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Editorial

Fungi and the Anthropocene: Biodiversity discovery in an epoch of loss

"Let me tell you how little we know of this planet on which we live. Fungi, including rusts, molds, lichen symbionts, microscopic fungi… estimated number of species known to science: 60,000. Number of species estimated by experts to actually exist: 1,500,000. To students here gathered who are thinking about a career in biology… I recommend mycology. Think of becoming a mycologist. If you went into that field you would be dealing with organisms absolutely fundamental to the maintenance of ecosystems ….At the end of the day, whether we pay attention to the rest of life, [the unknown] and endangered parts of it, is going to be an ethical decision… As the late John Sawhill said, 'A society is defined not just by what it builds, but by what it refuses to destroy'."

- E.O. Wilson, transcribed and redacted from his John M. Prather Lecture in Biology "Biodiversity and the Future of Biology", given April 5, 2010, at Harvard University (www.hmnh.harvard.edu/lectures-classes-events/2010-prather-lecture-series.html)

Mycologists are living through a golden age of natural history. The advent of molecular tools, including PCR, Sanger sequencing, and next-generation technologies, is providing unprecedented access to a biodiversity that was likely imagined but scarcely described by early mycologists. Discoveries of new species are routine and accelerating (Fig 1), and species known only from DNA sequence data are likely to be accepted as valid taxonomic entities in the very near future (Hibbett 2010). But habitat loss, pollution and climate change challenge us to engage in the work of scientific discovery during a time of great uncertainty.

The word Anthropocene is increasingly used to describe this current geological epoch, and its derivation is based on the manifold impacts of humans on the planet (Crutzen & Stoermer 2000). The Anthropocene may be defined to start at about the time James Watt invented the steam engine (Crutzen & Stoermer 2000), although others have proposed alternative start dates, including dates tied to the permanent record left by radioactive isotopes generated from atomic bombs (Kolbert 2010). A hallmark of the Anthropocene is biodiversity loss (Myers & Pimm 2003). The designation of a geological epoch defined in part by biodiversity loss speaks directly to the challenges and importance of describing and understanding species and their conservation.

Fungal biodiversity does matter. The Millennium Assessment describes four kinds of ecosystem services provided by biodiversity, including provisioning, regulating, cultural and supporting services (Millennium Ecosystem Assessment 2005); fungi provide every kind of ecosystem service. Fungi provision by providing food for many peoples, not least as fermenters of bread and beer. The more recent use of mycelia as packaging (www.ecovativedesign.com), and reliance on *Saccharomyces cerevisiae* as a genetic model, are intriguing modern services provided by fungi. Fungi regulate by driving Earth's biogeochemical cycles, perhaps especially as decomposers. One set of cultural services provided by fungi were famously described by Wasson (1957), but perhaps more carefully described by Andy Letcher in the book Shroom: A Cultural History of the Magic Mushroom (Lechter 2007, see also Stamets 2000). As Dr. Letcher quite rightly points out, "We are the Mushroom People." (p. 5). Fungi support ecosystems by playing key roles in weathering (Hoffland *et al.* 2004), soil formation and maintenance (Bossuyt *et al.* 2001; Gadd 2006), and agriculture (Gianinazzi *et al.* 2002). However, the scarce number of mycologists make these facts a surprise to most biologists, who have only experienced fungi in the contexts of a moldy coffee cup, damaged garden plant or yeast infection.

The confluence of events and data defines pressing questions in mycology. How are accelerating rates of biodiversity discovery reconciled with biodiversity loss (Hanken 1999)? How many fungi are already extinct? As Buller pointed out long ago, a single fruit body of even a small mushroom is capable of dispersing 5 000 000 000 spores (Buller 1909). Does this vast reproductive potential buffer against habitat loss and climate change, by enabling migration to favorable sites? Are certain fungi unlikely to go extinct? What kinds of functional redundancy reside within fungal biodiversity; is one mycorrhizal species enough to facilitate plant growth, or are the synergistic influences of the full complement of soil fungi required? Mycologists are grappling with these and other serious questions, and at the same time pursuing additional basic research in taxonomy, ecology and evolution. The recent

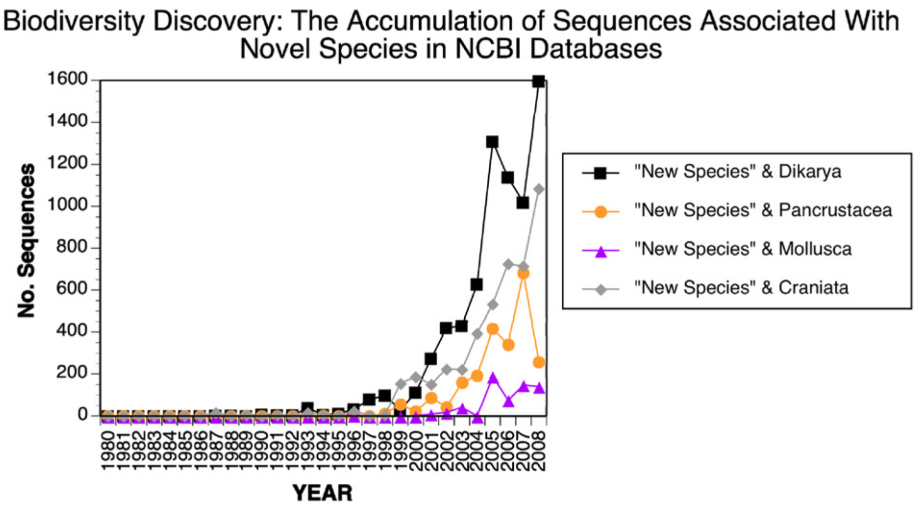

Fig 1 – Accelerating rates of biodiversity discovery illustrated using molecular data. The pattern is similar across groups of organisms but is especially pronounced among Dikarya. Data obtained through NCBI queries to identify the number of sequences catalogued for a given clade and associated with the search terms "new species" or "cryptic species". These values serve as a heuristic for understanding how many novel species have been identified through DNA sequencing.

founding of the International Society for Fungal Conservation is galvanizing mycologists around a set of common principles (www.fungal-conservation.org). But mycologists are also recognizing the broader communities of people engaged with similar questions and concerns. For example, fungi are increasingly the target of research on ecosystems (McGuire *et al.* 2010); data gathered by biogeochemists and ecosystem scientists are directly relevant to conservation. Moreover, information accumulating in databases like mushroomobserver.org and the Global Biodiversity Information Facility (GBIF) may soon facilitate the direct use of thousands of observations made by a global community of interested amateurs and professionals, and for example, enable the plotting of species' ranges.

This special issue of Fungal Ecology is another effort to address these questions. Our aim is to foster the creation of a coherent body of research directed at fungal conservation. Barron (2011) begins by providing a history of the research pioneered by Eef Arnolds, the United States Forest Service and others. She points to a need for dialogue among the different stakeholders invested in conservation. Molina *et al.* (2011) and Dahlberg & Mueller (2011) draw on decades of experience to make practical arguments for the management and red-listing of species which appear to be rare, and for species for which we have limited data. Both argue that despite uncertainties, it is time to move forward with concrete measures. Lilleskov *et al.* (2011) explore the consequences of biodiversity loss, and note that certain functional groups may well go extinct as a consequence of nitrogen deposition. Gange *et al.* (2011) describe an ecological consequence of climate change, and Boddy *et al.* (2011) provide an illustration of the kinds of synthetic natural history that can be pulled together and used to do the work recommended by Molina *et al.* (2011) and Dahlberg & Mueller (2011).

Conservation is both a scientific and a political endeavor. It presents a wide range of challenges and will force mycologists and other scientists to make difficult decisions about how and where to engage. Discovery of the unknown is a central tenet of the scientific process, and scientists will never have all of the data desired to make fully informed decisions. However, decisions about biodiversity are being made as rapidly as our understanding of fungi and fungal biodiversity is changing. If mycologists wish to engage in these decision-making processes, and if we believe that our knowledge will enhance the capacity available to address the challenges of the Anthropocene, then there is no reason to wait.

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