Biologia (2023) 78:2689–2700
https://doi.org/10.1007/s11756-023-01451-1

ORIGINAL ARTICLE

Chorology and phytosociological affinity of Greater Spearwort (*Ranunculus lingua* L.) in Slovakia

Matej Dudáš[1] · Richard Hrivnák[2] · Michal Slezák[3]

Received: 3 April 2023 / Accepted: 1 June 2023 / Published online: 22 June 2023

Abstract

Ranunculus lingua is an Euro-Siberian vascular plant species of freshwater habitats. Distribution and vegetation preferences of this rare species, which is native to the Slovak flora, have not yet been critically revised. The present paper aimed i) to provide the first complex distribution pattern of this species in Slovakia and ii) to analyse all available vegetation plots with species occurrence in order to elucidate the variability of plant communities. The distribution data were retrieved from herbarium specimens, literature records and field surveys. Our revision suggests that *R. lingua* was found particularly in the lowland areas of the western, south-western and south-eastern parts of the country. It was very rare in other regions of Slovakia, and several populations have become extinct due to drainage or habitat destruction. New localities of secondary origin were additionally documented in some human-made habitats. The temporal trend showed a strong decrease in the number of localities in natural habitats, mainly in the hilly and mountainous regions of the Western Carpathians from the 1980s to the end of the twentieth century. *R. lingua* was recorded in both forest and treeless swamp communities. Vegetation analysis revealed numerous records mainly in eutrophic marshes (*Phragmito-Magnocaricetea* class), willow and alder carrs (*Franguletea* and *Alnetea glutinosae*).

Keywords Central Europe · Distribution · Ranunculaceae · Red list species · Wetland vegetation

Introduction

European freshwater habitats are often reported among habitats under strong human pressure, although they host an important proportion of global plant diversity (García-Girón et al. 2021). Main threats are related to enormous destruction and changes in water regimes (Keddy 2000), which are multiplied by ongoing climate change and plant invasions (Short et al. 2016; Reid et al. 2019). Many species growing in these habitats (e. g. in open waters, marshes, wet meadows, floodplain and swamp forests) are threatened. Their populations have declined sharply in recent decades, and several of the wetland species have become extremely rare or threatened with extinction.

In Central Europe, the genus *Ranunculus* L. provides a good opportunity to study the chorology and ecology of an abundant group of threatened freshwater species. This genus is a cosmopolitan and the largest in the family Ranunculaceae Juss., with a diversity of almost 600 species (Tamura 1995). The presence of 36 species, including sect. *Batrachium*, has been reported from Slovakia (Futák 1982). This species group also includes *Ranunculus lingua* as a typical wetland plant, which is threatened throughout Europe and globally (Bilz et al. 2011; https://www.iucnredlist.org/search?query=ranunculus%20lingua&searchType=species) and is evenly recorded in several national Plant Red Lists in Central Europe. For example, it is listed as critically threatened in the Czech Republic (Grulich 2012), vulnerable in Slovakia (Eliáš et al. 2015) and near threatened in Hungary (Király 2007). Several endangered vascular plants with a clear vegetation preference for wetland habitats have recently been studied in Slovakia (e. g. *Beckmannia eruciformis* – Dítě et al. 2011; *Ludwigia palustris* – Dítě et al. 2017; *Calla palustris* – Dudáš et al. 2021), but the

✉ Matej Dudáš
dudas.mato@gmail.com

[1] Department of Botany, Faculty of Science, Pavol Jozef Šafárik University, Mánesova 23, 040 01 Košice, Slovakia

[2] Institute of Botany, Plant Science and Biodiversity Center, Slovak Academy of Sciences, Dúbravská Cesta 9, 845 23 Bratislava, Slovakia

[3] Institute of Forest Ecology, Slovak Academy of Sciences, Ľ. Štúra 2, 960 01 Zvolen, Slovakia

distribution and vegetation patterns of the greater spearwort (*R. lingua*) have not yet been critically reviewed.

Ranunculus lingua L. (*Ranunculaceae*, sect. *Lingua*) is an Euro-Siberian species distributed in western part of the Palearctic region, mainly throughout the temperate zone of Eurasia, less frequently in boreal and northern part of the Mediterranean zones. It occurs from northern Spain and Great Britain, followed by France, Central European countries and Scandinavia to the Balkan Peninsula, extending eastwards to the Baltic States, Belarus, Ukraine and European Russia, including south-western and southern Siberia (Meusel et al. 1965; Jalas and Suominen 1989; Hörandl 2022). The species is absent from most Mediterranean inland areas and islands. In Central Europe the majority of localities are situated along large lowland rivers. *R. lingua* is scattered to rare in Hungary (Bartha et al. 2015), Czech Republic (Křísa 1988) and Slovakia (Futák 1982), but relatively common in Poland (Zając and Zając 2001). This herb species prefers meso-eutrophic wetland sites, such as channel beds, muddy depressions, semi-saline swamps, marshes, mires and ponds. It also thrives in submerged habitats with shallow water that may partially dry out in late spring or summer (Casper and Krausch 2008). It is classified as a helophyte with its overwintering buds submerged below the sediment surface (Johansson and Nilsson 1993).

In Slovakia, species *Ranunculus lingua* seems to be distributed throughout the country, but with expected regional discrepancies. Historical observations (Futák 1982) suggest that the species was more common in wetland habitats in the southern areas, while most of the scattered records in other areas were associated rather with minerotrophic mires or swamp forests. Contrary to this distribution pattern, vegetation characteristics of *R. lingua* have been almost completely missing. Therefore, we aimed to revise and summarise the chorology with insight into temporal trend and vegetation affinity for the species *R. lingua* in Slovakia.

Materials and methods

Revision of herbarium specimens in Central European public herbaria (BP, BRA, BRNM, BRNU, CL, EGR, HLO, HNTS, HUM, KO, LTM, MMI, MPS, NI, OL, OLM, PMK, POP, PR, PRC, SAV, SLO, SMBB, SNV, TM, VSMU, ZAM and ZV) accompanied by intensive field research was carried out by the authors in the years 2018–2022 (only some of the older localities were revised). Especially, older mentioned localities without any habitats suitable for *Ranunculus lingua* verified by authors of the paper in the field and/or the authors of the relevant published papers were signed as destroyed (see also Fig. 1).

The herbarium acronyms followed Thiers (2023 +) and small local museum collections were unified according to Vozárová and Sutorý (2001). Floristic records were also obtained from the JACQ – Virtual herbaria database (www.jacq.org), published literature sources and relevant unpublished works or manuscripts (mainly stored at the Institute of Botany, Plant Science and Biodiversity Center, Slovak Academy of Sciences, Bratislava, Slovakia). All these data sources were used to prepare the distribution map of the species in the program ArcGis, version 9.2. Historical and recent records were arranged according to the phytogeographical affiliation proposed by Futák (1984). They were also assigned to the quadrants of the Central European Flora Mapping grid (CEFMG) template (Niklfeld 1971; Jasičová and Zahradníková 1976).

List of individual localities taken from herbarium specimens includes the name of the collector, the year of collection and the herbarium acronym in parentheses. References for published records are given in abbreviated form, i.e. they comprise author of the publication, journal abbreviation and volume, page with *R. lingua* record and year of publication. For unpublished field records, the year of finding is followed by the name(s) of the author(s). Locality notes were translated, with a few exceptions where historical names of localities are given in their original form, indicated by parentheses (see Appendix).

Phytosociological relevés with the occurrence of *R. lingua* in Slovakia were obtained from the Slovak Vegetation Database (code EU-SK-001 in the Global Index of Vegetation-Plot Databases; Šibík 2012) and completed by one original plot. We compiled a total of 36 vegetation plots stored in the Turboveg database (Hennekens and Schaminée 2001), which were in the next step exported to the Juice program (Tichý 2002). Species taxonomy was unified using the concept of broadly defined plant taxa. Specifically, we used only three aggregate taxa, namely *Eleocharis palustris* agg. (*E. palustris*, *E. uniglumis*), *Galium palustre* s. lat. (*G. elongatum*, *G. palustre*) and *Valeriana dioica* agg. (*V. dioica*, *V. simplicifolia*). Bryophytes were excluded from the dataset because they were identified in only a part of the relevés. Numerical classification was performed with species merged into a single layer using the modified TWINSPAN algorithm (Roleček et al. 2009) with settings of four pseudospecies cut levels (0%, 5%, 25% and 50%) and total inertia as a measure of cluster heterogeneity. The differential species of each cluster were determined using frequency and fidelity thresholds (Φ – phi coefficient; Chytrý et al. 2002). The Fisher's exact test ($p < 0.05$) was used to eliminate species with a non-significant occurrence in a given cluster (Tichý and Chytrý 2006). Thus, differential species were defined as species that simultaneously had frequency ≥ 20%, phi coefficient ≥ 0.30 and difference in frequencies between clusters ≥ 20%. If a particular species was constant (reached

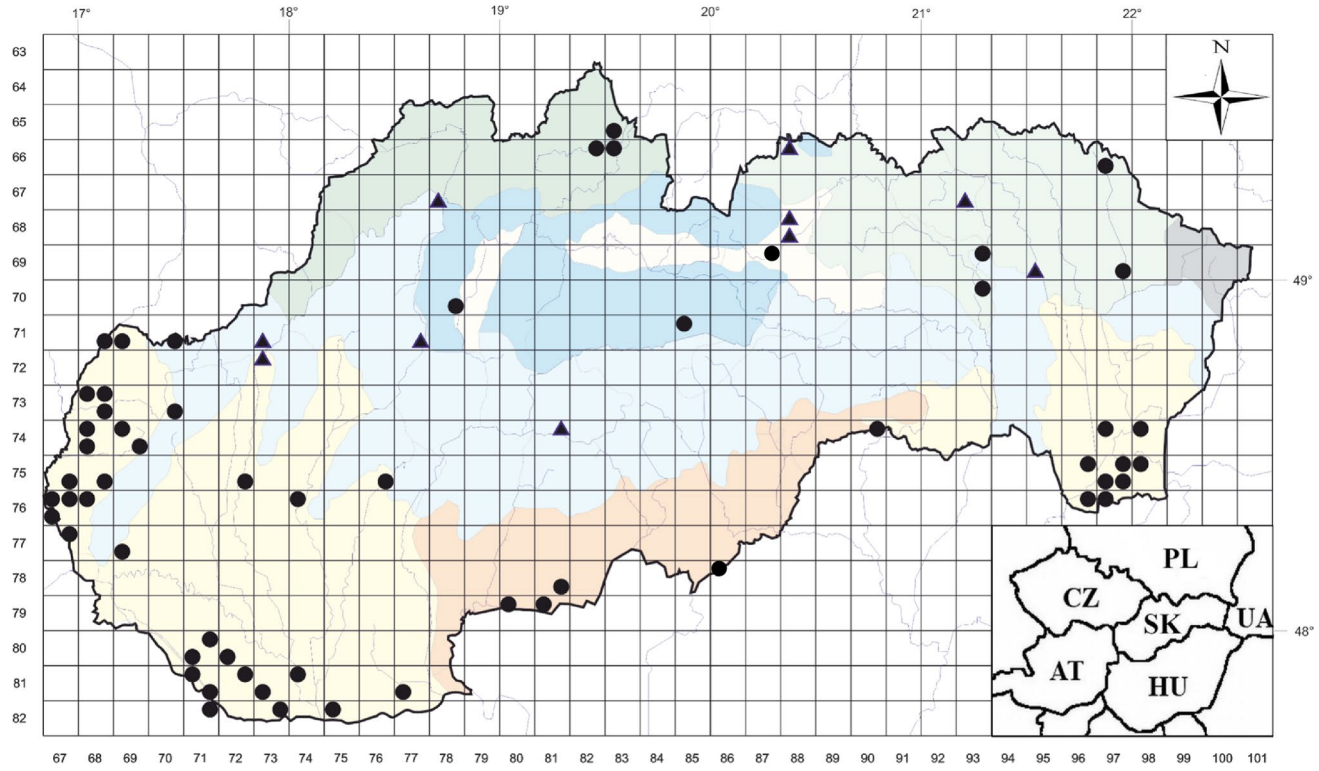

Fig. 1 Distribution of *Ranunculus lingua* in Slovakia. Black triangles indicate extinct populations or destroyed localities, and dots overall distribution. International codes of countries are shown. Coloured background corresponds to phytogeographical division of Slovakia according to Futák (1984)

frequency > 50%) in two or more clusters, it was not accepted as differential.

Nomenclature of plants and higher syntaxa follows checklists of Marhlod and Hindák (1998) and Mucina et al. (2016), respectively. Association names of plant communities are mentioned according to Slovak vegetation overviews (Valachovič 2001; Valachovič et al. 2021), and we also adopt the contemporary outcomes of European vegetation revisions (Douda et al. 2016; Landucci et al. 2020).

Results

Distribution of R. lingua in Slovakia

Localities of *R. lingua* in Slovakia are concentrated in the area of the Pannonian flora region, with distribution centres situated in the western, south-western and south-eastern parts of the country. They include mainly lowland areas (e. g. Záhorská, Podunajská and Východoslovenská nížina Lowlands) with some outposts in the northern Carpathian regions. Here, the species is rare and several populations have become extinct or suitable habitats for the species have changed (Fig. 1). We recorded *R. lingua* in 19 phytogeographical districts of Slovakia (out of 31 in total), including 5 in the Pannonian (*Pannonicum*) and 14 in the Western Carpathian (*Carpaticum*) biogeographical regions (Fig. 1, see Appendix for details).

Although the oldest record of *R. lingua* was reported by G. Reuss in the half of the nineteenth century, the increasing number of new localities started in the 1920s and peaked in period of the 1950s-1970s. The destroyed suitable habitats for existence of *R. lingua* created almost 16% of all CEFMG with the species distribution (Fig. 2).

Vegetation characteristics of R. lingua

Numerical classification using the Twinspan algorithm split phytosociological relevés with the occurrence of *R. lingua* into forest and non-forest wetlands (Table 1). Forest vegetation was mainly represented by willow and alder carrs (phytosociological classes *Franguletea* and *Alnetea glutinosae*), but species was also occasionally found in willow floodplain forests (*Alno glutinosae-Populetea albae*). Non-forest vegetation corresponded to marshy plant communities (*Phragmito-Magnocaricetea*), exceptionally to ephemeral wetland vegetation of exposed beds (*Isoëto-Nanojuncetea*). The most frequent co-occurring species were *Galium palustre* s. lat. (in 72% of the relevés), *Lysimachia vulgaris* (69%), *Lycopus europaeus* (61%) and *Lythrum salicaria* (61%), followed by

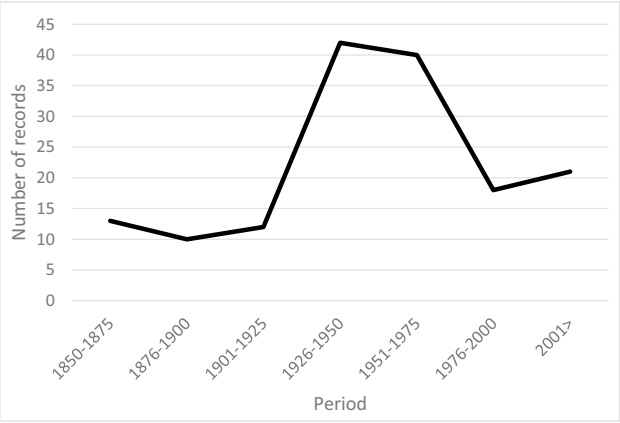

Fig. 2 Number of data records along temporal axis with quarterly periods

Equisetum fluviatile (44%), *Iris pseudacorus* (42%) and *Carex elata* (42%). These are typical species of marshes and swamps dominated by willows and alders.

The first cluster of relevés grouped flooded marshes with a constant presence of aquatic plants. This vegetation was syntaxonomically interpreted as the *Phragmition communis* alliance (associations *Glycerio-Sparganietum neglecti* and *Typhetum angustifoliae*). Mesotrophic stands of the *Magnocaricion elatae* alliance (as. *Caricetum diandrae*, *Menyathetum trifoliatae* and *Caricetum acitiformi-paniculatae*) were merged in the second cluster. The third cluster contained a wide range of typical eutrophic marsh communities dominated mainly by graminoids (i.e. tall sedges and grasses) of the alliances *Phragmition communis* (as. *Glycerio-Sparganietum neglecti* and *Glycerietum maximae*), *Magnocaricion elatae* (as. *Caricetum elatae* and *Carici elatae-Calamagrostietum canescentis*) and *Magnocaricion gracilis* (as. *Caricetum riparae*, *Caricetum vesicaria* and *Caricetum gracilis*). Vegetation of the exposed bottoms belonging to the *Nanocyperion* alliance was classified in the last 7th cluster (Table 1). Three clusters (no. 4–6, Table 1) were distinguished for different alliances of forest vegetation, namely willow floodplain forests of the *Salicion albae* (as. *Salicetum fragilis*; cluster 4), alder and willow swamps of the *Alnion glutinosae* (as. *Carici elongatae-Alnetum glutinosae* and *Carici acutiformis-Alnetum glutinosae*; clusters 5 and 6) and the *Salicion cinereae* (as. *Salicetum pentandro-auritae*; cluster 5). Early successional stages of swamp forests with the presence of numerous wet meadow plants were also found especially in cluster 6 (Table 1).

Discussion

The initial chorology of the species *Ranunculus lingua* in Slovakia reported by Futák (1982) is now outdated, as several localities were mentioned as historical at that time. Moreover, Futák already suggested that synergistic effect of various anthropogenic activities (e. g. drainage or gradual urbanisation of large areas) had induced pronounced environmental changes and destroyed many of the original populations. Expert revision of both herbarium specimens and available published data allowed us to update the distribution pattern of this species in Slovakia.

The first record of *R. lingua* reported by Reuss (1853) near Prešov is without a precise localisation or habitat description, similarly as the herbarium specimen collected by F.A. Hazslinszky (deposited in BP), whose botanical research in this region was probably performed in the second half of the nineteenth century. Revision of the specimens in other public herbaria suggests that this historical locality (localities) may correspond either to swamps near Šalgovík (specimens in SLO and MPS) or to Fulianka (specimen in SAV). However, our current floristic research has not proved the species occurrence there.

Our results indicate that *R. lingua* has not been observed in several mountainous regions of the Western Carpathians (e. g. Strážovské vrchy Mts, Poľana Mts, Lúčanská Fatra Mt., Pieniny Mts, Spišské vrchy Mts, the Čergov Mts) for many decades, in some cases for more than a century (Appendix), and species is therefore considered as regionally extinct. This could be explained mainly by habitat destruction or at least by severe modifications in environmental conditions (changes of water regimé caused especially by human or secondary succession). A similar situation has been recognized in other hilly and mountainous areas, such as the Orava region, the Biele Karpaty Mts, the Šarišská vrchovina upland and in the ponds near the village of Hrhov in the Slovenský kras karst. Although no original records have been newly found here, there are several suitable habitats with optimal ecological conditions where the species could still survive today. On the other hand, most of the historical data in the Podunajská nížina Lowland overlaps with the recent distribution of the species. The current localities were recorded particularly along swamps, channels and river oxbows of the Dunaj and Malý Dunaj or along the lower course of the Váh and Ipeľ rivers. Species is very scattered to rare in the lowlands of Borská nížina (Májeková and Zaliberová 2006) and Východoslovenská nížina. Outside the lowlands, *R. lingua* recently occurs only in localities situated close to the village of Machulince in western Slovakia, near the village of Polomka in central Slovakia (Fig. 3) and near Poprad in northern Slovakia (for details see list of

Table 1 Shortened synoptic table of plant communities with occurrence 412 of *Ranunculus lingua* in Slovakia is shown. Relative frequency of the species in given cluster with median cover values in upper index (cover values only in cluster 7) are presented. They are displayed in bold only for differential species of each cluster

Cluster No	1	2	3	4	5	6	7
No. of relevés	3	3	15	2	10	3	1
Eutrophic flooded marshes							
Stratiotes aloides	**100^{a}**	.	.	.	.	.	.
Hydrocharis morsus-ranae	**100^{3}**	.	.	.	.	.	.
Spirodela polyrhiza	**67^{+}**	.	.	.	.	.	.
Schoenoplectus tabernaemontani	**67^{+}**	.	7^{+}	.	.	.	.
Salvinia natans	**67^{+}**	.	.	.	10^{+}	.	.
Typha angustifolia	**67^{5}**	.	14^{r}	.	10^{+}	.	.
Mesotrophic marshes							
Carex nigra	.	**100^{+}**	.	.	.	.	.
Carex diandra	.	**100^{a}**	.	.	.	.	.
Valeriana dioica agg	.	**100^{1}**	7^{r}	.	.	.	.
Carex rostrata	.	**100^{a}**	7^{+}	.	.	.	.
Carex acutiformis	.	**67^{1}**	.	.	.	.	.
Eriophorum angustifolium	.	**67^{+}**	.	.	.	.	.
Juncus articulatus	.	**67^{r}**	.	.	.	.	.
Ranunculus flammula	.	**67^{+}**	7^{+}	.	.	.	.
Epilobium palustre	.	**67^{r}**	7^{r}	.	10^{+}	.	.
Eleocharis palustris agg	.	**67^{+}**	21^{+}	.	.	.	.
Euutrophic marshes							
Carex elata	33^{+}	33^{r}	**64^{4}**	.	40^{1}	.	.
Floodplian willow forests							
Fraxinus angustifolia (E_3)	.	.	.	**100^{3}**	10^{1}	.	.
Fraxinus angustifolia (E_2)	.	.	.	**100^{1}**	10^{a}	.	.
Salix fragilis (E_3)	.	.	.	**100^{1}**	20^{1}	.	.
Salix fragilis (E_2)	.	.	.	**100^{1}**	.	.	.
Quercus robur	.	.	.	**100^{1}**	.	.	.
Senecio paludosus	.	.	.	**100^{+}**	.	.	.
Phalaris arundinacea	.	.	27^{1}	**100^{m}**	10^{1}	.	.
Leucanthemella serotina	.	.	.	**100^{+}**	40^{+}	.	.
Cardamine pratensis	.	33^{r}	.	**100^{+}**	40^{+}	.	.
Typical willow and alder carrs							
Alnus glutinosa (E_1)	.	.	.	.	**60^{1}**	.	.
Alnus glutinosa (E_2)	.	.	.	.	50^{5}	100^{a}	.
Salix cinerea (E_2)	.	.	.	.	**90^{3}**	.	.
Cicuta virosa	33^{1}	.	.	.	**70^{+}**	.	.
Typha latifolia	.	.	7^{4}	.	**30^{+}**	.	.
Sambucus nigra (E_2)	.	.	.	.	**30^{+}**	.	.
Drier types of alder carrs							
Silaum silaus	.	.	.	.	.	**100^{+}**	.
Acorus calamus	.	.	.	.	.	**100^{1}**	.
Carex remota	.	.	.	.	.	**100^{1}**	.
Holcus lanatus	.	.	.	.	.	**100^{+}**	.
Dryopteris cristata	.	.	.	.	.	**100^{1}**	.
Filipendula ulmaria	.	.	.	.	10^{+}	**100^{+}**	.
Cirsium palustre	.	.	7^{+}	.	20^{+}	**100^{+}**	.
Scirpus sylvaticus	.	33^{r}	7^{1}	.	.	**100^{1}**	.
Mentha piperita agg	.	.	.	.	.	**67^{1}**	.
Rubus plicatus	.	.	.	.	.	**67^{+}**	.
Frangula alnus	.	.	.	.	.	**67^{+}**	.
Deschampsia cespitosa	.	.	.	50^{+}	.	**100^{+}**	.

Table 1 (continued)

Cluster No	1	2	3	4	5	6	7
Calystegia sepium	.	.	21^{+}	.	40^{+}	$\mathbf{100^{1}}$	.
Athyrium filix-femina	.	.	.	.	30^{1}	$\mathbf{67^{+}}$	.
Galium uliginosum	.	33^{+}	.	.	.	$\mathbf{67^{+}}$	.
Menyanthes trifoliata	.	33^{3}	.	.	20^{1}	$\mathbf{67^{1}}$	.
Exposed bottom vegetation							
Tripleurospermum inodorum	.	.	.	.	.	.	$\mathbf{100^{+}}$
Trifolium arvense	.	.	.	.	.	.	$\mathbf{100^{+}}$
Echinochloa crus-galli	.	.	.	.	.	.	$\mathbf{100^{3}}$
Rumex stenophyllus	.	.	.	.	.	.	$\mathbf{100^{1}}$
Lythrum hyssopifolia	.	.	.	.	.	.	$\mathbf{100^{3}}$
Limosella aquatica	.	.	.	.	.	.	$\mathbf{100^{b}}$
Potentilla supina	.	.	.	.	.	.	$\mathbf{100^{+}}$
Juncus bufonius	.	.	.	.	.	.	$\mathbf{100^{5}}$
Veronica anagalloides	.	.	.	.	.	.	$\mathbf{100^{+}}$
Alopecurus geniculatus	.	.	.	.	.	.	$\mathbf{100^{+}}$
Atriplex patula	.	.	.	.	.	.	$\mathbf{100^{+}}$
Plantago uliginosa	.	.	.	.	.	.	$\mathbf{100^{1}}$
Polygonum aviculare agg	.	.	.	.	.	.	$\mathbf{100^{a}}$
Elymus repens	.	.	.	.	.	.	$\mathbf{100^{+}}$
Anagallis arvensis	.	.	.	.	.	.	$\mathbf{100^{+}}$
Anagallis foemina	.	.	.	.	.	.	$\mathbf{100^{+}}$
Studied species							
Ranunculus lingua	100^{+}	100^{r}	100^{+}	100^{+}	100^{+}	100^{+}	100^{+}
Species with occurrence at least 6 relevés							
Galium palustre	.	100^{1}	86^{+}	100^{a}	80^{1}	33^{+}	.
Lysimachia vulgaris	.	33^{+}	64^{+}	100^{+}	100^{+}	100^{1}	.
Lythrum salicaria	67^{+}	67^{1}	86^{+}	50^{+}	40^{+}	.	100^{+}
Lycopus europaeus	.	33^{1}	47^{r}	100^{1}	100^{1}	100^{+}	.
Equisetum fluviatile	.	67^{a}	43^{+}	.	80^{1}	.	.
Iris pseudacorus	33^{3}	.	50^{+}	100^{+}	50^{+}	.	.
Glyceria maxima	67^{1}	.	43^{+}	50^{1}	50^{1}	.	.
Carex riparia	33^{1}	.	50^{+}	100^{a}	40^{a}	.	.
Sium latifolium	33^{+}	.	57^{+}	100^{1}	30^{+}	.	.
Stachys palustris	.	.	36^{+}	100^{1}	70^{+}	.	.
Calamagrostis canescens	33^{+}	33^{+}	14^{5}	.	60^{1}	100^{+}	.
Solanum dulcamara	.	.	.	50^{1}	90^{1}	100^{1}	.
Thelypteris palustris	33^{4}	.	.	.	90^{3}	100^{+}	.
Scutellaria galericulata	67^{r}	.	36^{+}	.	60^{1}	.	.
Mentha aquatica	67^{+}	.	43^{+}	100^{+}	10^{+}	33^{1}	.
Carex vesicaria	.	.	57^{+}	100^{1}	20^{1}	.	.
Phragmites australis	67^{+}	67^{1}	14^{+}	.	50^{a}	.	.
Symphytum officinale	.	.	29^{+}	100^{1}	50^{1}	.	.
Caltha palustris	67^{r}	.	14^{+}	100^{1}	20^{+}	67^{1}	
Peucedanum palustre	67^{+}	.	7^{+}	.	70^{1}	.	.
Lemna minor	67^{a}	.	21^{1}	.	10^{+}	100^{a}	.
Alisma plantago-aquatica	33^{a}	.	29^{+}	.	40^{+}	.	.
Rumex hydrolapathum	33^{+}	.	29^{+}	.	40^{+}	.	.
Sparganium erectum	33^{4}	33^{+}	40^{+}	.	10^{+}	.	.
Agrostis stolonifera	.	33^{r}	43^{+}	.	10^{1}	.	.
Ranunculus repens	.	.	21^{+}	50^{1}	40^{1}	.	.
Carex elongata	.	.	7^{r}	50^{+}	50^{1}	.	.

Table 1 (continued)

Cluster No	1	2	3	4	5	6	7
Persicaria amphibia	.	.	29^{+}	.	10^{+}	.	100^{+}
Carex pseudocyperus	33^{+}	.	.	.	50^{1}	.	.
Rorippa amphibia	.	.	29^{+}	.	20^{+}	.	.
Phellandrium aquaticum	.	.	21^{+}	.	30^{1}	.	.

List of sources

Cluster 1: Šomšák (1963), Východoslovenská rovina Lowland, 1 relevé; Šomšák (ined.), Východoslovenská rovina Lowland, 2 rels. – Cluster 2: Balátová-Tuláčková (1976), Borská nížina Lowland, 2 rels.; Rybníček & Rybníčková (1972), Oravská kotlina Basin, 1 rel. – Cluster 3: Balátová-Tuláčková (1976), Borská nížina Lowland, 4 rels.; Berta J. (1957), Podunajská nížina Lowland, 3 rels.; Bosáčková (1972), Podunajská nížina Lowland, 2 rels.; Svobodová & Řehořek (1972), Ipeľská kotlina Basin, 3 rels.; Hadač E. (ined.), Laborecká vrchovina Mts, 2 rels.; M. Slezák ined., Popradská kotlina Basin, 1 rel. – Cluster 4: Berta (1970), Východoslovenská rovina Lowland, 2 rels. – Cluster 5: Berta (1970), Východoslovenská rovina Lowland, 7 rels.; Šomšák (1963), Východoslovenská rovina Lowland, 3 rels. – Cluster 6: Krippel (1959), Borská nížina Lowland, 1 rel.; Krippel (1965), Borská nížina Lowland, 1 rel.; Krippel (1967), Borská nížina Lowland, 1 rel. – Cluster 7: Májeková (2005), Borská nížina Lowland, 1 rel. Complete header data, less frequent species and full relevés are available upon request in Slovak Vegetation Database

Fig. 3 *Ranunculus lingua* near the village of Strážne (left; author Daniel Dítě, 6.7.2009) and Polomka (right; author Martin Veverka, 1.7.2022)

localities and Fig. 1). It is considered to be rare in north-eastern Slovakia because several populations have became extinct and the last isolated occurrence in the Nature reserve Čertižnianské lúky has been confirmed in 2004 (see Appendix). For comparison, species is also rare in the adjacent hilly areas of south-eastern Poland, but the number of populations increases northwards in the lowland areas (Zając and Zając 2001).

The number of records has also been rapidly decreased in south-eastern Slovakia (mainly in alluvial pools of the Bodrog and Latorica rivers) over last 60 years, probably due to extensive melioration and drainage of the area (Bella 1971; Terek and Matas 1983). Several populations of *R. lingua* still exist near the village of Strážne (south-eastern of Slovakia) in a complex of terrain depressions between sandy dunes used for grazing and on the banks of channels (Fig. 3). This unique grazed wetland site, with the largest recent population of *R. lingua*, also hosts other rare and endangered species such as *Beckmannia eruciformis* (Dítě et al. 2011) or *Cirsium brachycephalum* (Mártonfi 2014). Along channels *R. lingua* grows in wetland vegetation dominated by tall-sedges and willow shrubs together with typical marsh and wet meadow species such as *Calystegia sepium, Glyceria maxima, Lythrum salicaria, Scutellaria galericulata, Schoenoplectus lacustris,* and *Stachys palustris*.

The species is a popular ornamental herb planted locally in small ponds. It can survive there for a long time (e. g. Kochjarová et al. 2013) and has the potential to spread to natural aquatic and wetland habitats, mainly if they are hydrologically connected. However, this accidental introduction pathway has not been found in Slovakia.

Futák (1982) provided only a brief insight into vegetation affinity of *R. lingua*, based on his empirical (expert-based) knowledge. It was listed as a characteristic species mainly in the alliances *Phragmition communis* and *Magnocaricion elatae*. Our vegetation analyses showed that *R. lingua* occurs in a wide range of wetland habitats, mainly floodplain forests, alder and willow carrs of the classes *Franguletea*, *Alnetea glutinosae*, *Alno glutinosae-Populetea albae* and freshwater treeless habitats of the class *Phragmito-Magnocaricetea*. They are characterised by spring or early summer floods followed by water level fluctuations with a relatively

long-term presence of water below the soil surface. These intra-annual variations in water levels have an important effect on the growth and reproduction of *R. lingua* (e. g. Johansson 1993; Rybka and Duchoslav 2007) and on the variability in species composition of plant communities. A similar vegetation niche of the species has also been reported from other Central European regions in Poland and Hungary (e. g. Solińska-Górnicka 1987; Matuszkiewicz 2008; Lóczy 2019). However, countries with a higher number of localities showed a wider range of habitats. For example, *R. lingua* is able to grow in wet meadows, oligotrophic lakes and pools, slowly flowing rivers, large shlallow lakes and mires as well (Wassen et al. 1995; Szoszkiewicz et al. 2010; Lukács et al. 2015; Chytrý et al. 2021). The species has been frequently observed throughout Europe in vegetation dominated by tall-sedges and grasses of the *Magnocaricetalia* order (Appendix S7 in Landucci et al. 2020), but also thrives in alder carrs (e. g. Solińska-Górnicka 1987). Several plant communities with *R. lingua* occurrence reported in other European countries are rare (e. g. *Caricetum diandrae*) or recently unlisted (*Menyathetum trifoliatae*) in Slovakia (Valachovič, 2001) due to strong changes in the lowland landscape in last decades.

Appendix

Localities of *Ranunculus lingua* in Slovakia

Pannonicum

(***Matricum***) **2. Ipeľsko-rimavská brázda Region:** Ipeľské Predmostie, swamp in village (Svobodová 1964 SAV; Svobodová, Acta fytotech., Nitra 14: 184, 1966; Svobodová & Řehořek 1972, Tab. 2, rel. 9). – Malá Čalomija (Svobodová, Acta fytotech., Nitra 16: 179, 1967; Svobodová & Řehořek 1972, Tab. 3, rels 1 and 3). – Dubno, in water course of the Gortva stream eastern from the village, near marsh (Hrivnák & Cvachová, Poiplie, Urban & Hrivnák, SAŽP, p. 20, 1997). – Koláre, Kolársky canal (Baláži & Tóthová, Acta Environ. Univ. Comen. 19/1: 54, 2011). – Opatovská Nová Ves, brook Čebovský potok (Baláži & Tóthová, l. c., p. 52). **3. Slovenský kras Karst:** Hrhov, S, *Sphagnetum*, in ditches and meadows (Brym 1930 PRC; Brym, Krásy Slov. 11: 104, 1932; Brym & Maloch, Sborn. Prír. Kl. Košíc 2: 148, 1935).

(***Eupannonicum***) **4. Záhorská nížina Lowland:** Holíč, brook Kyštor (Baláži & Tóthová, l. c., p. 56). – Skalica [Szakolczam] (Krzisch, Verhand. Ver. Nat. Presburg 3/2: 27, 1858). – Skalica, Rybník (Holuby, Correspond. Ver. Nat. Presb. 2: 83, 1863). – Kúty [Kutti] (Krzisch, l. c.). – Čáry [Csary] (Krzisch, l. c.). – Borský Peter, northen from the village (Balátová-Tuláčková, Veg. ČSSR, Table 5, relevé 4, 1976). – Plavecký Peter, Rudava river (Baláži & Tóthová, l. c., p. 58). – Záhorská Ves, 2,3 km NEE from railway station, field depression and Hlinec brook, 147 m (Májeková & Zaliberová, Bull. Slov. Bot. Spoločn. 28: 92, 2006). – Záhorská Ves, in canal 0,4 km NW from Lopaty hill (147,8), large population (Májeková & Zaliberová in Dítě (ed.), Bull. Slov. Bot. Spoločn. 26: 224, 2004). – between Uhorská Ves and Jakubov (Degen et al., Magy. Bot. Lapok. 22: 83, 1923). – Jakubov [Jakabfalva] (Andrasovszky 1915 BP). – Jakubov, willows, meadows (Ptačovský 1924 SAV). – Jakubov, S and NW meadows from Grófsky most towards Feldský most, 145 m (Ružička 1951 SAV). – Lakšárska Nová Ves, W, Pod vršky, swamp (Holzknecht 1946 BRNU). – Lakšárska Nová Ves, Červený rybník, 3,5 km W from village (Grulich 1985 MMI). – Veľké Leváre, Abrod (Součková 1949 BRNM). – swamps between Závod and Veľké Leváre, 160 m (Černoch 1950 BRNM, PR; Balátová-Tuláčková, l. c., Tab. 2, rel. 11). – Plavecký Štvrtok, Nature reserve Bezedné, alder carr (Krippel 1959, Tab. 1, rel. 6; 1965, Tab. 5, rel. 1; 1967, Tab. 1, rel. 3). – ditch and swamp along railway track between Plavecký Štvrtok and Malacky (Ptačovský 1923 SAV; Mikeš, Kvet. okr. Bratislava, p. 159, 1938). – Malacky, left bank of Pernecká Malina between Prvý and Druhý rybník pond, 206 m (Dítě in Eliáš jun. (ed.), Bull. Slov. Bot. Spoločn. 35/1: 78, 2013). – Moravský Svätý Ján (Kmeťová 1980 SAV; Balátová-Tuláčková, l. c., 1976, Tab. 7, rel. 5, Tab. 8, rel. 4). – Šaštín, meadows (Májovský & Michalko 1951 SLO). – Láb, Lábske jazero, meadows, 140 m (Fr. Nábělek 1936 SAV, 1941 SLO; Ptačovský 1943 SAV; Součková 1954 BRNM; Ružička 1954 SAV; Krippel s. dato SLO, Balátová-Tuláčková, l. c., Tab. 11, rel. 30). – Záhorie, Pustý Mlyn, the reeds (Hejný & Hejná 1944, 1949 SLO). – Vysoká pri Morave [Hochštetno], River Morava, 145 m (Krist 1936 BRNU). – Vysoká pri Morave, Rudávka River, swamp, 145 m (Dvořák 1949 BRNM; Skřivánek 1949 BRNM; Šmarda 1949 BRNM). – Devínska Nová Ves, Devínske jazero, dead oxbow of Morava river, with *Phragmites australis*, ca 160 m (Mikeš, l. c., p. 149; Kollár et al. in Dítě (ed.), Bull. Slov. Bot. Spoločn. 28: 278, 2006). – Jablonica, Búr, swamp Brezina (Scheffer 1922 BP; Nevole 1931 BRNU; Nevole, Práce Mor. Př. Sp. VI, 5: 118, 1931). **6. Podunajská nížina Lowland:** Leopoldov [Leopoldstadt] (Krzisch, l. c.). – Dražovce, Nitra river, forest (Schiller, Oest. Bot. Z. 13: 402, 1863). – Svätý Jur, Šúr [Svätojurský Šúr] (Kornhuber, Verh. Ver. Nat. Presb. III, 2: 34, 1858; Holuby 1911 PR, 1918 PR, PRC; Zigmundík 1914 BRA; Domin 1920 ined.; Trapl 1922 PRC; Ptačovský 1928 PRC, SAV; Schidlay 1932 SAV; Dlabačová 1934 PRC; Fr. Nábělek 1941, 1950 SAV; Futák 1941 SAV; Horňanský 1951 BRNM; Berta 1955 SLO; Murín in Májovský et al., Acta Fac. Rer. Natur. Univ. Comen., Ser. Bot. 25: 128, 1976, 2n = 128; Berta, (Msc.) 1957). – Jurová-Gombariská, canal (Oťahelová 1989, 1990 SAV). – Dunajská Streda, canal (Valenta 1938 BRA; Zahradníková 1960 SAV).

– Gabčíkovo, SE from the village, meadows near "Čierny háj" (Bosáčková 1972, Tab. 1, rel. 10) – Gabčíkovo, canal Slané jazero (Oťahelová 1988 SAV). – Gabčíkovo, towards Medveďov, in first canal on the left from road (Jasičová 1958 SAV). – Žitný ostrov, Horný Štál [Alistál] (Valenta 1937 BRNU). – Žitný ostrov, wet meadows between Ňárad [Čiližský Nárad] and Beš (Krist 1938 BRNU; Krist, Sborn. Kl. Přír. Brno 21: 44, 1939; Krist, Pr. Mor. Přír. Společn. Brno, 12/10: 77, 1940). – Medveďov [Medve] (Krist, l. c. 1939). – Boheľov (Hejný ined.). – Dolný Štál [Hroboňovo], wetland (Klokner 1973 PMK). – Dolný Štál [Hroboňovo], north margin of the village (Bosáčková 1972, Tab. 1, rel. 9) – Veľký Meder [Čalovo] (Májovský 1954 SLO). – Zemianska Olča [Vemesócsa] and Gúta (Krist, l. c. 1939; Krist 1938 BRNU). – Lohót, Lohótsky canal (Juhászová 1990 PMK; Dorotovičová, Limnologica 43. 282, 2013). = Ďulov Dvor, wetland (Klokner 1959 PMK). = Ďulovský kanál (Klokner 1971 PMK). – Zlatná na Ostrove (Vavro 1980 HLO). – Komárno, swamp between Gúta and Kameničná [Keszegfalva], 110 m (Gáyer, Magy. Bot. Lapok 15: 47, 1916; Krist 1938 BRNU). – Chotín [Hetín], railway station, 111 m (Osvačilová 1954 PR). – General data: Žitný ostrov (Resely Oester. Bot. Z., p. 53, 1867). **8. Východoslovenská nížina Lowland:** Zemplínske Jastrabie, alder forest (Berta, Veg. ČSSR, B1, p. 166–168, tab. 47, 1970). – Veľké Raškovce [Nagy Raska], dead oxbow, in mud (Staněk 1947 BRNM). – Streda nad Bodrogom (Kiss, Bot. Közl. 36/5–6: 214, 1939). – Somotor [Szomotor], Tajba [Tálya], swamp (Margittai, Bot. Közl. 5–6: 30, 1929; Margittai 1926 BP, 1931 PR). – Véč, Tice (Margittai 1928 BP). – Bodrog, majer Kerestúr, swamp (Záborský 1959 ined.). – Strážne, Opátsky piesok, complex of terrain depressions between sandy dunes towards former railway station (Bogoly, Východoslov. Tábor ochr. prír. 9: 33, 1985; Zlacká 2005 NI; Zlacká in Dítě (ed.), Bull. Slov. Bot. Spoločn. 28: 283, 2006; Bača in Eliáš jun. (ed.), Bull. Slov. Bot. Spoločn., 31/1: 106, 2009; Eliáš in Mártonfi (ed.), Bull. Slov. Bot. Spoločn. 36, Suppl. 1: 63, 2014; Sitášová, Nat. Carp. 57: 36, 2016). – Strážne, drainage canal Južný Svätušský kanál before confluence with Južný Horešský kanál, 100 m (Dudáš 2015 SAV, 2021 BRNU, KO). – Veľký Horeš, depression between sandy dunes S from Hill 115 (Šomšák, Acta Fac. Rer. Nat. Univ. Comen., ser. bot. 8/5–6: 251, tab. 4, 1963). – Hrušov, settlement Keresztúr, W, swamp between dunes (Šomšák, l. c., p. 258, tab. 5). – Svätuše [Szentes, Plešany], forest by the road (Opluštilová 1951 SAV). – Svätuše, terrain depression between sandy dunes (Šomšák, l. c., p. 258, tab. 5). – Boľ [Bôľ, Ból, Bóly] (Boros 1958 BP; J. Dvořák 1958 BRNM; M. Deyl 1958 PR). – Boľ, Guttmanov dvorec, grounded oxbow Tice (Berta, l. c., p. 136–137, tab. 44). – Solnička, grounded oxbow Tice (Májovský 1958 ined.; Šomšák, l. c., p. 285, tab. 11). – Poľany, S, dead oxbow Tice (Šomšák, l. c., p. 258, tab. 5). – Poľany, Ticze ér, dead oxbow (Staněk 1947 BRNM). – Poľany, meadow near collective farm [former JRD] (Májovský 1958 ined.). – Poľany, ca. 600 m SW, grounded oxbow Tice (Berta, l. c., p. 136–137, tab. 44, p. 166–168, tab. 47). – Poľany, Vilháň, forest Čierny les on left bank of Latorica (Berta, l. c., p. 222, tab. 49). – Leles [Lelesz], Ticze-ér, swamp, common (Buček, Sborn. Kl. Přír. Brno 14: 97, 1932; Staněk 1947 BRNM). – Kráľovský Chlmec [Királyhelmecz], swamp Nagy-Döbönyös (Margittai 1927 BP; Margittai, Bot. Közl. 5–6: 94, 1929). – Kráľovský Chlmec, NW, ca. 800 m right from road towards Plešany, grounded oxbow Tice, alder forest Dalmoš (Berta, l. c., p. 166–168, tab. 47). – Veľké Kapušany [N. Kapus], Ortov [Ortó], swamp (Margittai 1935 PR).

Carpaticum occidentale

(*Praecarpaticum*) 9. Biele Karpaty Mts (southern part): Vrbovce, Zimovci, brook Teplica (Baláži & Tóthová, l. c., p. 59). – Trenčianske Bohuslavice [Bohuszlavicz] (Holuby 1904 PR; Holuby, Trenc. Fl., p. 102, 1888). – Štvrtok, swamp (Holuby, Oest. Bot. Z., 15: 267, 1865; Holuby 1857 BP, 1882 PRC). **12. Tribeč Mts:** Machulince, clay mine NW from village, 46 plants (Eliáš sen. 2012 SLO). **13. Strážovské a Súľovské vrchy Mts:** Nedožery (Dvořák, Zborn. Přír. Kl. Třeb. 2: 54, 1938). **14d. Poľana Mts:** Vígľaš (Futák 1946s. Futák, l. c.).

(*Eucarpaticum*) 21a. Lúčanská Malá Fatra Mts: Žilina, Frambor-Potôčky (Urbanová 1984 ZAM, locality destroyed). – Prievidza, swamp between Nedožery and Nitrianske Pravno (Fr. Jičínský 1930 BRNU). **22. Nízke Tatry Mts:** Nízke Tatry, Polomka, peat-bog between road and railway track ca 500 m E from east edge of industrial area (former Drevokombinát), 592 m (Dítě in Eliáš jun. (ed.), Bull. Slov. Bot. Spoločn. 34/2: 215, 2012). **24. Pieniny Mts:** Červený Kláštor (Vraný, 1929: 141). – Červený Kláštor, Nižné Šváby, Virháňov potok, fishponds (Domin 1932 PRC [*non vidi!*] sec Futák, l. c.; Domin 1934a: 184). – Pieniny, Veľký Rybník (Filarszky, Jahr. Mag. Karp. Ver. 25: 48, 1898).

(*Intracarpaticum*) 25. Turčianska kotlina Basin: Ivančiná, 1 km W from the left bank of Turiec river, at road in direction to Slovenské Pravno, wetland (Škovirová 2009 TM). **26b. Spišské kotliny Basins:** between Huncovce [Hunfalva] and Veľká Lomnica [Kakas-Lomics], ditch along railway (Nyárády, Magy. Bot. Lapok, 10: 74, 1911). – Rakúsy (Kotula, Rozm. rośl. naczyn. w Tatrach., p. 248, 1890) – Poprad, Matejovce, margin of the Slavkovský potok stream (Slezák 2020 POP).

(*Beschidicum occidentale*) 28. Západné Beskydy Mts: Orava, Námestovo, peat-bog between Ťapešovo and Lokca, 620–630 m (Futák 1959 SAV; Rybníček & Rybníčková 1972). – Štefanov nad Oravou (Truchlý 1894 BP, BRA). – Tvrdošín [Turdossin], Bobrov [Bobró] (Szontagh,

Enumeratio p. 1083, 1863). – Ústie na Orave, Slanica, Biela Orava, wet meadows, *Sphagnetum* near Bobrovec brook (Hynšt 1951 OLM).

(***Beschidicum orientale***) **29. Spišské vrchy Mts:** Spišská Stará Ves (Vraný 1890a: 255 s Futák, l. c.). – Lechnica [bei Sub-Lechnitz und Altendorf], swamp "Grossen Weiher " (Vraný 1890 PR; Vraný, Jahr. Ung. Karp. Ver. 17: 255, 1890). **30a. Šarišská vrchovina hill area:** Prešov, [Saros Eperjes] (Hazslinszky s. dato BP, PR; Reuss, Kvet. Slov., p. 9, 1853). = Šalgovík, swamps near Sekčov river (Májovský 1949 SLO; s. coll. 1970 MPS). **30b. Čergov Mts:** Hertník (Dostál, Ochr. prír. okr. Bardejov, p. 17, 1981, population extinct). **30c. Nízke Beskydy hill area:** Bystré [Bisztro] (Hazslinszky s. dato BP sec Futák, l. c.). – Fulianka, former river oxbow of Sekčov river, behind railway track towards Tulčík (Ľ. Dostál 1973 SAV). – Čertižné, fen wet meadows [today Nature reserve Čertižnianske lúky] (Májovský 1975 SLO; Tlusták 1982 OLM; Dostál, Zborn. Východoslov. Múz. v Košiciach, prír. vedy 26: 43, 1985; Töröková 1990 HUM; data from Protected Landscape Area Východné Karpaty 2004). – Koškovce, canal near railway line south of village (Dostál, Zborn. Východoslov. Múz. v Košiciach, prír. vedy 26: 43, 1985).

Common data (not mapped):

Bratislava [Pressburg, Pozsony] (Schneller 1870 BP; Dobay s. dato BP).

Localities with secondary origin of *Ranuculus lingua* (cultivated, but with no evidence of spreading)—not mapped

2. Ipeľsko-rimavská brázda Region: Číž, small artificial pond in the spa (R. Hrivnák, 2017, unpublished data). **14e. Štiavnické vrchy Mts:** Počúvadlo, Počúvadlo water reservoir near Topky hotel (Kochjarová et al., Bull. Slov. Bot. Spoločn. 35: 107–118, 2013). **21c. Veľká Fatra Mts:** Blatnica, small pond in the south-east part of the village, near monument to the heroes of the Slovak national uprising (R. Hrivnák, 2021, herbarium of R. Hrivnák).

Acknowledgements The research was supported by the Science Grant Agency of the Ministry of Education of the Slovak Republic and the Slovak Academy of Sciences (VEGA 2/0053/23). We thank to Csilla Dorotovičová (Danube Region Museum, Komárno, Slovakia) for the consultation on actual distribution in south-western Slovakia and to Barbara Repčíková (CHKO Východné Karpaty, Medzilaborce, Slovakia) for the actual situation of this species in Nature reserve Čertižnianske lúky. We are also grateful to our colleagues Daniel Dítě and Martin Veverka for providing the photos.

Authors' contributions M. Dudáš – research designing, conducting herbarium and field research, writing the manuscript, R. Hrivnák – coenology study, writing manuscript, M. Slezák – coenology study, writing manuscript and designing.

Funding Open access funding provided by The Ministry of Education, Science, Research and Sport of the Slovak Republic in cooperation with Centre for Scientific and Technical Information of the Slovak Republic

Data availability Data are available upon request.

Declarations

Conflict of Interest None.

Ethical approval This is an observational study. No ethical approval is required.

Informed consent None.

References

Balátová-Tuláčková E (1976) Rieder-und Sumpfwiesen der Ordnung *Magnocaricetalia* in der Záhorie-Tiefebene und dem nordlich angrenzenden Gebiete. Synokologische Studie der *Magnocaricetalia*. Vegetácia ČSSR, ser. B 3

Bartha D, Király G, Schmidt D, Tiborcz V et al (2015) Distribution atlas of vascular plants of Hungary. University of West Hungary Press, Sopron

Bella V (1971) Vodohospodárske úpravy Východoslovenskej nížiny. Bratislava, Alfa

Berta J (1957) Vegetačné pomery Svätojurského Šúru. Diploma thesis. Comenius University

Berta J (1970) Waldgesellschaften und Bodenverhältnisse in der Theisstfefebene. Vegetácia ČSSR, Bratislava, B 1

Bilz M, Kell SP, Maxted N, Lansdown RV (2011) European Red List of Vascular Plants. Publications Office of the European Union, Luxembourg. https://data.europa.eu/doi/https://doi.org/10.2779/8515 Accessed 20 March 2023

Bosáčková E (1972) Súčasný stav a ochrana slatinnej vegetácie Žitného ostrova. Práce a štúdie ČSOP, Bratislava, ser. 1

Casper SJ, Krausch HD (2008) Süßwasserflora von Mitteleuropa. Pteridophyta und Anthophyta 2. Teil 2: Saururaceae bis Asteraceae. Spektrum Akademisher Verlag, Heildelberg

Chytrý M, Tichý L, Holt J, Botta-Dukát Z (2002) Determination of diagnostic species with statistical fidelity measures. J Veg Sci 13:79–90. https://doi.org/10.1111/j.1654-1103.2002.tb02025.x

Chytrý M, Danihelka J, Kaplan Z, Wild J, Holubová D, et al. (2021) Pladias Database of the Czech Flora and Vegetation. Preslia 93:1–87. https://doi.org/10.23855/preslia.2021.001

Dítě D, Eliáš P jun, Hrivnák R, Melečková Z (2011) *Beckmannia eruciformis* (L.) Host. in Slovakia – distribution, ecology and coenotic affinity. Hacquetia 10(2):171–181. https://doi.org/10.2478/v10028-011-0009-3

Dítě D, Jun Eliáš P, Dítě Z, Šimková A (2017) Recent distribution and phytosociological affiliation of *Ludwigia palustris* in Slovakia. Acta Soc Bot Pol 86:3544. https://doi.org/10.5586/asbp.3544

Douda J, Boublík K, Slezák M, Biurrun I, Nociar J et al (2016) Vegetation classification and biogeography of European floodplain forests and alder carrs. Appl Veg Sci 19:147–163. https://doi.org/10.1111/avsc.12201

Dudáš M, Slezák M, Hrivnák R (2021) Distribution, ecology and vegetation affinity of bog arum (*Calla palustris*) in Slovakia. Biologia 76:2021–2029. https://doi.org/10.1007/s11756-021-00779-w

Eliáš PJ, Dítě D, Kliment J, Hrivnák R, Feráková V (2015) Red list of ferns and flowering plants of Slovakia, 5th edition (October 2014). Biologia 70:218–228. https://doi.org/10.1515/biolog-2015-0018

Futák J (1982) *Ranunculus* L. – iskerník. In: Futák J, Bertová L (eds) Flóra Slovenska III. Bratislava, Veda, pp 144–197

Futák J (1984) Fytogeografické členenie Slovenska. In: Bertová L (ed) Flóra Slovenska IV/I. Veda, Bratislava, pp 418–420

García-Girón J, Heino J, Lønsmann Iversen L, Helm A, Alahuhta J (2021) Rarity in freshwater vascular plants across Europe and North America: Patterns, mechanisms and future scenarios. Sci Total Environ 786:147491. https://doi.org/10.1016/j.scitotenv.2021.147491

Grulich V (2012) Red List of vascular plants of the Czech Republic: 3rd edition. Preslia 84:631–645

Hennekens SM, Schaminée JHJ (2001) TURBOVEG, a comprehensive data base management system for vegetation data. J Veg Sci 12:589–591. https://doi.org/10.2307/3237010

Hörandl E (2022) Die *Ranunculaceae* der Flora von Zentraleuropa: *Ranunculus*. Gesselschaft zur Erforschung der Flora Deutschlands, Berlin. https://doi.org/10.21248/gups.66917

Jalas J, Suominen J (eds) (1989) Atlas Florae Europaeae 8. The Committee for Mapping the Flora of Europe and Societas Biologica Fennica Vanamo, Helsinki

Johansson ME (1993) Factors controlling the population dynamics of the clonal helophyte *Ranunculus lingua*. J Veg Sci 4:621–632. https://doi.org/10.2307/3236127

Johansson ME, Nilsson Ch (1993) Hydrochory, population dynamics and distribution of the clonal aquatic plant *Ranunculus lingua*. J Ecol 81:81–91. https://doi.org/10.2307/2261226

Jasičová M, Zahradníková K (1976) Organizácia a metodika mapovania rozšírenia rastlinných druhov v západnej tretine Slovenska. Biológia 31:74–80

Keddy PA (2000) Wetland Ecology Principles and Conservation. Cambridge University Press, New York

Király G (ed) (2007) Vörös Lista. A magyarországi edényes flóra veszélyeztetett fajai. [Red list of the vascular flora of Hungary]. Saját kiadás, Sopron

Kochjarová J, Hrivnák R, Oťaheľová H, Dúbravková D, Paľove-Balang P, Novikmec M, Hamerlík L, Svitok M (2013) Aktuálne údaje o výskyte niektorých vodných a močiarnych rastlín na Slovensku. Bull Slov Bot Spoločn 35(2):107–118

Krippel E (1959) Kvetena a rastlinné spoločenstvá Bezedného pri Plaveckom Štvrtku. Biol Práce SAV 5:37–66

Krippel E (1965) Postglaciálny vývoj lesov Záhorskej nížiny (Historicko-geobotanická štúdia). Biol Práce 11:1–99

Krippel E (1967) Slatinná jelšina (*Alnetum glutinosae*) na Záhorskej nížine. Geogr Čas 19(2):93–105

Křísa B (1988) *Ranunculus* L. – pryskyřník. In: Hejný S, Slavík B, Chrtek J, Tomšovic P, Kovanda M (eds) Květena České socialistické republiky 1. Academia, Praha, pp 425–446

Landucci F, Šumberová K, Tichý L, Hennekens SM, Aunna L et al (2020) Classification of the European marsh vegetation (*Phragmito-Magnocaricetea*) to the association level. Appl Veg Sci 23:297–316. https://doi.org/10.1111/avsc.12484

Lóczy D (ed) (2019) The Drava River Environmental Problems and Solutions. Springer International Publishing AG, Cham

Lukács BA, Tóthmérész B, Borics G, Várbíró G, Juhász P, Kiss B, Müller Z, Tóth G-L, Erős T (2015) Macrophyte diversity of lakes in the Pannon Ecoregion (Hungary). Limnologica 53:74–83. https://doi.org/10.1016/j.limno.2015.06.002

Májeková J (2005) Flóra a vegetácia na poliach a úhoroch Borskej nížiny. Diploma thesis. Comenius University

Májeková J, Zaliberová M (2006) Výskyt niektorých vzácnych a ohrozených druhov cievnatých rastlín na synantropných biotopoch Borskej nížiny. Bull Slov Bot Spoločn 28:87–93

Marhold K, Hindák F (eds) (1998) Checklist of non-vascular and vascular plants of Slovakia. Veda, Bratislava

Mártonfi P (ed) (2014) Flóra okolia Trebišova. Zborník výsledkov 48. Floristického kurzu SBS a ČBS v Trebišove. Bull Slov Bot Spoločn 36, Suppl. 1

Matuszkiewicz W (2008) Przewodnik do oznaczania zbiorovisk roślinnych Polski, 3rd edn. Wydawnictwo Naukowe PWN, Warszawa

Meusel H, Jäger E, Weinert EW (1965) Vergleichende Chorologie der Zentraleuropäischen Flora. Gustav Fisher Verlag, Jena

Mucina L, Bültmann H, Dierßen K, Theurillat J-P, Raus T et al (2016) Vegetation of Europe: hierarchical floristic classification system of vascular plant, bryophyte, lichen, and algal communities. Appl Veg Sci 19(suppl. 1):3–264. https://doi.org/10.1111/avsc.12257

Niklfeld H (1971) Bericht über die Kartierung der Flora Mitteleuropas. Taxon 20:545–571. https://doi.org/10.2307/1218258

Reid AJ, Carlson AK, Creed IF, Eliason EJ, Gell PA, Johnson PTJ, Kidd KA, MacCormack TJ, Olden JD, Ormerod SJ, Smol JP, Taylor WW, Tockner K, Vermaire JC, Dudgeon D, Cooke SJ (2019) Emerging threats and persistent conservation challenges for freshwater biodiversity. Biol Rev 94:849–873. https://doi.org/10.1111/brv.12480

Reuss G (1853) Května Slovenska čili Opis všech jevnosnubných na Slovensku divorostaucích a mnohých zahradních zrostlin podlé saustavy De Candolle-ovy. B. Štávnica

Roleček J, Tichý L, Zelený D, Chytrý M (2009) Modified TWINSPAN classification in which the hierarchy respects cluster heterogeneity. J Veg Sci 20:596–602. https://doi.org/10.1111/j.1654-1103.2009.01062.x

Rybka V, Duchoslav M (2007) Influence of water depth on growth and reproduction of *Ranunculus lingua*. Belg J Bot 140(1):130–135 (https://www.jstor.org/stable/20794630)

Rybníček K, Rybníčková E (1972) Nálezy vzácnych rašelinných mechorostů na Oravě. Biologia 27:795–798

Short FT, Kosten S, Morgan PA, Malone S, Moore GE (2016) Impacts of climate change on submerged and emergent wetland plants. Aquat Bot 135:3–17. https://doi.org/10.1016/j.aquabot.2016.06.006

Solińska-Górnicka B (1987) Alder (*Alnus glutinosa*) carr in Poland. Tuexenia 7:329–346

Svobodová Z, Řehořek V (1972) Fytocenologický a ekologický výskum lúčnych spoločenstiev v povodí Ipľa a Slanej. Záverečná správa úlohy II-5–8/7

Szoszkiewicz K, Jusik S, Lawniczak AE, Zgola T (2010) Macrophyte development in unimpacted lowland rivers in Poland. Hydrobiologia 656:117–131. https://doi.org/10.1007/s10750-010-0439-9

Šibík J (2012) Slovak Vegetation Database. Biodiv Ecol 4:429–429. https://doi.org/10.7809/b-e.00216

Šomšák L (1963) Močiarna vegetácia medzidunových zníženin južnej časti Potiskej nížiny. Acta Fac Rerum Nat Univ Comen, Ser Bot 8(5–6):229–302

Tamura M (1995) Angiospermae Ordnung Ranunculales. Fam. Ranunculaceae. II. Systematic part. In: Hiepko P (ed) Natürliche Pflanzenfamilien, 2nd edn. Duncker & Humblot, Berlin, pp 223–519

Terek J, Matas E (1983) Structure of the Landscape and Hydrological Regime in the Area „Medzibodrožie". Ecologia (CSSR) 4:407–413

Thiers B (2023+) [continuously updated] Index Herbariorum: A global directory of public herbaria and associated staff. New York Botanical Garden's Virtual Herbarium, New York. http://sweetgum.nybg.org/ih

Tichý L (2002) JUICE, software for vegetation classification. J Veg Sci 13:451–453. https://doi.org/10.1111/j.1654-1103.2002.tb02069.x

Tichý L, Chytrý M (2006) Statistical determination of diagnostic species for site groups of unequal size. J Veg Sci 17(6):809–818. https://doi.org/10.1111/j.1654-1103.2006.tb02504.x

Valachovič M (ed) (2001) Rastlinné spoločenstvá Slovenska 3. Vegetácia mokradí. Veda, Bratislava

Valachovič M, Kliment J, Hegedüšová Vantarová K (eds) (2021) Rastlinné spoločenstvá Slovenska 6. Vegetácia lesov a krovín. Veda, Bratislava

Vozárová M, Sutorý K (2001) Index herbariorum Reipublicae bohemicae et Reipublicae slovacae. Bull Slov Bot Spoločn Suppl 7:1–95

Wassen MJ, Olde Venterink HGM, de Swart EOAM (1995) Nutrient concentrations in mire vegetation as a measure of nutrient limitation in mire ecosystems. J Veg Sci 6:5–16. https://doi.org/10.2307/3236250

Zając A, Zając M (eds) (2001) Distribution atlas of vascular plants in Poland. Institute of Botany, Jagiellonian University and Fundation of Jagiellonian University, Cracow, Laboratory of Computer Chorology