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Remote locality of the littoral *Carex extensa* (Cyperaceae) in Hungary – long distance dispersal from coastal to inland salt marshes

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Abstract: A remarkable population of *Carex extensa* (Cyperaceae) was found south of Lake Fertő (Neusiedler See) in Hungary in 2012. This species typically occurs in coastal salt marshes in Europe and was hitherto unknown from the Pannonian Basin. The locality is situated in a territory which has been embanked in 1911. Keeping also in mind that the vegetation developed here from reed beds to saline habitats, we conclude that *C. extensa* reached the salt marshes of the area through long distance dispersal by water birds from the European coast in the last century. Nevertheless, several other maritime littoral species grow in the region, and the possibility that there is a hidden population of *C. extensa* at another site(s) nearby cannot be excluded. Lake Fertő is often described as the "westernmost steppe lake" and supports one of the richest European inland littoral floras. Although it appears likely that *C. extensa* has only recently colonised the site, we consider this discovery to be of significant biogeographical importance.

Key words: *Juncion maritimi*; biogeography; drainage; landscape history; long distance dispersal; salt marshes

Introduction

A new unexpected occurrence of the sedge *Carex extensa* (Fig. 1), which is typical of littoral salt marshes, was found on the Hungarian side of Lake Fertő (Neusiedler See) in May 2012. This species has never been reported from the Pannonian Basin; the locality at Lake Fertő is therefore the most remote inland outpost from its coastal range in Europe (Fig. 2).

From the perspective of biogeography and nature conservation, saline habitats such as salt steppes, pioneer swards, meadows, marshes and associated habitats are amongst the most important biotopes of the Pannonian Basin (Molnár & Borhidi 2003; Bölöni et al. 2011). Contrary to the species composition of the Great Plain ('Alföld' in Hungarian, with a geographical centre located east of the Danube) which more closely resembles that of eastern regions such as the steppes of Romania and the Ukraine, saline habitats to the west of the Danube (mainly in the areas surrounding Lake Balaton and Lake Fertő) have stronger affinities with southern and western European coastal vegetation (Soó 1964; Pócs 1981). Based on its flora and vegetation, Lake Fertő is often referred to as the "westernmost steppe lake in Europe" (Wendelberger 1943; Soó 1964; Csapody 1975).

In this paper we describe the details of the remarkable discovery, considering pedology, coenology and the landscape history of the locality. We also explain the possible circumstances of the introduction of the species to the area, arguing for a role of long distance dispersal.

Material and methods

Fieldwork was carried out between May and July 2012. Identification of the Hungarian specimens of *Carex extensa* was confirmed using descriptions of Stace (1997) and Jäger & Werner (2002). Geo-coordinates were determined by Trimble Nomad handheld GPS in WGS 84 projection. *Carex* material in the following herbaria was reviewed to locate previous overlooked records of the species from the Pannonian Basin (acronyms follow Thiers 2012): BP, DE, BPU, SAMU, JPU and W.

The phytosociological relevés were sampled using the Zürich-Montpellier approach employing the adapted nine-grade Braun-Blanquet scale (Barkman et al. 1964). All

Fig. 1. Fruiting inflorescence of *Carex extensa*; Hungary, near Fertőszéplak (13th June 2012), photo by G. Király.

relevés were stored in the TURBOVEG database (Hennekens & Schaminée 2001). Names of syntaxa follow Molnár & Borhidi (2003). The names of communities that are not mentioned in that work are presented here with the name(s) of the author(s) of the description. Nomenclature of flowering plants follows Király (2009) which was also used to identify associated plant species. The phytogeographical classification of NW Hungary is considered in accordance with the works of Soó (1964) and Király & Király (2008) as basis.

For the measurement of soil parameters we collected two soil samples near selected *C. extensa*-specimens from a root depth of 5-10 cm (sample coordinates: N 47°39′06″; E 16°48′18″ and N 47°39′22″; E 16°48′07″). The samples were analysed according to the Hungarian standards (Szabolcs 1966b). The following parameters were measured: acidity (pH_{H2O}, pH_{KCl}), calcium-carbonate content, total salt content, particle size distribution.

Results

Taxonomical status and morphological characteristics
Carex extensa Gooden. is a member of Genus *Carex* Section *Spirostachyae* (Drejer) Bailey, of which 4 species (*C. distans* L., *C. extensa, C. laevigata* Sm. and *C. punctata* Gaud.) occur in central Europe (Hultén & Fries 1986; Egorova 1999; Luceño & Escudero 2008). Our species of interest was included in a Europe-wide phylogeographic study (Escudero et al. 2010), which

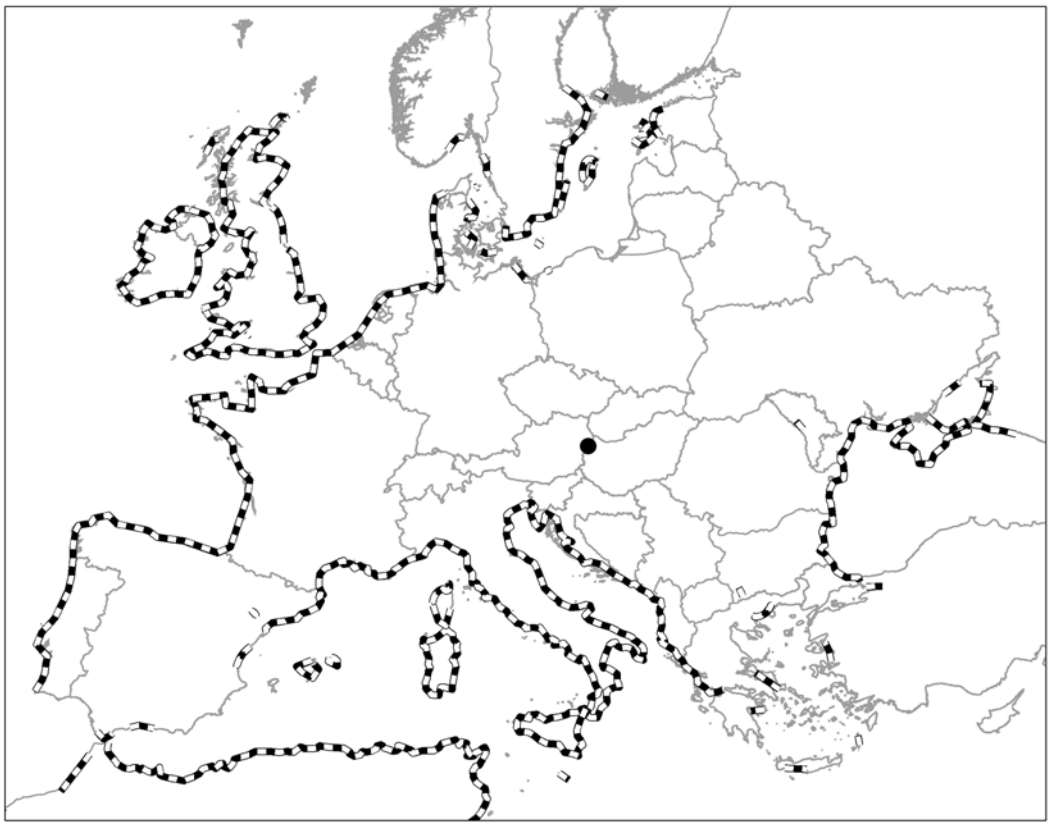

Fig. 2. The European distribution of *Carex extensa* (after Meusel et al. 1965; Hultén & Fries 1986, modified). The new inland locality is marked with a black dot.

identified two main lineages throughout its European range.

C. extensa is densely tufted, with stems to 30(–45) cm high with rounded angles. Female spikes oblong-ovate, 3–5 in an inflorescence, with at least 1–2 spikes set close to the terminal (male) spike; glumes acuminate. Utricles greyish-green, slightly angular, 3–4 mm long with a beak 0.5–1 mm long. The species is easily distinguished from *C. distans* and *C. punctata* by its patent to reflected leaf-like bracts which are longer than the inflorescence (Fig. 1), and by the bluish- or greyish-green leaves usually with enrolled margins. It differs from taxa of the *C. flava* group (Section *Ceratocystis* Dumort.) which have yellowish-green leaves; globular or short cylindrical female spikes with blunt glumes, and yellowish- or olive-green utricles (Stace 1997; Egorova 1999; Jäger & Werner 2002).

Distribution

Carex extensa occurs along the European coast from the Baltic Sea via the Atlantic coast and the Mediterranean Basin to the Black Sea, with a few occurrences in the Azores and Madeira, and also on the Caspian Sea in the East (Fig. 2). The species is considered to be introduced along the eastern coasts of the USA and South America; the origins of South African (Natal) populations is unclear (Meusel et al. 1965; Hultén & Fries 1986; Egorova 1999; Escudero et al. 2010). In central Europe it is rare on the coast of the Baltic, scattered in Estonia (Kukk & Kull 2005) and in Germany (Haeupler & Schoenfelder 1989; Benkert et al. 1996). Although it was reported to be extinct in Poland (Sobisz & Truchan 2009), it was subsequently rediscovered (Bosiacka & Więcław 2012). The species is known from numerous localities along the Adriatic coast from Italy (Pignatti 1982), Slovenia (Martinčič 2007), Croatia (Domac 2002; Pandža et al. 2007), Montenegro (Pulević 2005) and Albania (Vangjeli et al. 2000). Although the distribution of *C. extensa* is largely dictated by particular soil and habitat conditions, it was classified as an "advancing species" on European coasts in a conservation assessment (van der Maarel & van der Maarel-Versluys 1996). The occurrence of the species has not previously been published from Austria (Fischer et al. 2008) or from Hungary (Soó 1973; Lájer 2009). During a revision of *Carex* material in six important herbaria in Austria and Hungary no collections of *C. extensa* were found from either country.

Description of the Hungarian locality

The new locality of *Carex extensa* lies near the Hungarian-Austrian border to the south of Lake Fertő ('Neusiedler See' in German) in Hungary; in the vicinity of Fertőszéplak village, more precisely in the territory called 'Körgát' at an elevation of 112–113 meters above sea level. The area is located within grid square 8,366.2 of the Central European Flora Mapping Project (Niklfeld 1971), and as a part of the Lesser Plain ('Kisalföld') it belongs to the 'Fertő Basin' vegetation-based landscape region (Molnár et al. 2008), while phytogeographically it is placed in the Arrabonicum district of the Greater Plain (Eupannonicum) region (Soó 1964; Király & Király 2008). The population of *C. extensa* comprises >10 thousand individuals scattered over an area of 600 × 500 m (about 30 hectares). The geo-coordinates of the approximate centre of population are N 47°39′17″ and E 16°48′21″. Voucher specimens collected at the locality were deposited in BP, NI and W.

PH measurements show that the soil of the locality of *C. extensa* is slightly alkaline (pH 8.0 and 8.2). Demonstrable water soluble total salt content and significant (36 and 49%) calcium-carbonate content were found in both soil samples. The soil texture based on the fine particle fraction (59 and 71%) is clayey loam or clay. These soils have low water-absorbance capacity, but hold water well; they likely developed as sediment on the lake bed (Szabolcs & Ábrahám 1957), the significant rate of salination is due to a lack of regular flooding combined with the high water table in the region (Stefanovits et al. 1999). Similar soda-rich soils are known on the Danube-Tisza Interfluve in Hungary and in the Seewinkel in Austria (Szabolcs 1966a, Szendrei et al. 2006).

Ecology and phytosociology

Carex extensa is known as an oligohalophilous species (Nygaard & Lawesson 1998) with broad coeno-ecological preferences, since it is not restricted to a single type within the salt marsh vegetation (Adam 1977; Pandža et al. 2007).

The species was found at Lake Fertő in vegetation stands described in the relevés below (1, 2; both sampled by D. Dítě, P. Eliáš jun., Z. Melečková & G. Király):

Relevé 1, June 5, 2012, Lake Fertő, Fertőszéplak, 'Körgát' (N 47°39′05.3″; E 16°48′19.2″), salt-marsh, sampled area 16 m^2, 112 m a.s.l., E_0: 0%, E_1: 40%:

E_1: *Juncus maritimus* 2a, *Scorzonera parviflora* 2a, *Triglochin maritima* 2a, *Aster tripolium* 1, *Carex distans* 1, *Puccinellia limosa* 1, *Agrostis stolonifera* +, *Carex extensa* +, *Juncus compressus* +, *J. gerardii* +, *Lotus tenuis* +, *Phragmites australis* +, *Podospermum canum* +, *Salicornia prostrata* +.

Relevé 2, next to the previous (N 47°39′07.1″; E 16°48′ 18.4″), sampled area 16 m^2, E_0: 0%, E_1: 40%:

E_1: *Carex extensa* 2a, *Juncus maritimus* 2a, *Scorzonera parviflora* 2a, *Carex distans* 1, *Phragmites australis* 1, *Triglochin maritima* 1, *Agrostis stolonifera* +, *Aster tripolium* +, *Schoenus nigricans* +.

Two species typical of inland saline habitats in Europe; *Cladium mariscus* and *Taraxacum bessarabicum* occurred sporadically in the vegetation outside of the relevés. The species composition suggests that stands with *C. extensa* represent vegetation that is closer to coastal salt marshes than to the vegetation of salt-affected soils known from the Pannonian Basin. The vegetation is related to stands of salt marshes in the Croatian island of Pag (see relevé 3 for comparison).

Relevé 3, April 29, 2012, Pag Island, Malo Blato

(44°21′59.8″; 15°06′54.3″), salt marsh, sampled area 16 m^2, 1 m a.s.l., E_0: 0%, E_1: 60% (sampled by D. Dítě, P. Eliáš jun. & Z. Melečková):
E_1: *Scorzonera parviflora* 3, *Juncus maritimus* 2a, *Carex extensa* 1, *Cynodon dactylon* 1, *Agrostis stolonifera* +, *Carex distans* +, *Elymus repens* +, *Puccinellia festuciformis* +, *Schoenus nigricans* +.

This vegetation type was described by Horvatić (1934) as *Junceto-Scorzonero Candollei*. The author included it in the alliance *Juncion maritimi* Br.-Bl. 1930, which is considered typical of European coastal marshes (Bardat et al. 2004; Sanda et al. 2008; Šilc & Čarni 2012). On the other hand, Wendelberger (1943, 1950) characterized in detail the association *Scorzonero parviflorae-Juncetum gerardii* (Wenzl 1934) Wendelberger 1943 from the Austrian shore of Lake Fertő, which he included in the alliance *Scorzonero-Juncion gerardii* (Wendelberger 1943) Vicherek 1973, class *Puccinellio-Salicornietea* Ţopa 1939. This vegetation represents communities of continental salt marshes. Wendelberger (1943) also mentioned the presence of other sub-halophytes (*Potentilla anserina*, *Trifolium fragiferum*) or species not requiring higher salt content in the soil (*Eleocharis palustris*, *Juncus articulatus*, *Ranunculus repens*). The stands recorded by Wendelberger (l. c.) were relatively species-rich including approximately 15 species per relevé, but the author did not mention *Juncus maritimus*. In contrast, Wendelberger (1950) referred to the association *Juncetum maritimi balatonicum* Soó (1930) 1940 (alliance *Juncion maritimi* Br.-Bl. 1931) from Lake Fertő. This vegetation is extremely species-poor (two species per relevé), with *Juncus maritimus* dominant (> 75%), accompanied by *Schoenoplectus americanus*.

The relevés with *C. extensa* from Hungary are composed of species typical of *Junco maritimi-Caricetum extensae* (Gorill. 1953) Parriand 1975 ass., which has been published by Dubyna et al. (2007) from the Ukrainian Black Sea coast and has been included in the alliance *Juncion maritimi* Br.-Bl. ex Horvatić 1934, where *C. extensa* is one of the diagnostic species. Compared to the Ukrainian vegetation, the stand from Hungary is, however, more species-poor, and all species of the Asian salt-marshes (e.g. *Apera maritima, Lactuca tatarica*) are lacking. Eliáš jr. et al. (2013) also found *C. extensa* as an element of the most extreme salt-rich marshes of the Bulgarian Black Sea coast which they placed in the alliance *Salicornion fruticosae* Br.-Bl. 1933, class *Thero-Suaedetalia* Br.-Bl. et O. de Bolòs 1958. This species occurred in less than 1% of relevés. Lausi & Feoli (1979) found that communities in the Mediterranean area with a high frequency of *C. extensa*, *Agrostis stolonifera*, *Plantago maritima*, *Juncus gerardii* and *Juncus maritimus* appear to be distinct from other Mediterranean habitat types and are closer to continental stands dominated by *Agrostis stolonifera* and *Juncus gerardii*, although at a low similarity level. Those types have been assigned to *Juncion maritimi*, and it is likely that the Hungarian stand should also be assigned to this alliance.

As highlighted by the works above, *C. extensa* probably does not have a clear-cut relationship to one particular salt-marsh community. Definitive classification of stands with the species in Hungary will be the aim of future work.

Landscape history
The habitat development of the locality at Lake Fertő is well documented, and correlations between the introduction of *Carex extensa* and the history of the landscape seem to be clear. Hydrological conditions and the area of main vegetation units (especially of reed beds) of Lake Fertő have often been modified by man. Water enters the lake from two rivulets on the western shore; the water level depends mainly on long-term trends in precipitation. The lake dried out completely several times in the last 500 years, and, by contrast there have been frequent floods in the southern part of the Fertő Basin, exacerbated by the prevailing wind from the north. At the beginning of the 1900^s the lake had an open water surface of up to 90%, which has been reduced progressively through conversion to reed beds (Csapody 1975; Pannonhalmi & Sütheő 2007).

To reduce flooding in the south-eastern part of the lake, a dike (the so called 'Körgát') was dug through the reed bed-area in 1911 (Károlyi 1955). The inner part of the reed beds remains intact with a considerable proportion of *Cladium mariscus*, bordered by a narrow belt of *Molinion* and *Agrostion* communities. The outer part ('embankment area') has been transformed dramatically as a consequence of declining ground water level and salt accumulation in the upper horizons of the soil. The effects of these changes were similar of those of the embankments in the Netherlands (Beeftink 1975; Joenje & Verhoeven 1993) and in other Hungarian plain landscapes (Molnár & Borhidi 2003); the transformation of habitats rich in *Schoenus nigricans* at Lake Fertő was described and analysed by Lájer (2006). In the course of secondary succession, the vegetation became closer to that of salt marsh and meadow communities, with pioneer swards on the open soil surfaces (Fig. 3). Before the Second World War, this area was grazed periodically by cattle. After 1945 it became a "closed border area", and the habitats were managed only to serve military purposes. Several military tracks (with infrequently used lanes) crossed the site where *C. extensa* occurs, which constantly maintained bare saline areas. From the 1990s the area has started to be grazed again, the actual (sometimes over-) grazing guarantees optimal conditions for this species (compare also Bakker & Ruyter 1981).

Discussion

Inland observations of *Carex extensa* are very rare in Europe and are mainly restricted to a narrow strip not far from the coasts (see the Netherlands, Stichting Floron 2011; and Great Britain, Preston et al. 2002). As the farthest known inland occurrence, the species was reported from the Struma Valley in southern Bul-

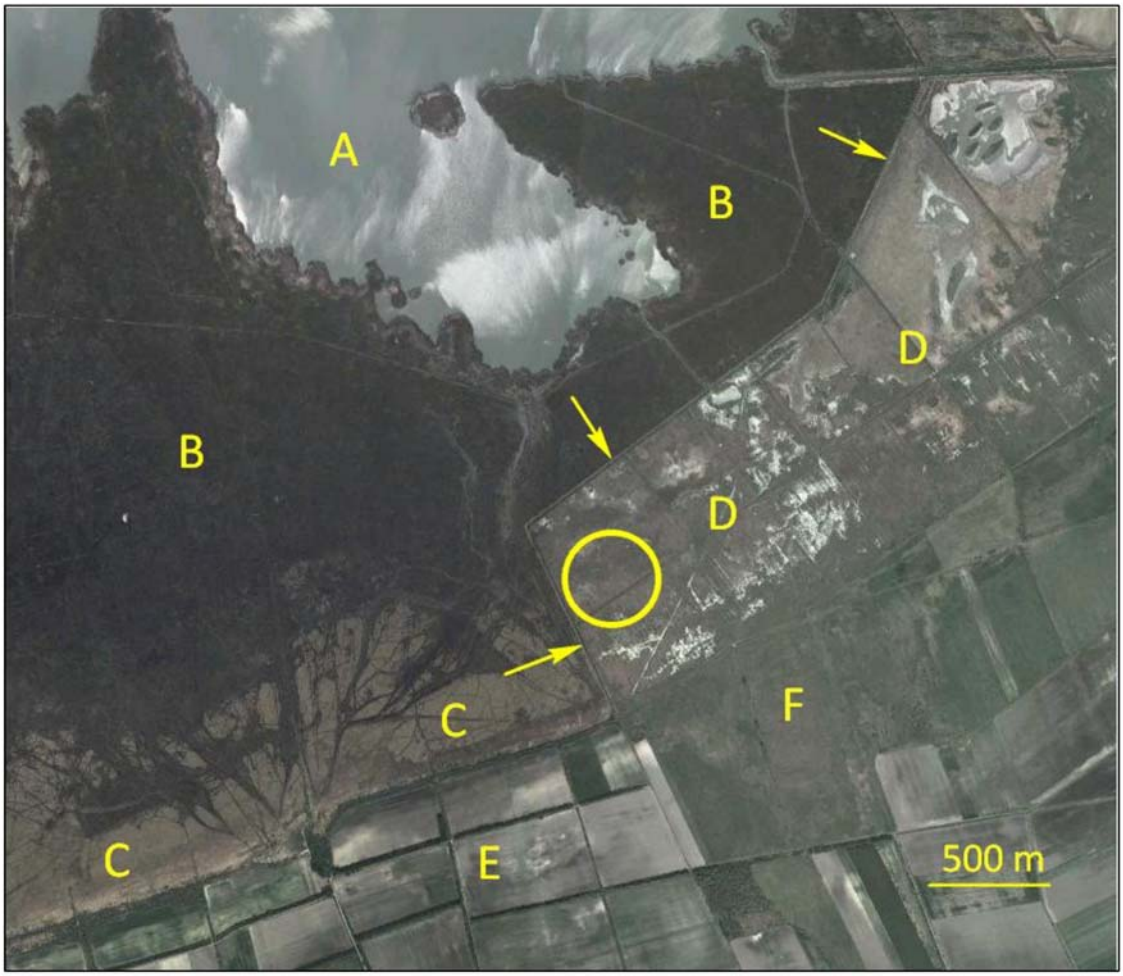

Fig. 3. Map of the locality of *Carex extensa* at Lake Fertő. Main vegetation units: A – Open water surface; B – Reed beds; C – *Cladietum* with fragments of *Molinion* and *Agrostion* communities; D – Embankment area with saline marshes and meadows (white patches represent pioneer swards); E – agricultural land; F – secondary grassland. The approximate locality of the population of *Carex extensa* is marked with a circle. The line of the dike 'Körgát' is shown with arrows.

garia at a distance of 80 km from the Aegean Sea (Dimitrov 2002), and the Prut Valley in Moldova, 200 km from the Black Sea (Aliona 2008). Since both these valleys open toward the sea and are directly connected to coastal saline habitats, their biogeographical position is quite different from those of the Pannonian Basin which is surrounded by high mountains. The nearest occurrences to the locality at Lake Fertő are recorded along the Adriatic (at a distance of 330 km) and the Baltic (750 km) coasts. Remote appearances of anemochorous species with minute propagulus are regularly reported from the Pannonian Basin (see the most recent examples by Molnár et al. 2008; Ekrt & Hrivnák 2010; Molnár et al. 2011), however, similar establishment of zoochorous species is probably more extraordinary.

As for possible explanations of the occurrence of *C. extensa* at Lake Fertő we argue against human introduction (e.g. accidental transference) because of the particularly remote and long-time closed locality. In our view the most likely scenario explaining the presence of the plant is colonisation as consequence of a long distance dispersal event. Lake Fertő is an important waterbird migration stopover site and wintering ground (Scott & Rose 1996; Bauer et al. 2005; Laber & Pellinger 2011; Faragó & Hangya 2012). It seems likely that seed will have been transported to the site by waders or geese from the European coasts, primarily abundant ducks and geese may play a key role in seed dispersal of wetland plants (e.g. Green at al. 2002; Brochet et al. 2009). Additionally, the possibility of epi- and endozoochorous dispersal of *Carex* species by waterfowl was also documented (Mueller & van der Valk 2002).

We cannot yet assess the exact time of introduction to Lake Fertő, but we assume that the species has arrived on the recent locality between 1930 and 1970. A later date is made unlikely by the significant size of the population at 'Körgát'. We cannot exclude the hidden presence of the species at other sites in the region from where it could have colonised the newly made current habitat patch.

Several other littoral species with main range along the Atlantic and/or Mediterranean coasts grow at Lake Fertő, thus arguing for the ability of the region to host such coastal plants. *Linum maritimum* was discovered in 1935 and subsequently at a few sites in the Austrian part of the region (Wendelberger 1957; Kästner

& Fischer 2011). *Juncus maritimus* and *Schoenoplectus litoralis* (both with scattered localities south of the lake and discovered as early as in the 20th century) were formerly presumed to be pre- or interglacial relics (Boros 1937) but were later considered by Soó (1973) to be of postglacial origin. Although none of these species has a consensus time of establishment (i.e. relics or relatively recent introductions), the occurrence of *C. extensa* at this inland site fits well to the list of maritime coastal species at Lake Fertő, and as such is of high biogeographic importance.

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