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Inventoring the fungi of Panama

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Abstract Records of fungi in Panama scattered in literature are presented in a preliminary annotated checklist which is published in Panama. It includes 1807 species and subspecific taxa in 646 genera. The data allow to trace more than 100 years of history of mycology in Panama, presented here for the first time. The species richness is analyzed numerically with respect to the systematic position of the species and their ecology. Considering the numbers of records for different regions of Panama, a comparison with numbers of species published for some other neotropical countries, as well as recent experience collecting fungi in Panama, the incompleteness of the checklist is evident. Values of relative species richness of different systematic groups in Panama compared to values of the same groups as known worldwide, show that our knowledge is fragmentary in Panama especially for Agaricales, Uredinales, and some groups of microfungi. We are still in the pioneer phase of mycological investigation in Panama.

Keywords Pioneer phase of mycological investigation in Panama · Records of Panamanian fungi · Relative species richness · Species richness of fungi

Introduction

Species richness constitutes a fundamental aspect of biodiversity as it reflects the presence of morphologically, physiologically, and ecologically different organisms. Fungi (true Fungi, fungus-like algae, and fungus-like protozoans) receive much less attention than animals and plants, although they are omnipresent and highly diverse in nature as saprophytes, pathogens, endophytes, and symbionts. For humans, numerous species mean many useful organisms (for fungi e.g. Rossman and Miller 1996; Wildman 1997; Pointing and Hyde 2001), ecosystem services (Hawksworth

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1993; Rayner 1995; Gilbert and Hubbell 1996; Watling 1997; Gilbert 2002), and organisms of aesthetic value (Fig. 1; e.g. Kunin and Lawton 1996). Although during the last ten years, the awareness of the importance of fungi with respect to estimated species numbers, ecological importance, and possibilities of being useful to humans has increased (Hawksworth 1997), basic mycological knowledge is still lacking, especially in tropical regions.

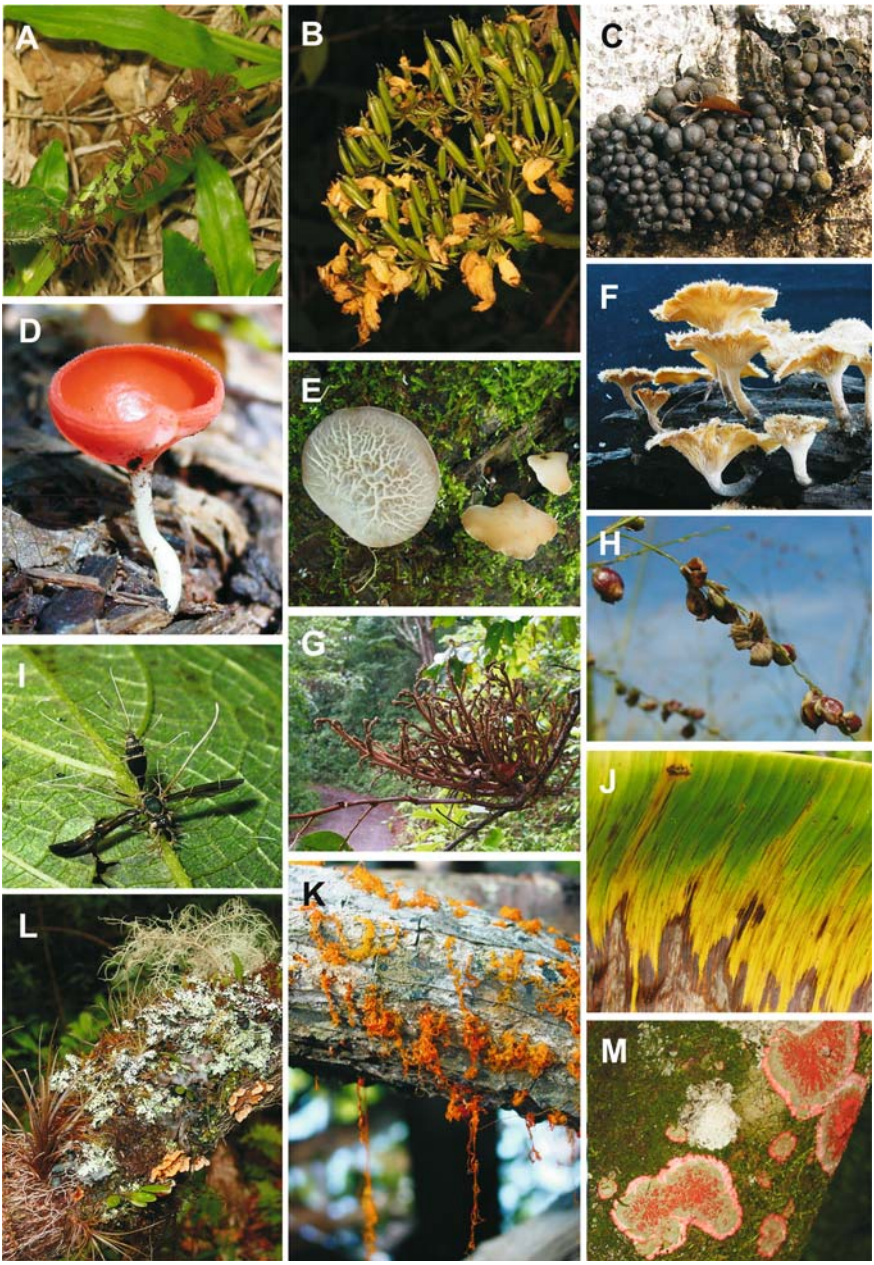
About 80,000 species of fungi are known worldwide, while the most widely accepted number of fungal species existing worldwide is estimated to correspond to about 1.5 million (Hawksworth 2003). A major part of the unknown taxa is supposed to live in tropical regions, where the diversity of fungi is supposed to be higher than in temperate regions because of mostly favourable environmental conditions all over the year, high diversity of vascular plants, and numerous niches and microhabitats in tropical forests (Hyde and Hawksworth 1997; Hawksworth 2001).

The first and up to now unique compilation of information on fungi in a neotropical country including keys and descriptions exists for Venezuela (Dennis 1970). For some other regions of the neotropics, checklists have been published or the authors only cite numbers (Table 1). For the identification of fungi by keys and descriptions, only a few monographs are available for the neotropics, e.g. those of the Flora Neotropica series (comp. http://www.nybg.org/bsci/spub/catl/). Of the 1,807 species and subspecific taxa known for Panama, only about 219 (12%) are recorded for Panama in this series. Apparently, large geographical areas in the neotropics are still unsampled and mycofloras, taxonomic revisions, as well as keys are lacking for many fungal groups and most geographic areas (Nishida 1989).

Bermúdez and Sánchez (2000) describe the state of knowledge of different botanical groups in Central American countries based on the experience of consulted professionals at national herbaria. According to them, in Panama only for the ecoregion including the area of the Panama canal some information exists on fungi and lichens. The level of knowledge in the rest of the country is low with the exception of the mountain forests in Western Panama where some information exists on lichens. According to Hawksworth (1993), checklists or other extensive compilations for Panama exist for plant diseases, scattered, mainly short papers on macromycetes as well as lichens, and nothing at all on micromycetes. In his interesting book on naturalists working in Panama, Heckadon-Moreno (2004) does not consider mycologists at all. As evident by the data now compiled in the checklist of fungi in Panama (Piepenbring 2006), not only the knowledge on Panamanian fungi, but also the knowledge about this knowledge is fragmentary. This is due to the fact that records of Panamanian fungi are scattered widely in publications all around the world.

►

Fig. 1 Fungi in Panama. (**A**) Myxomycetes. *Stemonitis* sp. on the leaf of a grass. (**B**–**D**) Ascomycota. (**B**) *Burenia myrrhidendri* in hypertrophic fruits of *Myrrhidendron donnell-smithii*. This is a new record for Panama. (**C**) *Phylacia sagraeana* (det. M. Stadler). (**D**) *Cookeina speciosa*. (**E**–**H**) Basidiomycota. (**E**) *Auricularia delicata*. (**F**) *Lentinus* sp. (**G**) A witches' broom caused by *Chaconia ingae* on *Inga* sp. (**H**) *Tilletia ayresii* in hypertrophic ovaries of *Panicum maximum*. (**I**–**K**) Anamorphic fungi. (**I**) *Hirsutella saussurei* (det. R. Kirschner) growing out of a killed wasp. (**J**) Lesions caused by *Pseudocercospora fijiensis* on a leaf of *Musa* sp. (**K**) Orange strands of conidia of *Cytospora rhizophorae* (det. R. Kirschner) growing out of a root of *Rhizophora mangle*. This is a new record for Panama. (**L**) Lichens, other fungi, mosses, and vascular plants on a branch from the canopy of an oak cloud forest. (**M**) *Cryptothecia rubrocincta* (lichen), apparently a new record for Panama although common in Chiriquí



The annotated checklist published by Piepenbring (2006) and the present publication are a starting point to become aware of the history of mycology in Panama, the data on fungi which exist for Panama, and the gaps of knowledge.

Table 1 Comparison of species richness of fungi known for different areas of the neotropics

	Approximate numbers of known taxa of fungi	References
Caribbean area	11,268	Minter et al. (2001)
Mexico	6710	Guzmán (1998)
Venezuela	6500 (without lichens)	Iturriaga et al. (2000)
Brazil (Batista)	3340	Da Silva and Minter (1995)
Panama	1807	Present publication
Bolivia	800 (without lichens)	Piepenbring (2004)

Material and methods

In order to find records of fungi in Panama, available databases, monographs, and numerous small publications as well as several colleagues were consulted. Synonyms were identified and related to currently accepted names with the help of recent monographs and the Index Fungorum (CABI-CBS FUNINDEX, http://www.indexfungorum.org). The checklist (Piepenbring 2006) includes for each species its systematic position, name, a note when the species has been described based on type material from Panama, data on the regions of Panama where each species has been collected, ecology, and references with citation of synonyms. The checklist includes only records of fungi cited for Panama in internationally available literature. Further data can be found in local publications and herbaria. Clinical fungi have been excluded because their distribution mainly depends on human activity.

The checklist is published together with data on major collecting activities in Panama, citation of publications on ecology of fungi in Panama, and a selection of colour photos of Panamanian fungi. It is available by the UNACHI and by the author.

Results

History of scientific mycology in Panama

Mycological investigation started relatively late in the area of Panama which was a province of Colombia until 1903. While several European mycologists were active in South America in the 19th century (Iturriaga et al. 2000), for Panama only some records of lichens and a lichenicolous fungus collected by the German botanist B. Seemann in 1847–1851 could be found (Hawksworth 2005 and citations therein). The Swedish microbiologist and mycologist N.G. Lagerheim collected some rusts in 1889–1892, while crossing Panama on the way to Ecuador (for references for this and following data see Piepenbring 2006).

During the second phase of construction of the canal 1907–1914, biologists of the USA became interested in the biota of the Canal Zone. The Swiss phanerogamist H. Pittier was responsible for the documentation of plants of this area (Dwyer 1973). He travelled to interior regions of Panama in 1911, where he worked together with W.R. Maxon, who was responsible for the collection of mosses, cacti, orchids, and bromelias (Heckadon-Moreno 2004). As shown by specimens of Tremellales, now Auriculariales, Maxon collected some fungi as well. A.S. Hitchcock, who participated in this expedition as a specialist for Poaceae, collected a grass with a smut

fungus which was published by G.L. Zundel as a new species. E.P. Killip collected hundreds of plants in 1917–1918, from which parasitic microfungi were published later by mycologists.

By the construction of the Panama canal, Barro Colorado Island (BCI) was created in the Gatun lake. Important contributions to the general knowledge of fungi on BCI were provided by P.C. Standley, W.H. Weston, J. Zetek, C.W. Dodge, and collaborators. F.L. Stevens travelled at least three times to Panama between 1913 and 1927 and published numerous new species of plant parasitic fungi based on the material he collected. G.W. Martin spent large periods of time in Panama collecting fungi belonging to different systematic groups. In 1952/1953 he collaborated with A.L. Welden. K.P. Dumont organized several mycological explorations in different neotropical countries including Panama in 1975 and 1978. In 1996, numerous fungi were collected on Coiba (Veraguas Province), a large island in the pacific ocean, and published by M.P. Núñez, F. Pando, and J. Etayo (1997). Etayo visited Panama again in 1997 and collected lichens in Chiriquí.

In addition to the mycologists cited here, numerous scientists travelled to Panama for short periods of time, collected fungi belonging to selected groups, and published the results in many different journals. Records of fungi in Panama have also been found among citations of specimens examined in some monographs of systematic groups of fungi.

During the last 15 years, studies on different ecological aspects of fungi in Panama have been published (see references in Piepenbring 2006). Due to incomplete to lacking basic data on alpha taxonomy of tropical fungi, limited availability of herbarium specimens, as well as lack of monographs and specialists, many ecologists are not able to apply names to the fungi, so they work without names using morphotypes or sequences (comp. Kursar et al. 1999). Nevertheless, they make valuable contributions to our understanding of the role of fungi in nature and offer important data for adequate management of natural resources.

Numerical analysis of the checklist

Records of fungi in Panama have been found in about 300 publications including books and numerous small publications in scientific journals. In total, these publications include about 3300 records of fungi in Panama. The records correspond to 1807 species and subspecific taxa in 646 different genera. 204 valid species and 17 varieties of fungi (12% of the species and subspecific taxa known for Panama) were described as new based on Panamanian type material. The species richness in different systematic groups of fungi is shown in Table 2.

The most frequently reported species are Myxomycota, with *Arcyria cinerea*, *A. denudata*, *Hemitrichia serpula*, and *Trichia favoginea* being cited for Panama in seven different publications each. They are followed by 15 species, including further Myxomycota, *Cookeina speciosa* (Fig. 1D) and other fungi, cited for Panama in six different publications. About 1050 species and subspecific taxa are mentioned for Panama in only one publication. Most new records of fungi for Panama have been published by F.L. Stevens (143 species) followed by J. Etayo (126 species of lichens), McGuire and Crandall (1967; 112 species of plant parasitic fungi), and Farrow (1954; 107 species of anamorphic fungi from soil).

As heterotrophic organisms, fungi live on different substrates. The numbers presented in Table 3 are tentative because numerous fungi can use different sub-

Table 2 Species richness (species and subspecific taxa) of fungi known for Panama in systematic groups at higher systematic level, in selected orders, and in some non systematic groups, in numbers and percentages. These numbers are compared to the species richness of fungi known worldwide according to Kirk et al. (2001, p 360 and other pages) and other authors. Sums include species in groups not cited here

		Species known in Panama		%	Species worldwide	%
Myxomycetes			108	6.0	798	1.0
Dictyosteliomycetes			1	0.1	46	0.1
Oomycota			18	1.0	808	1.0
Chytridiomycota			6	0.3	914	1.1
Zygomycota (without Glomales)			24	1.3	933	1.2
Glomeromycota (former Glomales)			14	0.8	157	0.2
Ascomycota	SUM		788	43.5	32,739	40.9
Erysiphales		2		0.1	494	0.6
Laboulbeniales		37		2.1	1869	2.3
Helotiales		31		1.7	2022	2.5
Rhytismatales		6		0.3	261	0.3
Meliolales		116		6.4	1583	2.0
Pezizales		21		1.2	1125	1.4
Saccharomycetales		1		0.1	276	0.3
Hypocreales		55		3.1	654	0.8
Phyllachorales		45		2.5	Approx. 1200	1.5
Sordariales		21		1.2	548	0.7
Xylariales		44		2.4	803	1.0
lichenized Ascomycota		325		18.0	Approx. 13,500	16.9
Basidiomycota	SUM		434	24.1	29,914	37.4
Agaricales		75		4.2	9387	11.7
Polyporales		127		7.0	2253	2.8
Dacrymycetales		13		0.7	71	0.1
Auriculariales and Tremellales		31 + 9		2.2	21 + 266	0.4
Uredinales		67		3.7	6929	8.7
Ustilaginales		16		0.9	672	0.8
anamorphic fungi[a] and species incertae sedis			414	22.9	15,945	19.9
SUM			1807	100.0	80,060	

[a]For Panama, species with teleomorph known for Panama have not been counted here. On the world-wide scale, anamorphic fungi are presented with their total number of species which is not included in the sum

strates and for many tropical fungi detailed ecological studies are lacking. The percentage of parasites on plants (37%) is somewhat high in relation to 33%, the estimation of 500,000 species of plant pathogenic fungi of 1.5 million species of fungi existing worldwide (Shivas and Hyde 1997).

Approximately 417 species are published for Panama without specimen data. These records can therefore never be checked. The locality data of the other records are used for an analysis of the state of knowledge of fungi in different parts of Panama (Fig. 2). Most records of species and subspecific taxa of fungi are from Central Panama, followed by Chiriquí and Veraguas. Within these regions, mycological collecting activities concentrated on BCI (Panama Province) and Coiba (Veraguas Province). No species known from Coiba has been recorded for mainland Veraguas yet, where our knowledge is therefore limited to 52 taxa. In Los Santos,

Table 3 Substrats and life forms of fungi known for Panama

Life form	Numbers of taxa	%
Saprobic	673	37
Phagocytotic (Myxomycetes)	109	6
Parasitic	665	37
on plants	561	31
on insects (including associated Laboulbeniales)	56	3
on other animals (nematodes, mites, spiders, frogs)	22	1
on fungi (mycoparasitic, lichenicolous)	27	1
Symbiotic	356	20
with vascular plants, mycorrhizal	20	1
with algae, lichens	329	18
with insects	7	0.4

Tentative numbers (of species and subspecific taxa) and percentages of total number of fungi known for Panama (1807) are presented

Herrera, Eastern and Western Panama on the Caribbean side, almost no mycological investigation has been carried out at all. 1141 (82%) of about 1385 taxa, for which locality data have been found, are reported from a single region. Only *Haematonectria haematococca* and *Tilletia ayresii* (Fig. 1H) are known from the maximum of five regions.

Discussion

General aspects of the checklist

The checklist of fungi in Panama (Piepenbring 2006) is preliminary in several aspects. With more effort looking for records of fungi in Panama in literature, more will be found. Specialists of the different systematic groups will notice numerous errors in most groups of fungi, like wrong identifications, synonyms, and wrong generic placement. A revision of the data, however, is difficult, because often voucher specimens are not available, fragmentary, or not cited at all. This is a general problem of taxonomic revisions of fungi, approximately 25% of the species of fungi recorded worldwide are known from a single, often fragmentary collection with an inadequate description (Cannon and Hawksworth 1995). With these facts in mind, the importance of intensive field work in the tropics as well as the preparation of good herbarium specimens, good descriptions, and informative illustrations seem to be more important than the revision of incomplete data published in the past. In addition to taxonomic problems and errors of identification, many groups of fungi cited in the checklist are in need of a modern systematic revision.

Our knowledge on fungal diversity in Panama can only be well understood by taking in account the historical background. The fragmentary knowledge of fungi in Panama and up to now lacking awareness of the existing data are mainly due to the fact that specialists from developed countries work in Panama during mostly short periods of time and travel to easily accessible areas. They take the specimens to their home countries and publish the results in journals and books often hardly accessible to mycologists in Panama (comp. Dumont et al. 1978; Nishida 1989).

How complete is the list of fungi in Panama?

There is no obvious means to determine how close to completion an inventory is (comp. Gaston 1996). Nevertheless, several observations indicate that the present list of fungi in Panama is very far from complete.

Panama is topographically highly diverse what is usually associated with high species richness (Gaston 1996). By its position as most Southern country on the Central American isthmus, species from Central and South America are present in Panama (e.g. Kursar et al. 1999). An elevated species richness of fungi can therefore be expected, especially when poorly investigated regions of the country (Fig. 2) are included in the investigation.

By assuming that the relative species richness of large systematic groups is somewhat similar worldwide, the relative species richness observed for a particular region, in this case Panama, may help to estimate how much effort has been realized to document the mycota (comp. Piepenbring 2004). This is suggested because new records can usually only be published in considerable number by a specialist of a certain systematic group. At the beginning of a mycological exploration, some systematic groups of fungi will therefore be overrepresented while others are neglected. With more different specialists working more time on the fungi of a given region, the relative species richness of different systematic groups will approach those observed worldwide, until differences in relative species richness, which certainly exist for different regions but which we mostly ignore up to now, will become evident.

In the case of Panama, the relative species richness of large groups, like Ascomycota, lichens, and anamorphic fungi, is close to the one observed worldwide (Table 2). Lichens are indeed supposed to be relatively well known (Sipman and Aptroot 2001), with new species only expected in tropical forests. Myxomycota and Glomeromycota are overrepresented in the checklist for Panama while Basidiomycota have been somewhat, Chytridiomycota almost completely neglected. Within the Basidiomycota especially Uredinales and Agaricales are poorly known, the latter being particularly difficult to identify in tropical regions due to the lack of monographs and taxonomic revisions for this group. Other Basidiomycota, like

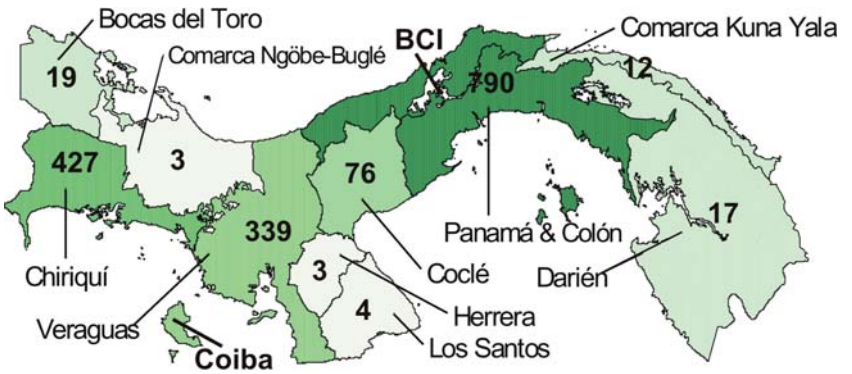


Fig. 2 Approximate numbers of species and subspecific taxa of fungi known from different regions in Panama. The provinces Panamá and Colón as well as the Canal Zone are designated as one area, called Central Panama, because the Canal Zone does not exist any more and it is difficult to interpret data concerning localities in this area. Written in bold: Islands from where numerous fungi have been reported, 450 for Barro Colorado Island (BCI; Panama province) and 287 for Coiba (Veraguas). Diagram elaborated with the help of J. Torres

Polyporales, Dacrymycetales, Auriculariales, and Tremellales received more attention. Within the Ascomycota, Meliolales, Phyllachorales, and Xylariales present high values of relative species richness for Panama probably due to the fact that they are more diverse in the tropics than in other parts of the world (see different contributions in Hyde 1997), with the reverse being observed for members of Erysiphales. Values of Saccharomycetales and Helotiales are low probably because these groups have been neglected, while the relative species richness of Hypocreales is high because this group has been intensively studied. It might also be more diverse in the tropics. The relative importance of these two explanatory aspects—intensity of study and elevated relative species richness in the tropics—is difficult to assess.

With respect to vascular plants, the area of Panama corresponds to a diversity hot spot (Barthlott et al. 1996). Hawksworth (1998) suggests, that the number of plant species can be multiplied by 5.3 for an estimate of the number of fungal species. In a recent checklist, Correa et al. (2004) cite approximately 9,500 species of vascular plants known in Panama. Therefore, about 50,350 species of fungi might be present in Panama. According to this estimate, only about 3.6% of the fungi existing in Panama are included in the checklist of fungi. Interestingly, this number is almost similar to the one cited for Mexico (3.5%) by Guzmán (1998). These estimates, however, are tentative, because our knowledge on patterns of diversity of tropical fungi is very limited.

By field work carried out for the collection of smut fungi, 14 of 26 species (54%) now known for Panama were new records (Piepenbring 2001). Although 116 species and varieties of Meliolales are already known for Panama, 16 of 24 recently collected species of Meliolales (67%) are new for Panama (Rodríguez Justavino and Piepenbring 2004). The easiness of making new records of fungi for Panama is also evident by the new records included in Fig. 1B, K, M. Among the recently collected species of Meliolales, there are at least two new species (Rodríguez Justavino and Piepenbring in preparation). It is relatively easy to find new records and new species of rust fungi in Panama as well (Piepenbring 2005; Hernández et al. in preparation). These recent results can be correlated with the high number of new species and varieties described from Panama in the past.

These observations indicate that the fungi cited in the checklist of Panama correspond only to a small fraction of the fungi existing in this country. Our knowledge of the fungi in Panama is still in the ''pioneer phase'', as it was noticed for tropical mycobiota in general by Hawksworth (1993). In comparison with other countries (Table 1), however, the situation in Panama is not exceptional. It might even be considered relatively good, because for many countries in the world, a checklist of fungi has not yet been published at all. For countries without checklists, myriads of scattered records of fungi accumulate over centuries making taxonomic research extremely tedious. Although the elaboration and publication of checklists requires considerable effort and courage, because checklists are never complete and generally include many errors, checklists are, together with monographs, crucial bases to facilitate efficient research. Hopefully, the present study challenges and inspires colleagues and students to contribute to the improvement of the checklist of fungi in Panama and to elaborate checklists of fungi for other countries.

Outlook

The preliminary checklist of fungi in Panama is useful for a wide range of activities (comp. Stork and Samways 1995). The data provide a first overview on the known

diversity of fungi in Panama, access to data published scattered in numerous small publications and books, a basis for ongoing and future taxonomic research on fungi in Panama, and references to literature containing tools for identification. The checklist can contribute to an analysis of the distribution of fungi in the neotropics and worldwide. It helps to identify beneficial and harmful species from the human point of view and to discover the origins of agricultural pests and diseases. It is useful for training students of mycology, the organization of a herbarium collection of fungi, and contributes to general public education by facilitating publications for a wider audience.

A more complete checklist will include data which provide information necessary for sustainable management of natural resources, like data on local diversity hotspots, endemisms, and other patterns of diversity and allows observations of changes of diversity over time and the identification of recently introduced fungi.

In order to promote knowledge on fungi in Panama, we have to promote teaching of mycology in this country, including ecological, morphological, systematical, physiological and molecular aspects. Within the National Herbarium PMA, we need a national fungal collection managed by professional mycologists. The herbarium plays a key function for the documentation of a nation's fungal biota making it available for taxonomic and systematic analyses as well as for bioprospecting (Hawksworth 2003). Especially for microfungi, which present many options for use by human beings, a genetic resource collection of living cultures (culture collection) is important, because the reisolation of a microfungus from nature can be very difficult (Hyde and Hawksworth 1997; Hawksworth 2004).

Progress of mycology in Panama should not only include new records and new species, but also ecological data based on long-term observations, discovery of interactions of fungi with other organisms, development of populations etc. These efforts will contribute to a better understanding of the ecology of fungi in tropical ecosystems, to a higher esteem for the high diversity of organisms, and might promote efforts to protect the habitats.

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