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Vegetation development in subsurface flow constructed wetlands in the Czech Republic

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ABSTRACT

Wetland macrophytes play many important indirect roles in constructed wetlands with horizontal subsurface flow (HF CWs) including insulation of the bed surface during winter, provision of substrate for attached bacteria in the rhizosphere or oxygen leakage into anoxic rhizosphere. In the Czech Republic, HF CWs are mostly planted with *Phragmites australis* (Common reed) or *Phalaris arundinacea* (Reed canarygrass) or with a combination of these two species. The early systems were planted only with *Phragmites* according to the then available information from abroad. Later, *Phalaris* was used because of easy planting and fast growth. In 2011, macrophyte survey of 55 HF CWs in the Czech Republic was carried out with the aim to identify "weedy" species, i.e., species which were not originally planted. During the survey, 83 macrophyte "weedy" species were recorded with more species being found in the outflow zone (74) as compared to inflow zone (46). However, most species were found only as individual plants in the filtration bed margins with the exception of *Urtica dioica* (Stinging nettle) in the inflow zone and *Epilobium hirsutum* (Hairy willowherb) in the outflow zone of several systems. It has been found that the number of "weedy" species decreases with increasing length of operation. In systems, where "weedy" species overgrew the originally planted species, treatment efficiency was not affected.

1. Introduction

The presence of macrophytes is one of the most conspicuous features of wetlands and their presence distinguishes constructed wetlands from unplanted soil filters or lagoons. The most important roles of macrophytes in constructed wetlands (CWs) with horizontal subsurface flow in cold and temperate climate are: (1) insulation of the bed during winter, (2) provision of substrate (roots and rhizomes) for growth of attached bacteria, (3) oxygen release to otherwise anoxic/anaerobic rhizosphere, (4) nutrient uptake and storage, and (5) release of root exudates with antimicrobial properties (e.g., Seidel, 1976; Brix, 1997; Mander and Jenssen, 2003; Gagnon et al., 2006; Brisson and Chazarenc, 2009; Vymazal, 2007, 2011a).

Constructed wetlands have been used in the Czech Republic since 1989 (Vymazal, 1990). At present, there are about 280 constructed wetlands and all systems have been designed as horizontal sub-surface flow constructed wetlands. Treatment performance of these systems has been reviewed several times in the past (Vymazal, 2002, 2010, 2011b). The early systems in the Czech Republic were planted only with *Phragmites australis* (Cav.) Trin. ex Steud. (Common reed) based on then available literature (Kickuth, 1982; Boon, 1986; Brix, 1987; Cooper, 1990). In few systems also *Typha latifolia* L. (Broadleaf cattail) was added. Since the mid 1990s, *Phalaris arundinacea* L. (Reed canarygrass) has been often used in combination with *P. australis* (Vymazal and Kröpfelová, 2005). Recently, many systems have been planted only with *P. arundinacea*. The major reasons for the use *P. arundinacea* were: (1) excellent germination from the seeds, (2) easy planting, (3) fast growth, creating full cover of the surface during the first growing season if planted in spring, and (4) provision of good insulation during the winter. During the last 10 years, also *Glyceria maxima* (Hartman) Holmberg (Mannagrass) was used for constructed wetlands for similar reasons as *P. arundinacea*, especially for vigorous growth and easy planting.

Since the mid-1990s, most municipal constructed wetlands in the Czech Republic have been planted with a combination of *P. australis* and *P. arundinacea* in bands perpendicular to water flow. This combination turned out to be very suitable from insulation point of view as *P. arundinacea* creates dense aboveground biomass very quickly while *P. australis* growth is slow and does not provide good insulation after the first growing season. In a long-term run,

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P. australis usually outcompetes *P. arundinacea* but this encroachment does not influence the treatment performance of the system (Vymazal and Kröpfelová, 2005).

P. australis and *P. arundinacea*, the most commonly used species in the Czech constructed wetlands, differ in several growth characteristics. *P. arundinacea* usually produces less aboveground biomass than *P. australis*. During the survey in the early 2000s, Vymazal and Kröpfelová (2005) reported maximum *Phragmites* aboveground biomass in 12 CWs between 1652 and 5070 g m^{-2} with an average value of 3266 g m^{-2}. During the same study, the aboveground biomass of *Phalaris* varied between 345 and 1902 g m^{-2} in seven CWs with an average value of 1286 g m^{-2}. The authors also pointed out that the maximum biomass of *P. arundinacea* usually occurs during the second growing season while *P. australis* peak biomass occurs only after 3–5 years. *P. arundinacea* penetrates in natural stands to a depth of about 30–40 cm, allowing for aggressive vegetative spread (Coops et al., 1996; Kätterer and Andrén, 1999) while *P.australis* penetrates to the depths of up to one meter (Vymazal and Kröpfelová, 2008). However, due to abundant nutrients and mostly anaerobic conditions in CWs with horizontal subsurface flow, the belowground biomass of *P. arundinacea* is mostly found only within the depth of 10–20 cm. *P. australis* grows deeper but most of the belowground biomass is found within the top 40–50 cm of the filtration bed (unpublished results). Coops et al. (1996) found out during their experiments that *Phragmites* has much larger gas space in rhizomes (61–67% of the cross sectional area) than *Phalaris* (19–23%). This may suggest better oxygenation of the belowground parts of *Phragmites*, and consequently better conditions for survival under anaerobic conditions.

Both *Phalaris* and *Phragmites* are planted with the density of 4–6 seedlings per square meter. During the years, the preparation of the seedlings has changed substantially. In the 1990s, the seedlings of *Phalaris* were grown from seeds collected either in natural stands or directly in constructed wetlands. *Phragmites* seedlings were pre-grown in nurseries from rhizomes or from plants growing in natural stands. The seedlings were transported in the flower pots and planted with soil. However, this technique including seedling preparation and transportation was found too costly. In addition, the soil from pots became loose after flooding and the soil added to clogging problems. Therefore, in the early 2000s a new technique was developed. The seedlings were prepared from plants growing in natural stands and were transported and planted without soil (Fig. 1A). The examples of *Phalaris* and *Phragmites* two months after planting (Fig. 1B) clearly show the difference between *Phalaris* and *Phragmites* – the former creates much more biomass than the latter.

There are no mandatory design guidelines for vegetation in constructed wetlands in the Czech Republic, and therefore, the vegetation in the constructed wetland is the designer's choice.

In the literature, there is very little information about the presence of "weedy" species in constructed wetlands and the potential effect of "weedy" species on treatment performance of the system. In constructed wetlands, a weed is considered a species which was not intentionally planted and voluntarily occurs in a constructed wetland (and therefore in the text, quotes are used to emphasize a slightly different meaning of this word). The objective of this paper was to evaluate the presence of "weed" species in the Czech constructed wetlands in relation to length of operation of these systems and with respect to originally planted species. Also, the potential influence of "weedy" species on the treatment performance was evaluated based on the available treatment performance information. To the author's knowledge, there have not been any similar studies which would be aimed at the presence of weedy species in constructed wetlands with horizontal subsurface flow and their potential effect on treatment performance.

2. Materials and methods

During the summer of 2011, fifty five constructed wetlands were visited and vegetation survey was performed in all systems (Table 1). The systems were selected with the aim to cover as broad as possible variation in the length of operation and also variation in originally planted species. The data in Table 1 indicate that the length of operation varied between 2 and 21 years and the most common original planting consisted of (1) monoculture of *P. australis*, (2) combination of *P. australis and P. arundinacea* and (3) monoculture of *P. arundinacea*. The list of surveyed constructed wetlands included systems designed for treatment of municipal wastewater (65-800 PE) and one on-site constructed wetland.

At each constructed wetland, all macrophyte species present were recorded in both inflow and outflow zones as it was obvious that the macropyhte composition differs in these two zones. For the purpose of this paper, the "inflow" and "outflow" zones represented a strip 5 m wide and adjacent to either distribution or collection zones. It has been observed that there were no "weedy" species in the middle part of the filtration beds with fully grown original vegetation.

3. Results and discussion

A total number of "weedy" species, i.e., plants which were not intentionally planted, amounted to 83 in 55 surveyed constructed wetlands (Table 2). There was a considerable higher number of species found in the outflow zone (74) as compared to inflow zone (46).

The highest number of "weedy" species in one system was 20 and it was recorded in two systems which have been in operation for 2 and 7 years. The highest number of "weedy" species in the inflow and outflow zones was 10 and 17, respectively.

The "weedy" species found in constructed wetlands may not necessarily be classified as wetland plants (Chytrý, 2011). Besides typical wetland plants also species which prefer or at least tolerate wet soil conditions were frequent. The list of species presented in Table 2 revealed that there were several plants which are considered as terrestrial, e.g., *Carduus acanthoides*, *Arrhenatherum elatius*, *Bromus sterilis* or *Chenopodim album*. Also, most "weedy" species found during the survey in constructed wetlands are indicators of elevated nitrogen in the substrate.

3.1. Weedy species in inflow zones

In the inflow zone, Stinging nettle (*Urtica dioica*) was found in 47 systems (Table 2) and it was by far the most frequent "weedy" species in the inflow zone (85% of all surveyed systems). In addition, *Urtica* was the only species which became a dominant species in several systems (Fig. 2). It has been observed that *Urtica* was present in zones originally planted with *Phragmites* as well as with *Phalaris* but in *Phalaris* stands, *Urtica* exhibited substantially denser growth. The more vigorous growth of *Urtica* was particularly observed in *Phalaris* zones which were not regularly mowed and the *Urtica* belowground organs were mostly found in the decaying litter of *Phalaris* above the filtration bed surface and, hence above the water level. This observation is in accordance with findings of Klimešová and Šrůtek (1995), that *Phalaris* and *Urtica* reacted differently to the lack of oxygen in the soil. While *Urtica* stops growing and starts to decay, *Phalaris* under the anoxic/anaerobic conditions continues to grow. Also, *Urtica* was present only in very low densities in inflow areas where surface ponding occurred. This is in accordance with findings of Klimešová (1994) that *Urtica* does not survive long-term flooding, especially during the spring and summer. Another reason