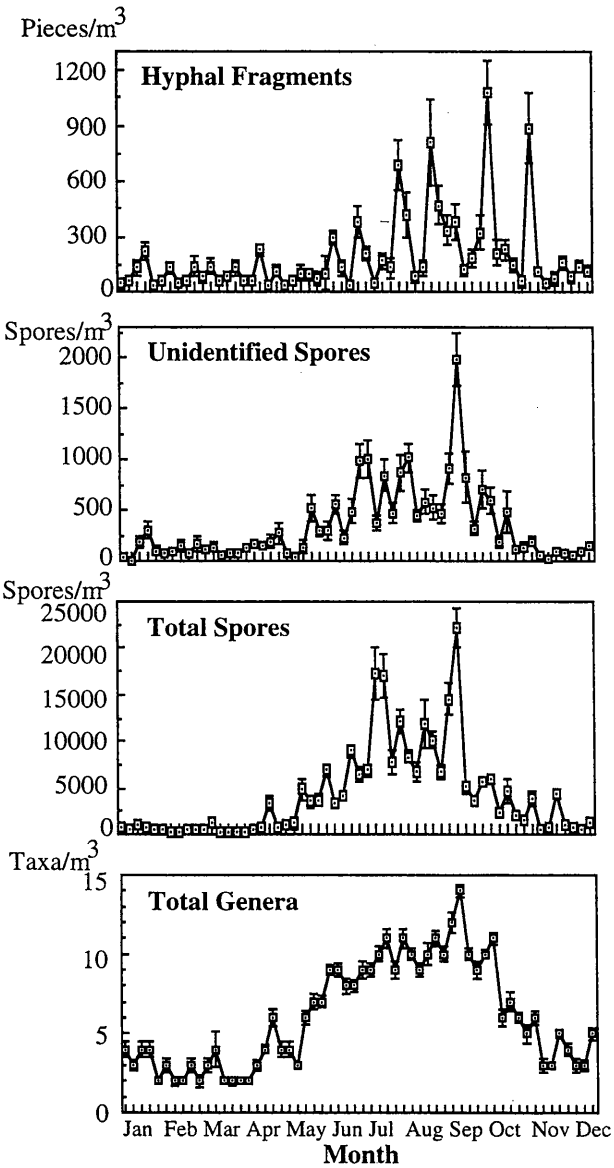

Fig. 6. Seasonal patterns of hyphal fragments, unidentified spores, total spores and genera.

DISCUSSION

Diurnal periodicity

Airborne fungal spore populations differ markedly at various times of the day. There is much less documented research on diurnal periodicities of airborne fungal spores than there is concerning seasonal patterns. One important obstacle is that research on diurnal periodicity is time- and labour-intensive, not only for sampling, but also for slide reading. The significance of diurnal periodicity is, however, attracting more and more attention, because of its relationship to respiratory allergies.

Characteristics of diurnal changes in spore concentration are determined by interactions among growth cycles of fungi, mechanisms of spore release, and fluctuations in meteorological conditions (Lacey 1981). Some fungi respond to light and dark cycles, and their spores may follow a periodicity in ripening (Moore-Landecker 1982).

The diurnal periodicities of *Cladosporium*, with a peak between 12:00 h and 14:00 h, and *Alternaria*, with a peak period from noon to afternoon, were similar to those reported by studies conducted in the UK and India (Hirst 1953, Vittal & Krishnamoorthi 1981). The diurnal patterns of *Cladosporium* and *Alternaria* are in fact similar in areas covering a wide geographic range from tropical to subarctic. In the present study *Epicoccum* showed a double-peak pattern, with a major peak period between 10:00 h and 14:00 h and a minor peak around midnight. Meredith (1966) found that *Epicoccum* showed a double-peak pattern in Nebraska, USA, also, but with one in the morning and the other in the afternoon. The difference in diurnal periodicity may be due to differences in meteorological and geographical factors. The diurnal periodicity of *Polythrincium* in the present study was analogous to that observed in the UK (Hirst 1953). Both studies showed a well-defined peak around noon. The non-significant pattern for *Aspergillus/Penicillium* may have been due, in part, to their small spore size. Even slight air currents can liberate these spores. Another reason may have been that both are large genera with many species (Hawksworth et al. 1983). Overlapping life cycles of different species could blur the diurnal pattern of airborne conidia of *Aspergillus/Penicillium*.

Most hyphomycetous conidia had daytime peaks in the present study, as well as in earlier studies (Hirst 1953, Sutton 1978, Vittal & Krishnamoorthi 1981, Lacey 1981, Cooperman et al. 1986, Alderman et al. 1987). The key factor here might be the spore release mechanism. The dry conidia of many hyphomycetes are freely exposed to the surrounding air and especially adapted to be freed from conidiophores by air currents (Moore-Landecker 1982). The lower atmosphere is much more turbulent during the day than at night (Gregory 1973). Therefore, more dry conidia would be released in the daylight hours.

Taxa requiring water for spore release show maximal spore concentrations from 20:00 to 22:00 h or from 02:00 to 04:00 h (Lacey 1990). The diurnal periodicity of *Leptosphaeria*, with a peak around 06:00 h, might be due to the interaction of light, temperature, RH, and dew formation. Dew formation plays a rule in affecting ascospore release. Similar diurnal patterns of *Leptosphaeria* were observed by Hasnain (1993). Ingold (1971) found that spore discharge of *Sordaria fimicola* (Rob.) Ces. et de Not. was stimulated by an increase of light and a change of RH. Numerous species with overlapping diurnal patterns presumably accounted for the non-significant pattern of unidentified ascospores. However, higher density of unidentified ascospores in the growing season were found mainly from 02:00 to 08:00 h, which is correlated with the dew formation period.

The diurnal pattern of *Ganoderma* was consistent with the patterns observed in other studies in the UK, India and Malaysia (Sreeramulu 1963, Vittal & Krishnamoorthi 1981, Ho & Nawawi 1986). By the observation of fruiting bodies in Malaysia it was found that the concentration of spores of *Ganoderma boninense* Pat. spores was low in the day, especially from noon to 16:00 h, but high at night from 22:00 to 06:00 h; the peak being around midnight (Ho & Nawawi 1986). A similar pattern was recorded in the UK for *Ganoderma applanatum* (Pers.) Pat. by Sreeramulu (1963). The diurnal pattern of *Ganoderma* seems not to be affected by differences in biogeography and climate. Most of the basidiospores of Coprinaceae in the present study were those of *Coprinus*. The patterns of *Coprinus* and unidentified basidiospores also showed peak periods at night in the present study and in that of Burge (1986). Webster et al. (1989) showed a very convincing evidence that the expansion of Buller's drop on basidiospores is by condensation of water vapour around hygroscopic material extruded from the hilar appendix. The Buller's drop is a crucial factor in releasing basidiospores and ballistospores (Moore-Landecker 1982, Webster & Davey 1985). The rising relative humidity at night-time may facilitate this mechanism.

The diurnal periodicities of *Alternaria* and hyphal fragments were similar. The results from path analysis showed that *Alternaria* had a close causal relation with hyphal fragments (Li & Kendrick, unpublished data). The diurnal pattern of unidentified spores, with a peak in the afternoon, suggested that a large portion of unidentified spores were dry spores, such as those of many conidia of hyphomycetes, conidia of the anamorphs of Erysiphales, and dry sporangiospores of some zygomycetes, all of which would be primarily released and dispersed by air currents (Ingold 1965). Since dry spores of conidial fungi such as *Cladosporium*, *Alternaria* and *Aspergillus/Penicillium* made up the largest fraction of total spores, the diurnal pattern of total spores, with highest spore counts in the afternoon, was determined by the spores of these major taxa. The total number of genera was lowest from 04:00 h to 08:00 h, because most diurnal periodicities were at their low points, except in the case of *Leptosphaeria* and some other ascomycetes.

Most diurnal periodicities in the non-growing season (November–April) did not have distinct patterns, except for *Epicoccum*. In the non-growing season most fungi were not

producing spores. The spores found during this period were thought to be mainly those resuspended by various local perturbations and those carried long distances through the air. *Epicoccum* had a very late seasonal pattern, mainly concentrated in fall from September to December. The high spore concentration in November and December contributed significantly to the diurnal pattern during the non-growing season.

Lacey (1990) thought that diurnal periodicities are modified if rain or snow occurs. This might be true of observations conducted only over a short period. But when long-term observations were made, the effects of rain and snow became attenuated.

Seasonal periodicities

In temperate regions, airborne fungal spores are usually fewest in winter and spring and most abundant in summer (Lacey 1990). In Canada, at least at Waterloo, this is certainly the case. Similar seasonal patterns of *Cladosporium*, *Alternaria*, *Epicoccum*, hyphal fragments and total spores were found in Austria (Ebner & Haselwandter 1989). The late seasonal pattern of *Epicoccum*, with a fall peak, was found both in the present study and in that of Ebner & Haselwandter (1989). *Epicoccum* numbers were very low during periods of snow cover, and may have been trapped after resuspension from plant surfaces within the tree canopies, which were not covered by snow. Since the culture method was used by Ebner & Haselwandter (1989), *Aspergillus* and *Penicillium* were identified separately. These authors found that *Aspergillus* had a well defined seasonal pattern, while *Penicillium* did not. A later study conducted by Ebner et al. (1992) in Austria found that both *Aspergillus* and *Penicillium* showed seasonal patterns, but the patterns were dissimilar. These results suggested that the absence of a seasonal pattern in the present study may be determined by the overlapping seasonal patterns of both genera.

The seasonal patterns of hyphomycetes observed in Egypt were much different from those in Canada and Austria (Abdel-Hafez & El-Said 1989, Ebner & Haselwandter 1989). The peak period in Egypt was around March (Abdel-Hafez & El-Said 1989). The key factor responsible for the differences in the areas is probably biogeography and climate. In Egypt temperature was never a limiting factor for fungal growth and spore release. Relative humidity and wind were more important factors for spore release. March is in dry season with minimum relative humidity in Egypt (Abdel-Hafez & El-Said 1989). Dry conditions should be suitable for the release of dry conidia. The short period during which *Polythrincium* was recorded may be due to a short spore release period. The durations of spore release in different species range from days to months (Shao et al. 1984).

The seasonal trends of *Leptosphaeria* and unidentified ascospores were found to be similar in the present study and those carried out in Thailand, with a peak period from May to October or November (Phanichyakarn et al. 1989). The difference was that in the present study the ascospore count was very low during the non-growing season, while in Thailand significant numbers of spores were still retrieved in the dry season. Rainfall plays an important role in ascospore release (Moore-Landecker 1982). Rain in Canada occurs mainly from late spring to mid-fall. In the "dry season" of tropical areas like Thailand from 10 mm to 60 mm of rain may still fall each month.

In the present study the seasonal patterns of Coprinaceae, *Ganoderma* and unidentified basidiospores, with a peak period from mid-spring to mid-fall, might be related to the characteristics of the life histories of these fungi in southern Ontario. We noted that many species of *Coprinus* occurred on dung throughout the growing season. Rantio-Lehtimäki et al. (1991) discovered that basidiospores of *Boletus* were mainly found in summer and fall in Finland. The spore maturation and release time and date are different for different species, and even for the same species in different areas. *Ganoderma applanatum* produces and releases spores from early spring to frost in fall in southern Ontario (Sinclair et al. 1987). *Paxillus panuoides* Fr. fruits from fall to winter on fallen wood in Mississippi (McCracken 1987). Observations in Thailand showed that unidentified basidiospores were more numerous in the rainy season than in the dry season (Phanichyakarn et al. 1989). Lacey (1990) also noted that in tropical areas, basidiospores are most abundant in the rainy season.

Since seasonal patterns of the airborne spores of common taxa in the present study were similar, with peaks during the growing season, it is not surprising to find that hyphal fragments, unidentified spores and total spores shared similar patterns with them. These results suggested that the interaction of development, spore production and spore release of fungi with climatic factors was a very important determinant for airborne fungal spores in southern Ontario with its four clearly defined seasons.

Studies on seasonal patterns of airborne fungi should be long-term. One year's observations are not enough; it is likely that data from at least three years, and possibly a longer period, would be required for valid predictions to become possible.

Although no sampler yet devised is ideal for taking outdoor spore samples (Chang et al. unpubl.), the Samplair design trapped adequate spore numbers at all times. For example, *Epicoccum*, with large conidia, was positively correlated with windspeed (Li & Kendrick 1994, Li & Kendrick, unpublished data). This means that the sampler trapped more of these spores as wind speeds increased, a reassuring sign of the efficiency of the Samplair. Turbulence may, on occasion, have affected sampling accuracy, but the number of samples is so large and results so consistent that this effect was presumably smoothed out over the long data gathering period.

Samplair is a compact, highly efficient, volumetric air sampler. The sampler with a fixed orifice at the top is not wind oriented and, therefore, vulnerable to precipitation.

This is one of the reasons why a weather guard was used in the present study. Another reason is that wind speed varies greatly, continously; a weather guard can improve isokinetic condition around the orifice so as to enhance the efficiency of the sampler.

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