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AlgaeBase: an on-line resource for Algae

Michael D. GUIRY^{a*}, Gwendoline M. GUIRY^a, Liam MORRISON^a,
Fabio RINDI^b, Salvador VALENZUELA MIRANDA^c,
Arthur C. MATHIESON^d, Bruce C. PARKER^e, Anders LANGANGEN^f,
David M. JOHN^g, Ignacio BÁRBARA^h, Christopher F. CARTERⁱ,
Pier KUIPERS^j & David J. GARBARY^k

^a*AlgaeBase and Irish Seaweed Research Group, Ryan Institute,
National University of Ireland, Galway, Ireland*

^b*Dipartimento di Scienze della Vita e dell' Ambiente, Università Politecnica delle
Marche, via Breccie Bianche, 60131 Ancona, Italy*

^c*13, Calle de Guzmán el Bueno, 28015 Madrid, Spain*

^d*Jackson Estuarine Laboratory, University of New Hampshire,
85 Adams Point Rd, Durham , NH 03824 , U.S.A.*

^e*Department of Biological Sciences, Virginia Tech, Blacksburg, VA 24061 U.S.A.*

^f*Hallagerbakken 82b, NO-1256 Oslo, Norway*

^g*Life Sciences Department, Genomics and Microbial Diversity,
The Natural History Museum, Cromwell Road, London SW7 5BD,
United Kingdom*

^h*Coastal Biology Research Group. Facultade de Ciencias, University of A Coruña.
Campus da Zapateira s/n. A Coruña, 15071, Spain*

ⁱ*6, Church View, Wootton, Northampton, NN4 7LJ, United Kingdom*

^j*Visual ID, 3015 Lake Drive, Citywest, Dublin 24, Ireland*

^k*Department of Biology, St. Francis Xavier University, Antigonish,
Nova Scotia, Canada, B2G2W5*

Abstract – In development since 1996, AlgaeBase (<http://www.algaebase.org>) is an on-line database providing free access to authoritative taxonomic, distributional and nomenclatural information of more than 135,000 names of species and infraspecific taxa of algae set in the context of a taxonomic hierarchy. The project was initially funded by the Higher Education Authority, Department of Education and Science (Ireland) and the European Union (the SeaweedAfrica Project), and more recently by an industry sponsor in Ireland (Ocean Harvest Technology) and various phycological societies and organisations. The database currently includes more than 50,000 bibliographic references and incorporates the entire contents of the main phycological journals in addition to taxonomic, ecological, physiological and biochemical references in current and classical works. Nearly 10,000 PDFs are included, many of them of 19th-century taxonomic works that are rare and difficult to

* Corresponding author: michael.guiry@algaebase.org

obtain. The data are searchable at all taxonomic levels from kingdom to species (and infraspecific names), and AlgaeBase strives to provide citations of the original publications of all taxa. For any of the 145,000 taxa (names of genera and above included), all subordinate taxa at the next lowest rank are indicated along with the number of species for each. Within each genus the species and infraspecific taxa are listed along with the current taxonomic status of each name. Nearly 17,000 images are provided for downloading and use in teaching or research, with copyright and other rights being retained by the original contributors or by AlgaeBase. This database is being used by 2,000-3,000 individual visitors each day with nearly 100,000 requests a day and receives over 7 million “hits” each year, increasing at about 20% per annum. A brief description of other main on-line algal resources such as *Index Nominum Algarum*, the Catalogue of Diatoms Names, CyanoDB, and *AlgaTerra* is provided.

On-line databases / algae / blue-green algae / Cyanobacteria / desmids / diatoms

Résumé – En développement, depuis 1996, AlgaeBase (<http://www.algaebase.org>) est une base de données en ligne offrant un accès libre à l'information taxonomique, la répartition des taxons et leur nomenclature (en particulier, leur autorité). Actuellement, cette base recense plus de 135 000 noms d'espèces et de taxons infraspécifiques d'algues qui sont présentés dans le contexte d'une classification taxonomique. Le projet a été financé par la Higher Education Authority, Ministère de l'Éducation et de la Science (Irlande), l'Union Européenne (le projet SeaweedAfrica), un commanditaire de l'industrie en Irlande (Ocean Harvest Technology), et diverses sociétés et organisations phylogéniques. La base de données comprend actuellement plus de 50 000 références bibliographiques et intègre le contenu des principales revues de phylogénie en plus des références taxonomiques, écologiques, physiologiques et biochimiques dans les travaux actuels et classiques. Près de 10 000 fichiers PDF sont inclus beaucoup d'entre eux correspondant à des travaux taxonomiques du XIX^e siècle qui sont rares et difficiles à obtenir. Les données sont consultables à tous les niveaux taxonomiques depuis les règnes jusqu'aux espèces (et les noms intraspécifiques), de plus, la citation des publications originales de tous les taxons est mentionnée dans la mesure du possible. Pour l'un des 145 000 taxons de rang générique ou supra générique, tous les taxons subordonnés de rang inférieur sont indiqués avec le nombre d'espèces pour chacun. Au sein de chaque genre, les espèces et les taxons infraspécifiques sont répertoriés avec la taxonomie actuelle de chaque nom. Près de 17 000 images sont fournies et disponibles pour le téléchargement et l'utilisation dans l'enseignement ou la recherche, les droits d'auteurs et autres droits étant conservés par les contributeurs d'origine ou par AlgaeBase. Cette base de données est utilisée par 2 000-3 000 visiteurs individuels chaque jour avec près de 100 000 demandes par jour et reçoit plus de 7 millions de « hits » chaque année, avec un accroissement moyen d'environ 20 % par an. Une brève description des autres principales ressources en ligne d'algues telles que l'*Index Nominum Algarum*, le catalogue de noms de diatomées, CyanoDB, et *AlgaTerra* est fourni.

Base de données en ligne / algues / algues bleues / Cyanobacteries / desmidiées / diatomées

INTRODUCTION

The starting point for the cataloguing of algal names, like fungal and plant names (International Code of Nomenclature for algae fungi and plants [ICNafp]; McNeill *et al.*, 2012), is Carl Linnaeus's *Species plantarum* (1753)¹. This

1. Art. 13.1(e) of the ICNafp Code, however, specifies later-starting-point dates for certain algal groups.

monumental work included all known plants of the day, listing 61 algae in the genera *Chara*, *Fucus*, *Ulva* and *Conferva* (see Spencer, Irvine & Jarvis, 2009). This innovative summation was followed by a period of intensive description of species and genera, culminating in the first encyclopedic treatment specifically for algae compiled by Carl Adolph Agardh (1785-1859), *Species algarum*, published in parts between 1820 and 1824, in which he listed and described most of the then-known algae in two relatively small volumes.

As the 19th century progressed, an explosion of taxonomic studies, partly fuelled by extensive extra-European explorations by colonial powers with competing ambitions, resulted in exponential increases in species and other taxon descriptions. C. Agardh's *Species plantarum* was trumped by works of Friedrich Traugott Kützing (1807-1893), notably *Synopsis diatomearum* (1833), *Phycologia generalis* (1843), *Species algarum* (1849), and *Tabulae phycologicae* (1846-1866). During this time, Jacob Georg Agardh (1813-1901), son of C. Agardh, published *Species, genera et ordines algarum* from 1848-1901, amongst other monographs, but the vast majority of the taxa were marine green, red and brown algae, and the freshwater and terrestrial algae so meticulously described by Kützing were not on J. Agardh's agenda. The development of high-quality microscopes by the mid-19th century led to a huge increase in descriptions of unicellular and colonial algae, particularly by Christian Gottfried Ehrenberg (1795-1876), whose astonishing meticulousness and productivity are exemplified by *Die Infusionsthierchen* (Ehrenberg, 1838).

By the end of the 19th century the huge numbers of additional names and a greater formalization of higher level taxonomy required a truly encyclopedic treatment. This was achieved by Giovanni Batista De Toni (1864-1924) in a series of comprehensive volumes entitled *Sylloge algarum omnium hucusque cognitarum* [Gathering of all algae hitherto known] published from 1889 to 1924 [including an account of the blue-green algae by Achille Italo Forti (1878-1937)]. Giuseppe De Toni (1907-1950), son of Giovanni, published *Bibliographia algologica universalis* in three fascicles (1931-1932), intended to supplement the *Sylloge*.

No publication comparable to De Toni's *Sylloge* has since appeared (Silva & Moe, 1999), with a few group-specific exceptions. Dawson (1962) compiled a list of new taxa published subsequent to De Toni; however, his list primarily treated marine algae and contained little information other than the new name and its publication source.

For desmids, Carl Fredrik Otto Nordstedt (1838-1924) published an *Index desmidiacearum* (1896, 1908), and Gerald Weber Prescott (1899-1988) supplemented it with his *Bibliographia desmidiacearum universalis* (1984), a comprehensive list of desmid publications.

For diatoms, Frederick William Mills (1868-1949) compiled *An Index to the Genera and Species of the Diatomaceae and their Synonyms* (1932-1935). Sam L. VanLandingham (1935-) published a *Catalogue of the Fossil and Recent Genera and Species of Diatoms and their Synonyms* in 8 volumes (1969-1979), treating diatom names known up to 1964. Intended as a revision of Mills's *Index*, VanLandingham's *Catalogue* contains 44,000 entries (18,000 more than Mills), including 4,000 entries published before 1935, which were omitted by Mills's *Index*.

For seaweeds, the *Catalogue of the Benthic Marine Algae of the Indian Ocean* by Silva, Basson & Moe (1996), was a work of global significance that provided the most detailed and accurate nomenclatural and taxonomic account of benthic marine blue-green, red, brown and green seaweeds of a major global ocean in the 20th century.

The above is an extremely brief account of the work of centuries, and the reader may wish to look elsewhere for a more comprehensive history.

The days of all-encompassing, paper-based works by dedicated authors are probably over, especially as the cost of publishing books and maintaining libraries to shelve them has soared. Our modern systems of employing taxonomists and nomenclaturalists, and publishing, certainly militate against such paper-based publication of large indices. Nonetheless, all is not lost as the invention and current pervasiveness of the Internet have provided in the last 25 years an opportunity to make the detailed information required by nomenclaturalists and taxonomists both instantly available and correctable.

Here we describe the history, programming, objectives and current status of AlgaeBase, an on-line, searchable database for phycology established in 1996 to take advantage of the proliferation of the Internet. We describe AlgaeBase in the context of other principal on-line resources for algae.

A BRIEF HISTORY OF ALGAEBASE

AlgaeBase was established by one of us (MDG) in March 1996, initially as a personal *aide-mémoire* and later that same year as an on-line database for users of the then-new world-wide-web. Data at first included only the seaweeds of Britain, Ireland and the Atlantic coast of France based on lists compiled for *The Species Directory of the Marine Fauna and Flora of the British Isles and Surrounding Seas* (Guiry, 1997) published by the Ulster Museum in Belfast, Northern Ireland and the Marine Conservation Society in Britain. Over the next few years this initial compilation was expanded into a list of seaweeds of the northeastern Atlantic and the Mediterranean for the *European Register of Marine Species* (Guiry, 2001), initially on-line, but later as a book by *Le Service du Patrimoine Naturel, Muséum National d'Histoire Naturelle*, Paris. The response to this initial compilation made it clear that an on-line taxonomic list of the world's benthic marine algae was urgently needed. Thus, a decision was made to expand the list for world coverage, basing this expansion on national check-lists, definitive regional treatments like the *Catalogue of the Benthic Marine Algae of the Indian Ocean*, monographs and other taxonomic treatments, with all the entered data traceable to a verifiable publication. To do this, a comprehensive bibliography was required that was sourced initially from an unpublished computer database compiled by one of us (DJG). This electronic bibliography was based on a private reprint collection accumulated over 15 years and supplemented by additional reprints kindly donated by Dr Janet Stein on her retirement from the University of British Columbia. The initial database (then known as PHYKOS) of about 9,000 entries was imported into the bibliography, and supplemented by further references from the books, reprint and journal collections at AlgaeBase.

Data entry and programming was funded from 2002-2009 by the Higher Education Authority, Ireland, under the Priority Research for Third-level Institutions Programme Cycles 3 and 4, and by the European Union as the SeaweedAfrica project (2002-2005, INCO-DEV). The latter project allowed the data on benthic marine algae to be first extended to Africa, then to the Indian Ocean, and later to all seas of the world. By 2004, it was clear that the FileMaker (<http://www.filemaker.com>) database used for data storage and dissemination would be inadequate to handle the growing on-line demand, so the data were transferred to MySQL (<http://www.mysql.com>) in one, integrated, relational

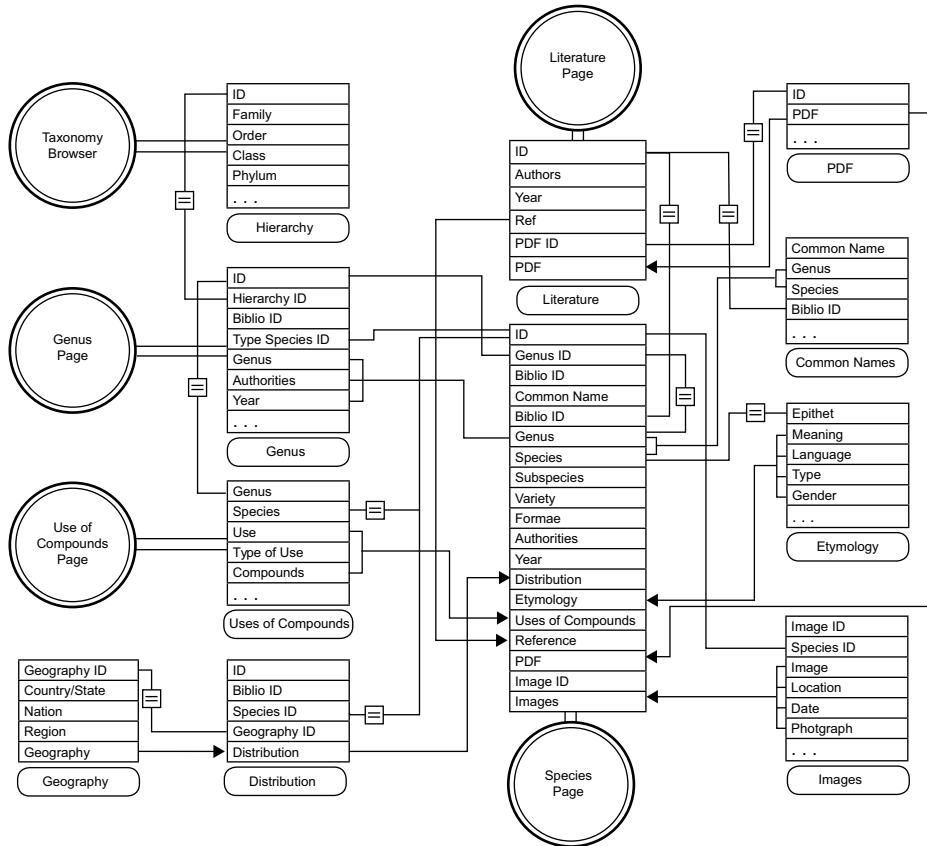


Fig. 1. Data schema of a part of AlgaeBase showing database (named below each table). Some of the page output to browsers is shown as large circles. Each of these pages is composed on request by relationships (indicated by lines with an “equals” sign, mostly by means of sequential identification numbers “IDs”) between data elements in the tables. Only some tables and some fields are shown.

database (Fig. 1). The AlgaeBase name was registered for on-line access (<http://www.algaebase.org>), giving the database a corporate identity. This version of the database, the programming for which was organised by one of us (PK), came on-line in September 2004. About this time, the benefits of including other algae became clear, and while the database at that time emphasized marine benthic algae (mainly seaweeds), freshwater and terrestrial algae, marine and freshwater phytoplankton were added as time and funding allowed.

WHAT IS ALGAEBASE?

AlgaeBase aims to be an on-line source for taxonomic and distributional information for all algae. In reality, as a resource it is best for those algae most frequently cited in the literature, and at present is least useful for obscure and

rarely found or mentioned taxa. Whilst nomenclatural data are included, AlgaeBase does not aim to be a definitive nomenclatural source; other resources such as *Index Nominum Algarum* (INA) and the *Catalogue of Diatom Names* (see p. 112) more than fulfill this need. AlgaeBase aims to excel in providing taxonomic information that links to identify published works allowing taxonomists to make an informed decision. And while it may not always be correct in its taxonomic placements, we always encourage users to contact us when they find errors or have different opinions. Unless these opinions are published, we may not be able to make changes, although we may add taxonomic and nomenclatural notes if appropriate.

AlgaeBase has led to significant improvement in the orthography of taxon names, but one weakness is that when a misinterpretation or error in AlgaeBase occurs, it tends to propagate throughout the system, mainly due to the efficiency of Google's search engines which index AlgaeBase daily. It has also helped standardize names and spellings of taxon authors' (authority) names. A decision was made from the beginning not to abbreviate authority names but to allow authors to make abbreviation decisions themselves or to follow one or other of the prevailing systems. AlgaeBase also seems to have led to improvements of citations in bibliographies of older phycological works, with many authors choosing to "cut-and-paste" its references into their works, which again are clearly identifiable from the style used by the database. The provision of PDFs of many of older works has benefitted numerous workers with limited access to library resources, particularly in "developing countries". About 10,000 such PDFs have been uploaded to date, although for copyright reasons many works after 1923 may not be visible or downloadable or if they are still subject to copyright restrictions.

Additional "cut-and-paste" activity occurs in relation to the distributional data, which was never intended for this purpose, and authors should treat the 250,000 or so distributional entries as a guide; the data should be verified and augmented prior to publication, particularly those for freshwater, terrestrial and fossil algae, which currently are under-represented.

AlgaeBase includes formal descriptions of many current algal genera. Many of these were initially prepared for the *Encyclopedia of Algal Genera* (EAG) sponsored by the Phycological Society of America (<http://www.psaalgae.org>). The EAG was under the editorial direction of one of us (BCP) and a some hardworking subeditors, and authorities throughout the world contributed the individual generic accounts². While the EAG project did not come to fruition as a paper or CD publication, the descriptions were a very valuable contribution to AlgaeBase. We encourage authors to submit revisions to these generic descriptions to keep the information up to date.

AlgaeBase also includes a comprehensive Glossary compiled by one of us (ACM): some 28,160 terms are currently defined and each one has a comprehensive explanation, and, where appropriate, detailed notes on the origin of each.

Details of the numbers of species and other taxa in AlgaeBase and estimates of the numbers of described taxa yet to be included are given in Guiry (2012), together with estimated numbers of undescribed species; presently (May 2014), 40,000 species of algae are included. Reference is made by Guiry (2012) to difficulties associated with morphospecies, biological species and molecular species — a difficulty afflicting all systematics in biology.

2. These contributors are listed at <http://www.algaebase.org/contributors/>

THE STRUCTURE OF ALGAEBASE

As mentioned above, AlgaeBase was never intended to be a primary source of nomenclatural information as *Index Nominum Algarum* admirably performs this function, but is primarily a taxonomic database. It therefore was designed with taxonomic data in mind. The primary unit of taxonomy is the species, so the main table in the database is the species table (Fig. 1); however, the primary unit of taxonomy is the genus and because quite a few generic homonyms exist, the species table is connected to the genus table (Fig. 1) by genus identification numbers (IDs) rather than by a relationship involving names. In turn the genus is connected by its genus ID to a single hierarchy table containing all the details of the higher taxonomy above the level of genus. The taxonomy browser is controlled by a Hierarchy table and it and the Literature, Uses of Compounds, Literature, Common Names, Etymology tables interact to produce species pages on the fly (Fig. 1). Taxonomy Browser, Genus, Literature pages are also produced on demand. Unlike the printed work, nothing is static in AlgaeBase: each page is produced on demand and the data can be corrected or augmented instantly.

OTHER MAJOR ALGAL ON-LINE RESOURCES

Index Nominum Algarum (INA) and the complementary *Bibliographia Phycologica Universalis* (BPU) are extraordinary testaments to the life-long commitment of Paul C. Silva (Jepson Herbarium, University of California at Berkeley), presently in his 92nd year, and his collaborators (notably Richard L. Moe and the late David E.G. Irvine) in assembling algal names and the literature on algal nomenclature. INA began as a card index in 1949 "...to fill a need for an up-to-date comprehensive index of algal names" (Silva & Moe, 1999). It currently includes about 200,000 names of "algae (in the broad sense)" at all taxonomic levels (see <http://ucjeps.berkeley.edu/INA.html> for further information). In the 1990s the cards were scanned and a TIFF image-file created for each. These were stored on compact disks, essential "... in insuring the card file against disaster" (Silva & Moe, 1999). Images were made available on-line in 1998 by the Center for Phycological Documentation (University and Jepson Herbarium, University of California, Berkeley; <http://ucjeps.berkeley.edu/INA.html>) using PERL (<http://www.perl.org>) to serve the TIFF files and the electronic cards from a hard-disk using a common index. The TIFF files are being indexed progressively, and the indexing of cards is by volunteers at Berkeley, the California Academy of Sciences, and the *AlgaTerra* team (see below), and is presently nearly complete; about 40,000 cards have now (May 2014) been keyed electronically (Moe, pers. comm.). The compilation is essentially a nomenclatural one, and information on taxonomy is only provided incidentally. The "cards" include the citations and associated nomenclatural commentary, including the type locality. It should be emphasised that the TIFF images of the cards often include the exact spelling used by the original author(s), while the indices generally include the name corrected as specified by the *International Code of Nomenclature for Algae, Fungi and Plants* (ICNafp; McNeill *et al.*, 2012).

Index Nominum Algarum has from the beginning of the AlgaeBase project in 1996 been of critical importance in the verification of names and taxon authorship, and we are pleased to acknowledge the huge and continuing contribution that INA makes to AlgaeBase. As we view the cards, we never fail to be awed by the fruits of Paul Silva's lifetime commitment. It might not be entirely appreciated by the users of both databases that one can spend an entire day ferreting out the truth of a single name from its taxonomic or nomenclatural burrow. Enjoyable as this can be at times, it can be very frustrating.

AlgaTerra (<http://www.algaterra.org>) is an "information system for terrestrial algal biodiversity: a synthesis of taxonomic, molecular and ecological information" that has been on-line since 2004, thanks to the efforts of Regine Jahn and Wolf-Hennig Kuber (Botanischer Garten und Botanisches Museum, Berlin-Dahlem, Freie Universität, Berlin). It incorporates taxonomic, morphological, ecological and molecular information for the included taxa, and is particularly strong on information on the oeuvre and collections of C.G. Ehrenberg and Friedrich Hustedt (1886-1968), and Horst Lange-Bertalot (1936-) and his co-workers and collaborators. Its objectives are to "...build a comprehensive information system including a database on terrestrial micro-algae, integrating taxon, type, name and collection data as well as ecological and molecular information." The *AlgaTerra* project has also a considerable input to INA through the task of completing the on-line indices, and is a very important resource for reliable information on terrestrial and freshwater algae.

Catalogue of Diatoms Names (CAS; <http://researcharchive.calacademy.org>) is an on-line compilation of names of diatom genera, species and taxa at infraspecific ranks and includes some 62,000 names. It has been assembled since 2000 by staff and former staff at the California Academy of Sciences, notably Elisabeth Fourtanier and Patrick Kociolek. It includes all scientific names of diatom genera, species, and taxa at infraspecific ranks. An initial set of 45,000 names was entered from the VanLandingham Catalogue (see above) and compared with an unpublished "New Species File" of the Academy of Natural Sciences of Philadelphia. The database was then compared with the *Index Nominum Algarum*, resulting in the addition of 11,000 names from the "New Species File", and 4,600 names from INA, as well as identification of numerous discrepancies. Like INA, CAS is essentially a nomenclatural database of similar quality and great accuracy, and is also a valuable source for AlgaeBase.

CyanoDB (Komárek & Hauer, 2012) is an on-line database of cyanobacterial (blue-green algal) genera compiled by Jiří Komárek (University of South Bohemia, České Budějovice, Czech Republic) and Tomáš Hauer (Academy of Sciences of the Czech Republic, Třeboň). Its aim (<http://www.cyanodb.cz>) is "to provide as sufficient information about cyanobacteria as possible to all people interested. Either from the scientific community or from outside, e.g., schools, environment monitoring services, public health protecting services, etc. The content of the database is based on work [of] Komárek 1992 and complemented with data from Geitler, Bourrelly, Desikachary, Drouet, Kondratyeva and many others. Newest works are also used".

In using these internet and other resources, one should bear in mind that in ancient Rome the *nomenclator* was a slave whose duty was to recall the names of persons his master met during a political campaign; so, the function of all of these databases, including AlgaeBase, is to help the nomenclaturist or taxonomist to arrive at an informed decision, and not to arbitrate. The nomenclators did not make the decisions.

WHAT IS THE FUTURE OF ALGAEBASE?

The future of AlgaeBase, and many other databases, depends on the energy and commitment of the data custodians, and on long-term funding. For reasons not entirely clear, institutional, governmental and international funding bodies seem not to comprehend that the databases they have supported require maintenance to remain effective sources. Unlike books or papers, which have clearly identifiable endpoints (the day they appear in print), databases lack the wonderful luxury of such finality and require continuous, long-term support. Book- or paper-writers (or paperback writers!) can walk away from their creations, once published; the on-line database custodian has no such comfort or feeling of finality.

Essentially, AlgaeBase has received no government funding since 2009, and the pace of revision and addition of data has accordingly slowed considerably. The service has been maintained from the original servers purchased from earlier Irish grant support. The Ryan Institute and the National University of Ireland Galway (NUIG), our home institution, have been very generous in providing a home for the servers and an office for AlgaeBase since 2009. Over the long term, however, this is not sustainable, as the university lacks the resources and the strategic imperative to employ a permanent custodian or to pay for the necessary programming.

The Copyright and Intellectual Property (IP) rights is in the process of transfer to a non-profit company (“The AlgaeBase Foundation”) registered as a charity in Ireland and are actively seeking sponsorship and funding to support database maintenance and enhancement. To date, support has come from industry sponsors Ocean Harvest Technology (<http://www.oceanharvest.ie>), the British Phycological Society, the International Phycological Society, the Phycological Society of America, and the Korean Phycological Society, for which we are very grateful.

For more than 15 years AlgaeBase has supported and driven by the authors of this account. Under its “umbrella”, information and data have been updated and distributed to phycologists, students, and the general public as free content in the context of our the new electronically-connected world. But, if AlgaeBase is to maintain its current importance as a “living” source of information, it needs to be continuously updated. As algae become increasingly the focus of advances in biotechnology and applications in industry and human affairs, there is a real need not only to maintain AlgaeBase in its current form, but to expand it to meet the needs of new generations of phycologists around the world.

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