Reinterpreting the distribution of *Polygonum graminifolium* (*Polygonaceae*) in Serbia on the basis of taxonomical revision and field research

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Abstract. This paper presents the results of literature and herbarium data survey related to the distribution of the rare Pannonic-Wallachian-Danubian endemic species *Polygonum graminifolium* in Serbia. The obtained results are compared with data of historical and recent water levels of the Danube and with the field investigation results obtained from historical and potential habitats of this species in Serbia. These results indicate that the species has gone extinct from its historical habitats in Serbia and that profound changes in river dynamics of the Danube associated with the construction of the Iron Gate Hydroelectric Power Station played an important role in this process. However, in the course of field investigations, the species was discovered in one new locality in Serbia (Prahovo) and thus its conservation status in Serbia has been estimated as Critically Endangered (CR).

Key words: chorology, *Nanocyperion* species, the Danube, the Iron Gate, wetlands

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Introduction

Sheer complexity of numerous, insufficiently known taxonomic, biogeographycal, phylogenetic and ecological relationships with the ensuing conservationist ramifications has long pervaded even the most ambitious efforts of dealing with taxa included in or related to genus *Polygonum* L. (for review see Galasso & al. 2009). Considering the widespread occurrence and morphological and ecological diversity of *Polygonum* s.str., with almost 60 taxonomic combinations listed for *P. aviculare* alone [http://www.worldfloraonline.org], it is quite evident that confusion in the nomenclature of *Polygonaceae* has been a major barrier to understanding its evolution (Sanchez & al. 2009). In the first edition of the *Flora of*

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SR Serbia, Polygonum s.str. is represented by four species and *Polygonum aviculare* is treated as an aggregate of four microspecies, including *P. graminifolium* (Slavnić 1972). However, *P. graminifolium* does not belong to the *P. aviculare* group, differing by its linear leaves and shiny nutlets distinctly exceeding the perianth lenght (Grințescu 1952, Webb & al. 1993). That treatment has been accepted in the latest edition of the *Flora of Serbia,* where *P. graminifolium* is set as a distinct species, along with five other species of *Polygonum* s.str. (Anačkov & al. 2022).

The specific ecological requirements of *P. graminifolium*, which occurs in wetland pioneer habitats, i.e., amphibious low gravel riverbanks and shoals (Heuffel 1858, Soó 1970, Grulich & al. 2016), are an important limiting factor for its distribution on the rapidly deteriorating remnants of habitats situated only in the freely flooding zone of River Danube, which typically emerge from the water in late summer.

The taxonomical intricacies and confusion hampering its identification, specific habitat requirements limiting the spatial and temporal possibilities for its investigation in the field, substantial changes in the river dynamics of the Danube, which have taken place in the area since the construction of the Iron Gate Hydroelectric Power Station and after the last known record of *P. graminifolium* in Serbia, all these contribute to the uncertainty surrounding the current existence of this species in Serbia.

In line with the foregoing facts, the aim of this study was to answer the question of presence of *P. graminifolium* in Serbia and to estimate its conservation status in the country, based on the revision and evaluation of all relevant published and herbarium data, as well as on field investigations of its historical and potential habitats in Serbia.

Material and methods

In order to direct the field investigations carried out between 2018 and 2020, a list of historical and potential habitats of *Polygonum graminifolium* in Serbia was created. This list was based on a comprehensive survey of the data published since 1842, revision of herbarium specimens deposited in the national botanical collections (BEOU, BEO, BUNS, PZZP) (Thiers 2016+), and a review of scanned specimens, including material available as HD pictures through official digital herbarium platforms or websites (Botanischer Garten, Freie Universität Berlin, Berlin; Universität Göttingen; Royal Botanic Gardens, Kew; Naturalis Biodiversity Center, Leiden; Université Claude Bernard Lyon 1; Université de Montpellier; Moscow State University; Muséum National d'Histoire Naturelle, Paris).

Voucher specimens have been deposited in the Herbarium Collection of the Faculty of Sciences, University of Novi Sad (BUNS) and the Herbarium Collection of the Institute for Nature Conservation of the Vojvodina Province in Novi Sad (PZZP). Nomenclature and synonymy follow The World Flora Online [http://www.worldfloraonline.org]. Author citations follow Rec. 46A, note 1 of the Code (Turland & al. 2018). Species distribution is mapped on 10 × 10 km MGRS UTM maps (Lampinen 2001) within UTM Grid Zone 34T. Geographical regionalization of Serbia is given according to Stevanović (1999). Herbarium collection abbreviations used in the text are given according to Thiers (2016+). Species description is based on Meisner (1856), Heuffel (1858), Neilreich (1867), Beck (1909), Ascherson & Graebner (1913), Webb & al. (1993), Grulich & al. (2016) and the authors' observations presented here for the first time.

Data on the historical and recent water levels of the Danube used for estimation of the species conservation status in accordance with the IUCN Red List Categories and Criteria (https://nc.iucnredlist.org/redlist/content/attachment_files/RedListGuidelines.pdf) are cited from the official publications (1963, 1964-1976, 1977-1985), or taken from the archives of the Republic Hydrometeorological Service of Serbia.

Results and discussion

***Polygonum graminifolium* Wierzb. ex Meisn.**, *Prodr.* [A. P. de Candolle] **14**(1): 95 (1856).

Syn. *P. graminifolium* Wierzb. ex Heuffel, *Verh. k. k. zool.-bot. Ges. Wien* **8**: 190 (1858); *P. graminifolium* Wierzb., *Flora* **25**: 280 (1842), nom. inval. (nom. nud.); *P. graminifolium* Wierzb., *Flora* **28**: 321 (1845), nom. inval. (nom. nud.); *"P. graminifolium"* sensu A. K. Becker, nom. in sched., nom. inval. (pro syn. of *P. salsugineum* M. Bieb.).

Ind. Loc.: „In ripis arenosis Danubii, ad monasterium Bazias, in Banatu (Heuffel!).". Lectotype (**here designated**): *Polygonum graminum*. Wierzb / Ad rippas Danubii prope Bazias / in Banatu. / Aug. / Legit Wierzbicki / Heuffel misit Sept. 1841." (K 000830446! [photo!] image available at http://specimens.kew.org/herbarium/K000830446); isolectotype: K 000830447!.

Description. Glabrous greyish green or ± glaucous (subsequently reddish tinged) annual, 10-30 (-40) cm long (Fig. 1A). *Stem* short, slender, prostrate, finely striate, usually with numerous ± flexuose branches. *Leaves* linear, 10-20 (-24) × 1-1.5 mm, leaf blade plane, entire, gradually tapers into elongated base, with one faintly visible midvein, distally ending with acute or subacute point which is often minutely falcate or recurved. *Ochreae* short, brownish to maroon near the base, with 6 scarcely distinct nerves, in the upper part silvery, hyaline, with bifid or lacerate margin. *Flowers* solitary or arranged in axillary clusters consisting of 2-3. Bracts leaf-like, longer than flowers. Pedicels short (1.5-2 mm long) and included within ochrea. Perianth 1.5-2 mm long [1.58-2.31 mm in our specimens], consisting of 5 tepals united in the lower part into a tube, from which in its upper part emerge 5 equal or subequal petaloid segments, longer than the tube [respectively 0.42-0.81 mm *vs*. 1.01-1.57 mm long in our specimens]. Segments free, white, greenish red on the outside. Stamens 8, styles 3. *Nut* ovate-trigonous, 2-2.5 mm long [1.67-2.33 mm in our specimens], exceeding the perianth, apiculate at the apex, brown, shiny, its pericarp very finely foveolate (Meisner 1856, Heuffel 1858, Neilreich 1867, Beck 1909, Ascherson & Graebner 1913, Webb & al. 1993, Grulich & al. 2016) [which, in order to be observed as is the case with our specimens, requires examination at 50 × magnification or more]. Reproduction time: VIII-X. Pollination: self-pollination or entomophily (Grulich & al. 2016). Seed dispersal: autochory and zoochory (Grulich & al. 2016), possibly hydrochory. Lectotype in Kew: K, no. 000830446 [available at http://specimens.kew.org/herbarium/K000830446] (Fig. 1B).

Fig. 1. A – *P. graminifolium* general habitus, Prahovo, September 2020; **B** - Lectotype of *P. graminifolium* deposited in K. Available on: http://specimens.kew.org/herbarium/K000830446.

Distribution. As far as it could be judged from specimens circulated across the botanical collections (*e.g.*, B, GOET, K, L, LY, MPU, MW, P), and bearing in mind the possibly erroneous records from SE Russia (cf. Komarov 1936), this species could be safely described as Pannonic-Wallachian-Danubian endemic (Soó 1970, Ciocârlan 2000). Its range, according to literature data, is confined to the middle and lower Danube Valley (Slovakia, Hungary, Serbia, Romania, Bulgaria) (Hayek 1924, Grințescu 1952, Grulich & al. 2016, Uotila 2017), with scattered records in areas northwards of the Danube Delta (Ukraine? cf. https://ukrbin.com/index.php?id=307660) and along river Mures in Romania (Ciocârlan 2000). The first accounts of this species reported by Meissner (1856), Heuffel (1858) and Beck (1909) were based on the specimens collected by Wierzbicki along the Danube at the Serbian/Romanian border ["*Bannat, am Donau-Ufer b. Uj-Palanka und Basias*"; "*monasterium Bazias*"; "*Szvinicza*, *Bazias*, *Moldava*"].

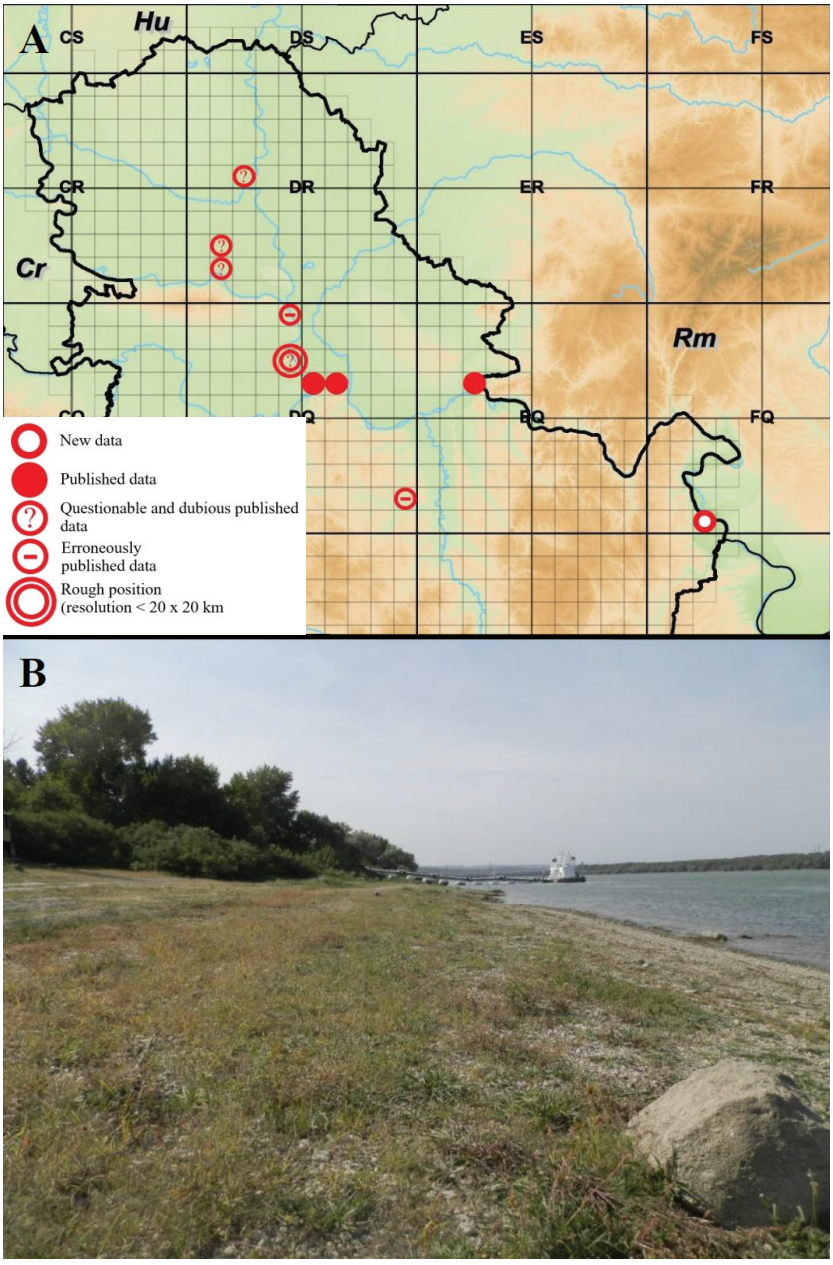

Fig. 2. A – Known distribution of *P. graminifolium* in Serbia; **B** – Habitat of *P. graminifolium* on the bank of the Danube near Prahovo.

Distribution in Serbia. On the basis of revision of herbarium specimens, field investigations of ecologically suitable habitats in the historical localities known from herbaria and literature sources, as well as of other potential habitats observed by the authors along the Serbian section of River Danube, it could be assumed that all historical records, where *P. graminifolium* has been so far detected in Serbia, are reduced to two relatively small areas: the vicinities of Banatska Palanka and Wider Belgrade Area (Fig. 2A). With its latest known precise records unequivocally supported with herbarium specimens collected in the indicated areas in 1840 and 1936, respectively, the species is supposed to be extinct presently in both areas. The newly discovered location in the vicinity of Prahovo in NE Serbia by the authors remains the only location for *P. graminifolium* in Serbia after more than 80 years. There is a similar situation in Hungary, where this species has been recorded again after 75 years and has been found in more localities ever since (Pintér & Bajor 2019; Molnár & al. 2019; Riezing 2020). Thus, the prospects of its finding in other areas along the Danube in Serbia cannot be ruled out. Its next re-

cords confirmed in the field came from the vicinity of Balta Verde-Izvoarele (Romania) (1 km upstream) (*Obradov, D.*, *Perić, R.* 15-Sep-2019, BUNS, PZZP) and near Solt in Hungary (697 km upstream) (*Obradov, D.*, *Marinković, S.* 30-Aug-2019, BUNS), while the next records based on literature data locate it near Moldava (189 km upstream) and Calafat (67 km downstream) (Oprea 2005). Over the past 150 years, various authors with different degree of botanical expertise have published records of *P. graminifolium* from the wider area of Novi Sad, Smederevska Palanka and river Tisa. Notwithstanding that some of these data emerged in standard publications, including *The Flora of SR Serbia* (Slavnić 1972), the latest edition of *The Flora of Serbia* (Anačkov & al. 2022), as well as *Atlas Florae Europaeae* (Jalas & Suominen 1979: 17), they all were based on: a) erroneously identified specimens (referring in fact to *P. aviculare*), or b) citations of ecologically and phytocoenologically improbable habitats (e.g., mountain or dry steppe habitats), which classifies them as erroneous/dubious or questionable.

New data

NE Serbia: FQ 20 Prahovo, along the Danube, 32 m a.s.l., 44° 17.546' N, 22° 36.157' E (*Obradov, D., Košutić, P.* 16-Sep-2020, BUNS; PZZP).

Unpublished herbarium data within known UTM squares:

Šumadija: **Belgrade**: DQ 56 Pančevački most [Most Kralja Petra II], close to the bridge, in a wet meadow along the Danube (*Đelfi, B.* 17-Sep-1936, BEO).

Published data:

Banat: EQ 26 **Stara Palanka** [Palanka]: on the bank of Danube (*Wierzbicki, P.* Jul-Sep [1839], No. 100279370, B; Nos. P04961963, P04961966, P04961967, P; No. K000830445, K; Nos. 1658816, 1658820, 1658821, 1658822, L; No. MPU015084, MPU; No. MW0771912, MW; Nos. WAG1449933, WAG1449934, WAG;1839, Wierzbicki 1845: 321), between the bridge on river Nera and Stara Palanka, in a willow thicket (14-Sep-1840, Wierzbicki 1842: 280).

Šumadija: **Belgrade**: DQ 66 Karaburma [Kajaburma, Kajabunar] (Beck 1909: 64), on the bank of Danube (Pančić 1874: 601) + Višnjica [Vischnitza] (*Bornmüller, J.* Aug/Sep-1888, No. 1658818, L; No. P04961964, P; No. 0621473, LY; *Bornmüller, J.* 1888, P05175369, P; No. 0521472, LY; Beck 1909: 64), by the river Danube (*Soška, T.* Jul-1932, BEO; „locus unicus", *Soška, T.* Jul-1933, BEO; *Soška, T.* Aug-1934, BEO; Adamović 1909: 347, photo!; Gajić 1964: 38; Slavnić 1972: 58), on gravelly sandy banks (*Bornmüller, J.*, [s. dat.] No. 1658819, L); DQ 56 Belgrade port („common", Borbás 1891: 12).

Imprecise published data: **Serbia** [Szerbiá] (Feichtinger 1870: 18; Ascherson & Graebner 1913: 862; Hayek 1924: 112; Gajić 1980a: 87; 1980b: 131; Trinajstić 1980: 856; Janković 1985: 156); **North Serbia** (Grulich & al. 2016: 514); **Vojvodina** (Grulich & al. 2016: 514); **Banat** [Banat Military Frontier, „legio Serbico-Banatica"]: in gravel [habitats] along the Danube [*Danubius*] (Neilreich 1867: 110); Šumadija (Gajić 1967: 185); **Belgrade** (Pančić 1888: 390; on sandy Danube banks; *Petrović, D.* Jul-1879, No. LY0745728, LY; *Jurišić, Ž.* Sep-1891, Nos. P04961959, P05175371, P; No. MW0771913, MW; Beck 1909: 64; Janković 1972: 164; Slavnić 1972: 58).

Questionable published data: DQ 56 **Zemun** [Zimony]: on the bank of Danube, in sandy gravel (Feichtinger 1870: 29).

Dubious published data: **Bačka**: DR 25 **Bečej** (Slavnić 1972: 58); DR 12 **Gospođinci** [Gospodincze]: vicinity of Rimski šanac [római sánczok], in fallows (Feichtinger 1870: 22; Slavnić 1972: 58); DR 11 **Novi Sad** [Ujvidék]-**Kać** [Katy] (Feichtinger 1870: 18), **Kać** (Slavnić 1972: 58); **Srem**: DQ 48-DQ 47 **Stari Banovci-Novi Banovci** [Banovci] (1972, Obradović 1978: 70).

Dubious & imprecise published data: **Novi Sad** (Obradović 1966: 138; Slavnić 1972: 58); Šajkaška [csajkások kerülete] (Feichtinger 1870: 28); **Fruška Gora Mt**. (central and eastern parts, sandy ruderal habitats, Obradović 1966: 138; northern slopes, sandy ground Obradović 1978: 70; Panjković-Matanović 1989: 124).

Erroneously published data:

[referring to *Polygonum aviculare* L.]

Srem: DQ 49 **Slankamen** (*Obradović, M.* 01-Nov-1963, BUNS; Obradović 1966: 138).

[referring to *Polygonum aviculare* L. var. *condensatum* Becker]

Pomoravlje: DQ 91 **Smederevska Palanka**: Glavaševa street, at roadside, in ruderal places (*Kočović, K.* 15-Aug-2001, BEOU; 2001-2002, Jakovljević & Jovanović 2005: 7).

Habitat. Temporary amphibious habitats developing on low, periodically inundated sandy and gravelly riverbanks with characteristically pioneer ephemeral vegetation of annual therophytes belonging to alliance *Nanocyperion flavescentis* W. Koch (Heuffel 1858, Soó 1970, Grulich & al. 2016). Literature data and the authors field experience in Serbia and Romania suggested that these typical habitats have not been much overwatered, due to a higher fraction of gravel (cf. Adamović 1909: 347, photo!), which ensured better drainage, similar to the places where the Danube meets more hilly terrains and where small running rivers and streams release mixed deposits of sand and gravel into the Danube forming islets and shoals. This is probably the reason why *P. graminifolium* was absent from the more waterlogged *Nanocyperion* sandy and muddy amphibious habitats developed along the Danube in Bačka and Srem. The habitat in Prahovo was a typical alluvial sandy and gravelly habitat developed on Holocene alluvial deposits in the Danube riverbed (*cf.* Dolić & Rakić 1974). Here, the population of *P. graminifolium* was relatively rich and scattered across an area covering approximately 3600 m^2 (Fig. 2B). The accompanying species were: *Cyperus fuscus* L., *Cyperus glomeratus* L., *Rorippa sylvestris* (L.) Besser, *Portulaca oleracea* L. and *Persicaria maculosa* Gray.

Conservation status. Because of its direct dependence on the seasonal river flooding, as well as on the presence of fine-grained sedimentary river soils (fluvisols) shaped by the freely inundating water into characteristic microrelief flat formations, the existence and proper functioning of pioneer amphibious habitats in the freshwater ecosystems of Europe are probably more likely than in the case of most other freshwater wetland habitats endangered by principal threats, *viz*. hydrological alterations, climate change, pollution and invasive species (Janssen & al. 2016; Ortmann-Ajkai & al. 2018). Comparison with maps from the 19th century (https://maps.arcanum.com/en/) and habitat photography published by Adamović (1909: 347), with modern satellite images available on Google Earth Pro [date of imagery: August 2022] and base maps available at Arcanum Maps site (https://maps.arcanum.com/en/) (Timár & al. 2006), suggests that the entire area of the Danube riverside in Belgrade between Karaburma and Višnjica has changed significantly and that the main causes of habitat loss and presumable extinction of *P. graminifolium* include rapid urbanization and hydroregulation activities. In a similar fashion, among the first impressions after the authors' field observations of habitats in the vicinity of Banatska Palanka and their comparison with old maps of the area (https://maps.arcanum.com/en/) is the absence of large strips of low riverbanks and shoals clearly visible on the Second Military Survey maps of the area (1819-1869) (Fig. 3). After the construction of the Iron Gate I Hydroelectric Power Station (completed in 1972), with the accompanying reservoir lake (Đerdap accumulation lake), the long-term properties and natural cycles of the River Danube level and flow upstream were strongly affected by high backwater levels (Stratimirović & al. 2021), permanently flooding over or washing down the river islands (e.g. Ada Kaleh, cf. Rustoiu & Vasile 2019), shoals, low banks and similar habitats of the amphibious wetland vegetation. The average values of the Danube water level for August and September (corresponding to the reproductive period of *P. graminifolium*) based on data collected at different periods of time (before and after the Iron Gate I Hydroelectric Power Station completion) from selected hydrometric stations along the Danube, covering the known distribution of *P. graminifolium* in Serbia, are highly instructive: the average water level height has increased almost by 3.5 m at Veliko Gradište Station in the past 90 years, by more than 3 m at Banatska Palanka (Stara Palanka) Station in the past 60 years, and almost by 1 m at Zemun (Wider Belgrade Area)

Table 1. Average values of the Danube water level for August and September based on data from selected hydrometric stations along the Danube, covering the known distribution of *P. graminifolium* in Serbia

Period of time/ stations	Zemun		Smederevo		Banatska Palanka		Veliko Gradište		Prahovo		
	VIII	IX	VIII	IX	VIII	IX	VIII	IX	VIII	IX	Month
1930-1940	195	184	272	263	/*	/*	264	255	254**	266**	Water level (cm)
1961-1971	169	149	256	231	277	262	278	249	256	239	
1972-1980	278	225	409	388	584	581	603	601	297	245	

* Station started working in 1959, with the first available data from 1961.
** Station started working in 1935; data originated from measurements performed from 1935 to 1940.

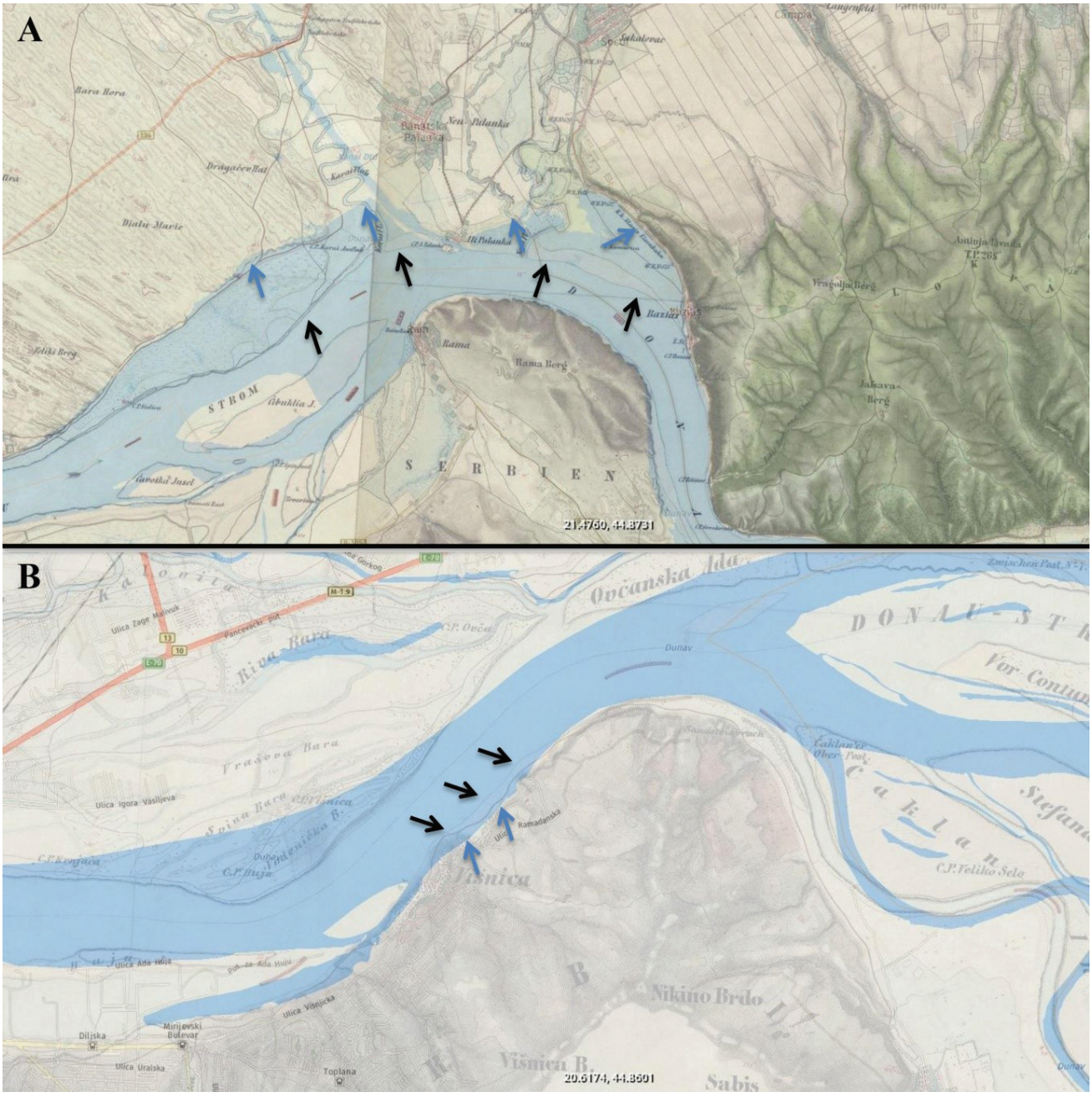

Fig. 3. The extent of flooding before and after the construction of the Iron Gate Hydroelectric Power Station based on the comparison of 19th century maps with modern base maps (https://maps.arcanum.com/en/) (Timár & al. 2006). Arrows refer to the historical (black) and present outlines (blue) of the Danube banks in the vicinity of Banatska Palanka (A) and Belgrade (B).

in the past 90 years (Table 1). Because of the associated habitat loss, these water level increases have been essential for the extinction or significant population decline of some important species in the Iron Gate area, e.g., *Crocus banaticus* J. Gay. (Ranđelović & Ranđelović 1999) and *Elatine triandra* (Blaženčić & Blaženčić 1999). The same circumstances have been crucial in understanding the habitat loss and extinction of *P. graminifolium* in the vicinity of Banatska Palanka.

On the other hand, the average value of the water level for the same period taken at Prahovo, downstream from the Iron Gate II Hydroelectric Power Station, has remained (as expected) almost unaltered, leaving relatively intact amphibious riverside habitats. Therefore, the section of the Danube near Prahovo is the only known recent habitat of *P. graminifolium* in Serbia. Considering its single location, limited population size (about 150 reproductive individuals) on a small area (3600 m^2) located between the harbor facilities, industrial park and the town itself, the prospects for its survival in the following decades appear to be very poor. According to the recent IUCN guidelines for the IUCN Red List Categories and Criteria (https://nc.iucnredlist.org/redlist/content/attachment_files/RedListGuidelines.pdf), the conservation status of *P. graminifolium* in Serbia is estimated as Critically Endangered (CR A2a,c + B2a).

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