Application of floating treatment wetlands in a highly eutrophic lake, Indonesia: a new tool for lake restoration and provision of microhabitat

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Abstract. Two sets of floating treatment wetlands (FTWs) have been evaluated as a tool for lake restoration and microhabitat provision for aquatic biota in a highly eutrophic and polymictic Lake Maninjau, Indonesia. Each FTW system consisted of 14 units square floating frame built using PVC pipes and palm sugar fibres as material mat transplanted onto net. All units of FTW were planted with different vegetation composition arrangement then placed inside the square metal frame attached on buoyant plastic drums to support the FTWs against the wave. The plants used in this study were Canna variegata, Vetiveria zizanioides, Cyperus papyrus, Echinodorus polaeifolius and Limnocharis flava. FTWs were evaluated for 7 months for nutrient removal efficiency and other water quality indicators. Despite unstable lake conditions accompanied by strong waves and lake mixing, the cage and the PVC frame of FTWs applied remained intact and providing the buoyancy to support the plant growth. The plants in FTWs grew and adapted well in the turbulence water and even in the hypoxic conditions. Improvement of lake water quality in the FTWs area may be small but the accumulated nutrients content in the plant shoots suggest high removal of nutrients. In total by the end of observation, one FTWs system could remove > 100 g N and > 7 g P from the lake water. During field observation, important local fish and diverse wildlife activities were recorded including inhabiting, foraging, breeding, nursing and resting in the FTWs. Our study suggests that FTWs can be a promising tool for lake restoration to improve lake water quality and for microhabitat provision.

1. Introduction
Lake eutrophication has been a worldwide problem due to excessive input of nutrients (nitrogen and phosphorus) derived from anthropogenic sources [1,2,3,4]. One of the major causes of lake eutrophication faced by Indonesian lakes is intensive floating cage aquaculture [3,5,6]. Excess nutrient enters the lake will likely to be accumulated in the sediment especially phosphorus which subsequently will be released back to the water column via microbial transformation [7]. Both external and internal loadings elevate P content in the lake triggering the harmful blue-green algal blooms. Excessive algal growth reduces water quality mostly dissolved oxygen (DO) level. Depletion of DO can cause fish kill and loss of other aquatic life [8,9]. Although it is not environmentally sound, the cage aquaculture has been a big challenge to be banned due to an economic issue for the local people. Undertaking effort to improve water quality by reducing the activity of cage aquaculture has been very slow. Therefore, an innovative treatment tool is highly needed not only to reduce excess nutrient directly in the lake water but to provide the microhabitat as well to conserve aquatic life especially the economic local fish.

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Floating treatment wetlands (FTWs) are a new innovative tool, a novel treatment concept that can be suitable to be applied to restore the lake suffering from eutrophication. FTWs offer a promising technique, low cost green approach for lake water quality improvement and microhabitat provision as well as aesthetic improvement at ponds or small lakes [10,11,12,13]. FTWs are basically cultivated emergent plants growing on a buoyant mat which can be deployed in the water bodies. The plant roots will develop down in the water column, creating root system which is important for the performance of the FTWs on the nutrient uptake and pollutant transformation. The root network system not only functions as a filter to entrap particulates but also provide extensive surface area for biofilm which is responsible for the biochemical transformation of contaminants [13,14,15, 16]. Several studies have demonstrated the effectiveness of FTWs on nutrient removal or other type of contaminants from various wastewater sources. The studies were done mostly in mesocosm laboratory scale [14,15] and in field application in ponds [16,17,18], but limited field studies were conducted in the river [11]. To the best of our knowledge no study has been reported in the big lake. The study mostly used a single type of plant, but limited study used a combination of two or several types of plants [12,14,19].

The application of FTWs for big lake restoration will face substantial challenges due to lake hydrodynamics. The lake is very susceptible to the influence of climate variability. Frequent lake mixing due to strong wind and big wave will affect the sustainability of FTW system. The phenomenon of lake upwelling triggering anoxic and rich nutrient bottom water pushed upward to the surface may cause a shock loading for the root system of FTWs. We investigated the FTW system in a highly eutrophic and polymictic Lake Maninjau, Indonesia for lake restoration and microhabitat provision as well. Lake is very unstable and susceptible to mixing due to the turbulence weather. We used a combination of four different type of emergent plants. The lake has been in hyper-eutrophic conditions for over a decade due to overloading of nutrient and organic matter from the waste input of intensive floating cage aquaculture. The lake water conditions were worsened by dead fish mass due to frequent fish kill incidents, and harmful algal blooms. This causes continuous decline on important local fish with economic value [3,7,8]. The objectives of this study were to (1) evaluate the performance of the FTW system on lake water quality improvement (2) investigate the sustainability of FTW system and the selection of plants (3) observe wildlife utilizing the FTW system for habitation or feeding.

2. Materials and methods

2.1. Study site

The FTWs study was conducted at Lake Maninjau, a caldera lake located at Agam District in the Western area of Sumatra, Indonesia (S 0°22’33.0”, E 100°11’35.1”). The lake is considered a big lake which has surface area of 9737.5 Ha and maximum depth of 165 m. The lake is utilized for hydropower and intensively for floating cage aquaculture. There were more than 17000 units of floating cage aquaculture reported throughout the lake periphery [7]. The lake is highly eutrophic with elevated nutrient concentration and frequent mass fish kill incidence reported several times in a year generally in rainy (November – February) and transitional season (March – May) during high climate variability. High climate variability induces strong wind with heavy rain causing lake mixing and lake upwelling subsequently. Figure 1 shows the map of Lake Maninjau and the location where the FTWs were set and the pictures of indication of heavily eutrophic conditions of lake water with dead fish. One FTW was placed at the periphery of the lake outlet area of Muko-Muko (FTW_MK) where it is close to the hydropower turbine in which the water current is relatively stronger. The other FTW was placed at Bayur area (FTW_BYR) where the fish cage units were very dense and less affected by the water current.

2.2. Design of Floating Treatment Wetland (FTW) systems

Two FTWs systems were applied in Lake Maninjau in August 2016. The system each consisted of 14 units of small FTWs. FTWs system was planted with different vegetation composition arrangement then was placed inside the square metal frame attached on buoyant plastic drums to support the FTWs against
the wave (figure 2). The net (mesh 2 x 2.5 cm) was put underneath as a fence to protect the plant roots grazing. Each unit of FTWs (1m x 0.6 m, L x W) built with PVC pipes (3-inch Ø) (square floating frame) as buoyant material, palm sugar fibres as material mat transplanted onto net (mesh size of 4 x 4 cm).

![Figure 1. Map of Lake Maninjau (middle) and the FTWs sites (Muko-Muko area (FTW_MK), top right and Bayur area (FTW_BYR), bottom right)). Indication of lake eutrophication with thick algal bloom and dead fish (left) (right) (Google Earth, 2018).](image)

![Figure 2. Schematic of Floating Treatment Wetlands (FTWs) system with different vegetation composition for each site. Plan-view (left and right) and cross-section of FTW unit (middle).](image)

Each unit FTW has 15 plants with single plant grown in the individual hydroponic plastic cup (6 cm Ø (bottom) x 15 cm (height) x 10 cm Ø (top)) filled with growth media. The plastic cup was removed from the plant before being planted on fibres mat. The compost was added on the mat around the plant. The plants used in this study were *Canna variegata* (4 units; total of 60 plants), *Vetiveria zizanioides* (4 units, total of 45 plants), *Cyperus papyrus* (4 units; total of 60 plants), *Echinodorus palaefolius* (small type) (4 units, total of 45 plants) for the FTW_MK and *Canna variegata* (4 units; total of 60 plants),
Physicochemical data are shown in figure 3. Water temperatures in the FTWs ranged from 27 to 29 °C which were slightly cooler than the lake water temperatures (28 to 30 °C). The water temperatures are much cooler in October 2016 and February 2017. September through February are usually the period of the rainy season and March is the period of transition season from the wet to the hot seasons in the lake area [8]. The pH values ranged from 6.8 to 8.2; conductivity ranged from 125 to 160 µS/cm while dissolved oxygen (DO) ranged from very low of 1 mg/L to the highest of 8 mg/L in the lake water and in the FTWs systems. All the physicochemical parameters measured were not shown significant difference between the lake water and the water in the FTW systems, although DO concentrations in the FTWs and in the lake water at the outlet area (MK) were much higher than those in the FTWs and in the lake at the area with dense floating fish cages (BYR). Very low DO concentrations of 1-2 mg/L were recorded in September, October 2016 and February 2017 indicating the lake was in hypoxic condition [1,3,6]. At the time of measurements in those months, it was also recorded the upwelling phenomena

**Limnocharis flava** (4 units, total of 45 plants), *Cyperus papyrus* (4 units; total of 60 plants) and *Echinodorus palaeolius* (4 units, total of 45 plants) for the FTW BYR.

### 2.3. Sampling and lake water analysis

Direct water quality measurement and water sampling were conducted one on the inside of FTW system and one on the lake not far from the FTWs (over 10 m distance) one month after the FTWs was well established which was started in September 2016, in October 2016 then in January, February and March 2017. The water was collected at a depth of at least 20 cm. Physicochemical parameters were: pH and conductivity, measured directly in the water column using a Water Quality Meter (Horiba U-10), while temperature and dissolved oxygen (DO) were measured using a DO meter (YSI 6000). The evaluated parameters were: Total Nitrogen (TN), Total Phosphorus (TP), and Total Kjeldahl Nitrogen (TKN), analysed using spectrophotometric methods; chlorophyll-a, prior to lab analyses water sample was added with saturated MgCO₃ and filtered by using Whatman (GF/F) filter paper. Filtrates were then extracted and measured using a standard spectrophotometric technique; total suspended solids (TSS) determined using a gravimetric method. All lab analyses procedures were done according to APHA standard methods [20]. The samples prepared by spectrophotometric methods were measured by using Shimadzu UV 2100 Spectrophotometer.

### 2.4. Plant growth and microhabitat provision

The growth of plants was observed by measuring randomly shoot length (*C. variegata*), the shoot length and number (*V. zizanioides* and *C. papyrus*), the shoot length (*E. palaeolius* and *L. flava*). The root length was measured on September 16 and in March 2017 and plant biomass (dry weight) of the plants were estimated from samples data in January 2017 and in March 2017. Biomass estimation (dry weight analysis) was conducted only on the above parts of plants (shoot) for *C. variegata*, *V. zizanioides* and *C. papyrus* where 3 selected plants were harvested for each type of plants and air dried and then oven dried (50°C) until the constant weight was obtained. Plant productivity was estimated according to Olguín [17].

### 2.5. Statistical analysis

The mean and standard deviation were calculated for the plant shoot length and number and root length. Statistical analysis of a simple t-test was done to compare the plant growth of two FTW systems studied. One-way ANOVA was also conducted to compare water quality data between FTW systems and the lake water in a different location. Pearson correlation analyses were also conducted for TN, TP and chlorophyll-a data. All statistical analyses were conducted with SPSS (24 version) and Microsoft Office Excel (2013).

### 3. Results and discussion

#### 3.1. Water Quality

Physicochemical data are shown in figure 3. Water temperatures in the FTWs ranged from 27 to 29 °C which were slightly cooler than the lake water temperatures (28 to 30 °C). The water temperatures are much cooler in October 2016 and February 2017. September through February are usually the period of the rainy season and March is the period of transition season from the wet to the hot seasons in the lake area [8]. The pH values ranged from 6.8 to 8.2; conductivity ranged from 125 to 160 µS/cm while dissolved oxygen (DO) ranged from very low of 1 mg/L to the highest of 8 mg/L in the lake water and in the FTWs systems. All the physicochemical parameters measured were not shown significant difference between the lake water and the water in the FTW systems, although DO concentrations in the FTWs and in the lake water at the outlet area (MK) were much higher than those in the FTWs and in the lake at the area with dense floating fish cages (BYR). Very low DO concentrations of 1-2 mg/L were recorded in September, October 2016 and February 2017 indicating the lake was in hypoxic condition [1,3,6]. At the time of measurements in those months, it was also recorded the upwelling phenomena
occurrence which caused the mass fish kill. The lake appeared to have needed longer time to recover from this hypoxic condition. In fact, DO level could only reach as high as 4 mg/L until March 2017. Slightly elevated DO of 8 mg/L was recorded at the outlet lake area which probably was due to stronger water flow. The hypoxic condition severely impacts the lake conditions by creating a stressful environment for aquatic life especially local fish, shrimps and molluscs. The growth of the plants in the FTWs and associated organisms such as microbial biofilm will also be affected by these hypoxic condition [18]. During this hypoxic condition the local fish, shrimps and mollusces were observed on the water surface and attached on the FTWs mats suggesting the presence of FTWs could support aquatic life during the lake extreme condition.

![Temperature Graph](image1)
![DO Graph](image2)
![pH Graph](image3)
![Conductivity Graph](image4)

**Figure 3.** Temporal variation of temperature, pH, dissolved oxygen (DO) and conductivity in the lake water and the water inside the FTW system at two locations.

Temporal variation of concentrations of total nitrogen (TN), total phosphorus (TP), chlorophyll-a and total suspended solids (TSS) in the lake water and FTW systems are shown in figure 4. The results of the ANOVA test showed no significant different on nutrients, chlorophyll-a and TSS concentrations between the lake water and the water in the FTW systems at two locations (p>0.05) although some numbers for TN, TP and chlorophyll-a were relatively higher between the lake water and between the FTWs in two locations. Calculated removal efficiency (RE) based on the value difference of the FTWs and the lake water for each location showed high TN removal of around 82 % and 40% in September 2016 and in March 2017 respectively for the FTW_BYR while for the FTW_MK, TN removal reached only as high as 25 %. TP removal efficiency reached as high as 54% for the FTW_MK in October 2016 and in March 2017 while the FTW_BYR only had < 15 % of TP removal. Both FTWs gave around 50 % of chlorophyll-a removal in October 2016 and in March 2017. Both of FTWs did not have good removal efficiency (RE) for TSS. This probably is due to the lake often suffers from extreme weather causing waves and turbulence in the waters. Our study gave close removal percentage of TN and TP with the FTWs of the previous study [14]. The FTW field study using a combination of *Cyperus papyrus* and *Pontederia sagittata* in a eutrophic pond gave phosphate and nitrate removal percentage with the
highest average of 76% and 67% respectively [19]. TN, TP and chlorophyll-a concentrations were around < 1.5 mg/L, < 0.15 mg/L and < 25 mg/L respectively in the FTWs and in the lake waters in this study. These numbers were similar to the numbers reported in Lake Maninjau and eutrophic ponds of previous studies [3,8,17,18, 19]. The chlorophyll-a concentrations measured in this study were considered low for Lake Maninjau compared to the previous studies results. Chlorophyll-a concentrations in Lake Maninjau could reach as high as 75 - 100 mg/L during hypereutrophic condition [3,8]. More cloud periods and hypoxic condition at the time of observations influenced the phytoplankton productivity and slowed the photosynthetic process [19]. Chlorophyll-a was positively correlated with TP with a high Pearson correlation coefficient of 0.627 (p<0.05) and had a weak correlation with TN (table 1). The results indicate that phosphorus was the limiting factor for phytoplankton productivity and controlled the chlorophyll-a concentration [3,21].

![Figure 4](image)

**Figure 4.** Temporal variation of total nitrogen (TN), total phosphorus (TP), chlorophyll-a and total suspended solids (TSS) concentrations in the lake water and the water inside the FTW system at two locations.

### 3.2. FTW vegetation stability and Plant growth

Evaluation of the application of FTWs in a big lake should include the sustainability of the FTW frame and the vegetation growth. During anomaly weather in the rainy and transition seasons, heavy rain accompanied by strong wind will cause the turbulence and strong waves in the lake studied. In these conditions the lake will experience mixing upwelling subsequently causing deeper anoxic water column pushed upward to the surface lead to hypoxic lake conditions. During the observation, the lake has experienced these phenomena supported by observed DO level in the lake. Despite experiencing heavy...
waves and lake mixing, the cage and the PVC frame of the FTWs applied remained intact and providing the buoyancy to support the plant growth. The plants in both FTWs grew and adapted well in high wave and even in the hypoxic condition. However, the hypoxic condition did affect the growth of the plants in the FTW_BYR where the area is packed with floating cage aquaculture and has little effect by the water flow. The growth of *C. variegata, C. papyrus* and *E. palaeolius* were slightly slower indicated by the shoot length measured. The plants were less dense in comparison to the plants in the FTW_MK which was influenced by water flow and slightly higher DO level (figures 5,6,7). *C. variegata and C. papyrus* especially grew faster in the FTW_MK and the leaves of *C. variegata* were bigger while *C. papyrus* had higher shoot numbers. *V. zizanioides* also grew well but not *L. flava*. One third of *L. flava* were dead. Results of t test (p<0.05) indicated significant different for shoot length and number for *C. variegata, C. papyrus* and *E. palaeolius* in the FTW_MK and the FTW_BYR. Nonetheless, the beautiful appearance of plants especially *C. variegata* with bright flowers provided an aesthetic contribution to the lake.

**Table 1.** Correlation of chlorophyll a, total phosphorus (TP) and total nitrogen (TN).

|       | CHL   | TP     | TN     |
|-------|-------|--------|--------|
| CHL   | 1     | .627** | 0.264  |
| Sig. (2-tailed) | 0.009 | 0.322  |
| N     | 16    | 16     | 16     |
| TP    | .627**| 1      | 0.347  |
| Sig. (2-tailed) | 0.009 | 0.188  |
| N     | 16    | 16     | 16     |
| TN    | -0.264| -0.347 | 1      |
| Sig. (2-tailed) | 0.322 | 0.188  |
| N     | 16    | 16     | 16     |

** Correlation is significant at the 0.01 level (2-tailed).**

CHL: chlorophyll-a
Figure 5. Temporal variation of plant growth for *Canna variegata* (shoot length) and *Cyperus papyrus* (shoot length and number; mean ± standard deviation) at the two FTW systems.

Figure 6. Temporal variation of plant growth for *E. palaeolius* (shoot length), *V. zizanioides* (shoot length and number) and *L. flava* (shoot length) at the two FTW systems.
The productivity of plant biomass (shoot part only) were estimated for *C. variegata*, *C. papyrus* and *V. zizanioides* (table 2). *C. variegata* had the highest biomass productivity. These numbers are much smaller than the numbers estimated by the previous study [17]. They estimated plant productivity to a maximum of 536 g/m². d (based on dry weight). This was because in this study a big type of *Cyperus* was used, which had more masses than *C. papyrus* used in this study.

The root length increased from the lowest of 10 – 20 % for *L. flava* to the highest of 40 - 50% for *C. variegata*, *C. papyrus* and *E. palaefolius* (figure 8), the root masses of *V. zizanioides* and *C. papyrus* were denser than those of *C. variegata* and *E. palaefolius*. The root masses of *L. flava* were the least. Results of t test (p<0.05) indicated significant differences for the root length of *C. variegata*, *C. papyrus* and *E. palaefolius* in the FTW_MK and the FTW_BYR. Our lab scale FTWs study demonstrated better root development and much denser root masses for those plants [22]. The development of the root system of the plants play an important role in the nutrients removal. The root system in the FTWs provide extensive surface area for microbial biofilms attachment and the roots uptake the nutrients while microbial biofilm transforms the nutrients which changes the environmental conditions beneath the mat [14,16].

**Table 2.** The productivity of FTWs plants.

| Plants               | Productivity (g/m². d) |
|----------------------|------------------------|
| *Canna variegata*    | 100.28                 |
| *Cyperus papyrus*    | 29.72                  |
| *Vetiveria zizanioides* | 20.42             |
Figure 8. Comparison of the root length for *Canna variegata*, *Cyperus papyrus*, *E. palaeolius*, *Limnocharis flava* (Lim.) and *Vetiveria zizanioides* (Vet.) at the two FTWs systems in September 2016 (Month-1) and in March 2017 (Month-7).

FTWs performance in field studies generally was assessed by determining nutrient uptake by plants. In field studies with large volume and continuous water flow, the lake water constantly mixes and pass by the FTWs much faster than in a controlled batch system giving insufficient time for the pollutant in the water into contact with the network root system of the FTWs. Total N and P accumulated in the plant were calculated from the highest biomass density. The TKN content in the plant ranged from 1.2 – 1.9 g/kg and TP ranged from 0.05 to 0.18 g/kg. The TKN content in the plants in this study much lower but somewhat similar TP content in the plant with those in the previous study [17]. *C. variegata* had the highest N and P accumulation (table 3).

Total N and P accumulated in plants from this study were quite higher than those reported from other field studies [19]. Assessment of nutrient uptake rate in the FTW field study was usually done by measuring nutrient content in the plant tissues using harvesting strategy of the FTW plants in a specified area [17, 19]. Plant harvesting strategy resulted in high nutrient removal by FTWs [17,18,19]. In total, one FTW system in this study could remove > 100 g N and > 7 g P from the lake water. Our study showed that the FTWs in an area that has little effect of flow water (FTW_BYR) had lower N and P uptake and accumulation in plants. During turbulent weather both area where FTWs applied certainly were influenced by a wave and turbulent water in which causing the plants distress and probably affected the nutrient uptake. Tanner and Headley [12] demonstrated that the FTWs in batch trails gave much higher areal removal rate of TN and TP than in flow-through field trials. Unstable lake conditions and often experiencing hypoxic condition influenced the performance of FTWs. Hypoxic condition can disrupt pollutant transformation process by aerobic microbial biofilm on the root system [17,19].
Table 3. Nitrogen and phosphorus content in plant shoot.

| Plants             | N (g/m²) | P (g/m²) | N (g/m²) | P (g/m²) |
|--------------------|----------|----------|----------|----------|
| Canna variegata    | 35.61    | 14.95    | 2.31     | 2.34     |
| Cyperus papyrus    | 8.06     | 6.61     | 1.17     | 1.66     |
| Vetiveria zizanioides | 8.12   | 0.38     |          |          |

3.3. Microhabitat provision based on wildlife observation

The plants, the plant roots and the mats of FTWs show great potential for the creation of microhabitat and the lake restoration. There were few wild plants species observed to be thriving in the new habitat of the FTWs. Beside the grass type of plants there was paddy plant (Oryza sativa) spotted in which probably their seeds were dropped by the birds to the FTWs. The plants and the FTW raft appeared to attract some wildlife and the local aquatic life. The fauna spotted at the FTWs were birds, insects, and several types of dragon flies, snails, a snake, frogs, water rats and a big lizard which probably needed a shelter and were looking for food. The flowers of C. variegata appeared to attract dragon flies. Small local fish were spotted swimming under the roots, while shrimps and small molluscs were spotted in the area of the roots. At the early monitoring, it was found the fish eggs attached on the palm fibres and also on the roots. During in the hypoxic condition, small local fish population appeared on the surface water inside the FTWs area. At the end of observation, during the plants harvesting, freshwater eels were caught hiding in sugar palm fibres. More than 10 good size of tilapia (15 – 20 cm) were captured inside the net fence which was placed underneath the FTW (section 2.2). Common grass carp were captured in the protective fence of FTWs applied in a eutrophic pond [18]. The FTWs clearly could create the habitat which support not only the life of economic local lake’s aquatic biota but also other types of terrestrial fauna. Different trophic levels inhabited and frequently visited the FTWs. The FTWs serves as feeding ground or foraging place, a place for reproduction, nursery and a place for shelter. The interaction between trophic levels develop the food web in the FTW ecosystem. Freshwater eels for instance which is the type of animal lives inside the muds, the palm fibres become a suitable media for their habitat and obviously the FTWs provide the food for them as well. Similar studies have been reported on organism inhabited the FTWs [17,18].

Prolonged lake hypoxic condition and frequent algal blooms have decreased the population of economic local fish and molluscs. During these conditions those local fish and molluscs were observed in the FTWs. The presence of FTWs can have benefit to the lake ecosystem by increasing DO level to support aquatic life and creating aerobic conditions for microorganisms responsible in the lake self-purification process [17,19]. In the long term, the FTWs could help maintaining the lake’s ecosystem health.

4. Conclusion

Our first application of floating treatment wetlands (FTWs) in a quite big lake gave good evidence that our FTWs system and the plants selected could thrive in the unstable lake conditions such as turbulent water and hypoxic condition. The plants adapted and grew well with good biomass productivity. Improvement of lake water quality in the FTW area may not be apparent but the accumulated nutrients content in the plant shoots suggest high removal of nutrients. In total by the end of observation, one FTWs system could remove > 100 g N and > 7 g P from the lake water. The presence of FTWs will have benefit for the area surrounding not only to maintain better water quality but to provide microhabitat as well for local economic fish, shrimps and molluscs. The FTWs could be developed more in the lake periphery to serve as a conservation area for lake biota. Our study suggests that FTWs can be a promising tool for lake restoration to improve lake water quality and for microhabitat provision. Canna variegata, Vetiveria zizanioides and Cyperus papyrus can be used in FTWs application under a slight stressful environment such as under low DO conditions and turbulent waters.
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