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# Halophyte filter beds for treatment of saline wastewater from aquaculture

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ABSTRACT

The expansion of aquaculture and the recent development of more intensive land-based marine farms require efficient and cost-effective systems for treatment of highly nutrient-rich saline wastewater. Constructed wetlands with halophytic plants offer the potential for waste-stream treatment combined with production of valuable secondary plant crops. Pilot wetland filter beds, constructed in triplicate and planted with the salt-marsh plant *Salicornia europaea*, were evaluated over 88 days under commercial operating conditions on a marine fish and shrimp farm. Nitrogen waste was primarily in the form of dissolved inorganic nitrogen (TDIN) and was removed by 98.2 ± 2.2% under ambient loadings of 109–383 μmol $l^{-1}$. There was a linear relationship between TDIN uptake and loading over the range of inputs tested. At peak loadings of up to 8185 ± 590 μmol $l^{-1}$ (equivalent to 600 mmol N $m^{-2}$ $d^{-1}$), the filter beds removed between 30 and 58% (250 mmol N $m^{-2}$ $d^{-1}$) of influent TDIN. Influent dissolved inorganic phosphorus levels ranged from 34 to 90 μmol $l^{-1}$, with 36–89% reduction under routine operations. Dissolved organic nitrogen (DON) loadings were lower (11–144 μmol $l^{-1}$), and between 23 and 69% of influent DON was removed during routine operation, with no significant removal of DON under high TDIN loading. Over the 88-day study, cumulative nitrogen removal was 1.28 mol $m^{-2}$, of which 1.09 mol $m^{-2}$ was retained in plant tissue, with plant uptake ranging from 2.4 to 27.0 mmol N $g^{-1}$ dry weight $d^{-1}$. The results demonstrate the effectiveness of N and P removal from wastewater from land-based intensive marine aquaculture farms by constructed wetlands planted with *S. europaea*.



## 1. Introduction

Recent estimates show that aquaculture provides 47% (51 million MT) of global human fish consumption (FAO, 2009). In order to keep up with population growth and increasing *per capita* fish consumption, aquaculture output is set to increase by a further 60–100% over the next 20–30 years (FAO, 2009). Marine and coastal aquaculture represent a significant component of seafood production and current expansion of this sector is largely the result of the intensification of marine farming of carnivorous fish and shrimp species in coastal cages and ponds. In the main, these are ‘flow through’ or ‘open systems’ which can discharge high volumes of wastewater containing suspended solids (excreta and food waste) and

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dissolved metabolites in the form of organic matter and inorganic nitrogen and phosphorus. With fish farms being subject to best practice codes of conduct (Boyd, 2003), and legislation imposing financial penalties on the polluter (e.g. EU Water Framework Directive 2000/60/CE), development of land-based intensive marine recirculating aquaculture systems (RAS) offers significant potential to treat reduced volumes of wastewater prior to discharge (Tal et al., 2009).

In conventional aquaculture wastewater treatment systems, solids are removed by gravitational and/or mechanical methods. Settlement is used to remove the denser solids, while filtration (commonly screen filtration, expandable granular biofilters (EGBs), and foam fractionation) is used for removing suspended and fine solids (Cripps and Bergheim, 2000; Piedrahita, 2003). Removal of dissolved metabolites requires oxidation of organic matter and steps to promote nitrification or denitrification. Ion-exchange and carbon filters are quickly biofouled and ion-exchange filters are rendered inactive in ion-rich seawater and these methods, although effective, are costly both in terms of capital investment, energy consumption and maintenance requirements.

Constructed wetlands (CW) are a well-established, cost-effective, method for treating wastewater, such as municipal or domestic sewage, industrial and agricultural wastewater, landfill leachate, and stormwater runoff. A constructed wetland is a system engineered to recreate the vegetation, sediment, and microbial assemblages found within its naturally occurring counterparts, whilst utilizing the biogeochemical processes occurring therein (Vymazal, 2005). The role of the higher plants is crucial in establishing a successful CW since they maintain the hydraulic conductivity of the substrate, increase microbial assemblages in the root zone and participate in nutrient uptake. CW design usually consists of a lined bed filled with porous media (generally rock or gravel) and planted with emergent hydrophytes and commonly employed designs incorporate horizontal subsurface flow (HF), where pre-treated waste water enters the CW at the inlet and travels slowly down the length of the bed, passing through the filtration media under the surface of the bed until it reaches the outlet/discharge point. Remediation relies on a combination of physical, chemical and biological processes, sedimentation, precipitation, volatilization, adsorption to soil particles, plant uptake and microbial conversion. Several pilot scale and field studies have been carried out and demonstrated the viability of using CWs to treat aquaculture wastewater, mainly in freshwater and some in brackish water systems (e.g. Lin et al., 2005), however, to date there has been limited work using CWs with marine systems (Lymbery et al., 2006).

Freshwater RASs are ideally suited to aquaponics, where plants are grown in an inert medium (e.g. perlite, sand, gravel, rockwool) supplied with wastewater from the RAS, with the aim of reducing overall organic and inorganic nutrient load while producing a crop (Lennard and Leonard, 2006). To apply a similar approach to marine systems would require a commercially-valuable halophytic plant that can thrive in saline wastewater (Calheiros et al., 2012). One of the few candidates is samphire (*Salicornia* spp.), an edible succulent leafless genus that grows in saltmarshes and saline environments (Davy et al., 2001). *Salicornia* spp. have a commercial value as an oil seed crop, a seasonal vegetable and also for potential use in the health, beauty and nutraceutical industries (Glenn et al., 1991; Rhee et al., 2009). The present study set out to test the effectiveness of a CW planted with *Salicornia europaea* agg. (L) for treating effluent water from a commercially-operating marine fish and shrimp RAS.

## 2. Materials and methods

### 2.1. Filter design and operation

Triplicate pilot water treatment filter beds were installed in a single span poly-tunnel, 5 m × 20 m (W × *L*) on an intensive marine fish farm in Pwllheli, North Wales, UK. Each bed had 14.5 $m^2$ surface area and 4.35 $m^3$ volume (1 m × 14.5 m × 0.3 m, *W* × *L* × *H* ). The filter beds were constructed of timber frames on a sand base, with butyl rubber liners, and filled to 200 mm depth with 40 mm clean, graded, single size smooth limestone (Cefn Graianog Quarry, Chwilog, UK), to allow subsurface flow. This was overlaid with a 100 mm layer of ≤6 mm, mixed M grade quarry to a depth of 100 mm (Fig. 1). The two layers were separated by a sheet of plastic mesh (2 $mm^2$ pore size; www.boddingtons-ltd.com insect mesh, ref. 47000) overlaid with 17 g $m^{-2}$ geotextile frost protection fleece (http://www.lbsgardenwarehouse.co.uk, ref. R-F2050). This combination was designed to provide a semi-permeable barrier, preventing sand from falling into the pore spaces between the larger stones below, whilst allowing root growth into the lower stone layer. At each end, a perforated 300 mm diameter PVC pipe was fitted vertically through the gravel and sand layers, serving as both filling and sampling points as well as water level indicators.

*Salicornia europaea* agg (L) were grown from seeds taken from 2nd generation cultivated plants. Germination took place in a controlled environment greenhouse (photoperiod of 16 light:8 dark and temperature of 18 °C). Seeds were sown onto the surface of P576 plug trays filled with John Innes No.1 compost and irrigated with fresh water. After two weeks, seedlings emerged and the trays were thinned out to 1 plant per plug. Irrigation salinity was increased to 10 psu with TROPICMARIN™ artificial sea salt and seedlings received Phostrogen soluble plant feed (N:P:K 14:10:27 + trace elements; Bayer CropScience Ltd, Cambridge, UK). Two-month old plants were transplanted into the filter beds at a density of 90 $m^{-2}$, so that each bed contained approximately 1250 plants.

The pilot filter beds processed waste water from a commercially-operating intensive recirculating marine aquaculture facility (Llyn Aquaculture Ltd) producing shrimp, sole and turbot (Fig. 2). They were operated on a batch-treatment, flood and drain system, as standard water management for the facility requires once-daily discharge of batches of waste water flushed from sediment traps, and weekly batches of waste water used to backflush biofilter and bead filter units. All wastewater drained to an outdoor, uncovered settlement pond (10 × 4 × 0.5 m), from which it was pumped (400 W 240 V automatic dirty water pump; www.screwfix.com) into a covered and lined 12 $m^3$ header tank via a 300 L vortex separation tank containing plastic biofilter