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The Encyclopedia of Life (EOL) as a scientific resource and outreach medium applied to the lichen family *Parmeliaceae* (Ascomycota: *Lecanorales*)

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Abstract: A brief discussion of the Encyclopedia of Life and the LifeDesks websites as a means to assemble and publish species pages and taxonomic information on the internet, for both the scientific community and the public, is provided. The lichen family *Parmeliaceae* is the first large group of lichenized fungi for which a concerted effort is currently being undertaken to produce substantial content for the EOL.

Keywords: BioSync, Index Fungorum, *Hypogymnia*, *Menegazzia*, *Parmotrema*

Introduction

Electronic media have revolutionized our means of communication (Lanham 1993; Jones 1998, 2003; Howard & Jones 2003). Among the advantages of electronic media are speed of publication and distribution, flexibility in format and display, low cost and broad accessibility. As a result, almost everyone nowadays turns to the world wide web when looking for information on a particular topic, and the verb 'to google' entered the Oxford English Dictionary in 2006 [http://en.wikipedia.org/wiki/Google_(verb)]. However, there are shortcomings when distributing information over the web, particularly when it comes to research that is, or should be, in the public domain. Widely disparate business models range from offering information for free to charging high prices for individual research articles. This causes an undesired bias with regard to the accessibility of information that is not based on quality or importance, but underlying financial considerations (Hurd 1996, 2004; Tenopir & King 2000; Björk *et al*. 2003; Houghton *et al*. 2006; Björk 2007; Roosendaal 2010). Also, the vast amount of information placed and accessible on the web undergoes only limited scrutiny and quality control, even on websites created and maintained by the scientific community (Tate & Alexander 1996; Sonora 2007). An example is the *Global Biodiversity Information Facility*, GBIF, which suffers from geographical bias and inaccurate taxonomic identifications of many of the nearly 200 million specimen records accessible through the portal (Chapman 2005; Yesson & Culham 2006*a*, *b*; Yesson *et al*. 2007; Lücking *et al*. 2011).

As a consequence, not only do researchers struggle to filter 'good' from 'bad' data offered on the web, the public is provided with information overflow without the possibility to critically evaluate available data. To add to this problem, many portals which, by their design, suggest they provide first-hand information to the user, in fact only mirror source

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databases and do not provide new data content. For example, when searching for lichen species names, apart from the primary provider *Index Fungorum* (*Species Fungorum*), a *Google* search usually retrieves hits from such diverse portals as the EOL, GBIF, *Wikispecies*, plants.usda.gov and also others, such as nomen.at, Gardenguides.com, plants.sagebud.com, flower-online.ws, and zipcodezoo.com. This creates a multitude of often empty stubs and appears to be superfluous information overload, unless such pages have original data to add or provide content in a form easily digestible for the public. In the print media, this would be comparable to publishing the same information content simultaneously in a multitude of book formats, one original and the other copies. Before the internet, the available information was restricted but with a substantially higher quality standard, filtered through established pathways of publication. With the internet, anything can be published some way or another. This is of particular concern since outreach components are required elements of research proposals when applying to public and private funding agencies (Franks *et al*. 2006; Balcom *et al*. 2009), and such outreach components almost invariably include electronic media on the internet.

The Encyclopedia of Life

In this context, the development of the *Encyclopedia of Life* [http://www.eol.org] offers an important step in attempting to centralize information on our planet's biodiversity and to provide means of quality control and usage filters, in order to present the compiled information in a concise form which appeals to a wide audience. As such, the EOL has the ambitious goal to appeal to and serve both the scientific community and the public and, if this goal can be met, will most certainly become the primary reference for biodiversity data focused on species. The idea of the EOL is to bring together all components relating to the biodiversity of life on our planet: species (taxon) pages; nomenclatural databases; specimen databases; genetic databases; hierarchical and phylogenetic classifications; image databases; identification tools; literature references.

Many of these components already exist in various forms and have done so for many years; they have served, and will continue to serve, the scientific community well without the EOL. These include the *International Plant Name Index*, IPNI [http://www.ipni.org] for plant and the *Index Fungorum* [http://www.indexfungorum.org] and *MycoBank* [http://www.mycobank.org] for fungal nomenclature, as well as the *International Code of Botanical Nomenclature*, ICBN [http://ibot.sav.sk/icbn/main.htm] and the *International Code of Zoological Nomenclature*, ICZN [http://www.nhm.ac.uk/hosted-sites/iczn/code], the *Global Biodiversity Information Facility*, GBIF [http://www.gbif.org] and the *Index Herbariorum* [http://sciweb.nybg.org/science2/IndexHerbariorum.asp] as direct and indirect portals for specimen databases, *GenBank* [http://www.ncbi.nlm.nih.gov/genbank] for genetic databases, the *Tree of Life* web project, TOLWEB [http://tolweb.org] for a global phylogeny of life and *Species Fungorum* [http://www.speciesfungorum.org] with a classification for the Fungi, the *DELTA – DEscription Language for TAxonomy* website [http://delta-intkey.com] providing the basic tools for interactive keys, and the *Biodiversity Heritage Library* [http://www.biodiversitylibrary.org] for literature references including most of the historic resources.

Rather than simply tapping these and other resources, the EOL bridges a gap regarding the design of species pages, as such pages currently exist on a very limited basis for individual groups of organisms on mostly locally or regionally focused websites. This includes the *Botany Taxon Pages* of the Field Museum of Natural History in Chicago [http://emuweb.fieldmuseum.org/botany/botanytaxon.php], which currently hold about 800 species pages for selected groups of lichenized fungi. The EOL aims at bringing the idea of species pages to a global level, not only regarding geographic and taxonomic coverage, but also the target audience.

This idea is not new and has been partially realized in *DiscoverLife* [http://www.discoverlife.org], the more phylogenetically structured *Tree of Life* web project [http://tolweb.org], *Symbiota* [http://symbiota.org], and the University of Michigan's *Animal Diversity Web* [http://animaldiversity.ummz.umich.edu/site/index.html], and even *Wikipedia* [http://www.wikipedia.org] and its diverse outlets, to name a few, but in scope and underlying technology, the EOL goes further. The EOL works with organizations and institutions in several countries to establish global EOL partnerships. These partnerships support EOL sister sites that use the software and branding of the EOL but provide their own funding and content development efforts, focusing on the flora and fauna of their region while using materials from the global EOL project to provide context. Content is also translated and shared between and among global partner EOLs and the main EOL site. Global EOL partnerships are already underway in Australia, China, the Arab Region, South Africa, Holland, Norway, North America and Central America. The challenge is to seamlessly integrate these components into an internet resource that combines the function of a first-hand database providing unique, original information with that of a second-hand portal merging data from other sources, and to make this resource appealing to a broad audience.

While this seems an overly ambitious goal to achieve, there is no alternative to such an approach. A global resource for biodiversity information requires bold moves. The problems with this approach are manifold, but they are practical rather than conceptual. This is where both the scientific community and funding sources are required to make a contribution. For the EOL, or any comparable initiative for that matter, to become a global biodiversity information source for both science and the public, much work is required. This work includes digitizing a huge amount of collection data and literature references, georeferencing most of the historic collections, updating species identifications in terms of nomenclature so as to reflect currently used names and synonymy and, especially, to ascertain complete and correct taxonomic identification of the databased specimens. In addition, where species data cannot be extracted from published monographs or databases, assembling such data from scratch is required. And to make this endeavour appealing to a wide audience, species pages must at least in part include outreach components. This information extends beyond taxonomy, systematics, and ecogeography and is work-intensive and can only be partially automated, such as scanning labels and extracting the data using OCR software, or automated georeferencing (although both with serious limitations). However, aspects such as nomenclature, taxonomy, and outreach components require high skill-levels and insight into the natural history of organisms that is provided only by trained biologists and taxonomists. Currently, the *EOL Rubenstein Fellowships* [http://www.eol.org/content/page/fellows] provide one possibility for early-career scientists to receive funding for getting content into the EOL. At roughly 6 000–10 000 funded species pages per year, this is a significant source of new and updated EOL content; yet it corresponds to only a small fraction of the millions of species that inhabit our planet.

For such an ambitious project as the EOL to be successful, not only is it necessary to determine authorities for each component and to dynamically integrate source databases, with the idea of updating information in just one place and then automatically updating it in all other places. It must also be recognized that a great deal of logistic support must go into the generation, management, and quality control of the integrated (meta-)data. Therefore, a positive side effect of the EOL initiative, from a scientific point of view, is the (hopefully) increased pressure on politics and funding agencies to provide the logistics and resources so that the scientific community can provide these data. Another emerging benefit of the EOL is the increased detection of errors in source materials. By presenting information from multiple partners side by side on a taxon page, and by bringing materials to the

attention of a greater audience of both specialists and enthusiasts, problems in the original data are exposed. Problem reports submitted on the EOL site are forwarded to content partners who then have a chance to rectify these errors.

How to get species data into the EOL

Currently there are several ways to put lichen species data into the EOL. One can sign up as a curator [http://www.eol.org/register] and then work on uploading data into the already existing species pages stubs, which have been created from source databases (e.g. *Species Fungorum*). While anybody can add information to EOL taxon pages, contributions from EOL curators, who are credentialed experts, immediately become part of the trusted EOL collection. Materials contributed by others are initially marked as unreviewed, and EOL curators assure the quality of EOL pages by reviewing content in their assigned group of organisms. In addition to being credited for any materials they have authored, curators are also cited as editors in a byline on the taxon pages for which they have curated contributions from other authors.

Anybody who has contributed biodiversity information to an online project should encourage their project leaders to sign up as an EOL content partner [http://www.eol.org/content_partner/register]. The EOL is interested in descriptive information about species, subspecies, genera, families, etc. Information about strains, varieties or provisional taxa may also be suitable. In addition to taxon descriptions, the EOL collects photographs, illustrations, videos, sounds, maps, bibliographic references, classification hierarchies, and lists of scientific as well as vernacular names. The EOL does not generally deal directly with specimen information; however, specimen images and information about type specimens are highly valuable for the project. Also, descriptive information derived from specimen records [e.g., cumulative occurrence or host records, information about phenology, morphometric data (ranges, averages) etc.] would be suitable for sharing with the EOL. Once a project has registered as an EOL content partner, EOL staff will provide assistance in implementing the data export.

For those who are not yet involved in an existing online project, the EOL also offers the *LifeDesk* platform [http://www.lifedesks.org]. LifeDesks are independent web sites where teams of researchers can collaboratively create and manage taxonomic hierarchies, taxon pages, image collections and bibliographies. LifeDesks offer taxon page templates based on the *TDWG Species Profile Model* [http://wiki.tdwg.org/SPM], and each LifeDesk can easily be configured to export its classification and taxon pages to the EOL. Weekly or monthly scheduled harvests can be used to keep content on EOL up to date. Taxon pages and images that are still under development can be kept in draft form on the LifeDesk (only visible to registered LifeDesk contributors) until they are ready for publication.

Currently, the following LifeDesk projects exist for lichenized fungi:

http://parmeliaceae.lifedesks.org (anonymous)
http://hypogymnia.lifedesks.org (Bruce McCune) (Fig. 1)
http://menegazzia.lifedesks.org (Benjamin Myles)
http://parmotrema.lifedesks.org (Kawinnat Buaruang)
http://psora.lifedesks.org (Einar Timdal)
http://ssplichens.lifedesks.org (Alan Fryday)
http://hundrednewlichens.lifedesks.org (Robert Lücking, Thorsten Lumbsch)

The last accompanies a recent publication describing 100 new lichen species in a global effort of 102 co-authors, documenting undiscovered species richness in lichenized fungi (Lumbsch *et al.* 2011) and has been used to assemble species pages subsequently submitted to the EOL. One advantage of the LifeDesk platform is that researchers can collaborate and contribute independently to a larger taxonomic project which can then

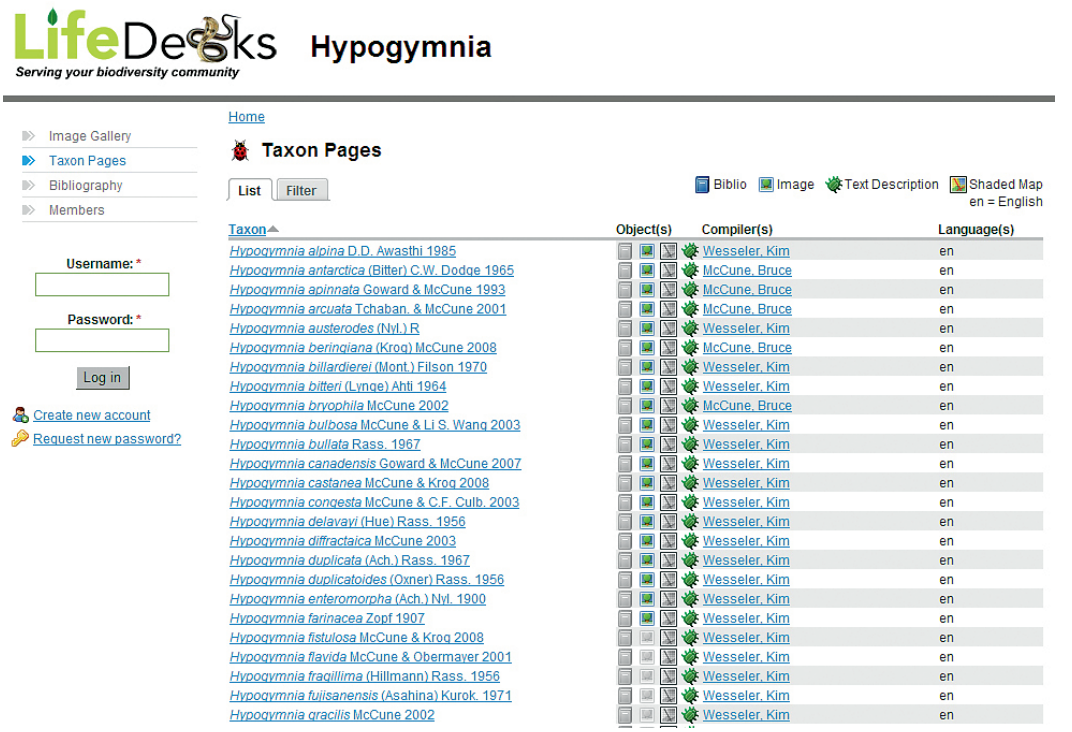

FIG. 1. Example of a LifeDesk page, the genus *Hypogymnia* (Bruce McCune). In colour online.

be published on the EOL, and permanent communication between LifeDesk and the EOL allows for continuous, automated updates of species pages modified in the LifeDesk environment.

The lichen family *Parmeliaceae* in the Encyclopedia of Life

Lichens are crucial for our understanding of the evolution of the fungal kingdom and the lichen symbiosis is one of the most successful nutritional systems within fungi. About one fifth of all known fungi form obligate lichen symbioses and about 25% of all Ascomycota (the largest fungal phylum) are lichenized. Lichens are found in nearly all terrestrial habitats from the poles to the tropics, ranging from marine (littoral) and fresh water aquatic habitats to xeric environments. They are dominant life forms in extreme habitats, such as polar, alpine and coastal habitats (Honegger 2001; Ott & Lumbsch 2001; Nash 2008). Estimates of the number of fungal species range from 1 to 1·5 million, with only a fraction currently known. At the same time, the number of taxonomists is decreasing worldwide. This is especially dramatic in traditionally neglected groups of organisms, such as lichens (Lücking 2008). Although communication is vastly improved through electronic media, personal contacts and meetings in which ideas can be discussed directly, and new collaborations initiated, continue to be extremely important.

Parmeliaceae is the largest and most well-known family of lichen-forming fungi and has a worldwide distribution; it includes the overwhelming majority of macrolichens. Estimates of the number of species in the *Parmeliaceae* range from 2000 to 2200, and they exhibit a remarkable diversity in morphology and secondary metabolites. The family includes many common and well-known species, such as *Parmelia sulcata,*

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FIG. 2. Participants of the EOL BioSync meeting on the *Parmeliaceae* in the Field Museum, Chicago, in May 2010. From left to right: Sarah Kim (The Field Museum, Chicago, USA), Adriano Spielmann and Luciana Cañez (Universidade de Santa Cruz do Sul, Brazil), Guillermo Amo de la Paz (Universidad Complutense de Madrid, Madrid, Spain), Dalip Upreti (National Botanical Research Institute, Lucknow, India), David Hawksworth (Universidad Complutense de Madrid, Madrid, Spain), Pradeep Divakar (Universidad Complutense de Madrid, Madrid, Spain), Jarle Bjerke (NINA, Tromsø, Norway), Ruth del Prado (Universidad Complutense de Madrid, Madrid, Spain), Steven Leavitt (Brigham Young University, Provo, USA), Paul Kirika (National Museum of Kenya, Nairobi, Kenya), Theodore Esslinger (North Dakota State University, Fargo, USA), Matt Nelsen (University of Chicago, Chicago, USA), Rosa Emilia Pérez (UCM, Mexico), Tiina Randlane and Andres Saag (University of Tartu, Tartu, Estonia), Inger Kristin Tronstad (Tromsø University Museum, Tromsø, Norway), Kawinnat Buaruang (Ramkamhaeng University, Bangkok, Thailand), Nathan Wilson (Field Museum, Chicago, USA), Thomas Nash (Arizona State University, Tempe, USA), Robert Egan (University of Nebraska, Omaha, USA), María de los Ángeles Herrera-Campos (Universidad Nacional Autonoma de Mexico, Mexico City, Mexico), Philippe Clerc (Conservatoire et Jardin botanique de la ville de Genève, Geneva, Switzerland), Eimy Rivas Plata (University of Illinois, Chicago, USA), Bruce McCune (Oregon State University, Corvallis, USA), Robert Lücking (The Field Museum, Chicago, USA), Arne Thell (Lund University, Lund, Sweden), Ana Crespo (Universidad Complutense de Madrid, Madrid, Spain), Gintaras Kantvilas (Tasmanian Herbarium, Hobart, Australia), Thorsten Lumbsch (The Field Museum, Chicago, USA), Mark Westneat (The Field Museum, Chicago, USA). In colour online.

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Flavoparmelia caperata, *Hypogymnia physodes* and *Punctelia subrudecta*, species that are frequently used as bioindicators for environmental health (Nimis *et al*. 2002; Crespo *et al*. 2004; Hawksworth *et al*. 2008).

To put forward efforts to feature *Parmeliaceae* species in the EOL, among other objectives, a first of two meetings of international collaborators organized by Ana Crespo, Thorsten Lumbsch and Robert Lücking was held as an EOL BioSync meeting [http://synthesis.eol.org] in Chicago in May 2010 (Fig. 2) (the second is planned to be held at the IAL symposium in Thailand in early 2012). This meeting provided a unique opportunity to enhance our efforts of capacity building and increase synergistic activities between current projects funded by numerous funding agencies (including NSF, European Commission, National Geographic, Spanish Ministry of Science and Innovation, etc.). It also correlated with the submission of a comprehensive manuscript with a new generic classification of parmelioid lichens (the largest clade in *Parmeliaceae* with *c*. 1500 species) based on a four-gene data set of 762 specimens. This is the largest data set so far analyzed in lichenized fungi (Crespo *et al*. 2010). An extension of these efforts towards the whole family is desirable and will allow us to revise fully the generic classification. The meeting also allowed us to deepen existing collaborative efforts and forge new partnerships, exemplified by a revised phylogenetic analysis of cetrarioid *Parmeliaceae* currently under preparation. We also focused on incorporating researchers from tropical countries to enhance our efforts of capacity building in these countries where *Parmeliaceae* have their greatest diversity.

As one outcome of the meeting, it was agreed to produce sample species pages, one species each, for each accepted genus within *Parmeliaceae*, as a LifeDesk project to be imported into the EOL. Once these sample species pages have been created, individual groups of colleagues will assume responsibility to add further species pages to each genus, to gradually extend and eventually complete the data set. Many of the data will initially be compiled from existing sources, such as Tom Nash's *Parmeliaceae* data stored in LIAS Light (Nash *et al*. 2002; Triebel *et al*. 2004) and compiled checklist data (Hawksworth *et al*. 2008; J. A. Elix, pers. comm. 2010).

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