

FLOATING TREATMENT WETLANDS: A NEW TOOL FOR NUTRIENT MANAGEMENT IN LAKES AND WATERWAYS

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Abstract

Floating treatment wetlands (FTWs) employing emergent aquatic plants growing on a buoyant mat are an innovative new tool for nutrient management in ponds, lakes and slow-flowing waters. Plant roots grow through the floating mat and into the water beneath, providing a large surface area for nutrient assimilation, growth of biofilms and entrapment of fine suspended particulates. By shading the surface and buffering water turbulence FTWs can also promote settling of suspended algae and solids beneath the mats. Microbial nutrient removal processes, such as nitrate conversion to N gases via denitrification, may also be stimulated through creation of localized anoxic zones beneath the mats. The ability of FTWs to be used on deep water bodies and to tolerate wide fluctuations in water depth, means they can be used to retrofit wetland treatment components into existing retention ponds, or used directly as nutrient management tools in ponds, lakes and waterways. Nutrient removal rates recorded in batch and flow-through mesocosm trials are reported. They appear to equal or exceed those reported under comparable conditions for conventional surface-flow wetlands.

Introduction

Floating treatment wetlands (FTWs) are an innovative new tool for nutrient management in ponds, lakes and slow-flowing waters (Headley and Tanner 2011). They involve emergent wetland plants growing on tethered buoyant mats or rafts on the water surface (Figure 1).

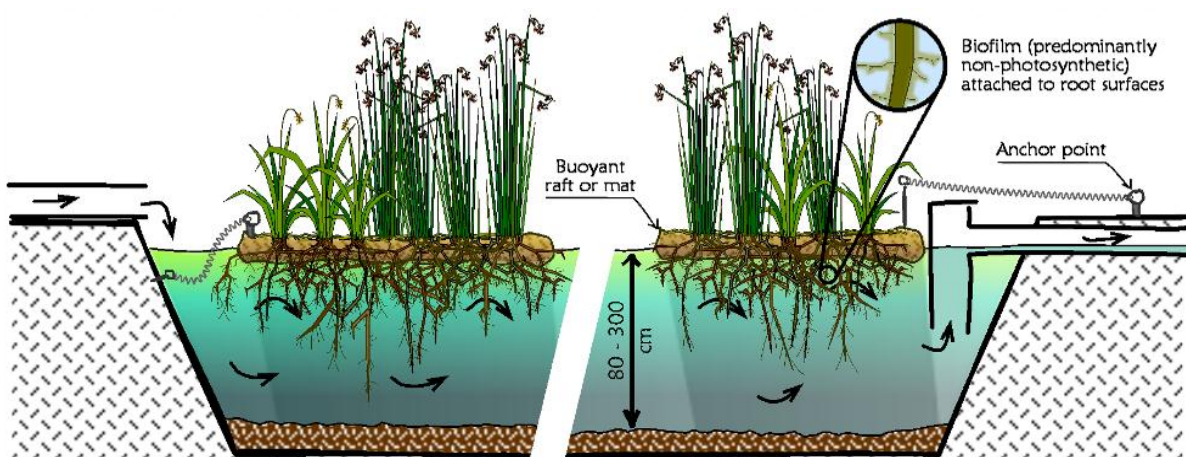


Figure 1: Cross-section of FTWs in a treatment pond (from Headley and Tanner, 2011).

The plant roots grow through the floating mat and into the water below. As well as assimilating nutrients directly from the water column (rather than the bottom sediments), the roots provide a large surface area for adsorption and biofilm attachment (Tanner and Headley, 2011). Because FTWs can tolerate deep and fluctuating water levels, they can be used in situations where use of conventional surface-flow wetlands with bottom-rooted emergent aquatic macrophytes would be precluded. As such, FTWs integrate the nutrient attenuation capabilities of wetlands with the flexibility of deeper pond systems, and so expand the range of situations where wetland ecotechnologies can be applied for water quality enhancement.

This paper briefly introduces the key elements of this novel new ecotechnology and summarises the results of two recent New Zealand studies evaluating their nutrient removal performance treating eutrophic lake and stream waters. Results of both batch- and flow-through mesocosm studies are presented. Previous studies have focused primarily on their potential for treatment of key contaminants in urban stormwaters (Headley and Tanner 2006, 2008, 2011; Tanner and Headley, 2011).

Methods

Batch mesocosms

A series of batch-loaded mesocosm experiments were conducted in 0.7m³ tanks at the Ruakura Agricultural Research Centre, Hamilton, New Zealand over the summer period from December 2007 to February 2008. The tanks were supplied with artificial lake water with nutrients concentrations similar to those found in eutrophic lakes. The FTW treatments consisted of squares of a fibrous polyester mat injected with expanded polyurethane to provide buoyancy (0.6 m × 0.6 m, BioHavenTM Floating Islands, Floating Island International, Sheperd, Montana, USA) (Figures 2 & 3). The centre of the mats were filled with a growth medium (8 cm deep) consisting of sand, peat and compost (1:2:1), and planted with one of three native emergent wetland macrophyte species (*Cyperus ustulatus*, CU; *Juncus edgariae* JE; or *Schoenoplectus tabernaemontani*, ST). These planted mats had been established over a period of 20 months and so had shoots extending 0.5-0.8m above the mats, and well developed root systems extending ~0.5 m beneath the mats. The control treatment comprised a 0.6 x 0.6 m square of plastic sheeting suspended over the mesocosm water surface, providing a similar area of shading to that of the floating mats. All treatments were replicated (n=3). After two initial screening trials, changes in nutrient levels and physico-chemical conditions in the mesocosms were monitored over four consecutive seven day batches with nitrogen supplied as either nitrate and ammonium or as nitrate alone (\pm organic carbon). Only the results of the first three experiments (without organic matter supplementation) will be discussed here; full experimental details are provided in Park et al. (2009) and Sukias et al. (2010a).

Flow-through mesocosms

Flow-through mesocosm trials were carried out on the southern shores of Lake Rotoehu, near Rotorua. The mesocosms comprised a modified steel shipping container split longitudinally to form two parallel mesocosm tanks, and coated with a non-toxic, epoxy coating (Fig. 4). One tank received a low inflow rate (110 mm d⁻¹) and one a high inflow rate (270 mm d⁻¹) of water pumped from the Maero Stream before it entered the lake. These hydraulic loading rates correspond to nominal hydraulic retention times of 9.4 and 3.6 days, respectively. Sediments collected from the lake were placed in the bottom of the tanks and pre-established FTWs planted with native sedges (*Carex virgata* and *Cyperus ustulatus*) were placed on the water surface. The FTWs used were 150 mm thick fibrous polyester mats injected with

patches of buoyant polyurethane foam (Floating Islands, Kauri Park, Kaiwaka, NZ). In this case plants were established directly into the mat matrix without any other growth media. The trial operated for a period of about a year, including a three month period of establishment followed by nine months of monthly water quality sampling August 2009—May 2010. Full details of experimental methods are outlined in Sukias et. al. (2010b).

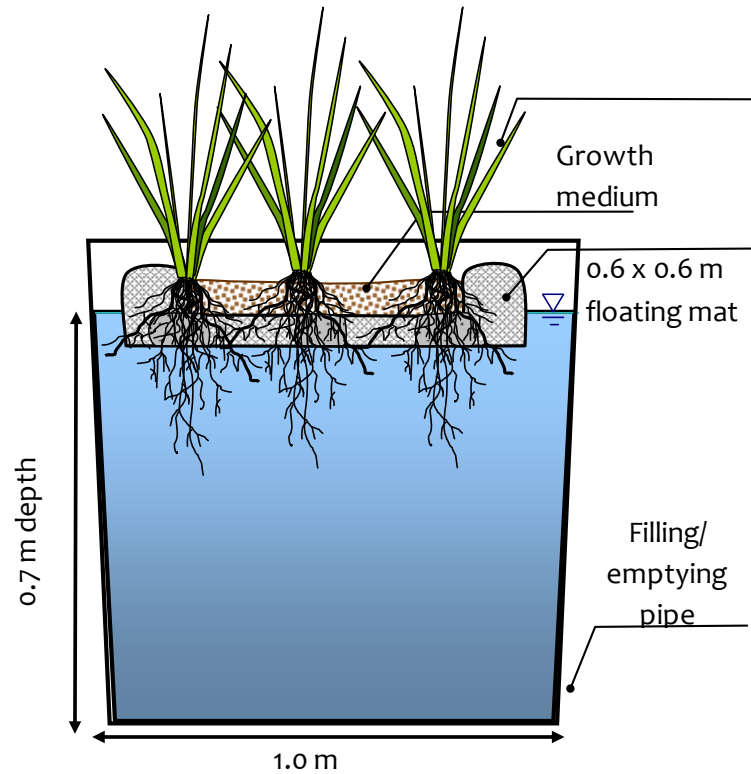


Figure 2: Cross section of the batch-fed experimental mesocosm tanks showing key components.



Figure 3: Batch-fed mesocosm tanks showing FTWs planted with *Cyperus ustulatus*, *Juncus edgariae* and *Schoenoplectus tabernaemontani* (left to right).



Figure 4: Flow-through mesocosm tanks at Rotoehu showing establishing FTWs.



Figure 5: View of the extensive subsurface root development in the flow-through mesocosms by the end of the trial (FTWs temporarily raised out of the water).

Results

Batch-fed mesocosms

Ammonium-N, oxidized -N and Total N concentrations all declined gradually during the week-long batch trials, with highest removal rates in the planted FTW treatments (e.g. Fig. 6). Areal TN mass removal rates of 638-762 mg/m³/d were recorded for the FTW treatments over the initial 3 days of the experiments (means of experiments 1-3).

DRP and TP concentrations also declined steadily during the batch trials, with greater removal generally observed in the FTW treatments, particularly those planted with *Schoenoplectus tabernaemontani*. Areal TP mass removal rates of 54-58 mg/m³/d (means of experiments 1-3) were recorded for the FTW treatments over the initial 3 days.

Lower rates of N and P removal occurred in the control treatments without FTWs. Elevated daytime pH and dissolved oxygen concentrations recorded in these mesocosms, suggest that significantly higher levels of algal photosynthesis were occurring than in the mesocosms with FTWs. Thus it is likely that nutrient removal in these control mesocosms would have been occurring predominantly through algal uptake. Despite provision of an equivalent area of shading of the water surface, it became evident during the experiment that the emergent plants growing on the FTWs were casting greater shade, reducing light availability to algae growing in the water column and on the walls of the mesocosm tanks. Plants and microbes associated with the FTWs would also have competed for nutrient uptake with algae.

Flow-through mesocosms

Marked reductions in concentrations of nitrate-N and DRP were recorded over the 9 month monitoring period in the outflows of the FTW mesocosms compared to the inflows (Figs 6 and 7). These highly biologically available forms, which dominated the N and P loads entering the mesocosms from the Maero Stream (76% of TP and 95% of TN; Table 1), were reduced by 70% and 82% for DRP and 57% and 92% for NO₃-N in the high and low-loaded mesocosms respectively.

Complete concentration and mass removal data for all measured forms of P and N are summarised in Table 1. While the lower-loaded mesocosm showed greater concentration reductions, the high loaded system removed approximately twice the mass of DRP and TP and ~1.5 times greater mass of nitrate-N and TN than the low loaded tanks (Table 1). Overall TP and TN removal was always lower than for the DRP and NO₃-N, because of generation of particulate organic matter and NH₄-N within the FTW systems.

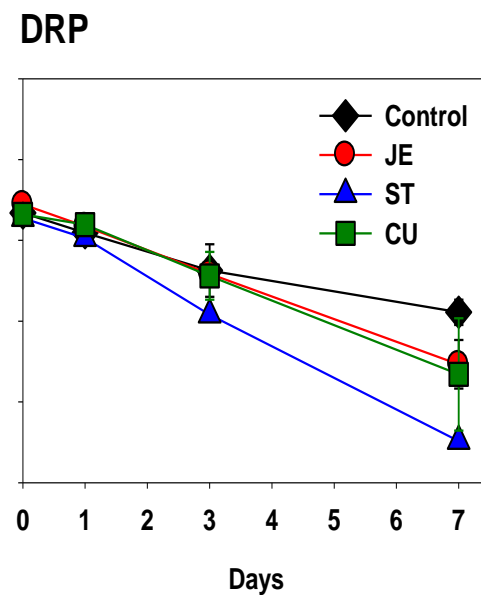
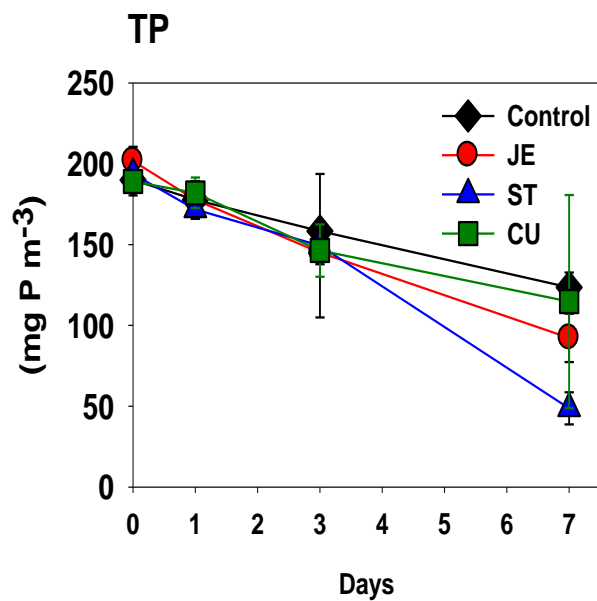
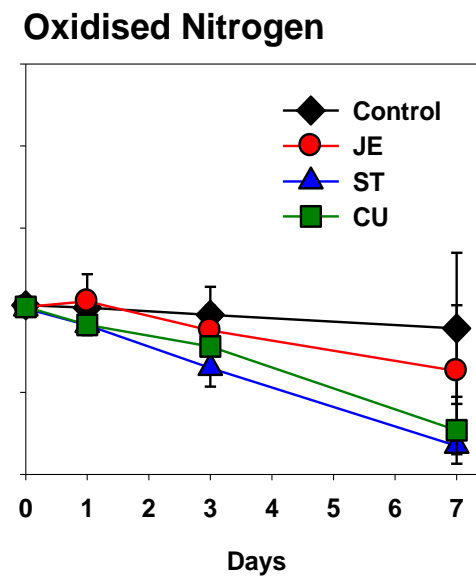
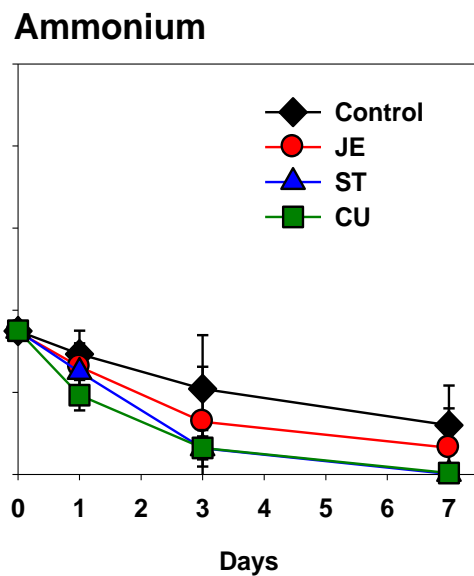
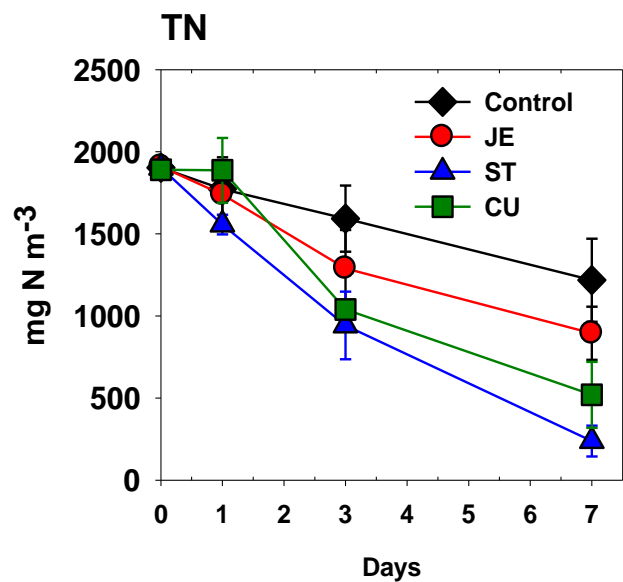


Figure 6: Removal key forms of N and P in batch-loaded tanks with control and planted FTWs (JE = *Juncus edgariae*, ST = *Schoenoplectus tabernaemontani*, CU = *Cyperus ustilatus*. (Experiment 1, Park et al. 2008;

Table 1: Summary of mean nutrient concentrations (\pm standard deviation), mass loadings/removals and percentage removal for the flow-through FTW mesocosms at Rotoehu.

Variable	High loading			Low loading		
	inflow	outflow	removal	inflow	outflow	removal
DRP						
Concentration (mg m^{-3})	51 (± 12)	15 (± 11)	70%	51 (± 12)	9 (± 7)	82%
Areal mass loading/removal rate ($\text{mg m}^{-2} \text{ day}^{-1}$)	13	3.9	8.9	4.9	0.9	4.1
Mass loading/ removal* (g m^{-2})	3.3	1.0	2.3	1.2	0.2	1.0
TP						
Concentration (mg m^{-3})	67 (± 14)	46 (± 26)	32%	67 (± 14)	43 (± 37)	35%
Areal mass loading/removal rate ($\text{mg m}^{-2} \text{ day}^{-1}$)	17	12	5.4	6.5	4.2	2.3
Mass loading/removal* (g m^{-2})	4.3	2.9	1.4	1.6	1.1	0.6
NH4-N						
Concentration (mg m^{-3})	9 (± 7)	32 (± 9)	increase	9 (± 7)	36 (± 25)	increase
Areal mass loading/removal rate ($\text{mg m}^{-2} \text{ day}^{-1}$)	2.3	8.2	-5.8	0.9	3.5	-2.6
Mass loading/removal* (g m^{-2})	0.6	2.1	-1.5	0.2	0.9	-0.7
NO3-N						
Concentration (mg m^{-3})	1976 (± 60)	850 (± 293)	57%	1976 (± 60)	158 (± 134)	92%
Areal mass loading/removal rate ($\text{mg m}^{-2} \text{ day}^{-1}$)	502	216	286	193	15	178
Mass loading/ removal* (g m^{-2})	126.5	54.4	72.1	48.6	3.8	44.8
TN						
Concentration (mg m^{-3})	2078 (± 57)	1136 (± 434)	45%	2078 (± 57)	473 (± 179)	77%
Areal mass loading/removal rate ($\text{mg m}^{-2} \text{ day}^{-1}$)	528	289	239	203	46	157
Mass loading/removal* (g m^{-2})	133.1	72.8	60.3	51.2	11.6	39.6

*Cumulative removal over the ~9 month (252 d) monitoring period.

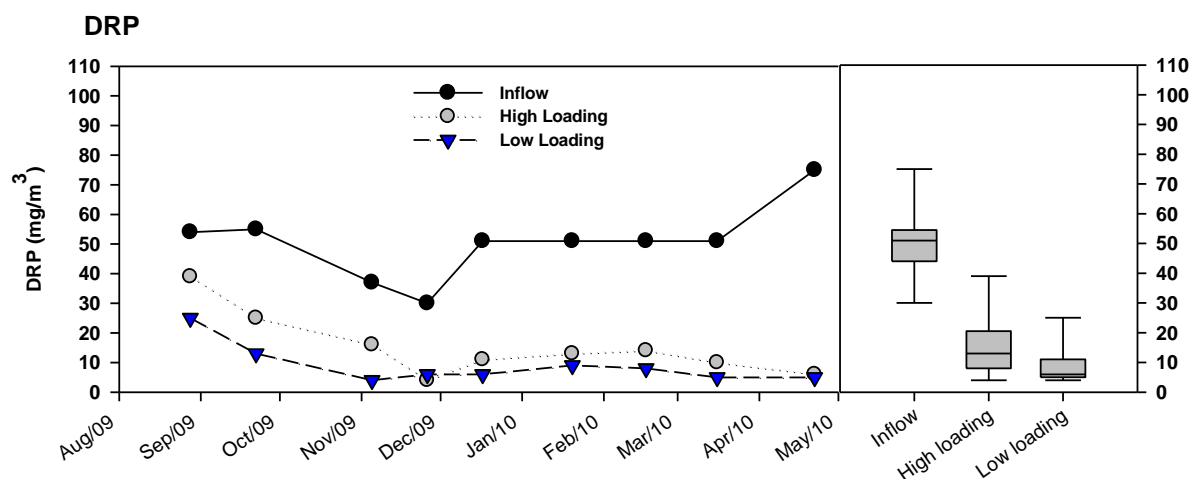


Figure 7. DRP concentrations in the inflows and outflows of the high- and low-loaded flow-through FTW mesocosms at Rotoehu. The boxplots to the right provide a summary of the data for the nine month sampling period; maximum and minimum values are delineated by the whiskers, the boxes delineate the 25 and 75 percentiles, and the central horizontal line shows the median.

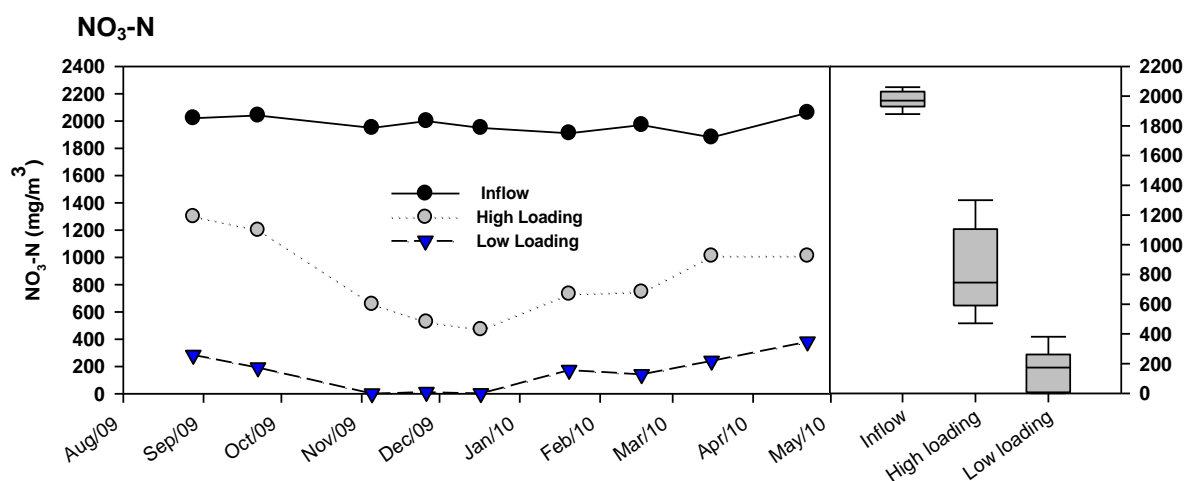


Figure 8. Nitrate-N concentrations in the inflows and outflows of the high- and low-loaded flow-through FTW mesocosms at Rotoehu. Other details as for Fig.8.

Discussion

The results of both the static and flow-through trials show FTWs are capable of removing substantial quantities of nutrients from waters with nutrient levels similar to those found in diffuse agricultural run-off and eutrophic lakes. Hubbard (2010) and Van de Moortel et al. (2010) have also reported enhanced nutrient removal from wastewaters in the presence of FTWs.

Finding directly comparable field data for conventional surface-flow wetlands is difficult, as the form of nutrients, and their concentration and loading rate greatly affect removal rates. In a review of 72 surface-flow wetlands receiving nitrate-rich inflows, Kadlec and Wallace (2009) report a median nitrate load removal of $140 \text{ g m}^{-2} \text{ d}^{-1}$, which is slightly less than that

reported here (at lower nitrate loadings) for the flow-through study. Mitsch et al. (2005) have summarised nitrate removal from river waters in the Mississippi River Basin for 12 wetland systems (total of 48 wetland years), defining an empirical relationship between the mass inflow and percentage nitrate-N mass removal. At equivalent loading rates, the percentage nitrate mass loads removed by the FTWs in the present study were in the high range recorded for these systems. These results suggest that the FTWs in the present study were exceeding the nitrogen removal rates expected for conventional constructed wetland treatment systems under comparable conditions. However, further studies at larger-scale and over longer time periods would be required to properly test this.

The native emergent aquatic plants selected showed good growth on the FTWs, producing dense root masses within and beneath the floating mats (Fig. 5). Previous studies (Tanner & Headley, 2011) suggest the plants contribute significantly to treatment performance by providing extensive attachment surfaces for microbial biofilms, assimilating nutrients from the water column, releasing bioactive exudates, and modifying environmental conditions beneath the mat. In particular, dissolved oxygen levels typically become depleted beneath the FTWs, due to shading of algal photosynthesis, respiratory oxygen demand of the roots and associated biofilms, and reduced exchange across the water-atmosphere interface. This and the release of exudates is likely to create conditions conducive to microbial denitrification, so enhancing nitrogen removal in FTWs. Indeed, the ratio of N:P removed from the water column in the experiments we report here were generally in the range of 40–70, much higher than shoot tissue N:P ratios of 11–16 found for the two test species at the end of the flow-through study (Sukias et al, 2010), or ratios of 10–20 commonly found for wetland plant shoot tissues (Gusewell et al. 2003). This suggests substantially higher N removal was occurring in the presence of FTWs than could be accounted for by plant uptake alone.

Conclusions

FTWs are a novel new tool for nutrient management in nutrient enriched waterways and water bodies. They are currently being trialled or applied for water quality enhancement in a wide range of situations in New Zealand (Figs. 9 and 10) and around the world. In the studies reported here, areal TP removal rates of 54–58 mg/m²/d were recorded in batch trials and 2–5 mg/m²/d in flow-through field trials. Areal TN removal rates of 500–800 mg/m²/d were recorded in batch trials, whilst 160–240 mg/m²/d were recorded in flow-through field trials.

Although the key nutrient removal processes operating are likely to be similar to those operating in surface-flow wetlands, FTWs have a number of unique attributes which provide advantages in certain situations. In particular, tolerance of deep and fluctuating water levels, enables FTWs to be retrofitted into ponds, lakes and slow-flowing waterways. FTWs thus have the potential to attenuate nutrient loads and ameliorate water quality problems in dams, reservoirs, ponds, lakes and estuaries. The positive results shown in these mesocosm trials warrant larger-scale, longer-term investigations of FTWs across a range of applications to improve our understanding of their sustainable performance, and better define their niche within the available suite of wetland ecotechnologies.



Figure 9. Trial application of FTW for treatment of agricultural drain-flows into the Tukipo River, Hawkes Bay Regional Council.



Figure 10. Some New Zealand examples of FTW applications being tested for (clockwise from top left) treatment of urban stormwater (North Shore, Auckland) and road run-off (Northern Motorway, Auckland), lake water quality enhancement (Lake Rotoroa, Hamilton), and treatment of wastewaters (Shannon WTP, Manawatu)

Acknowledgements

The data reported in this paper are from studies carried out for and primarily funded by Environment Bay of Plenty. We thank Andy Bruere and John McIntosh for their assistance particularly for the Rotoehu trials, where they provided oversight of the project and undertook significant liaison with affected land owners and lake-user groups. Presentation of this work to a wider audience has been undertaken as part of the AgResearch-led Clean Water, Productive Land Programme (C10X1006) funded by the Ministry of Science and Innovation. Various other NIWA staff and visiting interns assisted with the project, particularly Joe Butterworth (routine sampling), John Nagels (sonde sampling), Jeremy Rutherford (site assistance), Mathieu Fabry (setting up of batch-testing facility), and Thomas Mann, Tim Wallis, Lex Brugger and Asaeli Tulagi (field assistance). Previous work commissioned by the Auckland Regional Council on application of FTWs for urban stormwater treatment has informed this work. A study grant provided by NIWA for Chris Tanner to visit Floating Islands International in Montana, USA in 2005 was instrumental in developing our interest in its application for water quality enhancement, and bringing this technology to New Zealand. We thank Floating Islands International (Montana, USA) and Kauri Park Nurseries (Kaiwaka, NZ) for assisting with provision of the experimental floating mats used in these studies. Kauri Park Nurseries also provided the wetland plants used in the experiments.

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