Progress in Slovak botany: a successful path to modern research on flora and vegetation

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Abstract

Here, we present a brief introduction to sixteen full-text research articles of the Special Issue “Progress in Slovak Botany: a successful path to modern research on flora and vegetation” which are more-less a reflection of the current state of the study of botany in Slovakia. The papers bring results of classification and syntaxonomical revision of shrubs and forest vegetation, followed by research into vegetation diversity, ecology, and taxonomy. Special attention is paid to molecular methods in the research of plant taxa; one of the contributions evaluates the use of these methods in the study of population genetics of forest trees in Slovakia in the past 40 years. The other three papers use the knowledge of flow cytometry for a taxonomic study of selected representatives of the genera *Tanacetum*, *Cotoneaster*, *Solanum* and *Nicotiana*. A special issue also includes a new version of the checklist and a red list of hornworts and liverworts which updates data published 20 years ago. The checklist is followed by a paper on new localities and phylogenetic relationships of *Leucoglossum leucosporum*, a geoglossoid fungus whose occurrence is poorly known. The last two contributions are devoted to the impact of the environmental burdens on biota.

Keywords Classification · Diversity · Ecology · Fungi · Plant communities · Phytotoxicity · Slovakia · Syntaxonomical revision · Taxonomy

Introduction

Botanical research in the territory of present-day Slovakia has a long tradition until the end of the sixteenth century. Manuscript medical-botanical and fruit-horticultural works of anonymous authors from this period have been preserved (Jurkovič 1970; Hrabovec 1979), as well as the first scientific study on the vegetation of the Pannonian region prepared by the French botanist Carolus Clusius was published in 1583 (Hrabovec 1974). The oldest herbarium created by the Kamaldul monk Cyprián has been preserved from the middle of the eighteenth century (Vozárová 1996).

While in the 17th and 18th centuries botanists of Austrian and Hungarian origin took part in botanical research in the territory of present-day Slovakia, from the nineteenth century, works by authors of Slovak origin began to be promoted and published (Dionýz Štúr, Andrej Kmet', Jozef Ľudovít Holuby). Thanks to G. Reuss, one of the first more comprehensive regional flora in Hungary, “Kvĕtna Slovenska = Flora of Slovakia” (Reuss 1853), was created. After the disintegration of the Austro-Hungarian Empire in connection with the First World War and the establishment of Czechoslovakia, Czech botanists became significantly involved in research (Hendrych 1996), because Hungarian and Austrian botanists mostly engaged in research outside of present-day Slovakia or left.

A long-term problem was the absence of a science-oriented university institution enabling the education of new generations of naturalists, including botanists. In the past, only a few educational institutions of the university type operated on the territory of today's Slovakia, several only temporarily, such as Trnava University in the years 1635–1777 (moved to Budapest) (Jankovič 1995) or Universitas Cassoviensis in Košice founded in 1657 (Mártonfiová et al. 2021). The Mining and Forestry Academy in Banská Štiavnica, founded

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in 1763 and moved to Sopron (SW Hungary) in 1919 (Konečný 2012), has been operating here for the longest time. Thus, most botanists working in present-day Slovakia received their education most often in Vienna, Prague, or Budapest. A significant turnaround took place in the late 1940s on the threshold of World War II. After the break-up of Czechoslovakia by the Nazis, the establishment of the first Slovak Republic (1939–1945) and the closure of Czech universities, there was an acute need to provide education in the natural sciences directly in Slovakia. In October 1939, the Institute of Botany was established within the Faculty of Arts of the Slovak University (renamed Comenius University during the war), led by the Czech botanist František Nábělek, and the following year the Faculty of Science was established. Among its important graduates were Ján Futák, one of the most important figures in Slovak post-war botany, the author of the first botanical monograph in modern Slovak (Futák 1943), and one of the first employees of the Institute of Botany of the Slovak Academy of Sciences founded in 1952 (Letz 2016). There is also a further development of science-oriented higher education, the University of Pavel Jozef Šafárik in Košice was founded as the second university in Slovakia in 1959.

Applied botanical disciplines such as agriculture and forestry were also developed, the Department of Forestry and Agricultural Engineering was established at the Slovak University of Technology in Bratislava and teaching began in 1941. From this department, Colleague of Agricultural and Forestry Engineering was founded in 1946 in Košice. Later, in 1952, as part of the reorganization of universities, this colleague was divided into two separate universities - the current Slovak University of Agriculture in Nitra and the Technical University in Zvolen providing education in the field of forestry and woodworking.

At present, in addition to the Institute of Botany of the Slovak Academy of Sciences, attention is being paid to scientific research in the field of botany at seven Slovak universities. We present the results of their work in this special issue.

The main contribution of the presented studies

The classification and syntaxonomical revision of vegetation are essential tools for scientific communication. In addition, they provide a reliable platform for land-use management and nature conservation. In Slovakia, it has a long tradition (Holub et al. 1967; Valachovič 1995; Valachovič 2001; Jarolímek et al. 1997; Kliment and Valachovič 2007; Hegedúšová Vantarová and Škodová 2014).

In the presented Special Issue, two of the studies provide insight into the classification of common hazel scrub (Kliment et al. 2021) and beech forests (Ujházyová et al. 2021). In Slovakia, common hazel-dominated stands represent a typical landscape component of colline to montane areas. Out of five

associations previously reported from Slovakia (Jurko 1964; Passarge 1979; Kontriš 1981; Hadač and Terray 1989) two of them, *Pruno spinosae-Coryletum* and *Lonicero nigrae-Coryletum* within one alliance *Populo tremulae-Corylion avellanae*, were accepted based on the syntaxonomical revision. Moreover, the authors compared West Carpathian communities with relevant Alpine and Hercynian ones and identified the climatic gradient as the main environmental drivers of the floristic composition of the hazel-dominated vegetation in Slovakia.

In Europe, the classification of beech, fir and mixed montane forests has already been unified at the rank of alliance and higher syntaxa in Europe by several authors (Dierschke 1998; Willner 2002; Willner and Grabherr 2007; Mucina et al. 2016; Willner et al. 2017). A complete syntaxonomical revision of these forest communities within the order *Fagetalia sylvaticae* was realised for the first time in Slovakia by Ujházyová et al. (2021). Finally, 18 associations were accepted within the alliances *Fagion sylvaticae*, *Symphyto cordati-Fagion*, *Lonicero alpigenae-Fagion* and *Sorbo-Fagion*. There were applied the concept of narrow orders and alliances (Mucina et al. 2016) in accordance with the actual concept of the Slovak national survey of forest communities.

Recently, much attention is paid on diversity and ecology of the alien species. According to Denisov et al. (2017), Jehlík et al. (2017), Vinogradova et al. (2017), Májeková et al. (2021) synanthropic plants connected with human activity find suitable conditions also on railway. On the other hand, some native thermophilous species, rare and threatened plants (Novinska and Czarna 2008; Májeková et al. 2014; Jasprica et al. 2017; Vinogradova et al. 2017) typical for other habitats are also occurred here. The authors present four species (*Euphorbia davidii*, *Galeopsis angustifolia*, *Geranium purpureum*, *Grindelia squarrosa*) that are typical examples of ferroviatic migration either in Slovakia or Ukraine.

The impact of global climate change on vegetation has become increasingly prominent over the past several decades. Understanding vegetation change and its response to climate can provide fundamental information for environmental resource management (Sun et al. 2021). Gradual climate warming has a crucial impact on alpine vegetation where tall grasses together with phanerophytes expand (Hedenäs et al. 2016; Vanneste et al. 2017). Climate changes along with land-use change, mainly grazing cessation, inspired Palaj and Kollár (2021) to study this question in the Tatra Mts. They confirmed increased frequency of phanerophytes, mainly *Pinus mugo*, lesser *Juniperus communis* and *Picea abies*. The most susceptible communities to the expansion of phanerophytes are *Juncion trifidi* grasslands and dwarf shrub communities dominated by ericaceous species. Moreover, the grasslands facing phanerophyte expansion are more light-demanding than others and phanerophytes significantly affect the light and temperature conditions on the sites. In

conclusion, the area of grasslands was reduced by more than 22% and simultaneously there is a visible transformation from grasslands into tree and shrub vegetation.

Climatic changes are also responsible for the decline of critically endangered species *Cladium mariscus* on Žitný ostrov Island (Procházka et al. 2021). In Slovakia, and several other European countries it has a rare occurrence (Feráková et al. 2001; Eliáš et al. 2003). The authors present analytic results of sedimentary-infilling from the locality where the occurrence of *Cladium mariscus* was reported in a palaeo-ecological sample radiocarbon-dated to 9.52 cal ka BP in the Early Holocene. The species persistence is depending on its sensitivity to changes in a hydrological regime which is often affected by anthropogenic activity (Theocharopoulos et al. 2006; Plóciennik et al. 2015; Gałka et al. 2017).

Another species that is dependent on the hydrological and nutrient regime is *Calla palustris* (Dudgeon et al. 2006; Richert et al. 2016). Its distribution, ecology and vegetation affinity are discussed in the article by Dudáš et al. (2021). After critical revision of all available phytosociological and herbarium material, the authors find that vulnerable *Cala palustris* the most frequently occurs in the vegetation of mires (classes *Scheuchzerio-Caricetea fuscae*, *Oxycocco-Sphagnetetea*, *Vaccinio-Piceetea*), alder carrs (*Alnetea glutinosae* class), and marshes (*Phragmito-Magnocaricetea* class) of the northern parts of Slovakia (the Nízke Beskydy Mts, Spišské vrchy Mts and Liptovská kotlina Basin) which are protected at national or international levels and included into Ramsar localities, NATURA 2000 sites, protected landscape areas, national parks or nature reserves.

One from important and rare wetland habitats are periodically exposed banks of stagnant water. As a result of water regulation in the past, these natural habitats mainly with vegetation of the class *Isoëto-Nanojuncetea* in Slovakia and the surrounding Central European countries have recently become scattered. In the current Special Issue, Dítě et al. (2021) provide insight into the vegetation on the shores of the Liptovská Mara water reservoir four decades after its construction. Even though, the water reservoirs vegetation have been relatively well documented in Slovakia (e.g. Jarolínek et al. 1997, 1999; Bernátová and Kučera 2010; Šumberová and Hrivnák 2013; Kochjarová et al. 2015), the data on Liptovská Mara water reservoir have not been published to date. The analysis of 52 phytosociological relevés identified three clearly distinct vegetation groups, 1. *Bidentio-Polygonetum hydropiperis* and *Rumici crispis-Agrostietum stoloniferae*, 2. *Junco bufonii-Gnaphalietum uliginosi*, 3. *Eleocharito acicularis-Limoselletum aquaticae*. Authors found that the main ecological factors responsible for the zonation of plant communities are the length of flooding, slope and soil texture. Despite the secondary origin of the study object, the species composition is natural, and the spreading of neophytes was not detected.

Molecular methods of speciation and phylogeny study of plant taxa are among the most important methods today. Relatively soon after their discovery, they began to be used in former Czechoslovakia, namely in the eighties (Kormuťák 1981; Kormuťák et al. 1982). One of the presented papers summarizes the development of population genetics and population genomics studies of forest trees in Slovakia during the past 40 years (Gömöry et al. 2021). To address several topics in evolutionary genetics and biogeography of trees, various protein and DNA markers have been applied during this period: allozymes uniparentally inherited chloroplast and mitochondrial markers, simple sequence repeats and single nucleotide polymorphisms. As a model species, *Fagus sylvatica* s. l. and eastern-Mediterranean firs (*Abies* Mill. section *Abies*) were selected and the divergence of genetic lineages (species and subspecific taxa) in time, as well as colonization of the current ranges during the Holocene were reconstructed. Intraspecific gene flow and homoploid hybridization focused on hybrid swarms *Pinus sylvestris*/*P. mugo* and firs were also studied (Kormuťák et al. 2005, 2008). Adaptations were studied both in field observations and common-garden experiments on *Picea abies*, *F. sylvatica* and *A. alba* (Longauer et al. 2001; Gömöry et al. 2015). Within this contribution, next-generation sequencing perspectives of ongoing research were shortly outlined, too (Gömöry et al. 2021).

Flow cytometry – another powerful method in molecular biology that provides rapid multi-parametric analysis of single cells in solution (McKinnon 2018) has been used in three papers included in this special issue, which deals with selected representatives of the genera *Tanacetum* (Pulišová et al. 2021), *Cotoneaster* (Kšňan et al. 2021), *Solanum* and *Nicotiana* (Fráková et al. 2021).

Pulišová et al. (2021) presented a comprehensive overview of the karyological and morphological variability of the *Tanacetum corymbosum* group in Slovakia. Flow cytometry analyses confirmed two predominant cytotypes within *T. corymbosum* group in Slovakia: diploids corresponding to *T. clusii* and tetraploids corresponding to *T. corymbosum*. A rare occurrence of minority cytotypes (triploids and pentaploids), as well as the occurrence of single triploid plant most probably of hybrid origin, was found. Morphological analyses showed that the number and size of stem leaves as well as capitula, and coloration of the margin of the involucre bracts were identified as the most useful for their determination. Based on this research, the authors recommend recognizing *T. clusii* and *T. corymbosum* as two separate species rather than subspecies.

Genome size analysed by flow cytometry is reliable diagnostic tool in the determination of closely related genera included in *Rosaceae* family (Hajrudinović et al. 2015; Macková et al. 2017; Žabka et al. 2018). Kšňan et al. (2021) try to find out, whether it is possible to distinguish close related *Cotoneaster* species based on the absolute genome size data. Flow cytometry revealed a significant difference in genome size between

pentaploid *C. tomentosus* and both tetraploid species *C. integerrimus* and *C. melanocarpus* agg. However, they found that the identification of tetraploid species *C. integerrimus* and *C. melanocarpus* agg. Based on nuclear DNA content is not possible.

Endopolyploidy plays a vital role during plant growth and development and in various stress responses (Ceccarelli et al. 2006). To better understand and characterise polysomatic species within the *Solanaceae*, Fráková et al. (2021) studied endopolyploidy in mature vegetative and reproductive organs of representative diploids within the genus *Capsicum* and diploid and tetraploids within the genus *Nicotiana* using flow cytometry. The presence of 2C–16C nuclei (rarely 32C) was detected in both genera, and the degree of endopolyploidisation was expressed using four different parameters for each organ analysed. Furthermore, genome size for each of the investigated species was determined in this study.

Checklists incorporate progress in plant taxonomy and nomenclature as possible and provide a taxonomic and nomenclatural basis for botanical studies, species surveys in nature conservation and vegetation and floristic databases (Danihelka et al. 2012). A global trend of permanent extinction of species or decline of their populations caused by human activity has led to the emergence of red lists of endangered species (Turis et al. 2014; Eliáš et al. 2015). The last checklist and the red list of liverworts (*Marchantiophyta*) and hornworts (*Anthocerotophyta*) were published 20 years ago in Slovakia (Kubinská et al. 2001a, 2001b) and did not correspond to current knowledge about this group of plants. Therefore, the revised checklist and red list of hornworts and liverworts were prepared by Mišíková et al. (2021) following the latest version of the Checklist of mosses (*Bryophyta*) (Mišíková et al. 2020). The presented checklist and red list include 231 liverwort and two hornwort species, with up to 22.9% liverworts are endangered species. Hornworts are not considered threatened.

Central Europe is a region with long study history of geoglossoid fungi, e. g. they are mentioned at the end of the eighteenth century from the territory of today's Slovakia (Lumnitzer 1791). Within this group, the small and poorly studied genus *Leucoglossum* is included. Kučera et al. (2021) recently recorded *L. leucosporum* in Germany, the Czech Republic, and Slovakia, reports from the Czech Republic and Slovakia representing the first data to those countries. Molecular phylogenetic analyse confirmed a separate position of the genus, which is more closely related to *Geoglossum* rather than *Trichoglossum* despite the presence of setae.

Heavily destroyed landscape in post-industrial areas is dominated mostly by anthropogenic vegetation (Kompáľ-Bába et al. 2019). Mine abandonment, decommissioning and repurposing may result in significant environmental impacts, such as soil and water contamination (Haddaway et al. 2019). *Orchidaceae* are an endangered group of plants that might spontaneously grow also in the anthropogenic environment

on initial soils (e.g. Woch 2017, 2018; Woch et al. 2016, 2018). Račko et al. (2021) investigated the influence of heavy metals on the populations of the orchids *Epipactis atrorubens*, *E. pontica*, *Cephalanthera longifolia* and *Platanthera bifolia* on three localities with different soil conditions and various composition of toxic elements. The authors found that elevated concentration of heavy metals and toxic elements in plant tissues is closely related to the occurrence and weathering of original contaminated substrates. Despite the high concentration of heavy metals and toxic elements in old mining sites orchids are able to adapt to these specific conditions.

Nosalj et al. (2021) evaluated the effect of remediation on three plots at the site Banská Štiavnica – Šobov (the Štiavnické vrchy Mts, central Slovakia) where a heap of mining residues was established in the past and remediation was done 20 years ago. Measurements of basic chemical properties at the study area confirmed ongoing acidification, with an effect on soil properties. Acidification of the soil environment is also reflected in the composition of microscopic filamentous fungi, *Penicillium* species predominated and *Zygomycota* species were randomly present. The structure of microfungal communities was directly influenced by soil reaction (pH) and closely linked to the soil type.

The last contribution of the special issue is also devoted to the impact of the environmental burden on the biota, specifically the possible transfer of antimony from abandoned antimony mines to the bodies of Macromycetes and higher plants (Kautmanová et al. 2021). The study showed the consumption of edible mushrooms and medicinal plants from the studied localities represents a risk of intoxication for humans. The highest values of arsenic and cadmium were recorded in *Agaricus arvensis*, *Suillus* accumulated high levels of mercury, antimony and chromium. The species *Cardamine amara* is considered as a hyperaccumulator of all tested elements because it is characterized by the highest values of all species. On the other hand, these species can be used for phytoremediation of contaminated sites.

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