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Artificial floating islands for water quality improvement

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1 **Artificial floating islands for water quality improvement**

2 **Yueya Chang, He Cui, Minsheng Huang, Yan He**

3 **Abstract:** Artificial floating islands (AFIs) are variation of wetland treatment systems for water
4 quality improvement. This paper provides a review concerning AFIs in terms of their development,
5 classification and applications in the removal of nutrients, heavy metals and chemical oxygen
6 demand (COD) on waterways. The role of microorganisms, aquatic plants and aquatic animals in
7 AFIs for water decontamination and purification was also discussed. Additionally, some key
8 factors influencing the AFIs' performances were discussed and comparisons between AFIs and
9 constructed wetlands were reviewed. Finally, further perspectives of artificial floating islands were
10 identified to possibly improve their performances. The understanding of the mechanisms in AFIs
11 that drive removal of various contaminants to improve water quality is crucial, which were also
12 highlighted in this paper.

13 **Key words:** artificial floating islands; applications; factors; constructed wetlands; performances

14 **1. Introduction**

15 **1.1 Definition**

16 Artificial floating islands (AFIs) are constructed with three layers, namely, the upper leaf and
17 the stem of plants, the middle floating body and the bottom root system including the related
18 ecological communities such as algae, biofilms, zooplankton, and other small invertebrates.
19 Beneath the bottom layer exists a free-water zone (or water column) whose depth varies with the
20 water level of the water body. A layer of organic sludge develops under the free-water zone over

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the native subsurface material. Fig. 1, as adopted from Harding (2009), shows a schematic drawing of a typical natural floating island consisting of a thick floating organic mat that supports the growth of plants.

1.2 History

The first ecological floating island was believed to be developed in Europe for the riparian ecosystem, rather than for the water quality purification. Until the 1980s, the first artificial floating island was built by Germans to remove silver, cobalt and strontium from polluted waters using water hyacinth (*Eichhornia crassipes*) and alligator weeds (*Alternanthera philoxeroides*) (Wolverton and McDonald, 1975). Constructed floating islands were developed in Japan in the 1990s, with *Canna generalis* being grown in floating beds to absorb nutrients from fish ponds and treatment basins (Wu et al., 2000). Twenty percent coverage of soil-less artificial floating islands, again using *Canna generalis*, was later recommended to improve water quality in China (Bing and Chen, 2001).

Traditional floating islands mainly depend on plant uptake and microbial metabolism for the removal of pollutants. While limited by the aquatic plant quantity, the plant root surface area and microbial species associated with the root, the removal efficiencies of chemical oxygen demand (COD) and other pollutants are relatively low. Subsequently, some scholars combined various auxiliary technologies with traditional floating islands to enhance the purification capacity that lead to the formation of some new types of ecological floating islands.

In China, Li et al. (2009) found that a micro-aerated floating island can remove the pollutants by 70% under the condition of inflow 6000~10000 m³/d and total aeration 50 m³/h. Zhang et al. (2011) treated rural sewage containing initial concentrations of COD of 161.58 mg L⁻¹, total

nitrogen (TN) 40.31 mg L^{-1} and total phosphorus (TP) 2.68 mg L^{-1} , using the combined biological purification tank-enhanced ecological floating raft system that effectively removed COD, TN and TP by 79.59%, 61.06% and 77.14%, respectively. Wang et al. (2012) integrated aquatic plants (*Ipomoea aquatica*), filter-feeding aquatic animals (*Hyriopsis cumingii*) and artificial medium to treat the lake water, where the aquatic animal and artificial medium enhanced the system removal ability significantly by removing TN, TP, and COD.

1.3 Classification

As mentioned above, the traditional floating islands have been developed over the past 30 years, and we can classify the AFIs into three technologies:

1.3.1 Traditional plant floating island technology

Traditional plant floating islands, which are composed of higher aquatic plants and a polymer material carrier, which uptake nitrogen (N), phosphorus (P) and other organic compounds in polluted water into parts of the plants. This kind of traditional floating islands can remove the nutrients to some extent, but the efficiency is low. For example, Chen et al. (2010) cultivated *Ipomoea aquatica* on a traditional artificial floating island to treat intensive aquaculture ponds with twenty percent of coverage. During the 90 days of the experiment, the concentrations of TN and TP were reduced from 8.00 mg L^{-1} to 5.08 mg L^{-1} and 0.51 mg L^{-1} to 0.28 mg L^{-1} , respectively, using this technology, while 52.35 kg hm^{-2} of TN and 5.39 of TP were removed with the harvest of *Ipomoea aquatica*. However, this removal rate was lower compared to other technologies. Based on the traditional floating island design, Xu et al. (2011) connected three floating islands units with three different plant species, and constructed a staged floating treating wetland (SFTW) to treat malodorous water of an industrial river in Shanghai, where the *Hydrocotyle vulgaris* unit

65 removed the most phosphorus.

66 1.3.2 Complex floating island technology

67 The complex floating island is a new technology compared to traditional floating islands. It
68 adds “fixed biofilms” or “biocords” as substrates that support the fixed films to purify water
69 through plant absorption, substrate adsorption and microbial association. Complex floating island
70 technology can be separated into two kinds, the combined type and the strengthening type. The
71 combined type increases the artificial medium and aquatic animals to prolong the food chain to
72 form the “plant-aquatic animal-microbe” ecological restoration system for improving the water
73 purification. For example, Xu et al. (2015) established a combined ecological floating bed by
74 hanging the bio-ceramic matrix under the roots of *Pistia stratiotes* in a pond to treat aquaculture
75 wastewater. As a result of the synergism of plant absorption, matrix adsorption and
76 microorganisms, the removal rates of TN, ammonia nitrogen ($\text{NH}_4^+\text{-N}$), nitrite nitrogen ($\text{NO}_2^-\text{-N}$),
77 TP, COD were 52.38%, 77.78%, 81.97%, 67.57% and 43.98%, respectively. The enhancing type
78 is a new type which adds aeration systems or some specific bacteria. For example, Cui and Hu
79 (2012) treated WWTP effluent under aeration conditions of dissolved oxygen (DO) of 4.8 mg/L,
80 hydraulic retention time of 1.5 days and water temperature (WT) of 17.8-21.5°C. The removal
81 rates of COD, TN, and TP were 44.0%, 44.9% and 50.97%, respectively. In addition, the effluent
82 COD concentration was much lower than the first level A criteria of ‘Discharge standard of
83 pollutants for municipal water treatment plant’ (GB18918-2002). For example, Li et al. (2009)
84 designed a biological grid device consisting of loaches (*Misgurnus anguillicaudatus*), *Canna*
85 plants, biofilms from microorganisms and combined packing to treat polluted river water. The size
86 of the device was 1000 mm×500 mm×600 mm, and loaches (*Misgurnus anguillicaudatus*) were

put randomly in the device with the density of 1200 g m^{-3} . The loach (*Misgurnus anguillicaudatus*) excretes special enzymes to decompose special organic substances and increase oxygen supply, and the removal rates of $\text{NH}_4^+\text{-N}$ and TP were 50.7% and 82.35%, respectively.

1.3.3 Moveable floating island-wetland technology

The moveable floating island-wetland is a combination of wetland and moveable floating island (Zhang et al., 2012). It is a technology based on “matrix filler + ecological bed”. In general, it often combines five parts of devices, namely, buoyancy control device, anchoring device, macrophytes bed, microbial bed and aeration device. Hu et al. (2008) selected ceramisites and hydrophilic miner fiber as support materials, *Festuca arundinacea* as plants to construct a moveable floating island-wetland to treat severely eutrophicated water bodies. During the 34 days of the experiment, the system showed good removal efficiencies, and there was strong nitrification-denitrification in the system. Meanwhile, Shi et al. (2014) also constructed a hybrid system combining plants and rice straw to remove 97.2%, 95.4% and 56.1% of $\text{NH}_4^+\text{-N}$, TN and TP, respectively.

The AFI has a variety of aliases depending on its scale, complexity, or the preference of those who name it, which includes artificial floating beds/wetlands, floating treatment wetland (FTW), floating plant bed system, integrated floating system, integrated ecological floating bed (IEFB), and so on. For the purpose of this review, however, the authors continue to use the term “artificial floating island (AFI)”. Other names will be used only when called for by the reviewed subjects (Naichia et al., 2015).

2. Applications of AFIs and influence factors

To date, water pollution is one of the most critical environmental issues, with human

activities adding different types of contaminants (Palma et al., 2010). For example, agricultural practices are altering water resources as a result of the massive use of fertilizers, pesticides and the spread of livestock wastes (Huo et al., 2009; Wu et al., 2013). Also industries release large quantities of heavy metals, organic matters and toxic chemicals to aquatic environments (Islam et al., 2015). As reported, up to 66% and 22% of lakes in China are eutrophic or hyper eutrophic, respectively (Jin and Hu, 2003).

Nitrogen and phosphorus are the two major nutrients affecting water eutrophication, the heavy metals released into the rivers can be dissolved to form ions or complexes, suspending as particulate matters or settling down as bed sediments resulted in the loss of water quality, and some toxic chemicals in water bodies threat aquatic animals or human beings greatly (Tuna et al., 2007; Stiling, 2011). AFI has been applied in many such fields, which will be discussed with the influence factors comprehensively, as there is no published paper available at present introducing influence factors of AFI in various applications. These should be considered carefully, thus, many insights can be gained into the influence factors and applications of AFI.

2.1 Nutrient removal and the influence factors

The main applications of AFI for nutrient removal strategies are mainly involved in the following:

- Rivers and storm waters (e.g., Sun et al., 2009; Lu et al., 2010; Li et al., 2010; Borne et al., 2014; Jeanette et al., 2015;)
- Industrial wastewater treatment (e.g., Hubbard et al. 2011; Chang et al., 2014)
- Livestock effluents (e.g., Hubbard et al., 2004; Nahlik and Mitsch, 2006)
- Aqua-culture and agriculture (e.g., Nduwimana et al., 2007; Li and Li, 2009)

Macrophytes have been widely applied in AFIs to remove nutrients as oxygen secreted by plant roots can form many anaerobic–anoxic–oxic micro areas; the situation is equivalent to many series–parallel A²/O units. These units can enhance the function of microbial nitrification and denitrification and improve nitrogen removal efficiency indirectly. In short, the combination of plants and microbes will enhance the effect of denitrification. Microbial nitrification and denitrification were the main nitrogen removal routes. Like nitrogen, phosphorus is a necessary nutrient for biological growth. However, phosphorus removal in AFIs is not as efficient as it is for biochemical oxygen demand or total suspended solids because removal processes, such as plant uptake, assimilation by microorganisms, adsorption and precipitation, are usually of minor significance (Wang et al., 2016).

The factors influencing AFI results, such as physiochemical, biological and other factors, are shown in detail below.

2.1.1 Physiochemical conditions

DO, WT, and pH are critical physiochemical conditions for an AFI operation. The higher DO would decrease the denitrification, while the lower DO can kill aquatic animals, and the WT affects the activities of bacteria, plants and aquatic animals. pH should be controlled in the range of 6.5–8.5, and WT should be between 15 and 28 °C. As these physiochemical factors can influence many physical, chemical and biological processes in the water body, DO should be controlled according to the removal goal, to remove N only, or to remove other pollutants together (Vymazal, 2007; Luo et al., 2010). For example, Li et al. (2009) developed a micro-aerated AFI with *Oenanthe javanica* and controlled the pH=6.49–8.37, WT=12.9–20.1 °C, DO<0.5 ml/L to remove the high concentration of NH₄⁺-N in black river water. Chen et al. (2010) planted *Ipomoea*

153 *aquatica* at 20% coverage with floating rafts and reared some fish in an aquaculture pond. In order
154 to receive a good removal of N, P, and COD, the pH=7.2~7.8 and DO=7.05~8.04 were controlled.

155 2.1.2 Island coverage

156 Island coverage is an extremely important factor, as floating islands can restrict oxygen
157 diffusion from the air into the water (Smith and Kalin, 2000). High cover (>50%) can cause
158 anoxia, while low cover (9 to 18%) may produce little additional treatment effect (Winston et al.,
159 2013). Usually, when the floating islands occupied 50% or more of the surface water area, the
160 reduction in treatment efficiency due to anoxia was found in several studies (Borne et al., 2014).
161 For example, an almost complete coverage by islands resulted in poor P retention in sediments due
162 to anoxia. Low % island cover had detrimental effects on treatment efficiency. TN removal was 48%
163 with 9% island cover in the Winston et al. (2013) study, but this increased to 88% TN removal
164 with 18% cover. Similarly, Chang et al. (2013) found only 14% TP removal with 9% cover during
165 storms, but outside of storm flows, this removal increased to 47%. Around 20% cover seems
166 optimal if the basin is to be maintained as an aerobic system without artificial aeration, and still
167 achieve good removal efficiency. Beyond this point, it is probably worth using 100% cover, with a
168 choice between a high nitrate removal anaerobic basins.

169 2.1.3 Macrophytes

170 Macrophytes offer a natural *in situ* system with relatively easy maintenance for AFIs.
171 Mechanisms involved in nutrient removal by aquatic macrophytes include incorporation of such
172 macrophytes into their own system or storage in tissues (Wang et al., 2009). Plant species in AFI
173 systems have different removal capacities of pollutants due to their specific biological properties
174 such as uptake efficiencies for nutrients, growth rate and root types. Therefore, AFI systems

175 vegetated with different aquatic species may show a great difference in the removal performance
176 of pollutants. For example, Zhang et al. (2014) found that microcosms planted with *Scirpus*
177 *validus* exhibited the greatest removal of TN, and those planted with *Canna generalis* showed a
178 large removal of nitrate nitrogen. In the research on AFI's purification in intensive aquaculture
179 ponds, water spinach (*Ipomoea aquatica*) floating bed had the highest direct absorption rates of
180 TN and TP; over 100 days, these were 52.35 and 5.39 kg hm⁻² a⁻¹, respectively (Chen et al., 2010).
181 Thus, *Canna* demonstrated a useful plant for sewage treatment, with its highest removal rates of N
182 and P were 130 and 23 kg hm⁻² a⁻¹, respectively (Li et al., 2011). If the AFI was made up of
183 *Canna* and other plants, its removal rates of nitrogen and phosphorus would be much better, and
184 could reach 314.6 and 156 kg hm⁻² a⁻¹ (Zheng et al., 2013). We can conclude that *Canna* had the
185 greater capacities to remove nitrogen and phosphorus from the wastewater than other macrophytes.
186 However, to receive good removal efficiencies, the plants screened should also be based on the
187 longer lifetime, higher capacities of nutrients, and should be easy to harvest.

188 Meanwhile, planting density is also an important factor. High density of plants may increase
189 the removal rate, while the chlorophyll content of plants may decrease (Li et al., 2011). The best
190 density should depend on the plant species and the remediation goal. Li et al. (2011) planted
191 *Ipomoea aquatica* in eutrophied waters, and soluble protein content was higher and chlorophyll
192 content was low under high plant density. They reported very dense growth of *Ipomoea aquatica*
193 with 66 plants per floating bed in the area of 2 m². In winter, under low temperature 8.5~10.5℃,
194 the density of 6 pots of *Oenanthe javanica*/(0.08 m²) of floating bed with 44.5% coverage had the
195 highest TN removal rate of 77.0%, while the density of 10 pots/(0.08 m²) had the best TP removal
196 rate of 92.6%. However, *Oenanthe javanica* should be harvested in a timely fashion as it could

197 affect the water purification (Xiang and Peng, 2015).

198 Harvesting is essential for AFIs, although it can help with permanent removal of nutrients, but
199 removal rates are typically low. The other reason is that, although shoot biomass tends to be larger
200 than root biomass, there is generally more N and P stored in the roots than in the shoots, especially
201 when autumn approaches (Winston et al., 2013). N is predominantly taken up by plants in the
202 form of ammonia, but also as nitrate, while much of this is returned to the system when tissues
203 senesce.

204 2.1.4 Biofilm bacteria

205 Biofilm bacteria are fixed mainly on the fiber fillers and plant roots in enhanced AFIs. An
206 enhanced AFI is a type of ecological restoration strengthening device, composed mainly of
207 microbial carrier packings and aquatic plants. The device uses the synergy of aquatic plants and
208 microbes to complete the function of ecological restoration. At the same time, the biofilm bacteria
209 can provide food for aquatic animals. The bacterial abundance was different with the change of
210 WT, pollutant concentration, bacteria metabolic activities and growth of plants. Stewart et al.
211 (2008) studied the microorganisms in municipal wastewater and the removal performances of
212 ammonium and nitrate in floating islands without plant species, indicating that the floating islands
213 with microorganisms had higher removals of both ammonium and nitrate than those without
214 microorganisms. Sun et al. (2009) confirmed that the removal efficiency of nitrogen was greatly
215 enhanced by adding the immobilized denitrifiers into water of floating islands. An enhanced AFI
216 device vegetated with *Canna* was used to treat a eutrophic lake with hydraulic retention time
217 efficiently within 4 days, where the bacteria were mainly attached on the fiber filling rather than
218 the root surface, and the codominant species attaching to the filling and plant was

219 *Nitrosomonadaceae* (Wu et al. 2016).

220 **2.1.5 Aquatic animals**

221 The introduction of aquatic animals can extend the food chain of floating-bed systems, and
222 promote the dissociation of organic nitrogen and phosphorus compounds. It improves the
223 biodegradability of particulate organic matters through the physiological activity of aquatic
224 animals including filter-feeding, digestion and excretion, which meliorate the substrate-supplying
225 condition for both plant absorption and biodegradation, resulting in an enhancement of the
226 purification performance of AFI (Li et al., 2010). Nutrient removal from aquaculture effluent
227 using floating islands (17% cover) planted with the aquatic *Ipomoea aquatica* was examined.
228 Aeration was supplied for 1 hour at 6:00 AM every morning and the pond was populated with
229 *Aristichthys nobilis* (silver carp), *Siniperca chuatsi* (mandarin fish; carnivorous) and *Carassius*
230 *auratus gibelio* (crucian carp). Around 34% of the TN and 18% of the TP was removed from the
231 system, and of this around one third (34%) of TP and TN were removed by fish (Li and Li, 2009).
232 Kania (2014, unpublished) also suggested sustainable growth of fish facilitated by AFI
233 significantly increases fish biomass that can be harvested from the waterway. Fish harvesting
234 enables P removal from the effluent with fish being made into meal, which can be used for pork or
235 poultry farming or in pet food. However, there must be no toxins or toxic metal contaminants in
236 the effluent, especially contaminants that may bioaccumulate. Also, if it is to be sold for human
237 consumption, the fish need to be cooked well, since there is the potential for contamination by
238 pathogens.

239 **2.2 Heavy metals removal and the influence factors**

240 Removal and accumulation of various heavy metals by AFIs were shown below in a number

241 of studies, including those cited below:

- 242 ● Rivers and storm waters (e.g., [Dushenkov et al., 1995](#); [Agunbiade et al., 2009](#); [Vesely et al.,](#)
243 [2011](#); [Chris et al., 2011](#); [Zhao et al., 2012](#))
- 244 ● Industrial wastewater treatment (e.g., [Deng et al., 2004](#); [Rai, 2009](#); [Hegazy et al., 2011](#); [Yadav](#)
245 [et al., 2011](#))

246 2.2.1 Macrophytes

247 Noticeably, macrophytes are known to differ widely in their absorption of heavy metals
248 depending on species. Mechanisms involved in metal removal by aquatic macrophytes are surface
249 adsorption and/or absorption and its incorporation into their own system or storage in tissues
250 in bound form. For example, Zhao et al. ([2012](#)) selected nine plants growing on an integrated AFI
251 to remove nutrients and heavy metals in a river, and found that the top three plants regarding Mg
252 content were frogbit (*Hydrocharis dubia*), water hyacinth (*Eichhirnia crasslpes*) and water lettuce
253 (*Pisitia stratiotes*) within the range of 3.5–4.6 g kg⁻¹, the plants with the top Fe content were
254 pickerelweed (*Pontederia cordata*), frogbit (*Hydrocharis dubia*) and water dragon (*Jussiaea*
255 *reppens*) within the range of 1.0–1.8 g kg⁻¹, and the top Mn contents were water dragon (*Jussiaea*
256 *reppens*), pennywort (*Hydrocotyle verticillata*) and pickerelweed (*Pontederia cordata*) among
257 6.7–3.6 g kg⁻¹, respectively. For Zn, the top three were water hyacinth (*Eichhirnia crasslpes*),
258 pickerelweed (*Pontederia cordata*) and pennywort (*Hydrocotyle verticillata*) with a range of
259 0.12–0.17 g kg⁻¹. The accumulation of trace elements in the tested plants was in the order of
260 Cu>Pb>Cr>As. Similarly, Dong et al. ([2014](#)) found that the accumulation of trace elements in the
261 nine tested plants was in the order of Cu>Pb>Cd growing in an AFI. The maximum Cu content of
262 pickerelweed (*Pontederia cordata*) was 248.23±6.19 mg kg⁻¹, and the plants with top Cd content

263 within the range of 3.96–5.61 g kg⁻¹ were umbrella plant (*Cyperus alternifolius*) and pickerelweed
264 (*Pontederia cordata*). Pickerelweed (*Pontederia cordata*) was the macrophyte that removed the
265 highest concentration of heavy metals and its root accumulated the highest amount of heavy
266 metals.

267 2.2.2 Aeration

268 Aeration, as a controlling factor, is becoming more and more important, especially with
269 micro-aeration. Overall, and different from nutrient removal mentioned above (100% island cover
270 of no aeration with a choice between a high nitrate removal anaerobic basin), micro-aeration is a
271 very good choice for heavy metals removal. Aeration rate is controlled based on the initial
272 concentration of heavy metals and their species. For example, different aeration rates have a
273 certain ability to remove the Cr⁶⁺ in the sewage the concentration of 0.5 mg L⁻¹: 7.5 L min⁻¹>10 L
274 min⁻¹>5 L min⁻¹>2.5 L min⁻¹>0 L min⁻¹. The pH of the influent was 7.1, and the WT was 11.5°, at
275 the end of the experiment within 30 days, the final removal rates of the 0 L min⁻¹, 2.5 L min⁻¹, 5 L
276 min⁻¹, 7.5 L min⁻¹ and 10 L min⁻¹ of the AFI reached 61.28%, 68.24%, 74.58%, 78.52% and
277 75.68%, respectively (Wu, 2015). Meanwhile, Chen et al. (2014) compared the removal efficiency
278 of Cu²⁺ by a micro-aeration floating bed (aeration ratio=2 L min⁻¹), a combined floating bed and a
279 traditional floating bed. The sewage initial concentration of Cu²⁺ was 1.24 mg L⁻¹, after the 30
280 days experiment, the final removal rates of micro-aeration floating bed, combined floating bed,
281 and traditional floating bed reached 87.21%, 69.21%, and 59.82%, respectively. The fast removal
282 efficiency was within the first week.

283 2.2.3 Endophytic bacteria

284 Plant-associated bacteria isolated from the rhizoplane and phyllo plane surfaces are known as

285 epiphytes, whereas those isolated from the interior of tissues, which they inhabit without causing
286 harm to the host, are called endophytes, with some bacterial populations fluctuating between
287 endophytic and epiphytic colonization (Compant et al., 2010). Rhizobacteria are the most studied
288 plant-associated bacteria and are often found to have beneficial effects on plant growth, e.g., via
289 the provision of essential elements, inhibition of colonization by pathogenic microorganisms, or
290 by helping the plant to overcome stress responses to environmental insults (Afzal et al., 2014).
291 Further, certain endophytes are heavy metal hyperaccumulators, which can endure high
292 concentrations of certain heavy metals, might have a distinct cell wall containing major functional
293 groups because of their special growing environment, and are expected to be promising
294 biosorbents (El-Deeb et al., 2012). For example, Guo et al. (2010) carried out experiments on
295 endophytic bacteria *Bacillus* sp. L14 (EBL14) isolated from the Cd hyperaccumulator *Solanum*
296 *nigrum* L. The bioremediation potential of EBL14 was observed in the presence of Cu^{2+} , Cd^{2+} , and
297 Pb^{2+} at a concentration of 10 mg/L. Within 24 hours of incubation, EBL14 could specifically
298 uptake 75.78, 80.48, and 21.25 % of Cd^{2+} , Pb^{2+} , and Cu^{2+} , respectively. In another study, from the
299 same Cd hyperaccumulator *S. nigrum* L. plant, *Microsphaeropsis* sp. LSE 10 was isolated by Xiao
300 et al. (2010) for biosorption of Cd^{2+} , where the maximum biosorption capacity was 247.5 mg/g.

301 2.3 COD removal and the influence factors

302 The main applications of AFI in COD removal are mainly involved in the following:

- 303 ● Rivers and storm waters (e.g., Ladislav et al., 2013; Huang et al., 2013)
- 304 ● Industrial wastewater treatment (e.g., Bankston et al., 2002; Bokare et al., 2010)
- 305 ● Livestock effluents (e.g., Hubbard et al., 2004; Nahlik and Mitsch, 2006)

306 Here, the chemical constituents of COD can, at time, be a mixture of compounds, which

could be less or more toxic. Many researchers have found that the roots of aquatic plants in AFIs provide a space for microorganisms to grow on the plant stems and root surfaces, which can improve the removal of more toxic chemicals (Watson et al., 1989; Brix and Schierup, 1990; Tanner, 2001; Sooknah and Wilkie, 2004). More toxic chemicals usually come from industrial effluents. For example, triclosan (TCS) is widely used in products such as antiseptic soaps, toothpastes, fabrics, and plastics as a broad-spectrum antibacterial and antifungal agent (Bokare et al., 2010). Another chemical, trichloroethylene (TCE), is also a nonflammable, colorless liquid mainly used as a solvent to remove grease from metal parts (Bankston et al., 2002). Less toxic chemicals consist of normal suspended organic matters, and can be easily adsorbed and intercepted in biological grid devices and degraded by microorganisms. For example, in plant–bacteria associations, bacteria are capable of contributing toward overall pollutant removal by degrading complex organic pollutants from 3.5% to 70.6%, with an inflow concentration of 55–99 mg/L (Wu et al., 2016).

2.3.1 Endophytic bacteria

The efficiency of AFIs can be improved by the use of certain pollutant-degrading bacteria (Newman and Reynolds, 2005; Weyens et al., 2013; Shehzadi et al., 2014; Ijaz et al., 2015). For example, Ijaz et al. (2015) studied the inoculation of three endophytic bacterial strains on the detoxification of sewage effluents in AFIs vegetated with *Brachiaria mutica*. The inoculated bacteria showed persistence in water as well as colonization in the root and shoot of the plant, and can be discharged in the environment without any environmental risks. Sun et al. (2009) also reported bacterially assisted *Canna*-carrying AFIs in sewage treatment. These studies provide useful evidences of endophyte-assisted AFIs to be a sustainable and affordable approach for in situ

329 remediation of sewage effluents.

330 2.3.2 Macrophytes

331 The macrophytes and their rhizospheres may play important roles during phytoremediation.
332 For example, Huang et al. (2013) demonstrated the clear potential of floating bed
333 phytoremediation techniques by cultured *Sesuvium portulacastrum* for reducing organic pollution
334 degree in brackish environment of the polluted Yundang Lagoon (southeastern China). The
335 floating bed experiment for phenol removal was carried out by Wang et al. (2015) and confirmed
336 for phenol removal, the optimum conditions of *Polygonum orientale* were to have a 5 mg L⁻¹
337 initial phenol concentration, 100% daylight, and a 12-day treatment time. The optimum conditions
338 for *Canna indica* to remove phenol had a 2.5 mg L⁻¹ initial phenol concentration, 100% daylight,
339 and a 30-day treatment time. Meanwhile, 1 mg L⁻¹ initial phenol concentration, 100% daylight,
340 and a 16-day treatment time were the optimum conditions of *Phragmites australis* for phenol
341 removal. For the removal of phenol, phenol concentration, light condition, and treatment time are
342 three factors that had different impacts.

343 3. Comparison between constructed wetlands and AFIs

344 AFIs and constructed wetlands both have been acknowledged to contribute to the aesthetic
345 quality of an area. However, there are advantages and possible problems when AFIs and
346 constructed wetlands are compared (Wu et al., 2015; Ibekwe et al., 2016; Hu et al., 2016).

347 3.1 Advantages and possible problems of AFIs

348 AFIs are affordable methods of remediating wastewater as they do not require specifically
349 designed experimental fields or instrumentations, which may save up to 80% of process energy
350 and 50% of material input (Luederitz et al., 2001). Being a process based on the natural

351 remediating power of plants and their associated microbes harbored on floating mats, AFIs are
352 also sustainable and environment-friendly as they can provide long-term remediation and pollutant
353 degradation with minimal environmental intervention. Other advantages of AFIs are their
354 capability to cope with variations in water levels, their esthetic values, and provisions of habitats
355 for invertebrates, fish, and birds ([Keizer-Vlek et al., 2014](#)).

356 However, certain efficient water purification plants can be dangerous to the innate ecosystem
357 when introduced to the areas outside their native distribution areas ([Vera et al., 2010](#)). Improperly
358 chosen and managed AFIs could cause undesirable influences on the local agriculture, aquaculture,
359 and biodiversity due to invasive species. Further, the decayed, long soaked floating materials can
360 also become a source of pollution ([Yeh et al., 2015](#)).

361 **3.2 Advantages and possible problems of constructed wetlands**

362 Constructed wetlands (CWs) have been widely employed since their first full-scale
363 application in the late 1960s. Being similar to AFIs, CWs have extensively been applied to treat
364 domestic sewages, agricultural wastewaters, industrial effluents, mine drainages, landfill leachates,
365 urban runoffs, and polluted river waters in the last several decades because of their low-cost,
366 easy-operation/maintenance ([Wu et al., 2015](#)).

367 However, CWs also have some intrinsic drawbacks that can limit their applications and
368 long-term stabilities. Among them, substrate clogging is the biggest concern especially when CWs
369 are used in wastewater treatment with high organic and suspended solid loading rates ([Ruiz et al.,](#)
370 [2010](#)). Moreover, CWs sometimes have low nitrogen removal efficiencies; they may be
371 nitrification limited as a result of low oxygen transfer or denitrification limited due to low
372 amounts of available organics ([Wu et al., 2014](#)), especially under high nitrogen loading rates.

373 Furthermore, some recalcitrant pollutants and heavy metals in industrial wastewater also present
374 challenges to the performance of CWs ([Melián et al., 2008](#)).

375 **4. Discussion and conclusions**

376 AFI is an innovative variant of wetlands, aquatic or terrestrial plants, growing in a hydroponic
377 manner with buoyant frames floating on the surface of water bodies. Factors such as plant species,
378 microbes, and physiochemical conditions are crucial for AFI operation to achieve sustainable
379 treatment performances. Considering the successful and sustainable application of AFIs and
380 constructed wetlands, the advantages and possible problems of AFIs and constructed wetlands are
381 compared.

382 However, with the deteriorating environment and stringent discharge standards, including the
383 emphasis on effluent reuse, AFI systems operating as stand-alone technologies are, in some cases,
384 unable to meet the requirements of new guidelines despite of improvements in design and
385 operational strategies and the utilization of intensified systems such as flow direction reciprocation,
386 artificial aeration, tidal flow, etc. Thus, combining or integrating AFIs with other existent or
387 emerging technologies, such as membrane bio-reactor (MBR), electrochemical oxidation,
388 microbial fuel cells (MFCs) etc., may be an effective way forward, with the aim of maximizing the
389 individual advantages in terms of wastewater treatment.

390 MBR technology is often utilized for advanced wastewater treatment to achieve water
391 reclamation and reuse due to its simultaneous biological treatment and filtration effects. Moreover,
392 MBR has the advantage of removing suspended solids, while simultaneously simplifying the
393 whole treatment process by eliminating the need for a secondary clarifier when compared with
394 conventional wastewater treatment processes (say activated sludge process) ([Lin et al., 2013](#)).

395 However, MBRs can sometimes fail to achieve satisfactory removal of nutrients, especially when
396 low-cost materials are used as the membrane module in order to reduce the investment (Khan et
397 al., 2013). Therefore, there is a motivation to combine MBR technology with AFIs to
398 simultaneously achieve low-cost operation while satisfying effluent quality demands. As such, the
399 effluent of the MBR can be further polished in AFIs while the MBR, acting as “pre-treatment”
400 step, could prolong their lifetime.

401 Since Liu et al. (2004) utilized the MFC technology to treat domestic wastewater; the studies
402 for wastewater treatment and simultaneous energy extraction from organics-containing
403 wastewaters have intensified. AFI system, especially with artificial aeration, can develop a
404 significant redox gradient along its depth, i.e. aerobic environment at the upper part and anaerobic
405 environment at the bottom of the water body. This redox distribution offers the possibility of
406 integrating MFC technology into AFIs.

407 Further, the engineered bacteria should be studied more comprehensively for removing the
408 specific pollutants without bringing risks to environment.

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414 References

415 Afzal, M., Khan, Q.M., and Sessitsch, A. 2014. Endophytic bacteria: prospects and
416 applications for the phytoremediation of organic pollutants. Chemosphere. 117:

- 417 232–242.
- 418 Agunbiade, F.O., Olu-Owolabi, B.I., and Adebowale, K.O. 2009. Phytoremediation potential
419 of *Eichornia crassipes* in metal-contaminated coastal water. *Bioresour Technol.* 100:
420 4521–4526.
- 421 Bankston, J.L., Sola, D.L., Komor, A.T., and Dwyer, D.F. 2002. Degradation of
422 trichloroethylene in wetland microcosms containing broad-leaved cattail and eastern
423 cottonwood. *Water Res.* 36: 1539–1546.
- 424 Bing, X.W., and Chen, J.C. 2001. The control of eutrophic water in ponds by floating-bed
425 soilless culture of plants. *Journal of Zhanjiang Ocean University.* 21(3): 29–33.
- 426 Bokare, V., Murugesan, K., Kim, Y.M., Jeon, J.R., Kim, E.J., and Chang, Y.S. 2010.
427 Degradation of triclosan by an integrated nano-bio redox process. *Bioresour Technol.*
428 101: 6354–6360.
- 429 Borne, K., Fassman-Beck, E., and Tanner, C.C. 2014. Floating Treatment Wetland influences
430 on the fate of metals in road runoff retention ponds. *Water Res.* 48: 430–442.
- 431 Brix, H., and Schierup, H.H. 1990. Soil oxygenation in constructed reed beds: the role of
432 macrophyte and soil-atmosphere interface oxygen transport. In: Cooper, P.F., Findlater,
433 B.C. (Eds.), *Constructed Wetlands in Water Pollution Control*. Pergamon Press, New
434 York, USA, 53–66.
- 435 Chang, N.B., Xuan, Z., Marimon, Z., Islam, K., and Wanielista, M.P. 2013. Exploring
436 hydrobiogeochemical processes of floating treatment wetlands in a subtropical
437 stormwater wet detention pond. *Ecol. Eng.* 54: 66–76.
- 438 Chang, Y.H., Ku, C.R., and Yeh, N. 2014. Solar powered artificial floating island for

- 439 landscape ecology and water quality improvement. *Ecol. Eng.* 69: 8-16.
- 440 Chen, J.Z., Meng, S.L., Hu, G.D., Qu, J.H., and Fan, L.M. 2010. Effect of *Ipomoea aquatica*
441 cultivation on artificial floating rafts on water quality of intensive aquaculture ponds. *J.*
442 *Ecol. Rural Environ.* 26(2): 155-159.
- 443 Chen, Z., Fu, Y.S., and Zhang, Z.Q. 2014. Study on the removal efficiency of heavy metal
444 copper using different types of ecological floating beds. *Chin. Sci. Technol. Rev.* 18:
445 134.
- 446 Chris, C.T., and Tom, R.H. 2011. Components of floating emergent macrophyte treatment
447 wetlands influencing removal of stormwater pollutants. *Ecol. Eng.* 37(3): 474-486.
- 448 Compant, S., Clément, C., and Sessitsch, A. 2010. Plant growth-promoting bacteria in the
449 rhizo- and endosphere of plants: their role, colonization, mechanisms involved and
450 prospects for utilization. *Soil Biol. Biochem.* 42: 669-678.
- 451 Cui, D.C., and Hu, F. 2012. Bioremediation of WWTP effluent using an enhanced hybrid
452 ecological bed under aeration condition. *Water Saving Irri.* 10: 18-20.
- 453 Deng, H., Ye, Z.H., and Wong, M.H. 2004. Accumulation of lead, zinc, copper and cadmium
454 by 12 wetland plants species thriving in metal contaminated sites in China. *Environ.*
455 *Pollut.* 132(1): 29-40.
- 456 Dong, X.X., Yan, C.Z., Wang, Z.S., Zhao, P.H., Zhou, S.L., and Wang, M. 2014. Removal
457 efficiency and accumulation characteristics of Cu, Pb and Cd in combined purification
458 systems. *Chin. J. Environ. Eng.* 8(4): 1447-1453.
- 459 Dushenkov, V., Kumar, P., Motto, H., and Raskin, I. 1995. Rhizofiltration: the use of plants to
460 remove heavy metals from aqueous streams. *Environ. Sci. Technol.* 29(5): 1239-1245.

- 461 El-Deeb, B., Gherbawy, Y., and Hassan, S. 2012. Molecular characterization of endophytic
462 bacteria from metal hyperaccumulator aquatic plant (*Eichhornia crassipes*) and its role
463 in heavy metal removal. Geomicrobiol. J. 29(10): 906–915.
- 464 Guo, H., Luo, S., Chen, L., Xiao, X., Xi, Q., Wei, W., Zeng, G., Liu, C., Wan, Y., Chen, J., and
465 He, Y. 2010. Bioremediation of heavy metals by growing hyperaccumulator endophytic
466 bacterium *Bacillus* sp. L14. Bioresour Technol. 101: 8599–8605.
- 467 Harding, B. 2009. Biohaven floating islands. Inland scape SA. 2: 30–32.
468 (<http://www.floatingislandinternational.com/wp-content/plugins/fii/news/5.pdf>).
- 469 Hegazy, A.K., Abdel-Ghani, N.T., and El-Chaghaby, G.A. 2011. Phytoremediation of
470 industrial wastewater potentiality by *Typha domingensis*. Int. J. Environ. Sci. Technol. 8:
471 639–648.
- 472 Hu, M.H., Yuan, J.H., Yang, X.E., and He, Z.L. 2010. Effects of temperature on purification
473 of eutrophic water by floating eco-island system. Acta Ecol. Sin. 30(6): 310-318.
- 474 Hu, X.Q., Li, Z.H., Wang, C.X., Zheng, X.Q., and Ren, H.Y. 2008. Static experiments on
475 purification of eutrophicated water body by complex ecological floating island. Journal
476 of Hubei University (Natural Science). 30(3): 309-312.
- 477 Hu, Y., He, F., Ma, L., Zhang, Y., and Wu, Z.B. 2016. Microbial nitrogen removal pathways in
478 integrated vertical-flow constructed wetland systems. Bioresour Technol. 207: 339-345.
- 479 Huang, L.F., Zhuo, J.F., Guo, W.D., Spencer, R.G.M., Zhang, Z.Y., and Xu, J. 2013. Tracing
480 organic matter removal in polluted coastal wastewaters via floating bed phytoremediation.
481 Marine Pollution Bulletin. 71(1-2): 74-82.
- 482 Hubbard, R.K., Anderson, W.F., Newton, G.L., Ruter, J.M., and Wilson, J.P. 2011. Plant

- 483 growth and elemental uptake by floating vegetation on a single-stage swine wastewater
484 lagoon. *Trans. ASABE*. 54(3): 837–845.
- 485 Hubbard, R.K., Gascho, G.J., and Newton, G.L. 2004. Use of floating vegetation to remove
486 nutrients from swine lagoon wastewater. *Trans. ASABE*. 47(6): 1963-1972.
- 487 Huo, T., Wang, G.Y., and Ren, L. 2009. A study on impact of livestock and poultry breeding
488 pollution on water environment safety in Shandong Province. *Adv. Water Resour.*
489 *Hydraul. Eng.* 1(6): 525–530.
- 490 Ibekwe, A.M., Ma, J., Murinda, S., and Reddy, G.B. 2016. Bacterial community dynamics in
491 surface flow constructed wetlands for the treatment of swine waste. *Sci. Total Environ.*
492 544: 68-76.
- 493 Ijaz, A., Shabir, G., Khan, Q.M., and Afzal, M. 2015. Enhanced remediation of sewage
494 effluent by endophyte-assisted floating treatment wetlands. *Ecol. Eng.* 84: 58-66.
- 495 Islam, M.S., Ahmed, M.K., Raknuzzaman, M., Habibullah-Al-Mamun, M., and Islam, M.K.
496 2015. Heavy metal pollution in surface water and sediment: a preliminary assessment of
497 an urban river in a developing country. *Ecol. Indic.* 48: 282–291.
- 498 Jeanette, L., Laurie, J.F., James, S.O.Jr., and David, J.S. 2015. Evaluation of commercial
499 floating treatment wetland technologies for nutrient remediation of stormwater. *Ecol.*
500 *Eng.* 75: 61-69.
- 501 Jin, X., and Hu, X. 2003. A comprehensive plan for treating the major polluted regions of
502 Lake Taihu, China. *Lakes Reservoirs: Res. Manage.* 8: 217–230.
- 503 Kania, B.G., (n.d.). 2014. Bold Gold and Garney Green. Floating Island International.
504 (<http://www.floatingislandinternational.com/wp-content/plugins/fii/news/38.pdf>.)

- 505 Keizer-Vlek, H.E., Verdonshot, P.F., Verdonshot, R.C., and Dekkers, D. 2014. The
506 contribution of plant uptake to nutrient removal by floating treatment wetlands. *Ecol.*
507 *Eng.* 73: 684–690.
- 508 Khan, S.J., Ilyas, S., and Rehman, Z.U. 2013. Impact of nitrogen loading rates on treatment
509 performance of domestic wastewater and fouling propensity in submerged membrane
510 bioreactor (MBR). *Bioresour Technol.* 141: 46–49.
- 511 Ladislas, S., Gérente, C., Chazarenc, F., Brisson, J., and Andrès, Y. 2013. Performances of
512 two macrophytes species in floating treatment wetlands for cadmium, nickel and zinc
513 removal from urban stormwater runoff. *Water Air Soil Pollut.* 224: 1408.
- 514 Li, H.Y., Li, W.C., Feng, M.H., and Pan, J.Z. 2009. Characteristics and contribution of
515 *Oenanthe javanica* uptake to nitrogen and phosphorus removal based on a micro-aerated
516 ecological floating bed. *J. Agro-Environ. Sci.* 28(9): 1908-1913.
- 517 Li, H.Y., Yang, H.H., Ke, P., Peng, M.H., and Li, W.C. 2009. Purification effect and biofilm
518 characteristics of micro-aerated ecological floating bed. *Chin. Water Wastewater.* 25(7):
519 35-40.
- 520 Li, L., Yang, Y., Yang, F. J., and Pan, H. 2011. Growth characteristic features and behaviors of
521 aquatic plants in the polluted water. *J. Safety Environ.* 11(3): 14-19.
- 522 Li, W., and Li, Z. 2009. In situ nutrient removal from aquaculture wastewater by aquatic
523 vegetable *Ipomoea aquatica* on floating beds. *Water Sci. Technol.* 59(10): 1937-1943.
- 524 Li, X.N., Song, H.L., Li, W., Lu, X.W., and Nishimura, O. 2010. An integrated ecological
525 floating-bed employing plant, freshwater clam and biofilm carrier for purification of
526 eutrophic water. *Ecol. Eng.* 36: 382–390.

- 527 Li, X.Y., Yang, Q.H., Meng, F.Q., Zhang, H., and Zhao, D. 2009. Function of loach on the
528 pollutants removal from polluted river water using a BGD device. *Chin. J. Appl. Environ.*
529 *Bio.* 15(1): 82-86.
- 530 Li, Y.Q., Li, Z.H., Jiang, Y.H., Wan, J., and Zhao, L.Y. 2011. Study on the changes of
531 physiological indexes of water spinach in eutrophication water. *J. Anhui Agri. Sci.* 39(7):
532 4129-4131.
- 533 Lin, H., Peng, W., Zhang, M., Chen, J., Hong, H., and Zhang, Y. 2013. A review on anaerobic
534 membrane bioreactors: applications, membrane fouling and future perspectives. *Desalination.*
535 314: 169–188.
- 536 Liu, H., Ramanarayanan, R., and Logan, B.E. 2004. Production of electricity during
537 wastewater treatment using a single chamber microbial fuel cell. *Environ. Sci. Technol.*
538 38: 2281–2285.
- 539 Liu, J.N., Wang, J.M., Zhao, C.C., Hay, A.G., Xie, H.J., and Zhan, J. 2016. Triclosan removal
540 in wetlands constructed with different aquatic plants. *Environ. Biot.* 100(3): 1459-1467.
- 541 Lu, Q., He, Z. L.L., Graetz, D.A., Stoffella, P.J., and Yang, X.E. 2010. Phytoremediation to
542 remove nutrients and improve eutrophic stormwaters using water lettuce (*Pistia*
543 *stratiotes* L.). *Environ. Sci. Pollut. Res.* 17: 84–96.
- 544 Luederitz, V., Eckert, E., Lange-Weber, M., Lange, A., and Gersberg, R.M. 2001. Nutrient
545 removal efficiency and resource economics of vertical flow and horizontal flow
546 constructed wetlands. *Ecol. Eng.* 18: 157–171.
- 547 Luo, G.Y., Bu, F.P., Xu, X.Y., Cao, J., and Shu, W.Q. 2010. Effect of temperature on the
548 ecological floating bed system. *Chin. Environ. Sci.* 30(4): 499-503.

- 549 Melián, J.A.H., Araña, J., Ortega, J.A., Muñoz, F.M., Rendón, E.T., and Peña, J. P. 2008.
550 Comparative study of phenolics degradation between biological and photocatalytic
551 systems. *J. Sol. Energy Eng.* 130(4): 1–7.
- 552 Nahlik, A.M., and Mitsch, W.J. 2006. Tropical treatment wetlands dominated by free-floating
553 macrophytes for water quality improvement in Costa Rica. *Ecol. Eng.* 28(3): 246–257.
- 554 Naichia, Y., Pulin, Y., and Yuan-Hsiou, C. 2015. Artificial floating islands for environmental
555 improvement. *Renewable Sus. Energy Rev.* 14: 616–622.
- 556 Nduwimana, A., Yang, X.L., and Wang, L.R. 2007. Evaluation of a cost effective technique
557 for treating aquaculture water discharge using *Lolium perenne* Lam. as a biofilter. *J.*
558 *Environ. Sci. (China)*.19: 1079–1085.
- 559 Newman, L.A., and Reynolds, C.M. 2005. Bacteria and phytoremediation: new uses for
560 endophytic bacteria in plants. *Trends Biotechnol.* 23: 6–8.
- 561 Palma, P., Alvarenga, P., Palma, V.L., Fernandes, R.M., Soares, A.M.V.M., and Barbosa, I.R.
562 2010. Assessment of anthropogenic sources of water pollution using multivariate
563 statistical techniques: a case study of the Alqueva's reservoir, Portugal. *Environ. Monit.*
564 *Assess.* 165: 539–552.
- 565 Rai, P.K. 2009. Heavy metal phytoremediation from aquatic ecosystems with special
566 reference to macrophytes. *Crit. Rev. Environ. Sci. Technol.* 39: 697–753.
- 567 Ruiz, I., Díaz, M.A., Crujeiras, B., García, J., and Soto, M. 2010. Solids hydrolysis and
568 accumulation in a hybrid anaerobic digester-constructed wetlands system. *Ecol. Eng.*
569 36(8): 1007–1016.
- 570 Shehzadi, M., Afzal, M., Islam, E., Mobin, A., Anwar, S., and Khan, Q.M. 2014. Enhanced

- 571 degradation of textile effluent in constructed wetland system using *Typha domingensis*
572 and textile effluent-degrading endophytic bacteria. Water Res. 58: 152–159.
- 573 Shi, L.L., Cao, W.P., Cheng, Y.R., Han, X.R., and Huang, H. 2014. Performance and
574 characteristics of different hybrid plants' ecological floating bed about purifying polluted
575 water body with different matrix. Chin. Rural Water Hydr. 2: 13-17.
- 576 Smith, M., and Kalin, M. 2000. Floating wetland vegetation covers for suspended solids
577 removal. Proceedings of the Quebec 2000: Millennium Wetland Event. Quebec City,
578 Quebec, pp. 244.
- 579 Sooknah, R.D., and Wilkie, A.C. 2004. Nutrient removal by floating aquatic macrophytes
580 cultured in anaerobically digested dairy manure wastewater. Ecol. Eng. 22(1):
581 27–42.
- 582 Stewart, F.M., Mulholland, T., Cunningham, A.B., Kania, B.G., and Osterlund, M.T. 2008.
583 Floating islands as an alternative to constructed wetlands for treatment of excess
584 nutrients from agricultural and municipal wastes-results of laboratory scale tests. Land
585 Contam. Reclam. 16: 25–34.
- 586 Stiling, P.D. 2011. Ecology: Global Insights and Investigations. McGraw-Hill, New York.
- 587 Sun, L.P., Liu, Y., and Jin, H. 2009. Nitrogen removal from polluted river by enhanced
588 floating bed grown *Canna*. Ecol. Eng. 35(1): 135-140.
- 589 Tanner, C.C. 2001. Plants as ecosystem engineers in subsurface-flow treatment wetlands.
590 Water Sci. Technol. 44(11–12): 9–17.
- 591 Tuna, A.L., Yilmaz, F., Demirak, A., and Ozdemir, N. 2007. Sources and distribution of trace
592 metals in the Saricay stream basin of southwestern Turkey. Environ. Monit. Assess. 125:

- 593 47–57.
- 594 Vera, L.M., Davie, A., Taylor, J.F., and Migaud, H. 2010. Differential light intensity and
595 spectral sensitivities of Atlantic salmon, European sea bass and Atlantic cod pineal
596 glands *ex vivo*. Gen. Comp. Endocrinol. 165: 25–33.
- 597 Vesely, T., Tlustos, P., and Szakova, J. 2011. The use of water lettuce (*Pistia stratiotes* L.) for
598 rhizofiltration of a highly polluted solution by cadmium and lead. Int. J.
599 Phytoremediation. 13: 859–872.
- 600 Vymazal, J. 2007. Removal of nutrients in various types of constructed wetlands. Sci. Total Envir.
601 380: 48–65.
- 602 Wang, G.F., Wang, X.J., Wu, L., and Li, X.N. 2012. Contribution and purification mechanism
603 of bio-components to pollutants removal in an integrated ecological floating bed. J. Civil
604 Arch. Environ. Eng. 34(4): 136-141.
- 605 Wang, G.X., Zhang, L.M., Chua, H., Li, X.D., Xia, M.F., and Pu, P.M. 2009. A mosaic
606 community of macrophytes for the ecological remediation of eutrophic shallow lakes.
607 Ecol. Eng. 35: 582-590.
- 608 Wang, K., Cai, J., Xie, S.L., Feng, J., and Wang, T. 2015. Phytoremediation of phenol using
609 *Polygonum orientale* and its antioxidative response. Archives Enviro. Protection. 41(3):
610 39-46.
- 611 Watson, J.T., Reed, S.C., Kadlec, R.H., Knight, R.L., and Whitehouse, A.E. 1989.
612 Performance Expectations and Loading Rates for Constructed Wetlands. In: Hammer,
613 D.A. (Ed.), Constructed Wetlands for Wastewater Treatment.
- 614 Weyens, N., van der Lelie, D., Taghavi, S., and Vangronsveld, J. 2013. The poplar endophyte

- 615 *Pseudomonas putida* W619 as a Key to a successful phytoremediation of volatile organic
616 contaminants. In: de Bruijn, F.A. (Ed.), Molecular Microbial Ecology of the Rhizosphere.
617 John Wiley and Sons, Inc., Hoboken, NJ, USA, 429–435.
- 618 Winston, R.J., Hunt, W.F., Kennedy, S.G., Merriman, L.S., Chandler, J., and Brown, D. 2013.
619 Evaluation of floating treatment wetlands as retrofits to existing stormwater retention
620 ponds. Ecol. Eng. 54: 254–265.
- 621 Wolverton, B.C., and McDonald, R.C. 1975. Water hyacinth and alligator weeds for removal
622 of silver, cobalt and strontium from polluted waters. Nasa Technical Memorandum. 72:
623 727.
- 624 Wu, H.M., Zhang, J., Ngo, H.H., Guo, W.S., Hu, Z., Liang, S., Fan, J.J., and Liu, H. 2015. A
625 review on the sustainability of constructed wetlands for wastewater treatment: Design
626 and operation. Bioresour Technol. 175: 594-601.
- 627 Wu, L.J. 2015. Study on the removal efficiency of heavy metal-Cr(□) in sewage using the
628 micro-aerated strengthen ecological floating bed [D]. Chengdu: Southwest Jiaotong
629 University.
- 630 Wu, M., Tang, X., Li, Q., Yang, W., Hua, F., Tang, M., and Sholz, M. 2013. Review of
631 ecological engineering solutions for rural non-point source water pollution control in
632 Hubei province, China. Water Air Soil Pollut. 224(5): 1561.
- 633 Wu, Q., Hu, Y., Li, S.Q., Sen, P., and Zhao, H.B. 2016. Microbial mechanisms of using
634 enhanced ecological floating beds for eutrophic water improvement. Bioresour Technol.
635 211: 451-456.
- 636 Wu, S., Kuschik, P., Brix, H., Vymazal, J., and Dong, R. 2014. Development of constructed

- 637 wetlands in performance intensifications for wastewater treatment: a nitrogen and
638 organic matter targeted review. *Water Res.* 57: 40–55.
- 639 Wu, W., Song, X., Jin, Q., Ying, H., and Zou, G. 2000. Study on soilless culture of *Canna* on
640 fish pond. *Chin. J. Applied Environ. Bio.* 6: 206–210.
- 641 Xiang, W.Y., and Peng, Y. 2015. Remediation of eutrophic water by *Oenanthe javanica*
642 eco-floating bed in Chongqing in winter. *Chin. J. Environ. Eng.* 9(11): 5393-5398.
- 643 Xiao, X., Luo, S., Zeng, G., Wei, W., Wan, Y., Chen, L., Guo, H., Cao, Z., Yang, L., Chen, J.,
644 and Xi, Q. 2010. Biosorption of cadmium by endophytic fungus (EF) *Microsphaeropsis*
645 *sp.* LSE10 isolated from cadmium hyperaccumulator *Solanum nigrum* L. *Bioresour*
646 *Technol.* 101: 1668–1674.
- 647 Xu, G.J., Duan, D.X., Du, X.H., Tian, G.T., Zhang, M.L., and Liu, F. 2015. Purification effect
648 of combined ecological floating bed on aquaculture wastewater. *J. Shanghai Ocean*
649 *University.* 24(1): 94-101.
- 650 Xu, H., Zhang, Y., Huang, M.S., Luo, J.H., and He, Y. 2011. Study on the effect of SFTWs for
651 phosphorus removal from malodorous water. *J. East China Normal University (Natural*
652 *Science).* 1: 119-125.
- 653 Yadav, B.K., Siebel, M.A., and van Bruggen, J.J.A. 2011. Rhizofiltration of a heavy metal
654 (lead) containing wastewater using the wetland plant *Carex pendula*. *Clean-Soil Air*
655 *Water.* 39: 467–474.
- 656 Yeh, N., Yeh, P., and Chang, Y.H. 2015. Artificial floating islands for environmental improvement.
657 *Renew. Sustain. Energy Rev.* 47: 616–622.
- 658 Zhang, C.B., Liu, W.L., Pan, X.C., Guan, M., Liu, S.Y., Ge, Y., and Chang, J. 2014.

- 659 Comparison of effects of plant and biofilm bacterial community parameters on removal
660 performances of pollutants in floating island systems. *Ecol. Eng.* 73: 58-63.
- 661 Zhang, R.B., Qian, X., Zheng, S.R., Yuan, X.C., and Xia, B.S. 2012. Purification efficiency of
662 lightly polluted water by vertical moveable eco-bed and ecological floating bed. *Environ.*
663 *Chem.* 31(11): 1705-1710.
- 664 Zhang, Z.S., Zhao, J.F., and Chen, L. 2011. Analyses on applicable technology of
665 CBPT-EEFR system of treatment for rural sewage. *Sci. Res.* 586-589.
- 666 Zhao, F.L., Xi, S., Yang, X., Yang, W.D., Li, J.J., Gu, B.H., and He, Z.L. 2012. Purifying
667 eutrophic river waters with integrated floating island systems. *Ecol. Eng.* 40: 53–60.
- 668 Zheng, Y.Z., Li, G., Du, J., Peng, C.R., and Liu, J.T. 2013. Effect of biological floating island
669 on water quality and algae in a tributary bay typical of the three-gorge reservoir. *J. Ecol.*
670 *Rural Envir.* 29(3): 278-283.

Fig. 1. Schematic of an artificial floating island (also called integrated floating treatment wetland or integrated ecological floating bed) ([Harding, 2009](#))