available at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/funeco

Biogeography of aquatic hyphomycetes: Current knowledge and future perspectives

Sofia DUARTE[a,*], Felix BÄRLOCHER[b], Cláudia PASCOAL[a], Fernanda CÁSSIO[a]

[a]Centre of Molecular and Environmental Biology (CBMA), Department of Biology, University of Minho Campus de Gualtar, 4710-057 Braga, Portugal

[b]Department of Biology, Mount Allison University, Sackville, New Brunswick E4L 1G7, Canada

ARTICLE INFO

Article history:
Received 2 March 2015
Revision received 26 May 2015
Accepted 5 June 2015
Available online 1 August 2015
Corresponding editor:
Lynne Boddy

Keywords:
Aquatic hyphomycetes
Biogeography
Phylogeography
Metagenomics
Morphospecies
Genetic diversity
Next-generation sequencing

ABSTRACT

Since Ingold's (1942) initial description, mycologists have been interested in deciphering global distribution patterns of aquatic hyphomycetes, a group of fungi that play a key role in plant-litter decomposition in freshwaters. However, many questions remain largely unanswered. In this review, we used distribution data of morphospecies from studies throughout the world in an attempt to better understand the magnitude of global species richness, patterns of biodiversity and the extent of cosmopolitanism *versus* endemism. Sampling efforts have varied among geographic regions, and correlate significantly with species richness. Community similarity decreased with geographic or latitudinal distance. Species richness was highest at mid-latitudes (temperate streams), and high community similarities were found between geographically distant locations in similar climatic zones. Studies relying on morphotypes have undoubtedly provided relevant information on the geographic distribution of aquatic hyphomycetes. However, metagenomic approaches combining taxonomic, phylogenetic and functional diversity in coordinated surveys will be the best option to better decipher diversity patterns of these fungi and their functional roles at a global scale.

Introduction

Fungi are widely distributed across all biomes and play a major role in the recycling of organic matter with more than 600 species reported from freshwaters (Wong et al., 1998; Shearer et al., 2007). Ingoldian fungi or aquatic hyphomycetes abound in well-aerated waters and are regarded as the dominant microbial decomposers of leaves decaying in streams (Bärlocher, 2016). Members of this ecologically defined group regularly sporulate under water, and have large conidia (often spanning more than 50 μm) of two predominant shapes: branched and often tetraradiate or multiradiate (stauroid), and sigmoid or worm-like (scolecoid) (Gulis et al., 2005; Shearer et al., 2007) (Fig. 1). Much of our knowledge on aquatic hyphomycete diversity in freshwaters emerges from species classification based on their characteristic conidial shapes. Though slightly heavier than water, conidia are readily trapped in foam or scum, which accumulates in streams (Ingold, 1975). Conidia can also be sampled from the water column by filtration or from naturally colonized submerged substrata

* Corresponding author.
E-mail address: sduarte@bio.uminho.pt (S. Duarte).
http://dx.doi.org/10.1016/j.funeco.2015.06.002

(e.g. leaves, twigs) and substrate baits after inducing sporulation in the laboratory (Gulis et al., 2005).

De Wildeman (1893, 1894, 1895) was the first to recognize some of the typical conidial forms of aquatic hyphomycetes and described species of several genera (*Clavariopsis*, *Lemonniera* and *Tetracladium*) (Fig. 1). However, these fungi only gained relevance nearly half a century later when Ingold (1942) described 16 forms of conidia and traced them back to mycelia on decaying alder leaves in a stream near Leicester, in England. In the first of many papers devoted to aquatic hyphomycetes, Ingold (1942) wrote: "My observations on aquatic hyphomycetes have been limited, so far, to the immediate neighbourhood of Cropston in Leicestershire, but it is of interest to know if they are of wide occurrence". In subsequent years, he found identical or similar spores in samples from many regions in Britain (Ingold, 1943a,b), and other parts of the world, including Europe (e.g. Switzerland: Ingold, 1949), Africa (Nigeria: Ingold, 1956, 1959; Uganda and Zimbabwe: Ingold, 1958; Swaziland: Ingold, 1973), North America (Canada: Ingold, 1960) and Caribbean Islands (e.g. Jamaica: Hudson and Ingold, 1960), thus demonstrating the world-wide occurrence of aquatic hyphomycetes. Studies by other researchers confirmed their global distribution (e.g. California: Ranzoni, 1953; Japan: Tubaki, 1957; eastern USA: Petersen 1962, 1963a,b; Scandinavia: Nilsson, 1958, 1964; South Africa: Greathead, 1961; Australia: Cowling and Waid, 1963; Cuba: Marvanová

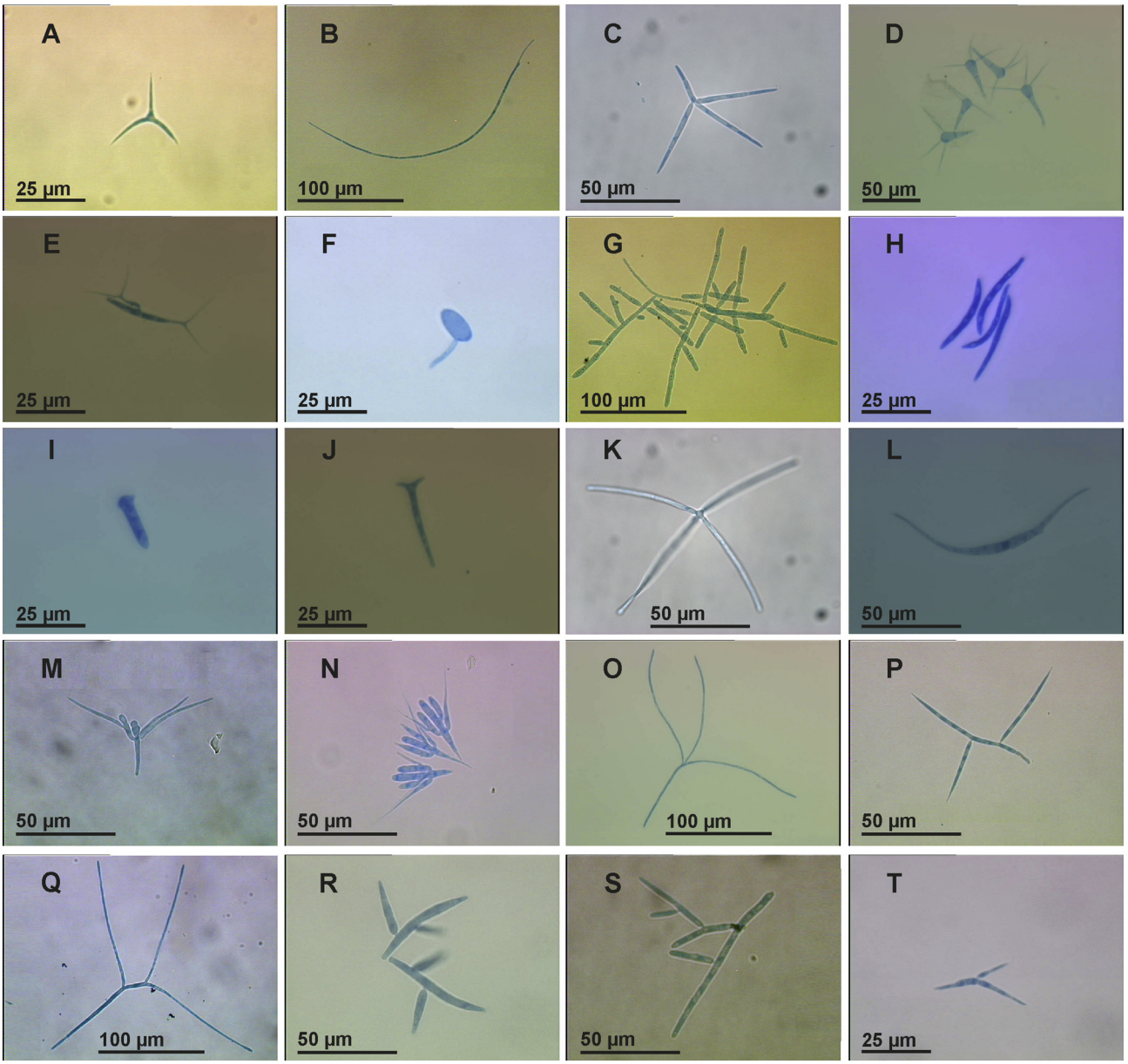

Fig. 1 – Conidia of aquatic hyphomycetes. A, *Alatospora acuminata*; B, *Anguillospora filiformis*; C, *Articulospora tetracladia*; D, *Clavariopsis aquatica*; E, *Collembolispora barbata*; F, *Dimorphospora foliicola*; G, *Dendrospora erecta*; H, *Flagellospora penicillioides*; I, *Heliscus lugdunensis*; J, *Heliscus submersus*; K, *Lemonniera aquatica*; L, *Lunulospora curvula*; M, *Tetracladium marchalianum*; N, *Tetracladium setigerum*; O, *Tetrachaetum elegans*; P, *Tricladium attenuatum*; Q, *Tricladium chaetocladium*; R, *Tricladium splendens*; S, *Varicosporium elodeae*; and T, *Ypsilina graminea*.