FloraGREIF — virtual guide and plant database as a practical approach to the flora of Mongolia

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Source: Willdenowia, 41(2) : 371-379

Published By: Botanic Garden and Botanical Museum Berlin (BGBM)

URL: https://doi.org/10.3372/wi.41.41217

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Abstract

Rilke S. & Najmi U.: FloraGREIF – virtual guide and plant database as a practical approach to the flora of Mongolia. – Willdenowia 41: 371–379. December 2011. – Online ISSN 1868-6397; © 2011 BGBM Berlin-Dahlem.
Stable URL: http://dx.doi.org/10.3372/wi.41.41217

FloraGREIF is a web-based collaborative project on the flora of Mongolia. It presents a plant database and a virtual herbarium as an introduction to the flora of Mongolia and intends to be used as a digital information system providing taxonomic and biogeographical data. Moreover, it offers a virtual research environment which allows scientific online cooperation. This project refers to the ongoing long-term research cooperation between Germany and Mongolia. It brings together large herbarium collections and modern online communication facilities. The website is a dynamic system with two basic hierarchy levels. On the record level, as many records as possible for a taxon are included. A record is represented by location data, digital scans of herbarium specimens and images of living plants and their habitats. The taxon level presents information about a taxon such as short morphological description, taxonomic comments and hints for reliable identification. Plant data can be explored in a targeted way using various aspects as well as by browsing through the material to obtain an overview. The information can be downloaded at any time and place.

Additional key words: virtual research environment, digital herbarium specimens, plant identification, plant photo database, biodiversity informatics, webGIS

Introduction

Located in an extremely continental position on the edge of northern central Asia, Mongolia is populated by circumboreal and Eurasian flora elements in its northern part and dominated by desert and semidesert vegetation elements in the south. Vegetation zones from taiga to desert can be found here. Although agricultural use is not widespread, increasing nomadic grazing is affecting the sensitive steppe and desert flora intensively. Nearly 30 % of the sparse population of only 2.9 million people live nomadically or seminomadically. Pasture livestock increased from 25.8 million head in 1990 to 33.6 million head in 1999 (NSOM 2003). This continues to cause serious changes in the vegetation. Recent projects (e.g. Schickhoff 2007) are studying the process of degradation in detail and are developing proposals to protect and preserve the natural resources.

In the field of botany and plant sociology, Mongolian-German research cooperation dates back to the GDR (German Democratic Republic) era and is still very fruitful today. The joint research during expeditions and at special research stations has resulted in international conferences, many publications (Gubanov & Hilbig 1993; Dorofejuk & Gunin 2000), as well as various additions to the plant inventory, the description of new species and phytochemical analyses. Geobotanical and ecological investigations yielded detailed vegetation descriptions for different parts of the country and an extensive review of the Mongolian vegetational units and their site conditions as summarised by Hilbig (1995). Support was also given

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for the protection of nature in Mongolia, especially for planning and working out a concept for national parks, the establishment of protected areas and the work on red lists (Knapp & Tschimed-Otschir 2001; Dulamsuren & al. 2005). Hilbig (2006) deals with the intensive floristic research of German botanists in Mongolia in collaboration with their Mongolian partners during the last 40 years. In 1982, the publication of the series "Explorations into the biological resources of Mongolia" (Stubbe & al. 2007) was begun and up to now ten issues have been released. They include comprehensive issues as well as those dedicated to a particular topic.

FloraGREIF

Sizable collections of Mongolian plants have been brought together in the course of the Mongolian-German research cooperation. The herbarium of the University of Greifswald (GFW) holds some 5000 specimens, the herbarium of the University of Halle (HAL) about 10 500 specimens and the herbarium of the Plant Genetics Institute in Gatersleben (GAT) about 10 000 specimens, to name only the largest three. Collections of plant and habitat photographs, which are rapidly increasing thanks to digital photography, as well as vegetation and occurrence data are other existing resources complementing the herbarium specimen. Given the lack, on the other hand, of a modern Flora of Mongolia, the perspective has been developed to create a digital information system, which integrates electronically the various data sources from herbarium specimens and photographs to taxonomic and geobotanical information and at the same time serves as a digital working platform. Under the name FloraGREIF, this perspective became a joint project of the Institute of Botany and Landscape Ecology, the Institute of Geography and Geology and the Computer Centre of the University of Greifswald, funded by the DFG (German Research Society) from 2007 to 2010. During these three years, a basic system was established, which has been improved continually since then. Maintenance and sustainability, involving server uptime, hardware updates and database backups are secured by the Computer Centre of the University of Greifswald.

As the result, FloraGREIF (2008+) contains a digital database with taxonomic, biogeographical and ecological information accessible via internet. It allows easy species identification by means of visual comparison of scans of reliably identified herbarium specimens, macro photographs with taxonomic characteristics relevant for species identification, and photographs of living plants in their natural environment. The digitised specimens may serve also as a source for further taxonomic revisions. By means of a webGIS application, distribution data of the species permit spatial evaluation of distribution and habitat. Recently, a 'Herb-Scan' device has been purchased by the University of Greifswald and at some time in 2012 the entire Mongolian herbarium material at GFW will be available online as part of FloraGREIF.

Hence FloraGREIF provides a comprehensive digital information system for taxonomic and biogeographic data and image resources and offers a webbased virtual research environment which allows scientific online cooperation across the globe. It uses rapidly evolving standard technologies available all over the world, such as

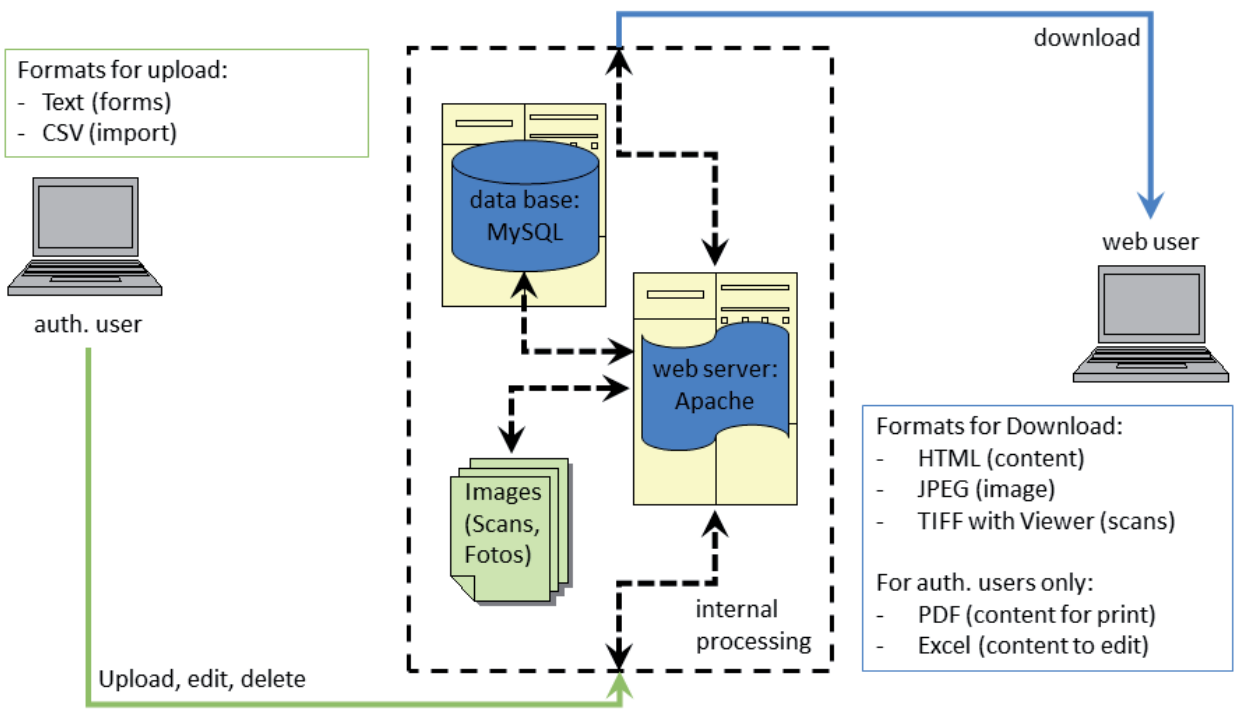

Fig. 1. Data access in FloraGREIF, greatly simplified.

digital photography to document plants, GPS systems to record exact coordinates for localities and the internet to disseminate information, making our findings accessible to all and can therefore be easily implemented everywhere.

System and datastructure

The system is completely based on open source components: MySQL (database), Zoomify Express (software used to minimise loading time for large image files), HTML (display), PHP (script programming language), and Apache-Webserver with Linux (Fig. 1). The FloraGREIF content management system can be reused for other projects as well. We will share the source code with any institution interested in non-commercial use of the system. Metadata are stored in the database, whereas image files are located in the file system. The database is queried for each search request; thus the user will always receive the latest updates. Internet users may query the information system online free of charge. The results will be displayed in the web interface; authorised users may download data as Excel or pdf files.

Editors themselves can add new data via the web interface instead of submitting it to an administrator. This functionality is already operational and will be tested by external users in the near future. At the record level, a data set consists of a herbarium specimen (with scans, photos, or both) or proof of the occurrence of a taxon by a photograph with a description of the location where it was found and of the date when it was found. A scan of a herbarium specimen as a TIFF file comprises c. 200 MB. Therefore, we use the free software Zoomify Express to prepare the files for online presentation. This special technique splits the large file systematically into tiles. Processing can take place as a batch process. This digital compression technology makes quick access to the scans of the herbarium specimens possible. Photo files can also be uploaded into the web interface. A timestamp is added to achieve unique file names. Thumbnails are created automatically.

Location data, in as much detail as available, are registered for each record. The given coordinates can be checked with webGIS functionality. Location data will be used for the planned compilation of distribution maps.

Record data sets can be edited in the public area or in another internal area. Records in the public area are immediately available online. Records in the internal area are visible for authorised users only. That way, editors can import their field lists, but also treat and publish the collected records individually.

Taxon data are edited in the public area only. Therefore, the user will always receive the current state of information on the website. Record sets and species information are linked dynamically (Fig. 2). Each record is identified as a taxon (species, subspecies or genus); an uncertain identification can be indicated. The following details are registered for each taxon: name, author,

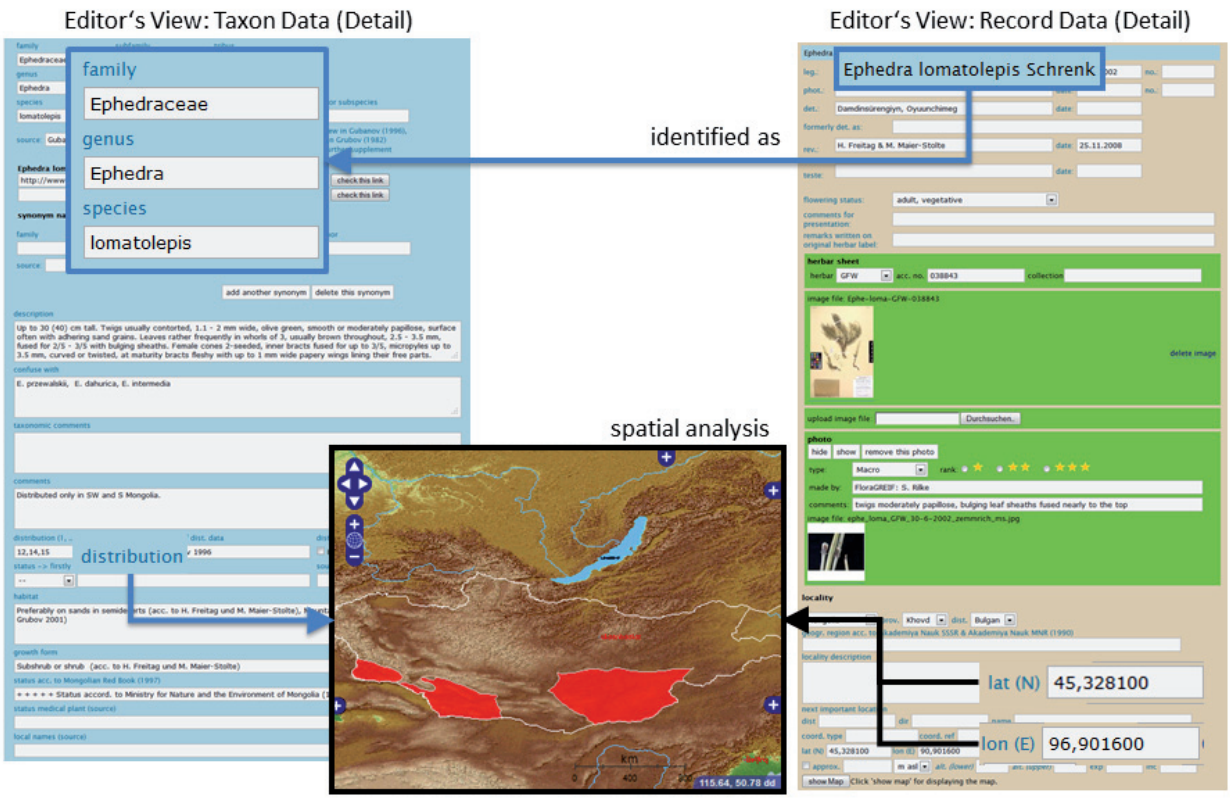

Fig. 2. Schematic diagram of data input in FloraGREIF.

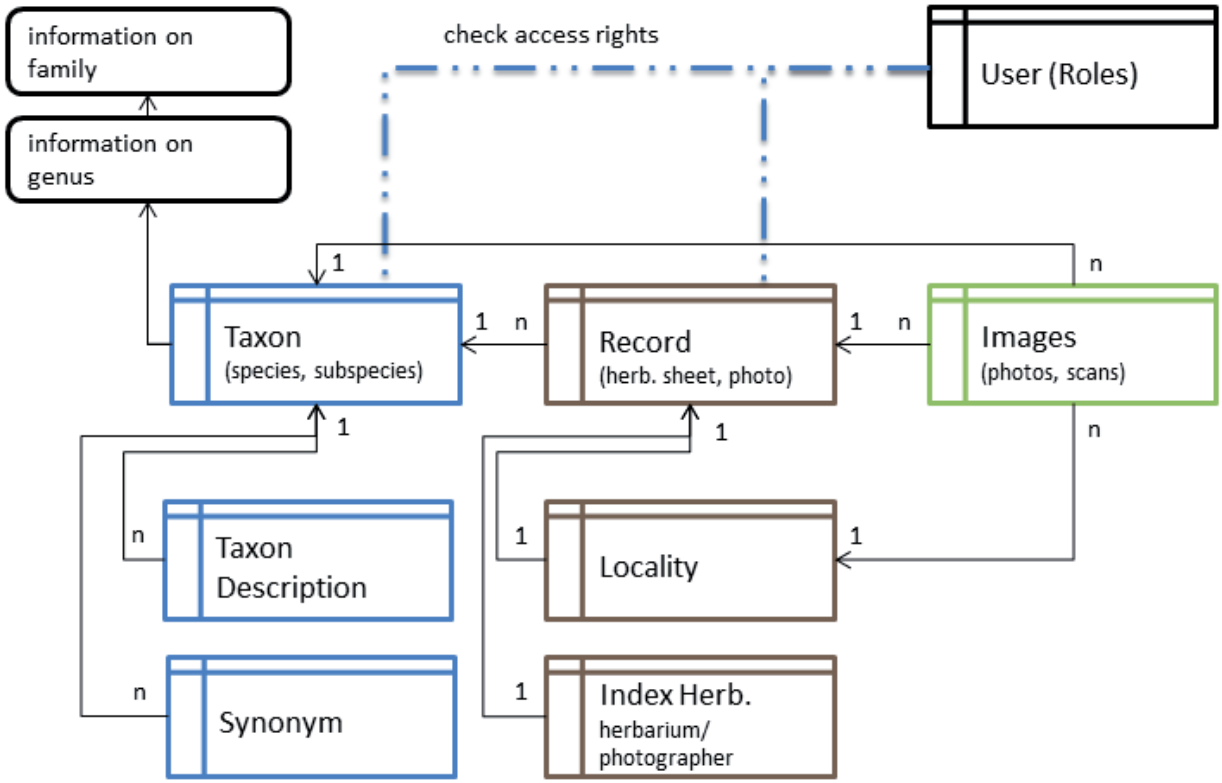

Fig. 3. Data structure of FloraGREIF, greatly simplified.

source, important synonyms, short description, taxonomic comments, habitat, status of endemism, red list status, distribution and, if applicable, the link to the species in the online version Flora of China (Wu & Raven 1994+).

Editors can add new data manually as record by record or taxon by taxon, or import mass data in prepared lists as an Excel/CSV file. Values are tested for plausibility before being imported: plant name against existing taxa list, locality against existing locality list, data type by string or number and field length. Each import list is given a unique identifier. That way, the editors can enter new data sets as well as update existing ones.

The database is structured in a way that allows both practical treatment and straightforward modification (Fig. 3). While preparing FloraGREIF, we discussed data models implemented in related projects. The Berlin Model is a concept of a database-driven application that clearly separates nomenclature from taxonomy as implemented in the project MoReTax (Berendsohn 2003). It is capable of even representing different taxonomic views and nomenclatural rules. In the context of the practical approach to our information system, this structure is too complex to meet the needs of our application. The focus of the hands-on project FloraGREIF is on the given comprehensive checklists enhanced by the latest floristic and taxonomic literature. The taxon datasets are cross-checked in most instances with established systems: IPNI (IPNI 2004+) and NCU (Greuter & al. 1993). Only NCU is checked automatically by running a script.

The FloraGREIF project implements a simplified taxon structure: each data set represents a species or subspecies. Each species can be linked to additional information, e.g. a comparative table of the important characteristics for diverse and hard to identify genera. Furthermore, editors can enter information on a genus or a family, such as descriptions and remarks on the treatment. For further reference, the editor's name is also registered.

Technically, record and taxon are linked by the allocation table "flora_identifications". The flag 'current' indicates whether it is the current or a revised identification.

Each record is stored as data set in the table "flora_records" with the following information: identified as, collected by, determined/revised/confirmed by, date, locality, habitat, presentation remarks, flowering status. Details on the locality such as country, province, district, etc. are stored separately in the table "flora_locality"; specifications on the herbaria are stored in the table "flora_index_herbariorum". Whether the record is public or internal is indicated by a flag of true/false for each data set.

Metadata on images, such as name of the photographer and description of the contents, is stored in the table "flora_photos". An image is allocated to a record with a locality. Furthermore, images can be allocated to localities to illustrate the habitat. Images can also be allocated to a taxon; currently, this is in use only for herbarium sheet scans.

User management is basically a role management. Each user action, such as enter new record/taxon, edit one's own record, edit others' records, edit taxon, delete record, delete taxon, is defined as a capability. The system administrator is responsible for organising the capabilities as roles that are assigned to the users.

The data output is organised as HTML in the web front end by default. All public data including taxon, record and image data can be downloaded this way. In the editor's area, the user may download all data as Excel files for further treatment or import and as pdf files for printing.

The user can specify a search request by providing detailed parameters. These parameters are encoded in the URL, e.g. http://greif.uni-greifswald.de/floragreif/?flora_search=Record&fam=Ephedraceae, which shows all records for the family *Ephedraceae*. This facilitates linking to FloraGREIF from external web pages, e.g. from the given family in Wikipedia (2011).

Right from the start, FloraGREIF has been designed as a web application. This offers a variety of possibilities for online cooperation with experts worldwide, such as revising herbarium specimens, editing taxon nomenclature and descriptions, sharing comments on taxa, analysing and updating distribution information and identifying plant images.

Browse and search interface

Online users can browse through the treatments by family and genus name. The user immediately receives an overview about the occurring taxa including the genera belonging to each family and the species in each genus, the available records, images, and further remarks on the family or genus, as well as the editor's name. Icons characterise the images by their types: scan of herbarium specimen, photo of living plant, photo of plant in its habitat (Fig. 4).

Moreover, users can search the database targeted at the levels: Taxon – Record – Image (Fig. 5). Search results are well-arranged; levels of information are linked to each other. Thus, the user can quickly navigate from taxon to record or image data and vice versa.

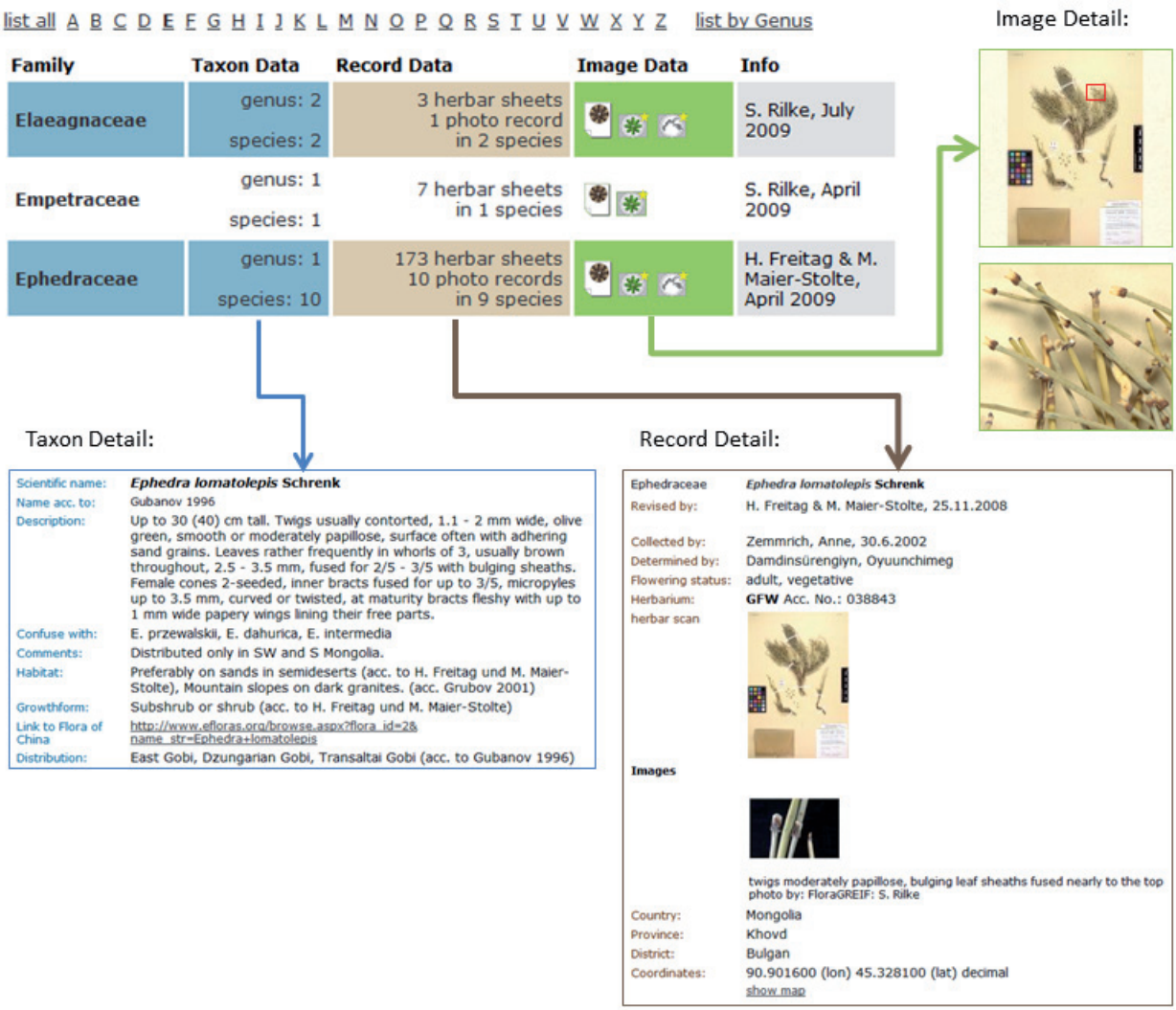

Fig. 4. Web search with FloraGREIF: browse content.

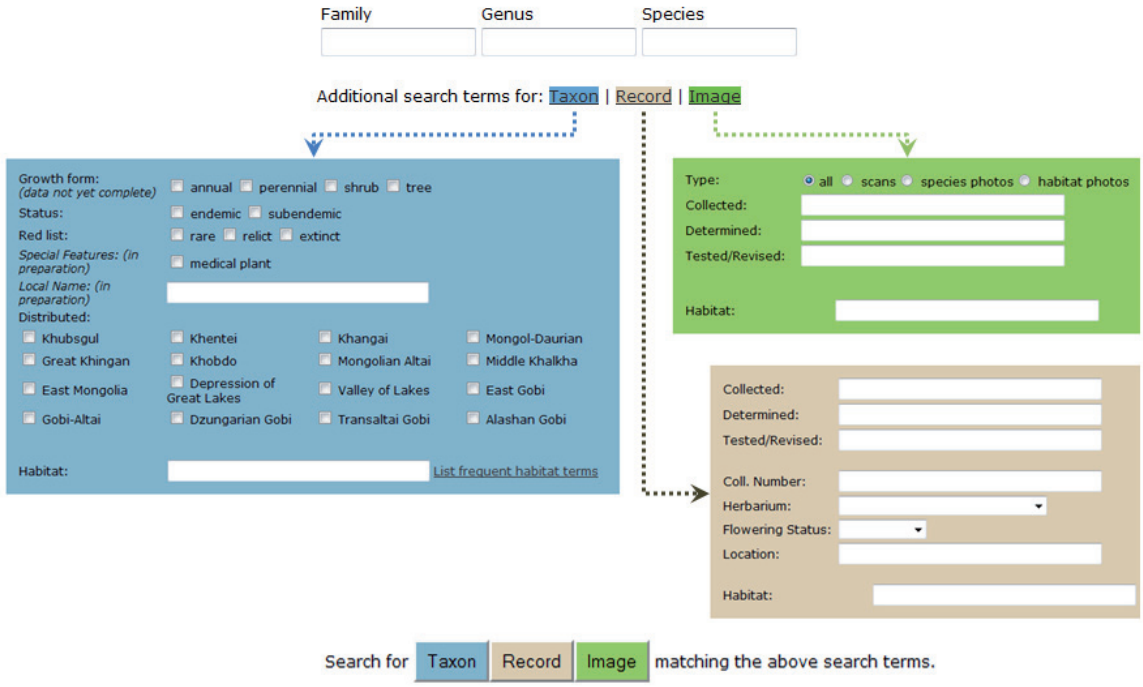

Fig. 5. Targeted web search with FloraGREIF: parameters.

Search results are generated dynamically from the current status of the database. Therefore, users will always receive the latest information.

The information system can be searched with the following parameters:

(1) Taxon data:
- Name: family, genus, species (including synonyms)
- Growth form: annual, perennial, shrub, tree
- Special features (in preparation): medicinal plant
- Status: endemic, subendemic
- Red list status: rare, relict, extinct
- Distribution area (geobotanical units acc. to Grubov 1952, 1955 modified): Khubsgul, Khentei, Khangai, Mongol-Daurian, Great Khingan, Khobdo, Mongolian Altai, Middle Khalkha, East Mongolia, Depression of Great Lakes, Valley of Lakes, East Gobi, Gobi-Altai, Dzungarian Gobi, Transaltai Gobi, Alashan Gobi
- Habitat (frequent terms for habitat description are listed)

(2) Record data:
- Collector/ coll. number
- Determined by, tested/revised by
- Herbarium
- Flowering status (phenology): vegetative, flowering, fruiting
- Habitat
- Location

(3) Images (always related to a record):
- Type: scan of herbarium specimen, species or macro photo, habitat photo
- Photographer

Floristic content and statistics

Currently, 2870 species of vascular plants are included in the "Virtual guide and plant database to the flora of Mongolia" (FloraGREIF 2011).

The species inventory is based on Gubanov's (1996) checklist, which contains 2823 taxa in 662 genera from 128 families. It updates and broadens Grubov's (1982) essential field guide, which provides a very practical key and concise descriptions for 2239 species. This taxonomic backbone was gradually expanded to the current size from publications and through revisions, e.g. Gubanov (1999), Ebel & Rudaya (2002), Neuffer & al. (2003), Dulamsuren (2004), Friesen & al. (2006), Scholz (2010).

For all species, the name and source of the name, synonyms of names from the relevant literature, status of endemism, typical habitat and information on distribution are available. In case of difficult or deviating taxon names, the nomenclature was checked using the available literature and cross-checking with IPNI (2004+). The nomenclature of genera was checked with NCU (Greuter & al. 1993) but accepted according to editors' concepts. The families are treated according to APG III (Stevens 2001+).

The distribution of the species in Mongolia is recorded in the geobotanical units (phytogeographical regions) according to Grubov & Yunatov (1952, Grubov 1955 modified) and shown in layers, depicted as red distribution areas (Fig. 6) using the webGIS functionality.

1009 species, 35 % of the flora, have been edited in depth: scans of herbarium specimens and photos are available for 827 species, descriptions and comments are available for another 297 species. Currently, 6553 spe-

cies photos are included. They show habit, leaves, inflorescences, flowers, and fruits and thus focus on identification features. This goes along with our intention to visualise the most important key features in order to add to existing floras of Mongolia.

For an exemplary comprehensive treatment of 44 families, the available material from B, GAT, GFW, HAL, JE, KAS, LE and OSBU (abbreviations following Thiers 2008+) was studied to be able to give a concise description, details about species easily confused and comments. For that purpose, the following sources were used: Flora of Central Asia (Grubov 1963–2008), Flora SSSR (Komarov 1934–63), the floras of adjacent Siberia (Malyshev & al. 1988–2003) and the Russian Far East (Kharkevich 1985–96), as well as Flora of China (Wu & Raven 1994+). An instructive herbarium specimen of each species with as many identification features as possible was chosen from the herbarium material at hand and is presented as a high resolution scan. Overview tables of related species groups (e.g. *Stipa, Carex, Suaeda* and *Tamarix*) or thematic views (e.g. water plants) are linked to the corresponding species.

The edited families are: *Adoxaceae, Alliaceae, Apiaceae* (p.p.), *Apocynaceae, Asclepiadaceae, Asteraceae (p.p.), Balsaminaceae, Biebersteiniaceae, Butomaceae, Callitrichaceae, Cannabaceae, Ceratophyllaceae, Chenopodiaceae, Cynomoriaceae, Cyperaceae, Dipsacaceae, Elaeagnaceae, Empetraceae, Ephedraceae, Fabaceae* (p.p.), *Frankeniaceae, Geraniaceae, Haloragaceae, Hippuridaceae, Hypecoaceae, Hypericaceae, Juncaginaceae, Malvaceae, Menispermaceae, Menyanthaceae, Najadaceae, Nymphaeaceae, Orobanchaceae, Paeoniaceae, Papaveraceae, Pinaceae, Poaceae* (p.p.), *Polygonaceae, Ranunculaceae, Rhamnaceae, Tamaricaceae, Thymelaeaceae* and *Verbenaceae.* These families were chosen with regard to their practical value. Families including genera dominating the vegetation (e.g. *Artemisia, Stipa, Anabasis* and *Suaeda*), key species for arid habitats or on salty soils and critical groups that are hard to determine (e.g. *Ephedra, Artemisia, Cichorieae, Chenopodiaceae, Poaceae*) were given priority.

Since we were supported by leading taxonomists for some critical taxon groups, FloraGREIF provides thoroughly revised material of these plant groups for Mongolia. Up to now, H. Freitag (*Suaeda,* Kassel), N. Friesen (*Allium,* Osnabrück), K. F. Günther (*Apiaceae,* Jena), P. Hanelt (*Papaveraceae,* Gatersleben), N. Kilian (*Cichorieae* p.p., Berlin), P. Kuss (*Pedicularis,* Wien), M. Maier-Stolte & H. Freitag (*Ephedra,* Kassel), D. Podlech (*Astragalus,* München), E. von Raab-Straube (*Saussurea,* Berlin), H. Scholz (*Eragrostis,* Berlin), R. Wisskirchen (*Polygonaceae,* Bonn) have contributed to our work.

Presented records

6152 plant records are currently online with 997 scans of herbarium specimens, 5837 species photos, 734 macro photos, and 734 habitat photos (date: September 2011). Most pictures were taken by M. Schnittler, M. Stubbe, M. Kretschmer, A. Zemmrich, F. Joly, M. Vesper and S. Rilke. The combination of digitied herbarium specimens and macro photos of living plants collected at the same location, stemming from our additional expeditions, is especially valuable. Because mature fruit is often missing in herbarium material, these excursions took place as late in the year as possible for phenological reasons. This particularly holds true for *Asteraceae, Boraginaceae, Brassicaceae, Chenopodiaceae* and *Fabaceae,* for which the essential distinguishing characteristics are to be found in the fruit.

Further content

734 records additionally provide one or more photos of the specimens in their natural habitat, so the user can gain an overview about the species' environment.

127 endemic plant species and 154 subendemic plant species are listed for the flora of Mongolia according to Gubanov (1996) and can be queried in FloraGREIF by choosing 'targeted search', entering the taxon search parameter, ticking the checkbox status: endemic or subendemic (Fig. 5). Further information about the endemic plants of the Altai Mountains is given by Pyak & al. (2008), but is not yet provided in this database. 97 rare, 23 relict and 2 extinct species are registered according to the Mongolian Red Book (Shiirevdamba & al. 1997) and can be found by 'targeted search' (see above).

The cited literature is searchable. It consists of all literature citations in FloraGREIF, supplemented by the bibliography on the vegetation of Mongolia (Zemmrich 2007). About 200 citations on vegetation and 120 citations on the flora of Mongolia are included.

WebGIS

Spatial analysis (webGIS) is facilitated by combinations of digital topographical maps, elevation models, and digital thematic maps (e.g. vegetation zones, soil zones and satellite data on the vegetation cover).

The web client is Open Layers, an open source software that has been modified to meet the project's requirements. The web mapping service Moskito-GIS is compliant with OGC (Open Geospatial Consortium). These standards specify methods, tools and services for data management (including definition and description): acquiring, processing, analysing, accessing, presenting and transferring geographic data in digital form between different users, systems and locations for geographic information (Fig. 6).

Features available are: (1) location of selected record in (a) base map layer, (b) map of provinces, (c) satellite images, (d) map of geobotanical units, (e) vegetation zones and (f) topographic map; (2) distribution of selected species in vegetation zones. Additional features to be

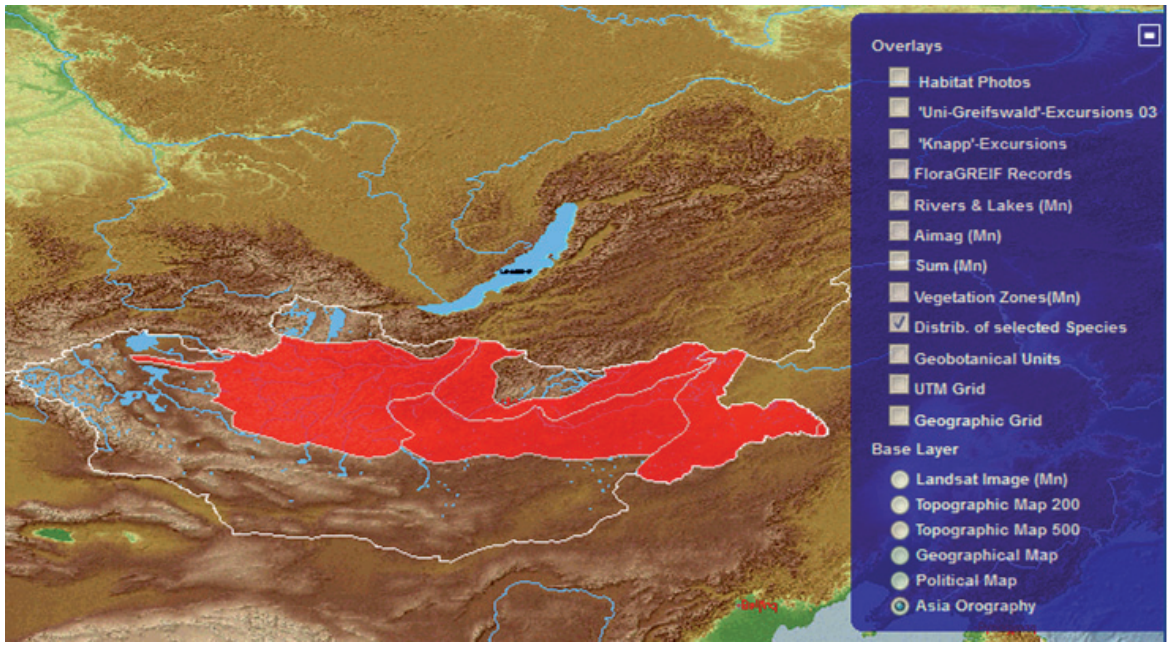

Fig. 6. Example of webGIS display with overlays and base layers of distribution data in FloraGREIF: distribution of *Stipa grandis*.

realised in near future are the display of record locations in maps, additional map layers (geographical regions, topographic maps 1: 500 000), additional point data layers (e.g. habitat photo sites to choose from the map) and a gazetteer service.

Next steps

Broadening the content base of FloraGREIF is a long-term perspective. Next steps concern the inclusion of already gathered records from the Ulaanbaatar Herbarium in the information system and the integration of digitised collections located in Görlitz (collection by K. Wesche) and Osnabrück (OSBU).

Currently in preparation is the implementation of interactive identification keys in FloraGREIF.

Since the prerequisites are already implemented, it is planned to open FloraGREIF to a wider community for direct data access, enabling experts in the field to add and edit taxon or record data in FloraGREIF online.

Further revisions will be added continually to the taxon and record database, e.g. *Caryophyllaceae, Zygophyllaceae* and *Fabaceae*.

Currently, the system is organised along the basic taxonomic levels of family, genus, species and subspecies. In the future, this structure will be expanded to include the intermediate ranks subfamily, section and tribe.

The export of specimen data will be extended from pdf (for printing) and Excel (for further treatment) to the standard ABCD (GBIF) using the BioCase Protocol.

Acknowledgements

We would like to thank the following people and institutions for making FloraGREIF possible: the project leaders Martin Schnittler and Reinhard Zölitz, the project members Jörg Hartleib, Susanne Starke, Anne Zemmrich (all Greifswald), the herbaria B, GAT, HAL, JE, KAS, LE, OSBU, W and their curators for making collections available directly, on loan or as digital images, the Mongolian Academy of Sciences, Ulaanbaatar (M. Urgamal & I. Tuvshintogtokh), University Khovd (D. Oyuunchimeg) and the DFG for project funding from 1.7.2007–5.11.2010.

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