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Causes and control measures for algae occurrence in a constructed wetland treating stream runoff from agricultural land use

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ABSTRACT

The constructed wetland (CW) was designed to treat impacted runoff stream water coming from a 221 ha agricultural watershed. The CW was composed of 7 cells in series including a sedimentation zone, deep marsh and shallow marsh. Water quality, sediment and plant monitoring on the CW was conducted since October 2009 and additional analyses were performed to recognize the causes of algae occurrence since 2012. Large amounts of *Haematococcus pluvialis* species was observed in the first five cells of the CW but no algae was seen at the last 2 cells prior to the outlet. Results indicated that the proportion of plant coverage to surface area in Cells 1 to 5 was very low (less than 6%). Findings revealed that nutrients were being transported into the CW from the catchment area with the soluble nutrients degraded by microbial activities in the sediments and released to the water table. Relatively high potassium content was found in Cell 1 of the CW which originated from the chemical fertilizers used in the paddy field. Algal bloom control and better design methods in the CW were suggested to prevent and regulate the algal bloom in CWs.

Keywords: Algal bloom control; Free water surface flow constructed wetland; *Haematococcus pluvialis*; Water quality; Plant density; Sediment

1. Introduction

Algae are a natural component of aquatic environments, and even when they are abundant; is not necessarily a problem. Often a proliferation of microscopic algae can have beneficial effects on fisheries and aquaculture industries such as by increasing the amount of food available [1]. However, large amounts of algae in intensity and frequency can cause public health concern and ecological problem, and some cases can be catastrophic to the environment. In a constructed wetland (CW), algal blooms could upset the delicate natural balance of plant and animal ecosystems when present in huge amount. CWs are increasingly used worldwide to improve the water quality of rivers and lakes; and to manage both point and non-point source (NPS) pollution from stormwater runoff, agricultural wastewaters, drainage waters, municipal sewage and other types of wastewaters [2–7].

There are complex, integrated systems of water, plants, soil, animals, microorganisms, and the environment [8]. But most of all, plants growing in CWs have several properties related to treatment processes that make them an essential component of the design of the CWs [9,10]. The density of plant affects detention time in a free water surface flow (FWS) CW; i.e., increases with plant density [11]. According to [12], unplanted cells had significantly higher temperature than cells and exhibited greater daily variation in temperature than vegetated cells. Both [9,13] highlighted the influence of plants on radiation insulation in the spring, which resulted in reduced algal growth and lower system operating temperature.

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The growth of algae in the CW is affected by several factors including suitable growing environment, nutrient availability, flushing rate, etc., [14]. To evaluate the occurrence of eutrophication, traditional parameters are usually evaluated and referred to be comprehensive such as the existence of index organism and the amount of algae, primary productivity, dissolved oxygen (DO), nitrogen and phosphorus concentrations [15]. In this research, the possible causes of algae occurrence in a FWS CW were investigated durinStag a 6-year monitoring period. Since 2012, large amounts of algae (*Haematococcus pluvialis*) were observed in the CW that occurred between May and October. The widespread occurrence of *Haematococcus* in temporary rather than permanent bodies of water is due at least in part to the fact that such pools are usually free of other competing algae, and not to any inherent characteristic of the pools. *Haematococcus* is considerably better suited for survival under conditions of expeditious and extreme fluctuations in light, temperature and salt concentration than most algae, due to its rapid ability to encyst [16]. *Haematococcus pluvialis* species is well known for its high content of the strong antioxidant astaxanthin (red katocarotenoid), which is important in aquaculture [17]. The accumulated carotenoids might function as a protective agent against oxidative stress damage [18, 19]. Based on the findings and monitoring experience, algal bloom control and better design methods in the CW were suggested to regulate algae.

2. Materials and methods

2.1. Description of the constructed wetland

The FWS CW designed by the Ministry of Environment in 2008 was located in Kongju City, Chungnam Province, Korea. The CW was built to treat impacted runoff stream water coming from a 221 ha agricultural area (99% wet paddy fields and 1% dry paddy field). The influent to the CW comes from the agricultural stream flow in the tributaries of Geum River during dry days and stormwater runoff from watershed area during wet days. The CW has a total surface area of 12,705 m^2 and a total storage volume of 11,235 m^3. The design hydraulic retention time (HRT) from the inlet to the outlet is approximately 28 h. The composition, design characteristics and sampling locations of the CW were shown in Fig. 1. The CW was composed of seven cells in series that include a sedimentation zone, deep marsh and shallow marsh. Plant species including *Oenanthe javanica* (OJ), *Acorus calamus* (AC), *Typha orientalis* (TO), *Phragmites australis* (PA) and floating plant (FP) bordered each cell of the CW.

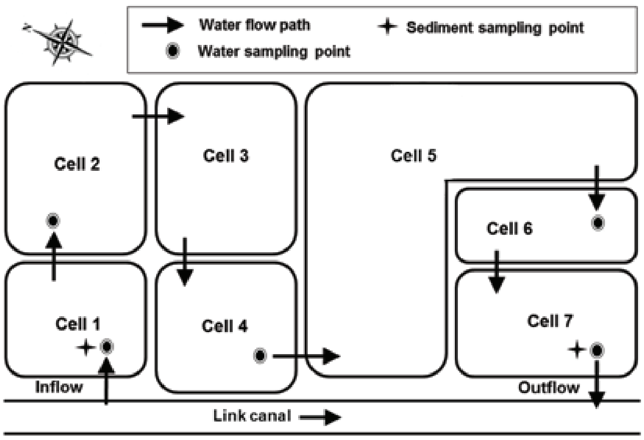
2.2. Monitoring and analyses

2.2.1. Non-algal bloom season monitoring

Water quality, sediment and plant monitoring on the CW during dry days was conducted since October 2009. Water quality samples were collected at five sampling locations in the CW as indicated in Fig. 1. These samples were analyzed for DO, pH and temperature which were all measured *in situ* using portable meters. Samples were then refrigerated after collection and quickly transported to the laboratory for analysis such as total suspended solid (TSS), biochemical oxygen demand (BOD), total nitrogen (TN), total phosphorus (TP) following the standard methods for the examination of water and wastewater [20]. Two sediment samples were also collected using a 5 cm diameter by 50 cm long acryl tube at the inlet and outlet of the CW. Collected sediment samples were analyzed for COD, TN, TP and Organic-P following the standard methods [20]. The plant coverage in the CW was measured and the proportion of plant coverage to surface area of each cell was calculated.

2.2.2. Algal bloom season monitoring

Since 2012, large amounts of algae were seen in the CW that occurred between May (late spring) and October (mid-fall). Various analyses were additionally performed to recognize the causes of algae occurrence and control measures during algal bloom season. The algae species emerging on the CW was investigated by direct observation using a digital microscope. Sediment sample of the paddy field in the upstream was analyzed to realize sediment pollution level of the CW. Sediment sampling points in the upstream was located 100 m away from CW inlet. The element-containing phases of the collected sediment samples were also investigated by direct



	SA (m^2)	SV (m^3)	WD (m)	HRT for DF (hr)	DP
Cell 1	1,168	1,155	0.99	2.9	OJ
Cell 2	1,723	1,484	0.86	3.7	AC, TO, PA
Cell 3	1,863	1,188	0.64	3.0	AC, TO, PA
Cell 4	1,634	929	0.57	2.3	TO, PA
Cell 5	4,811	5,352	1.11	13.5	AC, TO, PA
Cell 6	553	211	0.38	0.5	TO
Cell 7	953	916	0.96	2.3	FP
Total	12,705	11,235	-	28.2	-

SA: Surface area, **SV**: Storage volume, **WD**: Water depth,
HRT: Hydraulic retention time, **DF**: Design flow,
DP: Dominant plant, **OJ**: *Oenanthe javanica*, **AC**: *Acorus calamus*,
TO: *Typha orientalis*, **PA**: *Phragmites australis*,
FP: Floating plant (*Nelumbo nucifera* and *Spirodela polyrhiza*)

Fig. 1. Schematic diagram and design information of the CW (Cell 1 and 7: sedimentation zone, Cell 2 and 5: deep marsh, Cell 3 and 4: shallow and deep marsh, Cell 6: shallow marsh).

observation using scanning electron microscopy (SEM) with energy dispersive x-ray (EDX) analysis. The SEM instrument has a detection limit of ~0.5 weight % for most elements while the EDX system is able to detect elements with atomic number equal to or greater than six. In addition, DO concentration along the depth in the Cell 5 was measured.

2.2.3. Data analysis

Data on precipitation and air temperatures for the site were collected from the Korea Meteorological Administration. All statistical test were performed using SYSTAT 9.0 (Chicago, IL, USA, 2007) and OriginPro 8 SRO v8.0724 (B724) (Northampton, MA, USA, 1991–2007) software package. Physicochemical parameters were compared between each other using one-way ANOVA analysis. Differences were considered significant when p values were < 0.05.

3. Results and discussion

3.1. Precipitation and air temperature

The precipitation and air temperature of the region during monitoring period between January 2009 and December 2013 is shown in the Fig. 2. The climate of the region is monsoon and temperate. During the monitoring period, monthly average temperature ranged from 27.1 to –6.8°C. Temperature trends were consistent with 5-year averages from the CW site with an average maximum temperature of 17.4°C (maximum daily temperature 36.6°C) and average minimum temperature of 7.5°C (minimum daily temperature –18.0°C). Average seasonal temperatures were 11.3°C in spring (from March to May), 24.8°C in summer (from June to August), 13.8°C in fall (from September to November) and –1.5°C in winter (from December to February). The average annual precipitation was 1,326 mm of which more than half (52%) was concentrated during summer with highest temperatures, humidity levels and evaporation rates. On the other hand, only less than 1% of the annual precipitation has occurred during winter.

3.2. Water quality

Fig. 3 shows the water quality changes along the flow path of CW. The data on water quality in algal and non-algal bloom season were separated in the figure which were illustrated by the box plot (non-algal bloom season in 2009–2010 year) and line of average concentration (algal bloom season in 2012–2014 year). Although, no significant reduction was observed in the concentration levels of all parameters in each cell; the effluent was always below the influent levels. In addition, no significant difference in the concentration changes of parameters was observed between the algal and non-algal bloom seasons. The BOD and TSS concentrations increased to peak at Cell 5 and decreased after passing Cell 6 while DO concentration decreased from 10.0 mg/L in the influent to 7.3 mg/L in the inlet of Cell 6 especially during the algal bloom season. It was observed that low plant density was determined between Cell 1 and Cell 5. The presence of open, unshaded water near the outlet of a CW typically promotes seasonal blooms of phytoplanktonic algal species, which results in elevated concentrations of suspended solids and particulate nutrient forms in the effluent [21]. Moreover, a factor including the wind action was linked to a low plant density causing a high resuspension of sediments and sunlight penetration, and consequently an increase in TSS. The occurrence of algae bloom suggests that a lot of algae dead cells would occur in cells which resulted to the decrease the DO level, probably released by the microorganism decomposition. On the other hand, TN and TP concentrations were continuously decreased from inlet to outlet.

The average concentrations of TN and TP as well as the nitrogen to phosphorus ratio (N:P) at three sampling locations (inlet, outlet and algae occurrence point in the CW) during dry and wet days were compared between algal and non-algal bloom season (Table 1). Findings revealed that the TN and TP concentrations in the inlet during wet days were significantly higher by 5 to 7-fold compared to dry days signifying the addition of pollutants from NPS carried by runoff during storm events. Stormwater runoff from agricultural areas can be polluted with organic content, suspended solids, and excess nutrients, and negatively impacted receiving waters resulting in water quality problems such as eutrophication, low DO concentrations, etc., [22, 23]. The algae in the CW was temporarily removed and washed away to the stream by runoff during a storm event. However, after a storm event, the excess concentration of pollutants carried by runoff could possibly cause the occurrence and proliferation

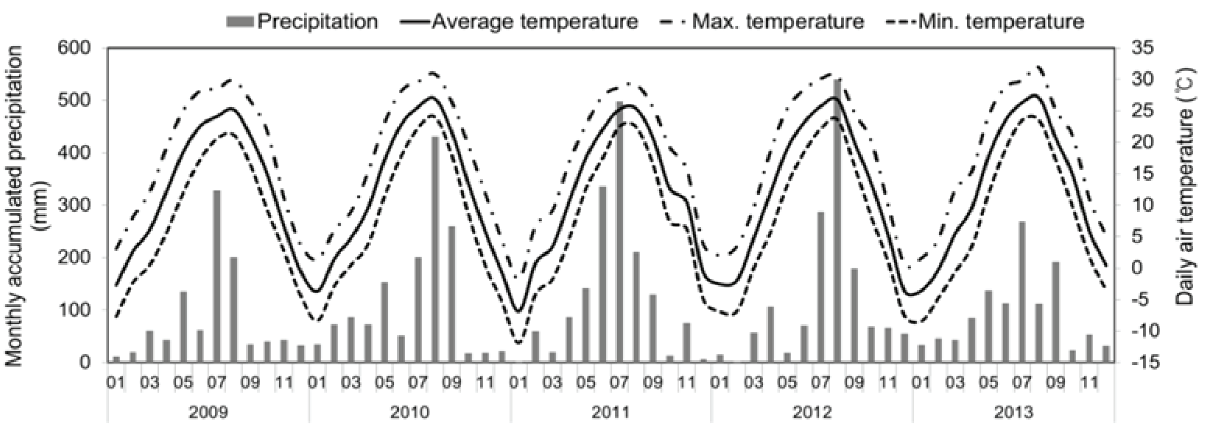


Fig. 2. Precipitation and air temperature characteristics of Kongju city in Korea during monitoring period.

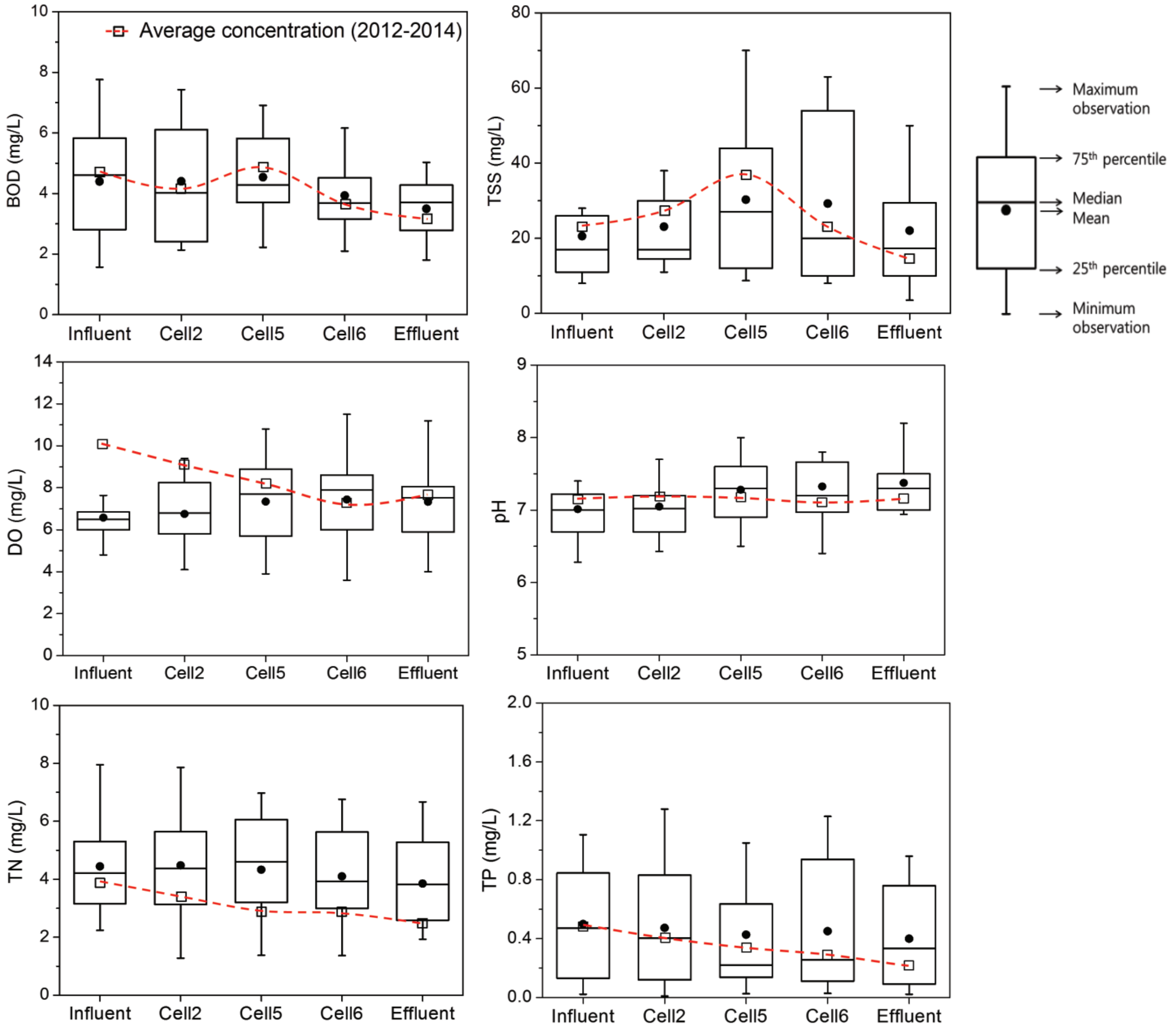


Fig. 3. Water quality changes at each sampling point in the CW during non-algal bloom (2009–2010) and algal bloom season (2012–2014).

Table 1
Comparison of the average TN and TP concentrations, and N:P ratio at various conditions and locations in the CW during algal and non-algal bloom season

Monitoring period	Non-algal bloom (2009–2010) and Algal bloom (2012–2014)						
	Dry day					Wet day	
Sampling point	Inlet	Outlet	Inlet	Outlet	Algae occurrence point	Inlet	Algae occurrence point
TN (mg/L)	4.4	3.9	3.9	2.5	17.0	20.3	21.2
TP (mg/L)	0.5	0.4	0.5	0.2	4.8	3.3	4.6
N:P	8.8	9.8	7.8	12.5	3.5	6.2	4.6

of algae bloom in the unplanted areas in the CW. A healthy wetland can be obtained by providing balanced nutrients. It has been recognized that a system with N:P ratio above 16:1 is generally non-eutrophic and will only experience algal bloom if excess phosphorus becomes available [24, 25]. Comparing the long-term average concentration of TN and TP at various sampling locations, it shows that the N:P ratio in the inlet (7.8 and 8.8 during dry days, and 6.2 during wet days) were lower than outlet values (9.8 and 12.5 during wet days). In general, the N:P ratios obtained were below 16:1 indicating that nitrogen is the limiting factor for controlling the eutrophication in the CW.

3.3. Plant coverage

Fig. 4 shows seasonal changes of plant coverage and average plant coverage of the different plant species at each treatment region during the monitoring period. The plants in the CW reached its maximum growth during the high temperature season in the summer (968.8 m^2) and slowed down sharply during the fall (761.6 m^2) and winter (21.4 m^2) with the decreased in temperature and began again when the temperature increased in the spring. In summer season, high concentrations of nutrients entering a CW during storm events resulted to high plant growth since many of the nutrients are assimilated and stored in the plant. The highest average plant coverage occurred in Cell 6 with 460.8 m^2 (planted with TO) while the lowest coverage occurred in Cell 1 with 13.0 m^2 (plant with TO and OJ). Among the plant species, TO grew very well in the CW because *Typha* spp. like cattails (*Typhaceae*) very often emerges in natural wetlands and displaces native species [26]. Also, PA and FP were observed to have high growth rate.

Fig. 5 shows some photographs of the planted and unplanted zone in the CW during algal bloom season in 2012. The photographs clearly depict the effect of plant coverage on algae growth. It was observed that large amounts of algae were visible from Cell 1 to Cell 5 resulting to only less than 6% proportion of plant coverage to surface area even though in summer season. However, algal bloom was not seen in Cells 6 and 7 with higher proportion of plant coverage to surface area (average value during summer: 100% for Cell 6, 14% for Cell 7). The results indicated that high plant density could possibly prevent algal growth leading to high sunlight penetration. Vegetation is important in CWs in creating better conditions for the algae growth, sedimentation of suspended solids, reducing the risk of erosion and resuspension, and stabilising the soil surface in treatment CWs [7,10].

3.4. Sediments

Fig. 6 shows the chemical characteristics of the sediment at the inlet and outlet of the CW and nearby paddy field between the algal and non-algal bloom season. The average concentrations of TP and org-P in the CW were higher than in the paddy field (TP: 1,208 ± 112 mg/kg, org-P: 468 ± 121 mg/kg); while the COD and TN concentrations in the CW were lower than the paddy field (COD: 58,050 ± 39,051 mg/kg, org-P: 1,288 ± 1,186 mg/kg). The substantial supply of nutrients in the CW from the catchment area during wet days assures a wide variety in the production of transportable organisms and associated dead organic material.

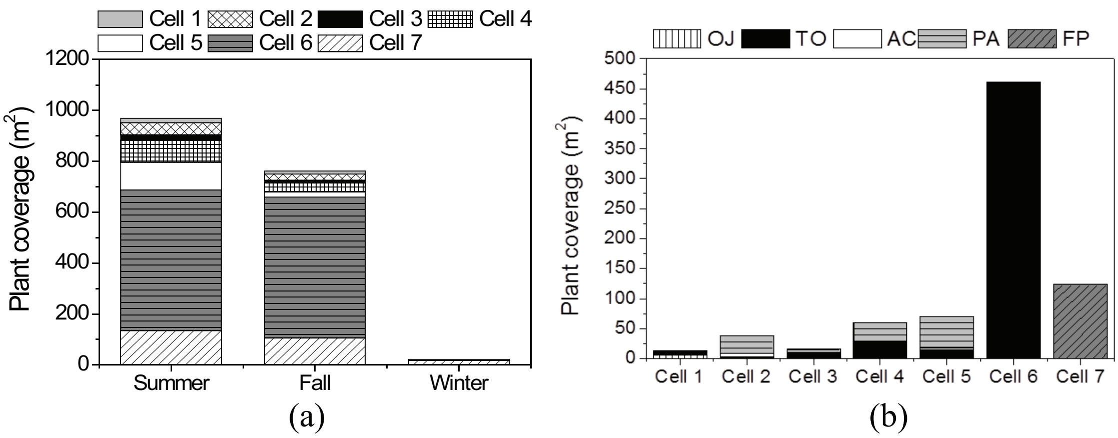


Fig. 4. (a) Seasonal changes of plant coverage and (b) average plant coverage of different plant species at each treatment region of CW.

(a) Unplanted zone (Cell 2) (b) Planted zone (Cell 6) (c) Planted zone (Cell 7)

Fig 5. Photographs of the planted and unplanted cells during algal bloom season in 2012; (a) Unplanted zone (Cell 2), (b) Planted zone (Cell 6), (c) Planted zone (Cell 7).

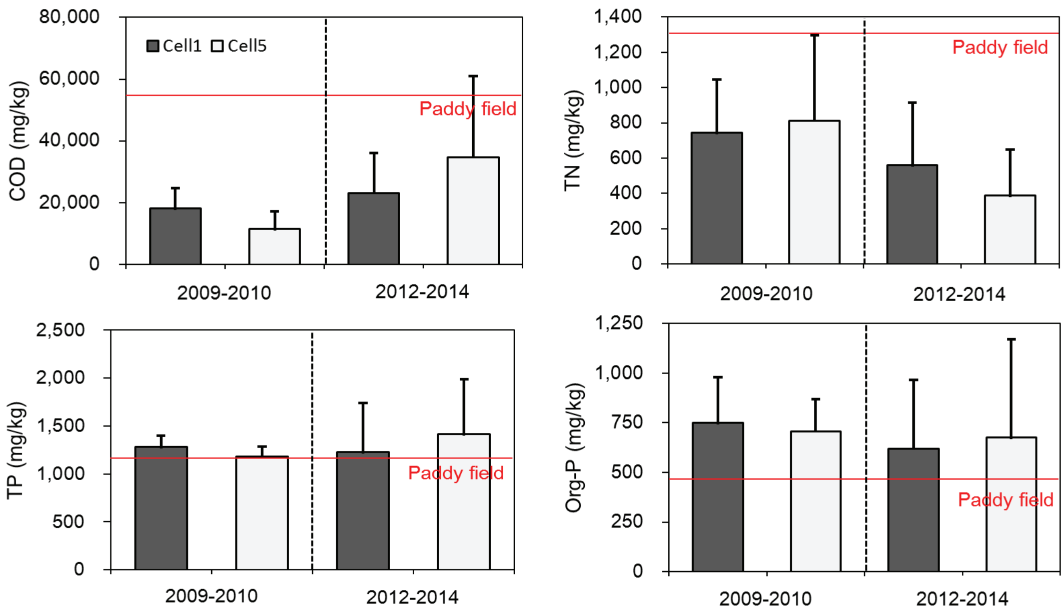


Fig 6. Comparison of the chemical characteristics in the sediment between algal and non-algal bloom season in the CW.

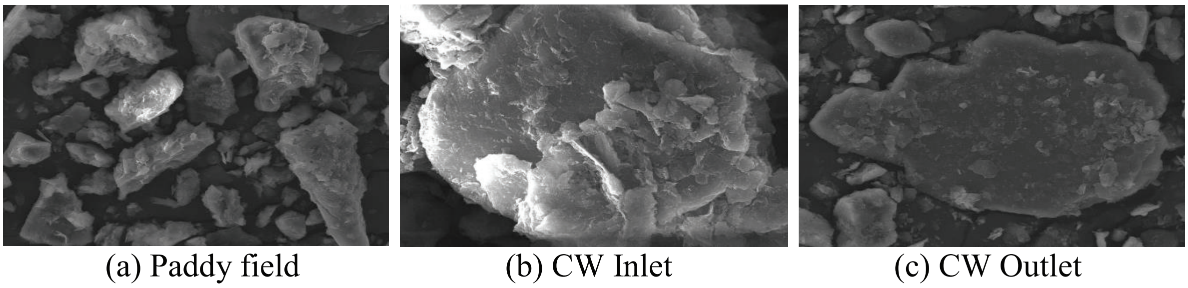


Fig. 7. SEM photographs of the sediment collected at respective sampling locations; (a) Paddy field, (b) CW Inlet, (c) CW Outlet.

The CW is characterized by a high water pollutant content especially chlorophyll and high sediment accumulation. Sediment may release contaminants when environmental conditions such as pH, temperature and DO concentration in the water change [27, 28]. In this study, the DO concentration from 0 to 165 cm depth in Cell 5 decreased along the depth from 6.1 to 0.03 mg/L because of the water temperature changes and organic matters in the water. Therefore, sediment in the CW could release contaminants in high temperature and low DO concentration on the bottom of the CW resulting to algal growth.

SEM and EDX analyses were performed to determine the chemical compositions of sediment useful to know the status of soil pollution by sedimentation and biodegradation. Fig. 7 shows the SEM photographs of the sediment at each sampling locations. Small components were found on the surface area of soil particles in the inlet, greater than in the outlet and paddy field indicating the evidence of adsorption by positively charged particles. However, the negatively charged particles such as NO_3–N and NO_2–N transferred by nitrifies could pass through the pores of soil layer and eventually might affect the groundwater. Findings showed that the main elements in Cell 1 of the CW were oxygen (60%), silica (10%), aluminium (7%) and carbon (5%). In addition, potassium was also observed in the CW due to the chemical fertilizers used in the paddy field.

3.5. Algal bloom control and better design method

Fig. 8 shows the result of the direct observation of *Haematococcus pluvialis* from a digital microscope. *Haematococcus pluvialis* is an ubiquitous green algae of the order volvocales (freshwater species) from the family haematococcaceae in temperate regions around the world. Their resting cysts are often responsible for the blood-red color seen in the bottom of dried out rock pools and bird baths. This color is caused by astaxanthin (red ketocarotenoid) which is believed to protect the resting cysts from the detrimental effect of UV-radiation when exposed to direct sunlight [29]. No toxicity associated with *Haematococcus* has ever been reported in the literature. However, large amounts of algae in the CW pose a negative effect on the landscape, water quality and potential human health problem. When blooms die and decompose rapidly they can use up all the oxygen in the water. Therefore, algal bloom control and better design methods were developed to regulate algae in the CW based on the findings and monitoring experience (Table 2).

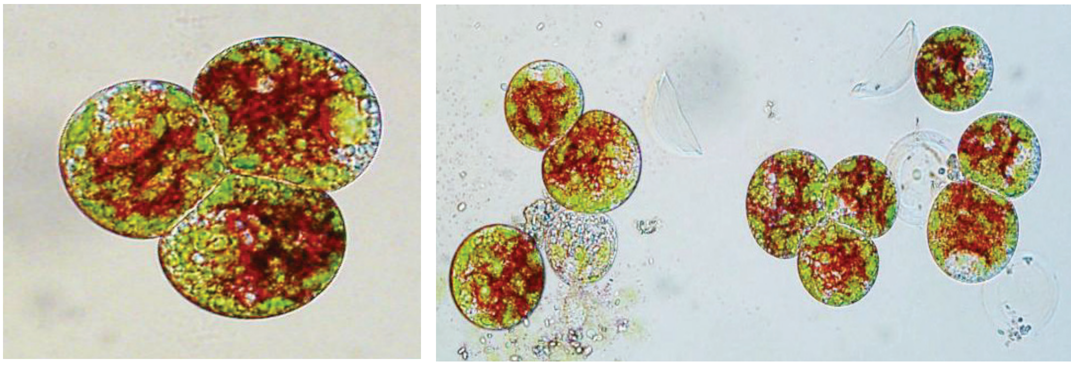


Fig. 8. Microscopic observation of algae species in the CW.

Table 2
Suggested algal bloom control and improved design methods for a CW

Advance control method (before blooming)	Regular monitoring needs for prevention of the bloom Close the flushing from watershed area which can reduce the flow including nutrients If harmful algae was observed during the monitoring, frequently monitor the algal growth
Post control method (after blooming)	In an appropriate time, copper sulfate and red clay should be sprayed to control harmful algae On the surface area, fence should be constructed to prevent the algae diffusion The sediment accumulated at the inlet and outlet areas should be removed
Better design method	Increase plant coverage which can decrease water temperature and reduce the algal photosynthesis – Plant the shrubs in the dead space or nearby outlet area of CW – Make an aquatic plant island and zone of floating leaved plants Induce minimum flow losses – Minimize the dead space in the CW – Channel type is better than pond type – If dead space was appeared after construction, plant the emerged and floating leaved plants in the dead space Increase removal efficiency of contaminants (Improve water quality) – First of all, consider characteristics of contaminants such as particle and organic matter, and nutrients etc. – Plants having a high density and cross sectional areas should be planted nearby the inlet area to remove particle matters – Plants having a high uptake rate should be planted nearby outlet area to remove soluble nitrogen and phosphorus.

4. Conclusions and recommendations

Algal blooms are a public health concern and an ecological problem in wetlands, lakes, rivers, estuaries and oceans. Since 2012, large amounts of algae (*Haematococcus pluvialis*) appeared in the first 5 cells of the CW except the latter two cells prior to the outlet. It was observed that the low proportion of plant coverage to surface area (only less than 6%) possibly cause the algae bloom. The plant is an essential component of a CW that could prevent algal growth leading to high sunlight penetration. A lot of algae dead cells released by the microorganism decomposition were the reasons of low DO levels in the CW. The findings revealed that nutrients were being transported into the CW from the catchment area during wet days with the soluble nutrients degraded by microbial activities in the sediments and released to the water table. Comparing the long-term average concentrations of TN and TP indicated that nitrogen was the limiting factor in controlling the eutrophication in the CW. The SEM and EDX analyses revealed that the high potassium content in the CW was obtained from the chemical fertilizers used in the paddy field. Moreover, the HRT in the CW was also found to be longer than the designed HRT (29 h). Consequently, the algae growing conditions was developed in the CW and based on the monitoring experience, suggestions were provided regarding algae control and better design methods to regulate algae in CWs.

References

[1] WRC (Water and Rivers Commission), Water Facts. Perth, Australia, 1998.

[2] G.A. Moshiri, Constructed Wetlands for Water Quality Improvement, CRC Press: Boca Raton, Florida, 1993, pp. 9–22.

[3] C.C. Tanner, J.S. Clayton, M.P. Upsdell, Effect of loading rate and planting on treatment of daily farm wastewaters in constructed wetlands: removal of nitrogen and phosphorus, Water Res., 29 (1995) 27–34.
[4] J. Vymazal, H. Brix, P.F. Cooper, M.B. Green, R. Haberl, Constructed Wetlands for Wastewater Treatment in Europe, Backhuys Publishers; Lerden, 1998, p. 366.
[5] N. Gottschall, C. Boutin, A. Crolla, C. Kinsley, P. Champagne, The Role of Plants in the Removal of Nutrients at a Constructed Wetland Treating Agricultural (Dairy) Wastewater, Vol. 29, Ecological Engineering: Canada, Ontario, 2007, pp. 154–163.
[6] H. Dong, Z. Qiang, T. Li, H. Jin, W. Chen, Effect of artificial aeration on the performance of vertical-flow constructed wetland treating heavily polluted river water, J. Environ. Sci., 24 (2012) 596–601.
[7] M. Martín, N. Oliver, C. Hernández-Crespo, S. Gargallo, M.C. Regidor, The use of free water surface constructed wetland to treat the eutrophicated waters of lake L'Albufera de Vakencia (Spain). Ecol. Eng., 50 (2013) 52–61.
[8] J.R.P. Aguilar, J.J.P. Cabriales, M.M. Vega, Identification and characterization of sulfur-oxidizing bacteria in an artificial wetland that treats wastewater from a tannery, Int. J. Phytorem., 10 (2008) 359–370.
[9] H. Brix, Functions of macrophytes in constructed wetlands., Water Sci. Technol., 29 (1994) 71–78.
[10] H. Brix, Do macrophytes play a role in constructed treatment wetlands? Water Sci. Technol., 35 (1997) 11–17.
[11] R.S. Jaddhav, S.G. Buchberger, Effects of vegetation on flow through free water surface wetlands, Ecol. Eng., 5 (1995) 481–496.
[12] D.T. Hill, J.D. Payton, Effect of plant fill ratio on water temperature in constructed wetlands, Bioresour. Technol., 71 (2000) 283–289.
[13] S.M. Haslam, Community regulation in Phragmites communis Trin. I. Monodominant stands, J. Ecol., 59 (1971) 65–73.
[14] S.R. Jing, Y.F. Lin, D.Y. Lee, T.W. Wang, Using constructed wetland system to remove solids from highly polluted river water., Water Sci. Technol.: Water Supply, 1 (2001) 89–96.
[15] M. Okada, R. Sudo, Phosphorus uptake and growth of bule-green algae, Microcystis aeruginosa, Biotechnol. Bioeng., 24 (1982) 143–152.
[16] V.W. Proctor, Some controlling factors in the distribution of *Haematococcus Pluvialis*, J. Ecol., 38 (1957) 457–462.
[17] R.T. Lorentz, G.R. Cysewski, Commerical potential for *Haematococcus* microalgae as a natural source of astaxanthin, Trends Biotechnol., 18 (2000) 160–167.
[18] A. Shaish, M.U. Pick, A. Ben-Amotz, Are active oxygen species involved in induction of ß-carotene in Dunaliella bardawil?, Planta, 190 (1993) 363–368.
[19] W.A. Schroeder, E.A. Johnson, Carotenoids protect Phaffia rhodozyma against singlet oxygen damage, J. Ind. Microbiol., 14 (1995) 502–507.
[20] American Public Health Association (APHA), American Water Works Association, and Water Environment Federation (WEF), A.E. Greenberg, L.S. Clesceri, A.D. Eaton (Eds.) Standard Methods for the Examination of Water and Wastewater (18th ed.), APHA, AWWA, WEF: Washington, D.C., 1992.
[21] US EPA (United States Environmental Protection Agency), Constructed Wetlands Treatment of Municipal Wastewater. United States Environmental Protection Agency, EPA/625/R-99/010, U.S.A., 1999.
[22] S.Y. Lee, M.C. Maniquiz, L.H. Kim, Characteristics of contaminants in water and sediment of a constructed wetland treating piggery wastewater effluent, J. Environ. Sci., 22 (2010) 940–945.
[23] M.C. Maniquiz, J.Y. Choi, S.Y. Lee, C.G. Kang, G.S. Yi, L.H. Kim, System design and treatment efficiency of a surface flow constructed wetland receiving runoff impacted stream water, Water Sci. Technol., 65 (2012) 525–532.
[24] N.A. Jaworski, Sources of Nutrients and the Scale of Eutrophication Problems in Estuaries, B.J. Neilson, L.E. Cronin (Eds.) Estuaries and Nutrients, Humana Press: Clifton, N.J., 1981, pp. 83–110.
[25] R.W. Howarth, Nutrient limitation of net primary production in marine ecosystems., Annu. Rev. Ecol., 19 (1988) 89–110.
[26] J. Vymazal, Emergent plants used in free water surface constructed wetlands: a review, Ecol. Eng., 61P (2013) 582–592.
[27] H.L. Golterman, Sediments as a Source of Phosphate for Algal Growth, H.L. Golterman (Ed.), Interactions between Sediments and Freshwater, Dr. W. Junk Publisher: The Hague, 1997, pp. 286–293.
[28] L. Lijklema, The Role of Iron in the Exchange of Phosphate between Water and Sediment, H.L. Golterman (Ed.), Interactions between Sediments and Freshwater, Dr. W. Junk Publisher: The Hague, 1977, pp. 313–317.
[29] J.R. Dore, G.R. Cysewski, *Haematococcus* Algae Meal as a Source of Natural Astaxanthin for Aquaculture Feeds, Cyanotech Corporation: Hawaii, 2003.