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LIVING ISLANDS - THE DEVELOPMENT OF AUTO-BUOYANT VEGETATION MATS FOR WATER QUALITY IMPROVEMENT

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Abstract

Artificial floating vegetation assist in achieving good ecological status, one of the main objectives of the European Water Framework Directive. This study aims to develop auto-buoyant vegetation mats to establish riparian areas enhancing habitats and morphological structure following their natural counterparts, such as the Plaur in the Danube delta. The supporting structures are made of exclusively compostable materials and planted with suitable plants (reed-gabion). Development of the gabions and the vegetation was surveyed during the growing season of 2009 and 2010. The unplanted control lost almost 98 % of its initial buoyancy after seven months in contrast to vegetated reed-gabions which kept their buoyancy until the second growing season due to the aerenchyma tissue of their roots and rhizomes. The gabion planted with *Carex vesicaria* lost its buoyancy after one year. Although the fresh density of its below ground organs of 0.82 g cm^{-3} lead to a slower immersion of the reed-gabion, the overall density resulted in >1 g cm^{-3} due to the load of the above ground phytomass. *Phragmites australis* and a combination of four species (*Eriophorum angustifolium, Menyanthes trifoliata, Comarum palustre, Carex lasiocarpa*) retained their buoyancy. Their below ground organs had a fresh density of 0.68 g cm^{-3} and 0.63 g cm^{-3}, facilitating an overall density of <1 g cm^{-3} of the entire reed-gabion. The living underground phytomass contributed only 10-20 % to the total buoyancy of the reed-gabion. The majority of the buoyancy was provided by swamp gas generated due to anaerobic metabolisms enhanced by high oxygen consumption on account of the reed stalks. It can be concluded that the reed-gabion facilitated the development of auto-buoyant floating vegetation mats after the second year and would be suitable for providing long term enhancement of habitat diversity and water purification.

Keywords: Pond, riparian vegetation, wetland, vegetation technology

1. INTRODUCTION

Floating vegetation mats are used in treatment wetlands for water purification (Headley and Tanner, 2012; Kadlec and Bevis, 2009; Tanner and Headley, 2011) and for designing aquatic environments such as lake shorelines. Helophytes are set on floating structures such as artificial textile mats or rafts. Their roots hanging free in the water beneath those mats and provide high surface area for nutrient uptake, attached growth of microbial biofilms and entrapment of suspended solids from the water column (Smith and Kalin, 2000). Thus they provide a simple treatment technique for retrofitting artificial waterbodies, improve habitat diversity and add recreational and aesthetic benefits (Kerr-Upal et al., 2000; Knight et al., 2001). According to the European Water Framework directive (WFD) ninety percent of the water bodies in Germany have yet to achieve "good ecological status" and management measures are necessary. The main issues are: hydromorphological damage due to shipping, flood protection or hydro power and high levels input of nutrients due to farming or stormwater runoff from urban areas (BMU, 2013).

Large areas of floating vegetation mats are necessary to reduce the nutrient concentration significantly. In a channel with a flow rate of 100 m³/s a floating structure on both sides on a distance of 2 km was required to reduce the BOD from 8 mg O_2/l to 4 mg O_2/l. A time of 10-15 years is essential for the development of the vegetation (Oksijuk and Stolberg, 1986). Often floating structures receive their buoyancy from inert and non-rotting material, such as PE, PP, metals or synthetic foam. However inert materials do not facilitate biological activity thus they provide less water purification potential (Brauns et al., 2011).

Natural floating vegetation mats are part of early and late succession stages in the development of lakes (Tallis, 1983). The mats usually consist of pure organic material from living and dead phytomass of the mat building vegetation (Mitsch and Gosselink, 2007; Sasser et al., 1996). With time the floating mats develop natural auto-buoyancy and float freely on the water surface. The auto-buoyancy is caused by two "internal" (Kratz and DeWitt, 1986) factors: i). The air, contained in the aerenchyma tissue, can occupy more than sixty percent of the entire root volume (Crawford, 1983) and is regarded as the main cause for buoyancy of floating vegetation mats especially during the early stages of development (Hogg and Wein, 1988a; Kausch et al., 1981; Sculthorpe, 1985; Sjörs, 1983; Succow and Josten, 2001). ii) Anaerobic conditions in the mat and the underlying free water column arise because the mat hinders oxygen supply from the atmosphere, and reduces dissolved oxygen by decomposition of organic matter (Donselaar-Ten Bokkel Huinik, 1961; Haraguchi, 1992). The generated gases CH_4, $C0_2$ and N_2 are trapped as bubbles in the dense intertwined network of roots, rhizomes and decomposed organic matter (Fechner-Levy and Hemond, 1996; King, 1984). The floating islands in the Danube delta (Plaur) are estimated to float since more than hundred years (Rodewald-Rudescu, 1974). Different organic materials have varying recalcitrance and therefore resist decomposition more or less. The objective of this study is to test whether mats of dry reed-stalks provide buoyancy and which plant species compensate best for the expected loss of buoyancy?

2. METHODS

2.1 lifting body and vegetation

Panels of dry reed stalks of *Phragmites australis* (Hiss Reet) were cut to 65 cm length. Both basal parts and tips were used. Each reed-stalk had two truncated internodes on both ends leading to a volume and dry bulk density between 28.0 cm³ / 0.28 g cm^{-3} and 34.4 cm³/ 0.34 g cm^{-3}. The stalks were placed in two layers crosswise to each other, in order to achieve a sufficient strength to remain flat. The reed-stalks were assembled into reed-gabions using a annealed iron wire mesh (70 x 70 x 10 cm L x W x H). The resulting mass of an average reed-gabion was 7056.27 g with a dry bulk density of 0.39 g cm³.Helophytes were selected which have been known to occur on natural floating vegetation mats. *Phragmites australis* (PHAU) and *Carex vesicaria* (CAVE) were placed individually on the reed-gabion, *Eriophorum angustifolium*, *Menyanthes trifoliata*, *Comarum palustre* and *Carex lasiocarpa* were planted together as a society (ERIO). In addition a unplanted reed-gabion (SCHK) and open barrels (WASS) were surveyed.

2.2 Experimental setup

A gabion was placed in 8 repetitions of each type of water barrel (truncated cone, 100 cm diameter, 100 cm height, 480 l volume). An additional repetition of the variants CAVE-R, ERIO-R and PHAU-R was placed on an adjacent basin (24 m²). Starting in the vegetation period of 2010 the barrels were aerated to mix the water and introduce oxygen into the root zone. Buoyancy of each individual reed-gabion was measured using a force meter (±1N, Sauter) placed orthogonally to the gabions centre after it is pushed under the surface of the water. Buoyancy was measured using the "peak function" after the island was released and emerged back to the water surface. Aboveground phytomass was harvested and dried to constant weight at 80°C. Belowground phytomass was determined at the end of 2010 after harvesting the aboveground phytomass by cutting out a cylindric core of 10 cm in diameter. The sample was sorted according to the reed-stalks and to the plants living phytomass. Fresh density of the reed-stalks (excluding the air volume of their internodes) and the living phytomass was determined using the Archimedes´ principal in a calibrated glass cylinder (+-10 ml). Fresh weight and fresh volume are used to calculate fresh density of each material leading to an average total fresh density and total buoyancy of the reed-gabion (Formula 1).

Formula 1.

$$\rho_{total} = \frac{(m_{RG}+m_{BG}+m_{AG})}{(V_{RG}+V_{BG})}$$

m_{RG}: fresh mass reed-gabion (g)
m_{BG}: fresh mass below ground roots / rhizomes (g)
m_{AG}: fresh mass above ground phytomass (g)
V_{RG}: volume reed-gabion (cm³)
V_{BG}: volume roots / rhizomes (cm³)

The oxygen saturation was measured using an LDO Dissolved Oxygen Sensor (range 0.1 to 20.0 mg l^{-1}) and the pH with a pH sensor (range -2.0 - 14.0 pH) from Hach Lange. Water samples were taken at 10 cm depth of the water body and cooled until analysis. Ammonium, nitrate and phosphorus were determined on CFA (Continuous Flow Analyzer) and iron by atomic absorption spectrometry (AAS).

3. RESULTS

3.1 Buoyancy

The buoyancy measurements are summarized in Table 1. In June 2009 shortly after the gabions came on the water, a force of 139 N was required to keep them under water regardless of the species ($p > 0.05$).

Thus, buoyancy is provided by the dry stalks of the reed-gabions. The calculated weight force necessary to immerse all stalks used in a reed-gabion is between 158 N (dry bulk density 0.28 g cm^{-3}) and 117 N (dry bulk density 0.34 g cm^{-3}). The buoyancy of the unplanted variant (SCHK) decreased continuously and none of the repetitions remained floating, finally. CAVE lost 96.3 % of their initial buoyancy at the end of 2009. In contrast, ERIO and PHAU lost their buoyancy markedly slower and still had 6.6 % and 13.8 % of their initial buoyancy at the end of 2009. Their buoyancy even increased in the end of 2010 in tendency but not significantly. The single repetition in the adjacent basin behaved analogous to the experimental islands. CAVE-R also lost its buoyancy, while buoyancy of PHAU-R and the ERIO-R reincreased in the second year, enabling them to float over the entire experimental time.

Table 1. Buoyancy of the reed-gabions in N

Plant species	06/2009 (N)		10/2009 (N)		06/2010 (N)		10/2010 (N)	
	mean sd	n	mean sd	n	mean sd	n	mean sd	n
SCHK	140 ± 22	8	3 ± 2	5	2 ± 1	2	1 na	1
CAVE	150 ± 21	8	6 ± 4	7	5 ± 1	5	3 na	1
ERIO	151 ± 26	8	10 ± 5	6	15 ± 7	6	29 ±9	8
PHAU	153 ± 31	8	20 ± 7	4	12 ± 8	6	13 ± 9	6
CAVE-R	118	1	20	1	15	1	na	0
ERIO-R	167	1	22	1	14	1	17	1
PHAU-R	96	1	20	1	17	1	21	1

3.2 Living phytomass

Aboveground living phytomass in the period under survey was between 47.2 gDM m^{-2} (ERIO) to 317.4 gDM m^{-2} (CAVE) ($p < 0.05$), the belowground living phytomass is between 318.3 gDM m^{-2} (CAVE) and 763.9 gDM m^{-2} (PHAU) ($p < 0.05$). Thus, the ratio of above and belowground phytomass of CAVE is nearly balanced at 1:1, while belowground phytomass of PHAU and ERIO predominates 1:4 or 1:6 (Table 2).

Table 2. Total phytomass dry weight of the plants above- and below-ground phytomass developed in 2009 and 2010

Plant species	2009 Above-ground		2010 Above-ground		2010 Below-ground				
	DM ($g\ m^{-2}$)	Moist. (%)	DM ($g\ m^{-2}$)	Moist. (%)	DM ($g\ m^{-2}$)	Moist. (%)	Roots below gabion (%)	Fresh density ($g\ cm^{-3}$)*)	Ratio (b/a)
CAVE	55.9 ±7.6	61	317.4 ±42.7	65	318.3 ±42.9	87	9.46	0.82 ±0.0	1.05
ERIO	35.0 ±6.9	62	47.2 ±7.9	61	279.8 ±36.5	88	5.56	0.63 ±0.1	5.96
PHAU	67.1 ±11.7	54	199.1 ±22. 5	48	764.0 ±81.2	83	32.57	0.68 ±0.0	3.76
CAVE-R	87.4	61	363.7	72	585.7	87	13.4	0.80	1.61
ERIO-R	218.0	71	332.9	65	2966.7	83	21.91	0.76	8.91
PHAU-R	335.2	57	556.1	43	2088.1	86	28.99	0.73	3.75

3.3 Reed-stalks

The moisture of the reed-stalks in 2010 was 76.3 % regardless of the variant ($n = 35$, $p > 0.05$) resulting in a fresh density of 1.06 g cm^{-3}, thus the stalks lost their buoyancy. Dry matter loss was about 38 %, caused mainly due to the decomposition of leaf sheaths ($p < 0.05$). Their initial dry matter of 3.4 g ($n=30$) is reduced to 0.3 g ($n=37$), while dry matter of the recalcitrant organic matter remained approximately the same ($p > 0.05$).

3.4 Total density of the reed-gabions

Table 3 shows the fresh weight and volume of the reed stalks and the living belowground phytomass of the reed-gabion together with the resulting total density according to Formula 1. PHAU and the ERIO show a buoyancy (<1) while CAVE is negative (>1). ERIO-R and PHAU-R have developed a significantly higher phytomass, which reduces the overall density of less than one. The phytomass of CAVE-R is also even higher, leading to a loss of buoyancy.

Table 3. Total density of the reed-gabions according to formula1

	RG			**BG**			**AG**	**total**		**Buoyancy**	**ρ**
species	m (g)	V (cm^{-3})	P (gcm^{-3})	m (g)	V (cm^{-3})	ρ (gcm^{-3})	m (g)	m (g)	V (cm^{-3})	(N)	(gcm^{-3})
SCHK	16 123.8	15 274.3	1.06	na	na	na	na	16 123.8	15 274.4	-8.3	1.06
CAVE	17 110.1	16 200.8	1.06	1 206.3	1 467.3	0.82	441.0	18 734.9	17 668.1	-10.47	1.06
ERIO	15 157.3	14 143.9	1.07	2 358.3	3 743.3	0.63	60.0	17 572.9	17 887.2	3.1	0.98
PHAU	16 559.5	15 831.1	1.05	2 363.2	3 494.2	0.68	185.9	19 241.2	19 348.6	1.1	0.99
CAVE-R	16 183.6	15 124.9	1.07	2 246.0	2 807.5	0.80	636.7	19 006.3	17 932.4	-11.1	1.11
ERIO-R	14 929.6	14 218.7	1.05	8 609.7	11 395.1	0.76	460.8	24 000.1	25 613.8	15.8	0.94
PHAU-R	17 132.0	16 533.0	1.04	7 318.2	9 982.2	0.73	477.1	25 327.3	26 583.4	15.6	0.95

*(RG: reed-gabion; BG: below ground phytomass (roots + rhizomes); AG: above ground phytomass; m: mass; V: volume; buoyancy (N)= (V_t-m_t)*9.81m s^{-2}; ρ: fresh density)*

3.5 Water

Due to decomposition process in the reed-gabions reducing conditions developed in the barrels and dissolved oxygen decreased to 0 mg O_2 l^{-1} in September 2009 (16.5°C), while WASS contained 11 mg O_2 l^{-1}. Due to artificial ventilation during the growing season 2010 dissolved oxygen increased up to 7-8 mg O_2 l^{-1} in June 2010 (13.6°C). After aeration ceased, dissolved oxygen levels decreased to 1.4-2.8 mg O_2 l^{-1} in the upper layers and to 0 mg O_2 l^{-1} in the deeper layers in September 2010 (16.3°C). The pH value of the water was between pH 7 and pH 8 throughout the barrel.

4. DISCUSSION

4.1 Fresh density and buoyancy of the reed-stalks

The fresh density of all reed stalks is 1.06 g cm^{-3} regardless of presence or type of living plants. For reference humified peat is reported with a fresh density of 1.02 - 1.08 g cm^{-3} (Pousette 1965 in Erlingsson, 1996; Päivänen, 1969). Due to soaking up water the reed-gabions were nearly completely submerged in the water after 7 months. Anaerobic conditions inside the reed-gabions resemble water-saturated, peat soils. Obviously ninety percent of the leaf sheaths were decomposed after 36 months, while the reed-stalks still showed no significant dry matter loss. In general the easily degradable organic matter is decomposed in the first two months (Swift et al., 1979). Thereafter, the proportion of persistent compounds increases, resulting in a decreasing decomposition rate (Olson, 1963; Wider and Lang, 1982). The decomposition rate is strongly affected by lignin content (Richert, 2001), which is extremely stable especially under anaerobic conditions (Collberg, 1988). The lignin content of reed stalks as used for the reed-gabion is about 24 % (Rodewald-Rudescu, 1974). Because the density of the reed stalks almost reached the density of strongly decomposed peat, no major increase of the density is to be expected if the anaerobic conditions in the reed-gabion are preserved in the future. Thus, the value of the reed-stalks fresh density of 1.06 g cm³ can be used for the subsequent calculation of the total density together with the living phytomass.

4.2 Fresh density and calculated buoyancy of the living phytomass

After 36 months CAVE developed an above and belowground dry mass of 317.4/ 318.31, ERIO 47.2/ 279.78 und PHAU 199.1/ 763.95 gDM m^{-2}. However the phytomass of the variants in the adjacent basin exceeded this masses: CAVE-R: 363.7/ 586, ERIO-R: 332.9/ 2 967, PHAU-R: 556.1/ 2 088 gDM m^{-2}. In natural stands belowground phytomass reaches values from 3000 to 6000 gDM m^{-2} (Dykyjova and Hradecka, 1973; Fiala, 1976; Kvet and Westlake, 1998). Depending on species, a period of 3-6 years is required to reach this mass. In hydroponic experiments using artificial nutrient solution *P. australis* developed an belowground phytomass of 493 gDM m^{-2} in the first year, the second 2730 gDM m^{-2} and the third 8886 gDM m^{-2} (Dykyjova and Veber, 1978). The majority of the phytomass is developed as belowground organs (Hejny, 1960; Pallis, 1917; Sculthorpe, 1985; Westlake, 1965). Thus the variant´s below ground phytomass in the basin are nearly reaching the literature data (Figure 1). Obviously the reed-stalks used for the gabions led to less favorable site conditions in the barrels. Thus belowground phytomass and buoyancy development was reduced. Additionally, unfavorable site conditions are caused due to the oxidation / reduction of the wire mesh in the aerobic/ anaerobic environment. In September 2010 the iron content in the water barrels reached values between 1.1- 3.7, in the adjacent basin (-R) 1.0 mg Fe l^{-1} and no iron could be detected in the water variant WASS. The lack of oxygen below any gabion indicates, that this iron is ferrous iron. The iron content in the water barrels correlates with the value of phosphorus (P_{mean} = 0,7 mg l^{-1}, $R^2 = 0.87$). Thermodynamic calculations indicate that the solubility of vivanite - a ferrous iron phosphate - is exceeded by a factor of at least 12 in all waters which contain gabions in September of 2010. No further speciation of iron and phosphorus was done. We therefore hypothesize that most of the phosphate is not available to the plant roots due to precipitation as vivianite in the water barrels. Ratios of N and P concentrations in the plants above ground phytomass also indicates phosphorus limitation (data not shown here).

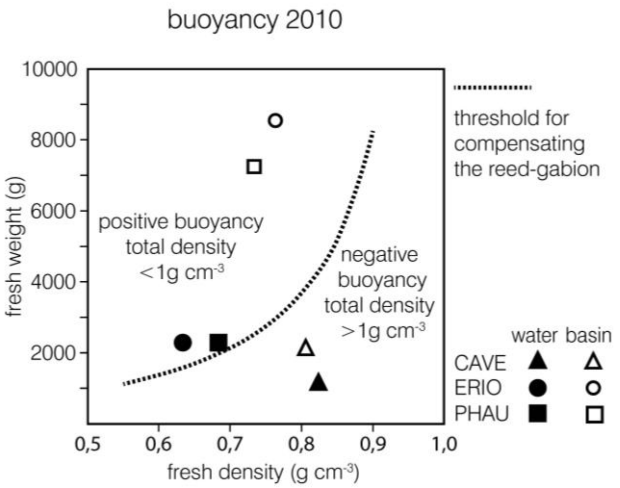

Figure 1.Threshold of fresh weight and fresh density for compensating buoyancy of the reed-gabion (m=16213 g; ρ: 1.06 g cm^{-3}) shown together with the fresh weight and fresh density of the species under investigation.

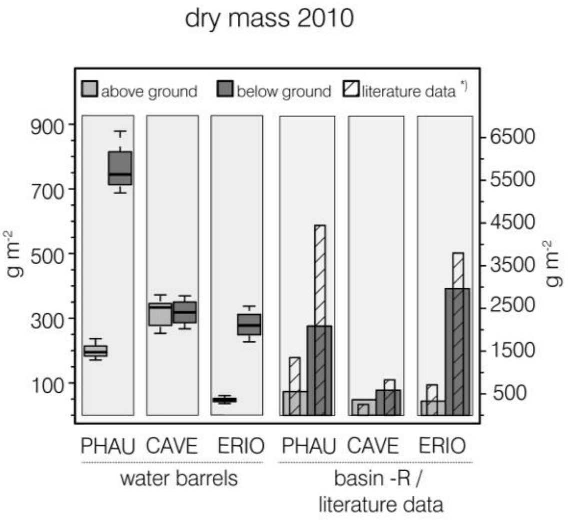

Figure 2.above- and belowground standing phytomass *)authors of literature data: (Bernard and Fiala, 1986; Dykyjova and Veber, 1978; Fiala, 1976; Sjörs, 1991; Soukupova, 1994)

The fresh density of the plant´s underground organs is less than that of water due to their aerenchyma tissue (Gessner, 1959; Iversen, 1949; Smirnoff and Crawford, 1983). Highest fresh density of the species studied is that of CAVE with values of 0.8 g cm^{-3}. At the same time this species has the lowest porosity (percentage of air filled volume) of 11.6 to 22.1 % (Koncalova, 1990) and does not expand its tissue under anaerobic conditions (Soukupova, 1994). The fresh density of the belowground organs of PHAU is 0.7 g cm^{-3}. The porosity of the aerenchyma tissue is much higher coming up with 23 to 60 % in the rhizomes (Gries et al., 1990; Justin and Armstrong, 1987). The ERIO belowground organs consist of the 4 species used, species specific porosity is between 10 % and 70 % (*C. lasiocarpa*: 20,4 % (Lu, 2011), *E. angustifolium*: 42 %; *Comarum palustre*: 10 % (Crawford, 1982; Crawford, 1983) *Menyanthes trifoliata*: 69 % (Coult, 1964)), and thus result in the lowest fresh density of 0.6 g cm^{-3}. Little information can be found on the measurement of fresh density of helophyte species in literature. Values for *P. australis* are reported with <0.8 g cm^{-3} (Iversen, 1949) and for *Typha glauca* with 0.58- 0.73 g cm^{-3} (Hogg and Wein, 1988b). Due to the amount and fresh density of its belowground organs PHAU is able to compensate the loss of the reed-stalks buoyancy with a buoyancy of 1.1 N per island. In this ERIO even achieves a buoyancy of 3.1 N for each island. Although belowground phytomass of CAVE does have a density of less than one, its aboveground weight is too large for buoyancy (Table 3, Figure 2). Therefore harvesting of aboveground phytomass in 2009 reduced the load, and the buoyancy of the reed-gabion increased. But aboveground phytomass development in 2010 resulted in a complete loss of the variants buoyancy. However, the unplanted control lost its buoyancy already after 7 months.

4.3 Buoyancy measurements

While buoyancy measurement is 13.2 N for PHAU and 28.6 N for ERIO, the calculated buoyancy based on the living phytomass is only 1.1 N for PHAU and 3.1 N for ERIO. Thus only a small proportion (7-10 %) of the measured buoyancy can be explained with the living phytomass. The major part, a difference of 12.2 N for PHAU and 25.5 N for ERIO must have arised from other factors. The main factor for buoyancy is the swamp gas entrapped in the floating mats (Fechner-Levy and Hemond, 1996; King, 1984). In a 20-year old floating *Typha*-mat Hogg and Wein (1988a) concluded that 92 % of the total buoyancy is provided by the swamp gas. Due to the high solubility of CO_2 this is assumed to consist mainly of methane. The difference between total buoyancy and calculated buoyancy lies within these values (PHAU 92 %, ERIO 89 %). We could not determine the amount and quality of swamp gas, but when measuring total buoyancy of ERIO, gas bubbles escaped. This pathway for swamp gas is called "episodic ebullution" (Coulthard et al., 2009). The amount of gas trapped in the pores of water-saturated organic soils and floating vegetation mats was specified to be about ten percent of the soil volume (Hogg and Wein, 1988b; Kiene, 1991) which would correspondent to 1500 ml in our gabions and provides a buoyancy of 14.7 N that equals to the difference of buoyancy of the PHAU. ERIO should have an even greater amount of swamp gas within the reed-gabion. The dense intertwined roots in organic soils may be spaces in which a large amount of gas is produced and retained in the form of gas bubbles (Christensen et al., 2003; Coulthard et al., 2009). The amount of storage of gas bubbles in organic soils as well as plant-specific characteristics influences are still under discussion (Coulthard et al., 2009; Glaser and Chanton, 2009). In stands of *E. angustifolium* a particularly high gas bubble formation was observed (Green and Baird, 2012). *C. lasiocarpa* forms fine roots on its entire belowground organs (Bernard and Fiala, 1986) whose dense network can serve as a surface for the formation and entrapment of gas bubbles. Thus the high difference of calculated and measured buoyancy of ERIO may be due to a plant specific high gas production and storage in the dense root network inside the reed-gabion.

5. CONCLUSION

The reed-gabion is suitable for initiating auto-buoyant floating vegetation mats. Due to the vegetation, the former reed-gabion becomes an organic mat densely perfoliated by the roots and rhizomes. Contrary to the initial assumption, swamp gas can already provide up to ninety percent of the total buoyancy in the second year of development. The gas is generated under the anaerobic conditions caused by the microbial decomposition of the organic matter. Thus the reed-gabion passes into stable self-preservation ensuring permanent auto-buoyancy.

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REFERENCES

Bernard, J.M., Fiala, K. 1986, Distribution and standing crop of living and dead roots in three wetland Carex species. *Boll. Tor. Bot. Clb.*, **113**, 1-15.

BMU - Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit 2013, *Die Wasserrahmenrichtlinie. Eine Zwischenbilanz zur Umsetzung der Maßnahmenprogramme 2012.* 36p.

Brauns, M., Gücker, B., Wagner, C., Garcia, X.-F., Walz, N., Pusch, M.T. 2011, Human lakeshore development alters the structure and trophic basis of littoral food webs. *J. Appl. Ecol.*, **48**, 916-925.

Christensen, T.R., Panikov, N., Mastepanov, M., A. Joabsson, A. Stewart, M. Öquist, Sommerkorn, M., Reynaud, S., Svensson, B. 2003, Biotic controls on CO2 and CH4 exchange in wetlands - A closed environment study. *Biogeochemistry*, **64**, 337-354.

Collberg, P. 1988, *Anaerobic Microbial Degradation of Cellulose, Lignin, Oligolignols, and Monoaromatic Lignin Derivatives*. In: Zehnder, A.J.B. ed. *Biology of anaerobic microorganisms*, New York. 333-372p.

Coult, D.A. 1964, Observations on Gas Movement in the Rhizome of Menyanthes trifoliata L., with Comments on the Role of the Endodermis. *J. Exp. Bot.*, **15**, 205-218.

Coulthard, T.J., Baird, A.J., Ramirez, J., Waddington, J.M. 2009, *Modeling methane dynamics in peat: Importance of shallow peats and a novel reduced-complexity approach for modeling ebullition*. In: Baird, A.J. ed. *Carbon Cycling in Northern Peatlands* 184, AGU, Washington, D. C.. 173-185p.

Crawford, R.M.M. 1982, *Physiological responses to flooding*. In: Lange, O.L. ed. *Physiological Plant Ecology II*, Berlin. 453-477p.

Crawford, R.M.M. 1983, *Root survival in flooded soils*. In: Gore, A.J.P. ed. *Mires: Swamp, Bog, Fen and Moor. General studies. Ecosystems of the world 4A.*, Amsterdam. 257-283p.

Donselaar-Ten Bokkel Huinik, W.A.E.v. 1961, An Ecological Study of the Vegetation in three former River Beds. *Wentia*, **5**, 112-162.

Dykyjova, D., Hradecka, D. 1973, Productivity of reed-bed stands in relation to the ecotype, microclimate and trophic condition of the habitat. *Pol. Arch. Hydrobiol.*, **20**, 111-119.

Dykyjova, D., Veber, K. 1978, *Experimental Hydroponic Cultivation of Helophytes*. In: Dykyjová, D., Květ, J. eds. *Pond littoral ecosystems. Structure and Functioning*. *Ecological Studies. Analysis and Synthesis* 28, Berlin. 181-192p.

Erlingsson, U. 1996, *The Arenal Reservoir, Appendix 3: The "Gamalote" Floating Islands Problem*. Report for AB Hydroconsult, Uppsala, Sweden, for the Instituto Costarricense de Electricidad, Cost Rica. 20p.

Fechner-Levy, E.J., Hemond, H.F. 1996, Trapped Methane Volume and Potential Effects on Methane Ebullition in a Northern Peatland. *Limnol. Oceanogr.*, **41**, 1375-1383.

Fiala, K. 1976, Underground organs of Phragmites communis: their growth, biomass, and net production. *Folia Geobot. Phytotaxon.*, **11**, 225-259.

Gessner, F. 1959, *Hydrobotanik: Die physiologischen Grundlagen der Pflanzenverbreitung im Wasser* Band 2: Stoffhaushalt. VEB Deutscher Verlag der Wissenschaften, Berlin. 701p.

Glaser, P.H., Chanton, J.P. 2009, *Methane Accumulation and Release From Deep Peat: Measurements, Conceptual Models, and Biogeochemical Significance*. In: Baird, A.J. ed. *Carbon Cycling in Northern Peatlands* 184, AGU, Washington, D. C. . 145-158p.

Green, S.M., Baird, A.J. 2012, A mesocosm study of the role of the sedge Eriophorum angustifolium in the efflux of methane -including that due to episodic ebullition- from peatlands. *Plant Soil*, **351**, 207-218.

Gries, C., Kappen, L., Losch, R. 1990, Mechanism of flood tolerance in reed, Phragmites australis (Cav.) Trin.ex Steudel. *New Phytol.*, **114**, 589-593.

Haraguchi, A. 1992, Seasonal change in the redox property of peat and its relation to vegetation in a system of floating mat and pond. *Ecol. Res.*, **7**, 205-212.

Headley, T.R., Tanner, C.C. 2012, Constructed Wetlands With Floating Emergent Macrophytes: An Innovative Stormwater Treatment Technology. *Crit. Rev. Environ. Sci. Technol.*, **42**, 2261-2310.

Hejny, S. 1960, *Ökologische Charakteristik der Wasser- und Sumpfpflanzen in den Slowakischen Tiefebenen (Donau- und Theissgebiet)*. Verlag der Slowakischen Akademie der Wissenschaften, Bratislava. 488p.

Hogg, E.H., Wein, R.W. 1988a, The contribution of Typha components to floating mat buoyancy. *Ecology*, **69**, 1025-1031.

Hogg, E.H., Wein, R.W. 1988b, Seasonal Change in Gas Content and Buoyancy of Floating Typha Mats. *J. Ecol.*, **76**, 1055-1068.

Iversen, J. 1949, Determinations of the specific gravity of the roots of swamp. *Oikos*, **1**, 1-5.

Justin, S.H.F.W., Armstrong, W. 1987, The anatomical characteristics of roots and plant response to soil flooding. *New Phytol.*, **106**, 465-495.

Kadlec, R.H., Bevis, F.B. 2009, Wastewater treatment at the Houghton Lake wetland: Vegetation response. *Ecol. Eng.*, **35**, 1312-1332.

Kausch, A.P., Seago, J.L., Marsh, L.C. 1981, Changes in starch distribution in the overwintering organs of Typha latifolia (Typhaceae). *Am. J. Bot.*, **68**, 877-880.

Kerr-Upal, M., Seasons, M., Mulamoottil, G. 2000, Retrofitting a stormwater management facility with a wetland component. *J. Environ. Sci. Health*, **A35**, 1289-1307.

Kiene, R.P. 1991, *Production and consumption of methane in aquatic systems*. In: Rodgers, J.E., Whitmann, W.B. eds. *Microbial production and consumption of greenhouse gases: methane, nitrogen, oxides and halomethanes*, Washington D.C. 111-146p.

King, G.M. 1984, *Methane Production in Okefenokee Peats*. In: Cohen, A.D., Casagrande, D.J., Andrejko, M.J., Best, G.R. eds. *The Okefenokee Swamp: Its natural History, Geology, and Geochemistry*, Los Alamos, NM. 371-379p.

Knight, R.L., Clarke, R.A., Bastian, R.K. 2001, Surface flow (SF) treatment wetlands as a habitat for wildlife and humans. *Water Sci. Technol.*, **44**, 27-37.

Koncalova, H. 1990, Anatomical adaptations to waterlogging in roots of wetland graminoids: limitations and drawbacks. *Aquat. Bot.*, **38,**, 127-134.

Kratz, T.K., Dewitt, C. B. 1986, Internal Factors controlling peatland-lake ecosystems development. *Ecology*, **67**, 100-107.

Kvet, J., Westlake, D.F. 1998, *Primary production in wetlands*. In: Westlake, D.F., Kvet, J., Szczepanski, A. eds. *The production ecology of wetlands. The IBP Synthesis*, Cambridge. 77-168p.

Lu, Y. 2011, Growth and morphological responses to water level variations in two Carex species from Sanjiang Plain, China. *Afr. J. Agr. Res.*, **6**, 28-34.

Mitsch, W.J., Gosselink, J.G. 2007, *Wetlands* 4ed. John Wiley & Sons, New Jersey. 735p.

Oksijuk, O.P., Stolberg, F.W. 1986, *Upravlenie kacestvom vody v kanalach - [Control of water quality in canals] (in Russian). Naukova Dumka Kiev*. 173p.

Olson, J.S. 1963, Energy Storage and the Balance of Producers and Decomposers in Ecological Systems. *Ecology*, **44**, 322-331.

Päivänen, J. 1969, The bulk density of peat and its determination. *Silva Fenn.*, **3**, 1-19.

Pallis, M. 1917, The structure and history of Plav: the floating fen of the danube. *J. Linn. Soc.*, **43**, 233-291.

Richert, M. 2001, *Wurzelabbau und seine Bedeutung für die Torfbildung*. In: Kratz, R., Pfadenhauer, J. eds. *Ökosystemmanagement für Niedermoore. Strategien und Verfahren zur Renaturierung*, Stuttgart. 120-124p.

Rodewald-Rudescu, L. 1974, *Das Schilfrohr Phragmites communis Trinius.* In: Thienemann, A. ed. *Die Binnengewässer. Einzeldarstellungen aus der Limnologie und ihren Nachbargebieten* 27, Stuttgart. 302p.

Sasser, C.E., Gosselink, J.G., Swenson, E.M., Swarzenski, C.M., Leibowitz, N.C. 1996, Vegetation, Substrate and Hydrology in Floating Marshes in the Mississippi River Delta Plain Wetlands, USA. *Vegetatio,* **122**, 129-142.

Sculthorpe, C.D. 1985, *The biology of aquatic vascular plants.* Edward Arnold, London. 610p.

Sjörs, H. 1983, *Mires of Sweden*. In: Goodall, D.W. ed. *Mires: Swamp, Bog, Fen and Moor. Regional studies. Ecosystems of the world 4B.*, Amsterdam. 69-94p.

Sjörs, H. 1991, Phyto- and Necromass above and below Ground in a Fen. *Holarctic Ecology,* **14**, 208-218.

Smirnoff, N., Crawford, R.M.M. 1983, Variation in the Structure and Response to Flooding of Root Aerenchyma in some Wetland Plants. *Ann. Bot.,* **51**, 237-249.

Smith, M.P., Kalin, M. 2000, *Floating Wetland Vegetation Covers for Suspended Solids Removal*, pp. 143-148 in HILL, C.M. *Proceedings of the Quebec 2000: Millennium Wetland Event (Selected Papers), "Treatment Wetlands for Water Quality Removal". Quebec City, Canada. 6-12.08.2000*

Soukupova, L. 1994, Allocation Plasticity and Modular Structure in Clonal Graminoides in Response to Waterlogging. *Folia Geobot. Phytotaxon.,* **29**, 227-236.

Succow, M., Josten, H. 2001, *Landschaftsökologische Moorkunde*, Edit. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart. 622p.

Swift, M.J., Heal, O.W., Anderson, J.M. 1979, *Decomposition in Terrestrial Ecosystems*. *Studies in Ecology* 5. University of California Press. 372p.

Tallis, J.H. 1983, *Changes in wetland communities*. In: Gore, A.J.P. ed. *Mires: Swamp, Bog, Fen and Moor. General studies. Ecosystems of the world 4A.,* Amsterdam. 311-347p.

Tanner, C.C., Headley, T.R. 2011, Components of floating emergent macrophyte treatment wetlands influencing removal of stormwater pollutants. *Ecol. Eng.,* **37**, 474-486.

Westlake, D.F. 1965, Some basic data for investigations of the productivity of aquatic macrophytes. *Mem. Inst. Idrobiol.,* **18**, 229-248.

Wider, R.K., Lang, G.E. 1982, A critique of tha analytical methods used in examining decomposition data obtaind from litter bags. *Ecology*, **63**, 1636-1642.