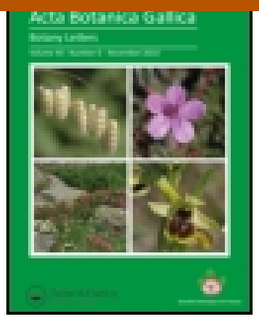

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Distribution, morphology and habitats of *Elatine triandra* (Elatinaceae) in Europe, with particular reference to the central part of the continent

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Abstract: *Elatine triandra* Schkuhr is the most variable and widespread species within the genus *Elatine* L.; it has been recorded in all continents, except Antarctica, but it is mainly located in Europe. The study is based on an extensive data set of European literature, herbaria and web data that covers the period 1828–2012. The range of the species in Europe is disjunctive, covering the southern and western parts of the Central European Plain and the southern part of the Fennoscandian Shield. At a smaller scale, the species can also be found along some river valleys. In Central Europe many localities, particularly isolated ones in the northern part of the range, are now only historical. From the data set we determined that *E. triandra* may be best observed between May and October. We found that species records show a near-significant shift since 1828. Depending on the environmental conditions, individuals of the taxon develop as one of two morphs: terrestrial or aquatic. The aquatic morph is characterized by stems, internodes, lamina and petiole that are twice as long as those of the terrestrial form. *Elatine triandra* seeds show consistent characteristics, both in terms of morphs and populations. Our studies show that the best diagnostic features, in addition to the construction of flowers, are the size, shape and surface structure of seeds. In Central Europe, *E. triandra* occurs exclusively in communities classified as Isoëto-Nano-Juncetea.

Keywords: chorology; ephemerophyte; Isoëto-Nano-Juncetea; phytogeography; vegetation; morphology; maps; phenology

Introduction

Understanding the distribution patterns and biology of rare and endangered species is essential for the development of nature conservation policies. Many species of the class Isoëto-Nano-Juncetea are rare elements of the European flora, and many are threatened with extinction. From this perspective, species of the genus *Elatine* L. are especially important. The genus includes about 27 species of small ephemerophytes that appear periodically on bare soil in intermittent water bodies. Their range includes areas with temperate climate on all continents, except Antarctica. The genus *Elatine* belongs to the family Elatinaceae; however, the origin and taxonomic relations of the family are not fully clarified (Seubert 1845; Niedenzu 1925; Davis and Chase 2004; Popiela and Łysko 2011; Popiela et al. 2012; Kubitzki 2013).

The distribution patterns of the genus *Elatine* are still relatively unknown. Comprehensive studies have been carried out only on *Elatine alsinastrum* L., *Elatine hexandra* (Lapierre) DC., *Elatine hydropiper* L., *Elatine macropoda* Gruss. and *Elatine hungarica* Moesz (e.g. Meusel 1978; Hultén and Fries 1986; Lampe 1996; Popiela and Łysko 2010; Popiela et al. 2011, 2012; Takács et al. 2013). The species of the genus are distributed mostly in the northern hemisphere, predominantly in areas with temperate climate. Some species have wide geographical ranges, such as *E. alsinastrum* and *E. hydropiper* (Popiela et al. 2012; Popiela, Łysko, and Molnár 2013). Others are limited only to Europe, such as *E. hexandra* (Popiela et al. 2011) and *E. hungarica* (Takács et al. 2013), or are known from very restricted areas, such as *Elatine paramoana* Schmidt-M. & Bernal (Schmidt-Mumm & Bernal 1995), *Elatine ojibwayensis* Garneu (Garneu 2006) and *Elatine gussonei* (Sommier) Brullo Lanfr., Pavone and Ronsisv. (Molnár, Popiela, and Lukács 2013).

Elatine triandra Schkuhr [synonyms: *Elatine callitrichoides* (Nyl.) Kauffm., *Elatine chilensis* Gray, *Elatine inaperta* J. Lloyd, *Elatine triandra* var. *callitrichoides* Nyl., *Elatine orientalis* Makino] is the most widespread species within the genus, occurring on all continents, except Antarctica; however, the majority of its recorded locations are in Europe (e.g. Tucker 1986). *Elatine triandra* belongs to the section *Triandra* Seub. [= *Crypta* (Nutt.) Seub.], which is characterized by trimerous flowers showing haplostemony (an arrangement of 16 stamens in a single whorl opposite the sepals with equal numbers of anthers and sepals). *Elatine triandra* is a species of small aquatic and terrestrial plants with a prostrate stem with many

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secondary branches, rooted at nodes. Leaves are opposite, blade lanceolate-linear to narrowly lanceolate to oblong with distinct hydatodes, and triangular stipules. Flowers are single at the nodes, sessile or rarely very short-stalked, with two to three sepals and usually three petals and three stamens. Capsules are subglobose, somewhat depressed at the apex, seeds cylindrical, greenish- to yellowish-brown with conspicuous pits [2n = 40] (Tucker 1986; Uotila 2010).

The aims of this paper are: (1) to present the current distribution of *E. triandra* in Europe; (2) to describe the taxonomic and phenological features of the species; and (3) to indicate the communities in which the species occurs and its conservation status in the central part of the continent.

Material and methods

Research on the distribution of *E. triandra* was based on analysis of floristic literature, distribution atlases, web sources and examination of specimens deposited in the herbaria listed in Table 1.

Data on the distribution of the species were gathered, giving priority to the literature over web sources. The data set contains 1959 records (1353 from the literature and herbaria, 606 from the internet), covering the period 1828–2012. Web sources were used only if considered to be reliable (e.g. if they did not deviate from the range or had an author and exact location or were delivered by herbarium servers). Altogether, 427 web data were removed.

The exact time of species observation was recorded. The observation dates were transformed into Julian days. We calculated the relative frequency of species observations within a year; then the species phenology in time was analysed. The median Julian date of observations was plotted against time (1828–2012) and linear regression was computed. All analyses were made using Statistica 7.0 (StatSoft Inc., Tulsa, OK).

Table 1. Literature, web and herbaria sources used. Herbarium acronyms follow *Index Herbariorum* (Holmgren and Holmgren 1998).

Area	Data
Northern Europe (Finland, Norway, Sweden)	Uotila 2010; *Biodiversity occurrence data published by:* Hatikka Observation Data Gateway, Vascular plant collection of Jyväskylä University Museum *(Accessed through GBIF Data Portal, data.gbif.org, 2012-09-01),* Lampinen, Lahti, and Heikkinen 2015.
Eastern Europe (Lithuania, Russia)	Adylov 1983; Kuusk, Tabaka, and Yankyavichene 1996; Peshkova 2006; Ramenskaya and Andeeva 1982; Shishkin 1961; Shishkin 1974; Tolmatchev 1976; Tzvelev 1996. Specimens of the following herbaria: K, B, BM.
Central, Southern and South-Eastern Europe (Austria, Czech Republic, Hungary, Italy, Poland, Romania, Slovakia, the Balkans)	Blazenčič and Blazenčič 1999; Blečič 1972; Cesati, Passerini and Gibelli 1868–86; Dostál 1989; Fiori and Paleotti 1896; Fuss 1866; Hejný and Slavík 1990; Jakab 2005; Jogan 2001; Jordanov and Peev 1979; Koch, Berndhardt and Webhofer 2005; Langhe et al. 1983; Maurer 1996; Micevski 1995; Molnár and Gulyás 2001; Molnár and Pfeiffer 1999; Nikolić 1994; Peev 1984; Piccoli and Gerdol 1981; Pignatti 1982; Pinke et al. 2006; Popiela et al. 2014; Ranđelović et al. 2010; Sãvulescu 1950; Slavík 1990. Specimens of the following herbaria: K* B, BM, BP, DE.
Western and South-Western Europe (Belgium, France, Germany, Portugal, Spain, the Netherlands)	Benkert, Fukarek and. Korsch 1996; Berten 1993; Brinkkemper and al. 2007; Bugnon et al. 1998; Cirujano and Velayos 1993; Desfayes 2008; Franco 1971; Fukarek and Henker 2006; Gatterer and Nezadal 2003; Gerstberger and Vollrath 2007; Haeupler and Schönfelder 1989; Jeanmonod and Gamisans 2007; Lawalrée 1968; Muller 1995; Muller 2006; Netien 1993; Saint-Lager 1873; Specimens of the following herbaria: K, B, BM.*Biodiversity occurrence data published by:* Atlas de la Flore de Wallonie (accessed through www. bidiversite. wallonie, 2012-07-29),Atlas des Plantes Vasculaires de Lorraine (accessed through GBIF Data Portal, data.gbif.org, 1 September 2012); Bundesamt für Naturschutz / Netzwerk Phytodiversitaet Deutschland (accessed through GBIF Data Portal, data.gbif.org, 20 August 2012); Dutch Vegetation Database (LVD) (accessed through GBIF Data Portal, data.gbif.org, 20 July 2012); Herbarium Senckenbergianum (FR) (accessed through GBIF Data Portal, data.gbif.org, 30 June 2012); Inventaire National du Patrimoine Naturel (INPN) (accessed through GBIF Data Portal, data.gbif.org. 3 August 2012); Observations du Conservatoire Botanique National du Bassin Parisien (accessed through GBIF Data Portal, data.gbif.org, 1 September 2012); Information System of the plants of Spain. Real Jardín Botánico, CSIC - Fundación Biodiversidad (accessed through www.anthos.es, 2012-07-30).

The differences in seed and vegetative characteristics between the aquatic and terrestrial morphs of *E. triandra* were studied *in vitro*. Seeds of *E. triandra* were collected from indigenous populations in Hungary: Kisköre (47°29'37.42" N, 20°29'17.75" E). The plants were cultivated in the laboratory of the University of Debrecen. Seeds were sown in 12.5 × 8.5-cm plastic boxes on sterilized (autoclaved for 3 h at 180°C) soil that was continuously wetted. Plantlets were grown in climate-controlled rooms (with 14 h of light/day and 30 μmol m^{-2} sec^{-1} light intensity, temperature in light 22 ± 2°C and in darkness 18 ± 2°C).

Two 1-week-old seedlings were transplanted, then kept under aquatic conditions (continuous water cover) or terrestrial conditions (on wet mud) until they reached the fruiting stage. For the morphological study, six characters (length of stem, length of first mature internode, length of first mature lamina, width of first mature lamina, length of petiole, number of nodes) were measured on 50–50 fruiting stems of both aquatic and terrestrial morphs using calipers (0.1-mm accuracy). Four characters [curvature (°), number of pits/lateral row, first dimension (mm), second dimension (mm)] were measured from digital images (Figure 1).

To determinate the variability and diagnostic features of seeds of *E. triandra*, 50 seeds obtained from each of two Central European populations (a total of 100 seeds) approximately 600 km apart were studied: Poland: Janików (51°34'34.52" N, 14°57'23.35" E), and Hungary: Kisköre (47°29'37.42" N, 20°29'17.75" E). A total of 100 scanning electron microscope images of the seeds were obtained at × 300 magnification using a Zeiss Evo LS10. Characters were measured according to the method described above (Figure 1).

The occurrence of *E. triandra* in plant communities in Central Europe (Poland, southeast Germany, the Czech Republic and Slovakia, Hungary, and northern Italy) was studied using published synoptic tables in which the species had 60% constancy. The data from Poland were obtained from the Polish Vegetation Database (Kącki and Śliwiński 2012). This data set was supplemented with unpublished relevés (AMV, Hungary; AP, Poland, Germany; ZK, Poland). A total of 614 published relevés were used. We prepared the synoptic table using the Juice program (Tichý 2002) and showed species with constancy > 10%. Vegetation was classified according to the assignment of the authors of the original studies (Ubrizsy 1948, 1961 after Pietsch 1973a; Pignatti 1957 after Pietsch 1973b; Pietsch 1963, 1973a, b; Popiela 1996; Nowak and Nowak 2007; Šumberová and Hrivnák 2013). Unpublished data were assigned to particular syntaxonomic units using the Frequency-Positive Fidelity Index (Tichý 2005).

Results

In Europe, the main area of *E. triandra* extends from the north of the Alps to the southern part of the Scandinavian Peninsula and the Finnish Lake District, including the southern and western parts of the Central European Plain (primarily the Saxo-Lusatian Lowlands) and the northern shores of the Baltic Sea. *Elatine triandra* can also be found in single locations in the southern part of the Odra River valley and in the Elbe and Rhine valleys (Figure 2). Larger centres of occurrence are present in the Upper Saône valley, in the southeastern part of the Franconian Jura, in the Bohemian–Moravian Highlands, in the Pannonian Basin and along river valleys in the eastern part of the Alps (Figure 3). Small site clusters also occur in the Po valley, in the Maritsa River valley and at the mouth of the Rhône River. In addition, *E. triandra* has scattered locations: the westernmost sites are at the mouths of the Loire and the Tagus, the most southern locations are in Corsica and Sardinia and in southeastern continental Greece. The northernmost locations are on the northern shores of the Gulf of Bothnia and in the mouth and valley of the Torne River. *Elatine triandra* is not known from eastern Poland, Ukraine and Belarus and only one location is known in Lithuania. The species is reported from the eastern part of the East European Plain, beyond a large gap in its range.

Concerning the phenology of *E. triandra*, the species can be found between May and October, but the main season is from July to September (Figure 4). Linear regression between the median Julian day of observation as the dependent variable and years as the explanatory variable indicated that the first observation of the year of *E. triandra* has shifted to 8 days earlier ($R = -0.142$, $p = 0.0676$) since 1828 (Figure 5).

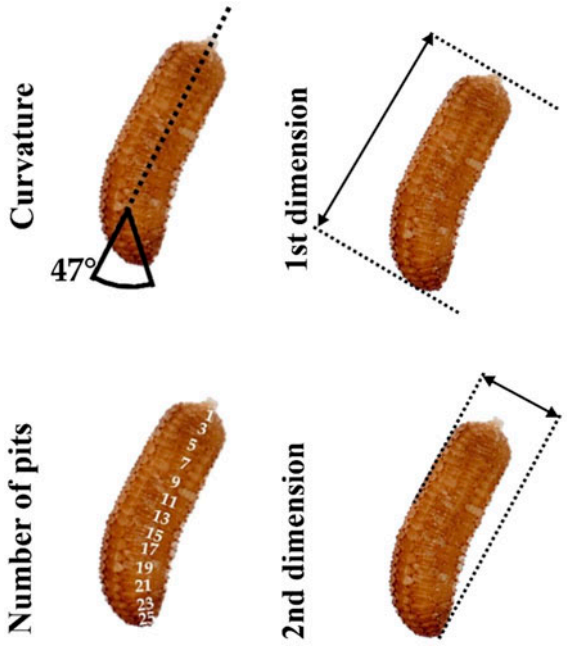

Figure 1. The method of seed measurement.

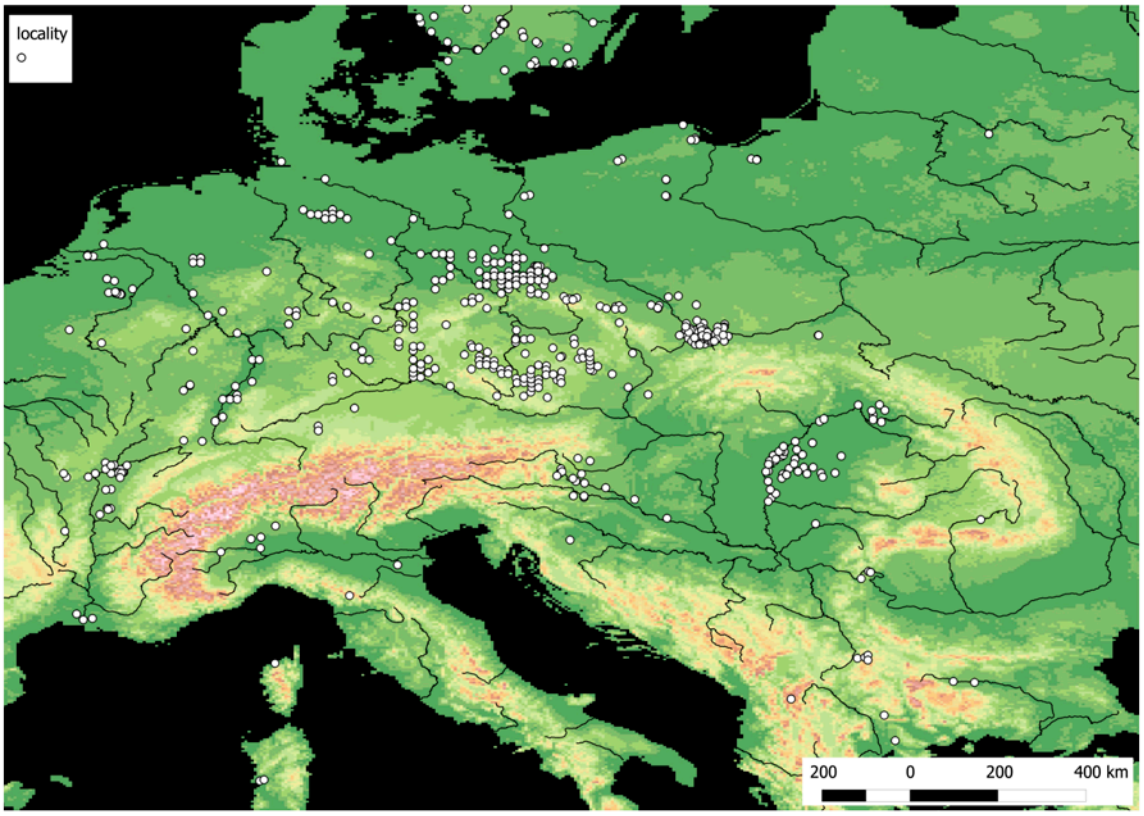

Figure 2. The distribution of *Elatine triandra* in central and the eastern part of Western Europe.

Depending on the environmental conditions, individuals of *E. triandra* develop as one of two morphs: terrestrial or aquatic. The aquatic morph has stems and internodes twice as long as those of the terrestrial morph, and also lamina and petiola almost doubled in length, but there are no differences in terms of lamina width or the number of nodes (Table 2, Figure 6). *Elatine triandra* seeds show consistent characteristics for each morph, as well as for populations originating from different parts of its range: length c.0.5 mm, straight or slightly bent in one dimension, and the number of pits in the seed coat is usually > 20 (Tables 2, 3, Figure 7).

In Central Europe, *E. triandra* occurs exclusively in communities entering into the Isoëto-Nano-Juncetea

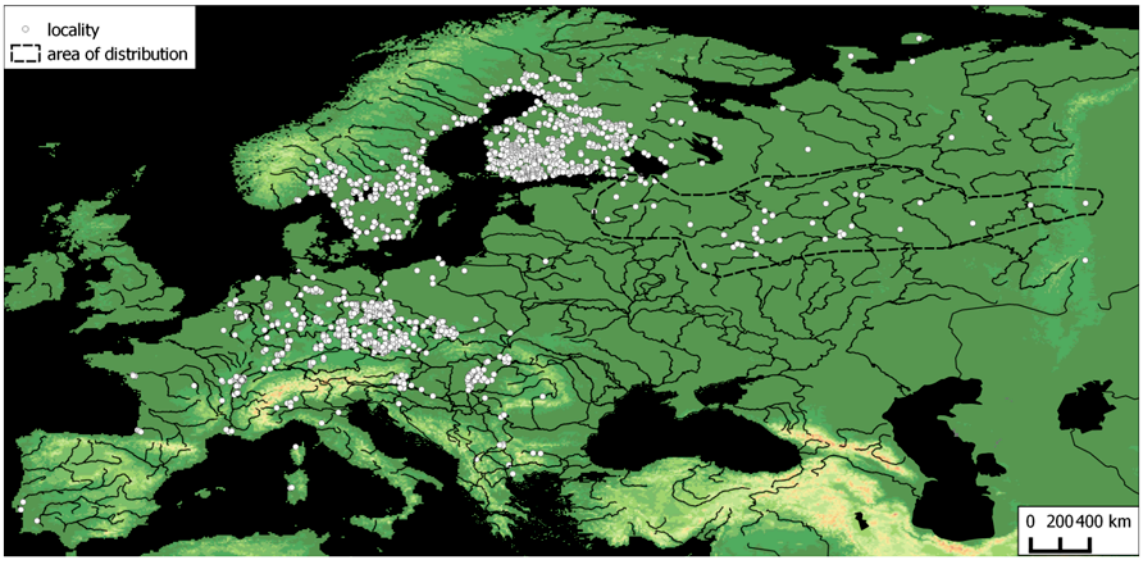

Figure 3. The distribution of *Elatine triandra* in Europe.

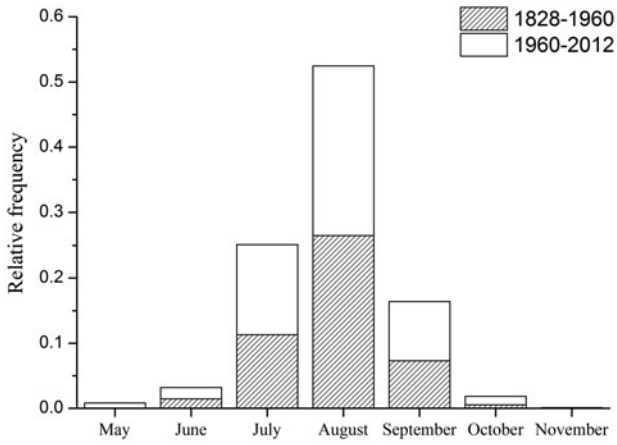

Figure 4. Relative frequency of *Elatine triandra* collections.

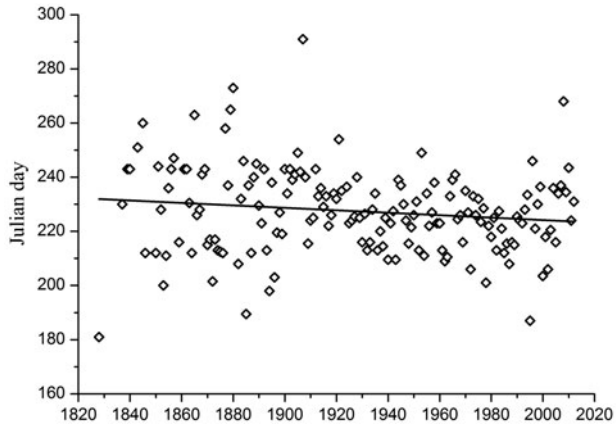

Figure 5. Dates of observation of *Elatine triandra* in a historical data set. Dots represent the medians of Julian day. Black lines are linear fit (Pearson's $r = -0.1422$).

class, mainly on the bottoms and in open water of fish ponds and on rice fields (Table 4), most often accompanied by *Eleocharis acicularis* (L.) Roem. & Schult., *Lythrum portula* (L.) D.A. Webb, *Filaginella uliginosa* (L.) Opiz and *Juncus bufonius* L. In the north, important constituents of the associated flora are *Eleocharis ovata* (Roth) Roem. & Schult., *Carex bohemica* Schreb. and *E. hexandra*, and in the south *Lindernia procumbens* (Krock.) Philcox and *E. hungarica.* Among the accompanying species, the predominant taxa are associated spatially with the waters and wetlands.

In Central Europe after 1990, populations of *E. triandra* were mostly recorded in four areas: the Lusatian Lowland, the Lower Odra and Vistula river valleys, the Bohemian–Moravian Highlands, and the Pannonian Basin (Figure 8). Many localities, especially isolated ones in the northern part of the range, are historical now. Therefore, the species has been included in national red books and lists of threatened species such as the IUCN list (IUCN 2014; Table 5).

Discussion

The range of *E. triandra* in Europe is disjunctive. A characteristic pattern of distribution was observed; it occurs in small or large clusters or alone, frequently along river valleys; the distances between locations are frequently as much as several hundred kilometres. In this respect, the distribution resembles that of other species in the same genus. This type of distribution is evidence that colonization of new areas is a slow process, although wet habitats and places that have been recently exposed after earlier floods and are devoid of other plants are not rare habitat types. The method of propagation of *E. triandra* in Europe is unclear (as it is for other *Elatine* species) and there is a lack of information about the location of the Pleistocene refuge area. Presumably the distribution range reflects the migration of waterfowl transferring diaspores (seeds and vegetative particles) from one place to another. Although this phenomenon is poorly documented (Kerner 1895), we suggest that diaspore transfer of *Elatine* species via waterfowl is probable. However, this mechanism does not explain the large gap in its distribution range, which

Table 2. Comparison of the median value of seed and vegetative characteristics between two different modifications of *Elatine triandra*.

	Terrestrial $n = 50$	Aquatic $n = 50$	Kruskall–Wallis test
Seed characteristics	Median±SD	Median±SD	*p*
Seed length (mm)	0.49±0.03	0.50±03	n. s.
Curvature (°)	47.5±23.2	40.5±19.6	n. s.
Number of pits	22±2.2	22.5±7.6	n. s.
Capsular seed number	22.5±7.6	22.5±6.9	n. s.
Vegetative characteristics			
Length of stem (mm)	10.2±1.8	16.15±5.3	<0.001
Length of internodes (mm)	2.7±1.1	5.0±2.3	<0.001
Length of lamina (mm)	4.5±0.8	8.3±1.5	<0.001
Width of lamina (mm)	2.2±0.4	2.1±0.3	n. s.
Length of petiolus (mm)	1.6±0.4	2.2±0.7	<0.001
Number of nodi (mm)	4.0±1.28	5.0±0.7	n. s.

Table 3. Values of seed characteristics of the two *Elatine triandra* populations studied (Hungary, $n = 50$; Poland, $n = 50$).

	_Median	SD	Min	Max
Length [mm]	0.49	0.03	0.41	0.55
Width [mm]	0.25	0.05	0.15	0.39
Curvature [^{o}]	45	21.46	45	45
number of pits	22	1.96	17	28

includes the commonest places of migrating birds with suitable habitats – e.g. there are no locations with *E. triandra* in the Warta River Mouth National Park (northwest Poland), which is one of the most important migration places of waterfowl in Central Europe.

The range of *E. triandra* in the East European Plain seems to be poorly known: the species has been reported in Russian floras without detailed locations, and so determination of the eastern boundaries of its range can be made only provisionally. At present, it is not possible to establish whether the lack of sites is caused by insufficient reconnaissance or because sites are naturally sparse. It seems quite certain that *E. triandra* is not present in the southern part of the East European Plain, most likely because of the dry, continental climate. The complete lack of occurrence in the western part of the East European Plain is very interesting. If this pattern is natural (not an artefact caused by lack of collection), that would suggest that in Central Europe the species has reached its limit of distribution density.

Land-use activities appear to have a great impact on the distribution range of *E. triandra* by forming suitable habitats for the species: rice paddies, fisheries, temporarily inundated agricultural fields and grazed shores. The question remains whether these are substitute habitats after anthropogenic destruction of many natural habitats, for instance after river regulation, or whether

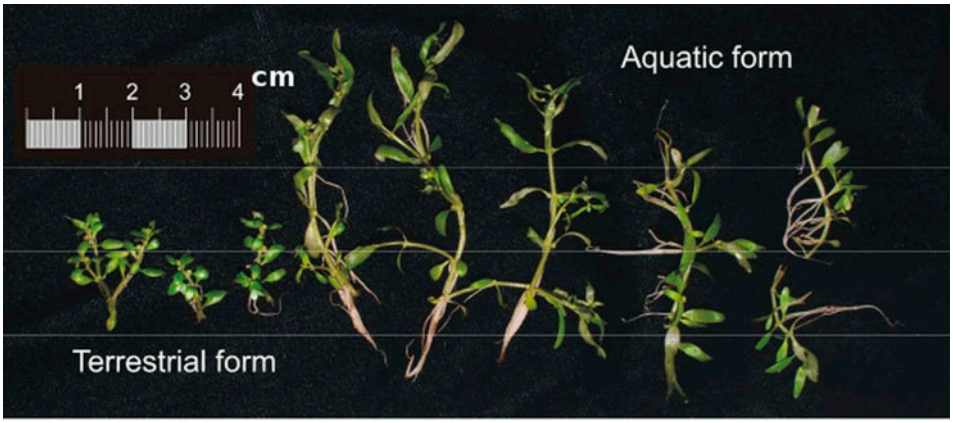

Figure 6. Morphology of terrestrial and aquatic modifications of *Elatine triandra*.

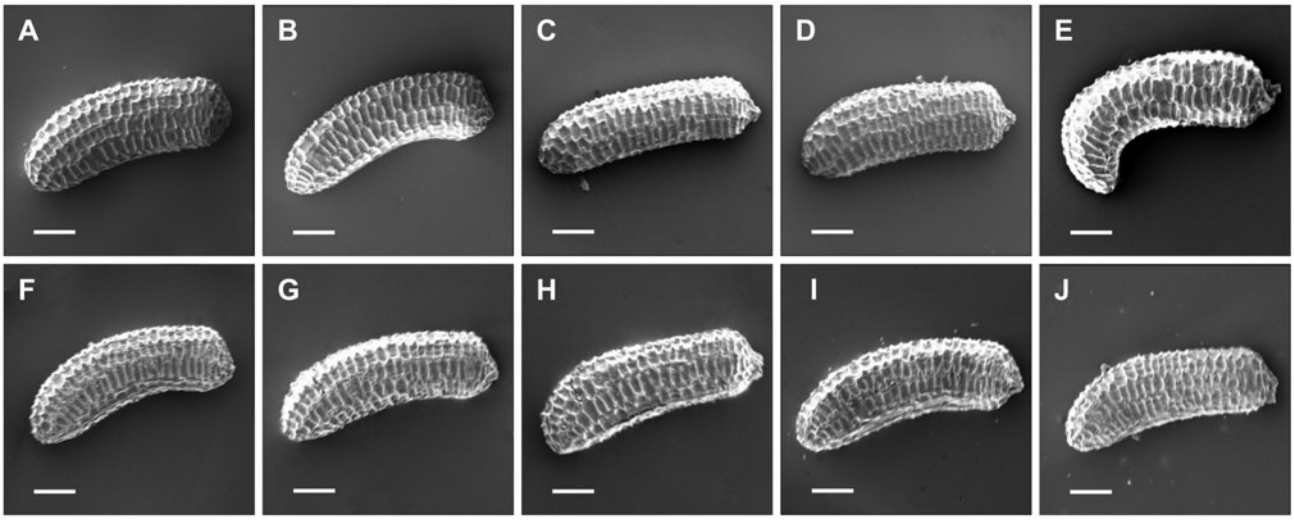

Figure 7. The diversity of seeds of *Elatine triandra*. Scale bars represent 0.1 mm.

Table 4. Synoptic table of the vegetation groups (1–11) of the Isoëto-Nanojuncetea class characterized by the presence of *Elatine triandra* with high degrees of constancy (III, IV, V) in the area of Central Europe (the table contains species reaching more than 20% of the presence only).

	1	2	3	4	5	6	7	8	9	10	11
Country	PL	PL	PL	GER	GER	CZ, SLO	HUN	HUN	HUN	HUN	IT
No. of relevés	6	12	11	15	13	356	14	7	93	34	45
Ch. *Isoëto-Nano-Juncetea*											
Elatine triandra	V	V	V	V	III	III	V	V	V	V	IV
Eleocharis acicularis	V	IV	V	V	V	II	IV	–	V	I	III
Lythrum portula	II	II	I	V	II	III	II	–	IV	III	–
Filaginella uliginosa	II	I	III	V	V	IV	–	–	–	I	III
Juncus bufonius	I	–	I	V	III	IV	–	–	II	II	–
Cyperus fuscus L.	V	–	–	–	V	I	I	–	IV	I	III
Limosella aquatica L.	V	III	–	–	–	IV	III	V	IV	II	–
Eleocharis ovata	V	–	IV	V	IV	IV	–	–	–	I	–
Lindernia procumbens	I	–	–	–	–	–	V	V	IV	IV	I
Carex bohemica	III	–	II	V	V	V	–	–	–	–	–
Elatine hydropiper	–	I	II	–	–	II	–	–	–	I	–
Elatine hexandra	–	IV	V	IV	IV	–	–	–	–	–	–
Lythrum hyssopifolia L.	–	–	I	–	–	I	I	–	III		–
Plantago major L. subsp. *intermedia*	–	–	–	V	V	I	–	–	–	–	–
Juncus tenageia L. f.	–	–	–	–	–	I	–	–	II	I	–
Elatine alsinastrum	–	–	–	II	III	–	V	II	–	II	–
Elatine hungarica	–	–	–	–	–	–	V	–	III	III	–
Cyperus flavescens L.	–	–	–	–	–	–	–	–	–	I	II
Lindernia dubia (L.) Pennell	–	–	–	–	–	–	–	–	–	I	V
Crassula aquatica (L.) Schönland	II	–	–	–	–	I	–	–	–	–	–
Gypsophila muralis L.	–	–	–	–	–	I	–	–	III		–
Coleanthus subtilis (Tratt.) Seidlitz	–	–	–	–	–	III	–	–	–	–	–
Elatine campylosperma Seub.								V			
Gnaphalium luteo-album L.	–	–	–	–	–	–	–	–	I		–
Scirpus setaceus L.	–	–	–	–	–	I	–	–	–	–	–
Other species											
Alisma plantago-aquatica L.	IV	III	II	–	IV	II	I	IV	III	I	IV
Bidens tripartita L.	I	I	I	III	I	I	–	–	II	I	II
Ranunculus sceleratus L.	I	I	I	–	–	III	II	–	I	I	–
Echinochloa crus-galli (L.) P.Beauv.	II	–	I	–	–	I	–	I	IV	III	V
Alisma lanceolatum With.	–	I	–	–	–	I	III	III	IV	II	III
Lemna minor L.	I	I	–	–	–	–	II	IV	II	II	III
Juncus articulatus L.	V	I	II	III	–	II	–	–	–	I	–
Scirpus maritimus L. subsp. *maritimus*	III	I	–	–	–	I	–	–	II	II	II
Plantago major L. subsp. *major*	–	–	–	–	–	I	I	–	III	II	I
Rorippa palustris (L.) Besser	V	I	–	–	III	IV	–	–	–	I	–
Alisma gramineum Lej.	I	–	–	–	–	I	III	IV	IV	II	–
Alopecurus aequalis Sobol.	I	–	I	V	–	V	–	–	–	II	–
Polygonum amphibium L.	–	–	III	II	III	I	–	–	–	II	–
Spirodela polyrhiza (L.) Schleid.	I	I	–	–	–	–	II	–	II	I	III
Eleocharis palustris aggr.	III	–	–	–	–	I	III	–	II	III	–
Juncus bulbosus L.	I	I	III	V	V	–	–	–	–	–	–
Alopecurus geniculatus L.	III	I	–	–	–	I	–	–	II	–	–
Epilobium tetragonum L.	I	I	–	–	–	I	–	–	–	I	–
Lycopus europaeus L.	II	–	I	–	–	I	–	–	–	I	–
Typha angustifolia L.	IV	I	–	–	–	–	–	–	V	II	–
Polygonum hydropiper L.	III	II	–	–	–	II	–	–	–	I	–
Polygonum lapathifolium L.	III	I	–	–	–	IV	–	–	–	I	–
Rorippa sylvestris (L.) Besser	–	–	–	–	–	–	II	–	IV	II	III
Bidens cernua L.	II	–	III	V	IV	–	–	–	–	–	II
Bidens frondosa L.	I	–	I	–	–	I	–	–	–	I	–
(Chara) div.	–	–	–	–	–	–	III	–	IV	I	II
Najas minor All.	–	–	–	–	–	–	I	IV–	I	I	IV
Phragmites australis (Cav.) Trin. ex Steud.	I	I	–	–	–	–	–	–	III	I	–
Callitriche palustris L.	–	III	–	–	–	IV	–	–	–	I	–
Lythrum salicaria L.	–	I	–	–	–	II	–	–	–	II	–
Matricaria perforata Mérat	–	I	–	–	–	I	–	–	–	I	–

(*Continued*)

Table 4. (*Continued*).

	1	2	3	4	5	6	7	8	9	10	11
Polygonum aviculare L.	–	–	–	–	–	I	–	–	II	II	–
Polygonum minus Huds.	–	I	–	–	–	I	–	–	–	I	–
Potentilla supina L.	–	–	–	–	–	I	–	–	I	I	–
Ranunculus flammula L.	II	II	–	–	–	I	–	–	–	–	–
Rumex maritimus L.	III	I	–	–	–	IV	–	–	–	–	–
Veronica anagallis-aquatica L.	I	I	–	–	–	I	–	–	–	–	–
Leersia oryzoides (L.) Sw.	II	–	–	–	III	I	–	–	–	–	–
Lemna trisulca L.	–	–	–	–	–	–	II	–	II		III
Salvinia natans (L.) All.	–	–	–	–	–	–	III	–	II		II
Utricularia vulgaris L.	–	–	–	–	–	–	I	–	III		III
Bidens radiata Thuill.	II	–	I	–	–	IV	–	–	–	–	–
Butomus umbellatus L.	–	–		–	–	–	–	–	III	I	II
Cyperus glomeratus L.	–	–		–	–	–	–	–	II	I	II
Mentha pulegium L.	–	–		–	–	–	–	–	III	I	II
Myosotis scorpioides L.	II	I		–	II	–	–	–	–	–	–
Schoenoplectus lacustris (L.) Palla	I	–		–	–	–	–	–	III	I	–
Schoenoplectus supinus (L.) Palla	–	–		–	–	–	II	–	V	III	–
Typha latifolia L.	–	I		–	–	–	–	–	II	III	–
Polygonum persicaria L.	–	–	–	–	–	I	–	–	–	I	–
Pulicaria vulgaris Gaertn.	–	–	–	–	–	I	–	–	–	I	–
Elymus repens (L.) Gould	–	–	–	–	–	I	–	–	–	I	–
Veronica scutellata L.	–	–	–	IV	–	I	–	–	–	–	–
Juncus compressus Jacq.	–	–		–	–	I	–	–	–	I	–
Lysimachia nummularia L.	–	–		–	–	I	–	–	–	I	–
Marsilea quadrifolia L.	–	–		–	–	–	–	–	IV		II
Poa annua L.	–	–		–	–	I	–	–	–	I	–
Ranunculus aquatilis L.	–	–		–	–	I	–	–	–	I	–
Taraxacum officinale agg.	–	–		–	–	I	–	–	–	I	–
Botrydium granulatum (Linnaeus) Greville	–	–		V	V	–	–	–	–	–	–
Callitriche stagnalis Scop.	–	–		III	I	–	–	–	–	–	–
Ceratophyllum demersum L.	–	I		–	–	–	–	–	–	I	–
Cirsium arvense (L.) Scop.	I	–		–	–	–	–	–	–	I	–
Drepanocladus aduncus (Hedw.) supprimer le	III	I		–	–	–	–	–	–	–	–
Trifolium repens L.	–	–	–	–	–	I	–	–	–	I	–
Glyceria maxima (Hartm.) Holmb.	III	–		–	–	I	–	–	–	–	–
Poa pratensis L.	–	–		–	–	I	–	–	–	I	–
Riccia glauca L.	I	–		–	III	–	–	–	–	–	–
Riccia huebeneriana Lindenb.	–	I		–	–	I	–	–	–	–	–
Scirpus mucronatus L.	–	–		–	–	–	–	–	–	II	II
Sparganium erectum L	II	–		–	–	–	–	–	–	I	–
Xanthium strumarium L.	–	–		–	–	–	–	–	I	I	–

Explanations: 1 – *Polygono-Eleocharetum ovatae* (Nowak and Nowak 2007; Popiela 1996, unpubl. relevés accessible in Polish Vegetation Database (Kącki & Śliwiński 2012). 2 – Community with *Elatine hexandra* (Nowak and Nowak 2007; Popiela 1996, unpubl. relevés accessible Polish Vegetation Database (Kącki & Śliwiński 2012). 3 – Community with *Elatine triandra* (Popiela, unpubl, 2005, 2007, 2014). 4 – *Eleocharito-Caricetum cyperoides* (Pietsch 1963, tab. 2). 5 – *Eleochrito-Caricetum* (Pietsch 1963, tab. 6). 6 – *Polygono-Eleocharitetum ovatae* (Šumberová & Hrivnák. 2013). 7 – *Elatini-Lindernietum pyxidariae* (Ubrizsy, 1948, 1961 after Pietsch 1973a/ tab.1/2). 8 – Drepanocladetum kneiffii (Ubrizsy 1961 after Pietsch 1973a/ tab.1/3). 9 –Eleocharito (acicularis)- Schoenoplecteum supini (Ubrizsy, 1961 after Pietsch 1973a/ tab.1/4). 10 – Molnar & Pfeiffer, unpublished 1999. 11 – *Elatini (triandrae)-Lindernietum dubiae* (Pignatti 1957, after Pietsch 1973b/ tab.3).
Abreviations: POL, Poland; GER, Germany; CZ, the Czech Republic; SLO, Slovakia; HUN, Hungary; IT, Italy.

the formation of new habitats has expanded the range anthropogenically.

The high variability of plant size, leaf shape and size as well as the length of internodes and pedicels (Mason 1956) are a characteristic feature of *E. triandra* and other *Elatine* species with trimerous flowers showing haplostemony [e.g. *Elatine ambigua* Wight, *Elatine gracilis* Mason, *Elatine gratioloides* Cunn, *Elatine oryzetorum* Kom., *Elatine brachysperma* Gray, *Elatine fassetiana* Steyermark, *Elatine ecuadorensis* Molau, *Elatine lorenziana* Hunz., *E. paramoana* Schmidt-Mumm and Bernal, *Elatine peruviana* Baehni and J.F. Macbr. and *Elatine americana* Pursh (Arn.)], (Walters 1969; Brinkkemper et al. 2008; Uotila 2009, 2010; Molnár et al. 2013). According to our herbarium studies (made in the Kew Herbarium by the first author) the accuracy of identification of these species is low. It is possible that these taxa represent different morphs within the species *E. triandra*, and so may be synonyms. Conversely, *E. triandra* s.s. may not be widespread. Tall plants with long internodes occurring in northern Europe have been distinguished as *E. callitrichoides* (Uotila 2010). In our opinion, a final decision about taxonomic problems of this taxon as well as other taxa from the section *Crypta* will

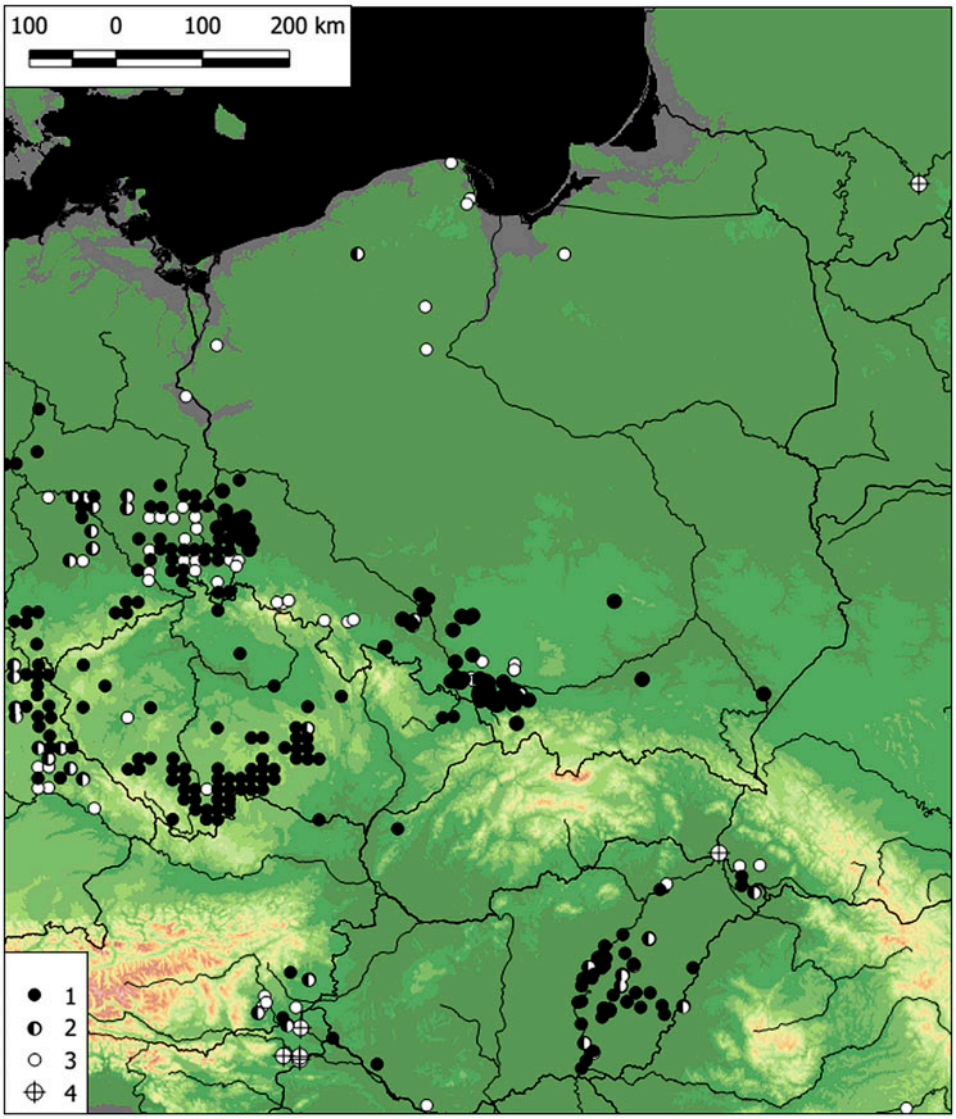

Figure 8. The diversity of *Elatine triandra* recording over time in Central Europe. 1, after 1990 (in Germany 1980), 2, in the years 1945–1990 (in Germany 1945–1980); 3, before 1945; 4, date unknown. Younger value covers the older one.

Table 5. Red list categories of *Elatine triandra* (IUCN, national in Central Europe).

Data source	Category
European Red List of Vascular Plants (Bilz et al. 2011)	LC
IUCN 2014	LC
Czech Republic (Grulich 2012)	EN
Germany (Ludwig and Schnittler 1996)	VU
Hungary (Király 2007)	NT
Poland (Kaźmierczakowa et al. 2014)	VU
Slovakia (Maglocký and Feráková 1993)	EX?
The Kaliningrad Region (Dedkov and Grisanov 2010)	EX

Abbreviations: EN, endangered; LC, least concern; NT, near threatened; EX, extinct; VU, vulnerable.

require collection of plants throughout the world and use of molecular methods.

In terms of the phenology of *E. triandra*, we detected a historical decrease in the first observation of the year since 1828. It is difficult to establish reasons for this pattern. The observed shift in the appearance of *E. triandra* is thought to have been caused by changes in precipitation patterns; however, this could not be confirmed from the environmental data set. The shifts may also have been caused by global climate warming and the

related acceleration of the growing season, or they may simply be an artefact resulting from collection activity.

Our studies confirm that the best features for identification of *E. triandra*, in addition to flower construction, are the size, shape and surface structure of seeds. Vegetative characters such as the lengths of the stem, internodes, lamina and petioles are variable and depend on water level. The vegetative values obtained in our experiment deviate from the measures from North Europe (Uotila 2010), namely flooded plants are smaller. This can be explained by the fact that under natural conditions in the field the size of the plant depends on environmental factors, most probably on the fertility of the waters.

Elatine triandra can be found on recently exposed soil in dried-out fishing ponds and on river banks and gently sloping shores of water bodies, as well as in rice paddies. It appears mainly in patches of *Polygono–Eleocharitetum ovatae* of the *Eleocharition ovatae* alliance (e.g. Moor 1937; Brullo and Minissale 1998; Šumberová 2011; Šumberová and Hrivnák 2013; Kącki, Czarniecka, and Swacha 2013), *Oryzo–Cyperetum difformis* (Pignatti 1957) and *Eleocharito acicularis–Schoenoplectetum supini* (Pietsch 1973b; Brullo and Minissale 1998) associations. In Hungary, the species was identified as an indicator species of rice paddy fields, and it also occurs in continental temporary ponds, mostly in inundated agricultural fields (Lukács, Sramkó and Molnár 2013). In the Scandinavian Peninsula, the species is mainly found in mesotrophic and eutrophic lakes, rivers and ponds (Murphy 2002; Uotila 2010). Our studies show that, in Central Europe, *E. triandra* occurs exclusively in communities classified as *Isoëto-Nano-Juncetea,* and is accompanied by 24 character taxa of the class.

As with other ephemeral vegetation, patches with *E. triandra* develop in different ways depending on the local habitat conditions and dynamic stage. These patches are developed most often on anthropogenic sites at the bottoms and edges of fish ponds and, in the southern part of the area studied, in rice paddies. *Elatine triandra* occurs in these patches, usually as the terrestrial morph.

Our research has also shown that at present in Central Europe populations of *E. triandra* are best preserved in western and southern Poland, in southeast Germany, the Czech Republic and eastern Hungary, and are under adequate protective status in these areas. Single isolated populations deserve special attention, because they may be the first to disappear.

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