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## Bambusicolous fungi: A review

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Hyde, K.D., Zhou, D.Q. and Dalisay, T. (2002). Bambusicolous fungi: A review. *Fungal Diversity* 9: 1-14.

More than 1100 species of fungi have been described or recorded world-wide from bamboo and include *ca.* 630 ascomycetes, 150 basidiomycetes and 330 mitosporic taxa (100 coelomycetes and 230 hyphomycetes). Most taxa have been recorded from Asia, with relatively fewer known from India and South America. The bamboo genera *Bambusa*, *Phyllostachys*, *Sasa*, and *Arundinaria* are rich sources of fungi yielding 253, 178, 84, and 82 species, respectively. Most species are saprobes found on decaying culms, although pathogens and endophytes have also been recorded. The most common families of ascomycetes on bamboo are the *Hypocreaceae*, *Phyllachoraceae* and *Xylariaceae*, represented by the common genera *Nectria*, *Phyllachora* and *Hypoxylon* respectively. The most well represented genera of hyphomycetes on bamboo are *Acrodactys*, *Coniosporium*, *Periconia*, *Podosporium* and *Sporidesmium*. Suggestions for future work on bamboo fungi are made.

**Key words:** bamboo, endophytes, host-specificity, pathogens, saprobes.

### Introduction

Grasses are the world's most important agricultural plants (Chapman and Peat, 1992). They include cereals, sugar cane, forage grasses for farm animals, ornamental grasses, and bamboos. Bamboos are useful in making furniture, building houses and are important in forest conservation and management, such as reduction of soil erosion and also important to Panda conservation (Chapman and Peat, 1992). *Poaceae* are one of the largest of the families of flowering plants ranking third in number of genera (*ca.* 600) and fifth in number of species (*ca.* 7,500) (Gould, 1968). Bamboo belongs in the *Poaceae* (*Gramineae*) and form tribe *Bambuseae* of the subfamily *Bambusoideae* (Dransfield and Widjaja, 1995; Moulik, 1997). There are an estimated 1000 species of bamboo belonging in 80 genera worldwide, and about 200 species are found in South-East Asia (Dransfield and Widjaja, 1995). Bamboo occurs in tropical, subtropical, and temperate regions of all continents, but with limited occurrence in Europe.

The genera of bamboo vary in habit. Some are clump forming or single-stemmed. They may be erect with drooping or pendulous tips, or slender and scrambling, or climbing. The main parts are the rhizome, shoot, culm, culm leaf, branch, leaf, inflorescence, and fruit. Their rhizome and branching systems, the presence or absence of bristles or hairs on the culms and culms sheaths, and structures of the inflorescences distinguish the genera of bamboo from each other.

### **Bamboo fungi**

Hino (1938) first used the term “fungorum bambusicolorum” (bambusicolous fungi), but did not give a definition. “Bambusicolous” means “living on bamboo”. Bambusicolous includes any fungi growing on any bamboo substrates, which include leaves, culms, branches, rhizomes and roots.

Our knowledge of bamboo fungi is limited and it is mostly in recent years that mycologists have catalogued fungi on bamboo. Eriksson and Yue (1998) re-examined all ascomycetes described as new species from bamboo and provided an annotated checklist, while Boa (1964, 1967) provided a list of common pathogens. There have been some taxonomic/ecological studies on bamboo fungi, but these are limited to particular localities such as France (Petrini *et al.*, 1989), Hong Kong (Hyde *et al.*, 2001, 2002), Japan (Hino, 1961) and the Philippines (Rehm, 1913a,b, 1914a,b, 1916; Sydow and Sydow, 1913, 1914). Many of the other bambusicolous records used in this paper are from the “Index of Fungi” (<http://nt.ars-grin.gov/fungalatabases/>).

There has been no comprehensive review of the literature on bamboo fungi and therefore this paper attempts to provide an overview of previous studies.

### **Economic importance**

Most economically important bambusicolous fungi are pathogens. *Ceratospheeria phyllostachydis* S. Zhang causes dieback of *Phyllostachys pubescens* Mazel (Kuai, 1996), and is broadly distributed across China. *Stereostromium corticioides* (Berk. & Broome) Magn. is a common rust on many bamboo species (Kuai, 1996). A list of diseases on bamboo is provided by Boa (1967). Although less noteworthy, the saprobes that degrade bamboo are also economically important as they degrade bamboo structures, such as houses and utensils. Some bambusicolous fungi are also medicinal. *Engleromyces goetzii* Henn., *Hypocrella bambusae* (Berk. & Broome) Sacc. and *Shiraia bambusicola* Henn. are used in traditional Chinese medicines to treat various human diseases (Ying *et al.*, 1987). *Dictyophora indusiata* (Vent.) Desv., which is often associated with bamboo, is well known for its medical and edible value (Ying *et al.*, 1987).

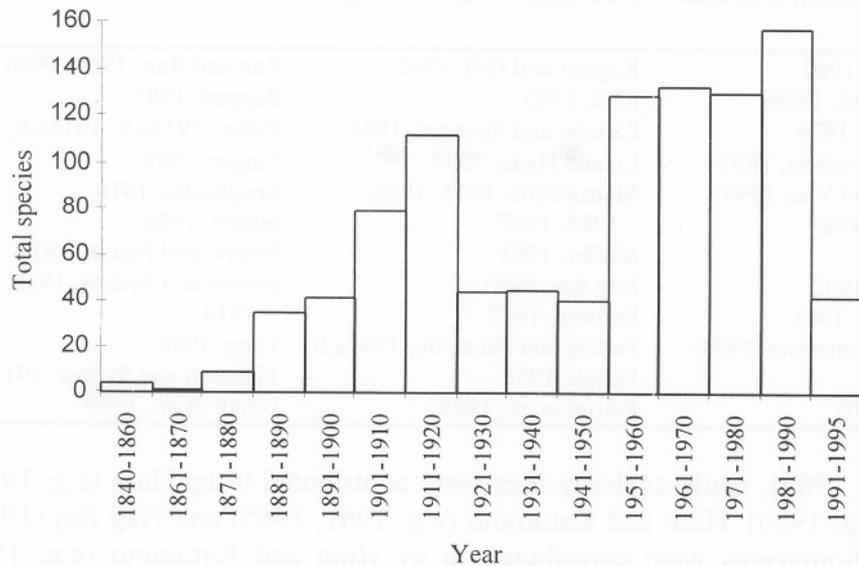


Fig. 1. Number of fungi described from bamboo to 1995.

### Historical Studies

The first records of fungi on bamboo are those of L veill  (1845) who described *Dothidea goudotii* L v. from leaves of *Chusquea* sp. and *Sphaeria bambusae* L v. from culms of *Bambusa arundinacea*. In the following year, L veille (1846) described another two ascomycetes from the same genera of bamboo, i.e. *Asterina microscopica* L v., from leaves of *Chusquea* sp. and *Sphaeria hypoxantha* L v. from culms of *Bambusa arundinacea*.

Between 1854-1856 *Sphaeria fusariispora* Mont. was recorded from *Bambusa* sp. and *Hypoxylon fuscopurpureum* (Schwein.) Berk. from *Phyllostachys* and *Sasa* sp. (Berkeley, 1854; Montagne, 1856a,b). Between 1870-1880, significant collections of bamboo substrates were carried out, which resulted in descriptions of eight new ascomycetes. There was a gradual increase in the number of species described between 1880-1920 (Fig. 1), most of which were ascomycetes, followed by basidiomycetes. A decline in the number of described species occurred before and after the Second World War. Between 1951-70, however, there was a remarkable increase (Fig. 1). Hino and Katumoto made a significant contribution during this period by recording 104 new species of ascomycetes (e.g. Hino and Katumoto, 1954-1966).

Most other fungal groups had many new species recorded from bamboo between 1971-1980. Contributions to the study of hyphomycetes on bamboo were made by Hino and Katumoto (1954-1966), Rao and Rao (e.g. 1964, 1966), Ellis (e.g. 1971, 1976), Matsushima (e.g. 1975, 1980, 1985, 1987) and

**Table 1.** Selected contributors to the study of bamboo fungi.

Boa, 1964, 1967	Kapoor and Gill, 1962	Rao and Rao, 1964, 1966
Corner, 1966, 1989	Kirk, 1985	Rappaz, 1987
Ellis, 1971, 1976	Læssøe and Spooner, 1994	Rehm, 1913a,b, 1914a,b, 1916
Ellis and Everhart, 1895	Lu and Hyde, 2000	Singer, 1989
Eriksson and Yue, 1998	Matsushima, 1975, 1980,	Spegazzini, 1910
Farr <i>et al.</i> , 1989	1985, 1987	Sutton, 1980
Hara, 1913	Möller, 1901	Sydow and Petrak, 1931
Hennings, 1902	Nag Raj, 1993	Sydow and Sydow, 1913,
Hino, 1938, 1961	Parbery, 1967	1914
Hino and Katumoto, 1954-	Penzig and Saccardo, 1897a,b	Teng, 1996
1966	Petrak, 1950	Theissen and Sydow, 1915
Höhnelt, 1909	Petrini <i>et al.</i> , 1989	Umali <i>et al.</i> , 1999

Kirk (e.g. 1985), while coelomycetes were contributed to by Hara (e.g. 1913), Petrak (e.g. 1950), Hino and Katumoto (e.g. 1961, 1965) and Nag Raj (1993), and basidiomycetes were contributed to by Hino and Katumoto (e.g. 1961, 1965), Singer (e.g. 1989) and Corner (e.g. 1966, 1989).

### **Biodiversity of bamboo fungi**

Our knowledge of bamboo fungi is still at the cataloguing stage. A review of the major literature on bamboo fungi reveals that more than 1100 species of fungi have been described or recorded from bamboo. This comprises more than 630 ascomycetes, 150 basidiomycetes and 330 mitosporic taxa (100 coelomycetes, and 230 hyphomycetes) (e.g. Rehm, 1913a,b, 1914a,b, 1916; Sydow and Sydow, 1913, 1914; Hino, 1961; Hino and Katumoto, 1954, 1957; Boa, 1964, 1967; Rao and Rao, 1964; Eriksson and Yue, 1998; Petrini *et al.*, 1989; Umali *et al.*, 1999; Hyde *et al.*, 2001, 2002). Selected contributions to the study of fungi on bamboo are listed in Table 1.

The genera of bamboo with the highest numbers of fungi recorded globally are *Arundinaria*, *Bambusa*, *Phyllostachys* and *Sasa* (Fig. 2). Species of *Bambusa* in particular have been found to support a high fungal diversity. This is probably due to a larger number of collections, as it is one of the most widespread genera in tropical and subtropical Asia (Dransfield and Widjaja, 1995), having a large number of species. It may also be due to mycologists use *Bambusa* as a general term for bamboo.

### **Geographical distribution**

The greatest diversity of fungi on bamboo is known from Asia with *ca.* 500 species, followed by South America (180), India (90) and North America (70) (Fig. 3). H. and P. Sydow, H. Rehm, F. Höhnelt, F. Petrak, I. Hino and K.

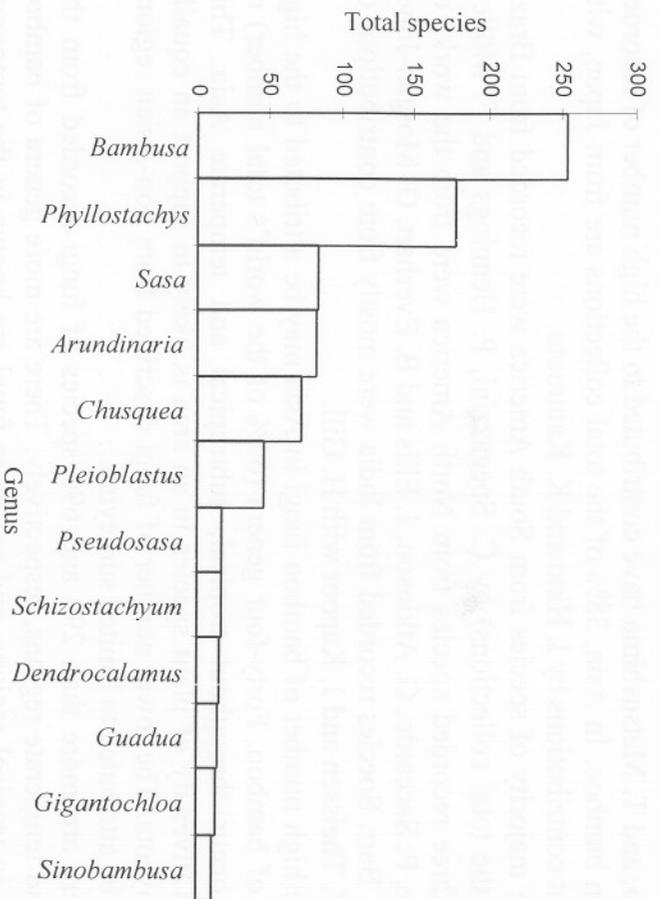


Fig. 2. Bamboo genera with more than 10 recorded fungal species.

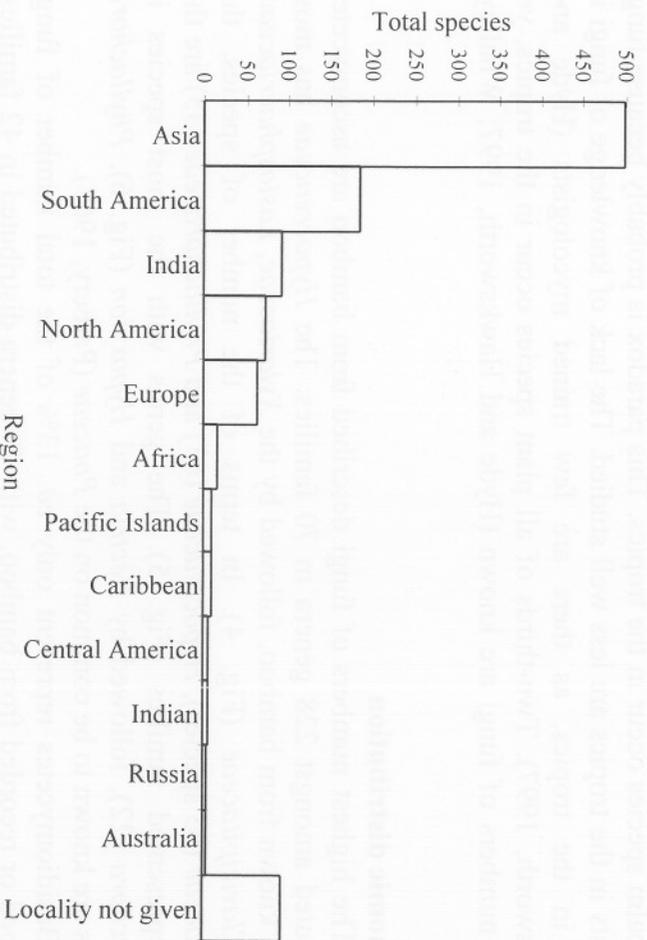


Fig. 3. Geographic distribution of known fungi on bamboo.

Katumoto, and T. Matsushima have contributed to the high number of recorded species on bamboo. In Asia, 38% of the total collections are from Japan, with significant contributions by I. Hino and K. Katamoto.

The majority of species from South America were recorded from Brazil (59% of the total collections) by C. Spegazzini, P. Hennings and F. Möller. Seventy-three recorded species from North America were from the works of M. Cooke, P. Saccardo, G. Atkinson, J. Ellis and B. Everhart, G. Morgan-Jones and M.E. Barr. Species recorded from India were mostly from contributions of D. Rao, F. Theissen and J. Kapoor with H. Gill.

The high number of bamboo fungi in Asia may be attributed to the high diversity of bamboo. Forty-four genera (60% of the world's total number) of bamboo occur throughout tropical, subtropical and temperate Asia. This enormous diversity of plant species in an area is likely to support an equally diverse mycota. The lower number of fungi described from non-Asian regions may also be attributed to limited surveying.

There are more than 290 and 690 species of fungi recorded from the tropics and temperate regions, respectively. There are more genera of bamboo occurring in tropical regions, and yet more fungi are known in the temperate regions. A high diversity of bamboo species in the tropics should support a diverse mycota, yet a poorer diversity is known. High numbers of palm fungi are also known from the temperate regions (Hyde *et al.*, 1997), even though most palm species occur in the tropics. This paradox is probably because fungi on hosts in the tropics are less well studied. The lack of knowledge of fungi is acute in the tropics, as there are few trained mycologists (Hyde and Hawksworth, 1997). Two-thirds of all plant species occur in the tropics, yet lower numbers of fungi are known (Hyde and Hawksworth, 1997; Whalley, 1997).

### **Taxonomic distribution**

The highest numbers of fungi described from bamboo are ascomycetes distributed amongst 228 genera in 70 families. The *Hypocreaceae* has most genera known from bamboo, followed by the *Xylariaceae*, *Lasiochaeraceae*, and *Clavicipitaceae* (Fig. 4). In terms of the number of species, the *Xylariaceae* (63 species), *Hypocreaceae* (63) and *Phyllachoraceae* (35) are the best-represented families (Fig. 5). The genus with the most species is *Phyllachora* (22), followed by *Nectria* and *Hypoxylon* (Fig. 6). *Phyllachora* species are known to be common on the *Poaceae* (Parbery, 1967).

Basidiomycetes represent only *ca.* 13% of the total number of fungi described or recorded from bamboo, with 70 genera distributed in 42 families. Only the *Tricholomataceae* has more than 10-recorded genera. This is probably

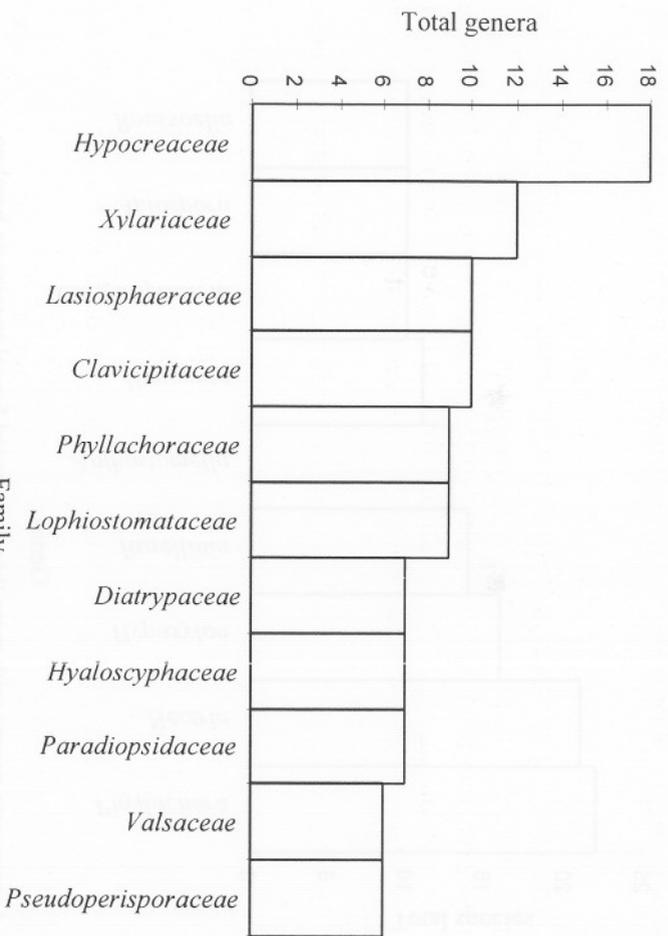


Fig. 4. Ascomycete families with more than 5 genera recorded on bamboo.

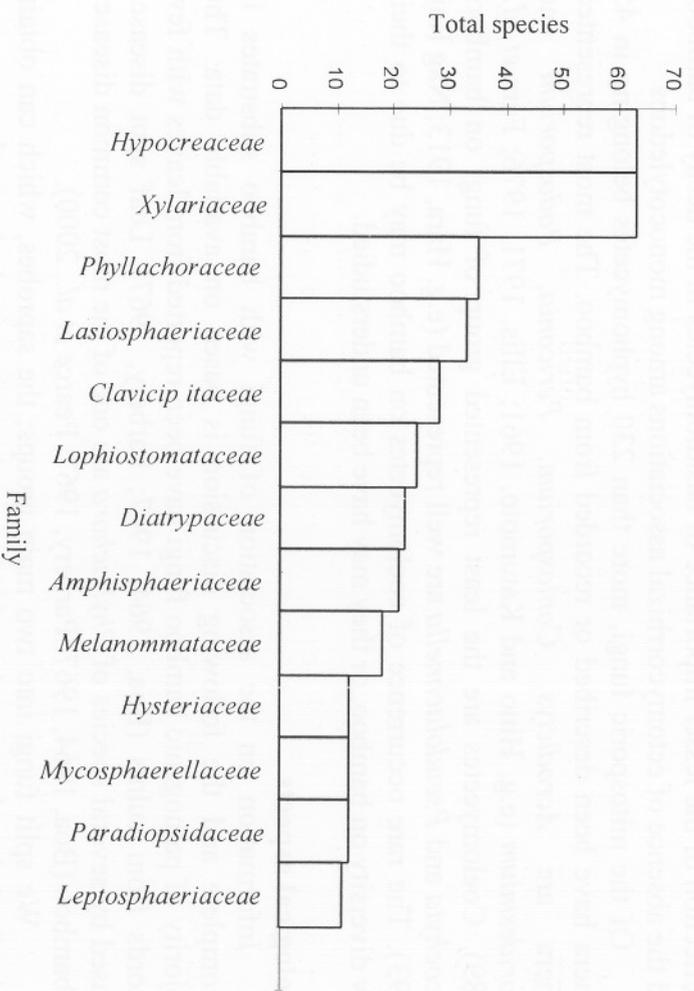


Fig. 5. Ascomycete families with more than 10 recorded fungal species on bamboo.

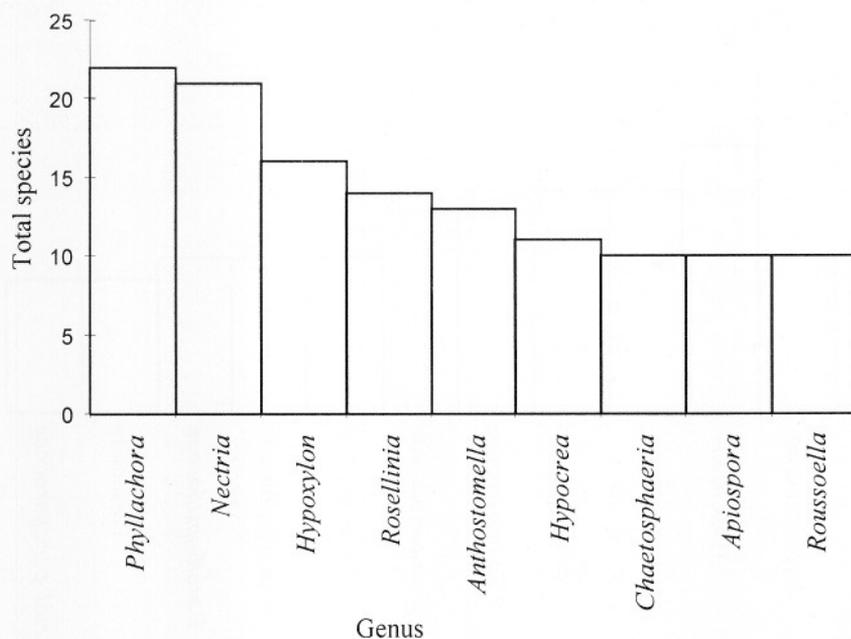


Fig. 6. Ascomycete genera with more than 9 recorded fungal species on bamboo.

a reflection of the lesser importance of basidiomycetes in the decay of bamboo, and the absence of ectomycorrhizal associations among monocotyledons.

Of the mitosporic fungi, more than 230 hyphomycetes belonging in 45 genera have been described or recorded from bamboo. The most represented genera are *Acrodictys*, *Coniosporium*, *Periconia*, *Podosporium* and *Sporidesmium* (e.g. Hino and Katumoto, 1961; Ellis, 1971, 1976; Farr *et al.*, 1989). Coelomycetes are the least represented group of fungi on bamboo. *Ascochyta* and *Pseudolachnella* are well represented (e.g. Hara, 1913; Nag Raj, 1993). The rare occurrence of coelomycetes on bamboo may be due to their low diversity on bamboo, or they may have been understudied.

### Ecological aspects

Information on the association of fungi with bamboo substrates is incomplete and the following discussion is based on available data. The majority of pathogenic bamboo fungi have been reported from leaves with few records from culms (Boa, 1964, 1967; Parbery, 1967). Leaf spot diseases caused by several species of *Phyllachora* are one of the most common diseases of bamboo (Boa, 1964, 1967; Parbery, 1967; Pearce *et al.*, 2000).

We split fungi into two main groups; the saprobes, which can obtain their food by decomposing dead organic matter and the pathogens and endophytes, which live on/in living plant tissues. In general the obligate

pathogens include species of *Puccinia*, *Stereostromum* and *Uredo*. Some of these fungi have very narrow host ranges and may occur on only a single variety (Shao *et al.*, 1984). *Fusarium*, *Phyllachora* and *Sclerotium* species are facultative parasites on bamboo. Thirty-seven taxa have also been isolated as endophytes of bamboo (Umali *et al.*, 1999). Most of the taxa identified were typical of endophytes of other monocotyledonous hosts.

### **Host-specificity/-recurrence**

Host-specificity infers a relationship between hosts and fungi, and has mostly been applied to plant pathogens (Lucas, 1998). Most fungi on bamboo are not pathogens, and therefore, are unlikely to be host-specific. They may, however, exhibit a host recurrence, i.e. occur repeatedly on the same host, but be absent or rare on adjacent hosts of the same family (Zhou and Hyde, 2001). This has been observed with *Oxydothis alexandrae*, which frequently occurred on *Archontophoenix alexandrae*, but was absent on adjacent palm hosts (Taylor *et al.*, 2000). Host-specificity in saprobic fungi is difficult to demonstrate and Hyde *et al.* (2001) could not find any evidence for host-specificity for the fungi on *Dendrocalamus* and *Bambusa*. They found a high diversity of fungi developing on *Bambusa* (75 species) indicating that the fungi on bamboo are extremely diverse. Such high species diversity at the subfamily level (*Bambusoideae*) would have a significant impact on species numbers. Hyde *et al.* (2001) also found certain fungi were recurrent on one host, but not apparent on the other host, even in the same location, indicating that fungi may exhibit some specificity (or are recurrent) on a particular host.

### **Tissue specificity**

Most fungi have been recorded from bamboo culms (514 species), followed by leaves (214), sheaths (16) and branches (12). The parts of bamboo with the least number of fungi recorded are the shoots, roots, and inflorescences. It is not known whether fungi are specific too, or are recurrent on certain bamboo tissues. Most pathogens of bamboo, e.g. *Phyllachora* spp. and *Puccinia* spp., are confined to the leaves (e.g. Pearce *et al.*, 2000), while most larger ascomycetes (e.g. *Astrosphaeriella* spp.) have only been recorded from decaying culms. Fungi have been found to be recurrent on various palm tissues, e.g. leaves vs rachides (Yanna *et al.*, 2001) and it would be interesting to establish if the situation was similar with bamboo.

### **Future studies**

Information on fungi from bamboo is incomplete. Further collections of bamboo are needed in order to provide a more complete understanding of the fungi involved in the decay of dead bamboo culms and leaves. Isolation and

identification of fungi from bamboos is still an essential step towards understanding ecosystem communities. Studies should be carried out on bamboo hosts, particularly in less well-studied regions (e.g. Indonesia, Papua New Guinea).

Umali *et al.* (1999) reported endophytes from leaves of *Bambusa tuldoides* in Hong Kong. Isolation of endophytes from other bamboo hosts, from other tissues of bamboos, and from other regions or countries should also be conducted in order to establish if endophytes are tissue specific. Endophytes may serve as effective biological control agents against pathogens. It would be interesting to conduct assays using endophytes against pathogenic fungi. Protocols are also needed in order to promote sporulation of endophytic mycelia sterilia in culture (e.g. Guo *et al.*, 1998), or molecular techniques need to be developed further (e.g. Guo *et al.*, 2000, 2001), so that non-sporulating endophytes can be identified, and their roles can be established.

Bamboo occurs along the banks of many streams and rivers in the tropics. Several new species of freshwater fungi have been described from bamboo (e.g. *Fluminicola coronata*; Wong and Hyde, 1999). The fungi on submerged bamboo are also more diverse, and in general differ from those on submerged wood (Goh and Hyde, 1999; Cai, Hyde and Zhang, pers. observ.). The fungi on submerged bamboo are therefore of interest and require further study in order to establish if these fungi on submerged bamboo differ from those on terrestrial bamboo. It may be that the close association of bamboo and water has provided a habitat in which freshwater fungi may have evolved into terrestrial fungi.

Cannon (1997) pointed out that lack of knowledge of host-specificity in most fungal species was a major obstacle in estimating fungal diversity even for small areas. There is, however, even less information on host-exclusivity or -recurrence (previously termed -preference), particularly in the case of bambusicolous fungi (Zhou and Hyde, 2001). Further surveys of various bamboo hosts in the same and different habitats are needed in order to reveal examples of host-exclusivity or -recurrence in saprobic bamboo fungi. This can be carried out in two stages: 1) to statistically make observations on various plants and 2) to establish the basis for host-recurrence.

There are presently no published reports of fungal succession on bamboo, and we have little idea if there is a sequence of fungi that degrade freshly dead to old bamboo culms. Frankland (1998) pointed out that each succession is unique, dependent on the host material and its environment. It is therefore desirable to study fungal succession on various substrata, including bamboo, and in different environments in order to establish the dynamics of fungal succession on these hosts.

### Acknowledgements

D. Zhou and T. Dalisay would like to thank The University of Hong Kong for the award of Postgraduate Studentship. E.B.G. Jones is thanked for commenting on the draft manuscript.

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(Received 10 October 2001; accepted 28 November 2001)