Peculiarities of species of *Elodea* (*Hydrocharitaceae*) in the aquatic ecosystems of Ukraine (East Europe)

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Abstract. Two species of *Elodea* – *E. canadensis* and *E. nuttallii*, and the closely related *Egeria densa*, have been recorded as alien species in the Ukrainian flora. One hundred and six waterbodies (reservoirs and rivers) in the central part of the Dnipro River Basin have been surveyed which resulted in the recording of 68 localities of alien macrophyte species. Morphometric studies have been conducted in selected populations of *E. canadensis* and *E. nuttallii* and the obtained data has been compared with these from North America (native distribution range of the species) and West Europe (alien distribution range of the species). It can be inferred that in the aquatic ecosystems of Ukraine, *E. densa* and *E. nuttallii* have wider ecological valence in relation to the content of nutrients in the water and both species actively expand the borders of their secondary distribution range in the region. On the contrary, *E. canadensis* shows vulnerability to anthropogenic eutrophication, and consequently, significant decrease in its coenotic activity, i.e. *E. canadensis* is in the stage of regressive changes in its secondary distribution area. In Ukraine, *E nuttalii* forms larger populations, with morphometric parameters higher than in its primary range, but smaller than in West Europe (plants are denser and less branched).

Key words: alien species, aquatic ecosystems, *Elodea*, morphometric features, Ukraine

Introduction

There are three species of genus *Elodea* Rich. spread across the aquatic ecosystems of Europe: *Elodea canadensis* Michx., *E. nuttallii* (Planch.) H.St. John and *E. callitrichoides* (Rich.) Casp. Closely related is *Egeria densa* Planch. which was considered by some authors in the past as a member of *Elodea* [*Elodea densa* (Planch.) Caspari]. All these species are widespread today in Belgium, France, Great Britain, Austria, Germany, etc. Meanwhile, *Elodea canadensis* is also widely spread in West and East Europe.

The history of macrophyte invasions across the European continent and the problems associated with them are widely covered in scientific literature (Jafari 2010; Njambuya & Triest 2010; Adebayo & al. 2011; Mironga & al. 2012; Koutika & Rainey 2015). Since mid-19th century *E. canadensis* had colonized the territory of Europe from the American continent. Early in the 20th century, *E. nuttallii* and *E. callitrichoides* (Simpson 1984) followed. In the 21st century, some other South American species were also introduced, namely, *Egeria densa*. Today all these plants are familiar elements in the aquatic flora of most European water bodies (Table 1).

In 1984, *E. canadensis* was recorded for the first time in Ukraine. The secondary range of expansion eastwards of the other three species did not happen so rapidly. *Elodea nuttallii* and *Egeria densa* appeared in Ukraine almost 100 years after their first finds in West Europe (2001–2005, respectively). No records of *Elodea callitrichoides* have been reported in East Europe.

Elodea nuttallii and *Egeria densa* are included in the list of the European and Mediterranean Plant Pro-

tection Organization (EPPO). They are also listed in the Adventive Species of Eastern Europe Database. *Elodea nuttallii* and *E. canadensis* are included in the list of most dangerous invasive alien species (EEA/SEBI 2010, Larsson & al. 2007).

Table 1. Distribution of *Elodea* and *Egeria* species in some countries in Europe (Simpson 1984; Protopopova 1991; Pohl 1993; Poorten & al. 2000; Sârbu & al. 2006; Bagatska 2007; Josefsson 2011; Petrova & al. 2013; Matthews & al. 2014; Prokopuk 2015; Dubyna & al. 2017; Poulis & Zervas, 2017; Hrivnak & al. 2019).

Country	*Elodea canadensis*	*Elodea nuttallii*	*Elodea callitrichoides*	*Egeria densa*
Austria	5	5	1	1
Belgium	5	5	0	0
Bulgaria	4	4	0	0
Belarus	5	0	0	1
Denmark	4	4	0	0
Estonia	5	0	0	0
European part of Russia	5	0	0	2
Finland	5	0	0	0
France	5	5	2	4
Germany	4	5	1	1
Great Britain	5	5	2	2
Greece	5	0	0	0
Hungary	5	4	0	4
Iceland	0	0	0	3
Ireland	5	4	0	0
Italy	4	4	0	4
Latvia	5	0	0	0
Lithuania	5	0	0	0
Netherlands	5	4	0	4
Norway	4	2	0	0
Poland	5	2	0	0
Romania	4	4	0	0
Slovakia	5	5	2	0
Spain	5	0	0	3
Sweden	4	3	1	1
Switzerland	5	4	0	4
Ukraine	5	3	0	2

0 – not found, 1 – single finds, 2 – rare, 3 – sporadic (locally), 4 – ordinary, 5 –widespread.

Material and methods

One hundred and six waterbodies (reservoirs and rivers) have been surveyed in the central part of the Dnipro River Basin (128 observation points; 72 water bodies in Kyiv and 34 in Kyiv, Cherkasy and Poltava regions). Of these, 68 localities of alien macrophyte species have been identified and investigated (Fig. 1). Population studies were conducted in 28 model reservoirs, including measurement of the morphometric indices of individuals.

Evaluation of ecological variability of the metapopulation of *Elodea* in Ukraine included measurements of the morphological features (main shoot length, number of lateral shoots, length of lateral shoots, leaf width and length, internode width, and leaf area). The morphometric features of 11 populations (110 individuals) of *Elodea nuttallii* and 10 of *Elodea canadensis* (100 individuals) were measured (Table 2). In order to evaluate their behavior strategies and possible threats to natural biotopes, we have compared the results of our morphometric studies with those obtained by Di Nino & al. (2007).

Table 2. Recorded localities of *Elodea* spp. in Ukraine.

No	Locality	Latitude (N)	Longitude (E)
	Elodea Canadensis		
1	Reservoir No 1 of the Zhukiv Ostriv Landscape Reserve	50°20'31.3"N	30°34'19.5"E
2	Reservoir No 2 near Babyne Lake	50°28'08.8"N	30°32'26.5"E
3	Lake near Syretskyi Hai Park	50°28'36.7"N	30°25'38.6"E
4	Verkhnie Vyhurivske Lake	50°31'27.8"N	30°37'46.0"E
5	Berizka Lake	50°26'15.9"N	30°34'42.5"E
6	Venetsianska Strait	50°26'54.5"N	30°34'29.3"E
7	Stuhna River	50°08'41.3"N	30°25'09.9"E
8	Troieshchynskyi Channel	50°30'39.2"N	30°37'36.8"E
9	Sapsaiv Pond	50°33'20.1"N	30°20'34.0"E
10	The pond in Peremoha Park	50°28'00.5"N	30°36'16.1"E
	Elodea nuttallii		
1	Babyne	50°28'08.9"N	30°32'40.4"E
2	Verkhnie Vyhurivske Lake	50°31'27.8"N	30°37'46.0"E
3	Desenka (Chortoryi) River	50°30'29.1"N	30°34'05.1"E
4	Bypass channel of Bortnitskaya Aeration Station	50°17'58"N	30°40'8"E
5	Berizka Lake	50°26'15.9"N	30°34'42.5"E
6	Sribnyi Kil Lake	50°23'50.8"N	30°37'15.9"E
7	Bobrovnia River	50°30'39.6"N	30°32'37.0"E
8	Halerna	50°22'08.2"N	30°33'16.4"E
9	Domania	50°32'05.0"N	30°33'58.0"E
10	Dnipro River	49°42'46.6"N	31°34'00.1"E
11	Dnipro River	49°42'53.0"N	31°34'32.0"E

See Thiebaut & Di Nino (2009) for 24 populations of *E. nuttallii* in North America (Canada, USA – primary range) and 16 populations in Europe (France, Great Britain, Switzerland, Belgium – secondary range).

Results and discussion

In Eastern Europe, *Elodea* is widespread in the reservoirs and streams of all hydrological types and trophic groups. However, highly productive coenoses are

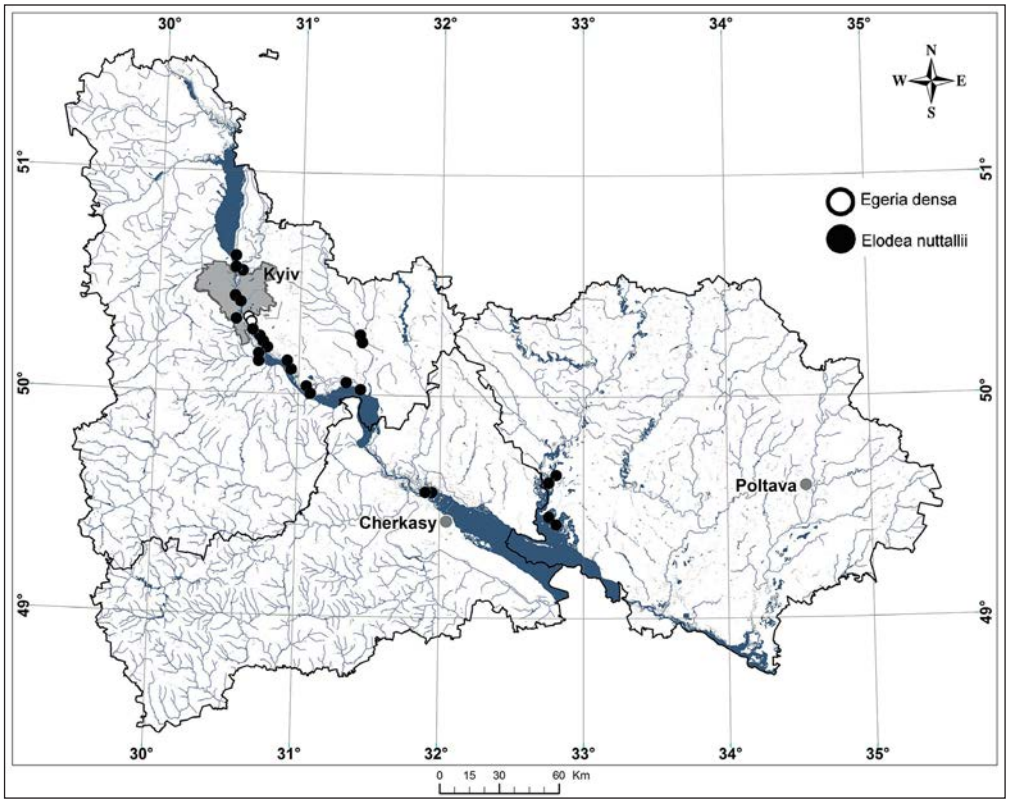

Fig. 1. Distribution map of the new invasions of *Elodea nuttalli* and *Egeria densa*.

formed in the high-trophic waters with good water exchange. Characteristically, *Elodea* species spread actively not only in anthropogenic but also in natural ecotopes. They form mainly monodominant and low-species group communities. The case of species of tropical origin, *Egeria densa*, the development of communities is ephemeral in character. It develops only in water bodies with appropriate water temperature. All species in the Ukrainian habitats have shown some regional-population and phytocoenotic features. Due to the peculiarities of their ecological-coenotic strategy, these species are capable of naturalization in natural ecosystems (Table 3).

In the last two decades, a decrease has been recorded in the coenotic activity of *E. canadensis* in the water bodies of Ukraine. Our observations have shown that an increase in the trophic status of reservoirs due to eutrophic causes leads to enhancing the anthropogenic eutrophication, which, in turn, may lead to degradation or elimination of the thickets of *E. canadensis*.

Table 3. Characteristics of the ecological conditions in the contemporary localities of *Elodea* in the central part of the Dnipro River Basin.

Species	Time of introduction	Pathway of introduction	Ecological characteristics of the biotope	Phytoceonotic characteristics of the biotope
Elodea canadensis	Neophyte (1898)	Xenophyte	Streams, ponds, melioration channels of mesotrophic and mesoeutrophic type, depths – 0.1–1.0 m, sediments – sand, muddy sand, silt, rocky sediments.	The species composition of the thickets – belt, fragmentary. Total number of species in communities – 2–14. Straight percentage cover in communities – 10–100 % (associations *Elodeetum canadensis, Elodeeto-Ceratophylletum*, *Elodeeto-Potamogetum).*
Elodea nuttallii	Neophyte (2004)	Xenophyte	Rivers, floodplains, reclamation canals with enhanced anthropogenic eutrophication, depths – 0.2–1.5 m, sediments – sand, muddy sand.	The species composition of the thickets – belt, fragmentary. Straight percentage cover in communities – 10–100 %. Total number of species in communities – 3–16 (associations *Elodeeto-Ceratophylletum*, *Elodeeto-Potamogetum*).
Egeria densa	Neophyte (2004)	Xenophyte	Water reservoirs with good water exchange (gravitates to canals, floodplain lakes, which have not lost contact with the main riverbed, low-flow streams), depths of 0.5–1.0 m, sediments – sand.	Straight percentage cover in communities usually – 80–90 %, less – 20–30 %, Total number of species in communities – 3–18 (associations *Egerietun densa*, *Egerieto-Ceratophylletum*).

Elodea nuttallii and *E. densa* are actively extending species within the boundaries of their secondary range. *Elodea nuttallii* has advanced actively both downstream and upstream the Dnipro River. In our opinion, in the coming years these species would penetrate into the Desna hydrological network and the upper reaches of the Kyiv Reservoir. The wide spread of the species originating from a moderate region and the speed of its contemporary distribution in the water bodies of Ukraine suggest its characterization as C-competitor, which not only gets naturalised, but acts as a transformer. In spite of the fact that in East Europe the development of the populations of *E. densa* is fluctuating (from outbreaks of mass development to extinction, and up to complete temporary disappearance from the hydrophytoceonoses), this species should be considered as a species with SR-strategy and possible transformer. The population of *E. densa* has not expanded beyond its place of introduction, but it regenerates. With the contemporary climate changes it has significant invasive capabilities.

Plants in the secondary range characteristically have lower growth energy, because of the various selection pressures (Di Nino 2007). They have considerable variability in morphometric and productive indices (Simpson 1988; Vanderpoorten & al. 2000; Thiebaut & Di Nino 2009; Kocic & al. 2014). In support of this, the analysis of the range of morphometric features of *E. nuttalli* and *E. canadensis* has shown broadly variabile morphometric parameters of the species in the studied reservoirs of Ukraine. The coefficients of variation (CV) ranged from 20–22 % (leaf width) to 70–80 % (length of internodes) (Table 4).

Most variable was the number of lateral shoots of *E. nuttallii* (CV = 108 %). Apparently, limnophilic conditions and lack of flows have contributed to more intensive branching of individuals within the population (increasing the number of lateral shoots and their length). The strong variations in morphometric parameters, both in different populations and within the local populations of *E. nuttallii* and *E. canadensis*, indicated plasticity of these species in Ukraine.

The coenopopulations of *E. nuttallii* in East Europe (the central part of Ukraine) exhibited broad morphometric variability (the range of values varied from 20 %), which indicated plasticity of species and the processes of their active adaptation. In the secondary distribution, *E. canadensis* was at the stage of regressive changes.

A comparison of the morphometric features of *E. nuttalli* in its primary range (North America), secondary range (West Europe) and the data of our studies (Table 5) has shown that in Ukraine the coenopopulations of *E. nuttallii* indicated wide morphometric

Table 4. Ranges of variation of morphometric features of *E. nuttallii* and *E. canadensis* in the water bodies of Ukraine.

Morphological traits	*Elodea nuttallii*				*Elodea canadensis*			
	Min-max	Mean	SD	CV	Min-max	Mean	SD	CV
Shoot length, cm	9.5–165.0	37.8	19.6	51.9	10.0–66.9	33.7	14.13	41.9
Number lateral shoots	0–35	6.5	7.09	108.4	0–10	2.9	1.88	64.8
Length lateral shoot, cm	0.4–35.5	5.3	4.49	84.6	0.6–34.0	5.8	7.19	124.0
Internode length,cm	0.1–5.0	0.7	0.56	78.9	0.1–3.0	0.6	0.42	70.0
Length leaf, cm	3.75–19.7	10.2	3.01	29.5	3.7–12.1	7.3	1.51	20.7
Width leaf, cm	0.75–4.3	1.9	0.41	21.6	1.3–5.5	2.4	0.53	22.1

Mean – arithmetic mean, SD – standard deviation, CV (%) – coefficient of variation

Table 5. Morphological features of the populations of *E. nuttallii* in North America, West Europe (Thiebaut 2009) and Ukraine .

Morphological traits	Morphological traits			The coefficient of variation (%)		
	North America (NA)	West Europe (WE)	East Europe (EE)	NA	WE	EE
Shoot length, cm	31.28±17.43	57.12±30.26	38.74±22.03	55.7	53.0	56.9
Number lateral shoots	5.50±4.64	7.65±4.67	6.54±7.09	84.4	61.0	108.4
Length lateral shoot, cm	35.64±39.4	61.82±63.00	5.31±4.49	110.5	101.9	84.6
Internode length,cm	0.56±0.28	0.74±0.33	0.71±0.56	29.2	44.6	78.9
Length leaf, cm	0.96±0.28	1.17±0.31	1.02±0.30	29.2	26.5	29.4
Width leaf, cm	0.15±0.05	0.22±0.09	0.19±0.04	33.3	40.9	21.1
Leaf area, cm^2	0.09±0.05	0.17±0.11	0.15±0.06	55.6	64.7	40.0

variability, which demonstrates plasticity of the species and the processes of their active adaptation. The populations were formed with morphometric parameters exceeding those in the primary range, but lower than in West Europe.

The length and width of the leaves have shown the lowest fluctuations of these features in the three regions, ranging within 20–40 %. The indicators of the main shoot length, number and length of lateral shoots, and leaf area for North America, West Europe, and Ukraine fluctuated stronger in their characteristics in the aggregate. In North America, the length of internodes is characteristically homogeneous, while in the secondary range this indicator varies greatly. This is especially valid for the populations of *Elodea* in Ukraine, where its distribution has occurred recently (65 years later than in West Europe (Belgium).

If in West Europe a number of morphometric indicators have been relatively stable (with variation range of 1–10 %), in Ukraine, variability of most parameters of the individuals was extremely high (from 40 % to 115 %), which testified to the process of active adaptation of the species to new conditions.

In Ukraine, the populations have morphometric parameters which are higher than those in the primary range, but smaller than in West Europe (plants are denser, less branched).

Conclusions

Egeria densa and *Elodea nuttallii* have wider ecological valence in relation to the content of nutrients in the water. They actively expand the borders of their secondary range in the region. On the contrary, *E. canadensis* shows vulnerability to anthropogenic eutrophication. We have recorded a significant decrease in its coenotic activity. In Ukraine, *E. canadensis* is in the stage of regressive changes in the secondary distribution area. In some reservoirs, it has disappeared from the aquatic flora.

The coenopopulations of *E. nuttallii* in East Europe (the central part of Ukraine) exhibit wide morphometric variability (the range of values starts from 20 %), which testifies to plasticity of the species and the processes of its active adaptation. In its secondary distribution, *E. canadensis* is at the stage of regressive changes.

In Ukraine, *E. nuttallii* forms larger populations, with morphometric parameters higher than in the primary range, but smaller than in West Europe (plants are denser, less branched).

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