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Current distribution, trends, abiotic and biotic preferences of two *Elodea* species in Bulgaria

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ABSTRACT:
Two invasive aquatic macrophyte species from the genus *Elodea* and their distribution in Bulgaria were studied. The research was based on 653 field surveys from the period 2009–2022. *Elodea* records constitute to only 6% of the database. Between the two species studied, *E. nuttallii* exhibited a wider distribution both in rivers and lakes (natural and artificial). Several instances of invaders' dominance were observed, with *E. nuttallii* showing dominance patterns mainly in lakes, and *E. canadensis* in rivers. Both species were distributed in aquatic habitats with a wide variation in abiotic characteristics, except for the dominant substrate. *E. nuttallii* showed a more significant altitudinal range reaching above 1500 m. Such altitudinal variations resulted in diverse ecological habitats in terms of abiotic factors such as temperature and light intensity. The studied aquatic macrophyte communities demonstrated average species richness. *Ceratophyllum demersum* and *Myriophyllum spicatum* were the most commonly recorded representatives of the native aquatic flora. Canadian waterweed demonstrated the ability to form dense communities in rivers, while Nuttall's waterweed retained average values of abundance. A case of natural disappearance within the *Elodea* species has been documented. The systematised information covering a 13-year period could serve to identify strategic areas for monitoring aquatic IAS and their management.

Keywords:
Elodea canadensis, *Elodea nuttallii*, invasive alien species.

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INTRODUCTION

Invasive species cause serious concern especially in sensitive aquatic ecosystems. *Elodea canadensis* Michx. and *Elodea nuttallii* (Planch.) H. St. John (*Hydrocharitaceae*), known as Canadian and Nuttall's waterweed, are native to temperate North America (Josefsson 2011). They are submerged aquatic perennial rooting plants. Vegetative reproduction by stem breakage (fragmentation) or specialised winter buds dominates and ensures the rapid increase of populations. The main growing season is from mid-April to mid-September. Between the two species, *E. canadensis* has a longer invasion history in Europe. It was first observed in 1836, in an Irish pond (Josefsson 2011). The first report of *E. nuttallii* was from Great Britain in 1914 (Josefsson 2011).

Elodea nuttallii is listed as an invasive alien species (IAS) according to the Regulation (EU) 1143/2014 and the list of IAS of Union concern. A major concern regarding *Elodea* species is their ability to rapidly develop dense monospecific stands, which in turn, limit light availability for other submerged species and may lead to slower flow velocity. In addition, *Elodea* stands have the potential to reduce lake recreational opportunities such as fishing. Nevertheless, reports suggest that adverse effects may be absent if *Elodea* forms part of macrophyte communities alongside other species. *Elodea* species did not influence native aquatic flora (*Myriophyllum spica-*

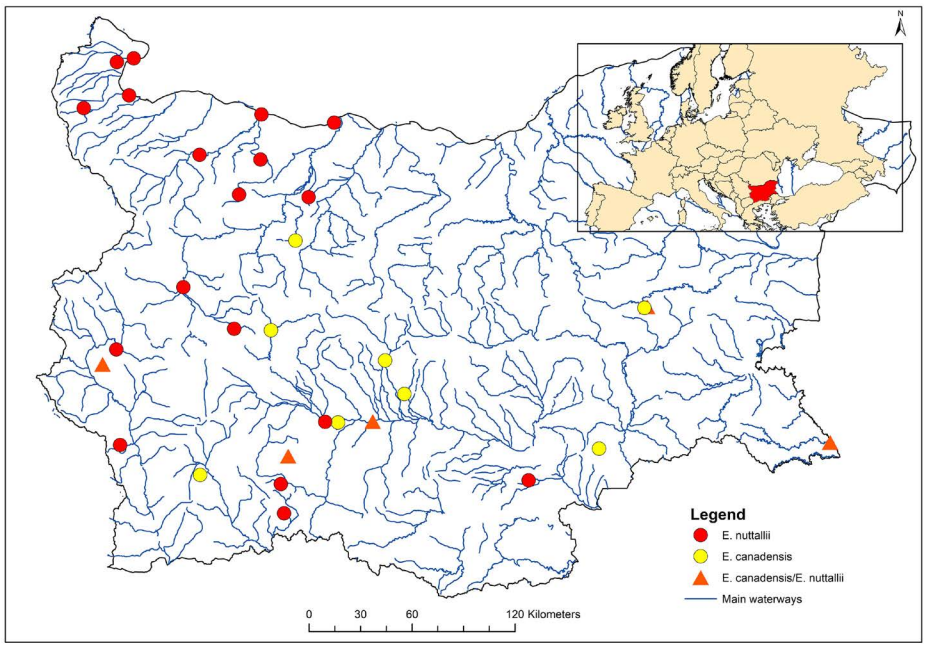

Fig. 1. The location of records of *Elodea* in Bulgaria (2009–2022).

tum L., *M. verticillatum* L., *Ceratophyllum demersum* L., *Potamogeton natans* L.) in northeast Slovenia (Zelnik *et al.* 2022). In addition, *E. canadensis* did not invade Slovenian heterogeneous watercourses with rich macrophyte communities (Kuhar *et al.* 2010). A hypothesis was proposed that the mass invasion of *E. canadensis* in a Norwegian lake had not only negative, but also some positive effects (Mjelde *et al.* 2012).

Both *E. canadensis* and *E. nuttallii* prefer slow flowing rivers and nutrient rich lakes with calcium rich water (pH 6.5–10) and are tolerant of low light conditions (Josefsson 2011). *Elodea nuttallii* has generally been found to have a competitive advantage over *E. canadensis* in nutrient rich waters and has replaced it in numerous locations. Recent research in Italy reported that in the last 10 years, *E. canadensis* was mostly found in canals, whereas *E. nuttallii* was predominant in rivers (Buldrini *et al.* 2023). Nevertheless, no discernable difference was observed in the occurrence of both species among canals, rivers and lakes. *Elodea canadensis* disappeared from reservoirs in Ukraine probably due to its susceptibility to anthropogenic eutrophication (Prokopuk & Zub 2019). A positive correlation between the abundance of *E. nuttallii* and water temperature was reported recently (Zelnik *et al.* 2022).

In Bulgaria *E. canadensis* was reported in 1929 (Petrova *et al.* 2013), years later after the first observation in Europe. *Elodea nuttallii* was recorded for the first time recently, in 2002 (Georgiev *et al.* 2011). Species distribution mainly in the northern and western parts of the country was linked to the Danube River as a major corridor for its introduction and further spread (Georgiev *et al.* 2019). The latest study pointed out that data about the size of the populations and the impact of the species are very scattered.

We have tried to summarise the available field records from Bulgaria for the last 13 years (2009–2022) and based on them to: (i) locate distribution spots; (ii) reveal tendencies in *Elodea* distribution and development; (iii) analyse preferred abiotic conditions and (iv) find possible effects on other aquatic plants and assemblages.

MATERIALS AND METHODS

The database contained 653 field protocols from the period 2009–2022. The sampling sites encompassed the entire territory of Bulgaria and represented all national river and lake types. The records of *Elodea* were made from 31 locations (Fig. 1). Of them 20 were rivers (15 natural) and 11 water bodies from the lake category, all of them highly modified and artificial (HMWB and AWB).

For each record the following information was retained: river/lake and location, national type, date and collector (Table 1). Additionally, for further analysis coordinates and habitat characteristics were used (altitude, mean width of rivers, mean depth, velocity, shading, dominant substrate, the presence of foreign substrata, pH and electrical conductivity). Flow velocity and shading were determined in a semi-quantitative way (Schaumburg *et al.* 2006). Velocity was recorded using a 6-point scale: 1 = not visible, 2 = barely visible, 3 = slowly running, 4 = rapidly running (current with moderate turbulence), 5 = rapidly running (turbulently running), 6 = torrential). Shading was noted based on a

Table 1. Records of *Elodea* in Bulgaria for the period 2009–2022. Abbreviations are as follows: Finder: B.B. = Borislav Borisov, G.G. = Gana Gecheva, G.G.2 = Georgi Gyuzelev, IB-BAS = Institute of Botany-Bulgarian Academy of Sciences, I.T. = Ivan Traykov, M.T. = Milcho Todorov, S.S. = Silviya Stankova; Site: * - demolished in 2012; ** - dried up in 2012.

Species	River/Lake	Site	National type	Date (DD/MM/YY)	Finder
Elodea nuttallii	Archar	Archar village	R8	17/07/2009	IB-BAS
Elodea nuttallii	Arkata	before Struma	R13	22/08/2009	IB-BAS
Elodea nuttallii	Arkata	before Struma	R13	18/08/2020	M.T.
Elodea canadensis	Bunovishtitsa	before mouth	R5	1/9/2020	B.B.
Elodea nuttallii	Iskar	Novi Iskar	R4	7/10/2009	IB-BAS
Elodea canadensis	Iztok	before mouth	R15	28/8/2020	M.T.
Elodea canadensis	Maritsa	Govedare	R12	17/08/2020	G.G.
Elodea nuttallii	Maritsa	Ognyanovo	R12	18/08/2020	G.G.
Elodea nuttallii/Elodea canadensis	Maritsa	Plovdiv	R12	7/6/2013	G.G.
Elodea canadensis	Maritsa	Plovdiv	R12	16/08/2020	G.G.
Elodea canadensis	Melnishka	before mouth	R14	8/9/2009	G.G.
Elodea nuttallii	Ogosta	Kobilyak	R7	19/07/2009	IB-BAS
Elodea nuttallii	Ogosta	mouth	R7	18/07/2009	IB-BAS
Elodea nuttallii	Skat	after Byala Slatina	R8	19/7/2009	IB-BAS
Elodea nuttallii	Skat	Golyamo peshene	R8	19/07/2009	IB-BAS
Elodea canadensis	Srebra	before Rakovski	R13	20/08/2009	G.G.
Elodea canadensis	Stryama	Pesnopoy	R5	26/08/2021	S.S.
Elodea nuttallii	Topolovets	Vidin, before mouth	R8	16/07/2009	IB-BAS
Elodea canadensis/Elodea nuttallii	Veleka	mouth	R16	29/08/2020	G.G.2
Elodea canadensis	Zlatna Panega	spring	R15	16/8/2020	B.B.
Elodea nuttallii	Danube	Baykal	R6	19/8/2015	G.G.
Elodea nuttallii	Danube	after Vidin	R6	18/08/2015	G.G.
Elodea canadensis	Batak Reservoir	whole WB	L3	19/09/2009	G.G.
Elodea canadensis/Elodea nuttallii	Batak Reservoir	whole WB	L3	4/7/2015	G.G.
Elodea canadensis/Elodea nuttallii	Batak Reservoir	whole WB	L3	27/07/2020	M.T.
Elodea canadensis/Elodea nuttallii	Choklyovo swamp	the whole WB	L4	25/09/2011	G.G.
Elodea canadensis	Choklyovo swamp	the whole WB	L4	15/07/2020	M.T.
Elodea nuttallii	Dospat Reservoir	whole WB	L11	9/7/2020	M.T.
Elodea nuttallii	Golyam Beglik Reservoir	whole WB	L3	8/7/2020	G.G.
Elodea nuttallii	Ivanovo*	tail and middle	L17	28/10/2011	G.G.
Elodea nuttallii	Ognyanovo Reservoir	whole WB	L2	4/8/2020	I.T.
Elodea nuttallii	Rabisha Reservoir	whole WB	L4	16/7/2020	I.T.
Elodea nuttallii	Stoykovtsi Reservoir		L13	30/10/2011	G.G.
Elodea canadensis/Elodea nuttallii	Skala 1 Lake	wall	L4	13/09/2011	G.G.
Elodea canadensis	Skala 2 Lake**	wall	L4	2/10/2011	G.G.
Elodea nuttallii	Telish Reservoir	whole WB	L12	19/7/2020	I.T.

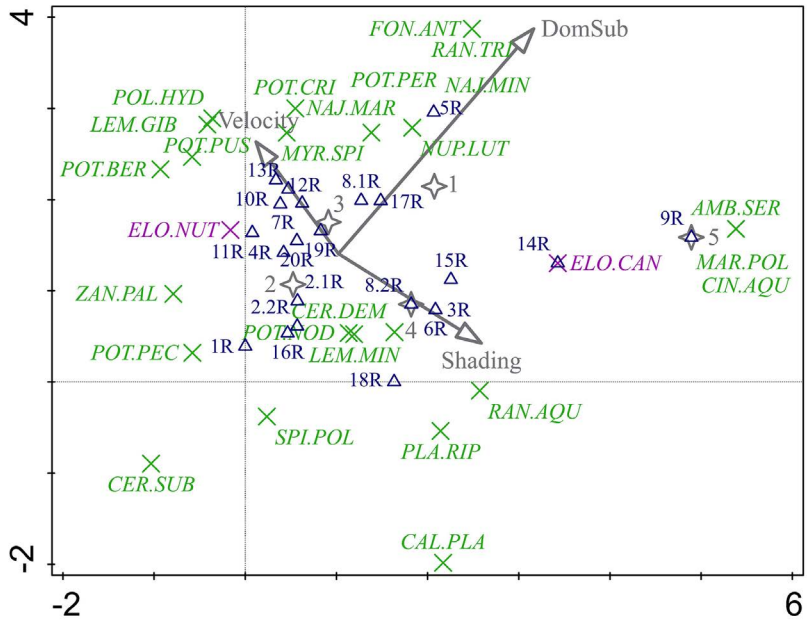

Fig. 2. The ordination analysis of aquatic macrophyte species in river field records with *Elodea* in Bulgaria. Legend: DomSub = dominant substrate; stars = abundance of *Elodea*. For the abbreviations of the species' names, see Table 2.

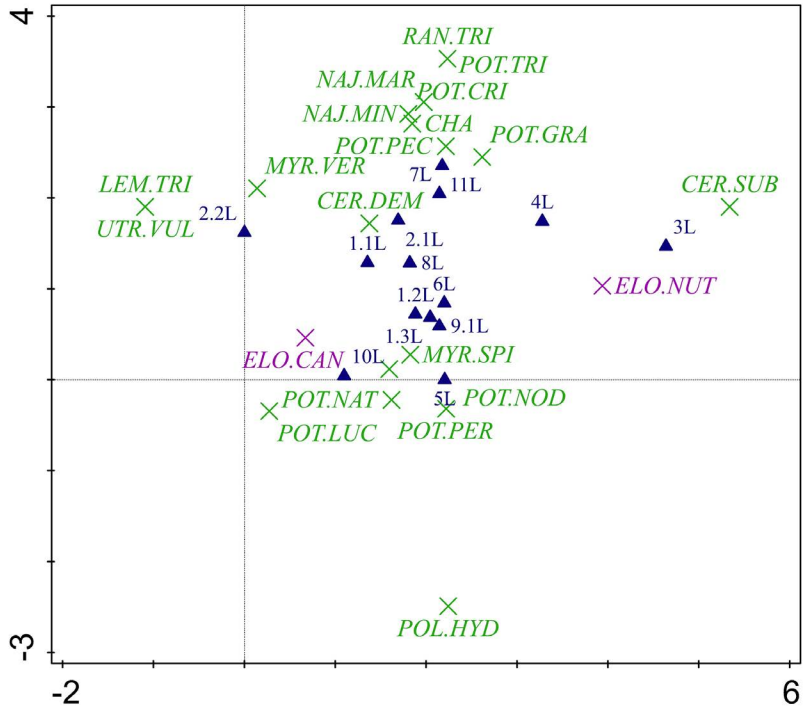

Fig. 3. The ordination analysis of aquatic macrophyte species in lake records with *Elodea* in Bulgaria. For the abbreviations of the species' names, see Table 2.

5-degree scale (from 1 = completely sunny to 5 = completely shaded). pH and electrical conductivity (EC, µS cm^{-1}) were measured *in situ*.

Elodea abundance, dominant species, accompanying species, ecological status/potential were also noted. Plant abundance followed the five-point-scale proposed by Kohler (1978): 1 = very rare; 2 = rare; 3 = common; 4 = frequent; 5 = abundant, predominant.

Ordination analysis (CANOCO 5, unconstrained analysis, DCA) was applied to reveal the relationships between aquatic macrophyte assemblages in rivers and lakes.

RESULTS

As a percentage share of the database, sites with registered *Elodea* represented only 6% of the sampling events. A total of thirty-seven macrophyte species were recorded (Table 2). Nuttall's waterweed was more widespread with records at 12 river sites and 10 standing water bod-

ies. The species dominated macrophyte communities at 5 sites, among them only 1 river. It was accompanied mainly by *Ceratophyllum demersum*. *E. canadensis* was recorded at 9 river sites and 4 standing water bodies, and dominated at 4 of them (3 rivers and 1 swamp). Both species were registered together at 4 sampling sites.

Elodea nuttallii was a permanent species at 2 river sites. At Arkata River it retained its abundance (between 2 and 3) during 2009–2020 in a community dominated by *C. demersum* and *Spirodela polyrhiza* (L.) Schleid. In Maritsa River it coexisted within an assemblage dominated by *E. canadensis* between 2013–2020, together with *Potamogeton crispus* L., *C. demersum*, *Myriophyllum spicatum*, *P. nodosus* Poir.

At Batak Reservoir a displacement of the dominant *E. canadensis* by *E. nuttallii* was registered over a 6-year period, retaining dominance for the following 5 years. A richer community was observed during the dominance of *E. canadensis* including *C. demersum*, *M. spicatum*, *M. verticillatum*, *Najas minor* All., *P. natans*, *P. crispus*, and *P. nodosus*. After *E. nuttallii* took over, the community was represented only by three species: *M. spicatum*, *C. demersum*, *P. nodosus*.

At Choklyovo swamp *E. canadensis* retained its dominance in a community with *M. verticillatum*, *C. demersum*, *Chara* sp., *N. marina* L. and *P. trichoides* Cham. & Schltdl.

Skala Lake (AWB) was an interesting case, where both *Elodea* disappeared nine years after their first record.

Rivers. River sites hosting *Elodea* were located at varying altitudes (between 4 and 759 m a.s.l.), along semi-mountainous areas (national type R4, R5, Table 1), large, medium and small Danube rivers (R7, R8), large, medium and small floodplain rivers (R12, R13), sub-Mediterranean regions (R14), Karst springs (R15), Black Sea river firths (R16) and the Danube (R6). Flow velocity varied between barely visible and rapid, and shading was in the range from completely sunny to half-shaded. The dominant substrate consisted of sand and mud. The water exhibited a median pH of 7.55, median conductivity = 273 μS cm^{-1}.

The abundance of *E. nuttallii* ranged between 2 and 3, while *E. canadensis* achieved higher abundance up to 5 in dense stands. The majority of the sites were assessed as being of good status/potential, 6 moderate and 1 poor.

Thirty species have been recorded in total, half of them with only one record. The most common were *C. demersum*, *L. minor* L., *M. spicatum*, *P. crispus* and *P. nodosus*. Species richness was between 1 and 13, median = 5. The dense clustering of localities (Fig. 2) corresponded to the similarity of aquatic macrophyte assemblages. Nevertheless, two specific communities can be distinguished: (i) a community dominated by *E. canadensis* with the highest abundance but still supported by aquatic bryophytes in a natural river site (9R to the right of the diagram) and (ii) a community dominated by *R. trichophyllus* Chaix in a karst river (5R at the top) with high velocity, shading and coarse substrate.

Table 2. List of recorded taxa and their codes. Nomenclature follows Hill *et al*. (2006) and Uotila (2011+).

Taxa		Code
Amblystegium serpens	(Hedw.) Schimp.	AMB.SER
Callitriche platycarpa	Kütz.	CAL.PLA
Ceratophyllum demersum	L.	CER.DEM
Ceratophyllum submersum	L.	CER.SUB
Chara		CHA
Cinclidotus aquaticus	(Hedw.) Bruch & Schimp.	CIN.AQU
Elodea canadensis	Michx.	ELO.CAN
Elodea nuttallii	(Planch.) H. St. John	ELO.NUT
Fontinalis antipyretica	Hedw.	FON.ANT
Lemna gibba	L.	LEM.GIB
Lemna minor	L.	LEM.MIN
Lemna trisulca	L.	LEM.TRI
Marchantia polymorpha	L.	MAR.POL
Myriophyllum spicatum	L.	MYR.SPI
Myriophyllum verticillatum	L.	MYR.VER
Najas marina	L.	NAJ.MAR
Najas minor	All.	NAJ.MIN
Nuphar lutea	(L.) Sm.	NUP.LUT
Platyhypnidium riparioides	(Hedw.) Dixon	PLA.RIP
Polygonum hydropiper	L.	POL.HYD
Potamogeton berchtoldii	Fieber	POT.BER
Potamogeton crispus	L.	POT.CRI
Potamogeton gramineus	L.	POT.GRA
Potamogeton lucens	L.	POT.LUC
Potamogeton natans	L.	POT.NAT
Potamogeton nodosus	Poir.	POT.NOD
Potamogeton pectinatus	L.	POT.PEC
Potamogeton perfoliatus	L.	POT.PER
Potamogeton pusillus	L.	POT.PUS
Potamogeton trichoides	Cham. & Schltdl.	POT.TRI
Ranunculus aquatilis	L.	RAN.AQU
Ranunculus trichophyllus	Chaix	RAN.TRI
Spirodela polyrhiza	(L.) Schleid.	SPI.POL
Trapa natans	L.	TRA.NAT
Utricularia vulgaris	L.	UTR.VUL
Vallisneria spiralis	L.	VAL.SPI
Zannichellia palustris	L.	ZAN.PAL

Lakes. Lake altitude varied even more then among the river sites (between 150 and 1528 m a.s.l.). The water bodies belong to several national types: mountain lakes (L2, L3, Table 1), lowland or semi-mountainous natural lakes (L4), large deep (L11), and small and medium size semi-mountainous reservoirs (L12, L13), small and medium size lowland reservoirs (L17). The waters had a median pH of 8.2. Similar to the rivers, the abundance of *E. nuttallii* was mainly between 2 and 3, while that of *E. canadensis* varied widely between 1 and 5. Half of the water bodies were assessed as being of good potential. Four cases with poor assessment coincided with the dominance of *E. nuttallii*.

Twenty-one species have been recorded in total, with the most common again being *C. demersum* and *M. spicatum*. The species richness was similar to that of the river sites, between 2 and 11, median = 5. As for the rivers, the sampling events were closely clustered (Fig. 3). The analysis singled out two localities: (i) the Choklyovo swamp record in 2020, when the community was dominated by *E. canadensis* and *Utricularia vulgaris* L. and (ii) the Dospat Reservoir (for electricity supply) with the poorest aquatic macrophyte assemblage (only *E. nuttallii* and *C. submersum*).

DISCUSSION

Elodea species were recorded in Bulgaria both in river and standing water bodies with a characteristic dominance of *E. nuttallii* in the lakes. Similar results were reported for the active floodplain of the Drava River, where *E. nuttallii* was present in all types but was dominant in the ponds (Zelnik *et al.* 2022). *Elodea nuttallii* exhibited a preference for lakes with deep and cold waters in northern Italy in contrast to *E. canadensis* which was observed mainly in canals with shallow and warm waters (Buldrini *et al.* 2023). The authors also linked the complete absence of *E. nuttallii* in the Mediterranean region of Italy to certain distinct climatic requirements, i.e. *E. nuttallii* is less thermophilous than *E. canadensis*. On the contrary, Nuttall's waterweed – the third most frequent aquatic neophyte in Serbia, predominantly occurred in running waters (Anđelković *et al.* 2016). The study reported that *E. nuttallii* was mostly distributed along the Danube, while *E. canadensis* mostly occurred along irrigation canals between 2007 and 2015.

Records of both waterweeds in sandy and muddy river sites confirmed the species' preference for firm, fine grained sediments (Josefsson & Andersson 2001; Josefsson 2011). Our study revealed that the light availability range of *Elodea* is larger than previously reported, indicating its capacity to also form dense stands in shaded habitats.

Elodea records in the river assemblages in Bulgaria were dominated by *C. demersum* in a third of the cases and in aquatic macrophyte communities dominated by *M. spicatum* in almost half the lakes. Similar records were reported for Sweden, where *E. nuttallii* grows together with *Ceratophyllum* and other species (Josefsson & Andersson 2001). However, in contrast to the same publication, in Bulgarian lakes the species is most abundant in a wider depth zone, up to 4 m. Depths of between 3 and 4 m were also reported as optimal for Canadian waterweed in the Norwegian Lake Steinsfjord (Mjelde *et al.* 2012). The accompanying species in more than 70% of the surveyed water bodies in Bulgaria were different species of *Potamogeton* similar to the watercourses in Slovenia (Kuhar *et al.* 2010). A recent suggestion that *E. canadensis* has outcompeted *M. spicatum* in the Slovenian Ljubljanica River (Germ *et al.* 2021) was not confirmed during the current study where in over half of the river sites *M. spicatum* grew together with *Elodea*.

As previously reported for the Danube River (Janauer *et al.* 2021), in the Bulgarian part we recorded *E. nuttallii* with low abundance together with *C. demersum*, *M. spicatum* and various *Potamogeton* species (*P. crispus*, *P. nodosus*, *P. pectinatus* L., *P. perfoliatus* L.). Also, as in the cited research, the coexistence of both *Elodea* species was not detected.

The two cases of a shift in the dominance and the preservation of dominance by *E. canadensis* were contradictory and did not provide sufficient evidence to either confirm or reject the opinion that *E. nuttallii* is more competitive (Georgiev *et al.* 2019).

Turions that had not overwintered due to desiccation could be the reason for the observed disappearance of both waterweeds in Skala 1 Lake between 2011 and 2020. Similar observations were reported from Slovenia where *E. canadensis* was absent in streams with frequent and extreme water level fluctuations (Kuhar *et al.* 2010). Another reason could be the natural collapse of the IAS populations after their rapid expansion reported by Simberloff & Gibbons (2004).

CONCLUSION

The occurrence records of *E. canadensis* and *E. nuttallii* represented a relatively low percentage of the available database. Despite the wider distribution of Nuttall's waterweed in Bulgaria (12 river sites and 10 standing water bodies), and its known competitive advantage, *E. canadensis* has still retained its dominance in natural sites, where both species were recorded together. Based on the available dataset, Canadian waterweed forms larger and denser masses in rivers, while mass occurrences of both *Elodea* species were registered in lakes.

Although further research is needed, it can be suggested that in *Elodea*-dominated communities, biodiversity is greater when Canadian waterweed dominates. Natural mechanisms that lead to the elimination of *Elodea*-dominated assemblages could be expected.

There is a possibility of a change in the distribution of the invasive alien species in the coming years, and their

distribution could be wider than documented by our study. Thus, future research on *Elodea's* effects on flow velocity, turbidity, dissolved oxygen levels, and nutrient availability are needed for a precise estimation of the effects on entire aquatic ecosystems.

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REZIME

Botanica SERBICA

Trenutna distribucija, trendovi, abiotičke i biotičke preferencije dve vrste *Elodea* u Bugarskoj

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Proučavane su dve invazivne vodene vrste makrofita iz roda *Elodea* i njihovo rasprostranjenje u Bugarskoj. Istraživanje je zasnovano na 653 terenska istraživanja iz perioda 2009–2022. Podaci o *Elodea* su predstavljali samo 6% baze podataka. Od ove dve vrste, *Elodea nuttallii* je imala širu rasprostranjenost kako u rekama tako i u jezerima (prirodnim i veštačkim). *Elodea nuttalliii* je uglavnom dominirala u jezerima, a *E. canadensis* u rekama. Obe vrste su bile rasprostranjene u vodenim staništima sa velikim variranjem abiotskih karakteristika, osim dominantnog supstrata. *Elodea nuttalliii* je pokazala veći raspon nadmorskih visina, dostižući 1500 m. Visinske varijacije su rezultirale različitim ekološkim staništima u pogledu abiotskih faktora kao što su temperatura i intenzitet svetlosti. Proučavane zajednice vodenih makrofita imale su prosečno bogatstvo vrsta. *Ceratophillum demersum* i *Miriophillum spicatum* bili su najčešće zabeleženi predstavnici autohtone vodene flore. Kanadska vodena kora je bila sposobna da formira guste zajednice u rekama, dok je Nuttall-ova vodena kora generalno zadržala prosečne vrednosti zastupljenosti. Dokumentovan je slučaj prirodnog nestanka vrste *Elodea*. Sistematizovane informacije za period od 13 godina mogle bi pomoći u identifikaciji strateških oblasti u kojima bi se trebalo pozabaviti praćenjem IAS u vodi i njihovim upravljanjem.

Ključne reči: *Elodea canadensis*, *Elodea nuttallii,* invazivne vrste.