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NATURAL WATER TREATMENT METHOD FOR INTENSIVE AQUACULTURE EFFLUENT PURIFICATION

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ABSTRACT
Several intensive flow-through fish production plants were established in Hungary in the last decades, representing a significant share of the total fish production. However, the full management of the discharged waste from such systems is still unsolved. Searching new sustainable methods for treatment and utilisation of output nutrients a pilot-scale constructed wetland system was built in Szarvas in 2000. The pilot-scale system consisted of two subsystems (total area of 1.4ha) of similar structure: one stabilisation pond and one fishpond connected serially; the water was channelled from the fishpond into macrophyte ponds (surface-flow wetlands) and additionally spread on one irrigated field. The nutrient removal of the wetland units was most efficient in the case of organic carbon in the subsystem "A"; for all nutrients the removal efficiency reached 90%, except for the phosphorus in the "A" subsystem, where the lowest efficiency was found (80%).
KEYWORDS: aquaculture, constructed wetland, macrophyte, water treatment, nutrient

INTRODUCTION

Aquaculture is a growing agriculture sector, which is bounded to the natural environment through diversified relationships. Fish production is impossible without the necessary water volume and quality; however recipient water bodies are endangered through nutrient discharge from fish production systems. Especially by intensive aquaculture is used large water volume and high protein content in feed resulting in significant amount of nutrient rich effluents. Except of closed recirculation systems, the used water is partly or completely channelled into the natural waver bodies. Therefore it is highly urgent to develop and expand the treatment measures of aquaculture effluents and minimize its adverse impact to the environment.

In Hungary approximately 14 percent of the total fish production originates from intensive flow-through systems (Pintér, 2007). Since the establishment of intensive production plants the environmental legislation and the social requirements have been changed. To obtain and maintain good water quality in natural water bodies is a highlighted objective of European and national legal regulation and NGO-s because the quality and quantity of freshwater recourses is one of the key factors of healthy human life. The discharged effluents cause eutrophication and deterioration of natural recipient ecosystems and furthermore the Nutrient Loading Fee is a remarkable incurring charge, these arguments force the producers to find efficacious and cost-effective treatment methods.

In the last decades the constructed wetlands have been rediscovered as effective method for waste water treatment. In wetland ecosystems the pollutant content is diminished by natural processes using renewable energy sources. The discharged suspended solids are settled and converted into soluble nutrients which are utilized though the organisms of wetlands. Constructed wetlands are sustainable technologies since:

- are effective in pollutant removal;
- minimal amount of fossil energy and chemicals are necessary;
- construction costs are lower, operation and maintenance costs considerable lower than those of artificial treatment systems;
- fit well into the natural environment and their notable aesthetical value results in higher acceptance under the society;
- creation of wetland habitats helps in preserving of rare wetland species.

With the combination of different wetland types the nutrient removal efficiency can be enhanced, furthermore by the integration of valuable species the nutrients are converted into marketable by-products. Stocking fish into a unit a certain proportion of discharged nutrient are reused in fish flesh and the necessary dissolved oxygen level ensures adequate conditions for aerobic processes. Several macrophytes tolerating the applied water level assimilate considerable quantity of biomass which is suitable for energy production or biofuel preparation. Some plant species serve as recourses in the chemical, cosmetic, construction and food industry.

Constructed wetlands were applied firstly in environmental restoration preventing polluted inflow into protected wetlands, later for treatment of municipal and industrial waste waters. The utilisation of constructed wetlands for agricultural effluents and liquids has not a long tradition. Numerous constructed wetlands are reported for aquaculture waste treatment in North America (Tilley et al., 2002.), and Europe (Schulz et al., 2003) Asia (Lin et al., 2005), however their application is not widespread.

In the African Catfish Site (ACS) module the treatment of effluent water of a flow-through African catfish farm was implemented in the series of different wetland types: stabilisation pond, fishpond and surface-flow wetlands. The objectives of the case study were: to purify the intensive aquaculture effluent efficiently by retaining significant amounts of discharged nutrients; to use the wasted nutrients as resources for the production of economically valuable crop cultivation, which generates an additional income for the fish farmers.

MATERIAL AND METHODS

Description of site studied

The African Catfish Site (ACS) is located at the Experimental Pond System of the Research Institute for Fisheries, Aquaculture and Irrigation (HAKI) in Szarvas, Hungary. A pilot-scale wetland system was constructed to treat effluent water of an intensive flow-through African catfish farm in 2000 (Subsystem 'A'). The total area of 1.1 hectare was able to receive 15% of the total discharged water volume of the intensive fish farm. Another 0.4 ha area was involved in the water treatment in 2007 (Subsystem 'B') (Figure 1). The wetland subsystems were constructed by the combination of a stabilisation pond, a fishpond and macrophyte pond units. The ponds were filled up with stored freshwater originating from the nearby oxbow lake of River Körös at the beginning of the operation period (May in 2007, February in 2008).

The effluent from the African catfish farm was channelled into the aerated stabilisation pond, where a paddle wheel aerator was operated and supplement river water was added. The water from the stabilisation pond was introduced into the fishpond unit, where a certain part of the nutrients were retained in fish biomass. The effluent from the fishpond unit was channelled into 4 surface-flow constructed wetlands planted with different energy plants: common reed (*Phragmites australis*), cattail (*Typha latifolia* and *angustifolia*), willow (*Salix viminalis*), giant reed (*Arundo donax*) and saltcedar (*Tamarix tetrandra*).

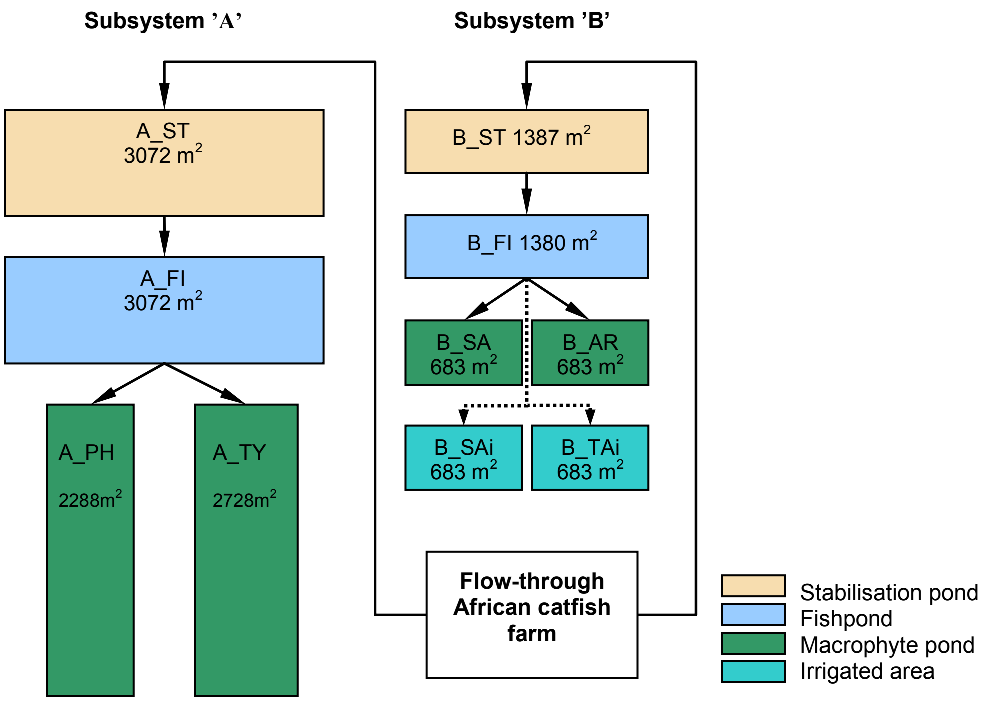

Fig 1: Schematic picture of the ACS case study design

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Table 2. Stocking characteristics in the fishpond units

Unit	Species	Stocking				Total weight (kg)	
		number (ind)		weight (g/ind)			
		2007	2008	2007	2008	2007	2008
A_FI	Common carp 1y	1250	1644	40	61	50	100
	Common carp 2y	143	-	350	-	50	-
	Grass carp	25	100	1700	80	42.5	8
	Silver carp	1500	123	100	1220	150	150
	Total	*2918*	*1867*	-	-	*292.5*	258
B_FI	Common carp 1y	625	822	40	61	25	50
	Common carp 2y	71	-	350	-	25	-
	Grass carp	15	50	1700	80	25.5	4
	Silver carp	710	61	100	1220	71	75
	Total	*1421*	*933*	-	-	*146.5*	*129*

The calculated hydraulic retention time was 18 days in each wetland unit. Two additional irrigated fields were connected to the Subsystem 'B' in 2008, where water level was maintained under the surface and sodium remediation capacity of energy willow and giant reed was examined. The average water depth in the stabilisation and fishponds was 1.2 m, and 0.5 m in the macrophyte ponds. Fish were stocked in polyculture: at stocking density of 900 kg/ha; 35% common carp (*Cyprinus carpio*), 60% silver carp (*Hypophthalmichthys molitrix*) and 5% grass carp (*Ctenopharyngodon idella*) in April and May (Table 2). The fish stocking structure was chosen to achieve the water treatment goals and to utilise the different natural food sources as effective as possible. There was no artificial feeding applied in fishponds. The fishponds were harvested in November, the water was drained and the bottom kept dry in winter (from November till February) (Table 3).

Table 3. Main features of the experimental units

Unit	Area	Water depth	Species	Comments
A_ST	3072 m^2	1.2 m	Duckweed (*Lemna* sp.)	Regularly removed
A_FI	3072 m^2	1.2 m	Carp polyculture	Stocked in April Harvested in November
A_PH	2288 m^2	0.5 m	common reed (*Phragmites australis*), duckweed	Harvested in November
A_TY	2728 m^2	0.5 m	cattail (*Typha latifolia*, *T. angustifolia*)	Harvested in November
B_ST	1387 m^2	1.2 m	Duckweed (*Lemna* sp.)	Regularly removed
B_FI	1380 m^2	1.2 m	Carp polyculture	Stocked in April Harvested in November
B_SA	683 m^2	0.5 m	Willow (*Salix viminalis*), *Typha* sp.	Planted in 2006, insufficient growth of willow, cattail invasion
B_AR	683 m^2	0.5 m	Giant reed (*Arundo donax*), *Typha* sp.	Planted in 2006, insufficient growth of giant reed, cattail invasion
B_SAi	683 m^2	n.a.	Willow (*Salix viminalis*)	Planted in 2007, irrigated with the outflow water from the fishpond (B_FI)
B_TAi	683 m^2	n.a.	saltcedar (*Tamarix tetrandra*)	Planted in 2007, irrigated with the outflow water from the fishpond (B_FI)

Water temperature, conductivity, pH and dissolved oxygen concentrations were measured with portable meters (WTW, model Oxi 315i; YSI 556 Multi Probe System) in situ three times a week at 10.00 a.m. Water samples were collected using a horizontal water sampler for laboratory analysis on biweekly basis between 09.00 and 10.00 a.m. Nutrient concentrations of the filling-up and make-up water were also determined, when they were supplied. During fish harvest, drainage water samples were collected from each pond when pond water levels were 80, 50 and 30 cm. Sediment samples were collected from five locations in each pond two times a year: at the beginning of the experiment and after harvesting. PVC tube with a diameter of 5 cm was used to take undisturbed sediment samples from the upper 7.5 cm sediment layers. The periphyton samples has been collected from epyphalotical (plastic pipes) habitats, samples of artificial substrates are taken fortnightly between May and September in both years. The effective fuel values of the harvested plant samples were measured by the TTZ Laboratory (Bremerhaven, Germany).

To examine the sodium remediation of plant species willow (*Salix viminalis*) and saltcedar (*Tamarix tetrandra*) two irrigated area were connected to the Subsystem 'B' in 2008. The effluent water was dosed relatively low amount in irrigated fields, because the depth of rainfall was high in this year, the total precipitation was 250 mm in the growing period. The total amount of irrigation was 80 mm, which were dosed at 8 times. The main irrigation time was in July and August. The soil samples were collected by Eijkelkamp type manual auger at spring and autumn season in 5 point from the 20cm upper layer of the soil, because there was an impermeable clay layer under the 20cm layer of the soil. The samplings of the water were per 30 days and 6 times. The analysis of pH, total salt, $CaCO_3$ were measured by the standard of MSZ-08-0206-2:1978, the K_A by the method of MSZ-08-0205:1978 standard, the organic content (OM) by MSZ-08-0210-2:1977, the nitrate-N: MSZ-20135:1999 were determined. The P_2O_5, K_2O content and Cu, Zn, Mn, Na elements of soils samples were analysed: with atomic absorption and by the method of MSZ 20135 (Hungarian standard). The elements (Ca, K, Mg, Na, P) of plant and water samples were determined by ICP technology (Application note by Thermo Scientific: 40756, 40755). The nitrogen content was measured by Kjeldahl method (MSZ EN ISO 5983-1:2005).

RESULTS AND DISCUSSION

In the effluent treatment system energy crops were cultivated as valuable by-products, since utilising them as fuel a considerable renewable energy source is produced. The plants were harvested in the macrophyte ponds in December 2007, the total biomass weighted 8,320 kg (Table 5). The harvested macrophyte biomass was estimated to 31,690 kg in 2008. The cattail showed the highest growing rate and the lowest rate was found for the willow plantation. In giant reed and willow ponds a strong spontaneous cattail growth occurred suppressing the development of planted species. Common reed had the highest fuel values with an average of 11,372 J/g. Willow had a value of 9,699 J/g. Cattail and giant reed showed comparatively low fuel values of 9,214 J/g and 8,611 J/g. High correlation between water content, harvesting time and heating value is clearly showed by Paist (2005). Within the seasons of autumn, winter and spring, the heating value was nearly doubling for reed and growing by 45% for cattail, while the water content was decreasing. These results indicate, to gain the highest heating value, between March and April is the best time in the year for the harvesting the wetland grops,0as the water content is |he lowest at that period and accordingly the calorific value is comparatively high.

Other scientific experiments indicate a much higher heating value for willow wood as the presented results, ranging from 16,169 to 22,572 J/g (Klasnja et al. 2002) for *Salix alba*, or 18,550 to 19,560 J/g for *Salix sp.,* including *Salix viminalis* (Szczukowski et al. 2002). In these articles, the harvesting date is not indicated, suggesting a similar reason for the lower values of SustainAqua like with reed and cattail. However, further reasons can lie in the insufficient growing behaviour of *Salix viminalis* in the Hungarian case study with growth rates of 1,5 m instead the usual 2,5 m. Similarly, higher heating values of up to 18,850 J/g are reported for *Arundo donax* in literature (Miles et al. 1995). However, it needs to be considered that the overall purpose of the wetland crops in the frame of SustainAqua was to purify wastewater from aquaculture. The cited research activities grew willow as energy crop in short-rotation plantations with optimal conditions.

Table 5: The harvested biomass and the fuel values of the plant species in ACS

Species	Biomass	Biomass	Effective fuel value	Total fuel value
	kg	kg/ha	J/g	MJ
Phragmites australis	2,440	10,664	11,372	27,747
Typha latifolia,T. angustifolia	3500	12,830	9,214	32,250
Typha sp. B_Sa	870	12,738	9,214	11,082
Typha sp. B_Ar	910	13,324	9,214	12,125
Salix viminalis	150	2,196	9,699	329
Arundo donax	450	6,589	8,611	2,965
Total	**8,320**	**10,738**	**-**	**86,498**
2008				
Phragmites australis	6¬254	27,333	11,³72	71,119
Typha latifolia,T. angustifolia	18,141	66,500	9,214	167,157
Typha sp. B_Ar	3,106	45,466	9,214	28,620
Salix viminalis	797	11,667	9,699	7,729
Arundo donax	776	11,367	8,611	8,682
Salix viminalis (irrigated)	2,277	33,333	9,699	75,899
Tamarix tetrandra (irrigated)	342	5,000	no data available	-
Total	31,692	40,903	-	359,207

Water input

Input water was introduced into the experimental system from two sources: African catfish farm effluent to be treated and river water from the River Cris to fill up ponds, supply oxygen and algae to the stabilisation ponds during the operation. The ponds were filled up initially with river water from the nearby branch of River Cris. The majority of the river water was used for filling up (13,829 m^3 in 2007; 11,173 m^3 in 2008); another 10,037 m^3 in 2007 and 17,089 m^3 in 2008 was added during the operation to the stabilisation ponds. The daily water consumption was in average 65.6 m^3 and 69.5 m^3 in 2007 and 2008, respectively. The theoretical daily volume was calculated because refreshing water input was supplied not routinely, only in case of unfavourable oxygen regime. The specific refreshing water consumption was computed for the treatment system and it was found that for 1 m^3 aquaculture effluent treatment 0.159-0.274 m^3 river water was used during the operation and altogether (with the initial filling up) 0.279-0.453 m^3 was applied (Table 6). After filling up started the aquaculture effluent introduction, in average 407 and 256 m^3/day effluent was added to the treatment wetland system in 2007 and 2008, respectively. The water volume was decreased in 2008, because the applicated load exceeded the treatment capacity of the system in 2007.

Table 6: Characteristics of input water sources and the specific water consumption

Input		Volume		Specific water consumption	
				operational	total
		m^3	m^3/day	m^3/effluent m^3	
2007	Aquaculture effluent	63,021	407	-	-
	River water	23,866	-	0.159	0.379
2008	Aquaculture effluent	62,375	256	-	-
	River water	28,226	-	0.274	0.453

The African catfish farm effluent was characterized by high relative conductivity due to the high sodium concentration in the used groundwater by the intensive fish farm. The ammonium nitrogen was the major inorganic nitrogen form of the effluent water and the amount of organic nitrogen was also significant: 26 and 42% of the total nitrogen content in 2007 and 2008, respectively. The phosphorus was discharged mainly in the form of reactive orthophosphate between 46 and 50% and while the total phosphorus concentration remain in the lower interval of 1.33-3.65 mg/l in 2007, the average orthophosphate and the total phosphorus content of the aquaculture effluent almost doubled in 2008. The suspended solid concentration was originated from the discharged organic compounds produced by the intensive fish production. The suspended solids concentrations were at least ten times higher in the discharged aquaculture effluent water than in the river water supplied for the quality improvement of the stabilisation ponds (Table 7).

Table 7: Average values of the water chemistry parameters in the input water sources in ACS (AQ: aquaculture effluent, COD: chemical oxygen demand, TSS: total suspended solids, VSS: volatile suspended solids)

Parameter		AQ Effluent (n=12)	River water (n=10)	AQ Effluent (n=16)	River water (n=19)
		2007		2008	
Conductivity	µS/cm	1260±49.1	402±27.3	1296±68.3	518±277
COD	mg/l	140.3±75.9	18.6±19.7	234.6±87.8	51.5±21.1
Ammonium N	mg/l	18.7±6.88	0.081±0.053	18.7±5.17	1.06±1.72
Nitrit N	mg/l	0.069±0.112	0.019±0.013	0.024±0.019	0.031±0.047
Nitrate N	mg/l	0.119±0.240	0.224±0.164	0.266±0.537	0.619±0.442
Total inorganic N	mg/l	18.9±6.73	0.324±0.186	19.0±5.06	1.74±1.62
Total organic N	mg/l	6.74±4.28	0.880±0.261	13.8±14.6	3.61±5.37
Total N	mg/l	25.7±7.12	1.20±0.205	32.8±13.2	5.36±5.57
Ortophosphate P	mg/l	1.17±0.654	0.145±0.082	2.06±2.51	0.153±0.086
Total P	mg/l	2.55±0.609	0.177±0.045	4.12±2.70	0.291±0.194
TSS	mg/l	121.0±79.6	25.0±24.8	167.0±136.9	27.0±17.0
VSS	mg/l	104.9±70.7	12.0±6.1	152.6±126.2	9.1±4.5

The river water showed the general water chemistry parameter values characteristic to the Hungarian surface waters, except of the phosphorus forms which were higher in the samples than expected in natural waters. The quality of the river water deteriorated in winter months when there was no water flow from the main river watercourse.

Water output

The water output was ensured at the outflow gate of the macrophyte ponds. During the retention time the inlet water volume decreased by the evaporation, evapotranspiration and seepage lost. Thus the output water volume was lower by 55-57% than the total input water volume.

Table 8: Average values of the water chemistry parameters in the output water samples of ACS in 2007 (COD: chemical oxygen demand, TSS: total suspended solids, VSS: volatile suspended solids, for sample sites indication see Fig. 1)

Parameter		A_PH (n=12)	A_TY (n=12)	B_SA (n=12)	B_AR (n=12)
Volume	m^3	16,785	13,970	4,099	4,219
Conductivity	µS/cm	854±214[a]	877±231[a]	1014±91.8[a]	990±95.5[a]
COD	mg/l	62.6±30.1[a]	65.1±24.7[a]	87.1±34.6[a]	62.6±22.9[a]
Ammonium N	mg/l	2.06±1.66[a]	1.39±2.26[a]	1.31±1.75[a]	1.24±1.62[a]
Nitrite N	mg/l	0.224±0.187[a]	0.082±0.151[a]	0.452±0.926[a]	0.272±0.512[a]
Nitrate N	mg/l	0.355±0.465[a]	0.031±0.042[a]	0.285±0.601[a]	0.376±0.857[a]
Total inorganic N	mg/l	2.64±2.03[a]	1.50±2.26[a]	2.04±2.47[a]	1.89±2.51[a]
Total organic N	mg/l	2.17±1.00[a]	1.96±1.13[a]	3.49±2.06[b]	2.39±1.01[ab]
Total N	mg/l	4.81±2.67[a]	3.46±2.29[a]	5.53±3.51[a]	4.27±3.30[a]
Ortophosphate P	mg/l	1.12±0.783[a]	1.07±0.570[a]	0.964±0.383[a]	0.899±0.210[a]
Total P	mg/l	1.25±0.555[a]	1.15±0.484[a]	1.28±0.560[a]	1.01±0.379[a]
TSS	mg/l	15.2±20.4[a]	8.9±10.6[a]	34.6±46.9[a]	14.4±11.9[a]
VSS	mg/l	8.3±9.1[a]	7.3±10.5[a]	29.3±43.3[a]	12.0±10.7[a]

The average values of the main water chemistry parameters of the outflow waters are given in Tables 8 and 9. The conductivity was two times higher than that of the recipient surface water, the chemical oxygen demand ranged from 62.6 to 87.1 mg/l. The major inorganic nitrogen form was the ammonium in 2007 and the nitrate also became higher in giant reed and willow ponds in 2008. The organic nitrogen content represented a remarkable fraction of the total nitrogen in all outflow samples: 45-63% in 2007 and 67-88% in 2008. The majority of the total phosphorus was found in the form of orthophosphate which average concentration altered between 0.899 and 1.12 mg/l; except in willow and giant reed ponds in 2008 when lower values of 0.422-0.440 mg/l were measured.

Table 9: Average values of the water chemistry parameters in the output water samples of ACS in 2008 (COD: chemical oxygen demand, TSS: total suspended solids, VSS: volatile suspended solids, for sample sites indication see Fig. 1)

Parameter		A_PH (n=14)	A_TY (n=13)	B_SA (n=10)	B_AR (n=10)
Volume	m^3	11,113	12,078	6,062	6,882
Conductivity	µS/cm	1006±159[a]	1024±127[a]	838±239[a]	901±193[a]
COD	mg/l	79.1±25.5[a]	81.3±29.5[a]	72.8±57.5[a]	70.1±35.8[a]
Ammonium N	mg/l	0.608±0.429[a]	0.453±0.394[a]	0.301±0.588[a]	0.240±0.351[a]
Nitrite N	mg/l	0.237±0.368[a]	0.072±0.145[a]	0.226±0.402[a]	0.331±0.588[a]
Nitrate N	mg/l	0.275±0.420[a]	0.133±0.225[a]	0.510±0.748[a]	0.659±0.934[a]
Total inorganic N	mg/l	1.11±1.05[a]	0.656±0.622[a]	0.995±1.18[a]	1.20±1.41[a]
Total organic N	mg/l	4.67±5.96[a]	4.78±6.18[a]	2.15±2.79[a]	2.47±2.95[a]
Total N	mg/l	5.78±5.63[a]	5.43±6.04[a]	3.15±2.96[a]	3.67±3.11[a]
Ortophosphate P	mg/l	1.07±0.515[a]	1.04±0.377[a]	0.422±0.442[b]	0.440±0.367[b]
Total P	mg/l	1.20±0.479[a]	1.20±0.334[a]	0.609±0.567[b]	0.673±0.408[b]
TSS	mg/l	7.4±6.0[a]	9.7±11.3[ab]	17.5±45.0[b]	29.4±27.8[b]
VSS	mg/l	6.4±4.7[a]	6.1±4.8[a]	11.1±42.0[a]	24.3±23.9[a]

The total suspended solids content in the outflow of ponds was lower than that of the river water, in average 6.00 and 22.9 mg/l, except of the willow pond in 2007 with the average value of 34.6 mg/l and the giant reed pond in 2008 with average value of 29.4 mg/l. The volatile suspended solids gave the majority of total suspended solids content (more than 80% in most outflow waters). The average values for stabilisation ponds and fishponds are summarised in Tables 10 and 11.

Table 10: Average values of the water chemistry parameters of the stabilization ponds and fishponds in ACS in 2007 (COD: chemical oxygen demand, TSS: total suspended solids, VSS: volatile suspended solids, for sample sites indication see Fig. 1)

Parameter		A_ST (n=12)	A_FI (n=12)	B_ST (n=12)	B_FI (n=12)
Conductivity	µS/cm	1002±239	918±209	1057±249	1017±195
COD	mg/l	92.0±42.3	79.3±39.2	109.7±59.8	105.3±54.8
Ammonium N	mg/l	9.21±5.96	5.15±3.73	10.3±8.12	3.27±3.45
Nitrite N	mg/l	1.42±2.95	1.48±2.22	1.16±1.98	2.35±3.29
Nitrate N	mg/l	0.118±0.294	0.118±0.301	0.039±0.103	1.52±2.14
Total inorganic N	mg/l	10.8±4.56	6.74±3.20	11.5±6.92	7.14±5.53
Total organic N	mg/l	3.71±2.55	2.77±1.81	3.58±2.22	3.33±1.95
Total N	mg/l	14.5±5.99	9.51±3.92	15.1±7.01	10.5±5.23
Ortophosphate P	mg/l	1.45±0.715	1.24±0.567	1.29±0.646	1.08±0.648
Total P	mg/l	1.95±0.526	1.67±0.758	2.02±0.824	1.64±0.831
TSS	mg/l	50.5±53.2	46.2±43.6	81.3±125	154.3±229.1
VSS	mg/l	40.2±36.3	31.4±30.0	66.2±109	63.9±53.6

Table 11: Average values of the water chemistry parameters of the stabilization ponds and fishponds in ACS in 2008 (COD: chemical oxygen demand, TSS: total suspended solids, VSS: volatile suspended solids, for sample sites indication see Fig. 1)

Parameter		A_ST (n=16)	A_FI (n=16)	B_ST (n=16)	B_FI (n=16)
Conductivity	µS/cm	1118±110	1023±122	1014±163	955±130
COD	mg/l	107.9±27.3	136.0±74.9	93.7±29.1	114±45.5
Ammonium N	mg/l	10.17±4.62	2.08±1.51	7.17±5.18	1.45±2.05
Nitrite N	mg/l	0.798±1.61	1.71±2.10	0.96±1.23	0.849±1.13
Nitrate N	mg/l	0.559±0.781	1.73±1.74	0.849±1.32	2.25±2.41
Total inorganic N	mg/l	11.5±3.84	5.16±2.71	8.94±4.45	4.51±2.64
Total organic N	mg/l	8.21±6.88	6.19±5.54	6.43±6.79	6.33±6.48
Total N	mg/l	19.7±5.97	11.4±5.35	15.4±6.62	10.8±6.02
Ortophosphate P	mg/l	1.56±0.566	0.790±0.440	1.20±0.577	0.673±0.487
Total P	mg/l	2.04±0.549	1.19±0.581	1.59±0.532	1.08±0.414
TSS	mg/l	30.6±18.5	77.1±47.1	34.6±20.3	101.6±49.9
VSS	mg/l	26.4±18.4	44.4±32.9	25.3±17.4	46.0±26.8

Nutrient removal

The removal capacity given for the main characteristic parameters was the highest for the total nitrogen and volatile suspended solids (more than 90%) and the lowest removal efficiency was found for COD and total phosphorus in 2007 (Table 12).

Table 12: Removal efficiency in % of the representative nutrient and organic matter forms

Parameter	2007				2008			
	Input (kg)	Output (kg)	Removal	Retention (kg/ha)	Input (kg)	Output (kg)	Removal	Retention (kg/ha)
TN	1,679	162	90.4%	1011	2,069	116	94.4%	1302
TP	167	44.8	73.1%	81.5	231	37.2	83.9%	129
COD	8,766	2,532	71.1%	4156	12,780	1,520	88.1%	7506
VSS	6,432	469	92.7%	3975	9,623	343	96.4%	6187

The combination of a stabilisation pond, a fishpond and macrophyte ponds enhanced the nutrient removal efficiency since the different wetland types were able to remove different nutrient forms. Due to higher specific loading level in 2007 the stabilisation pond 'A' retained a lesser fraction of nutrient than the stabilisation pond 'B' or in year 2008.

The stabilisation ponds were efficient in volatile suspended solids removal and also decreased by 20-40% the amount of highlighted parameters. Since in fishponds aerobic conditions existed, the nitrification was favoured and total ammonium nitrogen (TAN) concentration decreased significantly. Due to efficient TAN removal the total nitrogen content also declined by 25-40%, additionally. A considerable amount of total phosphorus and orthophosphate were fixed in fishponds. In macrophyte ponds the chemical oxygen demand decreased at high extent and the total nitrogen removal was improved as well.

Nutrient utilisation efficiency

The total nitrogen output was found to be 162 kg during the operational period in 2007, which corresponded to 1.05 kg/day discharge of the whole treatment system. In the output water less than 10% of the nitrogen amount was detected than in the input water sources. The total phosphorus output was 44.9 kg and the daily discharge was 0.29 kg, in the output water 27% of the input phosphorus amount was found. The carbon content of the water samples was calculated as the half of the volatile suspended solids amount: the total carbon output was 3,262 kg during the operation corresponding to 21.1 kg daily output. In the output water, less than 8% of the total organic carbon input was detected (Table 15).

Table15: Nutrient input, output and the nutrient removal of the pond units in ACS in 2007 (in brackets: removal calculated for the pond input, for sample sites indication see Fig. 1)

Unit	N			P			C		
	Input	Output	Removal	Input	Output	Removal	Input	Output	Removal
	kg	kg	%	kg	kg	%	kg	kg	%
A_ST	*1,167*	722	38.1	*117*	95.1	18.7	1,930	1,307	32.2
A_FI	722	404	27.2 (44.0)	95.1	69.0	22.3 (27.4)	1,307	1,022	14.8 (21.9)
A_PH	207	*77.4*	11.1 (62.6)	35.6	*20.5*	12.9 (42.4)	526	325	10.4 (38.2)
A_TY	196	*46.5*	12.8 (76.3)	33.4	*15.1*	15.6 (54.8)	495	279	11.2 (43.6)
A_Total	**1,167**	**124**	**89.4**	**117**	**35.6**	**69.6**	**1,930**	**605**	**68.7**
B_ST	512	235	54.1	50.0	31.9	36.2	813	561	31.0
B_FI	235	114	23.6 (51.5)	31.9	18.8	26.1 (41.0)	561	374	23.0 (33.4)
B_SA	56.4	21.1	6.90 (62.6)	9.30	5.13	8.36 (44.9)	188	108	9.82 (42.5)
B_AR	58.1	17.0	8.03 (70.8)	9.55	4.13	10.8 (56.7)	186	79.4	13.1 (57.3)
B_Total	**512**	**38.1**	**92.6**	**50.0**	**9.26**	**81.5**	**813**	**187**	**77.0**
Total	**1,679**	**162**	**90.3**	**167**	**44.9**	**73.1**	**2,743**	**792**	**71.1**

The total nitrogen output was amounted to 116 kg during the operational period in 2008, which corresponded to 0.48 kg/day discharge of the whole treatment system. In the output water less than 6% of the nitrogen amount was detected than in the input water sources. The total phosphorus output was 37.1 kg and the daily discharge was 0.15 kg, in the output water 16% of the input phosphorus amount was found. The total organic carbon output was 4,812 kg during the operation corresponding to 19.7 kg daily output. In the output water, less than 5% of the total organic carbon input was detected (Table 16). The nitrogen and phosphorus output was considerable lower in 2008 than in 2007, especially regarding the daily outputs which were nearly 50% less in 2008. The organic carbon output, according to the daily amounts, was found to be similar in both years.

Table 16: Nutrient input, output and the nutrient removal of the pond units in ACS in 2008 (in brackets: removal calculated for the pond input, for sample sites indication see Fig. 1)

Unit	N			P			C		
	Input	Output	Removal	Input	Output	Removal	Input	Output	Removal
	kg	kg	%	kg	kg	%	kg	kg	%
A_ST	1,352	865	36.0	152	95.9	37.0	2,646	1,304	50.7
A_FI	865	376	36.1 (56.5)	95.9	48.0	31.5 (49.9)	1,304	1,143	6.07 (12.3)
A_PH	184	*41.9*	10.5 (77.3)	23.7	15.5	5.36 (34.4)	562	161	15.2 (71.4)
A_TY	198	*37.1*	11.9 (81.2)	23.3	14.7	5.66 (36.9)	522	166	13.4 (68.1)
A_Total	**1,352**	**79.0**	**94.2**	**152**	**30.2**	**80.1**	**2,646**	**327**	**87.6**
B_ST	717	361	49.6	78.9	40.4	48.7	1,351	554	59.0
B_FI	361	184	24.7 (49.0)	40.4	19.3	26.7 (52.2)	554	503	3.78 (9.22)

B_SA	88.3	17.3	9.90 (80.4)	9.21	2.96	7.93 (67.9)	238	68.3	12.5 (71.3)
B_AR	99.0	19.5	11.1 (80.3)	9.78	3.97	7.36 (59.4)	257	80.1	13.1 (68.8)
B_Total	**717**	**36.8**	**94.9**	**78.9**	**6.93**	**91.2**	**1,351**	**148**	**89.0**
Total	**2,069**	**116**	**94.4**	**231**	**37.1**	**83.9**	**3,997**	**475**	**88.1**

A part of the nutrients in the ACS module were transformed into fish and energy plants as valuable by-products. Similar proportion of the input nutrients was converted into fish and plant biomass in both years: 1.0%, 1.8%, and 2.3-3.5% of nitrogen, phosphorus and organic carbon were retained in the harvested fish, respectively. Into energy plants, 3.7-4.0% nitrogen and 8.5-9.2% phosphorus were built in from the input nutrient amounts (Table 17).

Table 17: Nutrient outputs and nutrient retention in secondary products

Nutrient		Unit	2007			2008		
			N	P	C	N	P	C
Input		kg	1,679	167	2,743	2,069	231	3997
Output	Water	%	9.7	27	29	5.6	16	4.3
	Water at harvest	%	10	17	20	5.9	9.2	7.5
	Fish	%	1.0	1.8	3.5	0.99	1.7	2.3
	Plants	%	4.0	9.2	n.c.*	3.7	8.5	n.c.*

*not calculated

Sodium removal by plants

The element contents of the plants are showed in Table 18. The accumulated sodium and magnesium by the saltcedar were significantly higher than in the case of willow in the leaves and in the stem equally. The Na and Mg were stored preferably in the stem of the willow however the saltcedar accumulated them in their leaves owing to halophyte characteristic. The calcium content of the saltcedar leaves was higher than the willow leaves, but the amount of this element of the willow stem was major. In the case of phosphorus there was not significant deviation among the species. The uptake of the potassium was similar, it was higher in the leaves, but the element content was lower in the saltcedar stem. Total Na accumulation in tree biomass after 1 year of treatment was relatively low. The Na concentration in the leaves in the high-salt treatment of the saltcedar was more than twice than the levels of the willow. The traceable differences per unit area were calculated by the produced biomass data, which is enclosed in Table 19. The results of the first year experiments showed that the sodium and magnesium uptake by saltcedar was higher. However, the high biomass producing capacity of willow resulted in higher removal efficiency per unit area, neglected so far the subsequent sodification effect for the soil and the risk of the salt-tolerance of the plants.

Table 18: The average element content of the plant samples, 2008

Plants (n=4)	dry matter %	N %	K %	P %	Ca (mg/kg)	Mg (mg/kg)	Na (mg/kg)
Salix, leaf	33.725	3.193	1.793	0.377	11325	3175	437
SD	1.938	0.353	0.316	0.048	1212.09	359.1	157.88
Salix, stem	32.150	1.113	1.363	0.181	5380	1445	958
SD	2.533	0.215	0.394	0.019	1249.9	196.7	839.1
Tamarix, leaf	32.40	2.51	1.993	0.467	21925	7718	5525
SD	0.94	0.20	0.197	0.140	699	810	946
Tamarix, stem	57.750	1.595	0.818	0.196	4242.5	1887.5	1049.5
SD	2.601	0.317	0.023	0.022	552.7	204.0	232.2

Table 19. The calculated uptake capacity of the plants, 2008

	N	K	P	Ca	Mg	Na
	kg/ha					
Salix (leaf)	114.13	64.08	13.47	13.65	3.83	0.53
Salix (stem)	81.21	99.45	13.23	12.62	3.39	2.25
Salix (total)	**195.34**	**163.53**	**26.70**	**26.28**	**7.22**	**2.77**
Tamarix (eaf)	15.52	12.33	2.89	4.40	1.55	1.11
Tamarix (stem)	28.46	14.60	3.49	4.37	1.95	1.08
Tamarix (total)	**43.98**	**26.93**	**6.38**	**8.77**	**3.49**	**2.19**

CONCLUSIONS

The operation of the constructed wetland system was characterized by effective nutrient removal efficiency, positive energy budget and possibilities for diversification of income sources. The application of the examined treatment system decreased the amount of discharged nutrients of the intensive aquaculture by 1,300 kg N/ha, 130 kg P/ha and 7,500 kg COD/ha during the whole operation period from February to November in 2008. The ecological sustainability was enhanced by the production of 40,900 kg plant biomass; as potential renewable energy source. It could offset the burning of fossil gas, the savings of CO_2 emission would be 11,250 kg yearly.

The climatic conditions in Central and Eastern Europe limit the continuous operation of constructed wetlands under the same loading level in winter. At low temperature (under 15 ºC) it is recommended to reduce the effluent load by decreasing the concentration (filtering the suspended solids) or volume of used water (storage). The surface-flow wetlands assured advantageous conditions for reed and cattail however, the open water surface and the relatively thin soil layer were not optimal for the growth of willow and giant reed. Wet soils with deep fertile layer provide favourable growing conditions for these species.

The construction and successful operation require detailed planning and continuous control of the water quality in the units and the dissolved oxygen level in fishponds, because overloading the system may cause serious disturbance of the natural equilibrium in ponds functioning as constructed ecosystems.

The aquaculture producers are forced to minimize their nutrient and pollutant discharge and use sustainable purification methods. The combined wetland system provides an adequate treatment method that is able to meet the environmental standards and its construction and operation costs are lower than those of artificial purification technologies. Calculating with the average water quality parameters from the experiments, it would lead to 10.2 million HUF reduction in the water loading fee costs of the African catfish farm. It could be generate an additional 6.5 million HUF from cattail and fish production, while the total costs of operation would be under 4.6 million HUF.

The fishpond units are suitable for additional fish production, for example the culture of ornamental fish or species utilising natural food resources provides profitable opportunity to utilise wasted nutrients.

Natural treatment methods require low amount of non renewable energy, however are land intensive systems. Based on the results of the experimental years and taking into consideration climatic and economical considerations a wetland system of 13 ha area (consisted of 3 ponds: a stabilisation pond of 3 ha, a fish pond of 4 ha and a cattail pond of 6 ha) would be able to treat the 100% of the effluent water from a flow-through African catfish farm with a capacity of 500 t fish/year.

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