PLANT ECOLOGY and EVOLUTION

Continuation of *Belgian Journal of Botany*, founded 1862
Incorporating *Systematics and Geography of Plants*

143 2
2010

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Publication date of issue 143 (1): 29 Mar. 2010.

Cover design: Sven Bellanger

Cover photographs – Top left: *Xanthoceras sorbifolium*, endemic to China and Korea, is the sole member of Xanthoceraceae, a new family established in this issue (see pages 148–159) based on morphological, biogeographic and phylogenetic evidence. It is the basal most lineage within the sapindaceous clade, sister to Sapindaceae, Aceraceae and Hippocastanaceae. The large and attractive flowers make this tree a favourite in botanical gardens. The change in colour seen in the photograph may represent a cue for floral visitors. Photographed by Dr. Félix Forest at the Royal Botanic Gardens, Kew. – Top right: red mangrove *Rhizophora mucronata* (single tree with dark stem in the middle of the photograph) and the yellow mangrove *Ceriops tagal* (multiple trees with reddish stems) entangle mangrove propagules in their aerial root systems, eventually leading to the establishment and development of seedlings and young trees (foreground). This photograph was taken by Griet Neukermans in Gazi Bay (Kenya), the most intensively studied mangrove site in the world (see pages 225–232). – Bottom: *Rhinanthus angustifolius* in flower, photographed by Jérôme Vrancken in an experimental population at the University campus in Louvain-la-Neuve, Belgium (see pages 239–242).

ISSN 2032-3913 (print)
ISSN 2032-3921 (online)
Printed in Belgium

Plant Ecology and Evolution 143 (2): 225–232, 2010
doi:10.5091/plecevo.2010.439

SHORT COMMUNICATION

The 'Mangrove Reference Database and Herbarium'

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Background – In the light of loss of mangrove forests and related biodiversity world-wide the overall objective of the online 'Mangrove Reference Database and Herbarium' is to give a current and historic overview of the global, regional and particularly the local distribution of true mangrove species.
Databasing and website construction – All data are based on records containing species location information of all mangrove species (approximately 75). All the mangrove zones around the world are recorded in this database and a species list is available for the sites that have been studied or sampled. In addition, the database provides written and visual information on plant physiognomy, ecological adaptations to the intertidal mangrove habitat and nomenclature. Images of herbarium specimens are included as vouchers.
Objectives – The website (http://www.vliz.be/vmdcdata/mangroves/) wants: (1) to offer a **relational database** for all true mangrove plant species using an expandable **taxonomic tree**; (2) to display a **fact sheet** for each mangrove plant species; (3) to present a searchable online **distribution map** for each species based on point-locations submitted by researchers world-wide in order to display historic as well as current distribution maps using a GIS-interface; (4) to preserve a **herbarium reference specimen** for each true mangrove species; and (5) to provide an **automated determination key** to identify mangroves world-wide.
Results – The result is a functional database that can be rapidly updated and that provides information for research, management and conservation projects on the world's mangroves (biogeographical, forest management or ecological restoration in the light of species present).

Key words – auto-ecology, biodiversity, biogeography, database, diagnostic features, distribution, herbarium, identification, mangrove, taxonomy.

INTRODUCTION

Mangroves, defined as 'tree, shrub, palm or ground fern, generally exceeding one half meter in height, and which normally grow above mean sea level in the intertidal zone of marine coastal environments, or estuarine margins' (Duke 2006), constitute one of the most threatened ecosystems (Farnsworth & Ellison 1997, Valiela et al. 2001, Alongi 2002, Duke et al. 2007). Due to the widespread distributions of most mangrove tree species, few are listed on the IUCN Red List of Threatened Species™ (Polidoro et al. 2010), and many others are listed as 'least (global) concern'. Yet, both mangrove species and entire mangrove ecosystems are locally threatened throughout their distribution range despite their numerous goods and services.

Mangrove ecosystems provide habitats for numerous animals and micro-organisms (Cannicci et al. 2008, Nagelkerken et al. 2008), which live in close interaction with the mangrove vegetation (Bouillon et al. 2004, Kristensen et al. 2008). Mangrove forests provide essential functions and services, such as protection of the coastal zone (e.g. Badola & Hussain 2005, Dahdouh-Guebas et al. 2005b, Olwig et al. 2007, Barbier et al. 2008, Kaplan et al. 2009) and a variety of timber and non-timber forest products (Bandaranayake 1998, 2002, Walters et al. 2008).

Many mangroves have been degraded over time as evidenced by numerous retrospective research approaches (Dahdouh-Guebas & Koedam 2008, Ellison 2008). Next to direct anthropogenic degradation (Farnsworth & Ellison 1997, Alongi 2002), indirect degradation such as cryptic ecological degradation (Dahdouh-Guebas et al. 2005a) also threatens the survival of individual mangrove trees and vegetation assemblages. 'Cryptic ecological degradation' (sensu Dahdouh-Guebas et al. 2005a) indicates that introgressive mangrove-associated vegetation or minor mangrove species such as *Acrostichum aureum* L. slowly start to dominate a forest at the expense of typical, vulnerable, valuable and functional true mangrove species (qualitative degradation) but without loss of spatial extent (no change or increase in area). In addition, climatic change events such as sea-level rise (Gilman et al. 2008) threaten mangrove ecosystems world-wide.

It becomes increasingly important to understand the early drivers in mangrove dispersal (Di Nitto et al. 2008, Triest 2008), mangrove establishment (Krauss et al. 2008), adult mangrove growth and development (Komiyama et al. 2008), regenerative constraints (Bosire et al. 2005), and vegetation dynamics (Berger et al. 2008) in order to design mangrove recovery programmes (Kairo et al. 2001, Bosire et al. 2008).

Mangroves are distributed world-wide on all continents with tropical and subtropical coasts and occur in 124 countries and territories. According to the FAO (2007), the total area covered by mangroves is estimated to be between 15.6 and 19.8 million hectares. The northern extension limits of mangroves are in Japan (31ºN) and Bermuda (32ºN) and the southern extension limits are in South Australia (38.75ºS) and the east coast of South Africa (32.6ºS) (Tomlinson 1986). In some countries mangroves are not native such as in the Hawaiian Islands, but since the early 1900's, at least six species have been introduced there (Kathiresan & Bingham 2001). Also in countries with mangroves exotic mangrove species have been introduced; for instance *Nypa fruticans* (Thunb.) Wurmb, a mangrove species endemic to the Indo-West-Pacific region only, was introduced in West-Africa (Spalding et al. 1997). Inversely, some other species have gone extinct in some countries, such as *Bruguiera gymnorrhiza* (L.) Lam. in Yemen or *Heritiera littoralis* Dryand. in Bangladesh (loc. cit.).

To document and analyse the historic loss and current extent of mangrove ecosystems and mangrove biodiversity around the world, the 'Mangrove Reference Database and Herbarium' (further abbreviated MRDH) has been created. (http://www.vliz.be/vmdcdata/mangroves/). The concept of the MRDH is outlined here.

JUSTIFICATION OF THE WEBSITE

The past and present global or regional distributions of mangroves have been studied repeatedly (Spalding et al. 1997, 2010, FAO 2003, Taylor et al. 2003, Giesen et al. 2007, UNEP 2007). Species lists per country can be easily found but a global overview of the exact local distribution and bio-

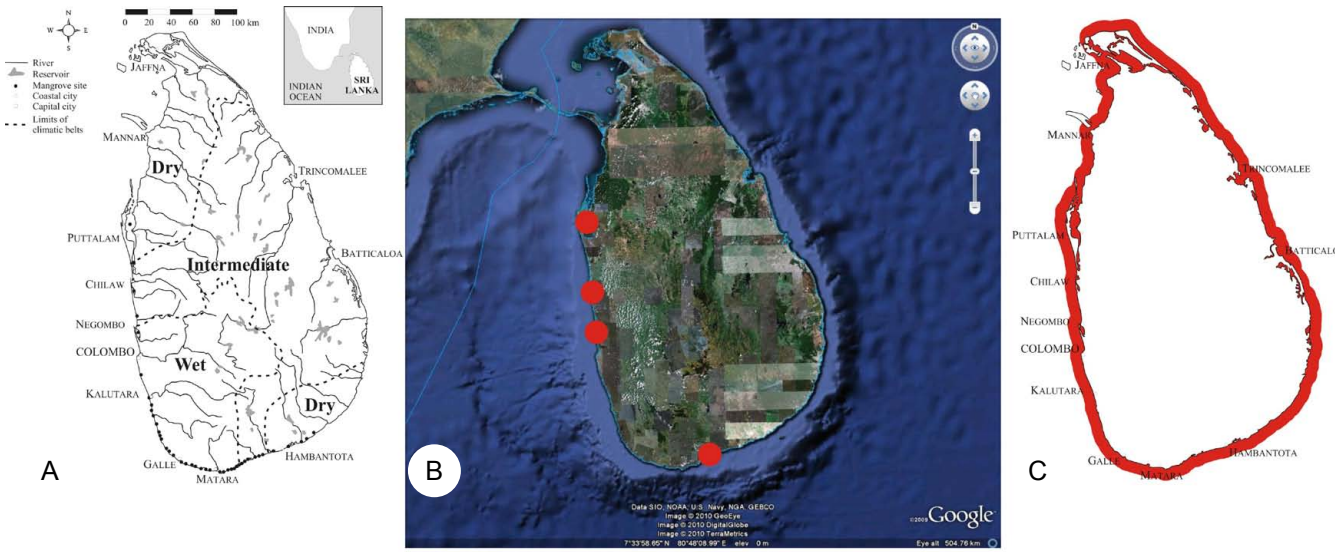

Figure 1 – A, generic map of Sri Lanka (adapted from Jayatissa et al., 2002) indicating all mangroves sites along a 400 km coastal stretch in the S and SW of the country. Climate belts are shown; B, distribution of *Ceriops tagal* according to field data in each of the 43 mangrove sites indicated in A. This species occurs only in the lagoons of Rekawa, Negombo, Pambala-Chilaw and Puttalam (loc. cit.). The figure is based on locality information from the Mangrove Reference Database and Herbarium; C, distribution of *C. tagal* according to the World Atlas of Mangroves (Spalding et al., 1997, 2010). By comparing B and C one should note the differences in distribution data resolution (according to the objectives of the respective distribution maps), hence the importance of having also access to local distribution data such as that stored in the Mangrove Reference Database and Herbarium.

diversity of mangrove species (on the level of mangrove estuaries, bays or lagoons) is still lacking. Yet, it is urgently needed because in some sites mangroves may display a strong dynamism in space (e.g. Dahdouh-Guebas et al. 2002) and in time (Dahdouh-Guebas et al. 2000, Fromard et al. 2004). Distribution data per country are often not representative for all mangrove sites within the country. This distribution may differ significantly with respect to climatic, oceanographic, anthropogenic and other factors driving local mangrove species composition. For example, *Ceriops tagal* C.B.Robinson is found in only four out of the 43 mangrove sites in Sri Lanka (fig. 1). As Jayatissa et al. (2002) demonstrated, highly resolved and correct distribution data on a local scale are essential in the light of biogeographical studies, remote sensing, in situ conservation or management, and restoration ecology of mangrove forests. Many global initiatives such as the World Atlas of Mangroves (Spalding et al. 1997, 2010) aim at global distribution maps, which may be correct on a global administrative level. However their country-wide distribution maps or tables are seldom applicable in the field, as the species representative on the (administrative) scale of a country are not present in each and every mangrove site (fig. 1C).

According to Pyke & Ehrlich (2010) projects that use biological collections and include, besides taxonomy and systematics, a focus on significant environmental and ecological issues, such as anthropogenic loss of biodiversity and associated ecosystem function, should be prioritized. The overall aim of this online database is to generate global or regional maps on mangrove distribution and composition that are correct on the scale of specific lagoons or even parts of a lagoon, and to perform further research on the past, current and future diversity and distribution of mangrove plant species in view of their ecological and socio-economical functions, goods and services.

SPECIFIC OBJECTIVES

The specific objectives, detailed in the sections 'History and Framework' and 'Data holdings of the Mangrove Reference Database and Herbarium', are listed below:

- to offer a **relational database** for all true mangrove plant species (c. 75 species) using a search engine (fig. 2A) and an expandable **taxonomic tree** (fig. 2B), at the time of the present publication based on the APG III classification (APG III 2009, Chase & Reveal 2009);
- to provide a **fact sheet** for each mangrove plant species including basic information with photographs, herbarium specimen scans and distribution data (figs 1B, 3);
- to present a searchable online GIS-based **distribution map** for each species. These maps are based on point-locations provided by researchers world-wide through peer-reviewed papers, herbaria, personal contacts or information inserted online (see fig. 1B). The aim is to display historic as well as current distribution maps by enabling filtering data with respect to the date of the occurrence records;
- to deposit and preserve a **herbarium reference specimen** for each true mangrove plant species at the Herbarium of the National Botanic Garden of Belgium (BR), at the Université Libre de Bruxelles (BRLU) or at the Vrije Universiteit Brussel (BRVU) while aiming at a single collection in one location (fig. 3D);
- to provide an **automated determination key** to identify true mangroves world-wide based on a multi-access key that operates a multivariate analysis tool to compare a species to be identified with its known diagnostic characters (the description of this task, currently in progress, is considered beyond the scope of this paper).

HISTORY AND FRAMEWORK

The MRDH was started in 2001, when the Flanders Marine Institute (Vlaams Instituut voor de Zee – VLIZ) created the Flanders Marine Data and Information Centre (VMDC). This centre became an integral part of international networks such as UNESCO's IOC Project Office for International Oceanographic Data and Information Exchange (IODE), OBIS, ESF Marine Board, MARS, EMODNET and other European networks. VMDC hosts the Mangrove Reference Database on its server and develops ICT tools to ease its use.

Since universities in Brussels and Flanders (Belgium) had played a long-standing role in research on mangrove ecosystems, at the origin focused on Kenya and Sri Lanka, but since then expanded to single case-studies or long-term projects in Mexico, Brazil, Mauritania, Gambia, Cameroon, Tanzania, Kenya, India, Malaysia, Vietnam and China, the idea seemed justified to start the current database collaboration with VLIZ, coordinated by the Université Libre de Bruxelles (U.L.B.) and the Vrije Universiteit Brussel (V.U.B.).

The larger framework of the MRDH involves also a real and virtual reference herbarium coordinated by the U.L.B. The real herbarium consists of herbarium sheets of each and every true mangrove species of the world and is hosted at the U.L.B. (herbarium acronym BRLU), the V.U.B. (BRVU), and the National Botanic Garden of Belgium (BR), each institute currently making its own efforts to aid the realisation of a complete true mangrove species collection. While currently distributed among these institutes, which are all located within a few kilometres from one another, we aim at establishing the complete mangrove reference herbarium collection in a single location. The virtual herbarium consists of scanned herbarium sheets with tools for high definition online viewing and is hosted on the website in collaboration with the Belgian Biodiversity Platform.

DATA HOLDINGS

All existing mangrove literature s. lat. records are browsed for true mangrove plant species lists and geographic coordinates, a dynamic task as, in order of importance, (1) new peer-reviewed papers continue to appear in scientific literature, (2) older papers and (3) grey scientific literature (e.g. university dissertations) are still in the process of being inserted, and (4) researchers and others world-wide continue to upload species lists, the latter of which are subject to higher quality control. Where such studies are estimated to provide exhaustive species lists, e.g. as part of a vegetation structure study, remote sensing study, etc., they were georeferenced, using geograph-

A

Mangrove Reference Database and Herbarium

Intro - Search taxa - Taxon tree - Distribution - Checklist - Specimens - Literature - Log in

Mangroves Taxon search

Enter the name of the taxon you want to look up. Genus and subgenus names should be included for species. Valid wildcards are '%' and '_' ('%' replaces zero or more characters, '_' replaces a single character; click here for details and examples). If you're not sure of the genus and/or subgenus of a species, replace them with a '%', followed by a space.

Search: Scientific Name | begins with

e.g. Chromadora kreisi, Siriella, ...

☑ Fuzzy matching (what's this?)
☑ Limit to accepted taxa
☑ Limit to marine taxa

Taxon rank: lower or equal to | Kingdom

Limit to taxa belonging to: Magnoliidae

e.g. Mysidae. Only taxa with rank above genus will be returned.

Search

Website and databases developed and hosted by VLIZ
Page generated 2010-06-18 GMT+1 · contact: Farid Dahdouh-Guebas

B

- Biota
  - Plantae
    - Viridaeplantae
      - Magnoliophyta
        - Equisetopsida
          - Magnoliidae
            - Asteranae
              - Ericales
              - Gentianales
              - Lamiales
                - Acanthaceae
                - *Acanthus*
                - *Avicennia*
                - Avicenniaceae accepted as Acanthaceae
            - Caryophyllanae
            - Lilianae
            - Rosanae
              - Malpighiales
                - Euphorbiaceae
                - Rhizophoraceae
                - *Bruguiera*
                - *Ceriops*
                - *Kandelia*
                - *Kandelia candel* (L.) Druce
                - *Kandelia obovata* Sheue, Liu & Yong
                - *Kandelia rheedii* Whight & Arnold accepted as *Kandelia candel* (L.) Druce
                - *Rhizophora*
                - *Selala* Guppy accepted as *Rhizophora*
              - Malvales
              - Myrtales
              - Rhizophorales accepted as Malpighiales
              - Sapindales
          - Polypodiidae

Figure 2 – A, screenshots of the search window; B, the expandable taxonomic tree of the MRDH.

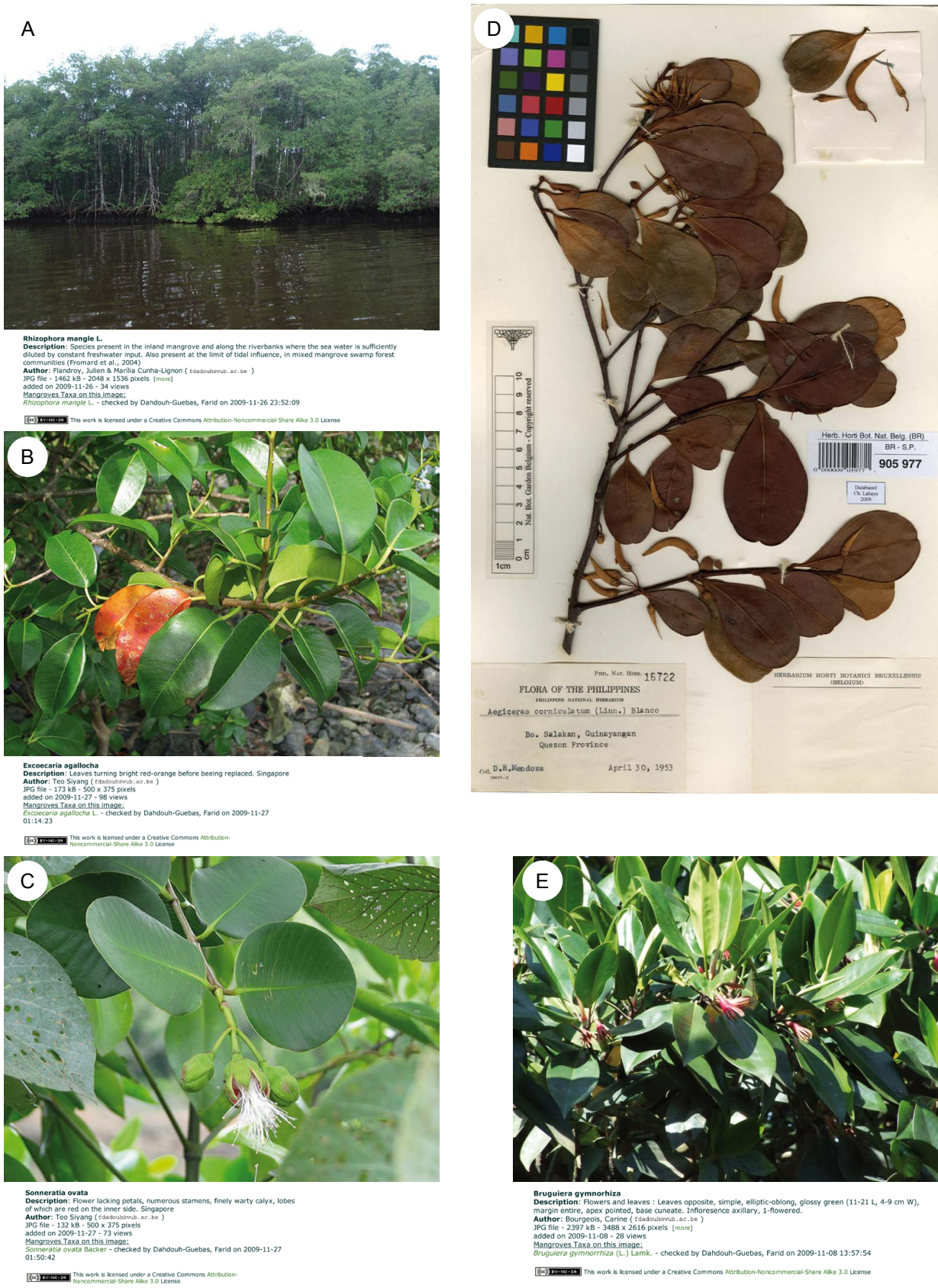

Figure 3 – Screenshots of the information in the fact sheets: A, the physiognomy and ecological growth conditions in *Rhizophora mangle* L.; B, the leaves in *Excoecaria agallocha* L.; C, flowers in *Sonneratia ovata* Backer; D, the herbarium sheet of *Aegiceras corniculatum* (L.) Blanco, specimen 905977, record ID 424868 at BR; E, leaves and flowers of *Bruguiera gymnorrhiza* (L.) Lam.

ic coordinates or maps provided by the authors or by existing gazetteers. The MRDH also links to the complete reference of the respective literature record, which is important in a historic research context. All studies in which the mangrove plant species lists proved impossible to be georeferenced below country-level are currently excluded from the database. This does not jeopardize the integrity of the database, since country-level data were acquired from global sources that were already included in the database (e.g. Spalding et al. 1997, 2010). All the studies focussing on a single species without reporting other species present in the area (e.g. studies on the extraction of biochemical substances from a particular species) are currently excluded as well, but they will be integrated at a later stage. In parallel to the introduction of literature records into the database, we also integrate historic mangrove distribution data through herbarium records. Data retrieved from herbarium specimens of collaborating institutions (see acknowledgements) can be recognized by their herbarium reference numbers and include: species identity, locality and year of collection.

Descriptions of mangrove species are mainly based on Tomlinson (1986) and Duke (2006), but it is worth emphasizing that, even though the mangrove plant species list from the database focuses on what are considered to be true mangrove plant species on a global scale, the database itself is dynamic and species lists can be expanded where needed. The project does not intend to provide exhaustive species lists of mangroves associates. As indicated above through the papers by Jayatissa et al. (2002) and Dahdouh-Guebas et al. (2005a, 2005b), the scientific interest in distinguishing true mangrove plant species (both major and minor components as defined by Tomlinson 1986) lies in the socio-ecological functionality of the species, e.g. representatives of the Rhizophoraceae are more vulnerable, more valuable and more functional than mangrove-associate species. Therefore their conservation is of prime importance.

The resulting distribution maps emphasize georeferenced points, but also indicate polygons for a particular country, representing the country-level information in studies that cannot be georeferenced below country-level or other global databases.

The MRDH is part of a larger database and IT platform called 'Aphia', hosted by VLIZ. Aphia (not an acronym, but a random fish genus) is also the taxonomic IT platform used by the World Register of Marine Species (WoRMS), which is now a collection of over twenty global, regional and thematic taxonomic databases (Appletans et al. 2010). The data in the MRDH is therefore immediately reflected on the WoRMS website. The data stored in Aphia are also contributed to other global initiatives such as the Encyclopedia of Life (EoL), the Global Biodiversity Information Facility (GBIF), the Global Names Index (GNI) and the distribution data will be made available to the Ocean Biogeographic Information System (OBIS), which is the information component of the Census of Marine Life (CoML).

The Aphia system provides password-controlled access to the database for 'editors' to validate, add, edit and/or remove information directly via the web interface. Access to the taxonomic information is restricted to recognized taxonomic editors, whereas literature references, distribution records, images, specimen details, etc. can be added by the academic staff involved in the coordination and maintenance of the database (after inquiring a personal login). The information is directly available to interested readers and researchers with access to the internet.

Finally, we refer to the aforementioned website for updated descriptions on database holdings, operation and maintenance.

ACKNOWLEDGMENTS

We thank the following institutes for logistic support, photographs or access to herbarium records: Academy of Natural Sciences, Philadephia, USA (PH); Annamalai University, Parangipettai, India; Australian National Herbarium, Canberra, Australia (CANB); Belgian Biodiversity Platform, Brussels, Belgium; Herbarium of the University of Puerto Rico, Río Piedras, Puerto Rico (UPR); Herbarium of the University of South Florida, Tampa, USA (USF); Missouri Botanical Garden, St. Louis, USA (MO); Herbier National de Paris, Paris, France (P), Muséum National d'Histoire Naturelle – MNHN, Paris, France; Museu Nacional de História Natural – Jardim Botânico, Lisboa, Portugal (LISU); Nationaal Herbarium Nederland, Leiden, The Netherlands (L); National Botanic Garden of Belgium, Meise, Belgium (BR); National Taiwan University, Taipe, Taiwan (TAI); Real Jardín Botánico de Madrid, Madrid, Spain (MA); Royal Ontario Museum Green Plant Herbarium, Toronto, Canada (TRT); United Nations Environment Programme – UNEP, World Conservation Monitoring Centre – WCMC, Cambridge, United Kingdom; Université Libre de Bruxelles – ULB, Brussels, Belgium (BRLU); University of California Davis Centre for Plant Diversity, Davis, USA (DAV); Vlaams Instituut voor de Zee – VLIZ, Oostende, Belgium; Vrije Universiteit Brussel – VUB, Brussels, Belgium (BRVU), and William and Lynda Steer Herbarium of the New York Botanical Garden, New York, USA (NY). We refer to the aforementioned website for support from other institutions obtained after publication of this paper. This research is published within the framework of the EC-funded Marie-Curie International Research Staff exchange Scheme entitled Coastal Research Network on Environmental Changes - CREC (Grant Agreement n° 247514). We thank Thomas Janssen for his critical comments on the paper. This paper is based on a poster presented at the Young Botanists Day 2009 organized by the Royal Botanical Society of Belgium, November 2009, Brussels.

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Manuscript received 20 Apr. 2010; accepted in revised version 26 May 2010.

Communicating Editor: Elmar Robbrecht.