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FloraGREIF – An Internet-Based Data Repository for Biogeographical Research in Mongolia

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Abstract FloraGREIF presents an internet-based information tool on the vascular plant flora of Mongolia combining taxon- and record-specific information, text and image information with map information and digitized plant specimens with images of living species and their habitats. Based on an updated checklist as taxonomic backbone, information is split into the "taxon" and the "record" level. At the taxon level the user finds taxonomic diagnoses, habitat information, and species distribution within the floristic regions of Mongolia. The latter is visualized in a Web GIS application. The record level offers information for all records assigned to one taxon, which may include locality data only or additional, high-resolution scans of herbarium specimens combined with images from living species and their habitats. Several query masks allow a flexible search and display of species lists. The interactive Web GIS application links taxon or record information with various map layers, comprising administrative units, topography and orography, floristic regions and vegetation zones of Mongolia. They present background information for the display of species distribution or record localities. FloraGREIF offers a virtual research environment to make the substantial information on Mongolia's flora mainly published in Russian accessible to the public.

Keywords Biogeography · Floristic database · Mongolia · Record · Taxon · Web GIS

Introduction

Mongolia, located in the interior of the Eurasian continent with an extremely continental climate, harbors vegetation zones from the taiga to steppes and deserts.

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Information about the country's flora and vegetation is mainly published in Russian and hardly accessible due to language barriers. As a result of four decades of biological research in Mongolia beginning in the early 1960s (Gubanov and Hilbig 1989; Pavlov et al. 2004; Hilbig 2006), extensive collections of herbarium specimen for vascular plants are preserved in several institutions in Russia, Mongolia and Germany (herbaria LE, UB, HAL, GAT, GFW). In recent years, revisions of the country's flora became subsumed in revised English publications on the flora of Central Asia (Grubov 1963–2008, 1999–2007), Siberia (Malyshev et al. 1988–2003), Russian Far East (Kharkevich 1985–1996), and China (Wu and Raven 1994+). Additional reviews of certain taxa are widespread in several journals (e.g., Friesen 1995; German 2001; Revushkin et al. 2001). The only consolidated treatments of the flora of Mongolia dates back to Grubov's annotated identification key (Grubov 1982) and to the checklist of Gubanov (1996, 1999). Several studies give spatial information on the biogeographical division of the country (Grubov and Yunatov 1952; Meusel and Jäger 1992; Malyshev 2000) and selected regions (Rachkovskaya and Sanchir 1983; Golubkova and Kamelin 1989), endemism (Grubov 1984; Wesche et al. 2005) and vegetation zoning of Mongolia (Lavrenko 1979; Gunin and Vostokova 1995), but little of this information has been compiled in maps and the few existing maps are hardly accessible in Western countries. As Mongolia harbors unique examples of non-fragmented native grasslands dominated by traditional nomadic grazing, ecosystem processes and their interactions receive increasing attention in ecological research (see as examples PEWM 2007; Fernandez-Gimenez 2011).

The rapid development of digital data processing and storage allows the provision of extensive biodiversity information in terms of species information, images, and spatial data in worldwide accessible internet databases. In Web GIS applications thematic map layers are laid over base maps and locality data can be visualized as points on thematic maps (CBIF 2006; USGS 2009). Internationally renowned large herbaria use virtual herbarium scans for the generation of "digital species loans" and digitize herbarium sheets using high resolution images. Most of those activities are taxonomy-oriented and focus on digitizing herbarium specimen from type collections. Spatial data are often excluded or do not provide more information on finding localities and habitats than what is written on herbarium labels (http://ww2.bgbm.org/herbarium/, http://www.aluka.org/). Information of plant species is often separately stored in floristic databases (Floraweb at http://www.floraweb.de/, USDA plant database at http://plants.usda.gov/). Several further initiatives use digital data technology and photography for electronic floras with various priorities. They may offer traditional taxonomic diagnostic systems (overview on http://www.efloras.org/) or interactive keys for species identification (e.g., for urban trees provided by the British Natural History Museum, http://www.nhm.ac.uk/nature-online/british-natural-history/urban-tree-survey/identify-trees/tree-key/index.html; for the *Carex* species of North America, http://utc.usu.edu/keys/Carex/Carex.html), they facilitate verifications of species identification using photographs (http://www.mobot.org/MOBOT/Madagasc/welcome.html, http://www.visualplants.de/) or provide multiple online information such as individual species distribution, ecology, conservation status etc. (http://www.eflora.bc.ca/). Most of these projects have a regional focus.

With FloraGREIF (Greifswald University 2010+) we present an internet-based information system on the vascular plant flora of Mongolia that pools several of those

approaches. It combines taxon-specific along with record-specific information, text information with map information, and digitized plant specimen with images of living species and their habitats. In addition, maps and thematic map layers are implemented within a Web GIS application that allows the visualization and the analysis of distribution data of Mongolia's flora. Database information is partitioned within two levels: the taxon level where manifold information about a species can be found and the record level, presenting detailed information on collected or recorded plant individuals. This data partition consistently offers brief general descriptions of species' and their habitats, but also enables reference to habitat and locality data for single records. Both data levels are linked by the name of the respective plant species. In this paper we give an introduction to structure and contents of FloraGREIF. We focus on spatial information inherent in text data and maps, the system capabilities for spatial visualization and provide examples how the database can be applied as an explorative tool at different data levels.

FloraGREIF Data Structure

Species Data

The essential components of FloraGREIF comprise a database of taxa (with focus on the species rank) and record data of Mongolian vascular plants, a complex query algorithm to search at both levels, and an interactive Web GIS application to visualize spatial information such as species distribution within the country's floristic regions, but also localities for records assigned to a certain taxon. In addition, an overview of literature, separately for cited and further biodiversity-oriented literature including main Russian publications in this field is provided (latter is given using English titles and keywords).

The taxonomic backbone of the database includes the ranks, family and genus plus species and infraspecific ranks in a hierarchical order. It is based on the checklist of Gubanov (1996, 1999) and has been updated for taxa recently reported from Mongolia. The Mongolian checklist sensu Gubanov (1996) comprises 2,823 species but the updated version in FloraGREIF based on recent revisions of certain taxa (e.g., Friesen 1995; Ebel 2000) contains 2,876 species. The nomenclature was cross-checked with IPNI and NCU (Greuter et al. 1993). Species with doubtful records for Mongolia were excluded from the databases but are given in a separate list with references for Mongolia and habitat information taken from plant keys of adjacent regions. Currently, we use a simple relational database to account for synonyms, which, however, does not allow considering cases where a taxon was revised to split into two (*pro parte*). For all taxa on species rank, the following are given in Table **1**: a taxonomic diagnosis, habitat specifications, the occurrence within the floristic regions of Mongolia and, where applicable, endemic and conservation status.

The record level comprises all information available for the respective plant specimen or plant record. Most simply, one record constitutes the locality description, essentially comprising the same information as a specimen label with locality description, coordinates, collector/observer/photographer, observation or collection date. As this does not allow verifying the species identification, most records include additional information

Table 1 Overview of data set components available in the FloraGREIF database

Taxon data	Record data	Image data
Family	*Available records*	Type of image (specimen scan, living plant, habitat)
Scientific name	***Scientific name***	***Scientific name***
Description	*Observer*	*Collector*, photographer*
	Accession number of the collector	*Accession number of the herbarium**
Comments on diagnostic characters and possible confusion with other species	Collecting date	Collecting*, photographing date
Habitat	Determined, confirmed, revised (*name*, date)	Confirmed, revised (*name*, date)*
Growth form	*Flowering status*	
Link to Flora of China	*Locality data (country, province, district, geographical region, GPS coordinates, elevation)*	
Status of endemism, conservation status acc. to Mongolian Red Book	*Habitat description*	
Distribution in floristic regions	Comments on specimen label	

Images need to be accompanied by locality data and are part of a record data set. In turn, a record data set is assigned to a taxon, and the data set for a taxon provides general information to that species. Searchable components are written in italics, those linking data sets in bold. Data specific for digitized herbarium sheets are indicated with an asterisk (*).

such as a high-resolution image of the respective herbarium specimen, photos of the living plant and its habitat and one to several macro images, showing details of the plant relevant for determination. Additional information may include phenological state (seedling, specimen sterile, vegetative, or in flowering, fruiting, etc.) and diagnostic characters (Table 1).

Information is presented first by an overview of families and associated taxa, records and images (Fig. 1). Different colors for each data type facilitate an easy perception of information and various icons indicate the image type. A targeted synonym-tolerant search on taxon, record and image level accesses the ranks of family, genus, and species and may apply most data components as search parameters for each data level (Table 1). A further query offers a search for records from certain collectors, habitats, or all records represented by specimen images. In addition, an image gallery including habitat views, scans of herbarium specimen or images of living plants for a taxon can be compiled. Scans of herbarium specimens are given first in low resolution, but similar to the map application in Google Earth, the user can zoom into certain details to view them at maximum resolution. Data levels are linked with each other and thus facilitate an easy navigation from family to genera to species and from taxon to record or image data and *vice versa*. Although a specific web design for portable devices has yet to be created, search functions work well on

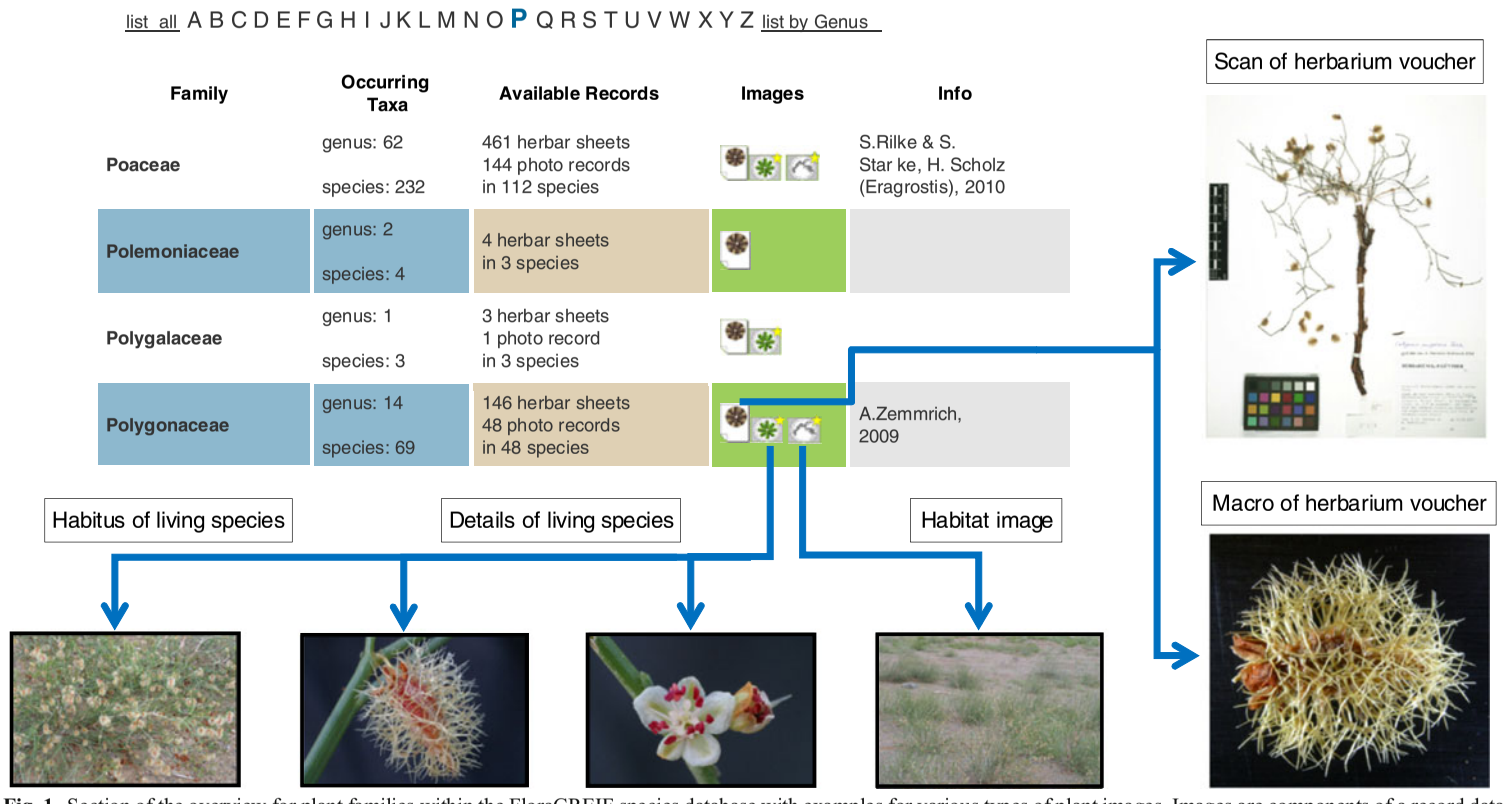

Fig. 1 Section of the overview for plant families within the FloraGREIF species database with examples for various types of plant images. Images are components of a record data set or constitute an independent record by itself, if provided with locality data

smartphones supporting the comparison of a plant in the field with data and images available in FloraGREIF.

Currently, in July 2012, 2,876 vascular plant species in 662 genera belonging to 128 families are listed for Mongolia. Of these, 1,009 species, covering 35 % of the country's flora, have been edited in depth. A total of 6,748 records representing 1,249 species provide locality data, digitalized herbarium specimens (975 species by 1,520 scans), images of living plants (731 species by 5,992 images) including close-ups (734 images), and habitat images (341 species by 775 images) or a combination of all, often representing the very same plant. Most images and macros of living plants and their habitats originate from former project activities in western Mongolia (Schickhoff and Zemmrich 2003), whereas the eastern and southern parts of the country are still underrepresented. A significant proportion of additional material came from collecting activities within joint German-Mongolian expeditions conducted over more than four decades (Hilbig 2006), with specimens mainly deposited in the herbaria Halle (HAL), Gatersleben (GAT), and Jena (JE). Families and genera were systematically revised, i.e. by families and genera, with support of specialists for critical taxa. Priority was given to taxa comprising dominant species of Mongolia's vegetation such as *Artemisia*, *Stipa*, Alliaceae, many genera of Chenopodiaceae, or critical taxa that are difficult to determine such as *Ephedra*, most *Cichorieae*, and Poaceae. The statistics included in the web portal gives a regularly updated overview of the continuously growing data set in FloraGREIF (from 6,450 records in January 2012 to 6,748 records in July 2012).

Database Structure

The digital system has been completely established using open source software components such as PHP as script programming language, MySQL for database, and HTML for display, Zoomify Express for zooming and panning of large image files by minimized loading time, and Apache-Webserver with Linux. Core functionality is realized using form templates, weblayout templates, database connection, and user administration on the basis of WordPress. The Dublin

Table 2 Overview of map layers and corresponding sources available in the Web GIS application of FloraGREIF

Map layer	Source
Geography of Mongolia	Akademiya Nauk SSSR and Akademiya Nauk MNR 1990
Topographic Map 1:200,000	UGZZG 1971–1990 (only available for Western region)
Topographic Map 1:500,000	UGZZG 1992–1993
Landsat 7 image mosaic	MacDonald Dettwiler and Associates Federal 2004
Administrative division of Mongolia	Tserennyam 2007a,b
Rivers and lakes	ESRI 2007
Floristic regions	Grubov and Yunatov 1952; Grubov 1955, 1963–2008, 1999–2007, modified
Vegetation zones	Lavrenko 1979, modified

Core set of the Open Archive Initiative (OAI) is used as metadata standard. OAI requests are implemented. The Web GIS uses standards of the Open Geospatial Consortium (OGC) and the map client is Open Layers. Further technical details of database structure are given by Rilke and Najmi (2011). Based on the content management system GREIF of Greifswald University, Germany, and a member of the Open Source Initiative, FloraGREIF is expected to be supported on a long-term basis.

Spatial Data and Explorative Application

Geographical Data

An integrated Web GIS application offers various thematic map layers overlaid onto a base map of Asia's orography generated from Space Shuttle Radar Topography Mission data (SRTM). Thematic map layers include the countries geography, topographic maps, geographic and UTM grid, Landsat image mosaic, the administrative division of Mongolia including provinces and districts, rivers and lakes, vegetation zones and floristic regions as reference maps for species distribution (Table **2**). The maps for vegetation zones and floristic regions are not published elsewhere and are described in detail below. Topographic maps of Mongolia 1 : 200,000, only available for the Western region, and 1 : 500,000, date back to the 1970s and 1990s and are part of the world series of topographic maps of former USSR (UGZZG 1971–1990, 1992–1993). They show a variety of

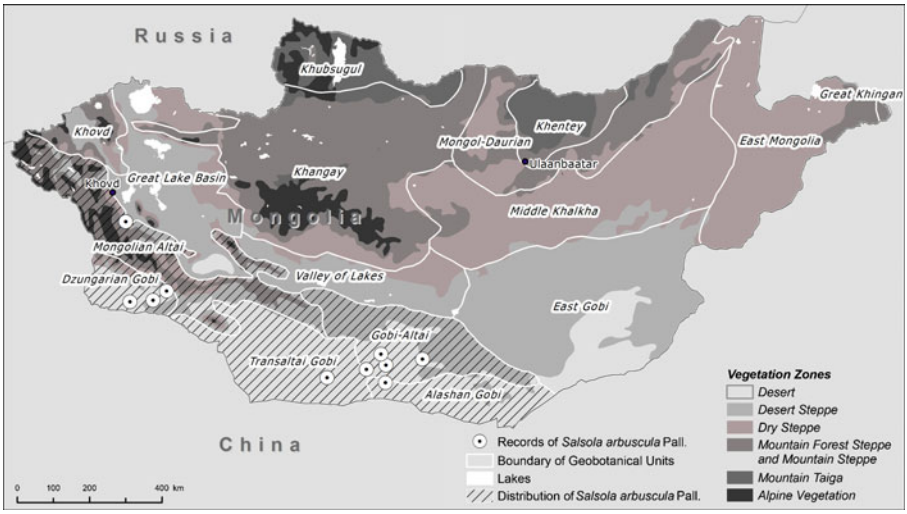

Fig. 2 Map based on FloraGREIF data with distribution and record findings for *Salsola arbuscula* Pall. projected against vegetation zones and floristic regions. The map layer of vegetation zones is based on Lavrenko (1979, modified) and the map layer of floristic regions on Grubov and Yunatov (1952), Grubov (1955, 1963–2008, 1999–2007, modified). This mapping function is currently being implemented and will be available for all species at the end of 2012

details like springs, wells including water capacity, winter pastures etc. and represent valuable sources for topographic details.

All thematic maps have been processed according to Web GIS standards (Fu and Sun 2010). They were scanned and geo-referenced into a geo-registered raster graphics and then digitized and converted into vector graphics. Both vector maps of floristic regions and vegetation zones were modified afterwards to adjust map unit borders to relief and topography (see following section). Species distribution as well as localities of all assigned records provided by GPS data can be displayed on these map layers (Fig. **2**). Map layers can be separately projected or combined as overlays. Access to all map types is possible via the taxon or the record fact sheet. If desired, these maps can be displayed in a separate larger map window.

For a more in-depth exploration of FloraGREIF maps and map layers reference catalogs that specify names of regions and places given in the maps are provided. They comprise I) provinces and districts including both province capitals and district centers, II) main geographical regions of Mongolia based on the country's national atlas (Akademiya Nauk SSSR and Akademiya Nauk MNR 1990), and III) floristic regions as reference units for species distribution as applied by Gubanov (1996). In addition, a list of uncommon habitat terms originating from Russian geobotanic school and used in English translations of floras of Central Asia is given with English translations (e.g., toyrim – saline soil places, clayey solonchaks; urema – deciduous floodplain forest). An overview of transliteration rules for Russian Cyrillic and Mongolian characters following Encyclopaedia Britannica, Inc. (1997) and UNGEGN (2003) as applied for the spatial data in FloraGREIF allows the re-transcription into the original spelling.

Maps of Floristic Regions and Vegetation Zones for Mongolia and Explorative Options

Maps of species distribution yield extensive information on the ecology of a certain taxon comprising soil and climate needs, on past and recent distribution shifts, propagation efficiency, and phylogenetic relationship among species (Jäger 2000). A first concept of Mongolia's floristic division was published by Grubov and Yunatov (1952), initially suggesting the individuality of the Mongolian flora in contrast to general beliefs at that time (see Grubov 2008; Hilbig and Jäger 2010). Two years later the country's floristic division was introduced by Grubov (1954) and became illustrated by a map sketch in his seminal work on Mongolia's flora (Grubov 1955). It resulted in 16 floristic regions each covering a climatically and ecologically unique area. Later, minor corrections ensued in the work on 'Plants of Central Asia' (Grubov 1963–2008, 1999–2007) resulting in the recently revised version as part of volume 14b of the series (Hilbig and Jäger 2010).

The thorough exploration and description of the country's floristic division contrasts the impossibility of mapping natural borders of species distribution, in particular for a vast country as Mongolia. In addition, pastoralism has influenced the country's vegetation for thousands of years with a considerable recent increase in livestock numbers. Here we introduce for the first time a digital map of Mongolia's floristic regions that serve as a reference map for the

distribution of species published in FloraGREIF. The mapping procedure follows Grubov and Yunatov (1952). Map units are based on Grubov (1955) and descriptions of the regions are as given by Grubov (1963–2008, 1999–2007). To increase geometric accuracy, a digital elevation model (DEM) was generated from SRTM-3 data (Shuttle Radar Topography Mission) with a geometric resolution of 3 arc sec (approx. 90 m × 90 m) visualizing hypsometric contours lines and elevation intervals. Geometric adjustments have been interactively conducted on screen, applying the following rules:

- The border between the basin around Khovd and the Mongolian Altai was adjusted along the 2,500 m a.s.l. contour line, Great Lake Basin – Kangay and Great Lake Basin – Mongolian Altai along 1,700 m a.s.l.
- The border of the Dzungarian Gobi was adjusted to an altitude between 1,700 and 2,000 m a.s.l., parts of the northern border of the Alashan Gobi to the 2,500 m a.s.l. contour line and parts of the northern border of the Gobi-Altai between 1,700 and 2,000 m a.s.l.
- The northern border of the Valley of Lakes was set along 1,700 m a.s.l., the western border of the Great Khingan along 1,000 m a.s.l., and the NW border of the Mongol-Daurian region along contours of two adjacent valleys.

The map layer for vegetation zones of Mongolia projecting the spatial distribution of zonal vegetation, is based on four high-precision map sheets at 1 : 500,000 (Lavrenko 1979) for all of Mongolia. It was established following a similar procedure. Layers for floristic regions or vegetation zones serve to map species records when provided with GPS data against the background of respective species distribution (Fig. **2**). Spatial information such as provinces, districts, geographical regions, topography etc. may be used to specify record localities. In a long-term perspective, these maps in combination with the growing record data provide a tool for range analyses of species distribution, conservation relevance assessments for species and habitats or studies on shifting distributions. An upload of collected records by users for projecting collected species against their distribution as an initial validation of species determination is envisaged. Moreover, with increasing numbers of record data, the map of floristic regions may be corrected and specified because demarcations of floristic map units is based on regional edificators. This term arising in Russian geobotanic terminology describes dominant species reflecting the climatic and edaphic conditions of a region (Zemmrich 2005).

Exploration of Habitat Data

Only few studies are available on habitat requirements of Mongolian plant species (Dulamsuren 2004; Wesche and Ronnenberg 2004; Dulamsuren et al. 2005; von Wehrden et al. 2009; Zemmrich et al. 2010) and indicator values *sensu* Ellenberg et al. (1992) are still unknown. Knowledge on particular habitat conditions of species for certain floristic regions may facilitate our understanding about threshold behavior of the dynamics of Mongolia's semi-arid vegetation (Fernandez-Gimenez and Allen-Diaz 1999; Zemmrich 2007).

Table 3 Comparison of taxon data with record data with respect to distribution, occurrence, and habitat for *Salsola arbuscula* Pall. Explanations of habitat terms used in Russian geobotanic school as provided by FloraGREIF are given below

Data level	Collection number	Habitat	Occurrence in geobotanical region	Occurrence in vegetation zone
Taxon	*Salsola arbuscula* Pall.	Thin sands, sandy-pebble and pebble-debris submontane plains and sanded debris bels* as edificator, but much more often as subordinate element of vegetation of deserts; as well as debris and stony tailings* and slopes of mountains and hills, margins of lake depressions and toyrims*; sparsely at sandy-pebble bottom and slopes of sayrs*, badlands and rocky slopes	Mongolian Altai, Gobi-Altai, Dzungarian Gobi, Transaltai Gobi, Alashan Gobi	Alpine vegetation, mountain forest steppe and mountain steppe, dry steppe, desert steppe, desert
Record	26.7.1979	Desert – semidesert	Transaltai Gobi	Desert
	561	Wind blown desert steppe in small depression, 1,495 m a.s.l.	Alashan Gobi	Desert
	5_478	Saxaul	Gobi-Altai	Desert
	3419	Mountain ridge with Saksaul, 1,500 m a.s.l.	Dzungarian Gobi	Dry steppe
	2761	Foothills, *Zygophyllum* scrub, 1,691 m a.s.l.	Gobi-Altai	Desert
	98	Riverine aspect in *Eurotia* steppe	Transaltai Gobi	Desert
	1078	Not reported	Alashan Gobi	Desert
	4195	*Populus diversifolia* stand, 1,453 m a.s.l.	Gobi-Altai	Desert
	351	*Populus* plot south of Nemegt Uul	Gobi-Altai	Desert
	Rel. 176	Gravel desert, 1,350 m a.s.l.	Dzungarian Gobi	Desert steppe
	3537	Sayr, 1,200 m a.s.l.	Dzungarian Gobi	Desert
	5_108	*Haloxylon* stand on alkaline soil	Dzungarian Gobi	Desert
	30.06.2002	Semidesert, 1,826 m a.s.l.	Dzungarian Gobi	Desert
	4652	Semidesert	Mongolian Altai	Desert steppe
	452/88	*Haloxylon ammodendron-Nitraria sibirica* desert, loamy sandy area covered by fine-debris, exposed to wind erosion, 1,590 m a.s.l.	Gobi-Altai	Desert

*Bel – pediment (shallow foothill region of mountains, in arid regions filled with rubble); *sayr – narrow, canyon-like beds of a temporary river (Arabic wadi, Afrikaans rivier); *tailing – originally means coarse sediment, often applied for pediment, similar to bel; *toyrim – saline soil places, clayey solonchaks (according to FloraGREIF).

But studies on the relative alteration of habitat requirements for species along climatic gradients or vegetation zones *sensu* Walter and Walter (1953) are missing to date. Otherwise, detailed habitat information for species within a particular region or vegetation zone might be of interest. To bridge this gap, the FloraGREIF species database allows the comparison of general habitat information given for each species with that from record findings for selected vegetation zone or floristic region (Table 3).

Outlook

In the ongoing project period (2012–2014) the gradual extension of the database by the inclusion of records and scans of herbarium specimens for further species, especially from the herbaria Ulaanbaatar (UB), Halle (HAL) and Osnabrück (OSBU) is in progress. In addition, the revision of further families will be conducted. Most importantly, the design of an interactive determination key allowing a user to determine a species down to the genus rank or to species groups in extremely diverse genera is intended. In contrast to published floras, the key will work across the borders of families and orders and preferentially makes use of those characters that can be easily assessed in the field. This will allow plant identification without special knowledge in systematic botany, simply by narrowing down the number of species where images in the system have to be compared with the plant in question and decisions on trait characteristics have to be done. In addition, future accumulation of plant records will enable a meaningful spatial data evaluation, e.g., by comparing point maps of records with thematic map layers. This would be especially interesting if the extensive body of data from vegetation relevés of various German research institutions can be included (Hilbig 2006). The trait data, indispensable for the determination key, can be used to provide also information on functional plant traits in future, which can be linked to all kinds of geographical information. The provision of a gazetteer service is currently being implemented and will be accessible in 2013.

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References

Akademiya Nauk SSSR and Akademiya Nauk MNR (1990) *Mongolskaya Narodnaya Respublika. Natsionalnyi atlas*. GUGK, Ulan Bator, Moskva

CBIF (Canadian Biodiversity Information Facility) (2006) *Canadian biodiversity information facility.* Government of Canada. Available at: http://www.cbif.gc.ca/ (accessed in December 2011)

Dulamsuren C (2004) Floristische Diversität. Vegetation und Standortsbedingungen in der Gebirgstaiga des Westkhentej, Nordmongolei. *Berichte des Forschungszentrums Waldökosysteme* 191:1–290

Dulamsuren C, Welk E, Jäger EJ, Hauck M, Mühlenberg M (2005) Range-habitat relationships of vascular plants at the taiga forest-steppe borderline in the western Khentey Mountains, northern Mongolia. *Flora* 200:376–397

Ebel AL (2000) Zametki po sistematike i geografii krestotsvetnykh (Brassicaceae) flory Altaya (Notes on taxonomy and geography of Brassicaceae of the Altai flora). *Turczaninowia* 3:18–43

Ellenberg H, Weber HE, Düll R, Wirth V, Werner W, Paulißen D (1992) Zeigerwerte von Pflanzen in Mitteleuropa. *Scripta Geobot* 18:1–258

Encyclopaedia Britannica Inc. (1997) Languages of the world. The Russian alphabet. In Encyclopaedia Britannica Inc. (ed) *The New Encyclopaedia Britannica, vol. 22, Macropaedia – Knowledge in Depth*. Encyclopaedia Britannica Inc., Chicago, p 681

ESRI (Environmental Systems Research Institute) (2007) *ESRI Data & Maps 2006.* Environmental Research Systems Institute, Inc., Redlands, CA

Fernandez-Gimenez ME (2011) *Mongolian rangelands and resilience (MOR2). Assessing impacts of climate change on Mongolia's rangelands and rural communities*. Warner College of Natural Resources, Colorado State University, Fort Collins, CO

Fernandez-Gimenez ME, Allen-Diaz B (1999) Testing a non-equilibrium model of rangeland vegetation dynamics in Mongolia. *J Appl Ecol* 36:871–885

Friesen N (1995) The genus *Allium* L. in the flora of Mongolia. *Feddes Repert* 106:59–81

Fu P, Sun J (2010) *Web GIS: Principles and applications*. ESRI Press, Redlands, CA

German DA (2001) K vidovomu sostavu krestotsvetnykh Mongolii (To the checklist of Mongolian Cruciferaceae). *Turczaninowia* 4:42–46

Golubkova NS, Kamelin RV (1989) *Flora Khangaya.* Nauka, Leningrad

Greifswald University (2010- continuously updated) *FloraGREIF – Virtual Flora of Mongolia*. Institute of Botany and Landscape Ecology, Institute of Geography and Geology, Computer Centre of University of Greifswald, Greifswald. Available at: http://greif.uni-greifswald.de/floragreif/ (accessed in December 2011)

Greuter W, Brummit RK, Farr E, Kilian N, Kirk PM, Silva PC (1993) NCU-3. Names in current use for extant plant genera. *Regnum Veg* 129:1–1464

Grubov VI (1954) Flora i botaniko-geograficheskoe raionirovanie Mongolskoi Narodnoi Respubliki (Flora and floristic division of the Mongolian People's Republic). *Voprosy Geogr* 35:172–201

Grubov VI (1955) *Konspekt flory Mongolskoi Narodnoi Respubliki (Survey of the flora of Mongolia).* Akademii Nauk SSSR, Moskva, Leningrad

Grubov VI (1982) *Opredelitel' sosudistykh rastenii Mongolii (Key to the vascular plants of Mongolia)*. Nauka, Leningrad

Grubov VI (1984) Endemichnye vidy flory Mongolskoi Narodnoi Respubliki (Endemic species in the flora of the Mongolian People's Republic). *Novosti Sist Vyssh Rast* 21:202–220

Grubov VI (ed) (1963–2008) *Rasteniya Tsentralnoi Azii po materialam Botanicheskogo Instituta im. V. L. Komarova (Plants of Central Asia based on plant collections from the Komarov Botanical Institute) 1–16.* Nauka, Leningrad, St. Petersburg, Moskva

Grubov VI (ed) (1999–2007) *Plants of Central Asia – plant collections from China and Mongolia 1–14a*. Science Publishers, Enfield

Grubov VI (2008) Zaklyuchenie k floristicheskoi svodke "Rasteniya Tsentral'noi Azii" (reabilitatsiya mongol'skoi flory) (Conclusion to the floristic account "Plants of Central Asia" (in favour of specificity of Mongolian flora)). In Tsvelev NN (ed) *Rasteniya Tsentral'noi Azii, Asteraceae: Cichorioideae, Vol. 14b. (Plants of Central Asia, Asteraceae: Cichorioideae,Vol. 14b)* Nauka, Moskva, pp 187–192

Grubov VI, Yunatov AA (1952) Osnovnye osobennosti flory Mongolskoi Narodnoi Respubliki v svyazi s eë raionirovaniem (Main peculiarities of the flora the Mongolian People's Republic in the framework of its spatial classification). *Bot Zhurn (Moscow & Leningrad)* 37: 45–64

Gubanov IA (1996) *Konspekt flory Vneshnei Mongolii (sosudistye rasteniya) (Conspectus of flora of Outer Mongolia (vascular plants)).* Valant, Moskva

Gubanov IA (1999) Dopolneniya i ispravleniya k "Konspektu Flory Vneshnei Mongolii (Sosudistye Rasteniya)" (Additions and corrections to the "Conspectus of flora of Outer Mongolia (vascular plants)"). *Turczaninowia* 2:19–23

Gubanov IA, Hilbig W (1989) Entwicklung und Stand der Erforschung der Gefäßpflanzenflora der Mongolische Volksrepublik. *Erforsch Biol Ressourcen Mongol Volksrepubl* 7:127–146

Gunin PD, Vostokova EA (eds) (1995) *Karta ekosistem Mongolii 1:1.000000 (Ecosystems of Mongolia 1:1.000000)*. GUGK, Ulaanbaatar

Hilbig W (2006) Der Beitrag deutscher Botaniker an der Erforschung von Flora und Vegetation in der Mongolei. *Feddes Repert* 117:321–366

Hilbig W, Jäger EJ (2010) Valerij Ivanovič Grubov (1917–2009) und die pflanzengeographische Gliederung Zentralasiens. *Feddes Repert* 121:1–6

Jäger EJ (2000) Auswertungsmöglichkeiten von Pflanzenverbreitungsmustern. *Leopoldina* 46:287–299

Kharkevich SS (ed) (1985–1996) *Sosudistye rasteniya Sovetskogo Dal'nego Vostoka 1–8 (Vascular plants of the Russian Far East 1–8)*. Nauka, St. Petersburg

Lavrenko EM (1979) *Vegetation map of Mongolian People's Republic 1 : 1.500.000 in 4 map sheets*. GUGK, Moskva

MacDonald Dettwiler and Associates Federal (2004) *Landsat GeoCover ETM + 2000 Edition Mosaic*. ETM-EarthSat-MrSID, 1.0, USGS, Sioux Falls, South Dakota

Malyshev LI (2000) Floristic division on the quantitative basis: Baikalian Sibiria, Tuva and Outer Mongolia. *Flora* 195:330–338

Malyshev LI, Krasnoborov IM, Polozhiy AV (1988–2003) *Flora Sibiri 1–11* (*Flora of Siberia 1–11*). Nauka, Novosibirsk

Meusel H, Jäger EJ (1992) *Vergleichende Chorologie der zentraleuropäischen Flora. Bd. III Text und Kartenband*. Gustav Fischer, Jena

Pavlov DS, Shagdarsuren O, Kamelin RV, Ulziikhutag N (2004) 35 years of the activity of the joint Russian-Mongolian complex biological expedition of Russian Academy of Science and Mongolian Academy of Science. *Arid Ecosystems* 10:13–16

PEWM (Pastoral Ecosystems in Western Mongolia) (2007) *Changing Pastoral Ecosystems in Western Mongolia*. University of Greifswald, Greifswald, University of Hamburg, Hamburg. Available at: http://www.geowiss.uni-hamburg.de/i-geogr/biogeographie/mongolia/welcome_english.html (accessed December 2011)

Rachkovskaya EI, Sanchir Ch (1983) Flora Zaaltayskoi Gobi. In Sokolov VE (ed) *Kompleksnaya kharakteristika pustynnykh ekosistem Zaaltayskoi Gobi. (Complex characterization of desert ecosystem of the Zaaltay Gobi)*. Academy of Science of USSR, Pushchino, pp 26–28, 92–104

Revushkin AS, Rudaya NA, Smorgov AE, Ebel AL, Shchegoleva NV (2001) Floristicheskie nakhodki v Zapadnoi Mongolii (Floristic findings in Western Mongolia). *Bot Zhurn (Moscow & Leningrad)* 38:142–151

Rilke S, Najmi U (2011) FloraGREIF – virtual guide and plant database as a practical approach to the flora of Mongolia. *Willdenowia* 41:371–379

Schickhoff U, Zemmrich A (2003) Assessing grazing land carrying capacity in West Mongolia/Altai Mountains – Basis for deriving strategies towards sustainable pastoral land use. *Bielefelder Ökologische Beiträge* 18:81–87

Tserennyam I (2007a) *Mongol Ulsyn Zasag Zakhirgaany Khuvaar. Masshtab 1 : 4.200 000*. (*Administrative division of Mongolia, map scale 1: 4.200 000)*. Gazaryn Zurag KHKHK, Ulaanbaatar

Tserennyam I (2007b) *Administrative division of Mongolia, map scale 1: 2.000 000*. Gazaryn Zurag Co., Ltd., Ulaanbaatar

UGZZG (1971–1990) *Mongolskaya Narodnaya Respublika 1:200 000. (Mongolian People's Republic 1:200,000)*. UGZZG, Ulaanbaatar

UGZZG (1992–1993) *Mongolskaya Narodnaya Respublika 1:500 000. (Mongolian People's Republic 1:200,000)*. UGZZG, Ulaanbaatar

UNGEGN (United Nations Group of Experts on Geographical Names) (2003) *Report on the current status of United Nations romanization systems for geographical names. Compiled by UNGEGN Working Group on Romanization Systems. Version 2.2*. Available at: http://www.eki.ee/wgrs/rom2_mn.pdf (accessed in December 2011)

USGS (U.S. Geological Survey) (2009) *NAS – Non-indigenous Aquatic Species. U.S. Department of the Interior and U.S. Geological Survey*. Available at: http://nas.er.usgs.gov/ (accessed in December 2011)

von Wehrden H, Zimmermann H, Hanspach J, Ronnenberg K, Wesche K (2009) Predictive Mapping of plant species and communities using GIS and Landsat Data in a Southern Mongolian mountain range. *Folia Geobot* 44:211–225

Walter H, Walter E (1953) Das Gesetz der relativen Standortskonstanz, das Wesen der Pflanzengesellschaften. *Ber Deutsch Bot Ges* 66:227–235

Wesche K, Jäger E, von Wehrden H, Undrakh R (2005) Status and distribution of four endemic vascular plants in the Gobi Altai. *Mongol J Biol Sci* 3:3–11

Wesche K, Ronnenberg K (2004) Phytosociological affinities and habitat preferences of *Juniperus sabina* L. and *Artemisia santolinifolia* TURCZ. ex BESS. in mountain sites of the south-eastern Gobi Altay, Mongolia. *Feddes Repert* 115:585–600

Wu ZY, Raven PH (1994+) *Flora of China.* Science Press, Beijing, Missouri Botanical Garden, St. Louis

Zemmrich A (2005) Die Steppengliederung der Mongolei aus Sicht der russischen und mongolischen Geobotanik. *Arch Naturschutz Landschaftsforsch* 44:17–35

Zemmrich A (2007) Equilibrium or non-equilibrium ecosystems? Scaling effects in rangeland ecosystems of Western Mongolia. *Erdkunde* 61:335–345

Zemmrich A, Manthey M, Zerbe S, Oyunchimeg D (2010) Driving environmental factors and the role of grazing in grassland communities: a comparative study along an altitudinal gradient in Western Mongolia. *J Arid Environm 74*:1271–1280

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