Spread of invasive macrophytes in Hungary

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Summary
We investigated the spread and distribution of three submerged water macrophytes in Hungary: Elodea canadensis Michx., E. nuttallii (Planch.) St. John and Cabomba caroliniana A. Gray. We used literature and herbarium data as well as records from recent mapping. The spread of Canadian waterweed in Hungary can be divided into four stages: before 1900, between 1901 and 1945, between 1946 and 1990, 1991 onward. After its initial abundant appearance, it disappeared completely from several localities for no obvious reason, while in eastern Hungary this species became established only after 1990. In Hungary, it became settled and locally abundant but remained scattered. Starting from a few isolated centres of spread its range increased concentrically and even in regions with dense water networks the linear spread was not significant. Nuttall’s waterweed was first found in 1991 in the upper reach of the River Danube. In 1992 and 1995 it was collected in the centre of Hungary as well. At present it is spreading in both regions dynamically, and has already become abundant in some parts of the Danube Plain canals south of Budapest. Nuttall’s waterweed spreads much more rapidly than Canadian waterweed and in contrast to that, it can be characterized by linear spread. In contrast to other countries in Europe, a quick displacement of these two species has not been observed in Hungary. The fanwort was earlier known to live freely in Hungary in thermal waters. It was first found in non-thermal water in 1995 in the Danube-Tisza Canal south of Budapest. Although it disappeared from that locality, it had infested altogether approx. 160 km in six canals on the Danube Plain by 2006 and is now spreading downstream rapidly. The disturbance of both species (cutting) and habitat is supposed to play a major role in the dispersal of fanwort. Phenological observations of Cabomba caroliniana are also described. The effect of the presented three invasive macrophytes on the indigenous flora is not unambiguous. The spread of Cabomba caroliniana, a species of tropical-subtropical origin, could be a consequence of global warming.

Key words: Cabomba caroliniana, distribution, Elodea canadensis, Elodea nuttallii, invasive aquatic plants, linear spread, neophytes, phenology

1. Introduction
The flora of a given area is not constant. As a result of environmental changes and human activity, species appear and disappear. Recently, this change of flora has accelerated especially due to human activity. While more and more habitats, together with the species that inhabit them, are lost as a consequence of expanding agricultural and industrial territories, increased human mobility allows other species to overcome barriers and reach new continents (Ashton & Mitchell 1989).

Documentation of the establishment and spreading of neophytes, especially of invasive species, is the first step to take towards their successful control. On the other hand, it also serves as a basis to study the mechanisms of invasion. While the interest of researchers in invasion has increased in the last few decades on an international level, there has been a lack of information on invasive species in

Hungary (Botta-Dukát 2004). This gap has recently been filled with two books on plant invasions in Hungary (Mihály & Botta-Dukát 2004, 2006).

Elodea canadensis Michx. appeared in Europe in the first half of the 19th century; however, the exact date of the first observation is the subject of discussions (Cook & Urmi-König 1985). Several factors led to its establishment in Europe such as introduction with American timber, accidental escape and deliberate introduction by botanists. Its population dynamics, explosive spread and subsequent disappearance are the subject of discussions. Although it became established long ago, its area of distribution is still changing.

Elodea nuttallii (Planch.) St. John was first found in Europe in 1939 and has rapidly spread in western and central Europe during the second half of the 20th century (Cook & Urmi-König 1985). Like E. canadensis, E. nuttallii reproduces only vegetatively. In Great Britain it was first found in 1966 and by 1982 it had occurred already in 40 vice-counties (Simpson 1984), a very good reflection of its spreading speed. Furthermore, it was shown to have replaced previously established species like E. canadensis (Simpson 1984, Barrat-Segretain 2001).

Cabomba caroliniana A. Gray was formerly known in Europe from only a few localities: Austria (Fischer et al. 2005), Great Britain (Stace 1999), Hungary (Felföldy 1990), Romania (Popa 1955) – in all cases, except Great Britain, in thermal waters. Recently it has been found in non-thermal water in Sweden (Jonsell 2001) and Hungary (Köder et al. 1999, Steták 2004).

While both Elodea species are widely studied and well-known (e.g. for phenology see Kunii 1984) as invasive plants, little is known about Cabomba, especially in Europe. A detailed morphological description of the fanwort is given by Ørgaard (1991) and Mackey & Swarbrick (1998).

The aim of our work was (1) to collect the recent Hungarian distribution data of Elodea canadensis Michx., E. nuttallii (Planch.) St. John and Cabomba caroliniana A. Gray., (2) to compare the spread of the two species of Elodea in Hungary and (3) to contribute to knowledge about the spread and phenology of Cabomba caroliniana in central Europe.

2. Materials and methods

To determine the area and the spread of Elodea canadensis, E. nuttallii and Cabomba caroliniana, we gathered data from three sources: Hungarian (1) literature and (2) herbaria and (3) records from recent flora mapping. For the two Elodea species we revised the collection of the following three herbaria: Herbarium Carpato-Pannonicum of the Hungarian Natural History Museum, Budapest (BP), Herbarium of the University Debrecen, Debrecen (DE), Herbarium of Savaria Museum, Szombathely (SZO). We used the unpublished data from the years 2002–2006 from the database of the Hungarian Flora Mapping Programme.

There is no herbarium data for Cabomba caroliniana. The spread of C. caroliniana was mapped in five canals of the Danube Plain in 2000 and 2001: Duna-Tisza Canal, Duna-völgyi Main Canal, Csorna-Foktői Canal, Maloméri Canal, Vajas Canal. From 2002, quantitative changes and spread were monitored yearly on the Csorna-Foktői Canal between Kalocsa and Foktő, where the fanwort was already established, and on the Duna-völgyi Main Canal at the lower end of the fanwort distribution, respectively. The Kohler method (Kohler 1978, Kohler & Janauer 1995) was used for mapping and
monitoring, which was carried out from a boat. By this method, the water bodies are divided into sections and the amount of macrophytes for each species and section is estimated with the help of a simple scale (1: very rare, 2: rare, 3: medium spread, 4: widespread, 5: mass). The phenological studies on fanwort were carried out between 16th March and 26th August 2001. For that purpose, plants were collected from the canals with a long-handled rake in Kalocsa (from the shore) and Dusnok (from the boat). We measured the length of the new main stems, total main stem length and the number of leaf pairs on the main stems.

The grid of the Central European Flora Mapping Programme has been used to provide the results on maps. The size of one grid cell is 3 minutes of latitude by 5 minutes of longitude.

3. Results

*Elodea canadensis*

According to Soó (1973) and Felföldy (1990) Canadian waterweed appeared in Hungary around 1870. This date however refers to a locality (Zlaté Moravce, Aranyosmarót) which today belongs to Slovakia (Moesz 1909), so the first observation within the recent area of Hungary dates back to 1885 in Budapest (Hermann ap. Moesz 1909). Its spread in Hungary can be divided into different stages (Fig. 1). Canadian waterweed became rapidly abundant in a small territory around the capital. Fish transport and deliberate introduction were the first agents of dispersal. At the beginning of the 20th century, two new centres of dispersal arose at the Lake Balaton and around Győr (NW Hungary, Soó 1938).

![Fig. 1: Stages of the spread of Elodea canadensis in Hungary. Empty circles: before 1900, circles with point: between 1901 and 1945, half-filled circles: between 1946 and 1990, filled circles: 1991 onwards.](image-url)
Its range did not increase significantly for quite some time after 1945, only a slow spread in the valley of the River Rába was observed. Moreover, in certain territories, e.g. at Lake Balaton, *E. canadensis* became locally even rare. After 1990 the species became established in eastern Hungary as well, though in some regions (e.g. between the River Danube and the River Tisza) the identity of the populations is not proven due to a lack of herbarium material.

Canadian waterweed grows mainly in oxbow lakes, artificial standing waters and slow-flowing canals. It occurs both in calcareous and acidophilous waters. After an initial abundant appearance it disappeared totally from several localities without any visible reason (e.g. changing environment, nature conservation treatment).

According to our data, *E. canadensis* became settled and locally abundant but remained scattered. Starting from a few isolated centres of spread its range increased concentrically. Even in regions with dense water networks the linear spread (along rivers and canals) was not significant.

**Elodea nuttallii**

In Hungary, Nuttall’s waterweed was first found in 1991 in the upper reach of the River Danube called Szigetköz (Ráth 1992). In 1992 and 1995 it was collected in the centre of Hungary as well, suggesting another centre of spread parallel to the one in northwest Hungary. However, due to the lack of an appropriate Hungarian key for its determination it is most likely that it has been overlooked for a long time. The first steps of spread could therefore be reconstructed only based on existing herbarium material. At present, it is spreading in both regions dynamical-ly and has become abundant in some parts of the Danube Plain canals south of Budapest (Sipos et al. 2003, Fig. 2). During its spread in the Danube Plain canals, Nuttall’s waterweed settles down first in cleaned angling places.

In Hungary, the habitat of Nuttall’s waterweed is similar to that of Canadian waterweed. Flowering is not rare, but only female plants have been reported so far.

**Cabomba caroliniana**

The fanwort is a popular aquatic plant which was known to live freely in Hungary in thermal waters (Felföldy 1990, Szabó 2002). It was first found in non-thermal water in 1995 in the Danube-Tisza Canal south of Budapest. Although it disappeared from that locality, it was already present by 1998 over at least 38 km in three other canals downstream on the Danube Plain (Apaji Canal, Harmincas Canal, Duna-völgyi Main Canal, Köder et al. 1999). By 2006 it had infested altogether approx. 160 km in six canals (Vajas Canal, Csorna-Foktői Canal, Maloméri Canal and the three above mentioned canals, Fig. 3) and between 2001 and 2006 it spread rapidly downstream by approx. 4 km steps per year in the Duna-völgyi Main Canal. It is present in the Duna-völ-
gyi Main Canal between Kunszentmiklós and Sükösd, in the Harmincas and Apaji Canals at Kunszentmiklós, in the Csorna-Foktői Canal between the Duna-völgyi Main Canal and Foktő and in the Vajas Canal between Kalocsa and Dusnok. Although several flowers and some young fruits were also observed, we suppose that it reproduces mainly via rhizome and shoot fragmentation. Cutting back the water vegetation without completely gathering the cut material (a usual management method of canals) promotes its expansion. Fanwort seems to have a two-step dispersal strategy. It often first settles down on cleaned angling places but remains rare for some years, growing suddenly later and expanding quickly.

According to Ørgaard (1991), wintering of fanwort is accomplished chiefly by means of defoliated stem fragments buried in the mud. In Hungary, old stem fragments floating on the water surface and even rooted specimens from the previous year (up to 90 cm long) were found on 16th March. By 25th April, old stem fragments were on the sediment and the lower nodes were defoliated. By mid-May, thin, white, yarn-like additional roots appeared on the lower nodes of the buried old stems. New stems grew both from the apical end and from the other nodes of the old stem. As time passed, more parts of the old stems were progressively buried and became rhizome. By the end of July no more leaves could be found on the old stems (rhizomes), and the length of the rhizome internodes varied between 1.5 and 3 cm, while the length of the internodes of the new stems were 1.5-4.0(-4.6), 2.0-4.5(-5.3) and 2.5-5.5(-7.6) cm on 8th June, 21st June and 21st July, respectively. Fig. 4 shows the length of the new and total main stems and the number of leaf pairs during the growing season in 2001.

Fig. 3: Distribution of *Cabomba caroliniana* in Hungary. Circles with point: thermal water, filled circles: non-thermal water.

Fig. 4: Growth of *Cabomba caroliniana* during the growing season in 2001 a: length of the main stem, b: number of leaf pairs on the main stem. Grey bar: Kalocsa, new stem, grated bar: Kalocsa, whole stem, white bar: Dusnok, new stem, black bar: Dusnok, whole stem (average ± standard deviation).
On 6th August, floating leaves and flower buds were found in Kalocsa. Most of them were still approx. 20 cm under the water surface, but some of them had already emerged. The flowers were totally open only between 11 p.m. and 3 a.m. By 26th August, fanwort became brownish and coated, some fruits were also observed. Young fruits are brownish green and have settled some centimetres under the water surface.

The canals studied have slow-flowing water (under 0.3 m/s, mainly under 0.1 m/s), 8-36 m wide, 120-280 cm deep, and the Secchi-transparency was between 55 and 100 % of the water depth. The canals are β-limnotype, hydrogen carbonate > calcium > magnesium type waters. The fanwort prefers silty sediment but it was found on sandy sediment as well. During the growing season of fanwort in 2001 the temperature of the canals was between 15.7 and 24.8 °C, the pH between 7.43 and 8.05.

4. Discussion

The determination of the Elodea species, and in some cases even their distinction from other genera of Hydrocharitaceae may be problematic. One reason is that in Europe they flower seldom and their vegetative form may look very similar. The lack of good keys for the vegetative parts also contributes to the uncertainty of their determination. With the help of herbarium material it is possible to safely separate the species, but this also means that it is difficult or even impossible to verify earlier (literature) records and to reconstruct the exact spread of these species.

The three investigated species Elodea canadensis, E. nuttallii and Cabomba caroliniana have some common features. They are submerged, perennial, freshwater macrophytes native to America, which over-winter mainly by stem fragments lying on the sediment. Probably most important, however, is their ability to self-propagate vegetatively through stem fragments (Sculthorpe 1967, Mackey & Swarbrick 1998). It ensures their capability of rapid and widespread dispersal, which is an important element of the invasion process (Ashton & Mitchell 1989).

The spread of the two Elodea species in Hungary differs. While E. nuttallii became abundant in the Danube Plain canals within a few years, E. canadensis remained sporadic despite its presence in that region since the first half of the 20th century. Nuttall’s waterweed spreads much more rapidly than Canadian waterweed and in contrast to that, it can be characterized by linear spread. In contrast to other countries in Europe (Simpson 1984, Barrat-Segretain 2001), a quick displacement of these two species has not been observed in Hungary. The reason for this might be the sparse overlap between the distributions of the two species.

The spread of Elodea nuttallii and Cabomba caroliniana shows some similarities as both species spread rapidly along the Danube Plain canals. The disturbance of habitat (cleaning of the angling places) and plant stands (cutting without gathering the cut material) is supposed to play a major role in the dispersal of these species (see also Van der Velde et al. 2002).

Cabomba caroliniana is considered to be a weed of national significance in Australia (Walton 2000), and it is regarded as an invasive macrophyte in Canada (Ontario state) and USA (Washington state). On the other hand, in England (Stace 1999) and Sweden (Karlsson pers. comm.) it has remained rare and it is no longer reported from Austria (Fischer et al. 2005). In Hungary, fanwort is not only spreading quickly in the Danube Plain canals, but it
also has the potential to infest other waters downstream, even beyond the Hungarian border. In 1999, large amounts of cut macrophyte material, mainly *Cabomba caroliniana*, were found drifting on the Danube (Janauer & Steták 2003). According to Sanders (1979), any detached shoot with at least one pair of expanded leaves is capable of growing into a mature plant and stem fragments may survive in water up to 6–8 weeks. Consequently, it can be declared invasive (according to Richardson et al. 2000) in central Europe.

Other established and potentially invasive macrophytes in Hungary include *Azolla filiculoides* L. and *Pistia stratiotes* L. which, together with *Cabomba caroliniana*, are of tropical-subtropical origin. Their establishment and dispersal in non-ther- mal water can possibly be regarded as a consequence of global warming. The effects of the presented macrophytes on the indigenous flora are not unambiguous. In several localities they exist together with sensitive, endangered species. On the other hand, due to environmental changes like water pollution or canalization of rivers, endangered species have already disappeared from some localities even without the presence of any invasive species. Only few cases are known where the disappearance of certain rare macrophytes might have been caused partly by the spread of these invasive species.

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