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MARTIN MADDISON

Dynamics of phytomass production and nutrient standing stock of cattail and its use for environment-friendly construction

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PRESS

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ORIGINAL PUBLICATIONS

The thesis is based on the following papers, which are referred to in the text by Roman numerals. The papers are reprinted with the kind permission of the publishers.

I **Maddison**, **M.**, Soosaar, K., Lõhmus, K. and Mander, Ü. (2005). Cattail Populations in Wastewater Treatment Wetlands in Estonia: Biomass Production, Retention of Nutrients and Heavy Metals in Phytomass. Journal of Environmental Science and Health, Part A – Toxic/Haz. Subst. & Environmental Eng., A, 40(6–7), 1157–1166.

II **Maddison, M.**, Mauring, T., Remm, K., Lesta, M. and Mander, Ü. (2008). Dynamics of *Typha latifolia* L. populations in treatment wetlands in Estonia. Ecol. Eng., doi:10.1016/j.ecoleng.2008.06.003 (Article in press).

III **Maddison**, **M.**, Soosaar, K., Mauring, T. and Mander, Ü. (2008). The biomass and nutrient and heavy metal content of cattails and reeds in wastewater treatment wetlands for the production of construction material in Estonia. Desalination xxx, 1–9 (Article in press).

IV **Maddison, M.**, Mauring, T., Kirsimäe, K. and Mander, Ü. (2008). The humidity buffer capacity of clay-sand plaster filled with phytomass from treatment wetlands. Building and Environment. (Submitted).

The contributions of the authors of the papers were as follows:

	I	**II**	**III**	**IV**
Original idea	ÜM	MM, ÜM	MM, ÜM	MM, ÜM
Study design	MM, ÜM	MM, ÜM	MM, ÜM	MM, ÜM, TM
Data collection	MM, KS	MM	MM, KS	MM
Data analysis	MM, KL, KS,	MM, KR, ML	MM	MM
Manuscript preparation	MM, ÜM, KL, KS	MM, ÜM, TM	MM, ÜM, TM	MM, ÜM, KK, TM

KL – Krista Lõhmus, KK – Kalle Kirsimäe, KR – Kalle Remm, KS – Kaido Soosaar, ML – Merje Lesta, MM – Martin Maddison, TM – Tõnu Mauring, ÜM – Ülo Mander,

ABSTRACT

Cattail and reeds are the most common plants in constructed and semi-natural wetlands for wastewater treatment, and can play an important role in nutrient retention. On the other hand, both plants are highly valued in environmental-friendly construction. In this PhD dissertation, the broadleaved cattail (*Typha latifolia* L.) biomass production and the nitrogen (N) and phosphorus (P) content in phytomass in three treatment wetland systems is evaluated and compared, in order to study the effect of added "fibre-wool" from cattail spadixes and cattail chips in clay-sand plaster on its humidity-exchange capability.

The cattail phytomass measurements were performed in autumn after the vegetation period, i.e. at the end of August and the beginning of September and also the following winter, i.e. at the end of January and the beginning of February, in the years 2002 to 2006. The biomass samples (roots/rhizomes, shoots with leaves and spadixes) and litter were collected from 1m×1m plots – 15 plots in the Tänassilma semi-natural wetland, 15 plots in the Põltsamaa free water surface (FWS) constructed wetland (CW), and 10 plots in the Häädemeeste FWS CW.

The average aboveground biomass of *T. latifolia* varied from 0.37 to 1.76 kg DW m^{-2} in autumn and from 0.33 to 1.38 kg DW m^{-2} in winter. The belowground biomass of the cattail varied from 0.61 to 1.31 kg DW m^{-2}.

The greatest average nitrogen (22.95 g N kg^{-1}) concentration was found in spadixes, and the phosphorus (6.5 g P kg^{-1}) concentration was measured in roots–rhizomes.

The average standing stock of nutrients in Tänassilma, Põltsamaa and Häädemeeste belowground phytomass varied from 11.6 to 19.4 g N m^{-2} and from 1.6 to 4.6 g P m^{-2}, and aboveground from 17.0 to 32.3 g N m^{-2} and from 2.6 to 6.0 g P m^{-2}. The corresponding results in winter were 4.4–7.5 g N m^{-2} and 0.6–1.0 g P m^{-2}.

The quantity of humidity absorption and desorption was measured in a climatic chamber where the humidity of ambient air was suddenly raised from 50% to 80% (absorption) and reduced from 80% to 50% (desorption). Over 12 hours, all of the samples released the same amount of water as they absorbed. The clay-sand plaster samples absorbed more slowly than they desorbed, whereas the gypsum wallboard required significantly more time for desorption. Added phytomass had positive effects by reducing the weight of the clay-sand plaster, accelerating and increasing humidity absorption.

1. INTRODUCTION

Wetlands are areas where saturated soil conditions and a prevalence of vegetation provide high primary production. Constructed treatment wetlands are defined as engineered wetlands that utilize natural processes involving wetland vegetation, soil and microorganisms to remove pollutants from wastewater (Kadlec and Knight, 1996).

Treatment wetlands-ecosystems are widely used for wastewater treatment throughout the world. These systems provide high treatment effectiveness in terms of removal of nutrients, suspended solids and enteric viruses, and generally improve water quality. Such low-tech treatment systems have lower energy demands and are easier to operate compared to active sludge and other wastewater treatment technologies (Kadlec and Knight, 1996; Brix, 1997; Mander et al., 2001a; Pinney et al., 2002; Vymazal, 2002).

Plants are an important part of wastewater treatment wetlands. Macrophytes absorb nitrogen, phosphorus and carbon that are assimilated in the tissues of the plants, provide a surface for microorganisms, prevent soil clogging and insulate the surface against frost during winter, control erosion, transport oxygen to the root zone from the atmosphere, as well as additional ecological roles like creating habitats for birds and mammals and increasing the aesthetic value of the site (Kadlec and Knight, 1996; Brix, 1997; Bachand and Horne, 1998).

Wetlands are considered to be among the most productive ecosystems in the world. The production of vegetation in constructed wetlands can vary from 700 to 11000 g m^{-2} (Kadlec and Knight, 1996; Vymazal, 2004), standing stock of nitrogen (N) from 12.5 to 585 g m^{-2}, and phosphorus (P) from 1.8 to 112.5 g m^{-2} (Kadlec and Knight, 1996; Brix, 1997).

Not all wetlands species are suitable for wastewater treatment because plants must be able to tolerate the combination of continuous flooding and exposure to wastewater containing relatively high and often variable concentrations of pollutants. The plants that are most often used in treatment wetlands are persistent emergent plants such as bulrushes (*Scripus* spp.) common reed (*Phragmites australis*) and cattails (*Typha spp.*) (Kadlec and Knight, 1996; Ennabili et al., 1998; Bachand and Horne, 2000, Vymazal, 2004).

As a consequence of nutrient uptake, large volumes of biomass that would be available for different uses are produced in planted wetlands (Mander et al., 2001a; Wild et al., 2001; Ciria et al., 2005; Toet et al., 2005). The long-term results of biomass production in wastewater treatment wetlands are confusing. The amount of reproduced biomass and the quality of the macrophytes contained therein must be determined for wastewater treatment wetlands producing macrophyte-based material.

Cattails in treatment wetlands

Cattails are very often part of natural and constructed treatment wetland ecosystems (Linde et al., 1976; Kadlec and Knight, 1996; Vymazal, 2007).

Cattail has been planted in constructed wetlands for primary and/or secondary treatment of domestic and industrial sewage (Ennabili et al., 1998; Shanon et al., 2000; Mander et al., 2001a; Lim et al., 2003; Solano et al., 2004; Toet et al., 2005; Álvarez and Bécares, 2006), industrial wastewater (Maine et al., 2006; Ye et al., 2001), runoff from agricultural irrigation systems (Ray and Inouye, 2007) and agricultural drainage (Borin and Tocchetto, 2007), waste-water from a tannery (Calheiros et al., 2007), farms (Hunt et al., 2003), a dairy (Newman and Clausen, 1997; Gottschall et al., 2007), fish farms (Maltais-Landry et al., 2007), a landfill (Maehlum, 1995, Bulc, 2006), wood waste (Mas-bough et al., 2005), contaminated groundwater from industrial areas (Machate et al., 1999) and mining (Mitsch and Wise, 1998; Lee; Bukaveckas, 2002), as well as urban runoff (Scholz and Xu, 2001).

Free water surface wetlands (FWS) covered by cattails can be considered valuable biotopes supporting biodiversity (Lacki et al., 1991; Kadlec and Knight, 1996; Wild et al., 2001).

Emergent macrophytes can influence nutrient removal processes in treatment wetlands. Plant surfaces in the water column and the sediment provide attachment surface for microbial communities including algae, and nitrifying, denitrifying, and other decomposing bacteria (Toet et al., 2005). There are no observed significant differences between the performance of cattail and other commonly used plants in treatment wetlands with regard to their purification ability (Solano et al., 2004).

Cattail phytomass

The shoots of cattail develop from leaf primordial in the base of the sprout. The sprout is formed at the end of the previous growing season. Growth in the base of the leaf pushes the maturing portions upward. Not all shoots produce a fruiting head. The average *Typha latifolia* spike produces 250,000 seeds. Seeds begin to shed as umbrella-like floss and are carried away by wind in winter (Linde et al., 1976).

Typha is persistent, spreads aggressively and has tremendous reproductive potential. Cattail can produce up to 3.0 kg m^{-2} annual aboveground biomass (Wild et al., 2002). Cattail can be a much greater producer of biomass (2.2 kg m^{-2}) than common reed (Solano et al., 2004).

The *Typha* leaf mass has high porosity and elasticity in the aerenchyma tissue. At the same time there is a uniform distribution of bast fibres. Thus the leaves have a high stability and show excellent insulation qualities. Furthermore, the leaf tissue has a high content of polyphenols, and so the dry raw material shows a high resistance to decay (Wild et al., 2002).

The *Typha* plants are perennial and can therefore be cultivated for a long period (Wild et al., 2002). Toet et al. (2005) has demonstrated that over two years the vitality of *Typha* did not decrease in the wetland system after mowing of the aboveground biomass. Also, *Typha* is able to survive a harvest in winter.

A cutting level 20 to 40 cm above ground level does not affect population development in the next vegetation period (Wild et al., 2002).

Nutrients in cattail

Emergent macrophytes are productive due to a high availability of water, light and nutrients in wastewater treatment wetlands. Therefore, a considerable amount of nutrients may be stored in the plant biomass. This storage is only temporary, as plant tissues senesce and nutrients are released again by decomposition of the litter. A permanent removal can be achieved by harvesting the aboveground plant material (Toet et al., 2005).

Nutrient removal due to harvesting of shoots of macrophytes is often insignificant in wetlands used for wastewater treatment in comparison to nutrient mass input, because plants only take up a small fraction of the passing nutrients (Vymazal, 2004). The *Typha* stands yield higher N and P removal efficiencies through shoots harvest than do the *Phragmites* stands (Toet et al., 2005).

The amount of nutrients that could be removed from wastewater via plant harvesting is given by nitrogen and phosphorus standing stock, which means the amount of nutrients stored in aboveground biomass. Nutrient standing stock in vegetation is commonly computed by multiplying nutrient concentration in the plant tissue by biomass per unit area. The nutrient standing stock in the biomass depends on both nutrient concentrations in the plant tissue as well as on the amount of plant tissue (Vymazal, 2004).

A lower nutrient supply may reduce the shoot biomass and nutrient standing stock of macrophytes. The *Typha* stands are more sensitive to a lower nutrient availability at N and P mass input rates (Toet et al., 2005).

In a temperate climate with seasonal growth, the date of the harvest is important. Nutrient removal is highest if shoots are cut toward the end of summer, when standing stocks of nutrients are at their peak. However, harvesting in summer would be detrimental to the plants because they would not have sufficient opportunity to withdraw nutrients and non-structural carbohydrates from the shoots to the belowground plant parts. These reserves are necessary for initial growth in spring (Linde et al., 1976; Toet et al., 2005). Therefore emergent macrophytes are usually harvested in winter (Vymazal, 2004). Long-term nutrient removal by cutting and harvesting shoots of *Typha* stands in October can be viewed as a sustainable form of management (Toet et al., 2005).

The use of cattail

By virtue of their material qualities, *Typha* leaves are particularly well suited to serve as raw material for several applications (Wild et al., 2002).

Some patent applications for *Typha* insulation products already exist in Germany (Wild et al., 2002). There is also some experience of using cattail for construction materials in Estonia.

All parts of the aboveground cattail biomass can be used. Cattail chips mixed with clay are used in the production of safe and cost-efficient building blocks. The material is light and has good thermal insulation properties. Since the blocks are air-dried, no fossil fuel energy is used in the drying process. The fundamental advantage of this technology is that the resulting house is considered very healthy because of a stable humidity in the rooms throughout the year. Fibre material from cattail spadixes is used as clay plaster reinforcement. The fibre is an ideal material to avoid cracks in clay plaster. Ready-made dry fibre and clay mixtures and cattail chips and clay blocks are produced and sold on the market (Mauring, 2003). The effect of added "fibre-wool" from cattail spadixes in clay plaster on its humidity-exchange capability is unknown.

The aboveground phytomass will be harvested in winter when the leaf mass has a minimum water content (Wild et al., 2002; Mauring, 2003). The harvesting technique has been adopted from a common reed harvest (Mander et al., 2001b).

Objectives

(1) To evaluate the annual biomass production of broad-leaved cattail (*Typha latifolia* L.) in free water surface flow constructed wetlands and in semi-natural treatment wetlands in Estonia (**I**, **II**, **III**).

(2) To determine the standing stock of N and P in the phytomass of *Typha* in treatment wetlands (**I**, **II**, **III**).

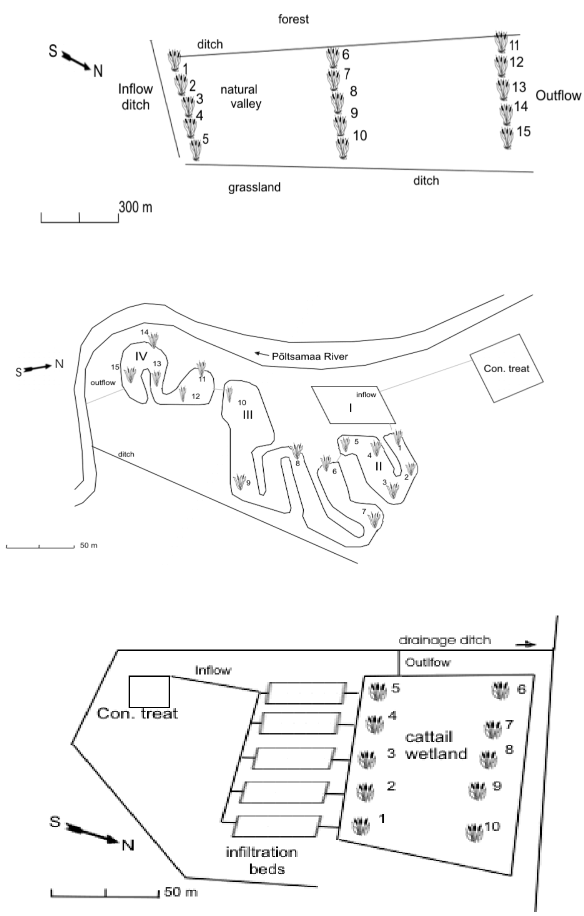
(3) To study the effect of added "fibre-wool" from cattail spadixes and cattail chips in clay plaster on its humidity-exchange capability (**IV**).

2. MATERIALS AND METHODS

2.1. Phytomass production and measurement of standing stock of nutrients

2.1.1. Site description

The fieldworks of studies (**I**, **II**, **III**) were carried out in three wetlands: in the subsurface flow semi-natural wetland in Tänassilma (58º22’ W 25º31’ N) and in two free water surface constructed wetlands in Põltsamaa (58º38’ W 25º58’ N) and Häädemeeste (58º5’ W 24º29’N) (Figure 1).



A

B

C

Figure 1. Location of sampling plots (1–15; 1–10) in test areas: A – Tänassilma semi-natural wetland; B – Põltsamaa constructed wetland; C – Häädemeeste constructed wetland.

The Tänassilma semi-natural wetland (total area 228 ha) is located in a primeval valley at the head of the Tänassilma River. The wetland is adapted to a high pollutant load of 15,000 population equivalents, and has received precipitation run-off and untreated municipal wastewater from the town of Viljandi from 1948 to 2005. The upper reach of the wetland (69 ha) used to be species-rich grassland and former swamp, but after wastewater had been discharged into the wetland, vegetation downstream was replaced by dense stands of broadleaved cattail. This area has almost no surface overflow and acts as a root system and peat filter (Nõges and Järvet, 2002). The new effluent of treated wastewater from the Viljandi treatment plant flows in a narrow ditch in the centre of the wetland. The average water level decreased in 2004, when the wastewater effluent was changed.

The Põltsamaa CW is a cascade of 4 serpentine ponds with a total area of 1.2 ha. The mean depth of the first pond is 100 cm, and that of the other three is approximately 70 cm. The system is located in the flood plain of the Põltsamaa River. The system is designed for the secondary treatment of wastewater from a conventional treatment plant, which consists of mechanical filters, sedimentation tanks and aeration tanks. It treats wastewater from the town of Põltsamaa (~5000 inhabitants) and from the food processing industry. It was constructed in 1997 (Mander et al., 2001a). Initially about 1200 cattail plants were planted in the soil at the bottom of the second and third ponds, and 500 young reed plants were planted in the fourth pond in summer 1998. Within a few years, the reed disappeared and the cattail colonised all of the ponds. The cattail rhizomes-roots became woven together and accumulated decaying leaf litter to form floating mats on the wetland surface.

The Häädemeeste wastewater treatment system consists of a conventional treatment plant, five infiltration ponds (total area 0.23 ha) planted with common reed, and a cattail (*Typha latifolia* L.) free water wetland (0.72 ha). The system is located half a kilometer from the Baltic Sea coast and treats the municipal water (max Q=160 m^3 day^{-1}) of the settlement of Häädemeeste. The system was built in 1999. The primary purpose of the wetland is the removal of N and P (Mauring, 2002). After five years (2004), the cattail basin was colonised by another local native species – common reed (*Phragmites australis* Cav.).

The average annual wastewater and nutrient loadings of the studied areas are presented in Table 1 (Ministry of the Environment, 2004).

Table 1. The average annual (2002 to 2003) hydraulic (L m^{-2} yr^{-1}) and nutrient (g m^{-2} y^{-1}) loadings of Tänassilma semi-natural wetland and Põltsamaa and Häädemeeste CWs

	Wetlands		
Loading	Tänassilma (69 ha)	Põltsamaa (1.21 ha)	Häädemeeste (0.95 ha)
Hydraulic (L m^{-2} yr^{-1})	278	26,436	10,421
N (g m^{-2} yr^{-1})	13.8	849.7	58.7
P (g m^{-2} yr^{-1})	2.6	170.3	22.2

2.1.2. Sampling and analysis of plant fractions

The cattail phytomass measurements were performed in autumn after the vegetation period, i.e. at the end of August and the beginning of September and also the following winter, i.e. at the end of January and the beginning of February, in the years 2002 to 2006 (**I**, **II**, **III**). The samples were collected from 1m^2 plots. The information on phytomass sampling and nutrient analysis in the plant fractions is given in Table 2.

Table 2. The pattern of phytomass sampling and analysis in the Tänassilma seminatural wetland and Põltsamaa and Häädemeeste CWs

Sampling and analysis	Fractions	Wetlands				
		Tänassilma		Põltsamaa		Häädemeeste
		autumn	winter	autumn	winter	autumn
Number of collected samples	Roots-rhizomes Litter Shoots Spadixes	15	– 15	15	– 15	10
Year of collected samples	Roots-rhizomes Litter Shoots Spadixes	2002–2006	– 2003–2006	2002–2006	– 2003–2006	2002–2006
Number of analysed samples	Roots-rhizomes Litter Shoots Spadixes	15	– 4	9	– 6	10
Years of analysed samples	Roots-rhizomes Litter Shoots Spadixes	2002–2003	– 2005	2002–2003	– 2005	2002–2003

Soil samples were taken from the topsoil in autumn and winter 2005. The above-ground biomass was harvested at the ground level, and the belowground root-rhizome samples were collected to a depth of 50 cm in Tänassilma and a depth of 20 cm in Häädemeeste and Põltsamaa, using an auger (Ø108.6 mm). It was not possible to bore deeper in Häädemeeste and Põltsamaa because of the thickness of the clay soil. Root samples were washed clean of soil. Cattail was divided into four fractions: roots-rhizomes, shoots with leaves, spadixes and litter. All samples were dried to a constant weight (DW) at 70°C. The nutrient (N, P) content was measured using the Kjeldahl technique and the automatic P analyzer (APHA, 1989). All chemical analyses were performed at the laboratories of Tartu Environmental Research Ltd.

2.1.3. Statistical analysis

The statistical analysis was carried out using the STATISTICA 7.0 (StatSoft Inc.) program. The normality of the variables was verified using the Lilliefors' and Shapiro-Wilk W tests. Biomass production and nutrient content variables were normally distributed (**I**, **II**, **III**). The 95% confidence intervals were used to compare the mean values of results. The level of significance $\alpha = 0.05$ was accepted in all cases.

2.2. Laboratory methods of experiment of added cattail phytomass in clay plaster

2.2.1. Clay-sand plaster

The mineralogical composition of the clay-sand plaster was analysed through X-ray diffraction using a Dron-3M diffractometer. The quantitative composition of unoriented powdered clay preparations was analysed in accordance with the Rietveld method, using Siroquant 3.0TM code (Tailor, 1991). The results of mineralogical showed that the most common component is quartz (54.7 weight % (wt%), followed by dolomite, calcite and albite (Table 3, **IV**). The clay minerals that give this mineral plaster its plasticity are represented by illite and illite-smectite type phases (4.5%), and kaolinite (1.9%). Traces of chlorite were also observed.

2.2.2. Raw material

The cattail and reed for the experiment was harvested in a wastewater treatment subsurface flow semi-natural wetland and in two free water surface constructed wetlands in Estonia. Shoots of *Typha* and *Phragmites* were minced to 2 x 20 mm chips (**IV**).

2.2.3. Gypsum wallboard

Gypsum wallboard is the most commonly used material in interiors in Estonia, and thus it was used as a reference material. It can be described as a flat board comprised of a gypsum core with an external surface that is covered with paperboard. The product is a three-layer composite composed of paper/gypsum/paper. For the study we used standard 15 mm thick gypsum wallboard (manufactured by Gyproc) (**IV**).

2.2.4. Climatic chamber

The humidity absorption and desorption quantity was measured in a climatic chamber, which was constructed by the Testing Centre of the University of Tartu, Estonia, using a refrigerator. The climatic chamber consisted of a freezer (for low humidity air), a convector (for suitable and constant temperatures), a setting panel (to change temperature and humidity), and a control sensor (Figure 2). Distilled water was used for air humidity manipulation. Changes in the weights of samples were measured using a balance (Kern and Sohn, model Kern PLS 510–3) controlled by a computer.

The moisture content and temperature of the chamber can be independently controlled between about + 10 and 37°C (± 0.2°C) and 50 to 80% (±4%) (<3 minutes) (**IV**).

2.2.5. Preparation of samples

A painted and wallpapered gypsum wallboard sample, a pure clay-sand plaster sample and 8 samples were made, and different amounts of cattail wool and cattail and reed chips were added to these (Table 3). The painted gypsum wallboard sample was covered once with a fine filler and twice with latex paint. The wallpapered gypsum wallboard sample was covered once with a fine filler and undercoated with latex paint, and then covered with the wallpaper (**IV**).

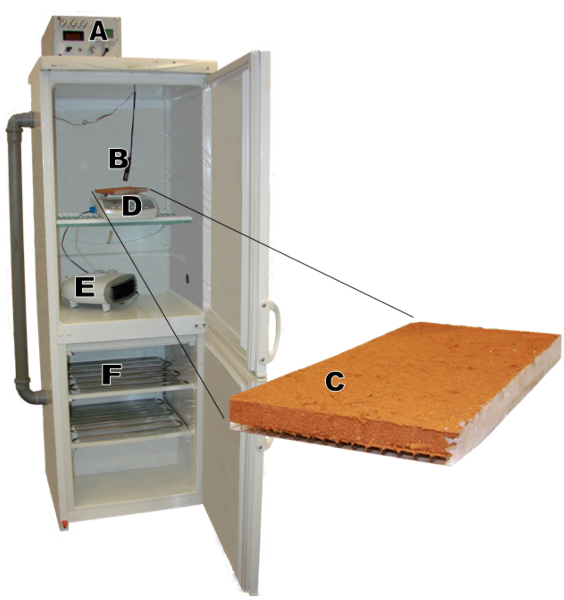


Figure 2. The climatic chamber and the clay-sand plaster sample. A – setting panel; B – control sensor; C – sample specimen; D – balance (Kern PLS 510–3); E – convector; F – freezer.

Table 3. Weight (g) of clay-sand plaster (with different content of cattail (*Typha latifolia*) wool and chips and reed (*Phragmites australis*) chips) and gypsum wallboard (painted and wallpapered) samples and content (wt%) of added phytomass in clay-sand plaster

ID (abbreviation) and full name of sample		Weight of sample (g)	Phytomass content (wt%)	
			wool	chips
CS	Clay-sand plaster	374.4	–	–
CST1w	Clay-sandplaster with *Typha* wool	333.2	1.0	–
CST2w	Clay-sand plaster with *Typha* wool	220.1	2.0	–
CST05c	Clay-sand plaster with *Typha* chips	342.7	–	0.5
CST1c	Clay-sand plaster with *Typha* chips	333.0	–	1.0
CST2c	Clay-sand plaster with *Typha* chips	312.3	–	2.0
CSP1c	Clay-sand plaster with *Phragmites* chips	352.2	–	1.0
CST05w025c	Clay-sand plaster with *Typha* wool and chips	356.1	0.5	0.25
CST1w05c	Clay-sand plaster with *Typha* wool and chips	332.0	1.0	0.5
PG	Painted gypsum wallboard	164.9	–	–
WG	Wallpapered gypsum wallboard	169.4	–	–

The tested specimen of clay-sand plaster had the dimensions 200 x 100 mm and was 10 mm thick, and the gypsum wallboard had dimensions 200 x 100 mm and was 15 mm thick.

Samples based on polycarbonate plates (200 x 100 mm) were dried at 25°C and the weight of the sample was measured after drying. The surface of the samples was left exposed, and the sides were isolated using paraffin. Samples were acclimatised for 24 h in a climatic chamber before measurement. The weight of each sample was measured after 15 minutes (**IV**).

3. RESULTS AND DISCUSSION

3.1. Biomass

The average aboveground biomass of *T. latifolia* varied from 0.37 to 1.76 kg DW m^{-2} in autumn and from 0.33 to 1.38 kg DW m^{-2} in winter for the three wetlands throughout the study period. The corresponding results for *P. australis* were from 0.61 to 1.32 kg DW m^{-2} and from 0.61 to 1.02 kg DW m^{-2} kg respectively (Figure 3).

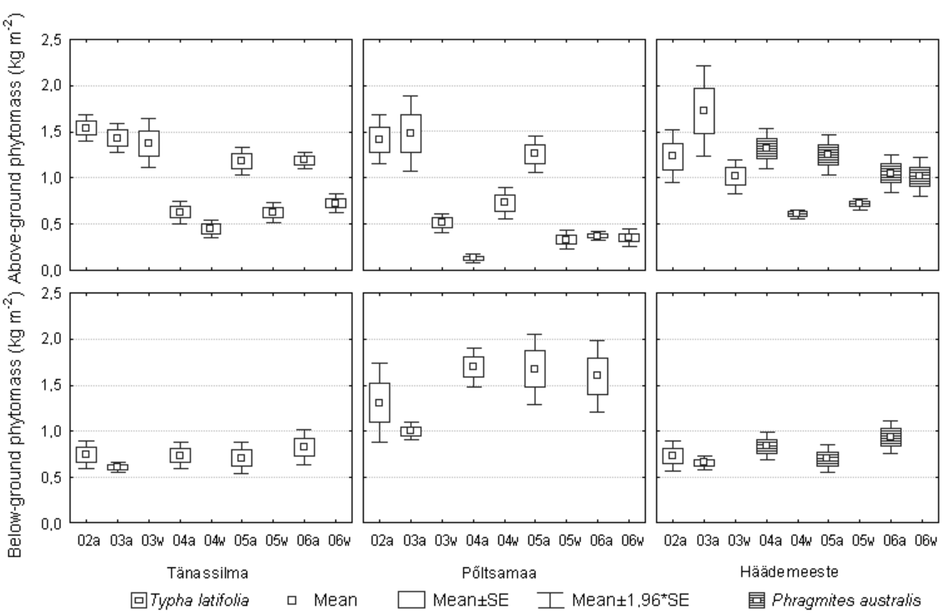


Figure 3. Above-ground and below-ground phytomasses (kg m^{-2}) of cattail (*T. latifolia*) and reed (*P. australis*) in Tänassilma semi-natural wetland, and Põltsamaa and Häädemeeste CWs in autumn (September; a) and winter (January; w) from 2002 to 2006.

The belowground biomass of the cattail varied from 0.61 to 1.31 kg DW m^{-2}, and reed from 1.60 to 1.69 kg DW m^{-2}.

The differences in aboveground phytomass values between the studied wetlands in autumn were only significant in Tänassilma in 2004 and Põltsamaa in 2006. The estimated biomass of cattail shoots varied from 0.56 to 1.07 kg m^{-2} in Tänassilma, 0.27–1.58 kg m^{-2} in Põltsamaa, and 0.47–1.21 kg m^{-2} in Häädemeeste (Figure 4). The phytomass of cattail litter was between 0.20–0.57 kg m^{-2} in Häädemeeste, and 0.07–0.35 kg m^{-2} and 0.09–0.48 kg m^{-2} correspondingly in Tänassilma and Põltsamaa. The average biomass of spadixes in Põltsamaa varied from 0.03 to 0.10 kg DW m^{-2}. The corresponding results in

Häädemeeste were 0.20–0.31 kg DW m^{-2}, and in Tänassilma 0.03–0.20 kg DW m^{-2}. The average phytomass of spadixes in winter was 0.15 kg DW m^{-2} in Häädemeeste, and the same results in Tänassilma and Põltsamaa varied from 0.02 to 0.16 kg DW m^{-2} and from 0 to 0.35 kg DW m^{-2} respectively. The average aboveground biomass of reed did not vary significantly from cattail, but there were more roots-rhizomes of reed than cattail (**I**, **II**, **III**).

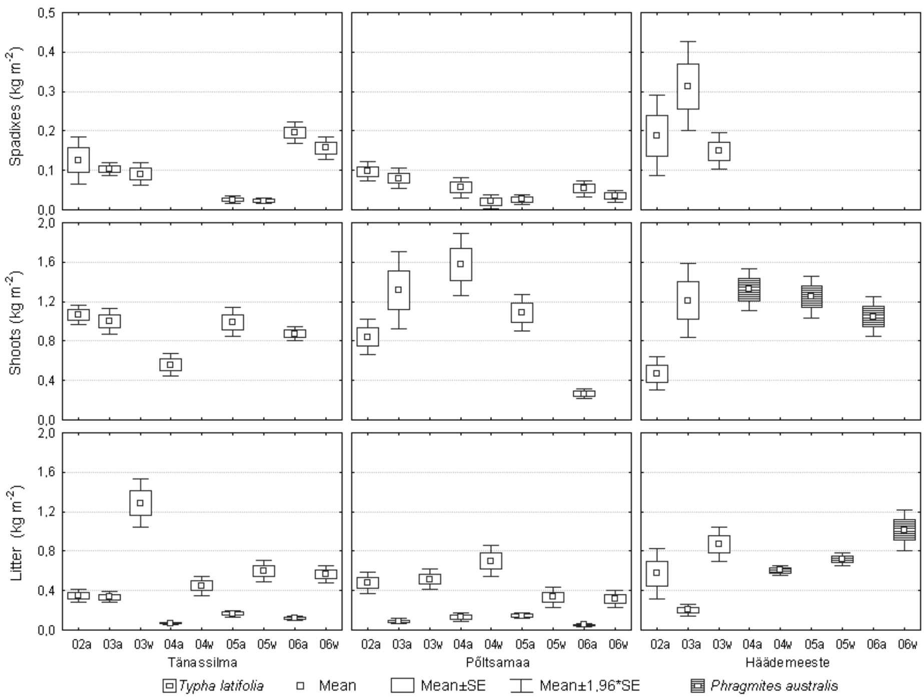


Figure 4. Aboveground phytomass fractions (kg m^{-2}) of cattail and reed in Tänassilma semi-natural wetland, and Põltsamaa and Häädemeeste CWs in autumn (September; a) and winter (January; w) from 2002 to 2006.

Up to 1 kg less aboveground phytomass of cattail was left in winter than at the end of the vegetation period in autumn. Phytomass loss was less when there were more spadixes in autumn. This is because fruiting shoots are more weather-resistant (Linde et al., 1976). There was half a kilogram less above-ground reed phytomass in winter than in autumn. Cattail biomass has a large temporal and spatial variation in productivity. This makes it difficult to use it as a raw material for construction and fibre production (**II**, **III**).

The litter, spadixes and shoots biomass values indicated that in free water surface CWs, plants grow and die more quickly than in subsurface wetlands. Therefore, in Tänassilma we found significantly less spadixes and litter than in Põltsamaa and Häädemeeste (**I**).

It is known that plants do not always bear fruit in stable quantities every year, but rather alternate between a year of high production and a year of low production. It is possible that heavy fruiting of cattail may also produce an imbalance within the plant that affects the next year's production (Linde et al., 1976). There were more spadixes in Häädemeeste than in Põltsamaa and Tänassilma in 2002 and 2003, but only a few cattail shoots survived, and common reed colonised the free water wetland surface in 2004. There were more spadixes in Tänassilma in 2003 than in 2002, but there were only a few spadixes and low production of aboveground phytomass in 2004. The cattail population on floating mats creates less spadixes, because fruiting shoots are heavy, and they cannot stand up if they are not fixed to the soil. This also caused extensive loss of aboveground phytomass in Põltsamaa in winter (**II**, **III**).

The average aboveground cattail biomass values (0.3–1.8 kg DW m^{-2}) in Tänassilma semi-natural wetland and Põltsamaa and Häädemeeste CWs were lower than reported by Toet at al. (2005) – 2.09 kg m^{-2}, Ennabili et al. (1998) – 2.16 kg m^{-2} and Fernandez and Miguel (2005) – 2.23 kg m^{-2}, but were similar to those found in Germany (1.3 – 1.45 kg m^{-2}; Wild et al., 2002). The cattail root and rhizome biomass values (0.6–1.3 kg DW m^{-2}) in the studied systems were similar to those recorded by Romero et al. (1999), varying from 0.7 to 1.6 kg m^{-2}, but were lower than those measured by Ennabili et al. (1998) – 3.5 kg m^{-2}. The average aboveground standing stock values of reeds in the studied areas were once again lower than those reported by Lesage et al. (2006) – 1.5 kg m^{-2}, Vymazal (2004) – 2.09 kg m^{-2}, Ennabili et al. (1998) – 2.3 kg m^{-2}, Bragato et al. (2005) – 2.5 kg m^{-2} and Toet et al. (2005) – 2.85 kg m^{-2} (**I**, **II**, **III**).

3.2. Nutrients

The concentration of N and P was highest in soils in Tänassilma, varying from 23.6 to 31.3 g kg^{-1} for N and 1.2–5.6 g kg^{-1} for P. In Põltsamaa and Häädemeeste the N concentrations were 0.8–28.2 and 0.4–1.5 g kg^{-1}, and P concentrations were 0.5–6.3 and 0.2–1.1 g kg^{-1} respectively (**I**, **II**, **III**). In Tänassilma the N concentrations in soil were significantly higher than in plant fractions, whereas in other wetlands an opposite relationship was found. In all studied treatment wetlands the P concentrations were higher in plant fractions than in the soil samples (Table 4).

The greatest average nitrogen concentration (22.95 g N kg^{-1}) was found in spadixes in 2002, and phosphorus concentration (6.5 g P kg^{-1}) was measured in roots-rhizomes in 2003. Phosphorus concentration in litter, shoots and roots-rhizomes was higher in 2003 than in 2002, but was lower in spadixes (**I**, **II**, **III**). For spadixes, the maximum average P concentration was measured at 4.76 g kg^{-1}, while in the case of litter the greatest P concentration was 2.7 g kg^{-1}. N and P concentrations in cattail shoots and litter were lower in winter than in autumn, but were higher in spadixes and roots-rhizomes (Table 4).

Table 4. The range (min-max) of N and P concentrations (in both soil and plant fractions; g kg^{-1}) and standing stock (g m^{-2}) in cattail plant fractions in the Tänassilma semi-natural wetland and Põltsamaa and Häädemeeste CWs in autumn and winter

		Wetlands				
		Tänassilma		Põltsamaa		Häädemeeste
Elements	Fractions	autumn	winter	autumn	winter	autumn
N (g kg^{-1})	Soil	23.6–28.0	26.6–31.3	1.6–28.2	0.8–5.4	0.4–1.45
	Roots-rhizomes	15.6–25.2	19.0–27.0	15.7–33.3	16.0–34.0	11.0–21.0
	Litter	8.2–19.2	8.0–12.0	9.5–19.9	7.0–14.0	7.3–18.1
	Shoots	12.7–24.1		14.7–27.4		12.8–23.1
	Spadixes	16.3–23.8	13.0–21.0	11.6–27.1	10.0–21.0	10.9–21.8
N (g m^{-2})	Roots-rhizomes	7.0–26.3	–	6.9–23.0	–	5.2–30.6
	Litter	1.9–6.4	3.0–7.0	0.5- 9.3	0.6–6.3	0.5–11.9
	Shoots	10.4–32.2		6.4–61.6		2.5–46.2
	Spadixes	0.5–6.3	1.2–4.5	1.3- 4.4	0.5–0.6	0.3–11.3
P (g kg^{-1})	Soil	1.2–4.4	1.9–5.6	0.9–6.3	0.5–1.5	0.2–1.1
	Roots-rhizomes	1.2–4.6	2.8–4.3	2.5–8.6	3.7–5.2	0.9–5.9
	Litter	1.6–3.7	0.6–1.3	1.3–3.8	0.2–1.9	0.9–2.9
	Shoots	1.6–4.3		2.3–4.4		1.7–3.9
	Spadixes	2.5–4.7	2.7–4.1	3.0–5.6	2.2–3.3	2.4–4.6
P (g m^{-2})	Roots-rhizomes	0.6–3.3	–	1.1- 7.2	–	0.5–7.2
	Litter	0.4–1.5	0.2–0.8	0.1- 2.0	0.01–0.7	0.1–1.9
	Shoots	1.5–6.0		1.1–10.2		0.4–6.4
	Spadixes	0.1–1.3	0.3–0.9	0.2- 0.9	0.1–0.1	0.1–2.4

Average nitrogen and phosphorus standing stock was higher in aboveground than belowground phytomass (Table 3). The average standing stock of nutrients in Tänassilma, Põltsamaa and Häädemeeste belowground phytomass varied from 11.6 to 19.4 g N m^{-2} and from 1.6 to 4.6 g P m^{-2}, and from 17.0 to 32.3 g N m^{-2} and from 2.6 to 6.0 g P m^{-2} in aboveground. The corresponding results in winter were 4.4–7.5 g N m^{-2} and 0.6–1.0 g P m^{-2}. The standing stock of nutrients depends on both the elements' concentrations in the plant tissue as well as on the amount of plant biomass (Vymazal, 2004).

We found that N and P were stored in reserve organs after the fruiting stage (**I**, **II**). Stored nutrients are available to help the plant develop new shoots the following spring. For instance, Vymazal (2004) reported that *Phragmites australis* translocates reserve products very late in the season, and the harvesting of this plant during the growing season may lead to serious damage to the stand. Therefore we recommend that the harvesting of cattail be undertaken after nutrient translocation.

The nutrient balance of treatment wetlands depends on many factors and can vary from year to year. In warm and sunny summers the accumulation of N and P in both belowground and aboveground phytomass can significantly increase (Mander et al., 2008). In subsurface flow CWs with low hydraulic and nutrient loadings, nutrient removal can be significant, although we should also consider that the pool of nutrients in filter material and sediments plays a more important role in phytomass production than direct wastewater inflow. For instance, the Tänassilma system received significantly higher loadings from the 1950s to 2000 (Nõges and Järvet, 2002), which has now fallen to 13.8g N m^{-2} y^{-1} and 2.6 g P m^{-2} y^{-1} (Table 1). Therefore the high nutrient accumulation in Tänassilma is largely due to the accumulated N and P in sediments. Thus the calculation of removal efficiency based only on initial wastewater loadings and annual nutrient uptake does not provide adequate results. A similar situation can be seen in the Häädemeeste FWS CW with low initial loadings. In Põltsamaa, on the other hand, both hydraulic and nutrient loadings are very high (Table 1), which would result in low removal efficiency if the plants were harvested: 0.5 % of N and 0.3 % of P of initial wastewater loadings. Thus removed nutrients via the harvesting of aboveground biomass from heavily loaded CWs in temperate and cold climates yield a very small portion of the inflow load, usually as little as < 1 %, and harvesting does not usually increase removal efficiency (Vymazal, 2004) (**II**).

Harvesting may be feasible if there is an application for macrophytes, e.g. construction (Mauring, 2003) or energy production (Mander et al., 2001b; Ciria et al., 2005). However, the stability of cattail re-growth after harvesting has not been thoroughly researched (Hellsten et al., 1999).

3.3. Added cattail phytomass in clay-sand plaster

One of the influences of phytomass added to clay-sand plaster samples was the reduction of their weight (Table 3). The lowest weight was measured in the case of clay-sand plasters that were mixed with 2 wt% of *Typha*-wool. On the other hand, this amount of phytomass significantly lowers the intensity of their air humidity absorption (Figure 5) (**IV**).

The experiments showed that the 10 mm thick layer of clay-sand (CS) plaster with added 2 wt% of *Typha* chips was able to absorb about 36.8 g of water per m^2 of wall surface in 12 hours if the humidity of ambient air was suddenly raised from 50% to 80% (Figure 5) (**IV**).

The desorption rates of clay-sand plasters and gypsum wallboards are shown in Figure 6 (**IV**).

All samples released the absorbed humidity over 12 hours. The most rapid desorption took place with plaster that contained 2% of weight of *Typha*-wool. The main reason for this was obviously the lower content of absorbed water in this material (**IV**).

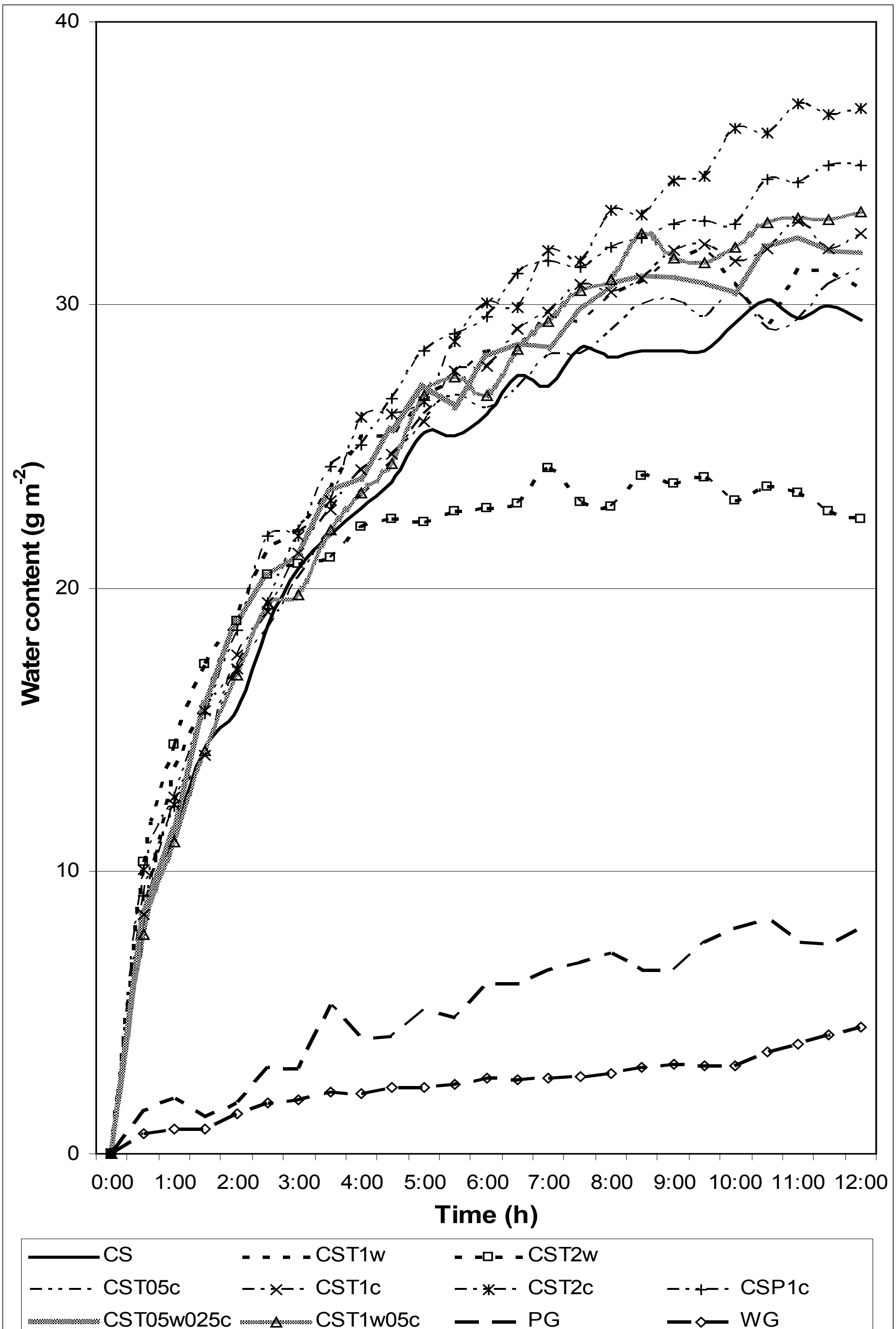


Figure 5. Absorption curve of samples, at a temperature of 21°C, with a sudden increase of humidity from 50% to 80%.

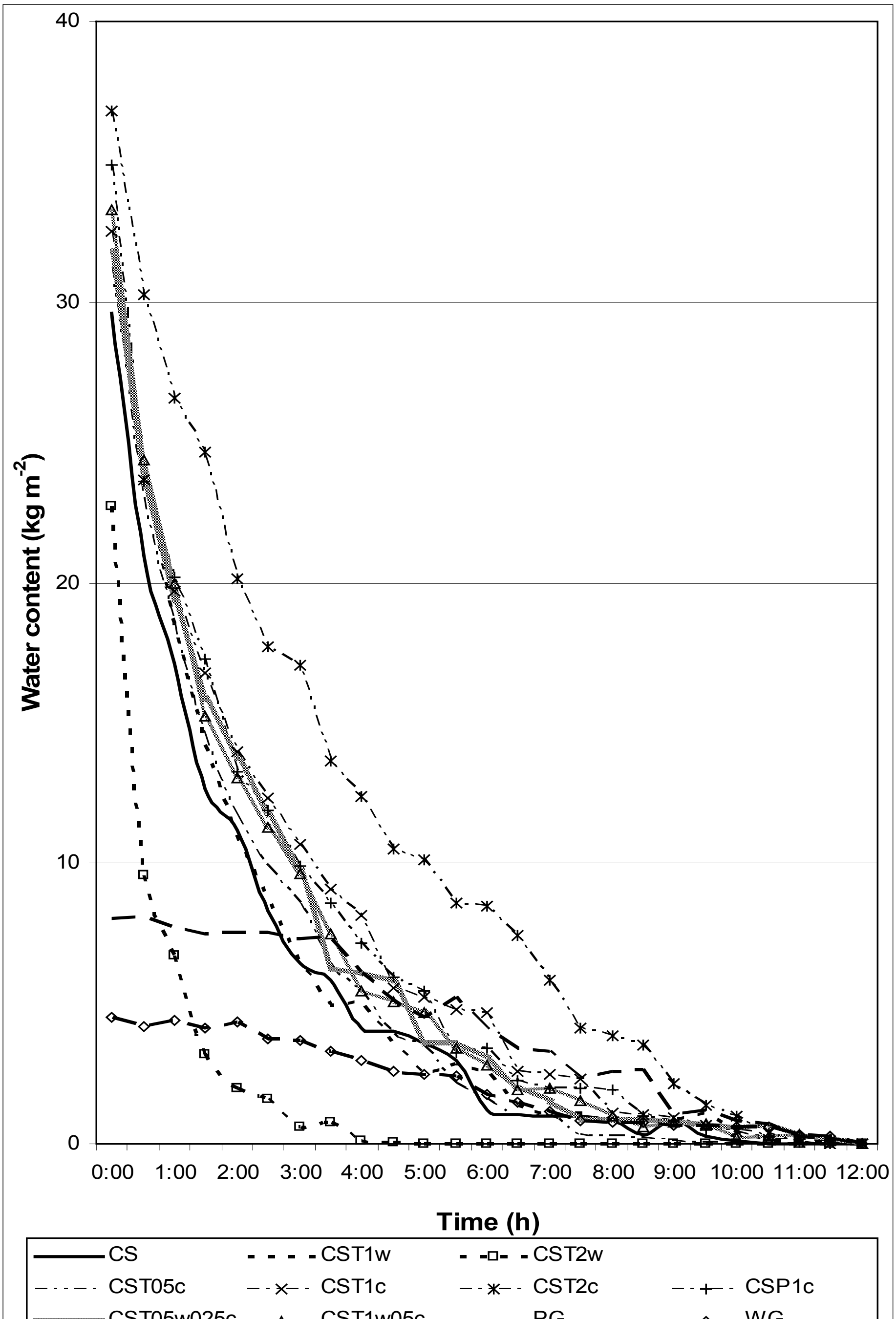


Figure 6. Desorption curve of samples, at a temperature of 21°C, with a sudden decrease in humidity from 80% to 50%.

The pure clay-sand plaster absorbed 11.3 g m^{-2} (38.2% of all humidity absorbed in 12 hours) in the first hour (Table 4, **IV**). Added phytomass in clay-sand plaster accelerated the absorption of air humidity in comparison with pure clay-sand plaster, except for clay-sand plaster where 1 wt% of *Typha*-wool and 0.5 wt% of chips was added, which absorbed only 11.0 g m^{-2} in the first hour (0.3 g m^{-2} less than pure clay-sand plaster).

The pure clay-sand plaster desorbed 42.2% (12.5 g m^{-2}) of all humidity absorbed in 12 hours in the first hour. The other clay-sand plaster samples released a smaller percentage of absorbed humidity than clay-sand plaster in the first hour, but the amount (g) of water was in some cases greater (CST1w: 13.3 g m^{-2}; CST05c: 12.7 g m^{-2}; CST1c: 12.8 g m^{-2}; CSP1c: 14.7 g m^{-2}; CST1w05c: 13.4 g m^{-2}). Painted and wallpapered gypsum wallboard absorbed only 1.9 g m^{-2} (24.2%) and 0.9 g m^{-2} (18.9%) respectively (**IV**).

In the first hour, 4.3% (0.3 g m^{-2}) and 2.2% (0.1 g m^{-2}) of absorbed humidity was desorbed by painted and wallpapered gypsum wallboard respectively (**IV**).

Clay-sand plaster samples absorbed the same amount of humidity more slowly than they desorbed it, with the exception of samples of clay-sand plasters with an added 1 wt% (CST1c) and 2 wt% (CST2c) of cattail chips. The gypsum wallboard demonstrated opposite results (Table 5, **IV**).

4. CONCLUSIONS

Plants are an important part of constructed wetlands for wastewater treatment. Macrophytes take up nutrients that are assimilated in the tissues of the plants, provide a surface for microorganisms, insulate the surface against frost during winter, transport oxygen from the atmosphere to littoral areas, create habitats for birds and mammals, and increase the aesthetic value of the site.

Average aboveground biomass of *T. latifolia* varied from 0.3 to 1.8 kg DW m^{-2}, and below-ground biomass from 0.3 to 1.4 kg DW m^{-2}, and the same results for *P. australis* were from 0.6 to 1.3 kg DW m^{-2} and 0.6 to 1.0 kg DW m^{-2} respectively (**I**, **II**, **III**).

The results showed that cattails in CW have a large temporal and spatial variation in terms of productivity, which makes it difficult to use them as a potential source for building material production. Thus further investigations in this field are required because of the increasing need for *Typha* wool as a valuable ingredient in clay plasters (**I**, **II**, **III**).

The nutrient uptake capacity of cattail was quite high. The average N and P concentration was higher in belowground than in aboveground biomass, whereas the belowground stock of both nutrients was lower than the aboveground stock (**I**, **II**, **III**).

The harvesting of aboveground biomass would have a remarkable influence on nutrient removal in systems with lower hydraulic and nutrient loadings (Tänassilma and Häädemeeste systems), and would not be significant in systems with overloaded free water surface treatment constructed wetlands (Põltsamaa) (**I**, **II**, **III**).

Plants grow and die more quickly in free water surface wetlands than in subsurface wetlands. Therefore significantly less spadixes and litter were found in Tänassilma than in Põltsamaa and Häädemeeste (**I**).

The N and P contents in plant fractions demonstrated that these nutrients were stored in reserve organs after the fruiting stage. In Põltsamaa the N and P content in all plant fractions was higher than in other test areas (**I**, **II**, **III**).

Added phytomass provided positive effects by reducing the weight of clay-sand plaster, and accelerating and increasing the amount of humidity absorbed. The quantity of absorption decreased when more than 1 wt% of *Typha*-wool was added to clay-sand plaster (**IV**).

All of the water absorbed in the 12 hours after a sudden rise in air humidity from 50% to 80% in the climatic chamber was released within 12 hours after a sudden decrease in air humidity from 80% to 50% (**IV**).

The clay-sand plaster samples absorbed the same amount of humidity more slowly than they desorbed it, whereas the gypsum wallboard demonstrated the opposite effect (**IV**).

Clay-sand plaster with phytomass of *Typha* is a promising and highly-valued building material for environmental-friendly construction (**IV**).

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SUMMARY IN ESTONIAN

Hundinuia produktsiooni ja toitainetesisalduse varieeruvus ning biomassi kasutamine loodussõbraliku toorainena

Käesoleva doktoritöö eesmärk on selgitada hundinuia populatsiooni produktsiooni ja toitainete sisalduste varieeruvust reoveepuhastuse märgalades Eestis ning analüüsida hundinuia tõlvikute villa ja pealsete hakke mõju saviliivakrohvi õhuniiskuse imamisvõimele.

Ökotehnoloogilise puhastusmeetodina kasutatakse reovee puhastamiseks ja kvaliteedi parandamiseks tehismärgalasid. Tänu madalatele ehitus- ja majanduskuludele ning suuremale töökindlusele on vabaveelised märgalad ja pinnasfiltrid odavaks alternatiiviks nõrgfiltritele ja aktiivmudapuhastitele. Heitveepuhastustehismärgalasid kasutatakse laialdaselt orgaanika, lämmastiku ja fosfori ühendite eemaldamiseks nii majapidamis-kui ka tööstusreoveest (Kadlec ja Knight, 1996; Brix, 1997; Mander *et al.*, 2001a; Pinney *et al.*, 2002; Vymazal, 2002).

Reoveepuhastuse märgalade taimede kaudu toimub päikeseenergia mõjul reoainete ümbertöötamine biomassiks. Puhastussüsteemi sissetulevast koormusest on taimestiku toitainete sidumisvõime hinnanguliselt kuni 10% (Vymazal, 2004). Biomassi tootlikkus ning toitainete sisaldus on olnud pikka aega spekuleerimise teema – erinevate allikate andmed ei ole olnud usaldusväärselt erineva suuruse ja tingimustega aladele üle kantavad.

Koos hariliku pillirooga (*Phragmites australis*) on laialeheline hundinui (*Typha latifolia*) levinumaks taimeliigiks tehismärgalades, mida kasutatakse heitvee puhastamiseks (Kadlec ja Knight, 1996; Ennabili *et al.*, 1998; Bachand ja Horne, 2000, Vymazal, 2004). Puhastusprotsessi kõrvalsaaduseks on biomass, mida on võimalik kasutada alternatiivse ehitusmaterjalina (Mander *et al.*, 2001a; Mauring, 2003).

Hundinuia lehe kude on hästi poorne ja elastne. Niinkiud on ühtlaselt jaotunud, mis tagavad lehtede ja varte ehitusmaterjalina kasutamisel püsivuse ning suurepärased isolatsiooniomadused. Kuivatatud toormaterjali vastupidavuse lagunemise vastu tagab kõrge polüfenoolide sisaldus (Wild *et al.*, 2002).

Kuivatatud biomassi kasutatakse soojusisolatsioonimattide valmistamiseks. Lisaks tehakse taime lehtedest ja vartest piki- ja ristikiudu lõigatud liistakuid, mida kasutatakse puiste-isolatsioonimaterjalina või lisatakse kergsaviplokkidele. Savikrohvile pannakse sisse hundinuia seemneid, mis muudavad krohvi elastsemaks ja pragunemiskindlamaks. Tükeldatud hundinuia biomassi ja kergsavi plokkidega soojustatud ning taimse armatuurkiu ja savikrohviga viimistletud majas on aastaringselt tasakaalustatud õhuniiskus- ja temperatuur (Mauring, 2003).

Hundinuiakoosluste biomassi tootlikkuse ning lämmastiku ja fosfori sisalduse varieeruvuse analüüsimiseks uuriti kolme erineva vanuse, suuruse ning toitainete koormusega reovee puhastamiseks kasutatavat märgala. Uuritavateks aladeks olid Tänassilma poollooduslik märgala ning Põltsamaa ja Häädemeeste avaveelised tehismärgalad. Taimefraktsioonide (juurte-risoomide, võsude, tõlvikut ja varise) massid kaaluti, proovid nende keemilisteks analüüsideks võeti 1-m^2 suurustelt prooviruutudelt. Tänassilmas oli 15 prooviruut, Põltsamaal samuti 15 ning Häädemeestel 10. Tööd toimusid septembris ja jaanuaris 2002– 2006.

Taimeproovide keemiline analüüs tehti Tartu Keskkonnauuringute laboris. Süsinikusisaldus määrati IR meetodiga Skalar – Soca 100 süsinikuanalüsaatoriga. Lämmastikusisaldus määrati Kjeldahli meetodil Kjelteci analüsaatoril. Fosforianalüüs toimus ICP – seadmega, eeltöötluseks kasutati mikrolaineahju.

Maa-aluste osade proovide võtmiseks kasutati alaneva südamikuga monoliidipuuri, lõiketera läbimõõduga 108,6 mm. Igast ruudust võeti juhusliku paigutuse järgi 3 monoliiti, mille sügavus oli Tänassilmas 50 cm, Põltsamaal ja Häädemeestel ~20 cm. Põltsamaa ja Häädemeeste märgalades paiknes sügavamal suure lasuvustihedusega kiht, millesse puuri ei õnnestunud suruda. Suur lasuvustihedus takistab juurte ja risoomide tungimist sellesse kihti, mistõttu saadud tulemusi võib kasutada maa-aluse osa hinnanguna. Pealsed lõigati juure pealt maha ning koguti ka prooviruudule maha vajunud varis. Monoliidiproovidest pesti välja kõik elusad ja surnud juured ning risoomid. Proovid kuivatati 70 °C juures. Käesolevas töös on biomassiandmed esitatud absoluutkuivadena.

Andmeanalüüsil kasutati programme Excel ja STATISTICA 6,0 (StatSoft Inc.). Mõõdetud tunnuste jaotuste vastavust normaaljaotusele kontrolliti Kolmogorov-Smirnovi, Lillieforsi ja Shapiro Wilk W testidega. Shapiro-Wilk W ja Lillieforsi testide vastukäivate tulemuste korral kontrolliti erinevust normaaljaotusest ka hii-ruut testi abil. Juhinduti tugevama, s.t. hii-ruut testi tulemustest. Tänassilma, Põltsamaa ja Häädemeeste märgaladel hundinuia taimefraktsioonide fütomassid kui elementide sisalduste tulemused olid normaaljaotustega Kolmogorov-Smirnovi, Lilliefors' ja Shapiro Wilk W testide järgi. Kõigil juhtudel oli olulisuse nivoo α=0,05.

Hundinuia hakke ja kiuga saviliivakrohvi õhuniiskuse imamisvõime mõõtmiskatsed viidi läbi kliimakambris, kus sai muuta kiiresti õhuniiskust 50%lt 80%le ning vastupidi. Kliimakamber valmistati Tartu Ülikooli Katsekojas. Katsete jaoks tehti erineva hundinuia kiu (1–5%) ning hundinuia (0,5–2%) ja pilliroo (1%) hakkega (2 x 20 mm) saviliivakrohvi katsekehad (200 x 100 mm, paksus 10 mm) ning võrdluseks värvitud ning tapeediga kaetud kipsplaadi katsekehad (200 x 100 mm, paksus 15 mm). Proovikehad tehti õhukesele ja kergele polükarbamiidist alusele ja servad isoleeriti parafiiniga. Enne mõõtmise algust aklimatiseeriti proovikehi 24 tundi kliimakambris.

Keskmine maapealne hundinuia fütomass varieerus 0,37–1,76 kg m^{-2} peale vegetatsiooni perioodi, kusjuures talveks oli uuritavatele märgaladele alles jäänud 0,33 kuni 1,38 kg m^{-2}. Keskmine maa-alune hundinuia fütomass jäi vahemikku 0,61–1,31 kg m^{-2}.

Tänassilma, Põltsamaa ja Häädemeeste märgaladelt kogutud hundinuia maapealse osa produktsiooni tulemused (0,3–1,8 kg m^{-2}) olid väiksemad, kui kirjeldatud Toet at al. (2005; 2,1 kg m^{-2}) Fernandez ja Miguel (2005) ning Ennabili et al. (1998; 2,2 kg m^{-2}) poolt, kuid olid võrreldavad Saksamaal Donaumoosi katselalal saadud andmetega: 1,3–1,45 kg m^{-2} (Wild *et al*., 2002). Maa-aluse osa keskmiste fütomasside tulemused (0,6–1,3 kg m^{-2}) olid teistes töödes saadud tulemustega 0,7–1,6 kg m^{-2} (Ennabili *et al*., 1998; Romero *et al*., 1999) samas vahemikus.

Suurim keskmine fosforisisaldus hundinuias oli juurtes-risoomides (6,5 g P kg^{-1}) ning lämmastikusisaldus tõlvikutes – 22,95g N kg^{-1}. Sisalduste analüüsist selgus, et uurimisaladel toimub toitainete kogunemine tõlvikutesse. Samuti kinnitas sisalduste analüüs fraktsioonide masside analüüsi tulemusi. Hundinuia fraktsioonide elementide keskmised sisaldused ning nende varieeruvused olid suurimad Põltsamaal ja Häädemeestel.

Korrelatsioonianalüüs näitas, et varise osakaalu suurenemisel maapealses fütomassis suureneb elementide sisaldus nii võsudes kui ka tõlvikutes. Varise moodustumisel peale vegetatsiooniperioodi toimub fosfori liikumine lehtedest allesjäävatesse vartesse ja valmivatesse viljadesse. Seejärel lehed surevad ning moodustub varis. Positiivne korrelatsioon võsude ja tõlviku biomasside vahel näitas, et võsude suurema biomassi korral valmib ka rohkem tõlvikuid.

Keskmine toitainetvaru maa-aluses osas jäi vahemikku 11,6–19,4 g N m^{-2} ja 1,6–4,6 g P m^{-2} ning maapealses osas 17,0–32,3 g N m^{-2} ja 2,6–6,0 g P m^{-2}. Talvine maapealse fütomassi tulemused olid vastavalt 4,4–7,5 g N m^{-2} ja 0,6–1,0 g P m^{-2}.

Ruutmeeter saviliivakrohvi imas 30 g vett 12 tunni jooksul, kui kliimakambris tõsteti õhuniiskus 50%lt 80 %le. Samadel tingimustel imas saviliivakrohv, millele oli lisatud 2% hundinuia haket 36 g, 1 % tõlvikute kiudu 32 g, 1% kiudu ning 0,5% haket 33 g ning värvitud kipsplaat 10 g ja tapeediga kaetud kipsplaat 6 g vett.

Saviliivakrohvile lisatud taimne osa vähendas krohvi kaalu ning kiirendas ja suurendas õhuniiskuse imavust. Krohvi õhuniiskuse imavus vähenes, kui sellele oli lisatud rohkem kui 1% hundinuia tõlvikute kiudu. Kogu 12 tunni jooksul imatud õhuniiskus vabanes sama aja jooksul, kui kliimakambris vähendati niiskust 80%lt 50 %le. Õhuniiskus imendus aeglasemalt kui vabanes saviliivakrohvist. Kipsplaadis täheldati vastupidist tendentsi.

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PUBLICATIONS

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