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Taxonomic and Phytogeographical Databases in Systematics of the Flowering Plant Family Umbelliferae/Apiaceae

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Abstract. Since the 1980s several databases have been compiled in the Botanical Garden of Moscow State University in collaboration with the Faculty of Computational Mathematics and Cybernetics and the Computer Centre of the same university. These databases deal with various aspects of the systematics and geography of Umbelliferae, one of the largest and most complicated angiosperm plant families. The main goal is to incorporate, store, and retrieve large amounts of information related to genera and species, including scientific names, authors, synonyms, typification, characters, chromosome numbers, distribution, and references to classical and modern publications; and to help prepare monographs, revisions, and articles on various aspects of the family systematics. Placement of most databases on the Internet was beyond the scope of our work, due to limited possibilities. The following databases have been developed—GNOM (Generic NOMenclator: on nomenclature, synonymy, and distribution of world Umbelliferae genera), CARUM (CARYologia UMBelliferarum: on chromosome numbers and karyotypes of world Umbelliferae species), and ASIUM (ASIatic UMBelliferae: on the systematics and geography of the Umbelliferae genera and species of Asia. The monographs *The Genera of the Umbelliferae. A Nomenclator* (based on GNOM; Pimenov & Leonov; Kew, 1993) and “The Karyotaxonomic Analysis on the Umbelliferae” (based on CARUM; Pimenov, Vasil’eva, Leonov & Daushkevich; Enfield, NH, 2002) were published. All three databases are widely used in current work with the prospect of electronic publications. For the monograph *The Umbelliferae of Russia* (Pimenov & Ostroumova; Moscow, 2012) a computer key based on diagnostic character database was compiled.

Keywords: Databases · Taxonomy · Phytogeography · Karyology · Flora · Umbelliferae · Apiaceae · Asia

1 Introduction

Documenting plant diversity is now one of the main tasks of any botanical community, being applicable in plant taxonomy, geography, ecology, conservation, and protection, as well as applied botany. The use of databases is one of the most effective ways to register taxa and their distribution. Taxonomic databases are of key significance in the general issue of biodiversity information, in particular in plant systematics, especially in large scale researches of big polymorphic taxa (e.g. families and further), revised on a broad geographical - even global - basis and studied in terms of integrative taxonomy.

The first phytotaxonomic databases appeared at the beginning of the 1970s. They covered grasses (Poaceae) of Australia [1] and Fabaceae, first the tribe Viciae, then a whole family ([2–4]). Information on these pioneer studies and publications can be found in the monograph “Databases in systematics” [5] and some other reviews [6–8].

The family Umbelliferae (Apiaceae, carrot family, зонтичные) is a taxon, now under critical study in various countries. It has been a traditional object for botanical investigations at Moscow University since the beginning of the 19th century when a German-Moscow botanist Prof. Georg Franz Hoffmann [9, 10], the first University professor of botany and founder of the scientific Botanical Garden, wrote the first monograph on Umbelliferae genera. This has become a tradition. Since the 1970s, the family has been a matter of intensive research in the Botanical Garden at Moscow State University, carried out with the help of the so called multidisciplinary approach, including taxonomy, nomenclature, phylogeny, morphology, micromorphology, anatomy (especially carpoanatomy), phytochemistry, molecular systematics, as well as phytogeography and ecology. Besides numerous particular revisions of genera, mainly Asian, several accompanying summaries [11, 12], some regional treatments were published on the Umbelliferae—of Middle Asia [13], Tajikistan [14], the Russian Far East [15], Siberia [16], Kirghizia [17], and Russia [18]. Participation in such international projects as *Flora Iranica*, *Flora of China* and *Families and Genera of Flowering Plants* should also be mentioned. We have been observing and collecting Umbelliferae in various regions and countries of Asia since 1960. Plants of numerous species have been grown in the Botanical Garden of Moscow State University. Geographically, the research program is focused on Asia (all countries) and the Mediterranean, both being the main diversity centres of the world Umbelliferae.

2 The Botanical Databases Carried Out at Moscow University

The above mentioned early survey works were based on quite large amounts of information, which, however, stored on paper carriers (card files). The necessity of taxonomic and phytogeographical databasing in this work has been evident from the very beginning, even before the era of personal computers and the Internet. Although very useful, those mainly not specialized plant taxonomy databases such as [19–24] did not completely suit our purposes. They did not allow to observe all details of nomenclature and typification, essential for Umbelliferae systematics with its unstable

generic concept and resulting extensive synonymy. In the most comprehensive information system “Catalogue of Life”, always available online, plant name synonymy borrowed from some authoritative Floras is rather limited and sometimes inconsistent. Using university facilities and close contacts with its scientists from various fields, some databases on different aspects of taxonomy and geography of the Umbelliferae were compiled by experts from the Moscow State University Botanical Garden together with the Faculty of Computational Mathematics and Cybernetics (databases GNOM, CARUM, ASIUM). These databases are like living monographs on various aspects of Umbelliferae systematics.

During last decades more botanical taxonomic databases appeared in Moscow University; some completed (with new data added and retrieved), others in progress, or only at the early stage. The history of database technology used in our project may be of interest, since it mirrors the international IT and programming from the late 1980s until the early 21st century.

3 Databases Published in the Past as Monographs (GNOM and CARUM)

The first one was GNOM (Generis NOmenclator), a database on taxonomy and distribution of the world Umbelliferae. It served as the basis for the monograph “The Genera of the Umbelliferae. A Nomenclator” [25] (Pimenov, Leonov, 1993) published in Kew (the U.K). The main part of the monograph (nomenclator) was generated from the database, first for domestic botany. Strictly speaking, we developed not just a database, but information systems with a developed user interface, the possibility of making of predefined, as well as dynamically generated queries, the most important of which was the output of nomenclature summaries for articles and monographs. The database contains data on the name of the genus, the author(s) of the generic name or a combination, the date and place of protologue publication, typification, references to lectotypification, synonyms (with the protologue and typification data), geographical distribution, the number of species and relevant literature. A menu of queries for the database enables one to get answers to many systematic and floristic questions, for example—to obtain a list of genera described by a particular taxonomist, at a certain time, a list of genera for some geographical area (a continent, a country etc.), a list of nontypified taxa, and a list of genera from each of traditional subfamilies (Hydrocotyloideae, Saniculoideae or Apioideae), tribes or subtribes. The main advantage of the database is that it is an moving monograph, readily reflecting current nomenclature modifications resulting from recent critical revisions, At the same time, however, it presents our personal concept of optimal nomenclature and synonymy of Umbelliferae genera. The first version of GNOM was operated on the EU-1045 under the network DBMS, developed at the MSU Faculty of Computation Mathematics and Cybernetics, and working with data on punch cards. It was also operated on a personal computer Yamaha, manufactured in Japan, using the adapted version of DBase II database (Novosibirsk).

Up to now, the Nomenclator is widely used as a reference system for generic nomenclature and taxonomy of the family. Our later databases are connected to GNOM, thus ensuring the use of only accepted generic names.

The second completed Umbelliferae database, concurrently developed by the same research team, was named CARUM (CARYologia Umbelliferarum). This is a computer database on karyotaxonomy, a special branch in biodiversity studies, that deals with the taxonomic diversity of chromosome number and karyotype morphology. The database contains information about haploid and diploid chromosome numbers, as well as references to karyotype morphology of Umbelliferae species all over the world, with the origin of the studied materials. Karyological data on each studied species are arranged chronologically. The menu of queries of CARUM database enables one to receive analytical answers to various requests concerning the distribution of chromosome numbers within subfamilies, tribes, subtribes, and genera, or chromosome numbers of species from a certain area, or a species, mentioned in this or that publication etc. When published [26] the database CARUM contained data on chromosome numbers and karyotypes of 1,750 species of the world Umbelliferae. The early life of CARUM was the same as that of GNOM. Then, after personal computers became available, both databases were reprogrammed for DBase III. Then a program was developed to convert data on punch cards to an array of batch input, intended already for PC information systems. Thanks to the experience gained with punch cards, we developed batch input for all subsequent systems together with interactive input. Not only did this option significantly speed up the input process, but it also facilitated the recovery of restore the databases in case of failure as well changing the database structure and switch on to new computers. After we had access to personal computers like IBM PC and IBM PC/AT, we moved on to DBase III Plus, KARAT (a russified Foxbase clone), and finally to a very convenient DBMS FoxPro.

During this development period, new botanical tasks were arising, and the challenge was the permanent upgrade of software components to include these tasks in the already prepared databases. Or, in the programming jargon, we repeatedly faced the so-called task of legacy databases. The method of software development itself was applied to prototyping, or rapid prototyping.

4 A Database Compiled and Ready for Publication, but Thus Far not Published

Currently under development the ASIUM database is described here in greater detail. It is a system for storage, retrieval and analysis of information on Asian Umbelliferae. Structurally, the ASIUM database consists of related files, which correspond to the principal objects of taxonomic study. These include the files of genera, species and infraspecific taxa, as well as their synonyms, files of type materials, literature references, author's names and their combinations, geographical distribution at three levels of administrative division (countries, regions, and districts) and, alternatively floristic regions and continents. A standard output file contains the accepted species name, authorship, data of the first publication, type locality according to the protologue, type specimen(s) and their localization in herbaria, both already known or newly found,

references to essential published Floras, monographs and critical articles; synonyms (with the same set of data as for the accepted name), geographical distribution (countries, as well as parts of countries (regions) and provinces for large countries), geographical distribution in big phytochories in Asia, overall distribution (in other continents). The ASIUM software, the related retrieval system, and the set of subsidiary utilities were initially developed with DBMS FoxPro for DOS, and then transferred to and further developed under Windows (95, 98, 2000, and XP). In order to use modern facilities for information retrieval, a database model was developed in the XML language, together with ASIUM convertors, a set of related XML documents, and programs to deal with them. In particular, an XMLBiblio program was created, allowing for the retrieval and editing of references in UNICODE with the use of diacritic symbols.

The ASIUM information system, in the course of its long life, required some new experimental solutions. Since the output of taxonomic summaries in the system was focused on encoding the MS DOS operating system, and the publications needed to be formatted in the Microsoft Word program, the “legacy database” was used as follows. A utility was written in the FoxPro language that inserted auxiliary symbols, like \$ and #, to mark special character design (italics for Latin names and collectors, boldface for accepted names etc.). Additionally, MS Word processor macros were written to convert those words marked with symbols to the necessary font. Thus, we succeeded in minimizing manual labor in the preparation of taxonomic reports.

Apart from standard options, the ASIUM information system has a set of queries most interesting for botanists: the calculation of the number of species and genera for regions of any level, the evaluation of similarity in Umbelliferae sets for any two regions, and the counting of endemics.

The choice of the accepted name for each species reflects our personal opinion, while proceeding from particular investigations. Genera, to which the species are attributed, on the whole correspond to our reference-book *The genera of the Umbelliferae. A Nomenclator* [25], with further additions and corrections made in the working database GNOM. The latter is connected to ASIUM; generic names, absent in GNOM, cannot be used in ASIUM, with rare exceptions of Umbelliferae species erroneously described in other families (*Valerianella*, *Euphorbia*, *Eranthis*, *Chrysosplenium*, *Limnanthemum*, *Ranunculus*, *Ophiorrhiza*, and *Geophila*).

The abbreviations or full transcriptions of the authorities of species and genera comply with the international standard – *The authors of plant names* by BRUMMITT & POWELL [27], except only Chinese botanists’ names. Together with [28], we believe that the abbreviations of the names of the Chinese authors of plant names, in the Western style (first initials and surnames) to be of little use; there are too many namesakes, even among botanists, in contrast with the diversity of given names. Therefore, Chinese personal names are used in their full form both in taxa authorities and in the reference list, so as to avoid any misunderstanding.

Abbreviations of periodicals in protologues are made according to the *Botanico-Periodicum-Huntianum* [29], and books after [30], if the bibliographical sources are included in these reference-books. In all other cases we proceeded from the database IPNI [19]. Original Cyrillic titles are transliterated to English using Latin letters; the titles are also translated into English, while some references are accompanied by Latin or German translations of original publications. Acronyms of herbaria correspond to [31].

The search of type materials was one of the most laborious and time-consuming activities when preparing the account. The challenges faced were legion; however, the proposed typification cannot be regarded as complete. There seems to be no end to this. At the first stages of the search for a potential type material, databases of various herbaria, available on the Internet, the so-called *virtual herbaria*, were widely used. It was both the global database of JSTOR (<https://plants.jstor.org>) and its partner herbaria as FI (Firenze, Museo di Storia Naturale dell'Università, FI, FT, FW; <https://plants.jstor.org/partner/FI>) and MPU (Montpellier, Herbar de l'Université Montpellier II, MPU; <https://plants.jstor.org/partner/MPU>), as well as individual databases of large herbaria of the world. Among the last are P (Paris, Muséum Nationale d'Histoire Naturelle; <https://www.mnhn.fr/fr/collections/ensembles-collections/botanique/plantes-vasculaires>), BM (London, Natural History Museum, (www.nhm.ac.uk), K (London, Royal Botanical Gardens Kew; apps.kew.org/herbcat/navigator.do), G (Genève, Conservatoire et Jardin Botaniques Genève; <http://www.ville-ge.ch/musinfo/bd/cjb/chg/>), W & WU (Wien, Naturhistorisches Museum & Universität Wien; <http://herbarium.univie.ac.at>), E (Royal Botanic Garden Edinburgh; <http://data.rbge.org.uk/search/herbarium/>), Moscow, (Moscow State University herbarium, MW; <https://plant.depo.msu.ru/>), B (Berlin, Botanischer Garten und Botanisches Museum, Berlin-Dahlem; <https://www.bgbm.org/en/herbarium>), S (Stockholm, Naturhistoriska riksmuseet; <http://herbarium.nrm.se/search/species/>), L & WAG (Leiden, Naturalis Biodiversity Center; <https://science.naturalis.nl/en/collection/naturalis-collections/botany>), GOET (Göttingen, Georg-August Universität; <https://www.uni-goettingen.de/de/185941.html>), M (München, Botanische Staatsammlung München; www.botanischestaatsammlung.de/general/herbarium.html); MSB (München, Ludwig-Maximilians-Universität; <http://botanik.biologie.uni-muenchen.de/botsyst/>), O (Oslo, Natural History Museum, Botanical Museum, University of Oslo; <https://www.nhm.uio.no/fagene/botanikk>), UC (Berkeley, California University Herbarium; <https://webapps.cspace.berkeley.edu/ucjeps/publicsearch/publicsearch/>), GB (Göteborg, University of Gothenburg, Herbarium, Dept. of Biological and Environmental Sciences; <http://bioenv.gu.se/forskning/forskningsresurser/herbarium>)

Then Umbelliferae collections have been studied in Russia and abroad, including famous centers of taxonomic botany as Kew, Geneva, St.Petersburg, Edinburgh, Vienna, Berlin-Dahlem, British Museum, Moscow, Paris, in numerous local herbaria in China, Turkey, Iran, India, and Nepal; some essential materials were obtained on loan by exchange. The full list of herbaria, whose materials were studied, is quite impressive, to include: A, AA, ANK, ASH, B, BAK, BEY, BLAT, BM, BP, C, CAL, CALI, CDBI, DD, E, ERE, FI, FRU, G, GB, HUB, HUJ, ISTE, IZM, JE, K, KATH, KW, KUN, KYO, L, LE, LINN, LIV, MANCH, M, MAK, MH, MHA, MPU, MW, NAS, NS, OXF, P, PE, TAD, TAK, TARI, TBI, TI, TK, UPS, VAN, VLA, W, WU, XJBI abbreviated according to [31]. We are grateful to the curators and staff of listed herbaria for the opportunity to examine the materials. The latest contribution is the addition to ASIUM of barcodes of type specimens kept in various herbaria (if existing).

A special option allows the arrangement of synonyms, which appear to be abundant in many Umbelliferae species, due to constant changes in generic nomenclature. A new term – *homotypic group* of synonyms – has been introduced. A homotypic group is

formed by names, based on the same type material. These names are also called nomenclatural synonyms. Names, based on different types (taxonomical or heterotypic synonyms) form different homotypic groups. Misapplied names are out of either group. Synonyms have been sorted manually, with the help of a special option, since there are no formal characters (homotypic synonyms might not have identical epithets).

References to botanical literature for each species' name have been made in the chronological order and in the abbreviated form – author(s), year of publication, and page number. Full bibliographical data are added to the reference list, which seems to be particularly useful with the Asian Umbelliferae bibliography. The database contains over 2,300 references, mainly on local Floras, monographs, and critical articles.

ASIUM is a living nomenclatural and phytogeographical monograph, open for additions and corrections. One can use its information to make various comparisons, including species lists of various territories, to obtain floristic similarity measures, to compile lists of endemic species, to produce lists of type specimens, kept in particular herbarium, etc. Intermediate results of registration of Asian Umbelliferae diversity were published [32–35].

ASIUM is a database, which accumulates massive data of various kinds, including 1. results of our own taxonomic and floristic investigations, made in different parts of Asia; 2. data from various herbaria, with special emphasis on type collections; and 3. data from published Floras and critical articles on taxonomy, phylogeny and phytogeography of Asian species.

5 Identification Keys

Umbelliferae belongs to the most complicated families of flowering plants, also in terms of species identification. Traditional printed dichotomous keys in large “Florae” are far from satisfying. They often demand leaf, flower and fruit characters, and the absence of petals or mature fruits makes identification impossible. Some important characters, e.g. leaf dissection, can hardly be described, and the keys often contain characters which are difficult to observe, e.g. small secretory ducts visible only on fruit transections at magnification x400. The way out this problem could be computer-assisted identification, based on descriptive data banks [36]. The first keys of this type appeared together with the first botanical databases; the early steps were described in the book *Biological Identification with Computers*, the proceedings of the 1973 Cambridge conference, edited by Pankhurst [37]. Interactive multi-entry polytomous keys with illustrations for personal computers are the most convenient instruments [36]. We developed software and compiled the key for Russian Umbelliferae (288 species) based on 55 structural characters and geographical distribution [38]. Character states are illustrated and thus can be used by the inexperienced people as well. The list of character states can easily be translated into any language; we have created Russian, English, German, and French versions.

Users begin identification with the most convenient characters of the specimen. After a few steps, they will have a short list of species with a chosen combination of character states, growing in a selected region. Our key contains photos of herbarium

specimens for all the Russian Umbelliferae, so identification could easily be verified. An advantage of our key is a table of character states that can be generated for any 1–5 species, with diagnostic characters being highlighted. Users can choose characters for further identification or check their results based on the overall list of characters.

The most labour-intensive part of creating keys is compiling the table of characters (descriptive data bank), in our case, 55 characters for 288 species. Gaps in the table make “noise” during testing and identification, thus decreasing the accuracy, so we had to put a lot of effort into minimizing the number of empty cells. The published descriptions differ in details and inconsistent terminology, therefore most of the data were checked on herbarium specimens, living plants and microscopic slides. The necessity of collecting a large body of data seems to be one reason why computer keys have not thus far been compiled for most groups of organisms.

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