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Performance of floating treatment wetlands (FTW) with the innovative Tech-IA® system

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To my lovely family :-)

Indice

Riassunto

Questo lavoro si occupa dei sistemi flottanti di fitodepurazione (FTWs), che consistono in particolari zone umide artificiali che sono in grado di depurare l'acqua inquinata direttamente in situ senza necessità di utilizzo di substrati differenti. La vegetazione cresce in acqua grazie all'utilizzo di elementi flottanti a cui sono ancorate le piante che possono in questo modo sviluppare le loro radici in acqua e diventare terreno ideale per lo sviluppo del biofilm. Attraverso quattro diversi esperimenti è stato possibile indagare diversi aspetti di questa nuova eco tecnologia, non ancora consolidata in Italia. Per questo studio sono stati utilizzati sistemi flottanti brevettati in Italia, chiamati Tech-IA.

Un esperimento in microcosmo è stato realizzato su radici per ricavare un tasso di utilizzo dell'ammoniaca (AUR). Per ottenere un'indicazione sul potenziale di nitrificazione dei biofilm adesi ai sistemi di fitodepurazione flottanti, sono state condotte analisi su radici e strisce di geotessuto prese da sotto i materassi flottanti posizionati in un sistema pilota costruito presso l'impianto di depurazione comunale di Pukete ad Hamilton, in Nuova Zelanda. Dopo cinque mesi dall'inizio del progetto di fitodepurazione flottante, le radici assieme alle strisce sono state prelevate e su di esse condotti alcuni test in laboratorio. E' stato preparato un substrato di coltura avente la medesima concentrazione di ammoniaca presente nel refluo originario in cui sono stati immersi i suddetti campioni in flaconi agitati meccanicamente, in condizioni controllate, per 48 ore. I risultati indicano valori mediani per AUR rispettivamente di 429 mg N m^{-2} biofilm d^{-1} per le strisce e di 1582 mg N m^{-2} biofilm d^{-1} per le radici. L'accumulo di nitrato misurato in alcune prove era trascurabile. Questa metodologia può fornire informazioni comparative sulle componenti dei sistemi flottanti di fitodepurazione, come il tipo di elementi flottanti, le specie di piante e l'ambiente per poter calcolare una superficie vegetata richiesta per rimuovere una predeterminata quantità di ammoniaca da un noto e specifico refluo.

Un esperimento condotto invece in mesocosmo è stato realizzato per testare lo sviluppo della vegetazione direttamente in acqua ovvero in condizioni idroponiche. Gli impianti

flottanti di fitodepurazione oltre a migliorare la qualità dell'acqua possono aumentare il valore estetico di uno specchio d'acqua grazie alla presenza di specie fiorite, nonché creare nuovi ambienti acquatici e spazi d'acqua urbani. Questo progetto è uno studio sull'attecchimento e la crescita di macrofite ornamentali usate per il trattamento dell'acqua con in più un alto valore estetico. Sono state studiate diverse specie per poter essere utilizzate nei sistemi galleggianti. Grazie a questa tecnica di coltivazione direttamente in acqua, le piante probabilmente avranno maggiori probabilità di sopravvivenza nei sistemi flottanti di fitodepurazione.

Gli ultimi due esperimenti consistono in progetti realizzati su scala reale. Un ampio bacino di sedimentazione nel nord Italia è stato dotato di un impianto FTW. Questo progetto è stato installato in un'area dove non erano presenti canali di deflusso naturali che potessero raccogliere il refluo proveniente dall'agricoltura, il quale, pertanto, confluiva direttamente nel sistema fognario. Quest'ultimo andava a raccogliere l'acqua proveniente dai campi ma anche reflui urbani e industriali provenienti dal depuratore comunale. Durante periodi di piogge abbondanti, il sistema fognario viene sovraccaricato si da scaricare parte dell'acqua in grandi bacini. Questi, dopo alcuni anni possono accumulare sedimenti e diventare totalmente impermeabili.

I principali obbiettivi di questo progetto sono quelli di migliorare la qualità dell'acqua mantenendone allo stesso tempo la capienza e di riutilizzare l'acqua depurata per scopi agricoli. Un ulteriore obiettivo è quello di recuperare l'area a fini naturalistici. Elementi flottanti sono stati legati tra loro a formare lunghi nastri che diventavano barriere filtranti poste perpendicolarmente ai punti di entrata e uscita dell'acqua dal bacino. 1800 elementi flottanti vegetati sono stati usati per comporre una superficie depurante di 900 mq con 1440 piante scelte per il loro alto valore depurante, per uno sviluppato sistema radicale e con un elevato impatto estetico (*Juncus sp., Iris pseudacorus, Typha latifolia, Phragmites australis*). In questo impianto è stata monitorata la qualità dell'acqua, lo sviluppo della vegetazione e possibili implicazioni gestionali. I risultati sulle performance di abbattimento per i valori mediani sono del 20% per l'azoto totale, del 43% per l'ammoniaca, 32% per il nitrato e 11% per il fosforo totale. L'abbattimento per il COD è del 54% al terzo percentile.

Un’altro esperimento su scala reale è stato un sistema di trattamento terziario per il refluo urbano. Unità di fitodepurazione diverse, combinate in serie possono portare ad una flessibilità e un maggiore tasso di trasformazione degli inquinanti caratteristico di ogni singolo sistema. Per aumentare la capacità di rimozione di un impianto di trattamento urbano, un esistente sistema misto di fitodepurazione è stato riadattato. Questo, localizzato alla fine di un impianto di trattamento tradizionale, si componeva di un vassoio anaerobico orizzontale vegetato e di un laghetto di sedimentazione. (superficie del vassoio e del laghetto 285 e 615 m^2 ,rispettivamente). I cambiamenti sono consistiti nella sostituzione della precedente vegetazione mediterranea xerofila piantata nel vassoio con *Phragmites australis* e con l’istallazione di un nuovo sistema flottante nel laghetto, dove 150 m^2 di elementi flottanti vegetati con *Phragmites Australis* and *Iris pseudacorus* erano stati installati. Per quantificare le potenzialità di trattamento dell’impianto, si è monitorato il refluo all’ingresso e all’uscita dal sistema. I risultati indicano abbattimenti sulle mediane circa del 70% per l’azoto totale, del 49% per l’ammoniaca e del 67% per il nitrato. I fosfati vengono abbattuti del 30% e il COD del 54%.

Summary

This work thesis deals with floating treatment wetlands (FTWs), particularly constructed wetlands that can treat polluted water directly in the water body without needing different substrates. Vegetation grows on water thanks to floating mats that can sustains the plants which can develop their roots in the water and became an ideal substrate for biofilm attachment. Through four different experiments it was possible to investigate different aspects of this eco-technology, not yet used in Italy. For this project an Italian patented floating element called Tech-IA has been used.

A microcosm experiment was conducted to obtain an ammonium utilization rate (AUR). In order to obtain an indication of the nitrification potential of the attached FTW biofilms, analyses were conducted from roots and attached geotextile test-strips retrieved from under floating mats deployed in a pilot-scale experiment at the Pukete Sewage Treatment plant in Hamilton, New Zealand. After 5 months from the beginning of the floating system project, roots together with strips were removed and laboratory-scale tests were set up. A culture medium with ammonium-N was prepared at the similar concentration as the original wastewater, samples were added to stirred flasks under controlled conditions for 48 h. Results indicate AUR for median values of 429 mg N m^{-2} biofilm d^{-1} for the strips and 1582 mg N m^{-2} biofilm d^{-1} for the roots respectively. NO_3 accumulation, measured in some of these trials, was negligible. This developed methodology could provide comparative information on the components of the floating island systems, such as the mats types, plant species and environment in order to calculate vegetated surface areas required to remove a certain quantity of NH_4-N from a specific and known wastewater.

Another mesocosm experiment was set up to test the growth of vegetation directly on water, in hydroponic conditions. In addition to improve water quality, FTWs can enhance the aesthetic value of a water body with the presence of flowering species, creating new water environments and urban water spaces. The floating elements can be vegetated with herbaceous species with colourful blooms and these can be distributed along the seasons. This project was a study on establishment and growth of

ornamental macrophytes for water treatment with a high aesthetical value too. Different species have been studied to be used in the floating systems. With this cultivation technique directly in water plants probably become more suitable to be planted in floating treatment wetland.

The last two experiments are full scale projects. A large sedimentation basin in North of Italy has been provided of a FTW. This project have been installed in an area where there aren't any natural water receptors that can collect wastewater from cultivated fields and this goes directly in drainage. This collects fields water but also industrial and urban water and brings them to a municipal depurator. During periods when rain is abundant sewerage is overcharged and it discharges part of water in big basins. This system is after several years can accumulate sediments and become absolutely waterproof. The main objectives of this project are to improve water quality in the basin maintaining at the same time the capacity and to reuse this depurated water in agriculture. Furthermore one aim was also to recover this area for environmental purposes. In the system floating elements were bounded together to form long tapes, which became five filtering barriers put perpendicular to the inlet and outlet points. 1800 vegetated floating elements were used form a depurative surface of 900 m^2 with 1400 plants chosen for their high cleansing power, big root system and nice aesthetic effect (*Juncus sp., Iris pseudacorus, Typha latifolia, Phragmites australis*). This plant has been monitored for water quality, plants development and possible management problems. Results on abatement performances for median values: 20% for total N, 43% for ammonia-N, 32% for nitrate and 11% for total P 46% is the abatement for COD at third percentile.

Another full scale project was a tertiary treatment system for urban wastewater. Unit wetlands combined in series can provide flexibility and higher pollutant transformation rates characteristic of each single system. In order to enhance the pollutants removal strength of a municipal wastewater treatment plant, an existing constructed wetland was modified. This constructed wetland, located at the end of the traditional treatment, was designed to have a horizontal anaerobic vessel and a sediment pond (SSF and pond surface 285 and 615 m^2 respectively). The changes consisted in the substitution of the previous evergreen Mediterranean vegetation planted in the vessel with *Phragmites australis*, and in the installation of a new FTW in the pond, where 150 m^2 of floating mats (Tech-IA® system) vegetated with *Ph. Australis* and *Iris pseudacorus,* were set. To understand the treatment capabilities of the plant, a monitoring on wastewater before and after the system has started. Results indicate abatement of the medians around 70% for total nitrogen, 49% for ammonia-N and 67% for nitrate. For phosphorus forms is around 30% and for COD is 54%.

General Introduction

Floating Islands are a novel ecotechnology for remediating polluted waters. This technique, known as “floating treatment wetlands” (FTWs), allows the water treatment directly into the water body (natural or artificial stream, river, channel, pond or lake) and works using different types of buoyant mats to grab aquatic plants and make them floating on the water surface (figure 1).

Constructed floating wetlands could be self-floating systems if they used free-floating aquatic plants (Lemna spp., Eichhornia crassipes, Trapa natans, Pistia strtiotes), but some species are tropical and so not able to grow at our latitudes because are susceptible to frost, moreover most of them do not develop extensive roots system to have an efficient biofilm development. Furthermore they can became weed species due to their great capacity of colonization all water surface and it is difficult to control them.

FTWs can avoid these problems; in these systems plant roots grow through the mat forming a dense mass of roots that hang into the water below. The artificial floating systems are based on structures that sustain no floating aquatic plants so that they can extend their roots in the water column, in calm or running waters. Using these system it is possible avoid to use huge surfaces usually needed for constructed wetlands, such as vertical or horizontal treatment wetlands because they don’t need wastewater to be drawn from its basin (Borin, 2003). Because they float on the water surface they can tolerate fluctuating water levels and are not constrained to shallow waters.

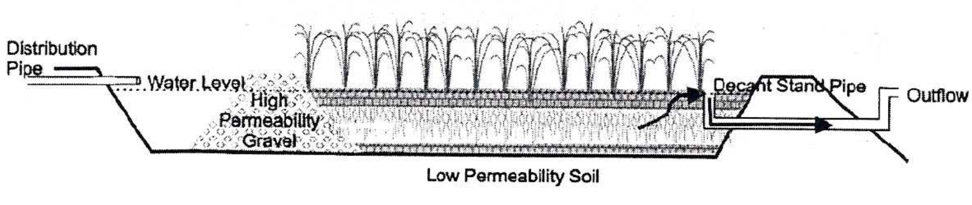


Figure 1 – Scheme of a transverse section of a FTW to treat wastewater (Headley T.R. e Tanner C.C., 2006).

These systems are working improving water quality as well the aesthetic value of a water body with the presence of flowering species, creating new water environments for fauna and get better urban water spaces. The floating element can be vegetated with herbaceous species with colorful blooms and these can be distributed along the seasons, it can be used for ornamental purposes and become a perfect element of urban fitment.

Natural floating islands, stable or temporarily, are commonly known in several environments (Van Duzer, 2004) and share many attributes with natural and surface-flow constructed wetlands with a similar range of natural treatment processes (Somodi and Botta-Dukat, 2004).

In FTWs, as the plant roots do not have access to nutrient sources in the sediment they develop larger root systems and take up their nutrient requirements directly from the water column. Biofilms develop on the extensive surface area provided by the roots increase organic matter breakdown, nutrient adsorption and trapping of fine particulates.

The floating mats shade the water column and create a quiescent environment that reduces algal growth and promotes settling of suspended solids and biofilms formation.

This system is efficient when it is used as singular depuration technique, but it performs very well also if associated with other traditional depuration techniques, to enhance the effectiveness and contribute to clean polluted water. Depuration efficiencies of these systems depend on which plants are used, on local climate conditions, on type of buoyant systems adopted, on the maintenance performed and on other technical, ecological and microbiological factors.

Because FTWs are a relatively new technology few researches have been undertaken to explore the way of using and the spread of this technique all over the world and to quantify their pollutant removal performance (Haedley and Tanner, 2006; Van de Moortel, 2011).

As it is listed in table 1, this technology is spread in many parts of the world and plants species used are chosen among the autochthonous ones. The more utilized macrophytes species for these purposes are from the botanical families of cyperaceae, thyphaceae, poaceae and juncaceae.

Also many different materials can be used as floating systems, natural or artificial and the elements could have a substrate with soil or synthetic material or be just an element that sustains plants and these are free to develop roots system in the water.

Table 1 – FTWs in the world, considering floating systems and plant species used and types of wastewater treated.

Location	Reference	Floating element	Plant species	Wastewater
Belgium	Van Acker *et al.* (2005)	PE-net+PE-foam with coconut fibres	*Carex spp., Phragmites australis, Shoenoplectus latifolia, Typha spp., iris pseudacorus*	Combined sewer overflow
USA, Las Vegas	Boutwell (2002)	HDPE-shipping pallets, stainless steel and coconut fibres	*Shoenoplectus spp., Typha spp*	Lake water
USA, Georgia	Hubbard *et al.* (2004)	PVC pipes and fibrous material	*Panicum hemitomon, Typha latifolia, Juncus effusus*	Swine lagoon
China	Hu *et al.* (2010)	Dredged sludge, industrial slag and expanded perlite	*Acorus calamus*	Lake water
India	Billore and Prashant (2008)	Bamboo, PVC fibres, galvanized iron wire and nylon coconut fibres	*Phragmites Karka*	Lake water
New Zealand	Headley and Tanner (2011)	polyester fibre injected with patches of polystyrene foam (BioHavenTM, Floating Islands)	*Carex dispacia, Carex virgata, Cyperus ustilatus, Eleocharis acutis, Juncus edgarae, Schoenoplectus tabernaemontani*	Stormwater
Canada	Smith and Kalin (2000)	Timber, plastic snow fences, fishing net, Styrofoam, plywood panels and Sphagnum spp. Moss on a burlap liner	*Typha spp.*	Acid mine drainage

Uganda	Kyambadde *et al.* (2005)		*Cyperus papyrus, Miscanthidium violaceum*	Stabilization pond
U.K., England	Revitt *et al.* (1997)	Plastic geotextile lattice	*Phragmites australis*	Stormwater
Belgium	Van de Moortel (2011)	Plastic pipes filled with foam and wire netting	*Carex acutiformis, Iris pseudacorus, Juncus effusus*	Combined sewer overflow
NewSouth Wales, Australia	Hart *et al.* (2003)		*Chrysopogon zizanioides*	Septic tank effluents
France	Ladislas *et al.* (2010)	Polyethylene plot with Puzzolana, polystyrene float.	*Juncus effuses, Carex riparia*	Stormwater
USA	Stewart et al., 2008	BioHaven® floating islands	Microbes only	Agricoltural and municipal wastewater

FTW can be used to treat different kind of wastewater; it has been used to treat eutrophication in lakes (Yangjun and Congjun, 2008; Boutwell, and Hutchings, 1999; Boutwell, 1999; Boutwell, 2002; Park et al., 2008) and have nitrate reduction up to 50%.

Useful in stormwater treating, thanks to its capacity of floating and fit to levels fluctuations (Tanner and Haedly, 2011; Ladislas *et al*., 2010); they have capacity in removal Cu, Zn, Cd, Ni, other metals and very fine suspended particulates playing a key role in the contaminant removal processes. Mass removal for Cu and Zn are calculated from 5,6 to 7,7 and from 25 to 104 mg m^2 d^{-1} respectively. For high concentration of Cd and Ni, macrophytes can accumulate in their roots, up to 5 and up to 60 µg/g of dry matter respectively.

FTws have been set up for attenuation of nutrients from river waters (Lakatos, 1998) to remove nitrogen and phosphorus and it seems to decrease the efficacy in colder temperatures. Here the removal efficiency was up to 60% for COD, 40% for total phosphorus and 35% for nitrogen.

Studies of floating wetlands for domestic wastewater treatment are also been conducted (Kyambadde *et al.,* 2005; Hart et al., 2003; Sekiranda, 1998), with higher results on nitrogen forms removal than phosphorus.

For treating agricultural and municipal wastewater (Steward et al., 2008; Van de Moortel, 2011), usually as tertiary treatment. Steward gave these results: 10600 mg of nitrate per day, 273 mg of ammonium per day and 428 mg phosphorus per day. Van de Moortel showed a removal efficiency of 57 mg L^{-1} for COD, 9 mg L^{-1} for ammonium, 38 mg L^{-1} for nitrate and 45 mg L^{-1} for total phosphorus.

In Italy the floating wetland system was applied in 2005 to treat water exiting a fish growing farm. A farm in the Sile River Natural Park was chosen, which uses groundwater to raise rainbow trout and discharges the outflow directly into the river. The floating system performed well in pollution control, abating the concentrations of inflow water due to roots development that intercepted the suspended and dissolved organic materials and absorbed the nutrient elements. The same system were after used in streams inside a Natural Reserve (N-E Italy) characterized by two wide channels with low pollutants concentrations to abate COD, nitrogen and phosphorus (De Stefani *et al.* 2011). Here COD was reduced from 28 to 66%, nitrate from 12 to 14 % and total nitrogen from 13 to 29%.

Vegetation

During this research period different macrophytes species have been used and investigated, some of them much more known in literature others new in constructed wetland.

***Iris pseudacorus* L.**

This species belongs to the family of iridaceae and it is famous for its big yellow flowers that blooms in early spring, from May to June and it is native of Europe where in the past was used as medicinal herb and as stain. It breeds from rhizome, has leaves that branch from the base of the plant and are large up to 3 cm. Every year plants release new shoots from the rhizomes. It grows in mid or full sun close to water but also submerge till about 15 cm with a wide range of pH, both acid or alkaline; it is very strong, can resist to flood and dry periods too. On average it grows more than one meter and widens till 60-70 cm (Speichert and Speichert, 2004). Iris is often used in constructed wetland for its capacity of pollution removal and in FTWs too (Van de Moortel , 2011).

***Typha latifolia* L.**

Aquatic macrophyte from the family of typhaceae, which is spread all around the world. This species can be normally seeded or be propagated by rhizomes. *T. latifolia* is spread in Europe, Asia, South Africa and Australia. It grows in wetlands till 2000 m above sea level and reach the height of 250 cm, needs middle or full sun in wet soil or in water till 30 cm deep. It blooms from June to August and its ear has a diameter of 30 mm. Its long and tick rhizome is at 8-10 cm depth in the soil and can grow till 70 cm long. Blooming is in spring and new rhizomes production in autumn. This species, common name cattail, is very resistant to different temperature between 6° to 28°C, that is way you can find it from tropical areas to cold temperate ones. (Speichert and Speichert, 2004). Can resist just short period of submersion. Because its high resistance to biological pollution, this species is often used in constructed wetlands (Boutwell, 2002; Hubbard et al., 2004).

***Phragmites australis* (Cav.) Trin. ex Steud.**

This species of aquatic macrophytes is native of Europe, Asia and Africa but is worldwide spread. It belongs to the family of graminaceae, has tick rhizomes and straight, empty and with nodes culms. Can reach 2 or 3 m of height and its roots system is massive to became very competitive with other species and have great below ground biomass. It blooms between July and October. It is very tolerant to different climatic and environmental conditions such as salinity, poverty of oxygen and pH variability. For these reason and because can stored pollutants, is very used in constructed wetland systems such as FTWs. (Van Acker et al.,2005; Revitt et al.,1997).

***Canna indica* L.**

This species has rhizomes and it is cultivated as ornamental plant. It reaches normally the height between 150 and 250 cm. The leaves and the flowers are very decorative and different varieties that bloom during summer can have different colors with lots of shades. Propagation exists by seeds or by subdivision of tubers. This species loves sun but can tolerate shadow too. In winter above ground vegetation disappears but rhizomes stay alive below ground, to grow in spring again. Often used in different constructed wetland for its capability to treat wastewater (Calheiros et al., 2007).

***Iris laevigata* Fisch.**

This species is originated from East Asia and is cultivated especially in Japan. Its name is due to its petals that are rotund, short and vertical. This iris needs humid soil all over the year and does not tolerate dryness; it prefers acid or neutral pH and loves to leave in water till 15 cm depth. It reaches more than 90 cm in height and cam be wide till 30 cm in width, depending in which climate it grows, even if it prefers temperate one. Flowers are about 7 to 10 cm long, and blooms in summer; they can be white, blue or red-purple (Speichert and Speichert, 2004).

***Juncus effusus* 'spiralis' L.**

This aquatic macrophyte, typical of wetlands, has smooth, lucid and bright green stem. Its green-brown inflorescence appears in summer. *J. effusus* 'spiralis' has its dark green stems that twist from the base of the plant. It can grow till 90 cm and be wide till about 60 cm. Can leave in humid or swampy soil and in swallow water too, it is excellent for aquatic garden and can tolerate overflow. (Bridgewater, 2004). This species is been used in FTWs (Van de Moortel, 2011; Hubbard et al., 2004).

Mentha aquatica **L.**

This plant is from the family of labiatae which includes lots of species often used in perfumery and medicine thanks to their production of essential oil composed mainly of menthol. Flowers of this herbaceous species are pink-purple and appear in summer; it can reach 80 cm in height, even if its aerial part is creeping. Its woody rhizomes produce above ground creeping stolons. It is typical of wetlands, such as on riverside, on bogs or swamps, in shadow and humid environments, from the sea to the mountains.

Pontederia cordata **L.**

This species belongs to pontederiaceae and is a typical plants that grow around lakes, it leaves are lucid and heart shape and its big decorative ear flowers could be white, blue, pink or lavender and blooms in summer. It has rhizomes and are native from North America but diffuse till the South. This plant is often used as water filter (McConnel et al., 1990). Normally these plants propagate by division of rhizomes in spring but they can also been seeded even if they need a period of dormancy with cold and humid conditions. To survive at cold temperatures is important that plants come from cultivar that grow in cold climate. (Kane et al, 1991). It can grow in full sun or middle scado in humid soil or in water till 25 cm depth. It reaches 60-75 cm in height. (Speichert and Speichert, 2004).

Sparganium erectum **L.**

This aquatic species that belongs to sparganiaceae is a perennial plant with creeping rhizomes that leaves in the riverside or submerge too. The aerial part reaches 60 cm or more and plants form colonies as cattail does. *Sparganium erectum* blooms all summer long and its flowers are formed by bunch of white-green round ballots. Leaves are bright and striking and from light green they can turn yellow-orange. This species is originated from Asia and Europe and grows till 500 m above sea level.

Thalia dealbata **Fraser ex Roscoe**

This ornamental aquatic microphyte from the family of marantaceae has particular large leaves that can be more than 90 cm long. Flowers are purple and above long stems. These plants are native from America's tropical areas and can propagate by division of rhizomes. They grow in sunny places but middle shadow too, love humid soil or can be submerged till 15 cm depth. It can reach 180 cm in height and its flowering happens in late summer with purple color. It produces lots of shoots and can be divided for replication to avoid huge development during years, the best moment to do this is late spring or summer and plantation should be immediate. (Speichert and Speichert, 2004).

Zantedeschia aethiopica **(L.) Sprengel**

Zantedeschia aetiopica belongs to the family of araceae and is a ornamental plant native in South Africa. Has rhizomes and his white flowers appear in April and June; it can reach more than 100 cm in height and has lots of cultivars (Speichert and Speichert , 2004). It is possible to seed or replicate them by division of rhizomes. This species needs wetlands and can be submerged too, till 30 cm depth. It cannot stand cold weather, so if conditions are mild it can stand all year in the ground, but if it is too cold it is necessary to remove rhizomes in winter and plant them again in spring.

Acorus calamus **L.**

Acorus calamus or sweet flag is a common plant species of the European wetlands but was introduced from India as a medicinal plant. It propagates vegetatively by rhizomes that are swallow with tick roots. The rhizomes are the most important storage organs in sweet flag. (Vojtíšková L. et al, 2004). It is a semi-aquatic plant in temperate or sub-temperate regions. The inflorescence consists of a leaf-like spate densely covered with yellow and green flowers. (Motley, 1994), but Plants are very rarely flower or set fruit.

Usually, only plants grown in water produce flowers. The spadix, at the time of expansion, can reach a length between 5 and 9 cm.

***Caltha palustris* L.**

Caltha is a genus of herbaceous plants in the family of ranuncolaceae native to marshes, fens, ditches and wet woodland in temperate regions of the Northern Hemisphere. C. palustris occurs in damp situations such as marshes, ditches and wet woods where the basal portions of the plant may be completely submerged. It is a perennial glabrous herb with creeping rhizome and bearing annual aerial stems and mostly radical leaves. Height is up to 80 cm and flowers are yellow with a diameter of 2–5 cm; appear in early spring to late summer. The flowers are visited by a great variety of insects for pollen.

***Oenanthe javanica* "flamingo" (Blume) DC**

Water celery (*Oenanthe javanica*) is a perennial with a broad distribution in China that is cultivated for its edible seedlings and leaves (Yang et al., 2008). O. javanica are fast-growing macrophytes capable of growing well in polluted water and tolerate freezing temperatures during winter. Its flourishing roots play an important role in polluted water remediation, and have made it one of the preferred organism for ecological floating beds in Asia. (Zhou and Wang, 2010). It is a perennial, smooth aquatic herb that has clusters of tiny white flowers in summer and light green-and-white foliage that blushes with pink when the weather gets cool. It lives in full sun to partial shade.

Tech-IA® system

TECH-IA system is a came up technology of Padua University spin-off PAN Ltd. In 2006 the patent demand was presented at the Italian Patent Office (Tech-IA®). The multitasking floating system is indicated as support for herbaceous and arboreal plants. Its main use is within the field of natural depuration in water bodies.

The single self-floating element of Tech-IA® is realized in EVA (ethylene vinyl acetate), a recyclable material, and it is of rectangular shape (45*90 cm) with eight windows each of them with grids that allows to sustain the plants (figure 2). His weight is 1732 g and may supports a weight of 20 kg. Two elements matched give one square meter of raft. The single elements can be easily linked to each other and anchored to the river sides, his frame presents six holes allowing the connection among elements and to the benches. The elements can be easily installed in different designs to fit the shape of the water body and intercept the pollutant flow.

The structure was created to be a support in wetland systems for no floating plants, but it can be used in several other sectors. It could become vegetated island for naturalistic and wildlife purposes, floating vegetated or no-vegetated barriers used for delimitation or signal. But also decorative island in natural, artificial, private or public water body, support for plants that grows in hydroponic system, creation of buoyant platforms and as support for fish farming environments.

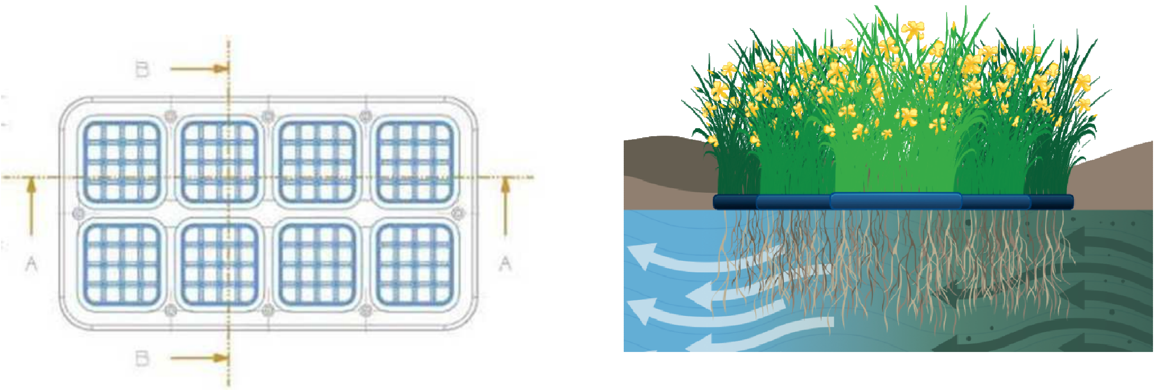


Figure 2: Tech-IA floating element and its working scheme

The innovative technical features of this structure are a high mechanical resistance of the material associated with biological, chemical and climatic resistance, a closed cell structure that doesn’t absorb water and easy installation and management. These structures may sustain aquatic plants, which are able to extend their roots in the water column, in calm or running waters, and perform the typical functions: physical filtering of the water flow and dissolved nutrients uptake (PAN,2010).

Research aims and structure

The research objectives were to investigate trough the FTWs technology, a technique that in Italy is not jet developed. The aims were to analyzed the processes involved with floating wetlands and in particular the roots of plants used, to explore the vegetation that can be planted on floating system in terms of suitable species and their performances in this particular environment and to assess the applicability of FTWs in real case studies. Therefore, different experiments in microcosm and mesocosm scale were set up and at same time two full scale plants were realized and monitored.

This thesis will start by analyzing, through a microcosm experiment, the ammonium utilization rate of attached biofilm associated with floating wetlands applied for treating domestic sewage, and try to find a replicable, effective and definite method to test the efficiency of any floating treatment wetlands. Another chapter will focused on vegetation thanks to a mesocosm scale experiment in order to used ornamental plants and set if they are suitable to be grown in floating systems, what are their yield in terms of survival, biomass production and nitrogen storage. Two different full scale projects will follow, the first one is about vegetation development, nitrogen storage and performances of a floating treatment wetland working as tertiary treatment for urban wastewater and the second one will discuss in particular removal efficiencies of a combined wetland containing a section with a FTW set up to treat municipal wastewater. To conclude a general discussion will follow to evaluate the results of the entire work.

Chapter I

Ammonium utilization rate of attached biofilms associated with floating wetlands treating domestic sewage

Introduction

Floating treatment wetlands (FTWs) are an innovative system to treat wastewater using vegetated floating mats. The roots hanging from the platforms can take the nutrients directly from water, and provide biofilm attachment surfaces that promote microbial nutrient transformations (Morris and Monier, 2003; Ramey *et al*., 2004). Biofilm is an association of bacterial communities that can product or degrade organic matter, can degrade many environmental pollutants and is important in the cycles of nitrogen, sulfur and many metals. (Davey and O'Toole, 2000). In particular the water system biofilm is highly complex and may contain corrosion products, clay material, fresh water diatoms and bacteria enclosed in a matrix of primarily polysaccharide material. The solid-liquid interface between root's surface and water provides an ideal environment for the attachment and growth of microorganisms. (Donlan, 2002).

Nitrification is the microbial transformation of ammonium-N to nitrate-N. In FTWs the reactions that lead to nitrification are reported by several authors (Li et al, 2010; Sun et al., 2009; Van de Morteel et al., 2009; Craggs et al, 2000). Many works tend to investigate nitrification looking at the communities of bacteria that compose biofilm, estimating bacterial abundance, analyzing biomass

and community structure and understanding their population dynamics in natural systems. We thought that the most important and practical thing to know about this process was to understand if the process is going on and at which rate, instead to understand exactly who is doing the process, because this is what we need to set up a wetland plant.

The aims of this study was to develop a methodology easy to manage and to replicate in different situations, for different vegetation and diverse types of wastewater to define how the floating system is working and if nitrification is taking place. In order to obtain an indication of the nitrification potential of the attached FTW biofilms (Bastviken *et al.,* 2003), analyses were conducted from roots and attached geotextile test-strips retrieved from under floating mats deployed in a pilot-scale experiment. First step was to set up the experiment in a clear and precise way to be replicable, to characterize the wastewater and find a buffer artificial one, to find a root's surface. Second step was to define the best moment for sampling and finally arrange the analysis.

Methods

Field facilities

This study analyses the biofilm behavior created in a floating treatment wetland (FTW) of a pilot-scale experiment at the Pukete Sewage Treatment plant in Hamilton, New Zealand.

The experiment consists of 3 set of 4 mesocosms in series, loaded with effluent coming out from the outflow of the plant's solid settling tanks and having different hydraulic retention time (HRT) of 12, 24 and 48 hours (figure 1).

Figure 1: Floating treatment wetland experiment set up and a detail of the floating mat and roots coming out from it.

Each mesocosm (1.1m^3) contains a vegetated floating mat (200 mm thick polyester fiber mat injected with patches of polystyrene foam to provide buoyancy; 1m^2 area) (figure 1). Plants growing in the floating mat develop their roots inside the polyester fiber and only the final parts come out from it. We investigated these final parts of the roots.

The first mesocosm of each set was provided with bubble aeration to enhance nitrification, while the following three mesocosms had no aeration allowing low dissolved oxygen conditions conducive to denitrification to occur.

The wastewater characteristics of the inflow's experiment in the period of this study (November 2010 – January 2011) are summarized as follows and values are expressed in mg/L: TSS 87; TN 44,3; NH_4 33,3; NO_2 0,006; NO_3 0,005 TKN 44,3; DRP 3,52; TP 5,37; BOD_5 128,3; DO 0,18. T° was 27,1 pH was 7,05 and CW 770 µs/cm.

The species used in this FTW experiment is *Carex virgata* L., an aquatic macrophyte native of New Zealand. It is tolerant of both wet and dry soils, and is fast growing. Usually grows in swamps and can tolerate flooding well. It is often used for depuration proposes in New Zealand; because its characteristic of great flexibility it is particularly suitable for be planted on floating islands. (Tanner and Headley, 2011).

The experiment on the biofilm was conducted in the 12 hours HRT set and in particular in the first aerated mesocosm (A) in the second (B) and in the forth (D) both aerated. In these reactors several strips (0.20 X 0.04 m) of geotextile (polypropylene mesh) were hung underneath the floating mats in December 2010 and left for a month establishment period (figure 2).

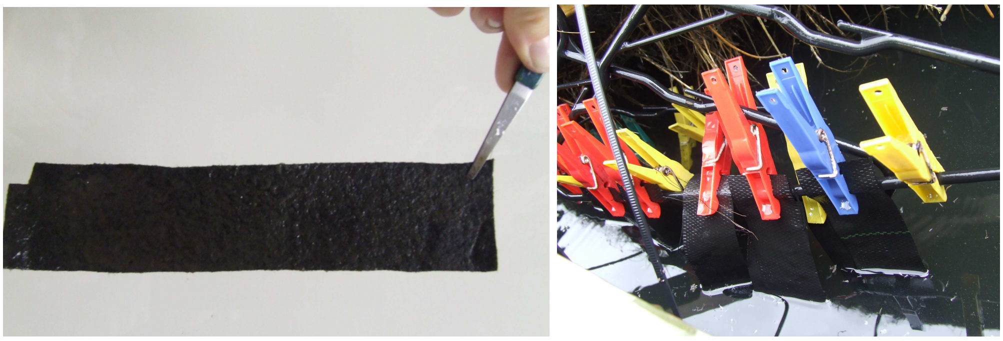


Figure 2: Sample of geotextile strip (0.20 X 0.04 m) used in the experiments and the way used to hang them underneath the floating mats.

Laboratory test

After 5 months from the beginning of the floating system project, roots together with strips were sampled from each mesocosm, once a week for five times.

A preliminary phase in the laboratory was to find a medium to make the samples collected grow, to be as stable as possible with pH and DO levels similar to the inflow wastewater coming to the mesocosms from the traditional treatment plant. To find the right medium in which the biofilm could grow and have stable conditions in order not to affect the experiments, many solutions were tested and different source of ammonium-N, such as CH_3COONH_4 and NH_4Cl, were used, according to those find in literature (H. Yoo *et al*. 1999, Craggs et al, 2000, Raj *et al.* 1998).

As the purpose was to check the variations in ammonium-N content in the solutions, after literary researches, we choose NH_4Cl as source of ammonia and we tested four different made out media, checking the pH variation on time of the different solutions (table 1).

Table 1: Characterization of the four tested media.

Compounds (mg/L)				
	1	**2**	**3**	**4**
$NaHCO_3$	24			420
KH_2PO_4	14	8,5	54	25
NH_4Cl	60	190	535	230
$(NH_4)6Mo7O_24*7H_2O$			0,037	
$CaCl_2$	18	4		
$MgSO_4*7H_2O$	24	2	49	6
NaCl		7	585	
$Na_2HPO_4*12H_2O$				67
K_2HPO_4		21,7		
Na_2HPO_4		33,4		
KCl			74	
$CaCl_2*2H_2O$			147	
$FeSO_4*7H_2O$			0,973	
H_2BO_3			0,049	
$MnSO_4*H_2O$			0,045	
$ZnSO_4*H_2O$			0,043	
$CuSO_4$			0,016	
$FeCL_3$				0,5
HEPES			19,1	
CRESOL RED			5	

Second step was to find the right surface upon which to base the calculations. Our aim was to calculate the ammonia utilization rate on time, reported on biofilm's attachment surface, in order to know how much ammonia is possible to remove from wastewater per m^2 of attachment surface. The geotextile strips' surface was easy to find because strips had constant size.

To calculate root's surface we took measurements of 6 similar roots sampled from all mesocosms, in particular we measured the total length, and the diameter at three different sections and numbers and length (30,4 ± 14,4) of secondary roots. This was made to have an ideal root's surface to relate to.

This work is been made just the first time before starting the experiment because during sampling in the field there was not possible to lose time on doing these measurements; the best thing to do was to start as soon as possible with the experiment, putting the roots in the culture medium and avoid to leave them in contact with air, in fact this risked to deteriorate the biofilm. All roots sampled for the experiment's trials have been selected to have similar length of the average calculated at the beginning.

Last step was to set up a laboratory-scale test where the culture medium with ammonium-N (NH_4Cl) was prepared at the similar concentration as the original wastewater, and added to stirred flasks (500 mL capacity) under controlled conditions (20 °C, shaking table 100rpm, dark) for 48 h, with either a sample of 5 roots or a geotextile strip.

From January to February 2011 (summer time in this hemisphere), we conducted 5 trials, one only with geotextile strips, one only with roots and the other three with both substrates. Every trial had three repetitions for each tank, for roots, strips or both; three repetitions were filled only with the culture medium to be used as control.

After a testing period with samples at different time (time 0, 6, 12, 24 and 48), we came to the conclusion that the more significant points to sample were at time 0, after 12 and 24 hours.

On water samples we analyzed pH and DO with specific meters: pH was measured using a TPS™ WP-81 portable meter, while DO and temperature were measured using a TPS™ WP-82Y portable meter (TPS Pty Ltd, Australia).

Chemical analysis were conducted to check the concentration of ammonium-N and nitrate-N with the spectrophotometer Hach-Lange, DR 2800 and special prepared cuvettes. In order to calculate an ammonium-N utilization rate (mg N m^{-2}), we considered the biofilm surface attachment as 160 cm^2 for the strips (4x20 cm each side) and calculated an average roots surface for *Carex virgata*:

1) $C_{end} – C_{start}$ = removal on time (mg N)
2) mg N/ m^2 = utilization rate per unit area

For every sampling we withdrew 50 ml of solutions from the flasks and so their concentrations was increasing during time. That is the reason way calculating ammonia balance, we took into account the real amount of water and at the end we related all measurements to the same level of solution (500mL) and so before step 1) we introduced this correction:

C_{end} = C_{end} *450/500 for the second sampling, C_{end} = C_{end} *400/500 for the third one, and so on.

To do a complete trial or experiment, it means collect roots and strips from the depuration plant, set up the experiment in the laboratory and do samples and the analysis, it took on week each time.

Results

Preliminary phase: medium and root's surface

One of the aim of this work was to find a proper methodology that could be simple to replicate. The first results we present deal with the preliminary methods we followed to set up in the best possible way the experiments that is to find the most representative culture solution in which make our samples growing.

Table 2: pH variation in 24 h for the four different media tested.

Time (h)	Average			
	1	**2**	**3**	**4**
0	**6,8**	**7,56**	**5,12**	**7,68**
18	**7,49**	**7,09**	**4,7**	**8,51**
24	**7,47**	**7,08**	**4,82**	**8,59**

Different solutions tested showed from the beginning different pH level on time (table 2). Medium number 3 had an environment too acid and was not suitable for our purposes; number 4 medium's pH was increasing too much as number 1. Monitoring the pH variations at different time we could see that the most stable and similar solution to the original wastewater came out to be number 2 with only 0,48 points of pH variations in 24 hours (6,35% of variation against 9,85% of medium 1 and 11,72% of medium 4).

Finally the medium we choose for the experiment had the composition of tested medium number 2, we just reduced the amount of NH_4Cl in order to better represent the ammonia concentration that the inflow had and where the substrates we were going to test came from; from 190 mg/L of NH_4Cl, we reduced the concentration to 153 mg/L .

To calculate an average roots length we considered measurements took from sampled roots, listed in table 3.

Table 3: Measurements of roots diameters at three different levels, their length and numbers of secondary roots, with average and standard deviation.

	Length (mm)	Section A (mm)	Section B (mm)	Section C (mm)	Sec. roots (n°)
	197	1,7	1,35	1,35	45
	142	2,1	2,3	2,05	71
	224	1,6	1,85	1,55	73
	241	1,95	1,72	1,43	72
	257	2,04	2,01	1,55	101
	182	1,63	1,77	1,65	60
Average	207	1,84	1,83	1,6	70,3
St.dev.	42,2	0,22	0,32	0,25	18,4

Diameters at section A and B are almost identical, while diameters at section C are smaller (figure 3). From these results we figured the root as divided in three parts, the first one from the apex was imaged as a cone and the other two were considered together as a cylinder. Estimating the surface of the cone and the cylinder we obtain an average root's surface of 8,98 cm^2.

Figure 3: Scheme of a root and the three section were the diameter was taken.

Water quality and abatements

An assumption on data's interpretation is necessary: biofilm developed in geotextile strips is sure younger than biofilm developed in roots, in fact strips where hung underneath the floating mats one month before the experiment started, but floating mats with plants were set up for the floating system 6 months before we started. This could have influenced the results we obtained on removal efficiency.

We monitored the DO and pH level on every wastewater sample we did during the experiments in flasks with roots, strips and control flasks, at 12, 24 and 48 hours.

The results for DO are shown in figures 4, 5 and 6. In all the water samples with strips and roots we saw that this level is increasing after 12 hours and then remains quite stable, but for the control DO level is decreasing on time (figure 4). In general DO level for strips and roots is higher than in the control (figure 5). If we consider the water samples coming from the three different tanks, DO level was lower in the flasks containing water from the first aerated tank (tank A) than in the other two tanks with no aeration (figure 6). This is probably due to greater respiratory oxygen utilization of roots and strips and attached biofilm that developed in tank A where there are greater aerated conditions with maximum organic matter (BOD) (Tanner and Headley, 2011).

We know that nitrification processes consume large amounts of oxygen but biofilm developed on the substrates are probably generating oxygen too, and perhaps that is why the control has the lowest values.

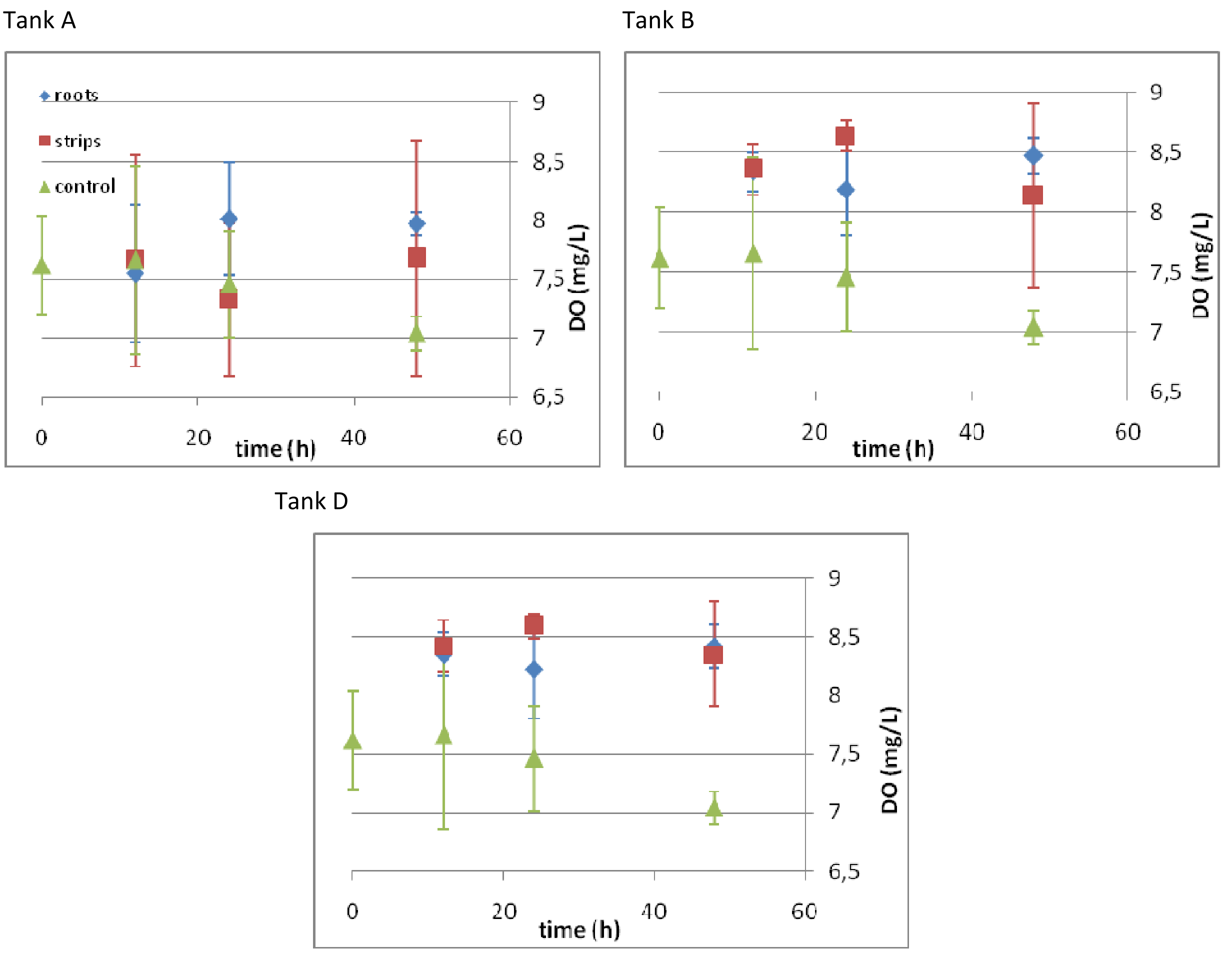


Figure 4: DO variations for roots, strips and control developed in tank A, B and D, after 12, 24 and 48 hours in the flasks with culture medium.

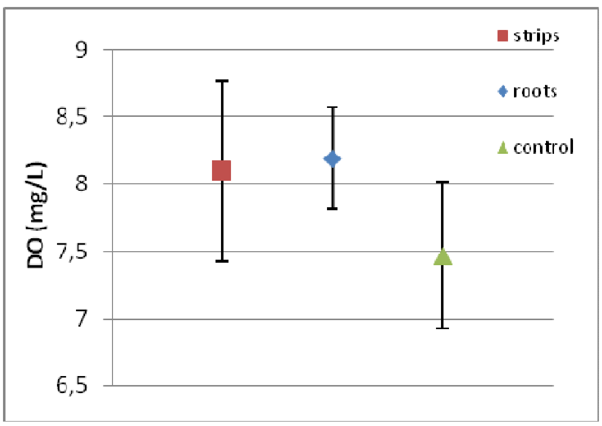


Figure 5: DO level for roots and strips developed in all mesocosms.

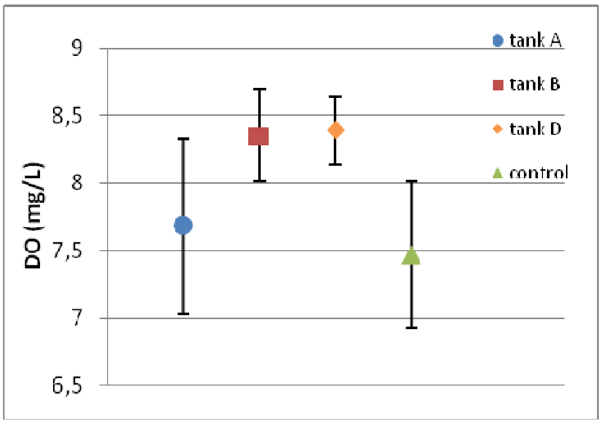
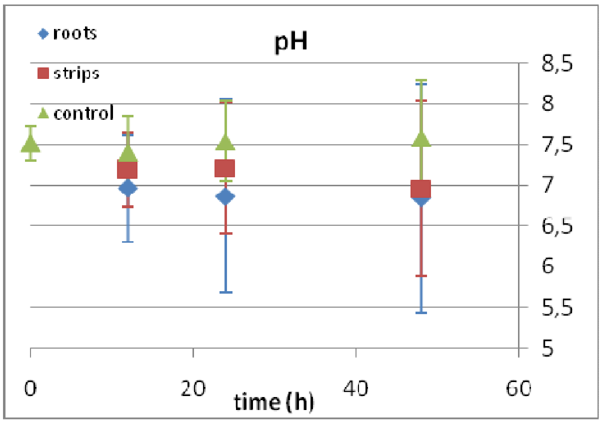


Figure 6: DO level for solutions with both roots and strips developed in mesocosms A, B and D.

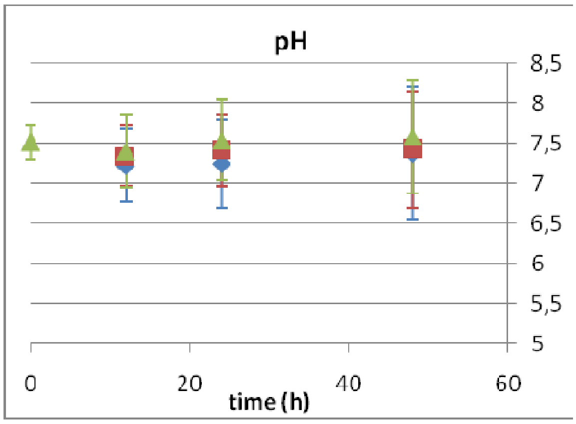
Regarding pH level, we can see that the solutions with strips and roots developed in mesocosms B and D have an higher pH level than those developed in mesocosm A (figure 7 and 9). This fact could mean that nitrification is occurring in mesocosm A. As result of nitrification we have acids production and alkalinity consumption (as calcium carbonate) and this characteristically causes pH reductions (Kadlec and Wallace, 2009). In the control this pH reduction is not present and in figure 8 we can see that flasks with roots have a pH level lower than other flasks with strips. This could be for the nitrification process more pushed with roots' biofilm.

The values of pH of solutions with strips and roots developed in mesocosms B and D can be higher maybe for denitrification processes, in fact roots and strips developed in mesocosms with no aeration. Denitrification does the opposite of nitrification at about half the rate and this will cause pH to rise in comparison of tank A (figure 9).

Tank A



Tank B



Tank D

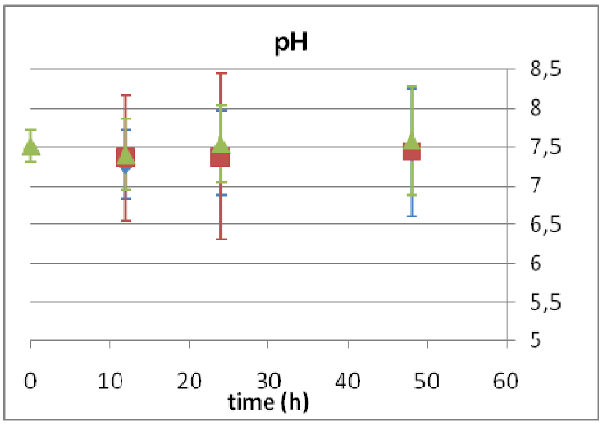


Figure 7: pH level for roots, strips and control developed in tanks A, B and D, after 12, 24 and 48 hours in the flasks with culture medium.

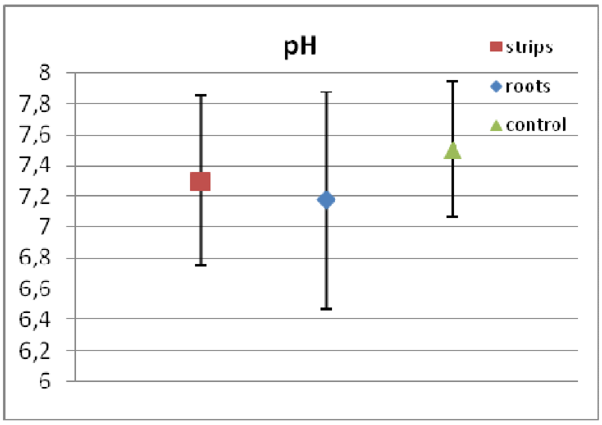


Figure 8: pH level for roots and strips developed in all mesocosms.

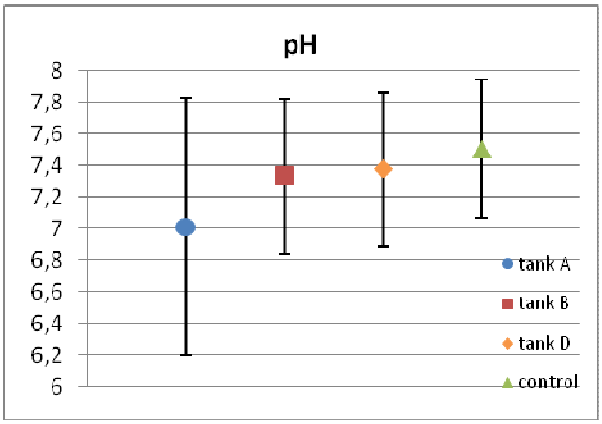
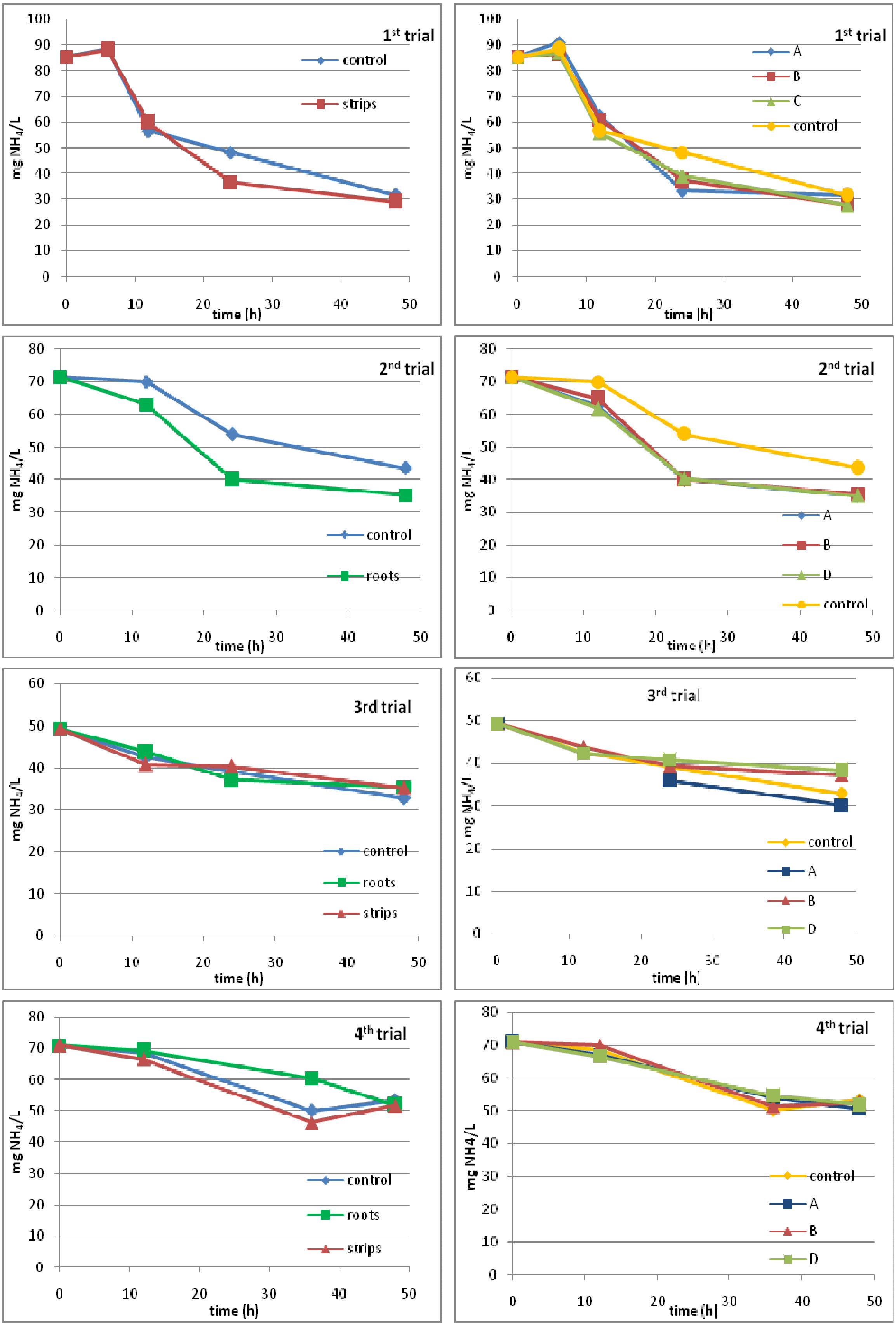


Figure 9: pH level for solutions with both roots and strips, developed in mesocosms A, B and D.

The ammonium-N concentrations we found in the five trials are shown in figure 10. There is a lot of variability on the trials regarding the way of conducting the experiment and the results we obtained, but at the end we tried to uniform the data to make comparisons. We did not consider the samples after 6 hours we did in the first trial and not either the samples after 36 hours we did in the third trial. These were only testing samples to check the better moment for sampling.

It is right also to consider that ammonium-N concentration at the beginning of every trial is not always the same.

We can see that these levels are decreasing on time for every experiment, even if some of them gave best reduction performances than others. Ammonium-N concentration is coming down in the control too probably due to ammonia volatilization (Jayaweera and Mikkelsen, 1991) but in the flasks containing strips or roots the levels are usually lower than the control.


1st trial
control
strips
mg NH4/L
time (h)
1st trial
A
B
C
control
mg NH4/L
time (h)
2nd trial
control
roots
mg NH4/L
time (h)
2nd trial
A
B
D
control
mg NH4/L
time (h)
3rd trial
control
roots
strips
mg NH4/L
time (h)
3rd trial
control
A
B
D
mg NH4/L
time (h)
4th trial
control
roots
strips
mg NH4/L
time (h)
4th trial
control
A
B
D
mg NH4/L
time (h)

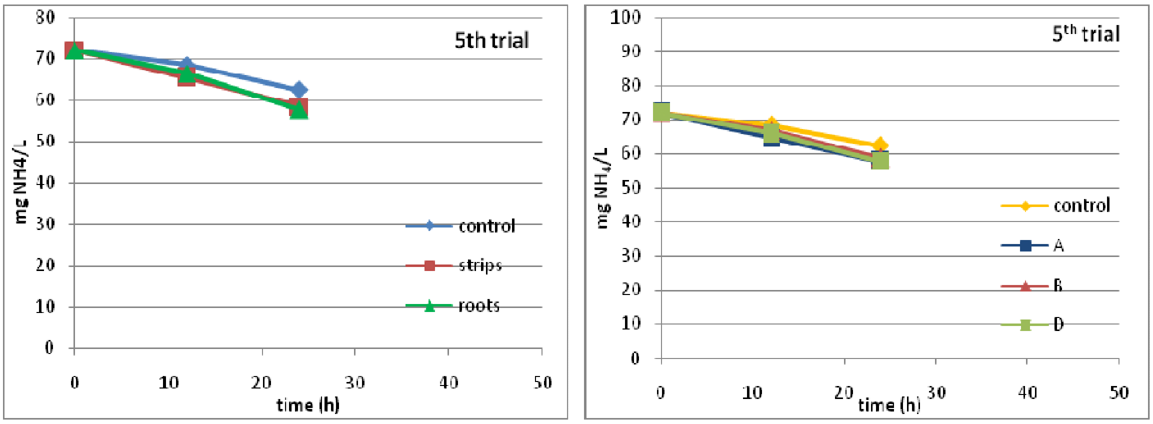


Figure 10: Ammonium- N concentrations (mg/L) on time (h) in the five trials. On the left comparison between strips and roots developed in all tanks; on the right comparison between substrates developed in the three different tanks (A,B and D).

Considering the graphics on the ammonium-N reduction (figure 10) for samples of roots and strips coming from the different mesocosms, focusing our attention on time, it's clear that the most of lowering of ammonium-N is within 24h. After one day (48h) reduction is quite negligible for biofilm attached on geotextile surface while we can see still ammonium-N removal on roots surface.

Percentage decreases respect the beginning of every trials have been calculated, for samples containing strips and roots (table K). The first trial we did was with geotextile strips and we saw that there was no decrease but an increase of 3% after six hours, so we decided not to sample anymore at that time. After 12 hours we noticed a decrease for every trials but the more significant one in percentage is after 24 hours. After 48 hours we still observed a decrease but the rate is lower.

Table 4: Percentage of concentration's value at the beginning of every trial, defined for different times, for samples with geotextile strips and for roots.

STRIPS	**trials**					
hours	**1**	**2**	**3**	**4**	**5**	**average**
6	103					
12	69,7		82,8	93,8	90,8	84,3
24	46,7		81,9		81,1	69,9
36				65,1		
48	34		71,3	72,7		59,3

ROOTS	**trials**					
hours	**1**	**2**	**3**	**4**	**5**	**average**
6						
12		88,4	88,8	97,6	92,2	91,7
24		56,1	75,3		80,1	70,5
36				85,2		
48		49,4	71,5	72,9		64,6

When we consider the ammonium utilization rate, concentrations are related to unit area and differences between different attachment surfaces or different environment where materials developed is clearer.

First effect to consider is time and what is happening along the experiment (figure 11); as we can see ammonium-N removal is greater after 24h: reduction is not so great in the first 12 hours as in 24 hours. The increase of removal after 48 hours is also less than in the first day.

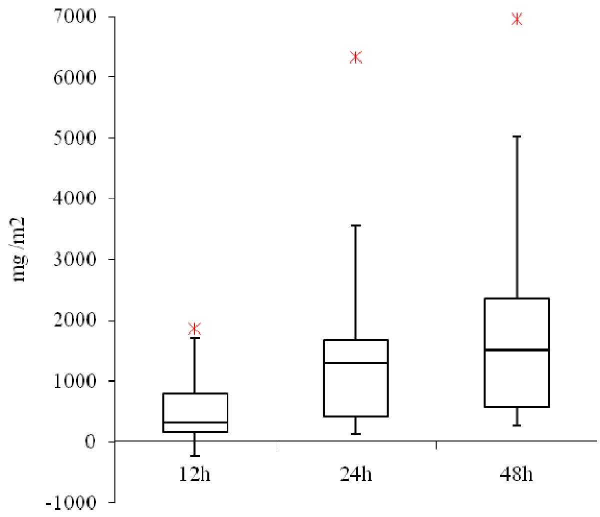


Figure 11: NH_4-N removal (mg/m^2) for roots and strips after 12, 24 and 48 hours.

Results indicate ammonium utilization rates (AUR) of 266 for the first quartile to 1251 for the third quartile (median 429) mg N m^{-2} biofilm d^{-1} for the strips and of 727 to 2327 (median 1582) for the roots respectively (figure 12). The variability is high especially for the roots where surface's attachment is alive but the biofilm developed on them seems to be much more efficient than that on geotextile (figure 12).

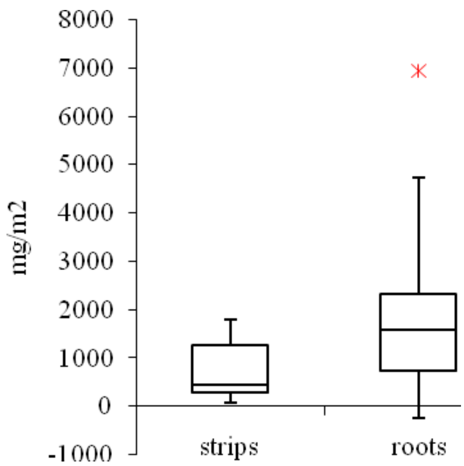


Figure 12: NH_4-N removal (mg/m^2) for roots and strips coming from all mesocosms.

Comparing the three different tanks, A with artificial aeration and B and D without aeration, no interesting differences are coming out (figure 13), considering the average both of strips and roots (median 669, 949 and 760 mg N m^{-2} biofilm for A, B and D respectively); variability on removal is the same from substrates coming from the three mesocosms.

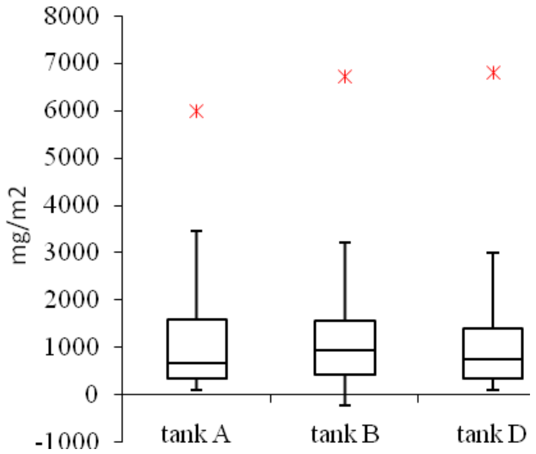


Figure 13: NH_4-N removal (mg/m^2) from biofilm coming from mesocosms A, B and D; both roots and geotextile strips as matrix.

Considering the removal on time we calculated for solutions containing different substrates (roots or geotextile strips), it is clear that biofilm attached on roots seems to work better in terms of ammonium-N reduction and that both biofilm developed on roots and strips need 24h to remove the most of it, even if roots can still remove something in the second day (figure 14).

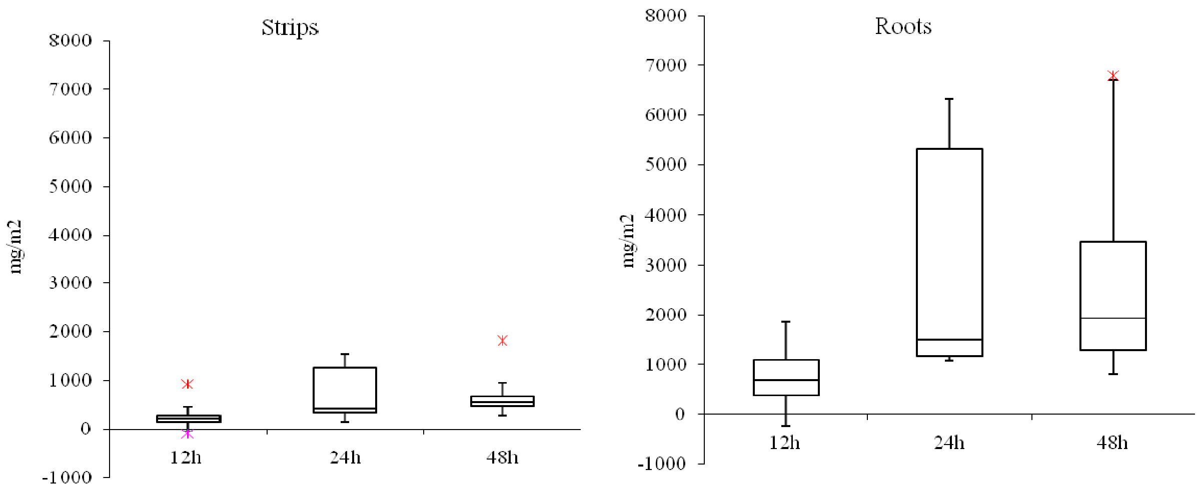
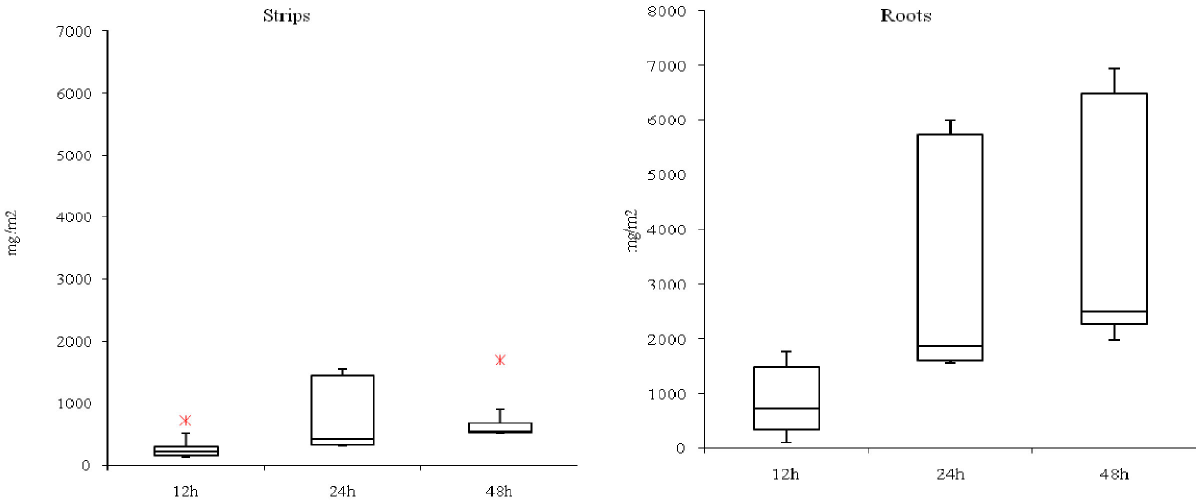


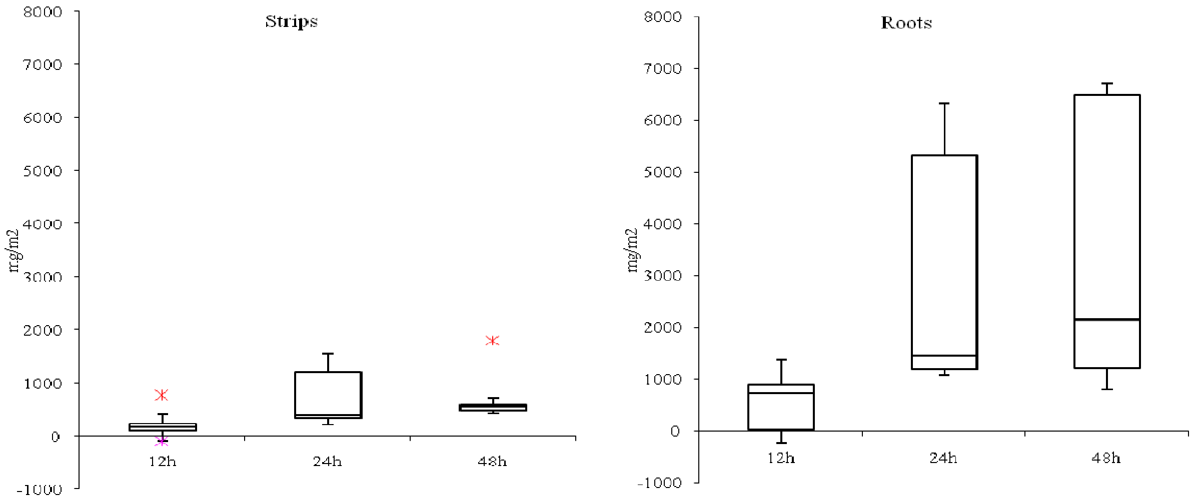
Figure 14: NH_4-N removal (mg/m^2) on time, from biofilm coming from roots and geotextile strips in all mesocosms.

Looking at the removal of ammonium-N on time for strips and roots developed in different mesocosms, it is confirmed that the removal is higher with biofilm attached on roots' surface than in geotextile's surface (figure 15). During the experiment the period in which there is the most of removal is the first 24 hours. There is no a strong difference in terms of removal from substrate coming from different mesocosms. What is to notice is that in samples with roots there is much more variability than in geotextile because of the high instability of a alive component.

Tank A


Strips
mg/m2
7000
6000
5000
4000
3000
2000
1000
0
12h
24h
48h
Roots
mg/m2
8000
7000
6000
5000
4000
3000
2000
1000
0
12h
24h
48h

Tank B


Strips
mg/m2
8000
7000
6000
5000
4000
3000
2000
1000
0
-1000
12h
24h
48h
Roots
mg/m2
8000
7000
6000
5000
4000
3000
2000
1000
0
-1000
12h
24h
48h

Tank D

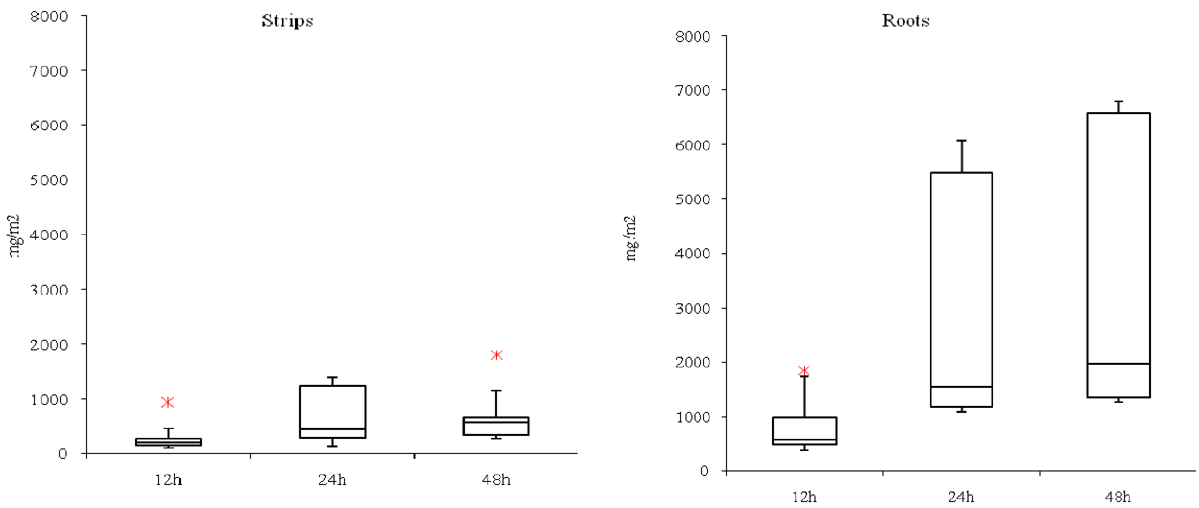


Figure 15: NH_4-N removal (mg/m^2) on time, from biofilm coming from roots and geotextile strips in mesocosm A, B and D.

Nitrification process is represented by these formulas:

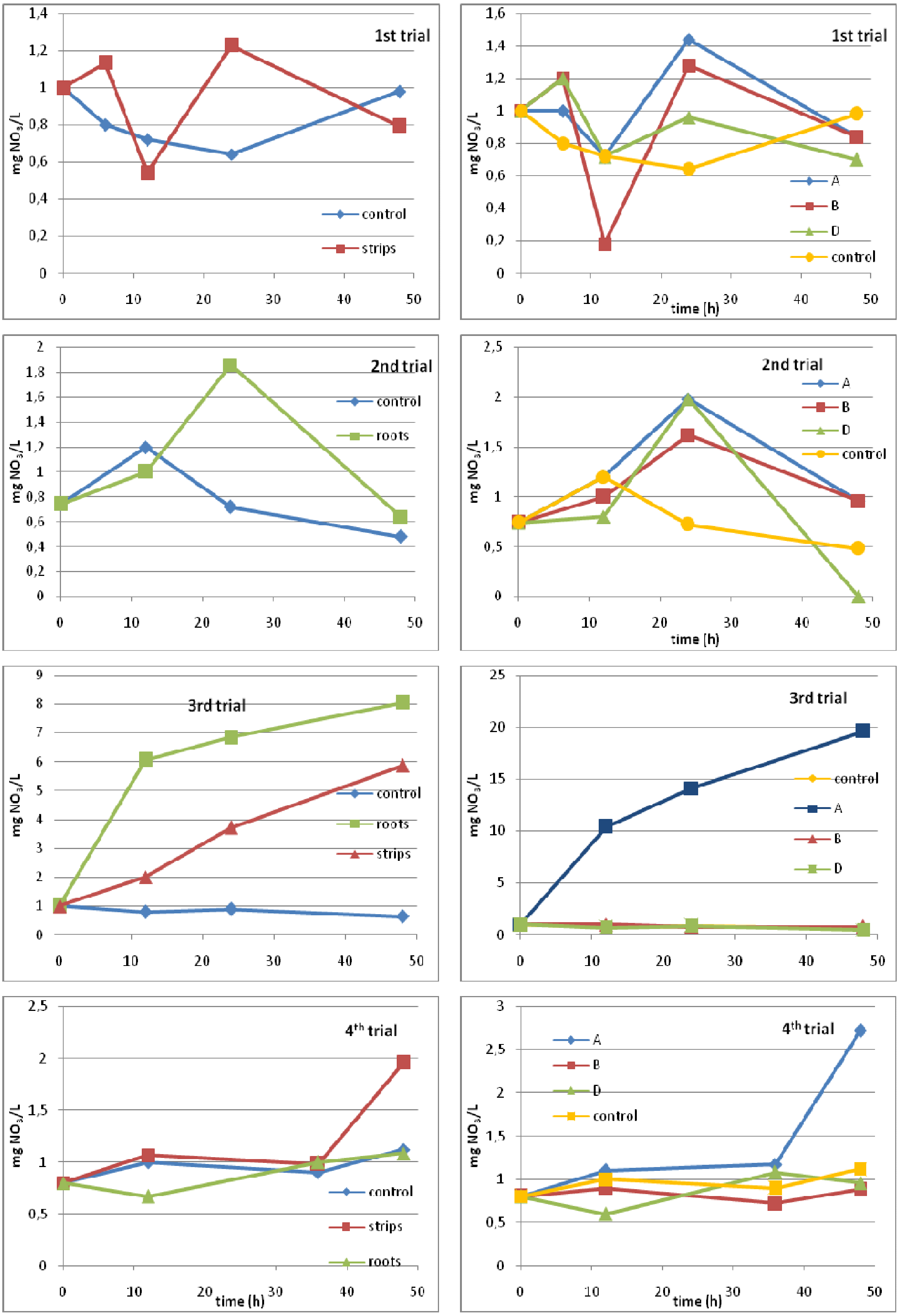
$NH_4^+ + 1{,}5\ O_2 \rightarrow 2H+ + H_2O + NO_2^-$

$NO_2^- + 0{,}5\ O_2 \rightarrow NO_3^-$

that overall we can summarize like this:

$NH_4^+ + 2\ O_2 \rightarrow 2H+ + H_2O + NO_3^-$

During our experiments we expected that NH_4 removal from the artificial wastewater was followed by NO_3 accumulation. But, as we can see from figure 14, this is not observed in the measurements of NO_3 concentration we did in some flasks for every trial.


1st trial
mg NO3/L
control
strips
1st trial
A
B
D
control
time (h)
2nd trial
control
roots
2nd trial
A
B
D
control
time (h)
3rd trial
control
roots
strips
3rd trial
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D
4th trial
control
strips
roots
time (h)
4th trial
A
B
D
control
time (h)

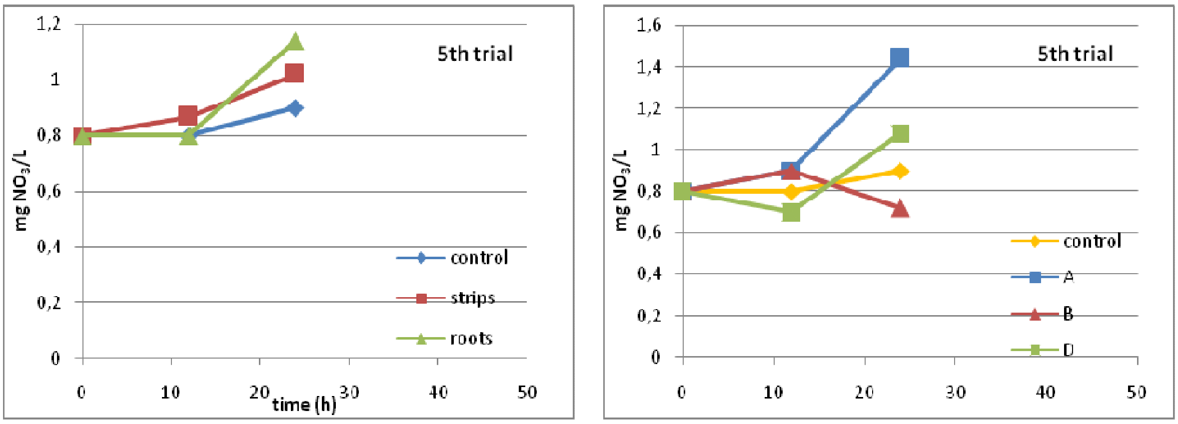


Figure 16: Nitrate concentrations (mg/L) on time (hours) in the five trials, for flasks containing strips (A,B,D) and roots (Ar,Br,Dr) coming from the three tanks of the floating wetland plant and the control.

The production of NO_3 was very negligible (figure 16), except for the third trial, where both roots and strips coming from the aerated tank A reached the average concentration of 22.9 and 16.3 mg NO_3/L respectively, which means 2431 and 479 mg m^{-2} biofilm d^{-1} for the strips and for the roots respectively. But in all other trials the NO_3concentrations reach not even 4 mg/L.

Conclusions

First achievement we had was to find a sensible and easy to replicate method to know if ammonia-N is been removing from wastewater and the rate of this removal per unit area of floating system.

This methodology could provide comparative information on the components of the floating island systems, such as the mats types, plant species and environment in order to calculate vegetated surface areas required to remove a certain quantity of ammonium-N from a specific and known wastewater. It could be a simple tool to check the efficiency of several types of FTW, treating different sources of wastewater and characterize it.

Decreasing of pH level on time especially for roots and strips developed in the aerated mesocosm supports the hypothesis that nitrification is occurring.

Ammonia-N reduction on time is visible both for strips and roots as substrate of attached biofilm and even if in the control the concentration is decreasing too, is always higher than thesis with surface of attached biofilm.

Analyzing AUR the removal rate is more clear because it is referred to unit area; for biofilms attached to the roots AUR is higher than that for the geotextile strips and this for substrates coming from any mesocosms and at each time of measurement; while we saw that there is not a wide difference in terms of removal for roots and strips coming from different tanks, aerated or not. Considering the period of time necessary for nitrification to occur, the more important ammonium-N decrease is reached in the first 24 hours, because after 12 hours not much is happening. After 48 hours we still have ammonium decrease but less than before.

These results can be used, in combination with removal rates measured from the mesocosms, to evaluate the importance of root biofilms in ammonium-N reduction. This method could be valid also to test NUR (nitrate utilization rate) and OUR (oxygen utilization rate).

Chapter II

Ornamental plants growing in a floating system

Introduction

FTWs are not used only to improve water quality but also they could became a tool to ameliorate the aesthetic and naturalist value of different environments, creating new spaces for flora and fauna. In an urban contest these systems could adduce better water spaces, such as channels or ponds, retraining and restoring usable areas.

Nakamura (1997) reports about the entire ecosystem created around the installation of floating island (habitat for birds and fish, breaking water in littoral zone and landscape improvement) and Boutwell (2002) adopt in the Las Vegas Bay (Lake Mead) a floating platform planted with different species to valorise the area.

Floating elements are adapt for being planted with different species of macrophytes with colourful blooms distributed along the seasons, in order to create different scenery during one year.

This project is a study on establishment and growth of ornamental aquatic macrophytes for water treatment with a high aesthetical value too. The aim of this project was to test growth and survival of different macrophytes species in order to find if they were suited to live in water and grow on floating systems so to hand some precious suggestions in nursery field. Different species have been studied to be used in the floating systems, especially for their aesthetic value. One of the most important features looked for were blooms with different colours that can create a good colour effect. But the aim was also to find plants able to guarantee a floral cover or at least green cover all over the year, in order to have floating elements vegetated with species that have with different times of bloom.

We wanted furthermore to test if this cultivation technique for macrophytes, directly in water, could make plants more suitable to be used in FTWs, avoiding adaptation problems after plantation.

Methods

Macrophytes, suitable for aquatic environments, with peculiar aesthetic value were chosen among those species easily to find as autochthonous, wild or from nursery. At the beginning of the experiment we selected eight different species listed in table 1. Plants were recovered and planted in early December 2009. All plants had rhizomes that had been divided to create new individuals, only few species had also the aerial part because most of them were dormant because of winter period (Cronk and Fennessy, 2001; Gregory, 2006).

Table 1: Family and species' names of used plants.

Code	**Species**	**Family**
1	*Zantedischia aethiopica* (L.) Sprengel	Araceae
2	*Iris laevigata* Fisch.	Iridaceae
3	*Thalia dealbata* Fraser ex Roscoe	Marantaceae
4	*Sparganium erectum* L.	Sparganiaceae
5	*Mentha aquatica* L.	Labiatae
6	*Canna indica* L.	Cannaceae
7	*Juncus effusus 'spiralis'* L.	Juncaceae
8	*Pontederia cordata* L.	Pontederiaceae

Plants have been grown in a covered space for 8 months, cultivation took place in a tunnel greenhouse (25 m x 12 m) of 6 m height. This was covered with a transparent plastic film (PE) and has side openings downs. The greenhouse was oriented along North-South direction.

Three polyethylene basins (Fito Star®) with capacity of 5000 L (250 cm x 200 cm x 60 cm of height) were used, they were provided with pipes (100 mm diameter) to fill them with tap water and valves at the bottom to discharge it. Each basin contained eight floating elements vegetated with the eight chosen species, each element supported two plants of a single species, for a total of 16 plants per basin (figure 1). The experiment set up consisted in three repetition per species (figure 2).

Figure 1: Tech-IA floating system used in the experiment. On the right side a single element, in the middle a basin with eight pieces and on the left the experimental set up with three repetitions.

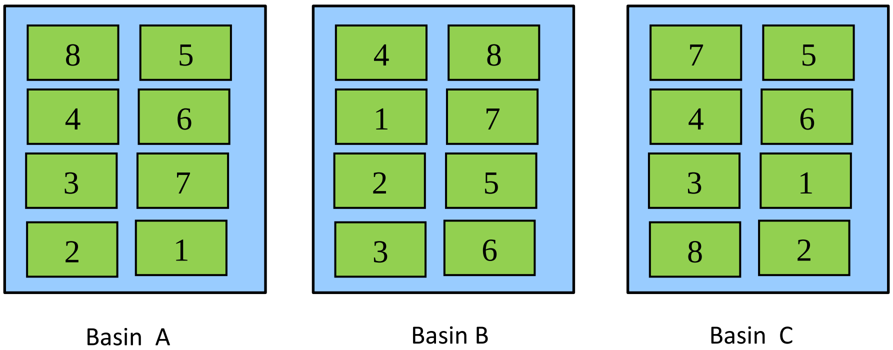


Figure 2: Experiment's set up. Different numbers are assigned to different plant species as showed in table 1.

During the experiment period (from December 2009 to July 2010) it has been necessary to replace some plants set in December because of their death or to substitute some species with others that turned out not to be suitable to grow directly in hydroponic conditions. At middle May three other species have been annexed in the experiment: *Caltha palustris* L. , *Oenanthe javanica* (Blume) DC. "flamingo" and *Acorus calamus* L..

Data on air and water temperature and air moisture were register with a detector provided with probes (Ecomorma s.a.s., FT2300).

Tap water was not enough rich in minerals to permit a good plants development for vegetation growing in water without soil, that is the reason why we added fertilizers. At the middle March we added Ferty 3® in order to reach a conductivity of 1000 µS cm-1, while a prepared fertilizer (table 2) was used at the begin of April.

The prepared fertilizer was made of different microelements and had the following chemical composition in mg/L: KCl 1,86; H_3BO_3 0,77; $MnSO_4*H_2O$ 0,17; $ZnSO_4*7\ H_2O$ 0,29; $CuSO_4*5\ H_2O$ 0,06; H_2MoO_4 (85% MoO_3) 0,04; HNO_3 214; $Ca(NO_3)_2$ 216; NH_4NO_3 63,6; KH_2PO_4 136; K_2SO_4 118; $MgSO_4$ 24,6; KNO_3 54; FeEDTA (6%) 7,5.

The basins were filled with an hydroponic solution . Its chemical and physical characteristics were also checked using specific probes (*Hach-Lange*) to detect electrical conductivity (ECw), dissolved oxygen (DO), temperature (°C) and pH. DO measurements were taken on water surface and at the bottom of the basin.

Water level and its consumption was controlled usually every 15 days. These parameters are important to control mineral nutrition trough the solution's refill. After water level measures and calculation of absorbed water volume, each basin was filled again with tap water.

Plants development was measured, taking floating elements out of the water (figure3). Height of aerial part, from the collar to the highest leaf and extend of roots till the longest one, were estimated. Sampling period was carried out for 6 months, from February to July 2010 and measurements were taken every week.

Figure 3: Lifting of the floating element to take plant’s measures. (Left, *Mentha aquatica* and right, *Canna indica*).

At the end of the experiment all aerial biomass was harvested; biomass were collected in October 2010, when every plant was harvested and wet material has been dried in oven at 65°C for 36 hours. After the material’s grinding the presence of nitrogen on dry matter has been detected with an elements’ analyzer (CNS).

Results

Temperature

Plants grew for several months inside the glasshouse (February to July 2010), but temperature changed following the outside temperature. So did the water in the basins (figure 10).

Air temperature goes from 14 to 36°C with minimum values at the beginning of February (14,5°C), then values rise till middle March to reach 24°C, and then drop very quickly. From the second week of April temperature increases again and at the end of July average value are 35°C.

Water temperature is the average from temperatures measured in each basins. Values from different basins were very similar as standard deviation attests (figure 4) . It varies from 15 to 30°C with peaks in April for spring (23,1°C) and in July for summer (29°C). The lowest temperature is from 14 and 16 °C and it was detectable from the beginning period to middle March.

Temperatures trends of air and water are different because of heat capacity of water, so its values are more steady. Some unstable values specially at the end of measurement's period are due to water supply that we did every 15 days, that lowered the values.

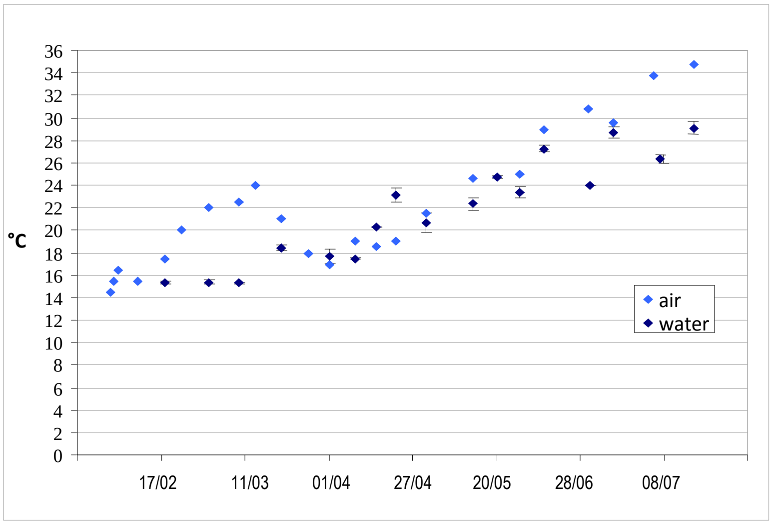


Figure 4: Air and water temperature variations from February to July 2010 inside the glasshouse, with st. dev. for water.

Water consumption

Water consumption is another parameter that affects vegetation growth. Water supply was given following plants absorption from 22nd of February to 15th of July, in six events.

Water consumption of plants gradually raised with increasing of ambient temperature and plants development too. Analyzing water supply, it results that the average consumption per week for each basin was 30,2 L from 22/02 to 21/04, 75 L from 22/04 to 6/05, 139 L from 7/05 to 1/07, 167 L from 2 to 8/07 and 216 L 9 to 15/7.

Every plant daily consumed 0,27 L from 22nd of February to 24th of March, 0,67 L from 25th of March to 7 of April, 1,24 L from 7 to 21 of April, 1,49 L from 21st of April to 6th of May and 1,94 L from 6 of May to 16 of July.

Total amount of water supply was 1542 L on average.

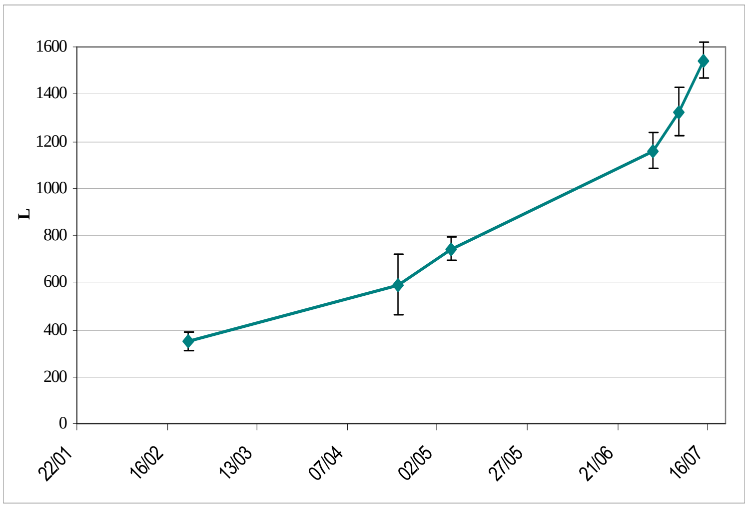


Figure 5: Average trend of cumulative water during experimental period with standard deviation.

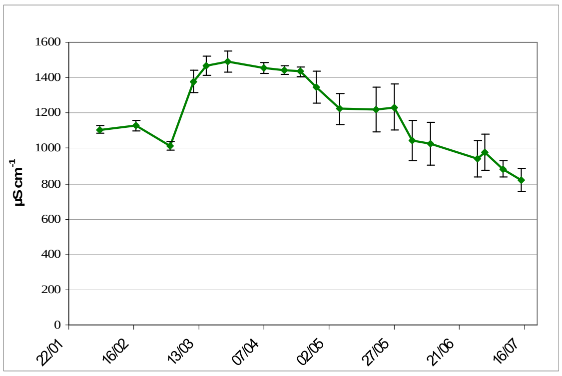
Electrical conductivity, pH and dissolved oxygen

Sampling on conductivity, pH, and DO in water were taken every week.

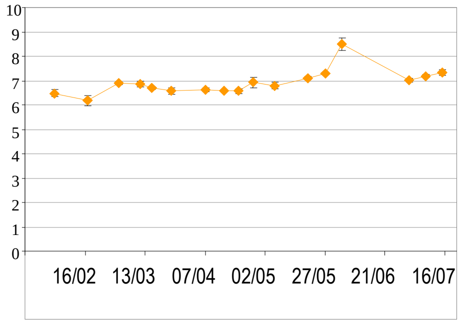
In figure 6 we can see the average conductivity calculated with values from each basin. The trend shows irregularly values that range from 800 e 1500 µS cm-1. If we compare this graph with that of figure 5, we can see that conductivity reduction are due to water supply. The rise of conductivity we see in spring coincide with fertilizer applied on 1st April 2010.

During the last period of the experiment, since 20th of May, conductivity is lower because of increasing of water supply and lack in fertilization. Considering standard deviation, we see that values are more variable on May and this is probably due to different water consumption from the plants in each basin, in fact they grow differently and some of them died and others were added.

ECw



pH



DO

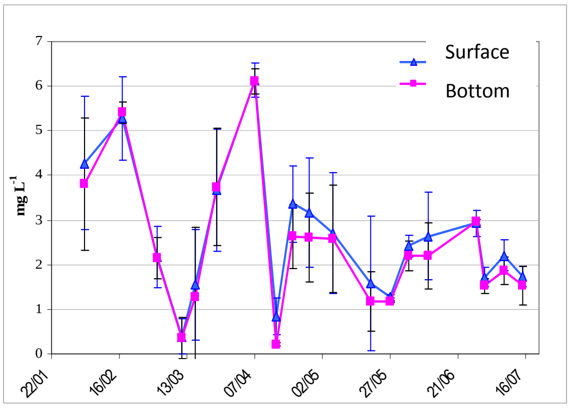


Figure 6: Average trend of conductivity (μs cm^{-1}) , pH and dissolved oxygen (mg L^{-1}) during the experiment with standard deviation.

Dealing with pH values of solution, these range between 6 and 9 (figure 6).

In the initial experimental phase values are quite stable till the end of May varying between 6 and 7 but in June they reached the average of 8,49.

Analyzing the content of DO in water (**Errore. L'origine riferimento non è stata trovata.**6), reported for shallow and deep samplings, we see that values are very irregular. The content of DO in shallow water is always higher than at the bottom of the basins, even if the difference is minimal. We have values that range between 0 and 6,50 mg/L. At 17thof February and 6thof May we can notice a rise of DO concentration due to water supply in that moment. We noticed also two values very low at 11thof March (0,39 mg/L for shallow DO and 0,36 mg/L for deep DO) and 15thof April. After the end of May situation is less irregular. Looking at standard deviation we noticed that variability inside the basin is high.

Plants growth

Results on plants growth gave different indications for different species.

Some species had no problems at all to grow in hydroponic conditions, for others it has been necessary to replace some plants of same species in different periods and others died completely.

Following these considerations, plant species are been categorized as in table 2:

1. Plant species that grow during all period of experiment;
2. Plant species that had some individuals died or replaced;
3. Plant species that did not survive.

Table 2: Partition of plant species in categories (*Caltha palustris, Oenanthe javanica* and *Acorus calamus* have been planted in May 2010, all other species in December 2009).

Plant species	**Categories**
Iris laevigata	1
Pontederia cordata	
Canna indica	
Thalia dealbata	
Caltha palustris	
Oenanthe javanica	
Acorus calamus	
Juncus effusus 'spiralis'	2
Mentha aquatica	
Zantedeschia aethiopica	3
Sparganium erectum	

Looking at the species planted in winter 2009 and that had no problems to grow in hydroponic conditions (figure x) we can say that *Canna Indica*, *Pontederia cordata* and *Thalia dealbata* gave very good results in development.

Canna indica reached 115 cm in height and had an early development in comparison with the others, started in middle February and continued to grow till July; the roots were very thick and dense and were at its maximum 36,5 cm long and stopped to grow in April. This plant species gave some problems for management, the individuals grew too much and became too heavy for the floating mat, some of them needed holders to stand and harvesting has been necessary in June, one month before other species.

Pontederia cordata started to grow in April and reached 101 cm on average in height and 62 cm was roots depth. Roots were very dense and were the longest between all the species tested in this experiment. Roots stopped to grow at beginning of May, but aerial part grew till end of June.

Thalia dealbata had an excellent growth from April and reached 104 cm at the end of June, after that period began to dry. The roots system remained almost the same length from planting to May and then reached 43,8 cm on average.

Iris laevigata did not grow as other species and did not develop so much to colonize the floating mat as did the others. It remained short till May and then reached the maximum height very quickly at the beginning of June, 71 cm, to began soon the phase of quiescence.

For all these species the variability between plants increases on time, when plants grow, especially for the aerial part and much less for roots system. The species with more similar measures among its individuals was *Pontederia cordata*. All species had lush flowerings, iris and canna were the more precocious. Iris and canna bloomed in May. *P. cordata* and *Thalia dealbata*made flowers in June (figure 10).

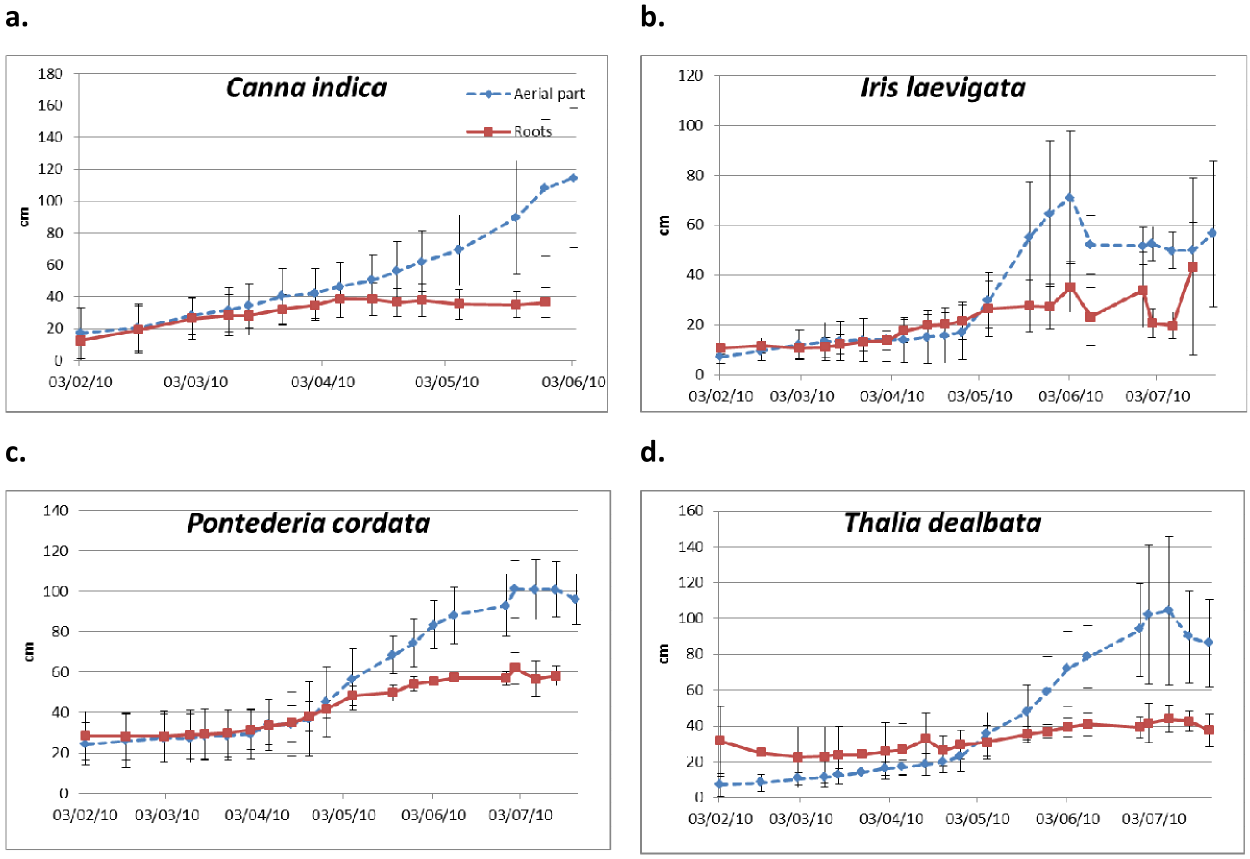


Figure 7: Growing of aerial part and roots for the species planted in December 2009 and stayed alive during all period of experiment

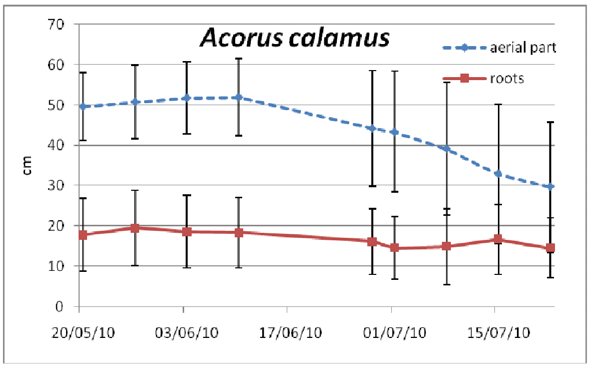
Acorus calamus, Oenanthe javanica "flamingo" and *Caltha palustris* (figure k) were planted in spring and did not spend winter time in the floating system like the previous species. Also this group of species did not have failed plants but not all had the same growth rate.

Acorus calamus seems not to be adapt to live and grow in hydroponic conditions, because its development was very low; roots remained steady and aerial part grew just few cm till the beginning of June, then started to dry. The roots system was the shorter of all species tested with 19,5 cm on average.

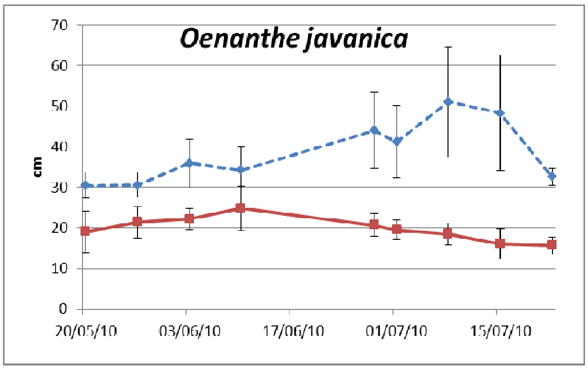
Oenanthe javanica had an huge development and colonized all floating mats surface in a short time after plantation, even if this species did not grow very high and roots were not so deep. Arial part grow to reach 44 cm in July and roots reached 24,8 cm in June, after they stopped.

Caltha palustris had a continuous growth during the experiment both for aerial part and roots; this species reached 35,2 cm in height and 30 cm in roots length on average. *Oenanthe javanica* flowered in June (figure 11).

a.



b.



c.

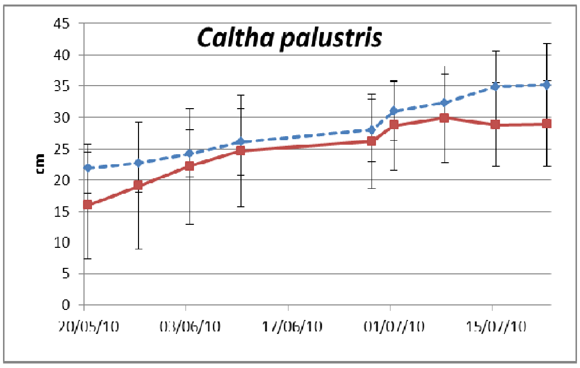


Figure 8: Growing of aerial part and roots for the species planted in May 2010 and stayed alive during all period of experiment.

To the second category, where plants have been replaced because some of them died, belong *Juncus effusus* "spiralis" and *Mentha aquatica.* Here the average has been calculated not always with six individuals and with some new plants.

For *Juncus effusus* only four of the six individuals planted in December 2009 survived and developed till middle of July, the other two plants have been replaced, one at the beginning of March and the other at the end of April. This species grew in height till the end of the experiment to reach 51 cm and the roots elongated till 55,3 cm, but plants were not large and roots were few and thin.

Regarding *Mentha aquatica* three plants have been replaced between April and May, but after the first period of adaptation all plants grew very dense and high for the species and just an individual alone is able to cover the floating mat. Aerial part grew double than roots and reached 94 cm, whereas roots grew till may and then remained steady. To notice that aerial parts of this species had few variability on time between individuals, as is possible to see from standard deviation (figure 4 b.). Mentha flowered in July (figure 10).

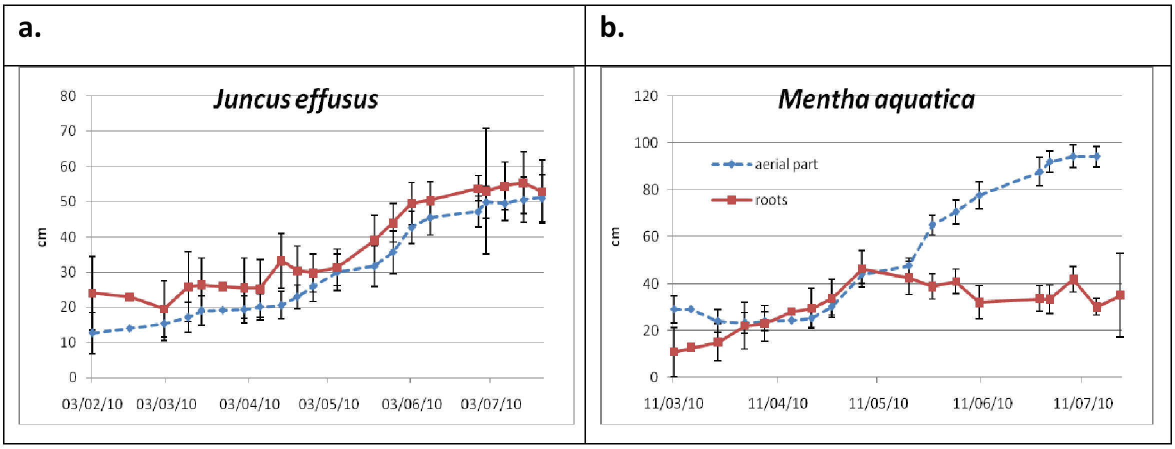
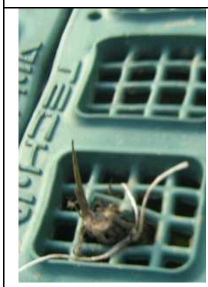


Figure 9: Growing of aerial part and roots for the two species planted in December 2009, of which some plants died and have been replaced.

For *Sparganium erectum* and *Zanthedeschia aetiopica* we had no results for surviving in this particular growing environment such as the floating mats.

Plants of *Sparganium erectum* died in March, in April we planted new individuals of the same species but they died again after one month. Their leaves became pale at the beginning and then turn yellow before dying.

For *Zantheschia aetiopica* we planted the rhizomes which never germinated and after two weeks they get waste.

<table>
<tr><th>March</th><th>April</th><th>May</th><th>June</th><th>July</th></tr>
<tr><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="5">Canna indica</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="5">Pontederia cordata</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="5">Thalia dealbata</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="5">Iris laevigata</td></tr>
</table>

				
Juncus effusus				
				
Mentha aquatica				

Figure 10: Monthly development of single species planted in December.

March	**May**	**June**	**July**
			
Oenanthe javanica			
			
Caltha palustris			

Figure 11: Monthly development of single species planted in May.

Biomass, dry weight and nitrogen accumulation

Fresh biomass of aerial part, measured for all species, show that the most productive was *Mentha aquatica* with an average weight of 3919 g per plant followed by *Canna Indica* with 3380 g. All other species were much more less productive and the worst were *Caltha palustris*, *Juncus effusus* and *Iris laevigata* with 63,8 72 and 76,3 g respectively.

As regards dry weight calculated per plant, *Mentha aquatica* and *Canna indica* were still the more productive with 790 and 410 g per plant respectively followed by *Thalia dealbata* with 141 g. The poorest ones in terms of yield were *Caltha palustris* with 8,38 g per plant on average.

The amount of nitrogen stored in each species per plant is showed in table x. Thanks to their great biomass *Mentha acquatica* and *Canna indica* were able to store 8,03 and 3,08 g of nitrogen per plant respectively; *Thalia dealbata* stored 1,41 g of nitrogen and all other species remained below zero.

Table 3: Average of fresh biomass, dry weight, total nitrogen stored, maximum height and maximum roots length, calculated by plant (for *Acorus calamus* was not possible to collect biomass).

SPECIES	Fresh biomass (g)	Dry weight (g)	% N	Total N (g)	Max height (cm)	Max roots lenght (cm)
Iris laevigata	72 ± 2	26 ± 2,85	1,02 ± 0,01	0,26 ± 0,03	71 ± 26,4	43,3 ± 35,4
Pontederia cordata	755 ± 526	106 ± 80,9	0,92 ± 0,02	0,46 ± 0,85	101 ± 13,8	62 ± 7,67
Canna indica	3380 ± 1790	410 ± 220	0,98 ± 0,11	3,08 ± 2,07	115 ± 43,6	36,5 ± 9,31
Thalia dealbata	583 ± 510	141 ± 122	1 ± 0,02	1,41 ± 1,23	104 ± 41,4	43,8 ± 7,6
Caltha palustris	63,8 ± 31,2	8,38 ± 3,77	1,02 ± 0,01	0,08 ± 0,04	35,2 ± 6,70	29,9 ± 7,07
Oenanthe javanica	212 ± 35	25,6 ± 1,89	1,01 ± 0,03	0,26 ± 0,02	44,1 ± 13,6	24,8 ± 5,59

Acorus calamus					51,9 ± 9,58	19,5 ± 9,3
Juncus effusus	76,3 ± 83	22,2 ± 13,5	1 ± 0,03	0,22 ± 0,14	51 ± 6,57	55,3 ± 8,8
Mentha aquatica	3919 ± 87,5	790 ± 313	1,01 ± 0,01	8,03 ± 3,24	94,2 ± 14	46,3 ± 7,53

Conclusions

The experiment on cultivation of different ornamental species on floating system gave good results for most of the tested species and in particular for *Pontederia cordata, Canna indica Mentha aquatica, Thalia dealbata, Caltha palustris* and *Oenanthe javanica.* For them we had good outcome for rooting and survival. *Pontedera cordata and Canna indica* had an immediately engraftment and development of aerial part and roots system.

Acorus calamus, Iris laevigata and *Juncus effusus* 'spiralis' have demonstrated to be less fit to grow in hydroponic conditions because many plants had problems to start growing or die during the experiment; but also if they remain alive their development was scarce.

Two species seems not to be suitable to grow on floating mats of the type we used: *Sparganium erectum* and *Zantedeschia aethiopica.* Not a single plant of those species survived at the experiment even different replacements.

Some species like *Canna indica, Thalia dealbata, Pontederia cordata* could became problematic for management; due to their huge development they can be very heavy and long and create instability to the floating system that risk to tip, so they need to be harvest more times than others species do.

Some species like *Mentha aquatica* and *Oenanthe javanica* could became weed species and cause damage to the others kind of vegetation planted together, suffocate and bring them to death.

All species that grew well in hydroponic conditions will have probably more chance to develop and fit for planting in floating systems.

Capitolo III

Vegetation development and performances of a floating treatment wetland as tertiary treatment for urban wastewater

Introduction

This floating treatment wetland has been installed in 2008, in a sewage sedimentation pound of Cazzago San Martino municipality located in the North East Italy (45°50'N, 10°04'E). This plant is a large basin where wastewater converge, coming from agricultural and municipal sources in particular corresponding to heavy and remarkable rainfall when the region cannot receive big amount of water and the sewer overflow. This region is in fact morphologically shaped as a depression and the channel network is not able to discharge the water outside. When the basin is full water is discharged in the near irrigation ditch where can be used for irrigation in agriculture. The wetland depuration system is risen to face the problem of enhance water quality and maintaining the basin's capacity. Furthermore one aim was also to recover this area for environmental purposes. That is the reason why it was proposed a floating treatment wetland (FTW).

This plant is been monitored for water quality, plants development and management aspects, these last ones being very important because this is a full scale project.

Methods

In August 2008 a new FTW was installed in the accumulation basin which is 1.1 ha wide, with a trapezoidal shape, an average depth of 5 m and capacity of 30.000 m^3. Pond's surface was covered with 900 m^2 vegetated floating elements from Tech-IA® system , that correspond at 1800 mats. Each element was vegetated with 8 plants for a total of 14.400 aquatic macrophytes of three different species.

The floating elements were combined together to form bands positioned at the inlet and outlet, before the pomp discharged the water in the ditch. There are five floating bands, three of 4 rows of elements and one with 6 rows that were set up as in figure 1 (a single line in the figure represents two rows band together).

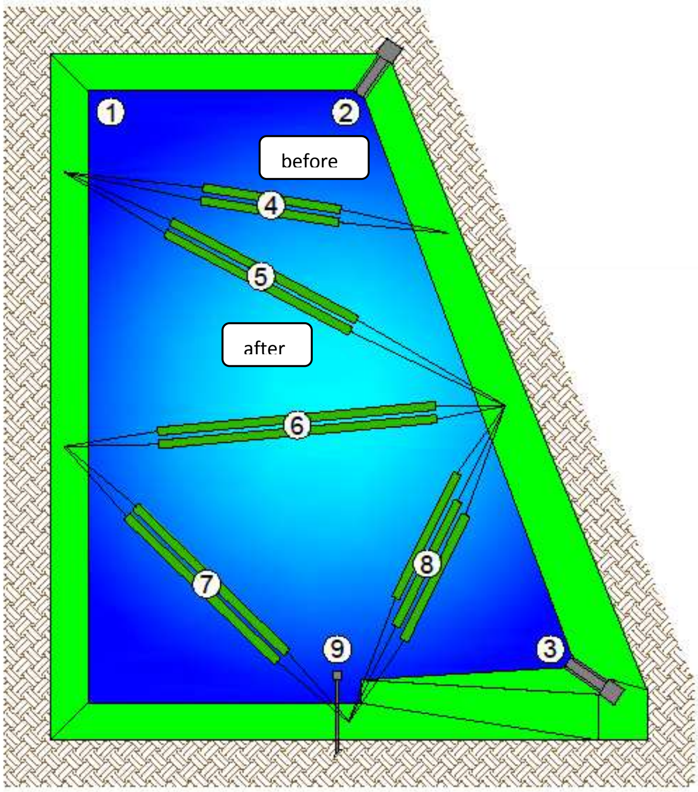


Figure 1: Set up of the floating treatment wetland.

1. Pond's surface; 2,3. Inlets; 4,5,6,7,8. Bands of vegetated floating elements joint in rows; 9. Outlet with pomp; Before: sampling point; After: sampling point

The vegetation used for this plant was selected from the well-known in literature species to be ones of the most utilized for constructed wetlands: *Iris pseudacorus* L.*,* *Typha latifolia* L. and *Phragmites australis (Cav.) Trin. ex Steud.* (Van de Moortel 2011, Hubbard *et al.,* 2004, Van Acker *et al.*, 2005). These species are chosen among autochthonous ones so they could be more adaptive and better survive of typical environment conditions of the territory and because they could give an aesthetic value to the pond too.

For this project we steadily sampled wastewater and monitored the vegetation. The monitoring on the FTW was carried forward for more than one year, with 16 monthly samples of water, from March 2009 to June 2010. The sampling points were one at the main inlet and the other one in the middle of the pond, to intercept the water before and after the flow through the first floating barriers.

The aim of these analysis was to look at an abatement of the pollutants after the settling up of the FTW and evaluate the performances. The main outlet was the first sampling point, but the outlet of the basin was too close to the secondary inlet and could have interferences in the concentrations, for these reason we referred the data of removal efficiency only for a part of FTW, that is after the first two floating barriers put transverse to the principal inlet and composed of 8 rows of floating elements.

It was possible to carry out some analysis in the field thanks to specific probes (Hach-Lange); the parameters recorded were ECw (µS/cm), dissolved oxygen (mg/L), temperature (°C) and pH.

Water samples were taken at the same point at two different depth: under 0.2 m and 1 m from the surface. Samples were collected and transported in cold case in the laboratory to determinate the concentration of the following parameters: total nitrogen, ammonia, nitrate, total phosphorus and COD. We did overall 315 analysis. Concentrations of ammonia-N, nitrate-N, total nitrogen, total phosphorus and COD were detected with a portable spectrophotometer and standard test kits (DR2800 and LCK tests by Hach-Lange).

The vegetation growing on the floating elements has been investigated. We recorded the length of aerial parts and roots of plants, calculated produced biomass of the aerial and submerged parts and found nitrogen concentration stored in both parts of macrophytes. The samples for calculating the biomass were collected at the end of the growing seasons, in November 2009 and 2010, and for each species, six floating mats were harvested both for the aerial part and roots. The wet material has been dried in oven at 65°C and with a macro elementar analyzer (CNS), presence of nitrogen on dry matter has been detected.

Results and discussion

Temperature

In figure 2 we can see variation of water temperature at the two sampling points that shows not significant difference between them. From July 2009 water temperature starts to decrease and the minimum was reached in January 2010, when during the last ten days, the basin was covered with ice. From February 2010 temperature began to rise again.

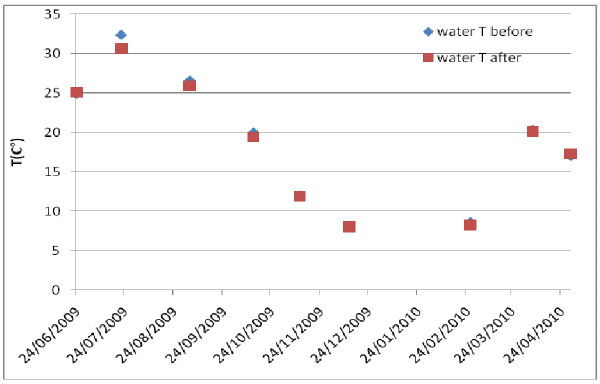


Figure 2: Water temperature during experiment sampling before and after the barriers.

Electrical conductivity, pH and dissolved oxygen

ECw is not different before and after the barriers and is steady from June to December 2009, after that period there is increase of the values as shown in figure 3.

Also for pH we cannot notice differences between the two sampling points; first months of monitoring the water is particularly basic, from September turns to neutral and in April tends to rise again. These differences are probably due to the heterogeneous wastewater coming in the basin.

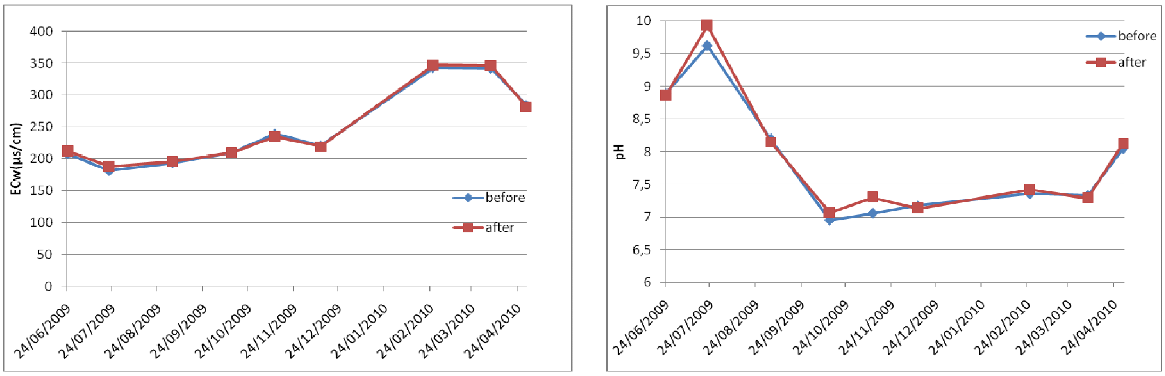


Figure 3: Electrical conductivity and pH variations during experiment sampling before and after the barriers.

DO level is higher in spring and summer than winter, anyway it seems to be very variable on time and this depend probably to the rainfall events and dry periods between them (figure 4).

Concentration of DO is a little bit higher after wastewater flow through the floating barriers (median 7,26 mg/L before and 7,77 after the barriers). In the winter period DO level is at its minimum.

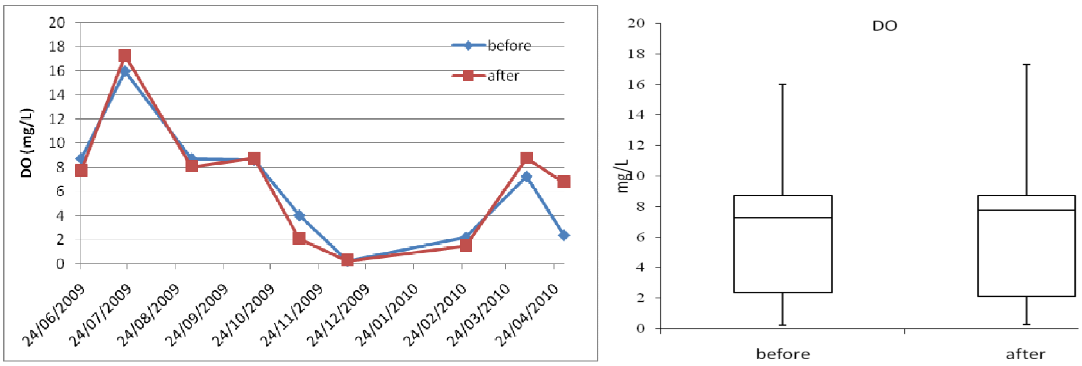


Figure 4: Dissolved oxygen in mg/L during experiment sampling before and after the barriers.

Looking at nitrogen forms from wastewater collected only 20 cm depth (figure 5) we can see that concentration of total N, ammonia and nitrate are decreasing after the water passage the floating barriers even if the variability remains high.

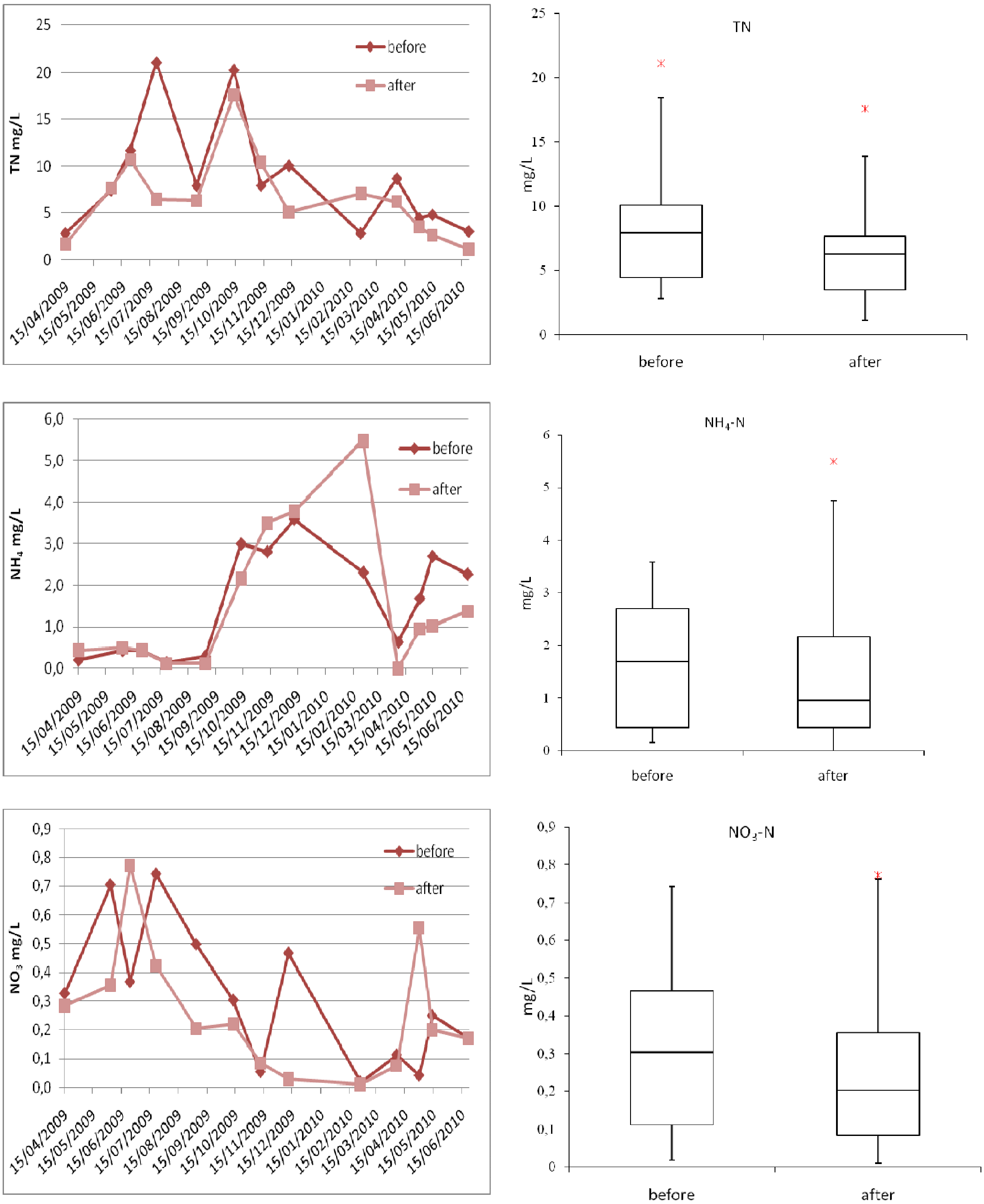


Figure 5: Concentration (mg/L) and abatement of total nitrogen, ammonia and nitrate after the wastewater flow through the floating wetland system.

COD concentration is also decreasing after the barriers, especially for high values in inlet. Median value is reduced of 26,2% and 75° percentile of 36% (figure 6).

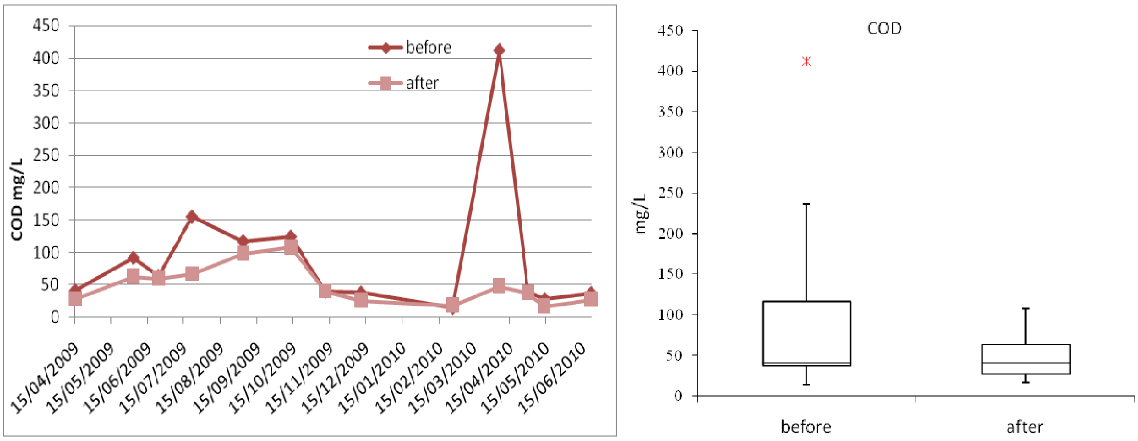


Figure 6: Concentration (mg/L) and abatement of chemical oxygen demand (COD) after the wastewater flow through the floating wetland system.

TP concentration reduction is not very high (figure 7), average 12,4%, comparing with other parameters analyzed, but the inlet concentration is very low (1,14 mg/L). The observed removal efficiency in other works is very variable, we have 45% reported by Van de Moortel (2010) and just 6% by Gray (2005).

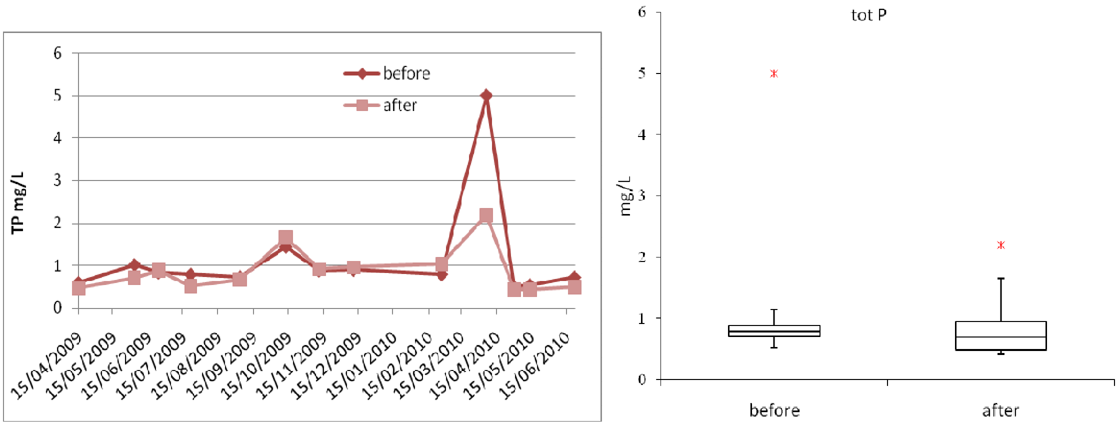


Figure 7: Concentration and abatement of total phosphorus after the wastewater flow through the floating wetland system.

Situation at the samples one meter depth is very similar from that one we discuss for concentrations at surface level, we didn't find significance differences.

Results on abatements are positive on all analyzed parameters even if concentrations of inlet values are very low. Abatements (table 1) shows the medians nitrogen forms reduced: total N of 20%, nitrate-N of 32% and ammonia-N of 43%. COD seems to have low reduction if we consider the median, but for high values (3^{rd} quartile) the reduction is 46%. Total phosphorus is reducing of 11%, but considering the single sampling, it is in winter time (from October to February) that removal efficiency doesn't exist, during the rest of the year removal is present instead.

Table 1: Abatements in % considering median and third quartile of the constructed wetland plant.

	Median %	**3^{rd} quartile %**
tot N	20,3	24
NH4-N	43,3	19,9
NO3-N	32,2	23,7
COD	1,96	46,2
tot P	10,9	-6,67

Biomass production and nitrogen stored in vegetation

The vegetation grew in two year at its maximum development, plants showed no problems in adaptation in growing in hydroponic system. Even during bad weather conditions in winter 2009, with the presence of ice in the basin that remain covered for two weeks in January, vegetation didn't suffer too much and following spring it restarted in a flourishing way. Some individuals had problems to survive principally due to predation of settled *Gallinula chloropus* (moorhen) in the basin. These animals use aquatic macrophytes to build their nests on the floating mats.

Data on plants growth were recorded during the maximum vegetative development, at the end of the autumn period; in table 2 are presented the mean values. During second year of sampling was not possible to measure *I. pseudacorus*, because after a storm the floating barriers were unfastened from the pond's bank and blocked on the side where for lacking of maintenance the vegetation on them died.

Table 2: Mean values and standard deviation of plant's aerial part and roots length.

	Length (cm)			
	2009		2010	
	aerial part	roots	aerial part	roots
T. latifolia	224 ± 32,3	86,2 ± 16,4	224 ± 50,4	53,3 ± 6,06
Ph. australis	159 ± 8,01	55,8 ± 18,5	235 ± 34,9	55 ± 14,8
I. pseudacorus	116 ± 15	55,5 ± 7,04		

For the first year we noticed that *T. latifolia* had the best growth reaching the mean height of 224 cm and the best roots length too with 86,2 cm, this denotes that cattail has initially rapid growth (Hubbard *et al.*, 2004). But in the second year *Ph. australis* grew even more reaching 235 cm in height. In 2010 both *T. latifolia* and *Ph. australis* had a root's mean length very similar (53,3 and 55 cm respectively) whereas *T. latifolia* had its roots much more longer in the first year than in the second.

Analyzing biomass of the sampled plants calculated per square meter of floating system, emerged that *T. latifolia* is the more productive species both for aerial and submerged part (mean dried weight for total plant is 5737 ± 2562 g/m^2) for the first year; but for the second year of monitoring we can see in table y that *Ph. australis* produced much more material than cattail in the aerial and submerged part too, for a total balance of 9385 ± 4113 g/m^2 against 8134 ± 2858 g/m^2 of cattail (table 3).

Table 3: Mean value and standard deviation of dried weight of aerial and submerged part of used species.

	Dried weight (g/m^2)					
	2009			2010		
	aerial part	roots	total	aerial part	roots	total
T. latifolia	1827 ± 628	3739 ± 2061	5737 ± 2562	2902 ± 1512	5296 ± 1508	8134 ± 2858
Ph. australis	1048 ± 367	2176 ± 1129	3225 ± 1125	4339 ± 1645	5046 ± 2609	9385 ± 4113
I. pseudacorus	1516 ± 367	801 ± 104	2317 ± 452			

I. pseudacorus gave positive results for biomass production in the aerial part (1516 ± 367 g/m^2) during the first year but as regards the roots biomass was the less productive, with only 801 ± 104 g/m^2 of production.

Nitrogen concentration stored in vegetation is been calculated in percentage both in aerial part and roots for the three plant species.

For all of them we observed that nitrogen concentration is higher in the submerged part than in the aerial one. Regarding nitrogen accumulation in the aerial part, *Ph. australis* stored more than other species and reached 1,89% in the first year, while *I. pseudacorus* in the same year reached 4,62% of nitrogen stored in the roots (table 4). The trend of nitrogen storage seems to decrease on time, infect values are lower for the second year of sampling.

Table 4: Mean value and standard deviation of nitrogen percentage of the aerial and submerged part of the three plant species used in the floating treatment wetland.

N (%)				
	2009		2010	
	aerial part	roots	aerial part	roots
T. latifolia	1.50 ± 0.31	3.31 ± 0.31	1.61± 0.43	2.50 ± 0.30
Ph. australis	1.89 ± 0.27	3.10 ± 0.39	1.42 ± 0.13	2.54 ± 0.29
I. pseudacorus	1.64 ± 0.24	4.62 ± 1.01		

Calculating the amount of nitrogen in g per square meter of floating surface (two Tech-IA® elements), we can see that *T. latifolia*, thanks to its big biomass production, is the more performance species in nitrogen removal from wastewater in the first year (128 ± 87.2 g/m^2) but *Ph. Australis* is the best species in 2010 (200 ± 59.2 g/m2) (table 5).

Table 5: Mean value and standard deviation of amount of nitrogen in the plants' aerial and submerged parts calculated in g/m^2.

N removed (g/m^2)						
	2009			2010		
	aerial part	roots	total	aerial part	roots	total
T. latifolia	27.9 ± 12.8	119.9 ± 64.2	128 ± 87.2	51.5 ± 8.52	122 ± 50.2	166 ± 57.4
Ph. australis	20.6 ± 9.8	65.4 ± 31.6	86 ± 32.3	61.7 ± 25.9	125 ± 56.3	200 ± 59.2
I. pseudacorus	24.7 ± 5.6	43.1 ± 8.51	61.3 ± 10.2			

In terms of practical fall-out the nitrogen stored in the aerial part is more interesting because it is possible to harvest that part from vegetation every year without endangering it and removing nitrogen accumulation from the system.

By harvesting aerial part of *Typha latifolia* it was possible to remove from the system, 21,9% the first year and 31% the second year of nitrogen stored in the entire plants, both aerial part and roots. For Phragmites australis 23,9% and 30,8% first and second year respectively and for *Iris pseudacorus,* for its first year of growth, 40,3% of the entire nitrogen stored was in the aerial part.

During one year of management of this FTW, we had to face some technical problems. It happened that some barriers of floating elements disengaged from the banks of the basin and went to lay on the sides; this brought some elements to remain out of the water and vegetation growing on them to die. Some plants of *Typha latifolia* have grown too much in height and with particular weather events, such as strong wind, made floating elements to overturn.

Another problem to deal with was the predation in the establishment phase for vegetation from some species of birds, that used leaves to build nests on floating elements.

Conclusion

The FTW of this particular project shows at the end of two years of monitoring that all checked parameters in the wastewater are decreasing, that is because the floating barriers with the hanging roots perform on trapping suspended and dissolved elements. And it seems working already during the first year of vegetation's settlement.

The system is working well with low inlet concentration and we suppose that pollutants reduction could be more effective if we had higher concentrations (Van De Moortel, 2011). Nitrogen forms are the pollutants that the system was more able to abate, COD removal is better with higher concentration and we noticed a scarce abatement for phosphorus, especially in winter period.

It is important to keep in mind that the covered surface with FTW was modest compared to the total area of the basin so its action of pollutant removal could surely increase with increasing of floating system surface.

Regarding vegetation, all used plant species showed a perfect development and adaptation at particular growing conditions already after the first spring, proving excellent ability to overcome critical winter weather conditions. In the establishment phase some plants died probably due to predation from aquatic birds, but after that plants established definitively propagating with their rhizomes.

Cattail has the greater total biomass production the first year, reed in the second one (mean value 9385 ± 4113 g/m^2). Nitrogen concentration is higher in roots than in aerial part for all tested species. Cattail is the most successful species in total removed nitrogen in 2009 but common reed overtook it in 2010 (mean value 200 ± 59.2 g/m^2).

Naturalization is been an important collateral effect of the settling of this plant (Nakamura and Mueller, 2008), environmental amelioration is been taken place with creation of new habitat for invertebrates and vertebrates such as amphibians, reptiles and birds that can find food, shelter and nesting sites in the floating treatment wetland.

Capitolo IV

Removal efficiency of a combined wetland in treating municipal wastewater

Introduction

Urban wastewater are a mixture of domestic, industrial and run off wastewater, directed into a sewerage system and coming from towns. This polluted water can hold lots of micro polluted elements such as hydrocarbons, pesticides, detergent sand rubber debris. Through traditional depuration it is possible to delete polluted substances from the water and it consists on a system based on mechanical, physical and biological processes .

Traditional depuration system is composed of four steps.

- Pretreatment: removal of coarse materials
- Primary treatment: physical operations of setting to separate organic and inorganic sediment particles that are suspended such as sands, oils and grease.
- Secondary treatment: removal of the remain solids and of organic dissolved matter thanks to oxidative processes.
- Tertiary treatment: different chemical and physical methods to abate the pollutants still present in the water, in particular nitrogen, phosphorus, suspended solids, heavy metals, microorganism and other polluted substances.

Wetland depuration technology for treating urban wastewater is widespread all around the world, and consists on natural processes obtained using vegetation and microorganisms in order to clean the water, simulating the same processes of self-depuration of aquatic habitats and wetlands.

Aquatic plants are able to create a suitable microhabitat for the microbial flora to grow, and these organisms play together to remove pollutants and depurate the water.

Constructed wetlands are used as secondary or tertiary treatments and like natural wetlands are characterized by the constant presence of water, typical vegetation adapted to grow in wet or submerged soils and anaerobic conditions or low presence of oxygen (Kadlec et al., 1996).

This study regards a plant, acting as a tertiary treatment, for treating polluted urban water coming from a small village (1800 pe) using a hybrid wetland system. The plant consists of a constructed wetland made of a horizontal sub-surface flow (HSSF) and a floating treatment wetland (FTW). The aim of this project was to increase the depuration efficiency of the traditional system, thinking of raising of population and industrial area's development.

Methods

The sewage treatment plant of Alonte, a small municipality in Veneto district, North-East of Italy (latitude 45.36689, longitude 11.42813) has been designed for 1000 pe. It was composed of a primary and secondary treatment plant provided of aerator, sedimentation and filter, followed by a tertiary treatment. This finishing plant was installed in 2002 and was composed of two sections. The first one was a anaerobic sedimentation vessel, a portion with gravel bed as medium and vegetated with evergreen xerophilus vegetation (*Laurus nobilis* L., *Eleagnus angustifolia* L., *Prunus laurocerasus L.* and *Pittosporum spp.*). From the section of the vessel (figure 1) we can see different layers, from the top: a gravel bed, a drilled cement plate that allows the roots to reach the wastewater underneath and a muddy deposit at the bottom.

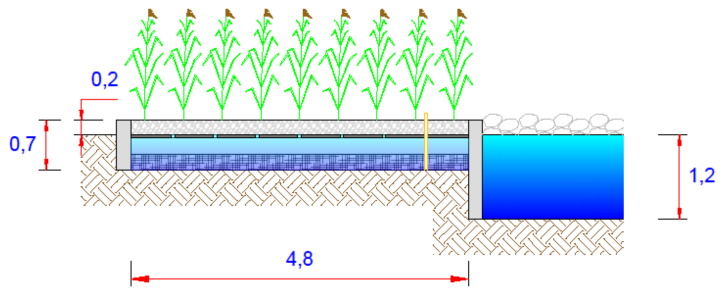


Figure 1: Section of sewerage treatment plant with part of anaerobic vessel and pond. All measures are expressed in meters.

The second portion was an artificial pool acting as sedimentation pond, vegetated with floating hydrophytes (*Lemna* spp.) and with aeration jets. The surface of the vessel is 250 m^2, while the pond that represents the second part of this constructed wetland and collect the water from the vessel is 467 $m^2$and 120 cm deep (figure 2).

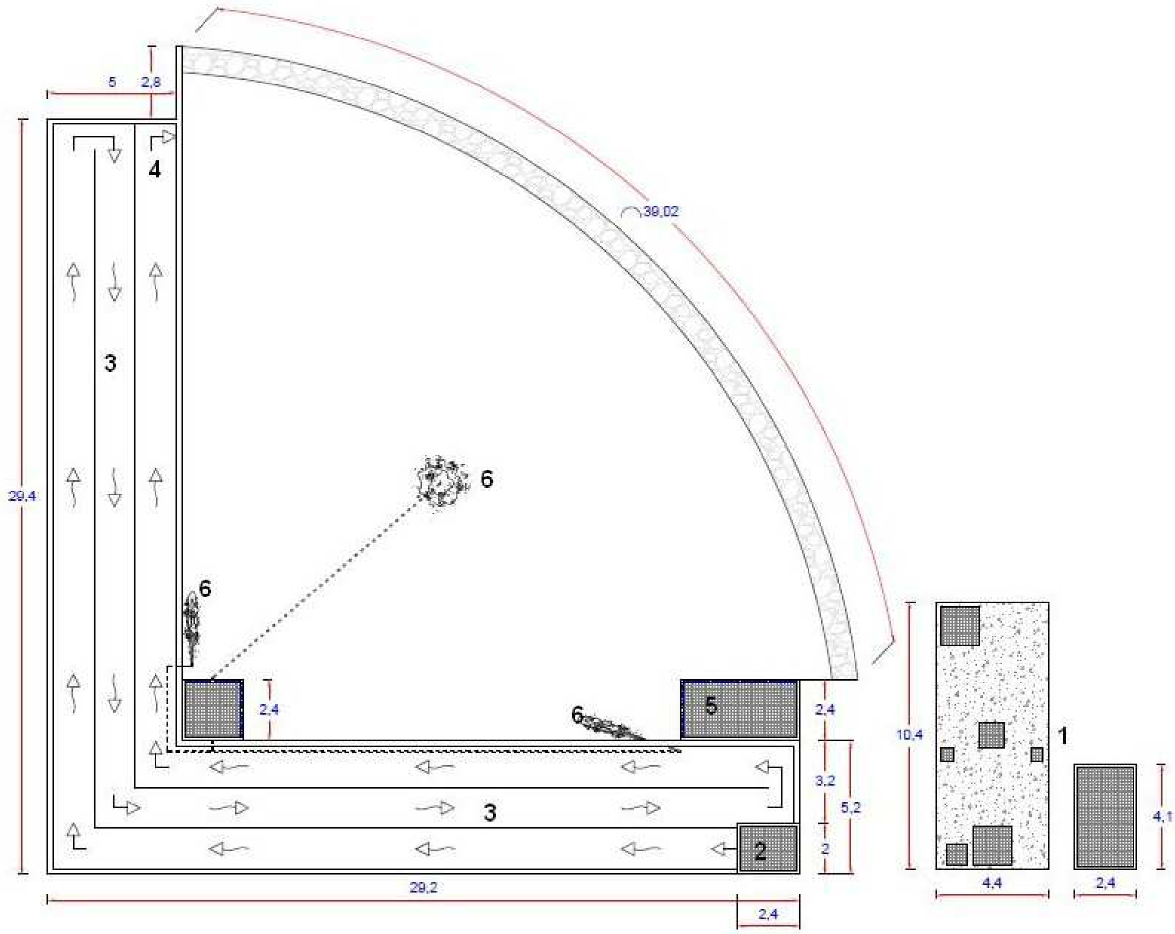


Figure 2: map of Alonte's sewerage treatment plant.

1. Primary and secondary sewerage plant.
2. Incoming tank with wastewater derived from traditional plant.
3. HSSF; the water course is showed by arrows.
4. Outlet of HSSF towards the pond.
5. Final outlet of the treated water.
6. Water jets for wastewater recirculation and aeration.

The tertiary wetland treatment had some problems of planning and functioning and, as result, also a low removal efficiency of pollutants. First of all the vegetation used in the HSSF was not suitable for remediation purposes: *Laurus nobilis L., Eleagnus angustifolia L., Prunus laurocerasus L., Pittosporum spp.* are species fitted for Mediterranean climate, they have particular leaves' surface, very coriaceous, that limits evapotranspiration. Because of adaptation of arid growing conditions, these plant species are not able to develop a deep root system if they grow in humid soil and so the plants didn't reach the saturated zone of the substrate and didn't have any interaction with the wastewater.

Pond's surface was covered with local floating hydrophytes that have low capacity in the cleaning processes; *Lemna spp.* have a very limited roots development, only 2 cm of growth and therefore a limited depuration capability respect to other macrophytes. Their high colonization power brought the entire water surface to be covered with vegetation, becoming a barrier for light and oxygen exchanges which are basic parameters for wetland systems.

To enhance depuration efficiency of the system, it has been necessary to do some modifications in the constructed wetland (figure 3).

In June 2010, the evergreen vegetation has been removed from the gravel bed of the vessel and replaced with common reed (*Phragmites australis* L.). The new plant of the vessel has been planted with five plants for square meter; young plants (0,07 m pot's diameter) came from a specialized nursery and were at 0,2 m height.

In the sedimentation pond floating plants have been removed and a floating treatment wetland (FTW) has been settled in. This FTW consists of floating platforms Tech-IA system on which were anchored two species of aquatic macrophytes: *Phragmites australis* L. and *Iris pseudacorus* L.; four plants for each platform.

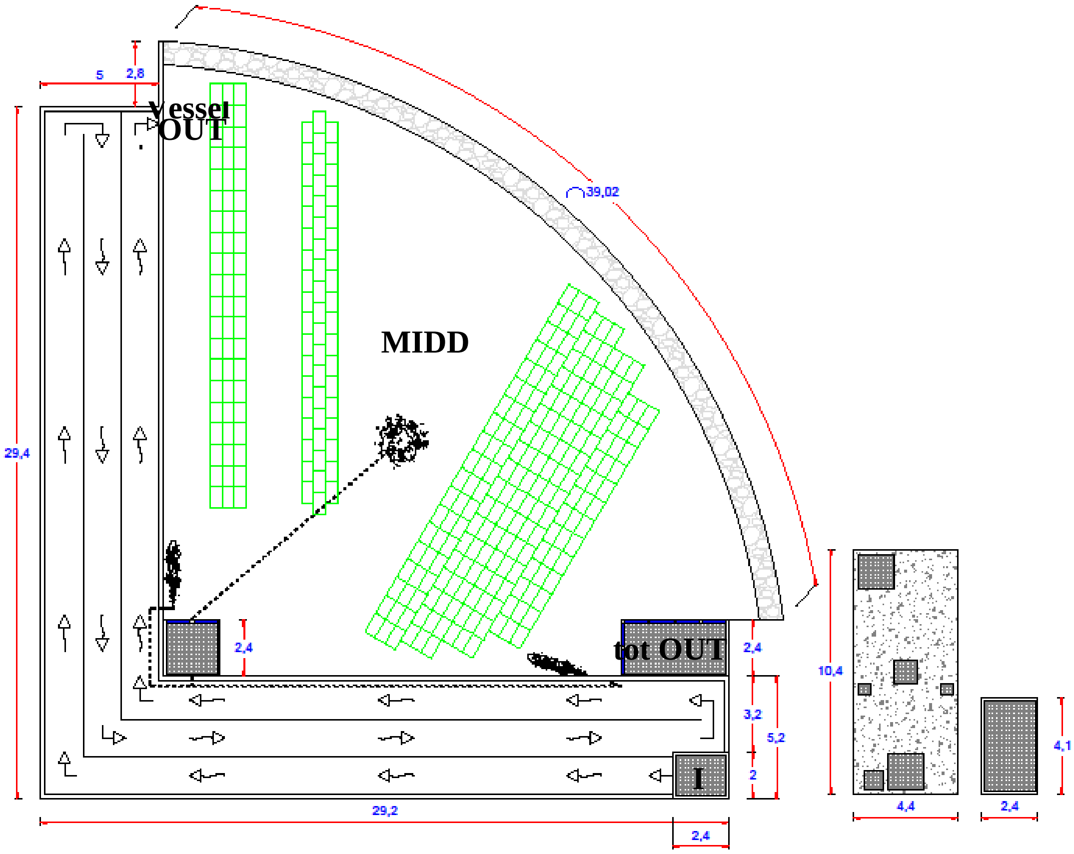


Figure 3: Map of the new sewerage treatment plant after the modifications and sampling points (IN, vessel OUT, MIDDLE and tot OUT).

In the pond, with a total surface of 467 m^2, have been settled in 300 floating elements (150 m^2 that is 32% of pond's surface), 115 vegetated with common reed and 185 with iris (table 1).

Table 1: Characteristics of the settled floating treatment wetland (FTW).

	Ph. australis	***I. pseudacorus***	**Total**
N° of Tech-IA elements	115	185	300
Surface with FTW (m^2)	57,5	92,5	150
% coverage	11	18	29

The monitoring concerned the sampling and analysis of the water and vegetation for testing depurative efficiency of wetland system.

Water samples were collected in four different points (figure 2) of the plant to control the wastewater during all the way through the system. First one was the inlet of the anaerobic vessel with the wastewater coming from the traditional treatment system, second was the outlet of the vessel that discharge water in the pond, followed by a sampling point in the middle of the pond in the FTW and last one was the outlet of the pond that is the discharge point of the entire wetland system.

The monitoring took place every months for one year, from July 2010 to August 2011.

Some parameters were detected directly in the field using specific probes (Hach-Lange) and were ECw (µS/cm), dissolved oxygen (mg/L), important for life of many organisms, temperature (°C) and pH. The meters measured approximately 200 mm below the water surface.

Turbidity was also evaluated in the field from the water samples, measured with a portable turbidimeter with read range from 0,01 to 1000 NTU, following the nefelometric principle that detects diffuse radiation of the analyzed material (Hach-Lange). For every sampling point we collected two samples, put them in the fridge for one day, till we did the analysis in the laboratory.

Chemical analysis to check the concentration of pollutants in the water were conducted with a portable spectrophotometer and standard test kits (DR2800 and LCK tests by Hach-Lange). The chemical parameters we detected were total nitrogen (totN), ammonia nitrogen (NH_4-N), nitrate (NO_3-N), total phosphorus (TP), orthophosphate (PO_4^{3-}) and chemical oxygen demand (COD).

A total of 56 water samples were collected and analyzed for each parameters mentioned above.

The removal efficiency of the system was calculated for each parameter as follow:

$$\text{Abatement (\%)} = \frac{C_{start} - C_{end}}{C_{start}} * 100$$

where C_{start} is the concentration of the parameter at the considered inlet and C_{end} concentration at the outlet.

In November 2011, after the monitoring period, samples of vegetation, both aerial parts and roots, were measured and harvested to calculate vegetative growth, biomass, dry weight and nitrogen and phosphorus concentration in the plants. For both plant species, iris growing on floating elements and common reed growing in the vessel, six samples were measured and data were referred per square meter; for iris we harvested 6 floating elements and for common reed 6 square meter samples taken at different distances along the vessel.

Results and discussion

Looking over the results of chemical analyses of the collected samples we have first to consider that all parameters detected were at low concentration in the output, after primary and secondary treatments.

Temperature, electrical conductivity, pH and dissolved oxygen

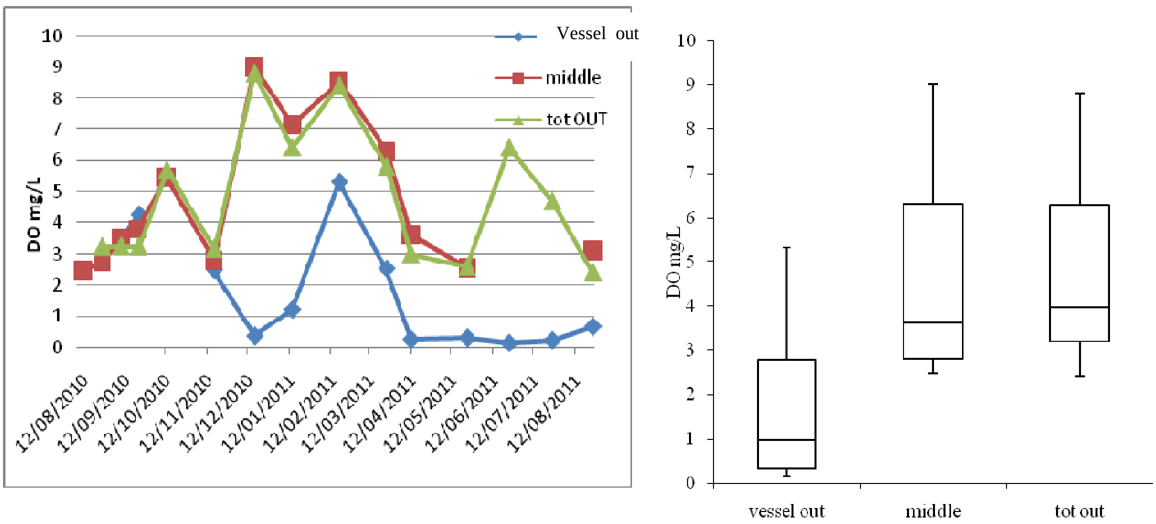


Figure 4: Dissolved oxygen in mg/L on time detected from three sampling points and box and whiskers of data.

The measure of dissolved oxygen concentration in the inlet, that is the outlet of traditional depuration system was not detectable because of the wastewater collected is moving due to the discharge pomp and this could alter measurements, that is why we measured DO only at the outlet of anaerobic vessel, in the center FTW and at the discharge point of the entire system.

The median DO concentration at the end of the vessel is 0,96 mg L^{-1}, where we noticed some higher levels in winter period and lower levels during summer. This low value is caused probably to a layer of sludge deposit at the bottom of the HSSF system, where the bacterial activity is more high during summer as the oxygen consumption rises. This will be confirmed with COD and NH4+ concentrations too. DO levels increase when the water reaches the pond with FTW, also thanks to aeration jets, where we recorded a median value of 3,97 mg L-1 at the end of the treatment (figure 4).

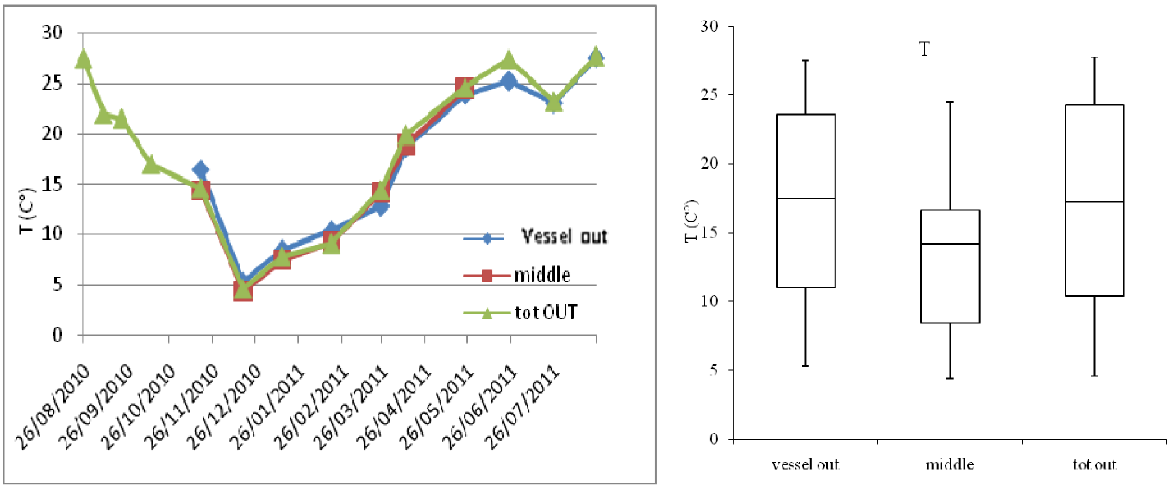


Figure 5: Temperature detected on time from three sampling points and box and whiskers of data.

Temperatures in the wetland system follow the season weather's ones. They are lower in the middle of the pond than in the HSSFW but after the passage through FTW are increasing again (figure 5).

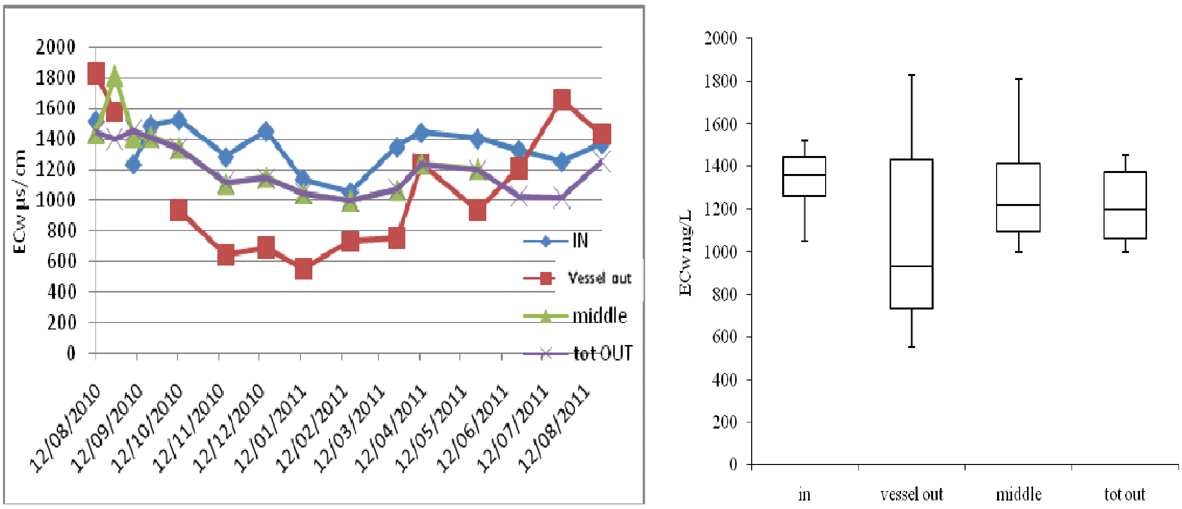


Figure 6: Electrical conductivity in µs/cm on time, detected from sampling points and box and whiskers of data.

We found values of conductivity around 1200 µs/cm for the median in the outlet, this value get lower after the vessel (936 µs/cm), probably due to decantation of salts in the layer of sludge at the bottom and get higher again, 1222 µs/cm, when wastewater reached the pond where recirculation with pumps brings sedimentation in suspension one more time (figure 6).

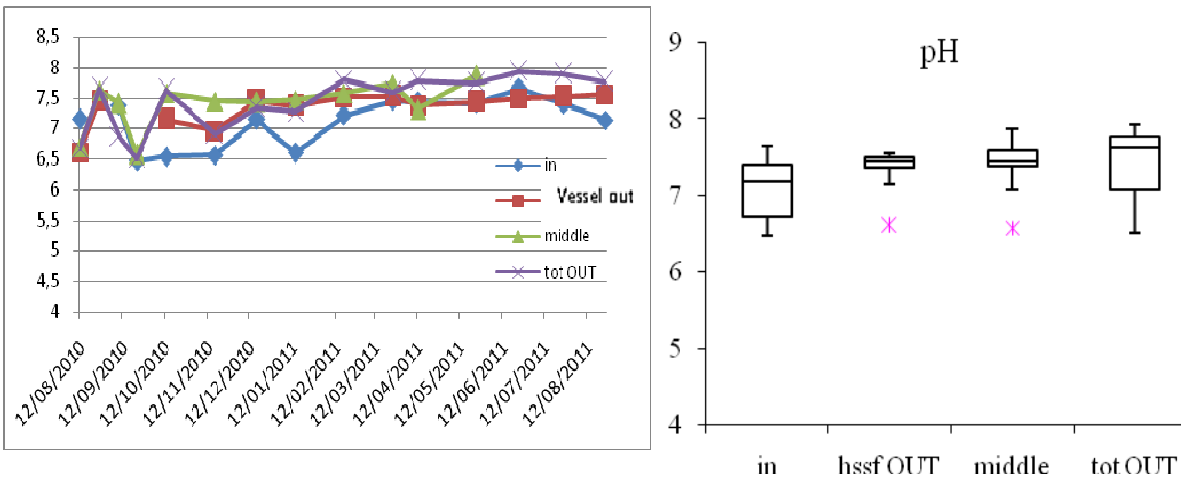


Figure 7: pH on time, detected from sampling points and box and whiskers of data.

The pH at the outlet was always higher than in the inlet (figure 7), as found Van de Moortel (2010) and varied on average between 7.1 and 7.4 .

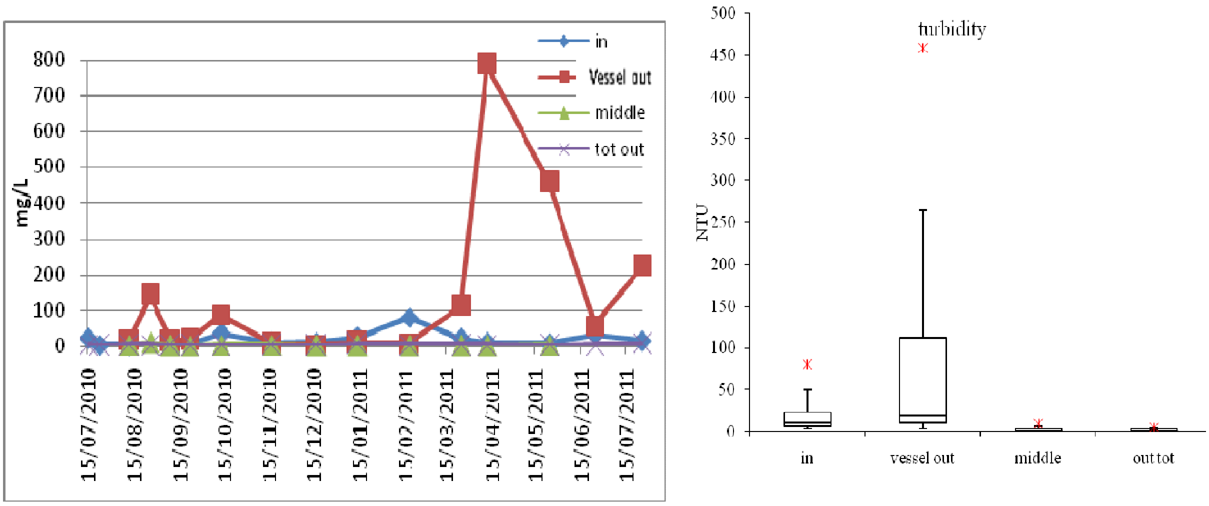


Figure 8: Turbidity level on time, detected from the sampling points and box and whiskers of data.

Turbidity was getting worst after the way through the anaerobic vessel, variability on that samples (vessel OUT) is very high due to the sampling and goes from 3.35 to 787 NTU (median value 37). Sometimes the water level was low and to reach the surface we need to fish at a lower level than 25 cm, with the problem of interception of the muddy layer at the bottom. This is the reason why sometimes turbidity is very high. When the wastewater reached the FTW, the sedimentation and plants' filtration processes brought the turbidity to very low levels, from 1.71 to 5.3 NTU (median 2,84), that is 97,8% of reduction (figure 8).

Pollutants abatement

Looking at the nitrogen forms (total N, ammonia-N and nitrate-N) it is clear that there are several behavior of the different parts of the wetland treatment plant on the removal of the nutrients.

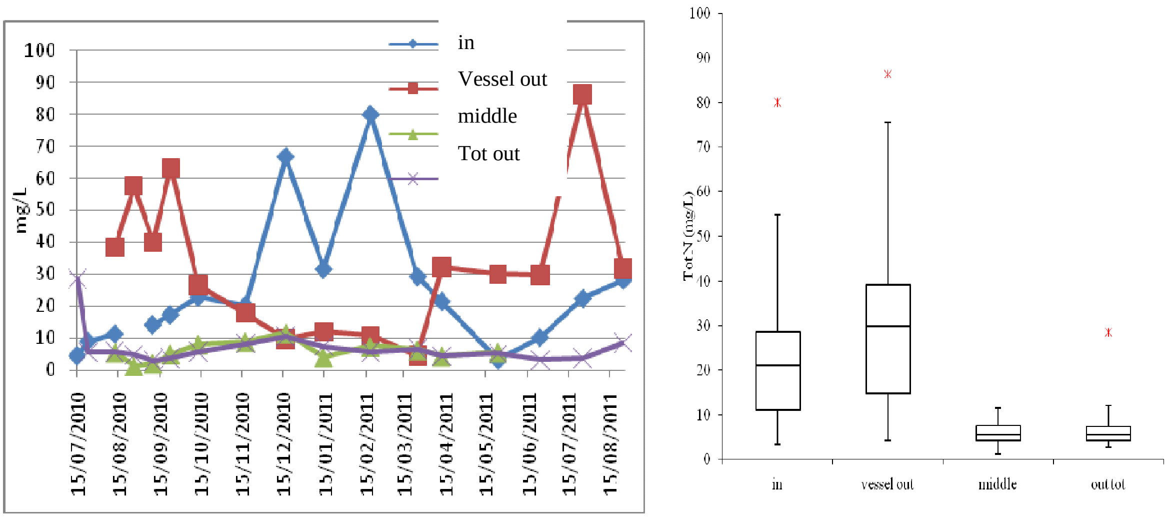


Figure 9: Total nitrogen concentration in mg/L on time, detected from sampling points and box and whiskers of data.

For total nitrogen that includes ammonia, nitrate and organic nitrogen, concentration level increases after the vessel, in particular in the hottest months and decreases in the FTW, where also variability is well reduced (figure 9).

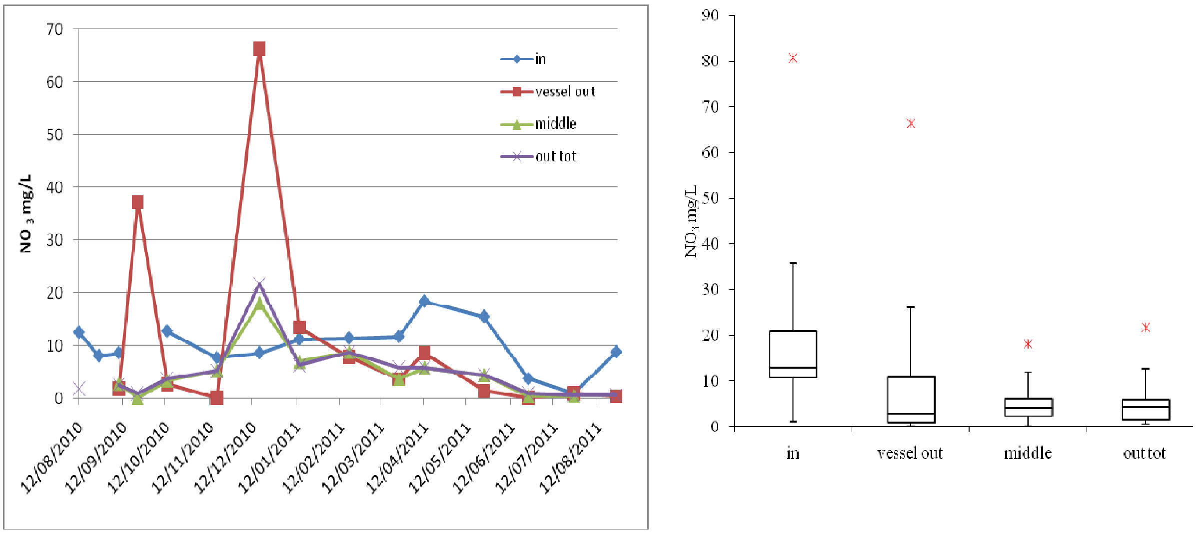


Figure 10: Nitrate concentration in mg/L on time, detected from sampling points and box and whiskers of data.

Nitrate concentrations is well abated already after the anaerobic vessel, where there are all conditions for the life of anoxic bacteria and so denitrification can occur. On the contrary in the FTW we can have the presence of more oxygen and nitrate is not removed anymore (figure10).

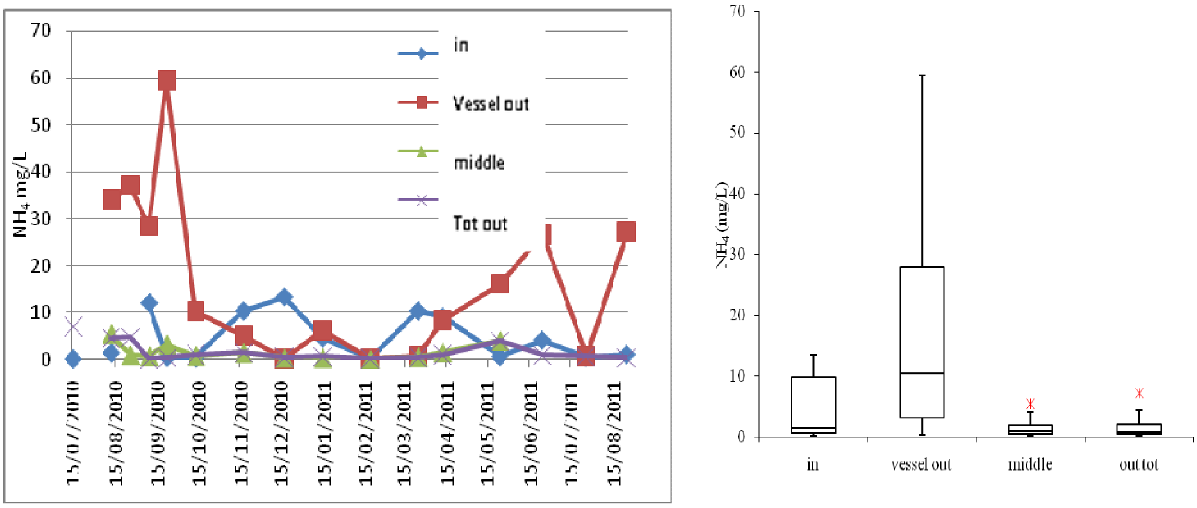


Figure 11: Ammonia concentration in mg/L on time, detected from sampling points and box and whiskers of data.

An opposite situation is visible for ammonia, that increases in the vessel. Oxygen is very low in concentration and conditions for nitrification are not present, farther the muddy layer and bacteria existing at the bottom could be responsible for the raising of ammonia especially in the summer period. In the FTW where oxygen is available again, ammonia concentration level is decreasing, turning to nitrate. This could be the reason why we can find a little increase in nitrate concentration level in the FTW (figure 11).

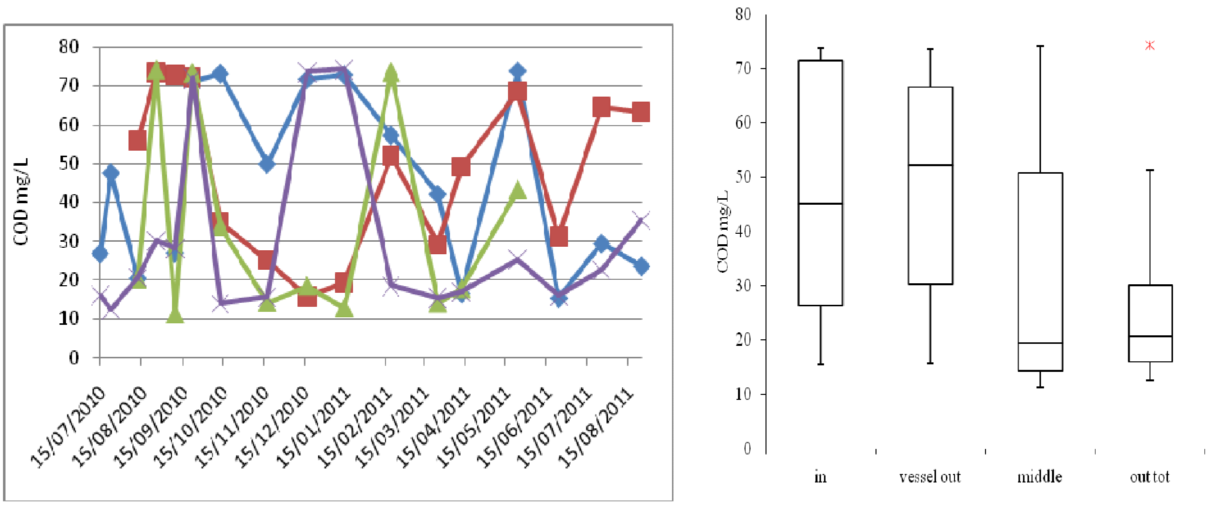
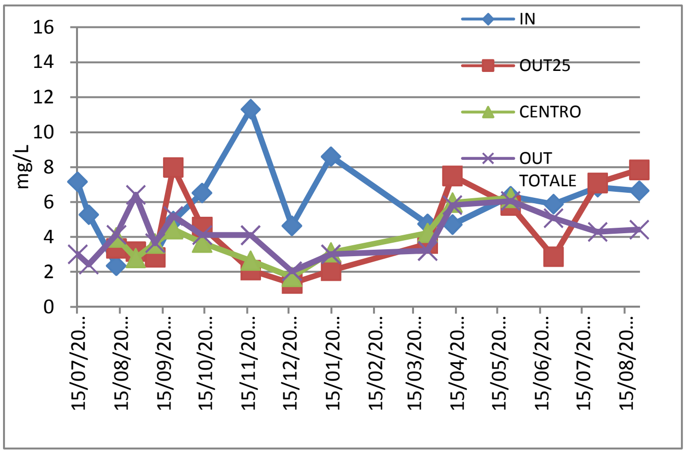


Figure 12: COD concentration in mg/L on time, detected from sampling points and box and whiskers of data.

The variability of COD concentration level is very high all over the year and is reduced only at the end of the treatment, at the final outlet. Also concentration is abated at the end, while after the way through the HSSF increased due to the oxygen demand of bacteria activated in the summer period in the sludgy bottom (figure 12).



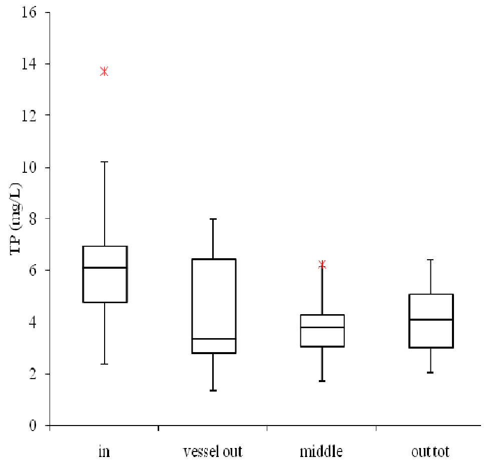
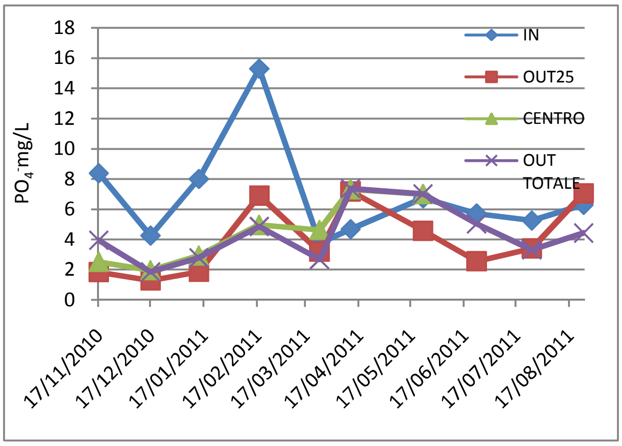


Figure 13: Total phosphorus concentration in mg/L on time, detected from sampling points and box and whiskers of data.

As the inflow concentration of total phosphorus is low (average 6.4 mg/L), the abetment is also limited, in fact as inflow concentrations increase, phosphorus load removal also increases. Total phosphorus and orthophosphate concentrations are decreasing after the vessel and this could be due to the wetland conditions that promote inter-conversion of all forms of phosphorus and readily move them in soils and sediments (Kadlec and Wallace, 2009). Moreover phosphorus can be stored in plant biomass and in wetland bed media even if the media is saturated during time and the system is already old (figure 13 and 14).

In the FTW the situation remains the same even if the variability decreases and the median value is a little higher than the outflow of the HSSF.

Comparing TP and PO4-P there are not a big difference of concentration levels across the wetland system and this testify that the phosphorus in this wastewater is almost all in soluble form.



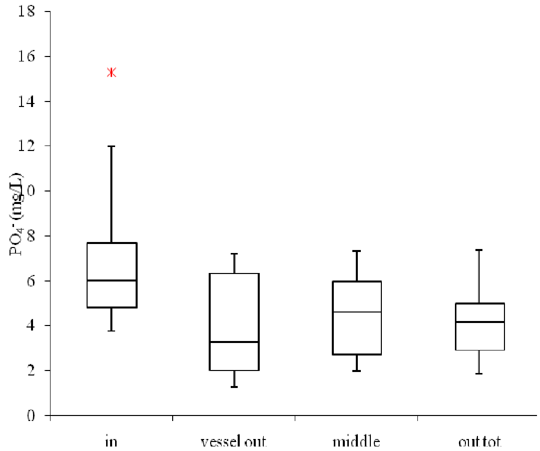


Figure 14: Dissolved phosphorus concentration in mg/L on time, detected from sampling points and box and whiskers of data.

To show the abatements reached after the constructed wetland treatment and understand how different components of the system work, data of the removal efficiency are presented in table 2. Here abatements are achieved from median values and 75 percentile of all single samplings.

Table 2: Median values and 75 percentile of % removal efficiency of the whole wetland depuration system, of the vessel and of the FTW for the different parameters analyzed.

	Entire system		**Vegetated vessel**		**FTW**	
	median	75%	median	75%	median	75%
COD	54,3	57,8	-16	6,62	60,6	54,8
TN	73,5	74,2	-42,2	-36,5	81,4	81,1
NH_4-N	49,1	79,2	-592	-184	92,6	92,7
NO_3-N	66,9	71,5	78,2	47	-51,8	46,3
TP	32,6	26,7	45,2	6,85	-23	21,4
PO_4^-	30,2	35,1	45,1	17,8	-27,2	21,1

If we consider the entire system action, regarding nitrogen forms the abatement of the medians are around 70% for total nitrogen, 49% for ammonia-N and 67% for nitrate. For phosphorus forms is around 30% and for COD is 54%. Ammonia-N is reduced more for high concentrations values, 79% for third quartile.

As we discuss previously, the anaerobic vegetated vessel is working more in removing phosphorus and nitrate-N, whereas the FTW is effective in removing COD and total and ammonia-N.

Since this project has been meant to have practical applications, it is important to evaluate the results in terms of the propose we wanted to achieve.

Considering the Italian law dealing with discharge limits on surface water (bylaw 152/2006), almost all parameters coming out from primary and secondary treatment are already below the limits. As is shown in table 3, inlet parameters almost always remain within the limits, except for nitrate-N and total P, but at the discharge point, all values become by law.

Table 3: Removal efficiency in % of the whole wetland depuration system, of the HSSFCW and of the FTW for the different parameters analyzed.

Discharging limits (d.lgs 152/2006)	**% values of exedance**	
	inlet	**outlet**
pH	5.5-9.5	0%
T(°C)	outlet T≤ inlet T + 3°C	
COD (mg/L)	≤ 160	0%
Total P (mg/L)	≤ 10	20%
NH4-N(mg/L)	≤15	0%
NO3-N(mg/L)	≤ 20	30%

Plant growth

The two plant species used in the wetland system showed excellent growth, iris in the floating mats with an extensive development of roots beneath the water and common reed in the gravel bed with a complete coverage.

After 12 months from plantation common reed reached the average length of 251 ± 48,9 cm. In the FTW iris grew to 136 ± 11,3 cm and the roots elongated to 46,3 ± 9,77 cm.

Biomass production is much higher for iris than for common reed, especially for above vegetation (iris 28567 ± 8624 g and common reed 9867± 4799), whereas for submerged part the difference is lower (table 4).

Table 4: Average plants growth in cm and fresh biomass in g, with standard deviation, for above and submerged vegetation.

	Length (cm)		**Fresh biomass (g)**	
	aerial part	roots	aerial part	roots
Ph. australis	251 ± 48,9		9867± 4799	19667 ± 6157
I. pseudacorus	136 ± 11,3	46,3 ± 9,77	28567 ± 8624	20183 ± 7654

Nitrogen percentage in vegetation is higher in iris than common reed, especially in the root system and phosphorus too (table 5).

Table 5: Percentage of nitrogen and phosphorus for above and submerged part of the two species used.

	N (%)		**P (%)**	
	aerial part	roots	aerial part	roots
Ph. australis	1,62 ± 0,36	1,62 ± 0,33	0,12 ± 0,01	0,23 ± 0,05
I. pseudacorus	1,89 ± 0,10	3,27 ± 0,72	0,21 ± 0,06	0,37 ± 0,08

Common reed has greater dry biomass production (g/m2) than iris, for aerial part and roots too, in spite of the greater iris's fresh biomass (figure x); but iris can remove more nitrogen compared to common reed per square meter of surface, because of greater nitrogen accumulation in its organs. Iris's roots can remove double nitrogen than Phragmites per square meter (figure x). Yet it is important to notice that iris grew in hydroponic condition whereas common reed in a gravel bed, so the capacity of roots for pollutants uptake could be different.

In general plants can accumulate less phosphorus than nitrogen, here we can see that roots can store more phosphorus and also for this element, iris can store more than common reed (table 6).

Table 6: Dry weight and nitrogen and phosphorus accumulation referred to unit area, in the two species used.

	Dry weight (g/m^2)		**N (g/m^2)**		**P (g/m^2)**	
	aerial part	roots	aerial part	roots	aerial part	roots
Ph. australis	3853 ± 2196	4676 ± 1880	60,3 ± 30,2	71 ± 17,6	5,42 ± 3,45	8,05 ± 1,61
I. pseudacorus	3693 ± 1003	3376 ± 1239	70,1 ± 19,9	114,9 ± 62	7,76 ± 3,35	12,3 ± 4,54

Conclusions

Monitoring on this wetland hybrid system gave positive results on abatement for all parameters and brought them below discharging limits in fresh water for Italian law. Abatement of nitrogen forms are around 70%, for phosphorus forms around 30% and for COD 54%, considering the entire system composed of an HSSF constructed wetland followed by a FTW. This last treatment in particular removes COD, total and ammonia nitrogen tanks to the aeration due to the surface flow.

Phragmites australis dry biomass referred to unit area is higher than that one of *Iris pseudacorus* but iris can remove more nitrogen per unit area because its greater percentage of this element stored in above and below ground parts.

We had some management problems to afford in particular with the FTW. At the beginning we vegetated some floating elements with *Phragmites australis* too, but this species was very desirable for a population of nutria (*Miocastor coypus*) that leaved around the area. And plants were all eaten by these animals. Another problem was the huge development of iris in the floating elements that made them overturn during a windy weather event.

This new installed wetland system improved the efficiency in pollutants removal in comparison with the primary treatment, considering that the new set up is just one year old and that vegetation and attached biofilm can grow and develop, it could surely better its performances.

General conclusions

After three years of studies regarding floating treatment wetlands and observation of experimental systems in mesocosms or in full scale, it is possible to get now some conclusions on what it was observed.

The general aim of this project thesis was to understand more about all aspects and processes involved in the FTWs and be able to give some indication of an operational nature in order to make this technology most known and used in Italy. In this country the knowledge of this particularly type of constructed wetlands is almost unknown or not considered as water treatment solution. Thanks to a patent of an Italian company that developed a new floating element called Tech-IA system, we were able to test FTWs and concentrate on the processes involved with biofilm attached on root system of vegetation used, on vegetation itself focusing on finding the best species in terms of removal capacity, elements storage and biomass production and on full scale system to test performances and have management solutions.

Regarding removal processes linked to root system and biofilm growing on it, we conducted a laboratory test to have an ammonium utilization rate (AUR); this developed experiment could represent a simple method to check the efficiency of several types of FTWs, with diverse floating elements or vegetation, treating different sources of wastewater and characterize them. As we known the rate of ammonium decrease, it is possible to calculate floating vegetated surface areas required to remove a certain quantity of ammonium-N from the wastewater we are treating. We also tested different material of biofilm's attachment and concluded that AUR is higher for biofilm developed on roots than that on geotextile. We also noticed that the most part of ammonia-N is removed in the first 24 hours.

In our FTWs experiments we used some conventional macrophytes species, such as *Ph. Australis, I. pseudacorus* and *Ty. Latifolia* but also other ornamental plant species suitable to live in water environment. *I. pseudacorus* and *Ty. Latifolia* gave the best results in full scale experiments for their adaptability in floating systems, for biomass production and for nitrogen and phosphorus removal. *Ph. australis* gave different results in the two full scale systems, in one it had optimal biomass production for above and below water vegetation, in the other one this species did not grow due to animal predation. We had some stabilization's system problems with *I. pseudacorus* and Ty. Latifolia for the floating elements.

We tested the cultivation of different ornamental species on floating system and the most adapted seemed to be *Pontederia cordata, Canna indica Mentha aquatica, Thalia dealbata, Caltha palustris* and *Oenanthe javanica,* with good roots development, great values of biomass and blooms. *Acorus calamus, Iris laevigata* and *Juncus effusus* 'spiralis' had some problems to establish and to develop, while *Sparganium erectum* and *Zantedeschia aethiopica* did not survive in this environment.

Removal efficiency have been tested in the two full scale plant where FTWs were installed as tertiary treatment for urban and agricultural wastewater. In the big basin this constructed wetland is working in low inlet concentration and pollutants reduction is effective: all forms of nitrogen detected have been abated, COD removal is higher with at higher concentrations, whereas we noticed a scarce abatement for phosphorus, especially in winter period. Also for the second mixed constructed wetland, the part of FTW gave positive results on abatement in particular COD, total and ammonia nitrogen, although inlet concentrations were low. Both this system could remove pollutants since the very first phases after installation, so with the growing of vegetation and biofilm attached we think they could reach even better performances.

With this experiments we gained the first knowledge of an innovative floating treatment system developed in Italy.

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