Aphyllophorales: Indicators of nature value and habitat formers

Ewald Langer

Abstract: Aphyllophorales comprise macrofungi with exposed hymenium and no gills. Although revealed to be an unnatural order of Basidiomycota, Aphyllophorales are still used to structure taxonomic treatises and diagnostic keys. Molecular methods detected Aphyllophorales in all main orders of Hymenomycetidae. Fungi with nature value often used to characterise naturalness of forest ecosystems comprise two thirds of the Aphyllophorales. The UNESCO World Natural Heritage National Park Kellerwald-Edersee in Germany was used to depict important Aphyllophorales as indicator species. Old tree stands and relict primeval forest fragments endow the National Park Kellerwald-Edersee with a high number of severely threatened and rare species of Aphyllophorales important for the creation of habitats inhabited by threatened animals.

1. Introduction

Rea introduced Aphyllophorales in 1922 as non-gilled Basidiomycota exposing their hymenium on pores, teeth, anastomosing lamellae or smooth surfaces. This concept, depending on the outer morphology of the basidiocarp was entirely contested by Donk (1964) by discussing and comparing the microanatomy of different genera, e.g. basidia, cystidia, hyphal systems and spore ornamentations. The most prominent example in his "Conspectus of the families of Aphyllophorales" (Donk 1964) is the description of common characteristics in genera by then not discussed as related, such as *Auriscalpium* Gray (toothed hymenium), *Lentinellus* P. Karst. (gilled), *Clavicorona* Doty (coralloid), *Hericium* Pers. (hydnoid) and *Gloiodon* P. Karst. (smooth), all sharing gloeocystidial hyphal systems and amyloid, ornamented spores like in the gilled mushrooms in *Russula* Pers. Consequently Oberwinkler (1977) and later refined (Oberwinkler 2012) presented five orders of "Aphyllophorales" with related genera comprising resupinate, console-like, stalked and stalked-pileate basidiocarps each. Polyporales, Boletales and Russulales even with relatives having agaricoid and gasteroid basidiocarps. One of the first applying molecular phylogenetic inference on a wide scope was Hibbett et al. (1997). Although testing the phylogenetic position of different gasteromycetes they confirmed the concept of Donk and Oberwinkler grouping genera with different basidiocarp morphology in "clades", e.g. a russuloid clade with *Bondarzewia* Singer (poroid), *Lentinellus* (gilled), *Clavicorona* (coralloid), *Auriscalpium* (toothed), *Russula* (gilled) and many more. Other Aphyllophorales detected to be related with the gasteromycetes *Sphaerobolus* and *Geastrum* Pers. were the clavarioid *Gomphus* Pers., *Clavariadelphus* Donk and *Ramaria* Holmsk. Later on molecular phylogenetic inferences included more and more species, coding and non-coding DNA-regions like in that of Binder

et al. (2005). Instead of using nomenclatoric terms, Binder et al. (2005) used terms like Polyporoid clade, Russuloid clade, Euagarics clade, Bolete clade, Hymenochaetoid clade and Cantharelloid clade to circumscribe entities with different basidiocarps but common operational taxonomic units in means of computational statistics as used in computer programs like PAUP (Swofford 2003), MrBayes (Ronquist & Huelsenbeck 2003), RAxML (Stamatakis 2006) and MrModeltest (Nylander 2004). Further on systematic studies concentrated on the extensive inference of many representatives of one group as outlined by Binder et al. (2005) leading to splitting of well known genera like *Hyphodontia* J. Erikss. monographed by Langer (1994) into paraphyletic clades within the Hymenochaetoid clade (Larsson et al. 2006) thus ending with the revival of old genus names like *Lagarobasidium* Jül., *Lyomyces* P. Karst., *Kneiffiella* P. Karst., *Schizopora* Velen. and *Xylodon* (Pers.) Gray for the new entities (Hjortstam & Ryvarden 2009). Larsson (2007) even resolved the unnatural family of Corticiaceae with resupinate basidiocarps relating many genera to new families and leaving a Corticiaceae core clade with a few genera like *Vuilleminia* Maire, *Erythricium* J. Erikss. & Hjortstam, *Laetisaria* Burds. and *Punctularia* Pat.

Although new insights from molecular inference complicated the view of Aphyllophorales for the interested naturalist, they traditionally still use this term when doing intensive surveys (e.g. Nationalpark Hainich 2010). The term Aphyllophorales is even used in the red lists of Germany (e.g. Benkert et al. 1996, Langer 2000). Within Aphyllophorales there are important wood-decomposers such as Polypores, corticioid and coralloid species. Blaschke et al. (2009) screened the opinion of German naturalists on species with nature value resulting in a list comprising over two thirds Aphyllophorales as important indicators for well developed coarse woody debris (CWD) and natural forest ecosystems. Christensen et al. (2004) proposed a list of 21 indicator species based on surveys of nearly natural forest ecosystems in Europe thereof 14 species are Aphyllophorales. Ódor et al. (2006) ranked the species found in semi-natural beech forests in Europe according IUCN Red List categories and criteria (IUCN 2012) providing a structured and sound evaluation tool for forest ecosystems. Consequently Langer et al. (2014, 2015) compared the fungal inventories of German beech forest reserves and national parks with species lists of near natural and primeval beech forests in the western Carpathians (Kuthan et al. 1999).

2. Materials and methods

Different species lists of nature reserves and national parks have been screened: National Park Hainich, Germany (Nationalpark Hainich 2010), National Park Kellerwald-Edersee, Germany (Mayr 1991, Langer & Bernauer 2009, Langer & Langer 2013), National Park Poloniny, Slovakia (Kuthan

et al. 1999, Adamçik et al. 2003, 2007, Holec 2008, 2013). Species ranking used categories introduced by Ódor et al. (2006) for species of interest (SSI) in dependence on the IUCN code:

SSI(A) = class A (IUCN ‘‘Endangered’’ to ‘‘Critically Endangered’’); widespread species regarded as very rare and severely threatened.

SSI(B) = class B (IUCN ‘‘Near Threatened’’ to ‘‘Vulnerable’’); widespread species regarded as rare all over Europe, and threatened in several countries.

SSI(C) = class C (IUCN ‘‘Vulnerable’’ to ‘‘Critically Endangered’’); threatened in one or several of the covered European countries/regions, but being frequent in others.

Indicator species of nature value follow Christensen et al. (2004) on European scale (I++) and Blaschke et al. (2009) on German scale (I+). Threat categories of fungi in red lists follow Benkert et al. (1996) for Germany (RL Ge) and Langer (2000) for Hesse (RL He) respectively. Red list categories are 1 = critically endangered, 2 = very endangered, 3 = endangered.

3. Results: Important indicator species of Aphyllophorales

The following list of Aphyllophorales is compiled from Langer et al. (2014, 2015) specifying important indicator species found in the National Park Kellerwald-Edersee.

SSI(A)

Spongipellis pachyodon (Pers.) Kotl. & Pouzar

Xylobolus frustulatus (Pers.: Fr.) Boidin, I+, RL Ge 2, RL He 1

SSI(B)

Hericium coralloides (Scop.: Fr.) Gray, I++, I+, RL Ge 2, RL He 2

Inonotus cuticularis (Bull.: Fr.) P. Karst., I++, I+, RL He 2

Ischnoderma resinosum (Fr.) P. Karst., I++, I+

Kavinia himantia (Schwein.: Fr.) J. Erikss., I+

SSI(C)

Gloeophyllum sepiarium (Wulfen: Fr.) P. Karst.

Inonotus nodulosus (Fr.) P. Karst.

Lenzites betulina (L.: Fr.) Fr.

Meripilus giganteus (Pers.: Fr.) P. Karst.

Polyporus badius (Pers.) Schwein. = *Royoporus badius* (Pers.) A.B. De, I+

Pycnoporus cinnabarinus (Jacq.: Fr.) P. Karst.

Species not assigned with IUCN criteria but nature valuable according to Blaschke et al. (2009) and Christensen et al. (2004)

Botryobasidium aureum Parmasto

Fomes fomentarius (L.) Fr.

Hapalopilus croceus (Fr.) Donk = *Aurantioporus croceus* (Pers.: Fr.) Murrill, RL Ge 1, RL He 1

Mycoacia nothofagi (G. Cunn.) Ryvarden, I++, I+

Phellinus pini (Brot.: Fr.) A. Ames = *Porodaedalea pini* (Brot.) Murrill, RL Ge 3

4. Discussion on ecological implications

Applying the highest IUCN criteria (SSI A) two species of special interest *Spongipellis pachyodon* (poroid) and *Xylobolus frustulatus* (corticioid, Fig. 1A) are indicators in near natural beech forests with a high amount of CWD and old tree stands. *Xylobolus frustulatus* is a very important creator of big cavities and humus soil within old oak trees (Fig. 1B) leading to habitats of endangered bats (Celuch & Kropil 2008) and wood beetles (Müller et al. 2008, Nilsson & Baranowski 1997).

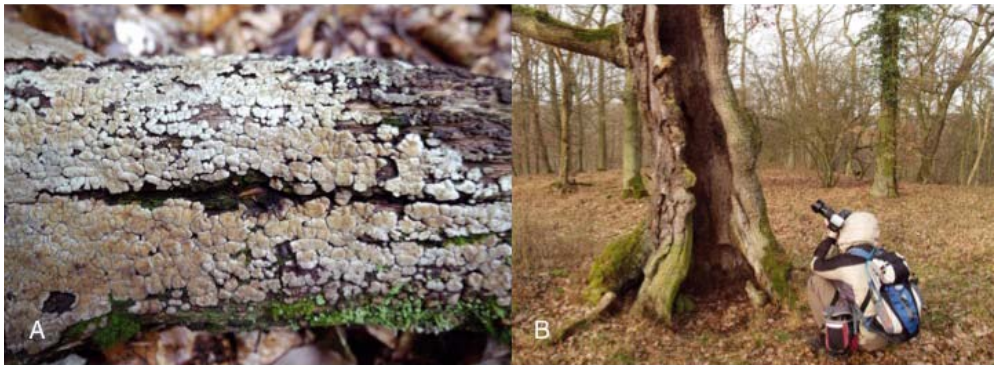

Fig. 1: Fresh basidiocarp of *Xylobolus frustulatus* on oak (A). Big cavity in an oak tree caused by *Xylobolus frustulatus* (B).

From the SSI B species *Ischnoderma resinosum* (poroid, Fig. 2A), *Kavinia himantia* (hydnoid, Fig. 2B) and *Hericium coralloides* (hydnoid, Fig. 2C), are known to be dependent not only on a high volume of CWD but also on its quality in means of a long and undisturbed forest tradition (Standovár & Kenderes 2003). *Hericium coralloides* and *K. himantia* are white-rotters and very important precursors of habitats for small animals such as spiders (Hsieh &

Linsenmair 2011) or gastropods (Kappes 2005). The top listed indicator species are always together and associated with very endangered animal species like the xylotrophic violet click-beetle *Limoniscus violaceus* Müller, the hermit beetle *Osmoderma eremita* Scopoli or the Bechstein's Bat *Myotis bechsteinii* Kuhl as present in the National Park Kellerwald-Edersee (Hessen Forst 2012).

Fig. 2: Fresh basidiocarps of *Ischnoderma resinosum* (A), *Kavinia himantia* (B), *Hericium coralloides* (C) and *Fomes fomentarius* (D).

SSI (C) species which are frequent all over Europe but endangered in one or several countries can be found also in managed forests if an appropriate amount of CWD is available (Schmidt et al. 2012, Schulze et al. 2014).

Although not listed under IUCN criteria and frequent in beech forests all over Europe, *Fomes fomentarius* (Fig. 2D) is one of the Aphyllophorales estimated as nature value indicator if a high abundance is given (Blaschke et al. 2009). The white-rotting activity of *F. fomentarius* is a prerequisite for the successful colonisation of different wood-pecker species in beech forests (Berger & Ehrendorfer 2011, Gorman 2004).

Hapalopilus croceus redlisted with category "critically endangered" in the federal states of Brandenburg, Lower Saxony, Saxony-Anhalt and Schleswig-Holstein and also on the German red list (Benkert et al. 1996) is a good ex-

ample for a high incongruence of our distribution knowledge on this particular species. *Botryobasidium aureum* and *Mycoacia nothofagi* are important nature value indicators from the corticioid group of Aphyllophorales (Blaschke et al. 2009, Christensen et al. 2004) living on highly degraded wood as final decomposers. Fungi with corticioid basidiocarps are often insufficently investigated in surveys due to lacking knowledge on this special group. Also knowledge on their special ecology or function as predecessor species for following organisms is poorly understood. First insights into their importance have been published by Lilleskov & Bruns (2005) identifying a food web from small soil arthropods to birds involved in spore dispersal.

Although systematics and taxonomy is more and more improved by application of molecular tools, our knowledge on the ecology and function of fungi within the forest ecosystem is still unsatisfactory. Therefore more studies in cooperation with forest zoologists, including long term inventories, have to be carried out to get a more complete understanding of the ecology in fungus-animal relationships.

5. Acknowledgements

Financial support from the administration of the Kellerwald-Edersee National Park during the mycological inventory is highly acknowledged. The "Landes-Offensive zur Entwicklung Wissenschaftlich-ökonomischer Exzellenz" of Hesse's Ministry of Higher Education, Research, and the Arts is gratefully acknowledged for funding in the framework of the IPF excellence cluster for Integrative Fungal Research.

6. References

Adamčik, S., Christensen, M., Heilmann-Clausen, J. & Walleyn, R. 2007: Fungal diversity in the Poloniny National Park with emphasis on indicator species of conservation value of beech forests in Europe. — Czech Mycol. **59**: 67–81.

Adamčik, S., Kučera, V., Lizoň, P., Ripka, J. & Ripkov, S. 2003: State of diversity research on macrofungi in Slovakia. — Czech Mycol. **55**: 201–213.

Benkert, D., Dörfelt, H., Hardtke, H.J., Hirsch, G., Kreisel, H., Krieglsteiner, G.J., Lüderitz, M., Runge, A,. Schmid, H., Schmitt, J.A., Winterhoff, W., Wöldecke, K. & Zehfuss, H.D. 1996: Rote Liste der Großpilze Deutschlands. — In Ludwig, G. & Schnittler, M. (eds.): Rote Liste der Pflanzen Deutschlands. Schriftenreihe für Vegetationskunde **28**: 377–426. — Bundesamt für Naturschutz., Bonn-Bad Godesberg.

Berger, R. & Ehrendorfer, F. 2011: Ökosystem Wien. Die Naturgeschichte einer Stadt. Bd. 2. — Wien: Böhlau.

Binder, M., Hibbett, D.S., Larsson, K-H., Larsson, E., Langer, E. & Langer, G. 2005: The phylogenetic distribution of resupinate forms across the major clades of mushroom-forming fungi (Homobasidiomycetes). — Syst. Biodivers. **3** (2): 113–157.

Blaschke, M., Helfer, W., Ostrow, H., Hahn, C., Loy, H., Bussler, H. & Krieglsteiner, L. 2009: Naturnähezeiger – Holz bewohnende Pilze als Indikatoren für Strukturqualität. — Natur u. Landschaft **84**: 560–566.

Celuch, M. & Kropil, R. 2008: Bats in a Carpathian beech-oak forest (Central Europe): habitat use, foraging assemblages and activity patterns. — Folia Zool. **57**: 358–372.

Christensen, M., Heilmann-Claussen, J., Walleyn, R. & Adamčik, S. 2004: Wood-inhabiting fungi as indicators of nature value in European beech forests. Monitoring and Indicators of Forest Biodiversity in Europe – From Ideas to Operationality. — EFI Proceedings No. 51.

Donk, M.A. 1964: A conspectus of the families of Aphyllophorales. — Persoonia **3**: 199–324.

Gorman, G. 2004: Woodpeckers of Europe. A study of the European Picidae, pp. 128–143. — Middlesex: Bruce Coleman.

Hessen Forst 2012: 3. Hessisches Naturwaldforum Buche, 68 pp. — Kassel: Landesbetrieb Hessen-Forst, Bertha-von-Suttner Str. 3, 34131.

Hibbett, D.S., Pine, E.M., Langer, E., Langer, G. & Donoghue, M.J. 1997: Evolution of gilled mushrooms and puffballs inferred from ribosomal DNA sequences. — Proc. Nat. Acad. Sci. USA **94**: 12002–12006.

Hjortstam, K. & Ryvarden, L. 2009: A checklist of names in *Hyphodontia* sensu stricto - sensu lato and *Schizopora* with new combinations in *Lagarobasidium, Lyomyces, Kneiffiella, Schizopora,* and *Xylodon*. — Syn. Fungorum **26**: 33–55.

Holec, J. 2008: Interesting macrofungi from the Eastern Carpathians, Ukraine and their value as bioindicators of primeval and near-natural forests. — Mycol. Balc. **5**: 55–67.

Holec, J. 2013: Fungi of the Carpathians-contributions of Czech mycologists with emphasis on newly described taxa. — Acta Biol. Crac. Ser. Bot. **55 (**suppl. 1): 45.

Hsieh, Y.L. & Linsenmair, K.E. 2011: Underestimated spider diversity in a temperate beech forest. — Biodivers. Conserv. **20**: 2953–2965.

IUCN 2012: IUCN Red List categories and criteria. Version 3.1. Second edition. — Switzerland and Cambridge: Gland.

Kappes, H. 2005: Influence of coarse woody debris on the gastropod community of a managed calcareous beech forest in western Europe. — J. Molluscan Stud. **71**: 85–91.

Kuthan, J., Adamčik, S., Terray, J. & Antonín, V. 1999: Huby národného parku Poloniny [Fungi of the national park Poloniny]. — Snina: Liptovský Mikuláš.

Langer, E. 1994: Die Gattung *Hyphodontia* John Eriksson. — Biblioth. Mycol. **154**: 1–298. — Dissertation Universität Tübingen.

Langer, E. 2000: Rote Liste der Großpilze Hessens. — Wiesbaden: Hessisches Ministerium für Umwelt, Landwirtschaft und Forsten.

Langer, E. & Bernauer, T. 2009: Fundbericht von der Tagung der DGfM an der Universität Kassel vom 2.10. –9.10.2008. — DGfM-Mitt. **19**: 15–24.

Langer, E. & Langer, G. 2013: Pilze im Nationalpark Kellerwald-Edersee. — AFZ – Der Wald **2013**(1): 21–23.

Langer, E., Langer, G., Striegel, M., Riebesehl, J. & Ordynets, A. 2014: Fungal diversity of the Kellerwald-Edersee National Park - indicator species of nature value and conservation. — Nova Hedwigia **99**: 129–144.

Langer, E., Langer, G., Popa, F., Rexer, K.-H., Striegel, M., Ordynets, A., Lysenko, L., Palme, S., Riebesehl, J. & Kost, G. 2015: Naturalness of selected European beech forests reflected by fungal inventories – A first check-list of fungi of the UNESCO World Natural Heritage National Park Kellerwald-Edersee in Germany. — Mycol. Prog. **14**: 102. (doi: 10.1007/s11557-015-1127-y)

Larsson, K.-H., Parmasto, E., Fischer, M., Langer, E., Nakasone, K.K. & Redhead, S.A. 2006: Hymenochaetales: a molecular phylogeny for the hymenochaetoid clade. — Mycologia 98: 926–936.

Larsson, K-H. 2007: Re-thinking the classification of corticioid fungi. — Mycol. Res. **111**: 1040–1063.

Lilleskov, E.A. & Bruns, T.D. 2005: Spore dispersal of a resupinate ectomycorrhizal fungus, *Tomentella sublilacina*, via soil food webs. — Mycologia **97**: 762 –769.

Mayr, R. 1991: Gutachten über die Großpilze des Waldschutzgebietes Kellerwald-Edersee. — Kassel: Regierungspräsidium Kassel.

Müller, J., Bussler, H. & Kneip, T. 2008: Saproxylic beetle assemblages related to silvicultural management intensity and stand structures in a beech forest in Southern Germany. — J. Insect Cons. **12**: 107 –124.

Nationalpark Hainich 2010: Artenbericht 2010. Tiere, Pflanzen und Pilze im Nationalpark Hainich. — Bad Langensalza: Nationalpark Hainich.

Nilsson, S.G. & Baranowski, R. 1997: Habitat predictability and the occurrence of wood beetles in old-growth beech forests. — Ecography **20**: 491–498.

Nylander J.A. 2004. MrModeltest. Version 2.2, Program distributed by the author. — Uppsala University: Evolutionary Biology Centre.

Oberwinkler, F. 1977: Das neue System der Basidiomyceten. — In Frey, W., Hurka, H. & Oberwinkler, F. (eds.): Beiträge zur Biologie der Niederen Pflanzen, pp. 59–105. — Stuttgart, New York: G. Fischer.

Oberwinkler, F. 2012: Evolutionary trends in Basidiomycota. — Stapfia **96**: 45–104.

Ódor, P., Heilmann-Claussen, J., Christensen, M., Aude, E., Van Dort, K.W., Piltaver, A., Siller, I., Veerkamp, M.T., Walleyn, R., Standovár, T., Van Hees, A.F.M., Kosec, J., Matočec, N., Kraigher, H. & Grebenc, T. 2006: Diversity of dead wood inhabiting fungal and bryophyte assemblages in semi-natural beech forests in Europe. — Biological Conserv. **131**: 58 –71.

Rea, C. 1922: British Basidiomycetaceae. A handbook of the larger British fungi. — Cambridge: Cambridge University Press.

Ronquist, F. & Huelsenbeck, J.P. 2003: MrBayes 3: Bayesian phylogenetic inference under mixed models. — Bioinformatics **19**: 1572–1574.

Schmidt, M., Meyer, P. & Langer, E. 2012: Holzbewohnende Pilze als Naturnähezeiger in Hessischen Wäldern. — AFZ-Der Wald **6**: 19–21.

Schulze, E.D., Bouriaud, L., Bussler, H., Gossner, M., Walentowski, H., Hessenmöller, D., Bouriaud, O. & Gadow, K.V. 2014: Opinion Paper: Forest management and biodiversity. — Web Ecology **14**: 3–10.

Stamatakis, A. 2006: RAxML-VI-HPC: maximum likelihood-based phylogenetic analyses with thousands of taxa and mixed models. — Bioinformatics **22**: 2688–2690.

Standovár, T. & Kenderes, K. 2003: A review on natural stand dynamics in beech woods of East Central Europe. — App. Ecol. Environ. Res. **1**: 19–46.

Swofford, D.L. 2003: PAUP*: Phylogenetic Analysis Using Parsimony (*and other methods). Version 4.0b510. — Sunderland, Massachusetts: Sinauer Associates.

Address of the author:

Prof. Dr. Ewald Langer
Universität Kassel, Fachbereich Naturwissenschaften Ökologie
Heinrich-Plett-Straße 40, D-34132 Kassel
Email: ewald.langer@uni-kassel.de