# Lichenized and saprobic fungal biodiversity of a single *Elaeocarpus* tree in Papua New Guinea, with the report of 200 species of ascomycetes associated with one tree

**André Aptroot**

Centraalbureau voor Schimmelcultures, P.O. Box 85167, NL-3508 AD Utrecht, The Netherlands; e-mail: aptroot@cbs.knaw.nl.

Aptroot, A. (2001). Lichenized and saprobic fungal biodiversity of a single *Elaeocarpus* tree in Papua New Guinea, with the report of 200 species of ascomycetes associated with one tree. Fungal Diversity 6: 1-11.

Although the ascomycete flora of Papua New Guinea is poorly known, results of recent expeditions indicate that it is among the most diverse in the world. The high biodiversity is a result of its diverse habitats, ranging from undisturbed lowland tropical rain forest to mountains with alpine vegetation. Exhaustive sampling of the above-ground parts of one single *Elaeocarpus* tree in montane forest showed the presence of over 200 species of ascomycetes, including 173 lichenized ascomycetes. This is the highest number of species ever recorded from a single tree. Many species are as yet undescribed and this single tree has been the source of two genera new to science: *Leptocucurthis* and *Lirellodisca*. It is notable that this high species number associated with one organism has been found by direct specialist observation rather than by experimental DNA techniques.

**Key words:** ascomycetes, biodiversity, *Elaeocarpus*, fungi, lichens, Papua New Guinea, saprobic, species numbers.

## Introduction

Interest in biodiversity has increased markedly during the last few years, following the rapid destruction of natural habitats and the consequent danger of extinction for many organisms. A review of the magnitude of fungal biodiversity (Hawksworth, 1991) stresses the potentially high species numbers in the tropics, based on the assumption that many species can be associated with one organism. However, little is known about the diversity of the largest group of fungi, the ascomycetes, especially in the tropics (Aptroot, 1997a; Aptroot and Sipman, 1997).

Most groups of organisms have their highest species diversity in the tropics. Usually this diversity is so conspicuous that it strikes even non-specialists. Ascomycetous fungi, and especially lichenized ascomycetes, are however most conspicuous in arctic and alpine environments, where they tend to form extensive carpets on the ground and strikingly colourful patches

on rock surfaces. In tropical environments they tend to be inconspicuous. Their significance in the tropics is therefore not self-evident, and little attention has been paid to their diversity, although the significance of tropical rain forest for lichen diversity has been stressed (Gradstein, 1992).

Papua New Guinea presently contains the largest uninterrupted area of undisturbed tropical forest in the world. It covers the eastern half of the second largest island in the world, situated on the equator between the Indian and the Pacific Ocean. The variation in its geology is huge, and it is tectonically active. The climate varies from dry tropical along the south coast, wet tropical along the east and north coast, extremely wet but cooler temperate in the mountains, up to alpine above the tree limit in the high mountains, which reach 4500 m.

The ascomycete flora from tropical areas is still scarcely known (Hyde, 1997). Corticolous ascomycetes are particularly undercollected in the tropics (Aptroot, 1997b). Papua New Guinea is no exception (Shaw, 1984), although recently many additional species have been reported or described (e.g. Aptroot and Sipman, 1991; Aptroot 1997c; Aptroot and van Iperen, 1998).

Exploration of the lichen flora of Papua New Guinea has been scattered until recent times. In 1950 only 224 species were known (Szatala, 1956). This figure was doubled 30 years later, when 495 species were reported (Streimann, 1986). The expedition by Aptroot and Sipman (1991) added over 112 species. The recent Benelux lichenological expedition to Papua New Guinea in 1992 provided many other species which were not yet known from the island. Of these, 336 have already been published (Aptroot *et al.*, 1995, 1997), while at least a further 300 species remain, which cannot at present be identified. Several additional species have been recently described or reported by various other authors. At the moment, 1079 species are considered to have been reliably reported from New Guinea. This means that the number of known lichen species in Papua New Guinea has again doubled over the last ten years.

**Materials and methods**

From 14 October to 3 November 1995 a collecting trip, the third in a series, was made to Papua New Guinea by the first author, together with Drs E. Sérusiaux, P. Lambley and H.J.M. Sipman. The main aim of this trip was to collect ascomycetes (including their anamorphs) from undisturbed tropical forests at various altitudinal zones.

The above-ground parts of one single *Elaeocarpus* sp. tree were extensively sampled. This tree had fallen two days before the collecting date, during a violent storm. It grew on the border of a rare, naturally grass-covered frost hollow in the middle of a vast area of undisturbed montane forest dominated by endemic species of the conifer genera *Phyllocladus* sp. and

*Podocarpus* sp. Frost hollows are among the very few areas with natural grassland in the tropics. They are the result of downward cold-aircurrents accumulating in deep valleys, leading to sub-zero temperatures lethal to tropical trees. The plants resistant to these circumstances are mainly grasses, treeferns and some herbs with temperate affinities. The collecting locality is situated in Myola, a tiny semi-permanent village in the Owen Stanley mountain range north of Port Moresby at 2100 m altitude. The tree was 25 m high and had an almost smooth, cylindrical stem with a diam. of 50 cm.

For the inventory of this tree, five zones were recognised within the tree, viz. the stem base (up to 5 m), stem, branches, twigs and leaves. Estimations were made of the % coverage of the total surface of one zone by the various groups of epiphytic organisms (algae, fungi, lichens, bryophytes, ferns and orchids) and of the individual species. The whole tree surface was accessible for research as the tree had not fallen completely onto the ground, but was hanging about 50 cm above the ground surface froming a natural bridge between some small, equally fallen trees. All branches and twigs have been cut up and examined at all side with a hand lens. All ascomycetes (including lichens) were exhaustively sampled. A total of over 500 collections were made from this tree.

All specimens were collected by the author and are preserved in ABL and CBS. Most isolations from these collections, as well as from random samples of soil, wood and other substrata are available from the CBS culture collection. In the enumeration below, only ascomycetes and their anamorphs are reported, but attempts were made to culture as many species as possible.

**Results**

The stembase, stem, branches and twigs were totally covered by epiphytes, even with more than 100% to overlap (Table 1). Surprisingly, most of the leaf surfaces were devoid of fungi. Lichen coverage was highest on the stems, whereas the highest number of species was found on the branches. Foliose and fruticose species, as well as lichens with cyanobacteria were most abundant on the branches.

In total 200 species of ascomycetes were found on this tree, including 173 lichens (Table 2). This is the highest number of ascomycete species so far recorded from one single tree. Not included in this number are some additional species, e.g. *Penicillium*, which were later isolated from branches and bark of the same tree. These have been omitted because it cannot be ruled out that only dormant conidia from airborne sources were present on this tree. For the same reason soil fungi from the same locality are not included in this figure.

**Table 1.** Ascomycetes on a single *Elaeocarpus* tree in Papua New Guinea

| | base(-5m) | stem | branches | twigs | leaves |
|---|---|---|---|---|---|
| **Surface (sq.m)** | 5 | 10 | 10 | 10 | 10 |
| **Coverage (%)** | | | | | |
| Algae | <1 | <1 | <1 | <1 | <1 |
| Fungi | <1 | <1 | <1 | <1 | 10 |
| Lichens | 50 | 99 | 80 | 70 | <1 |
| Bryophytes | 50 | 2 | 20 | 20 | - |
| Ferns | <1 | <1 | - | - | - |
| Orchids | 2 | <1 | 2 | <1 | - |
| **Species numbers** | | | | | |
| Ascomycetes | 2 | 5 | 2 | 6 | 2 |
| Lichenicolous | - | 4 | 5 | 5 | - |
| Lichenized | 41 | 67 | 93 | 62 | 1 |
| **Photosynthetic symbionts** | | | | | |
| Cyanobacteria | 7 | 5 | 15 | 16 | - |
| *Trentepohlia* | 16 | 28 | 35 | 16 | - |
| *Chlorococcales* | 18 | 34 | 43 | 30 | 1 |

This is also the highest number of lichenized ascomycetes so far recorded from one single tree. The highest numbers so far reported were from a temperate forest tree in England (Rose, 1992) and from a tree in lowland rain forest in French Guiana (Gradstein, 1992). All previous numbers were well below 100.

Two new genera (*Leptocucurthis* and *Lirellodisca*) and an additional new species (*Navicella pallida* Aptroot) have already been described from material collected on this tree (Aptroot and van Iperen, 1998). The presence of rarely collected pyrenocarpous lichens like *Musaespora gigas* (Zahlbr.) R.C. Harris (syn. *Musaespora corticola* Aptroot and Sipman), *Mycomicrothelia captiosa* (Krempelh.) D. Hawksw. and *Ornatopyrenis queenslandica* (Müll. Arg.) Aptroot (the last two in large quantities) is remarkable. Corticolous ascomycetes are undoubtedly undercollected in the tropics. Details on some of the identifications are published elsewhere (Aptroot, 1998; Aptroot and van Iperen, 1998).

The results of the identification of the samples are presented in Table 2. Many species could not be identified, partly due to the poor knowledge of the taxonomy of tropical lichens, partly due to poor or insufficient material that did not allow identification to species level, but was sufficiently different from other specimens to be recognised as separate taxa. Voucher specimens of all taxa separated form all different levels in the tree have been kept for future

**Table 2.** Ascomycetes on one single tree in Myola, Papua New Guinea (full list)
Coverage (%); x = coverage 1% or less

| | base | trunk | branch | twigs | leaf |
|---|---|---|---|---|---|
| **Non-lichenized ascomycetes** | | | | | |
| *Asterina* sp. | | | | | x |
| *Chaetomella* sp. | | | | x | |
| *Leptocucurthis quadrata* gen. and sp. nov. | | x | | | |
| *Lirellodisca pyrenulospora* gen. and sp. nov. | | | | x | |
| *Meliola* sp. | | | | | x |
| *Navicella pallida* sp. nov. | x | | | | |
| *Nectria coccophila* | | | x | x | |
| *Phoma* sp. nov. | x | | | | |
| *Phomopsis* sp. nov. | | x | | x | |
| cf. *Scutula* sp. | | x | | | |
| *Xylobotryum portentosum* | | x | | x | |
| Unidentifiable fungus 1 | | x | | | |
| Unidentifiable fungus 2 | | | x | | |
| Unidentifiable fungus 3 | | | | x | |
| **Lichenicolous fungi** | | | | | |
| cf. *Dactylospora* sp. | | x | | | |
| *Lichenopeltella ramalinae* | | x | x | | |
| *Lichenostigma maureri* | | | | x | |
| *Opegrapha* sp. | | x | | | |
| *Phacopsis oxyspora* | | | | x | |
| *Phoma* sp. nov. | | x | | | |
| *Pyrenidium* sp. | | x | | | |
| *Roselliniella atlantica* | | | | x | |
| cf. *Stigmidium* sp. | | | x | | |
| Undescribed genus sp. nov. | | | x | | |
| Unidentifiable lichenicolous fungus 1 | | | x | | |
| Unidentifiable lichenicolous fungus 2 | | | | x | |
| Unidentifiable lichenicolous fungus 3 | | | | x | |
| **Lichenized ascomycetes** | | | | | |
| *Anzia isidiolenta* | | | x | | |
| *Anzia isidiosa* | | x | x | | |
| *Anzia pustulata* | | | x | | |
| *Arthonia* sp. 1 | x | x | | x | |
| *Arthonia* sp. 2 | | x | | | |
| *Arthonia* sp. 3 | | x | | | |
| *Arthonia* sp. 4 | | | x | | |
| *Arthothelium* sp. 1 | x | x | | | |
| *Arthothelium* sp. 2 | | x | x | | |
| *Arthothelium* sp. 3 | | | x | | |
| *Brigantiaea lobulata* | 2 | 5 | | | |
| *Calopadia* sp. | | | | x | |

**Table 2.** (continued)

| | base | trunk | branch | twigs | leaf |
|---|---|---|---|---|---|
| *Catinaria* sp. 1 | | | x | | |
| *Catinaria* sp. 2 | | | x | x | |
| *Celothelium cinchonarum* | | | x | | |
| *Cetrelia chicitae* | | x | x | | |
| *Chiodecton congestulum* | 5 | 15 | x | | |
| *Chiodecton* cf. *leptosporum* | | x | | | |
| *Coccocarpia erythroxyli* | x | | | | |
| *Collema leptaleum* | | | | x | |
| *Cresponea proximata* | x | x | | | |
| *Cryptothecia subnidulans* | | | | x | |
| *Cryptothecia* sp. 1 | | | | x | |
| *Cryptothecia* sp. 2 | | | | x | |
| *Cyclographina hologlauca* | | 5 | 5 | | |
| *Cyclographina hypolepta* | | | | x | |
| *Dendriscocaulon* sp. | | | x | x | |
| *Dimerella weberi* | | | x | | |
| *Erioderma sorediatum* | | | | x | |
| *Everniastrum vexans* | x | | | | |
| *Graphidaceae* sp. 1 | | x | x | | |
| *Graphidaceae* sp. 2 | x | x | | | |
| *Graphidaceae* sp. 3 | | x | | | |
| *Graphidaceae* sp. 4 | x | | | | |
| *Graphidaceae* sp. 5 | x | | | | |
| *Graphidaceae* sp. 6 | | | x | | |
| *Graphidastra multiformis* | | | x | | |
| *Graphina* cf. *analoga* | | | | x | |
| *Graphina chlorocarpa* | | x | x | | |
| *Graphina streblocarpa* | | | x | | |
| *Graphina* sp. 1 | | | | x | |
| *Graphina* sp. 2 | | x | | | |
| *Graphis dumastii* | | x | x | | |
| *Graphis rimulosa* | x | x | x | | |
| *Graphis triticea* | | | x | | |
| *Graphis turgidula* | | | x | | |
| *Gyalectidium* sp. | | | | | x |
| *Heterodermia corallophora* | | x | x | | |
| *Heterodermia flabellata* | | | x | | |
| *Heterodermia galactophylla* | | x | x | | |
| *Heterodermia hypoleuca* | | | x | x | |
| *Heterodermia isidiophora* | | | x | | |
| *Heterodermia japonica* | x | x | | | |
| *Heterodermia leucomela* | x | x | x | x | |
| *Heterodermia microphylla* | | | x | | |
| *Heterodermia podocarpa* | | | | x | |
| *Heterodermia speciosa* | | | x | | |

**Table 2.** (continued)

| | base | trunk | branch | twigs | leaf |
|---|---|---|---|---|---|
| *Hypotrachyna croceopustulata* | | | x | | |
| *Hypotrachyna imbricatula* | | x | x | x | |
| *Hypotrachyna physcioides* | | | x | | |
| *Hypotrachyna rockii* | | | x | x | |
| *Hypotrachyna sinuosa* | | | | x | |
| *Lecidea* sp. | | | | x | |
| *Leioderma sorediata* | | | | x | |
| *Lepraria nigrocincta* | x | x | x | | |
| *Leptogium bullatulum* | | | x | x | |
| *Leptogium cyanescens* | | | x | | |
| *Leptogium phyllocarpum* | | | | x | |
| *Leptogium* sp. | | | x | | |
| *Lobaria clemensiae* | x | x | | | |
| *Lobaria isidiophora* | x | x | x | x | |
| *Megalospora pruinata* ssp. *fusca* | | x | x | x | |
| *Megalospora sulphurata* | x | x | x | | |
| *Megalospora* aff. *sulphurata* (isidiate) | | x | | | |
| *Megalospora tuberculosa* | | | | x | |
| *Melaspilea diplasiospora* | | | | x | |
| *Menegazzia* sp. nov. 1 (sorediate) | x | x | x | x | |
| *Menegazzia* sp. nov. 2 (non-sorediate) | | x | x | | |
| *Musaespora gigas* | | | | x | |
| *Mycoblastus affinis* | | | | x | |
| *Mycomicrothelia captiosa* | | | x | x | |
| *Nephroma tropicum* | | | x | | |
| *Opegrapha* sp. 1 | | x | | | |
| *Opegrapha* sp. 2 | | x | x | | |
| *Opegrapha* sp. 3 | x | x | | | |
| *Opegrapha* sp. 4 | | | x | | |
| *Opegrapha* sp. 5 (possibly lichenicolous) | | x | | | |
| *Ornatopyrenis queenslandica* | | | x | | |
| *Pannaria obscura* | | | x | | |
| *Pannaria* sp. 1 (non-isidiate) | | | x | x | |
| *Pannaria* sp. 2 (isidiate) | | | x | x | |
| cf. *Pannaria* sp. | x | x | | | |
| *Parmeliella nigrocincta* | | x | | | |
| *Parmotrema* cf. *rampoddensis* | | | | x | |
| *Parmotrema subarnoldii* | x | | x | | |
| *Pertusaria isidiosa* | | x | | | |
| *Pertusaria pseudodactylina* | x | | | | |
| *Pertusaria* cf. *subisidiosa* | | | x | x | |
| *Pertusaria* cf. *velana* | | | 5 | x | |
| cf. *Pertusaria* sp. 1 | | | x | | |
| cf. *Pertusaria* sp. 2 | | | | x | |
| cf. *Pertusaria* sp. 3 | | | | x | |

**Table 2.** (continued)

| | base | trunk | branch | twigs | leaf |
|---|---|---|---|---|---|
| cf. *Pertusaria* sp. 4 | | | | x | |
| cf. *Pertusaria* sp. 5 | | | | x | |
| cf. *Pertusaria* sp. 6 | x | x | | | |
| cf. *Pertusaria* sp. 7 | | x | | | |
| cf. *Pertusaria* sp. 8 | x | x | x | | |
| cf. *Pertusaria* sp. 9 | | x | x | | |
| cf. *Pertusaria* sp. 10 | | | x | | |
| cf. *Pertusaria* sp. 11 | | | x | | |
| cf. *Pertusaria* sp. 12 | | | x | | |
| cf. *Pertusaria* sp. 13 | | | x | | |
| *Phaeographina* cf. *ochracea* | | | x | | |
| *Phaeographis* sp. 1 | | | | x | |
| *Phaeographis* sp. 2 | | | x | | |
| *Phaeographis* sp. 3 | | | x | | |
| *Phaeographis* sp. 4 | | | x | | |
| *Phlyctis* sp. | | | x | | |
| *Phyllopsora buettneri* | | x | | | |
| *Phyllopsora confusa* | x | x | x | | |
| *Phyllopsora pannosa* | | x | | | |
| *Phyllopsora* sp. 1 | | x | | | |
| *Phyllopsora* sp. 2 | x | | | | |
| *Piccolia conspersa* | | x | | | |
| *Polychidium dendriscum* | | | | x | |
| *Porina tetracerae* | x | x | | | |
| *Pseudocyphellaria argyracea* | | | x | | |
| *Pseudocyphellaria aurata* | | | | x | |
| *Pseudocyphellaria crocata* | x | x | | x | |
| *Pseudocyphellaria desfontainii* | x | | x | x | |
| *Pseudocyphellaria gilva* | x | | | | |
| *Pseudocyphellaria intricata* | | | x | x | |
| *Pseudocyphellaria multifida* | | | x | | |
| *Pseudocyphellaria neglecta* | x | | | | |
| *Psoroma pannarioides* | x | | | | |
| *Pyrenula dermatodes* | x | x | x | x | |
| *Pyrenula macrocarpa* | x | x | x | | |
| *Pyrenula* cf. *macularis* | x | | | | |
| *Pyrenula media* | | | x | | |
| *Pyrenula pileata* | | | x | x | |
| *Pyrenula* sp. | | | x | | |
| *Ramalina javanica* | x | x | x | x | |
| *Rimelia reticulata* | | x | x | x | |
| *Rinodina albosorediata* | | | | x | |
| *Sarcographa heteroclita* | | | x | | |
| *Sporopodiopsis mortimeriana* | | | | x | |
| *Sticta boschiana* | | | x | | |

**Table 2.** (continued)

| | base | trunk | branch | twigs | leaf |
|---|---|---|---|---|---|
| *Sticta weigelii* | | | x | x | |
| *Strigula* sp. 1 | | | x | | |
| *Strigula* sp. 2 | | | x | | |
| *Strigula* sp. 3 | | | | x | |
| *Thelotrema* cf. *piduratalagalum* | | | x | x | |
| *Thelotrema porinoides* | x | x | | | |
| *Thelotrema subweberi* | x | x | x | x | |
| *Tricharia* sp. | | x | x | x | |
| *Usnea hossei* | x | x | x | x | |
| *Usnea misamisensis* | | | x | x | |
| Additional empty pyrenocarpous lichen | x | x | | | |
| *Arthoniales* gen. et sp. indet. | | x | x | | |
| Crustose lichen with pycnidia 1 | | x | | | |
| Crustose lichen with pycnidia 2 | x | | | | |
| Unidentified pink sorediate crustose lichen | | x | x | | |
| Sorediate crustose lichen (*Buellia griseovirens*-like) | | | | x | |
| Sorediate crustose lichen (*Thelotremataceae*-like) | | x | | | |
| Sterile crustose lichen (possibly lichenicolous) | | x | | | |
| Unidentified foliose lichen | | | | x | |
| Unidentified crustose lichen sp. 1 | | x | | | |
| Unidentified crustose lichen sp. 2 | | | | x | |
| Unidentified crustose lichen sp. 3 | | x | | | |
| Unidentified crustose lichen sp. 4 | | | x | | |
| Unidentified crustose lichen sp. 5 | | | x | | |
| Unidentified crustose lichen sp. 6 | | x | | | |

study. Among the identifiable species, some were rather unexpected, such as *Brigantiaea lobulata*, until recently known only from New Zealand, which covered *ca.* 5% of the stem surface.

## Discussion

The data presented here from Papua New Guinea show that ascomycete biodiversity in the tropics can be high. The examined tree was relatively small for a tropical tree, but situated at a unique spot along a natural border between two undisturbed tropical habitats, viz. the wet mountain forest and the frost hollow. The number of 200 species on one single tree is the highest ever reported. This was obtained by direct observation by a specialist, followed by careful taxonomic identification and culture work, rather than by experimental work on random samples using DNA techniques. The number of species is much higher than that obtained in any recent work on fungal biodiversity related to an individual organism, whether that organism is a plant (supporting various endophytes, mycorrhizal symbionts or phyllosphere colonizers) or an

animal (or a human). The number of ascomycetes connected to this tree is doubtlessly higher, as additional species may be expected to grow internally in the vessals (endophytes) of trunk, branches, leaves and roots, and externally in association with the roots (mycorrhiza). These microhabitats were however not sampled in the present study due to practical limitations (collecting, preserving and identifying 500 samples was already a considerable amount of work). That the number of species missed this way could be significant, is indicated by results from fungal diversity studies in the tropics that concentrated especially on endophytes. The highest number of endophytic species reported so far (Fröhlich and Hyde, 1999) is about 90 from one palm in Brunei, including only a few which are regularly found on bark. Therefore, it is likely that the number of species associated with the *Elaeocarpus* tree can be augmented by 50-100, giving a total of 250-300.

The number of bryophytes species on the same tree was in the region of 50-100.

**Acknowledgements**

Thanks are due to P. Diederich for the identification of lichenicolous fungi, to M.M.J. van Balgooy for the identification of the tree, to H.J.M. Sipman for the identification of species of *Anzia*, *Lobaria*, *Megalospora* and the *Thelotremataceae*. E. Sérusiaux and P.W. Lambley are warmly thanked for the organisation of the expeditions and for their companionship during these trips. The Netherlands Foundation for the Advancement of Tropical Research (WOTRO) is acknowledged for financially supporting the collecting trip.

## References

Aptroot, A. (1997a). Species diversity in tropical rainforest ascomycetes: lichenized versus non-lichenized; foliicolous versus corticolous. In: *Cryptogams in the Phyllosphere: Systematics, Distribution, Ecology and Use*. (eds E. Farkas and T. Pocs). Abstracta Botanica 21: 37-44.

Aptroot, A. (1997b). Lichen biodiversity in Papua New Guinea, with the report of 173 species on one tree. Bibliotheca Lichenologica 68: 203-213.

Aptroot, A. (1997c). Notes on the saprobic ascomycetes from Papua New Guinea, with the new genus *Papilionovela*. Mycological Research 101: 266-268.

Aptroot, A. (1998). New lichens and lichen records from Papua New Guinea, with the description of *Crustospathula*, a new genus in the *Bacidiaceae*. Tropical Bryology 14: 25-34.

Aptroot, A. and Iperen, A.L. van (1998). New ascomycetes and ascomycete records from Papua New Guinea. Nova Hedwigia 67: 481-497.

Aptroot, A. and Sipman, H. (1991). New lichens and lichen records from New Guinea. Willdenowia 20: 221-256.

Aptroot, A. and Sipman, H. (1997). Diversity of lichenized fungi in the tropics. In: Biodiversity of Tropical Microfungi (ed K.D. Hyde). Hong Kong University Press, Hong Kong: 93-106.

Aptroot, A., Diederich, P., Sérusiaux, E. and Sipman, H.J.M. (1995). Lichens and lichenicolous fungi of Laing Island (Papua New Guinea). Bibliotheca Lichenologica 57: 19-48.

Aptroot, A., Diederich, P., Sérusiaux, E. and Sipman, H. (1997). Lichens and lichenicolous fungi from New Guinea. Bibliotheca Lichenologica 64: 1-220.

Fröhlich, J. and Hyde, K.D. (1999). Biodiversity of palm fungi in the tropics: are global fungal diversity estimates realistic? Biodiversity and Conservation 8: 977-1004.

Gradstein, S.R. (1992). The vanishing tropical rain forest as an environment for bryophytes and lichens. In: *Bryophytes and Lichens in a Changing Environment* (eds J.W. Bates and A.M. Farmer). Clarendon Press, Oxford, UK: 232-256.

Hawksworth, D.L. (1991). The fungal dimension of biodiversity: magnitude, significance, and conservation. Mycological Research 95: 641-655.

Hyde, K.D. (ed) (1997). *Biodiversity of Tropical Microfungi*. Hong Kong University Press, Hong Kong.

Rose, F. (1992). Temperate forest management: its effects on bryophyte and lichen floras and habitats. In: *Bryophytes and Lichens in a Changing Environment* (eds J.W. Bates and A.M. Farmer). Clarendon Press, Oxford, UK: 211-233.

Shaw, D.E. (1984). *Microorganisms in Papua New Guinea*. Department of Primary Industry, Research Bulletin 33.

Streimann, H. (1986). Catalogue of the Lichens of Papua New Guinea and Irian Jaya. Bibliotheca Lichenologica 22: 1-145.

Szatala, Ö. (1956). Prodrome de la flore lichénologique de la Nouvelle Guinée. Annales Historico-Naturales. Museum Naturalis Hungarici, new series 7: 15-50.

(Received 10 May 2000, accepted 10 September 2000)