


Article

Using Green Water Farm to Improve Ecological Restoration

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Abstract: Artificial Floating Islands (AFIs) are human-made floating structures capable of supporting aquatic vegetation. Previous studies pointed out that most AFIs use aquatic plants to carry out improvement of water quality and ecological conservation. This study proposed a modified AFI system, named Green Water Farm (GWF), to increase the practical application value of traditional AFIs, and added a special design to create an environment that allows for terrestrial plants (including vegetables and flowers) to grow and to carry out improvement of water quality and ecological conservation. The research site was located at the waterfront of Li-tze Lake in Pitou Township, Taiwan. A GWF was established to evaluate the improvement of water quality and ecological conservation. During one year, water quality and ecological conservation assessments were recorded to investigate the performance of GWF system. The research results showed that GWF could improve water quality and ecological conservation. In addition, the results of this study can provide useful information for more food sources for humans and animals, and increase biodiversity and ecological conservation.

Keywords: Artificial Floating Island; Green Water Farm; ecological conservation

1. Introduction

While Artificial Floating Islands (AFI) have been created to conserve bird and wildlife habitats, and waterscape layouts, their potential to improve water quality was not researched until 1990 [1,2]. The AFI study group [3] and Will and Crawford [4] indicated that the first AFI was established in 1900 in lakes in the United States for the nests and habitats of birds. In Asia, Hirose [5] and the Environmental Protection Administration, R.O.C. [6] described the earliest use of AFI in Japan and Taiwan. In Japan, it acts as an egg bed for fish, while in Taiwan it originated from the Thao aboriginal people of Sun Moon Lake, who made bamboo into floating frames laid with grass carpets, and planted them with paddies to form floating farms. In addition, natural floating land is formed by the growth of hydrophilic plants in water areas, and dead or rotting plants form floating islands on the water surface [2,7].

In addition to environmental conservation, AFI can be effective at improving water quality. Nakamura and Mueller [8] and Wen [9] pointed out that the plant root system and floating structures of AFI can intercept contaminants, reduce water velocity, abate the dispersal of pollution, and absorb

waves to protect the banks of bodies of water from erosion. It can also effectively reduce organic contaminants in the water [10]. AFI is an effective method to treat eutrophic water, as water pollutants can be transformed and degraded by the combination of plants and microorganisms on the floating island, thus, increasing the efficiency of the natural water quality improving process [11,12]. Dai and Chiang [13] showed that, when using just plants to purify waste water on a floating island, the ammonia nitrogen removal rate is higher than 56%, and the total phosphorus removal rate is higher than 52%; thus, the effect is significant.

Chang et al. [14] pointed out that an AFI could reduce the electrical conductivity (EC) of domestic sewage by 50% and increase DO by 2.7 to 3 times. Zhang et al. [15] directed that, at a temperature higher than constant (30 ± 2 °C), when the algal density is 1.0×10^8 cells/L in a static condition, Odorous Black Water Agglomerate (OBWA) eutrophication occurs. When the Oxidation-Reduction Potential (ORP) value is -250 to -50 mV, the water becomes black and odorous. Therefore, OBWA will be initiated when the ORP value decreases to -300 MV. A floating island can uniformly mix water and inhibit algal growth, thus, reducing $\text{NH}_3\text{-N}$, $\text{NO}_3^- \text{-N}$, and $\text{NO}_2^- \text{-N}$ to rapidly upgrade water quality [16].

Keigo [17] constructed an AFI at the Tsuchiura port in Lake Kasumigaura in 1993, which has a length of 92 m, a width of 9.5 m, and consists of 40 segments. They also surveyed the characteristics of flora, vegetation succession, and the standing crop on the AFI in November 1996, and the results showed that, while the algae cell count was about 10 times higher in summer, the water sample with a floating island had no water blooms, and the cell count of phytoplankton was reduced by 94%. Dissolved oxygen (DO) and EC can influence the microorganisms in water, thus, indirectly influencing biological water quality. Kalff [18] indicated that, on the one hand, the DO concentration reflects the water temperature and photosynthesis in the water body; on the other hand, it reflects the oxygen volume consumed by microbial processes. A floating island can remove nitrogen and phosphorus pollutant content in water through absorbing the nourishment of agricultural plants, and the plants are harvested in appropriate seasons to avoid rotting in autumn [19].

In terms of ecological conservation, Carolin et al. [20] stated that agricultural environment measures differ in their capacity to simultaneously enhance the provision of multiple ecosystem services. As floating islands are isolated from land areas, they provide good invisibility for wildlife to inhabit, including birds, fishes, insects, aquatic insects, and amphibians, thus, maintaining biodiversity [4,7,21–24]. Pei [25] established that the Occurrence Index = (number of animals shot in an hour/effective working hours of camera in the hour \times 1000) represents the hedonic scale of target species for various sample points, where the number of organisms is calculated to represent the environmental organism occurrence rate. Wang and Eagles [26] offered that the formation of floating islands promotes the birth and development of waterscape ecology, which enhances global environmental protection and health.

In terms of the output value of agricultural crops, Yao et al. [27] and Yen et al. [28] indicated that agricultural landscapes can maintain surface drainage to reduce engineering maintenance costs and increase biodiversity, and that vegetated AFI can remove organic substances, such as nitrogen and phosphorus. Evans et al. [29] showed that, through low-carbon agriculture, the agricultural landscape could provide a highly cost-efficient system to resist carbon emissions, restore ecosystems, and present biodiversity. The floating island can enhance agricultural land use. Gagne et al. [30] and Fahrig et al. [31] proposed five high-strength land use factors, two of which are: a waterscape can reduce human-made interference on land; and, a waterscape can change land properties and enlarge the land area. Therefore, floating islands with farming are more beneficial than general AFI. The objective of this study is to investigate the improvement of water quality and ecological conservation using the Green Water Farm (GWF) system.

Previous studies pointed out that most AFIs used aquatic plants to carry out water quality improvement or ecological conservation [32–34]. This study proposes a modified AFI system, named Green Water Farm (GWF), to increase the practical application value of traditional AFIs, and adds a

special design to create an environment that allows for terrestrial plants (including vegetables and flowers) to grow and carry out water quality improvements. The results of this study can provide useful information for more food sources for humans and animals, and increase biodiversity and ecological conservation.

2. Materials and Methods

The study area is about 8.2 m² in an orchard at Pitou Township of Changhua County, Taiwan, 23°86'79"E, 120°49'33"N.

2.1. GWF Structure

The standard set-up of GWF system, as proposed in this study, is shown in Figure 1a,b. The GWF is integrated modularly, where various units have water space and are covered with soil for planting (Figure 1c). Cotton cloth and cotton strips are placed under the soil layer, and water is absorbed by capillary action to conserve the soil (Figure 1d). In addition, there is a green energy module for generating and storing power for night LED landscape lighting and aeration in water (Figure 1e,f).

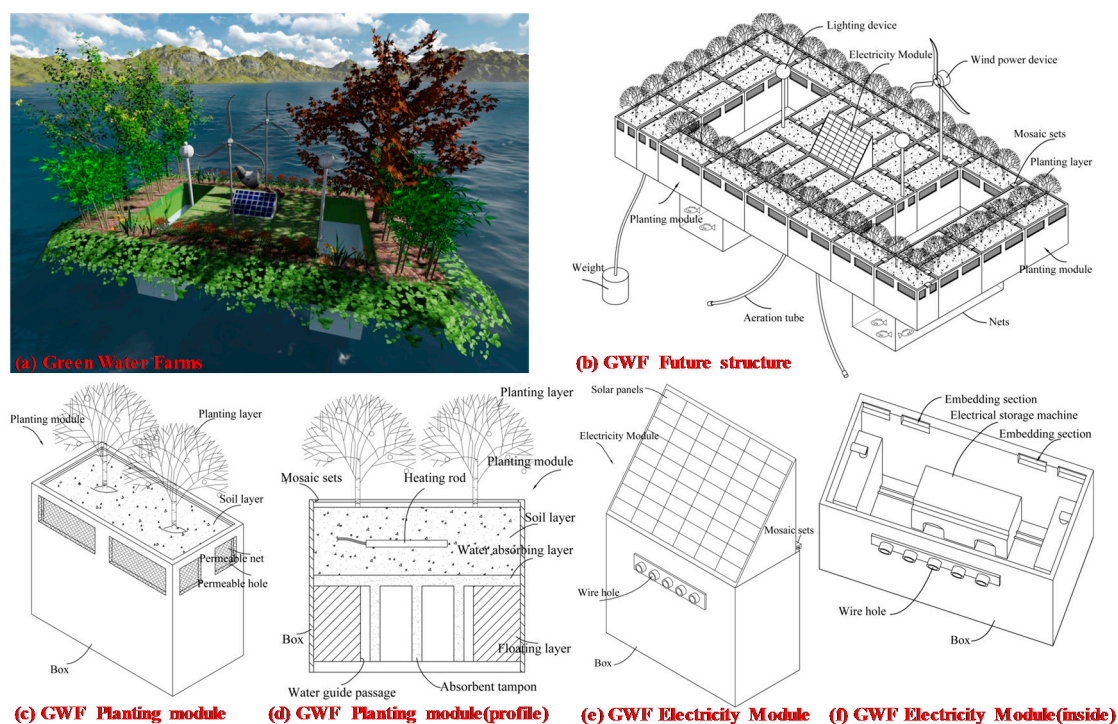


Figure 1. Standard set-up of Green Water Farms.

In order to implement this study on the practical research site, the above standard set-up of the GWF system is slightly adjusted for experimentation. The materials for the GWF system include two PVC water pipes with diameters of 4" and 3/2", eight pipe caps with diameters of 3/2", and four elbows with diameters of 4", forming a 70 × 70 cm floating island structure. In addition, there is a 65 × 65 cm black plastic mesh at the bottom to prevent the soil from dropping into the water. The soil pot size is 22 × 22 × 17 cm; the lower layer is a 3 cm thick coconut fiber mat; the middle layer is 12 cm thick culture soil. There are nine vegetables and another nine flowers planted on two floating islands to compare the differences. For vegetables, *Phaseolus vulgaris*, *Ocimum basilicum*, *Abelmoschus esculentus*, *Brassica oleracea* var. *capitata* f. *rubra*, *Allium fistulosum*, *Capsicum annuum*, *Lactuca sativa* var. *capitata* L., *Allium tuberosum*, *Rottler Allium odorum* L., and *Capsicum annuum* var. *grossum* were chosen. For flowers, *Chrysanthemum frutescens*, *Torenia fournieri*, *Cuphea ignea*, *Melampodium Lemon Delight*, *Lantana camara*,

Tagetes erecta, *Ixorachinensis* Lam., and *Rosmarinus officinalis*, *Crossostephium chinense* (L.) Makino are adopted. A 20 cm Lucite pipe filled with water absorbent cotton thread penetrates through a round hole with a radius of 2 cm in the pot bottom to increase the water absorption of the soil. The photovoltaic panel supplies power, the pipe base aeration opening is mounted, and air is pumped above the farm into the water to increase the DO content to improve water quality.

2.2. Measuring Instruments and Research Materials

2.2.1. Water Quality Measurement Equipment

There are five water quality experiments in this study. The five parameters of Water Temperature (T) °C, Electrical Conductivity (EC) C-μS/cm, Potential of Hydrogen (pH), Oxidation-Reduction Potential (ORP) mv, and Dissolved Oxygen (DO) mg/L are tested by a YSI-Pro Plus multi-parameter water quality analyzer throughout one year.

2.2.2. Ecological Environment Instrumentation

The GWF's biological and aquatic insect species are observed and recorded by a camera according to the visual encounter surveys between 15:00 and 20:00 every Wednesday from 10 March 2014 to 10 March 2015 [35]. The camera specification is SONY Xperia ZL, 13 mega pixels. At night, a reflective searchlight headlight is used to provide illumination for the researchers to work. The model of headlights' specification is the "PAN WORLD 3D05". More than 15 photos are captured and analyzed every Wednesday for each flume.

2.2.3. Solar Power Supply Equipment

Photovoltaic panel: 100 W monocrystal × 2, size: 160 cm × 108 cm; solar control box: 12 V and 20 A; and solar deep-cycle battery (EVX): 12 V 100 A with two excess power space × 2. The equipment is set up in the experimental mode field, matching the daylighting direction, and the photovoltaic panel tilts 23° southwards. Related equipment is installed under the photovoltaic panel, and power is supplied to GWFs D and E of the experimental group.

2.3. Physical Environment Instrumentation

The VS7LOGGER micro climatological observation instrument is installed in the experimental mode field, which measures five outdoor physical environment data: solar radiation, rainfall, illumination, humidity, and temperature. Data is recorded every 10 min, and this study automatically calculates the average monthly value of the variables throughout the year, in order to monitor the physical environment changes in the experimental mode field, and arrange the water quality experiment.

2.4. Water Body Grouping and Water Quality Research

The experimental field is about 1.5 m away from the bank. Two experimental groups (Waters D and E) and one control group (Water F) are designed and compared. Waters D and E are provided with a GWF, while Water F is without a GWF. The above three flumes (Waters D–F), with a diameter of 1.7 m and depth of 2 m, are dug at intervals of 20 cm; and are filled with the same volume of water.

The above waters needed for Water bodies D, E, and F are the daily-life mixed drainage, as obtained from Water body A (Figure 2a,b). The location of A is the discharge point of the daily-life mixed drainage from the student's dormitory. In order to observe the stratification of Waters D to F, this study collects water samples (Waters D to F) at three points, i.e., the upper point (5 cm below water surface), middle point (70 cm below water surface), and lower point (5 cm above bottom) layers.

Regarding the experimental design, the difference between Waters D and E is that only flowers (Water D) or vegetables (Water E) are planted on the GWF floating island. By comparing Waters D to F, we can obtain the benefit assessment of a GWF. According to the water quality test method of the Environmental Protection Administration, Executive Yuan, Water bodies D to F are tested between

14:00 and 15:00 every Wednesday from 10 March 2014 to 10 March 2015 (Figure 2c–e). There are five water quality experiments in this study, and the five water quality parameters of Temperature, EC, pH, ORP, and DO are tested by a YSI-Pro Plus multi-parameter water quality analyzer in order to analyze the changes throughout one year.



Figure 2. Water samples' distributed architecture.

2.5. Ecological Investigation Method

The investigation method follows the visual encounter surveys from 10 March 2014 to 10 March 2015, between 15:00 and 20:00 every Wednesday. The visual encounter survey records the number of all the species of insects, amphibians, etc., for a particular route or area within a specified time [35].

2.6. Statistical Analysis

In this study, Analysis of variance (ANOVA) available in SPSS Statistics is adopted to evaluate whether the differences between the three groups (samples D, E, and F) have reached statistical significance.

3. Results

3.1. Climatic Conditions

According to the instrument measurements of one year, the maximum daily radiation is from May to October 2014, the maximum value is 188.9 W/M^2 , the daily rainfall is apparently different in May to August 2014, and there is a stationary front in May; thus, the daily rainfall on the 19th day is as high as 126 mm, which is much higher than that in the other months. The maximum average air temperature is about 29°C from June to September, and the annual maximum temperature is 30°C in July, which is 15°C higher than the minimum temperature of 15°C from February of last year. The annual humidity is approximately 96–99%, as the mode field is located by the waterfront. This study integrates the climatic data, in order to discuss water purification (Figure 3).

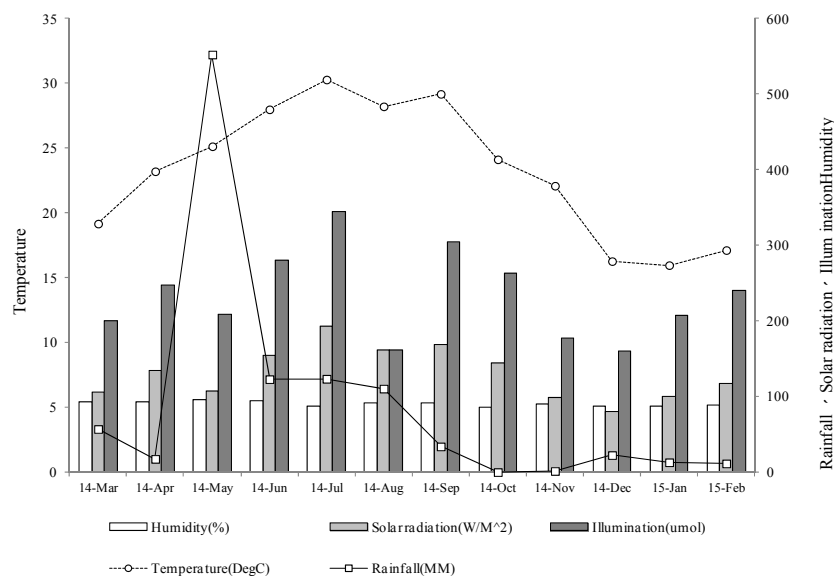


Figure 3. Climatic conditions for the experimental period.

3.2. Benefit of Water Quality Improvement

3.2.1. Water Temperature

The maximum temperatures of Waters D, E, and F are from June–September (Figure 4). By comparing Waters D to F, the differences among the upper, middle, and lower water temperatures of Water F (control group) are relatively greater than Waters D and E (experimental groups) (Figure 5). The maximum difference between the upper and lower water temperatures of Water F is 1.5 °C in February. The overall maximum temperature of Water A in June is 35.1 °C, which is 18.0 °C higher than the minimum lower temperature 17.1 °C of Water F in January. The temperature rises by about 1.03 times from June to August, and the temperature decreases by 33% from August to February, which is 1% higher than the upper of Water D.

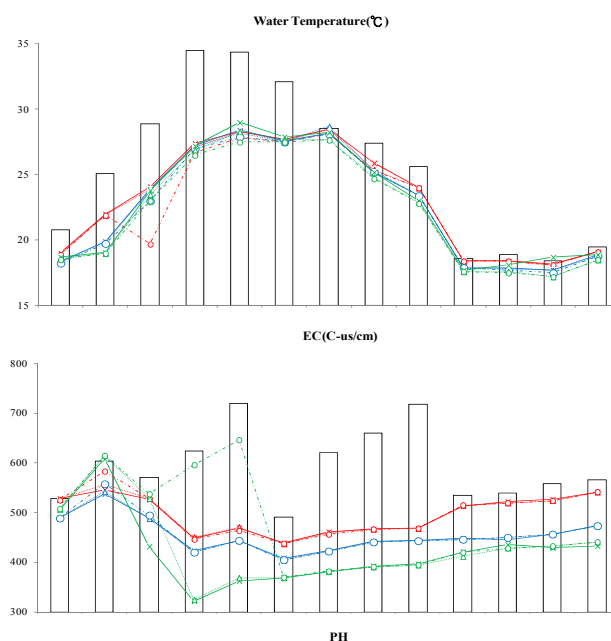


Figure 4. Cont.

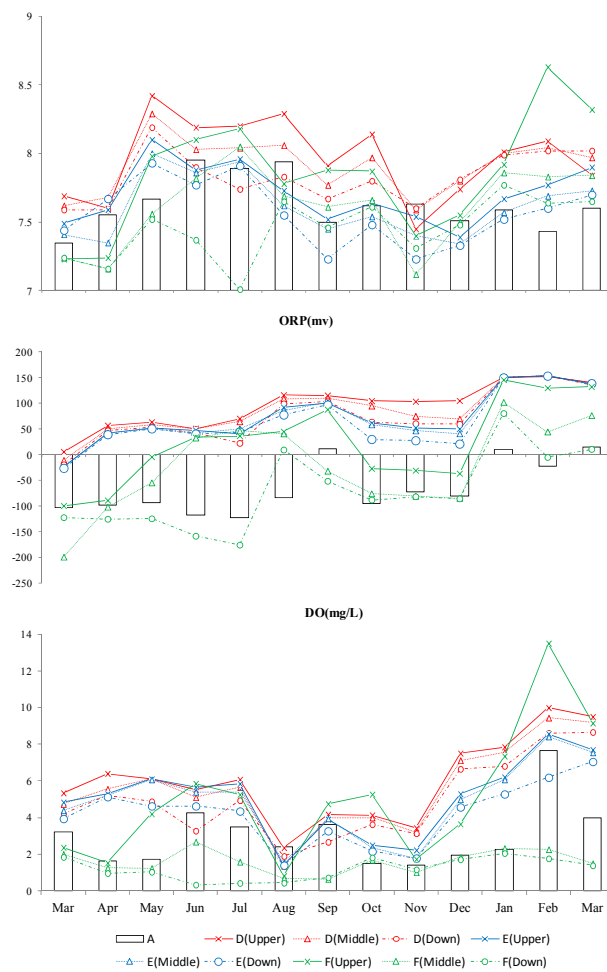


Figure 4. Experimental results of five water qualities (monthly).

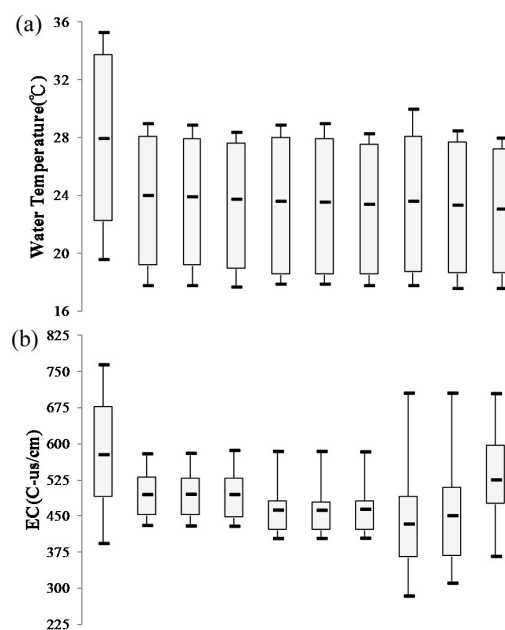


Figure 5. Cont.

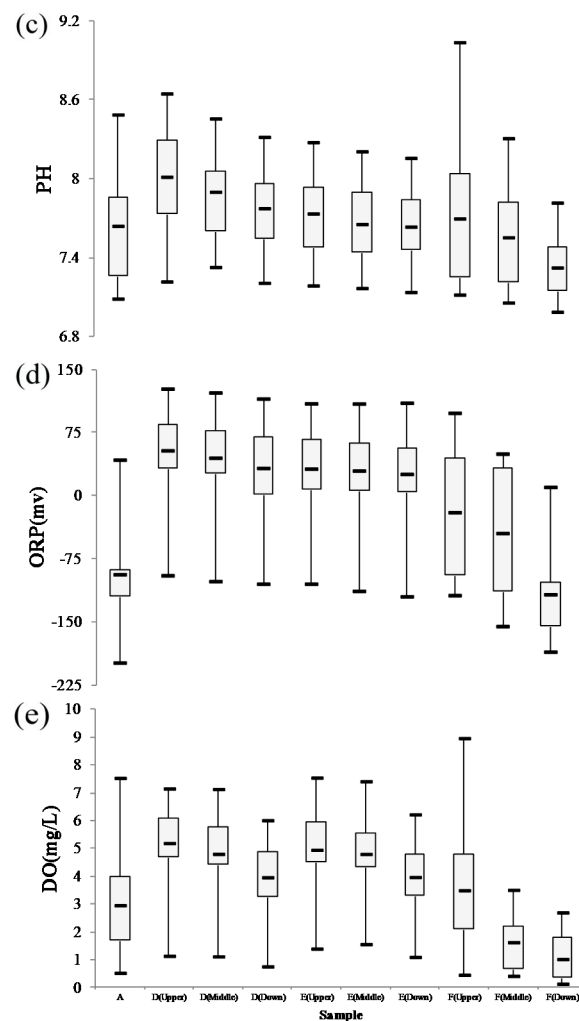


Figure 5. Experimental results of five water qualities (average).

3.2.2. Electrical Conductivity (EC)

Electrical conductivity is measured by the total amount of dissolved salt in the liquid, including inorganic cations (such as calcium, magnesium, sodium, and potassium) and anions (such as carbonate, sulfate, and chloride).

In Taiwan, the maximum allowable value of EC for the effluent standards is $750 \mu\text{S}/\text{cm}$ [36]. From Figures 4 and 5, it can be seen that all the values of the three points (i.e., upper, middle, and lower points) of EC for Waters D and E are within the effluent standards (i.e., $750 \mu\text{S}/\text{cm}$). By comparing Waters D to F, the differences among the three points of EC of Water F (control group) are relatively larger than Waters D and E (experimental groups) (Figure 5).

3.2.3. Potential of Hydrogen (pH)

In Taiwan, the allowable standard of potential of hydrogen (pH) for effluent standards is 6–9 [36].

The pH levels of the upper, middle, and lower layers of Waters D and E range at about 7.5–7.9, and there is no obvious stratification, meaning that the water is mixed uniformly. However, according to the comparison between the upper, middle, and lower layers of Water F, the pH difference between the upper and lower layers is 1.18 in July, while the maximum difference between the upper and lower layers of Waters D and E is about 0.4, meaning a GWF can thoroughly mix water to avoid stratification (Figure 4).

3.2.4. Oxidation-Reduction Potential (ORP)

According to the comparison among Waters D, E, and F, the upper, middle, and lower layers of Waters D and E have slight difference, and the minimum ORP is from March–May. Water D's ORP increases from 5.77 mv in March 2014 to 140.3 mv in March 2015, or greater by 134.5 mv, and is 152.8 mv in February. Water E increases from −23.4 mv to 153.4 mv at the end of the experiment, which is an increase of 176.8 mv. The maximum value is 153.4 mv in February, which is an increase of about 132%. On the other hand, the stratification of Water F is very apparent, the lower layer has a minimum value, and the difference between the upper and lower layers is 139.3 mv, from −99.6 mv to the final 132.2 mv, which an increase of 231.8 mV. Regarding the algae grown in large quantities in Water F in March 2015, as the algae performs photosynthesis and respiratory actions, the oxygen greatly increases, and ORP increases sharply. The changes in ORP of Waters D and E are stable from the beginning to the end of the experiment, while Water D increases by 286%. Thus, it can be seen that a GWF can increase the ORP content in a water body to improve water quality, as shown in Figure 5.

3.2.5. Dissolved Oxygen (DO)

In Taiwan, the minimum allowable value of dissolved oxygen (DO) for the effluent standards is 3.0 mg/L [36]. The amount of DO in water is important for aquatic organisms; for example, when the DO of a river is less than 3.0 mg/L, it is unfavorable for most fish.

By comparing Waters D, E, and F, the three layers of Waters D and E have slight difference; the maximum DO of Water D is 9.9 mg/L, which is an increase of about three times. The maximum DO of Water E is 8.5 mg/L, which an increase of about 2.4 times. The upper, middle, and lower layers of Water F have large differences in DO content, especially in spring; the maximum DO content difference between the upper and lower layers is 11.7mg/L, and the lower layer has a minimum DO content of 1.77 mg/L. This study result is similar to that proposed by Chang et al. [14], that DO is under the average value of 3.8 mg/L and relatively unstable in the sample without AFI. The upper layers of Waters E and F have the maximum difference in March, when Water E is 4.87 mg/L higher than F. As the water aerobics condition is provided by a solar-powered aerator in both Waters D and E, the values of DO are improved significantly. In the control group, Water F does not have the abovementioned aerator, thus, its DO content is relatively low. Therefore, GWF can increase the oxygen content in water and averagely distribute DO in the upper, middle, and lower layers, as shown in Figure 5. Table 1 represents the start, final, and difference data of five water qualities for Samples A, and E to F.

Table 1. Start, final, and difference data of five water qualities.

Project	Sample	Tempe (°C)	DO (mg/L)	EC (C-μS/cm)	pH	OR (mv)
A	Start	20.8	3.2	527.9	7.3	−103
	Final	19.5	4	566.5	7.6	14.8
	Difference	1.3	0.8	38.6	0.3	117.8
D	Start	18.9	4.7	526	7.6	−10.9
	Final	19.1	9.2	541	7.9	138
	Difference	0.2	4.5	15	0.3	148.9
E	Start	18.2	4.3	488.6	7.4	−24.5
	Final	18.8	7.5	473.3	7.7	138.7
	Difference	0.6	3.2	15.3	0.3	163.2
F	Start	18.5	2	507	7.2	−199
	Final	18.5	1.5	441	7.8	76.4
	Difference	0	0.5	66	0.6	275.4

Note: “Start” represents the first data of the entire experimental period; “Final” represents the final data of the entire experimental period; “Difference” is the difference between the first and final data.

3.3. Ecological Conservation Benefit

3.3.1. Biological Change of Sample D

In order to grow, sample D initially had *Polypedates megacephalus* (Tadpole) to absorb the nutrient substances in the water, and because *Tetragnatha mandibulata* comes up to prey on small insects, the water quality improved with time, and when *Papilionidae* (larva) appeared, it attracted a higher-level species, *Caelifera*, to settle, thus, forming a food chain. The maximum number of *Polypedates megacephalus* (Tadpole) is 52; the number of *Tetragnatha mandibulata* (spider) totals 30; the number of *Caelifera* totals 12; and, the number of *Papilionidae* (larva) totals 5. The external ambient temperature, solar radiation, and illumination increased in the mid- and late stages, ORP and DO increased by over two times, and *Polypedates megacephalus* and *Tetragnatha mandibulata* are produced and looked for food, thus, attracting later species *Papilionidae* (larva) and *Caelifera* to settle. Therefore, as GWF increased biodiversity and improved the environment, Sample D formed an ecological habitat (Figure 6). Chang et al. [37] conducted a study to explore the effects of the green energy landscape fountain (GLF) on ecological preservation. The results of this study agree with Chang et al. [37], that the improvement of water quality will result in increased species richness.

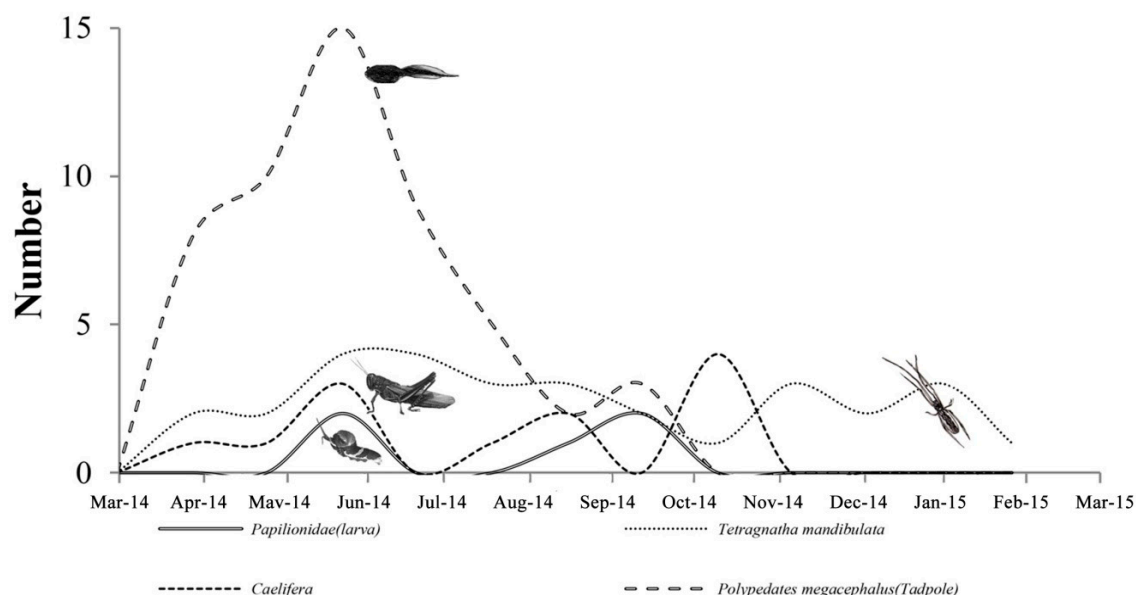


Figure 6. Number of each species for Water D (monthly).

3.3.2. Biological Change of Sample E

Polypedates megacephalus (Tadpole) and *Tetragnatha mandibulata* settled in Sample E in the beginning. As *Tetragnatha mandibulata* preys on small insects, when *Tetragnatha mandibulata* becomes stable, *Oxyopes macilentus* appears, and the *Papilionidae* (larva) and *Polypedates megacephalus* settle and look for food, thus, forming a food chain. The external ambient temperature, solar radiation, and illumination increased in the mid- and late stages, the ORP and DO are improved and restored to pristine condition, and the number of species increased. The species are abundant, and the high-level species *Statiliamaculata* preys on *Tetragnatha mandibulata* and *Oxyopes macilentus*, thus, forming a food chain and attracting the more advanced consumer *Polypedates megacephalus* to settle and reproduce (Figure 7). The results of this study agree with Yao et al. [27], that agricultural landscapes can improve biodiversity.

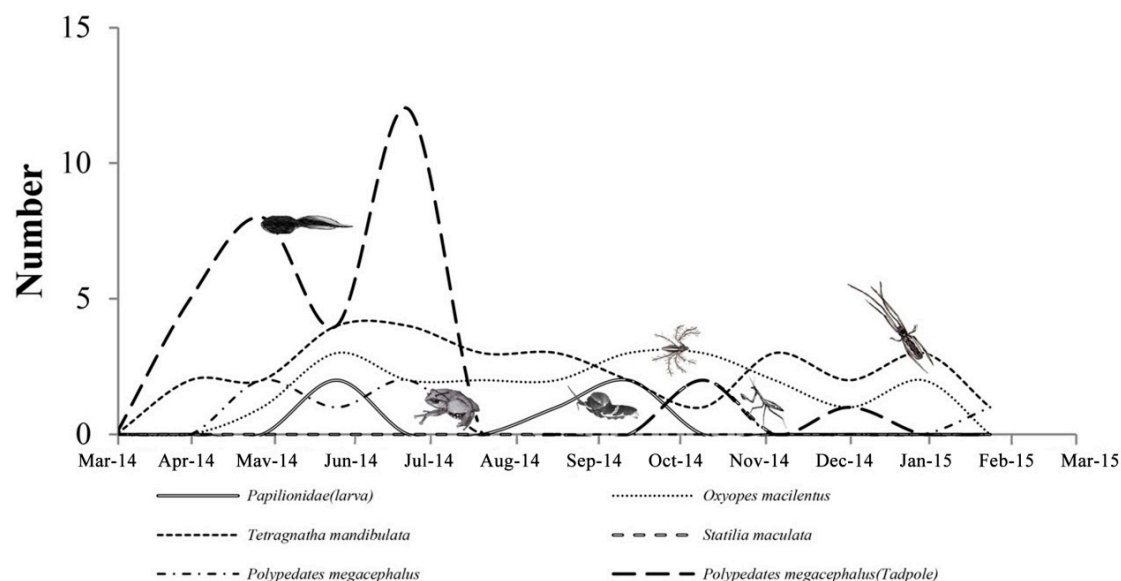


Figure 7. Number of each species for Water E (monthly).

3.3.3. Biological Change of Sample F

As there is no GWF in this sample and water quality stratification is apparent, the maximum DO difference between the upper layer and lower layer is over 11mg/L, and the minimum is only 1.77mg/L; thus, the aquatic environment is extreme and poor, and is inhabited by few species. However, many *Microvelia douglasi* appeared, which live in dark, damp, and still water areas, and have high fouling resistance, and because this environment is adverse to other predators, it reproduces in large quantities. When the water quality becomes worse in the late stage, the sewage organism *Chironomidae* appeared. Therefore, Sample F without a GWF has worse water quality, resulting in most of the species not surviving, and species diversity is relatively low (Figure 8).

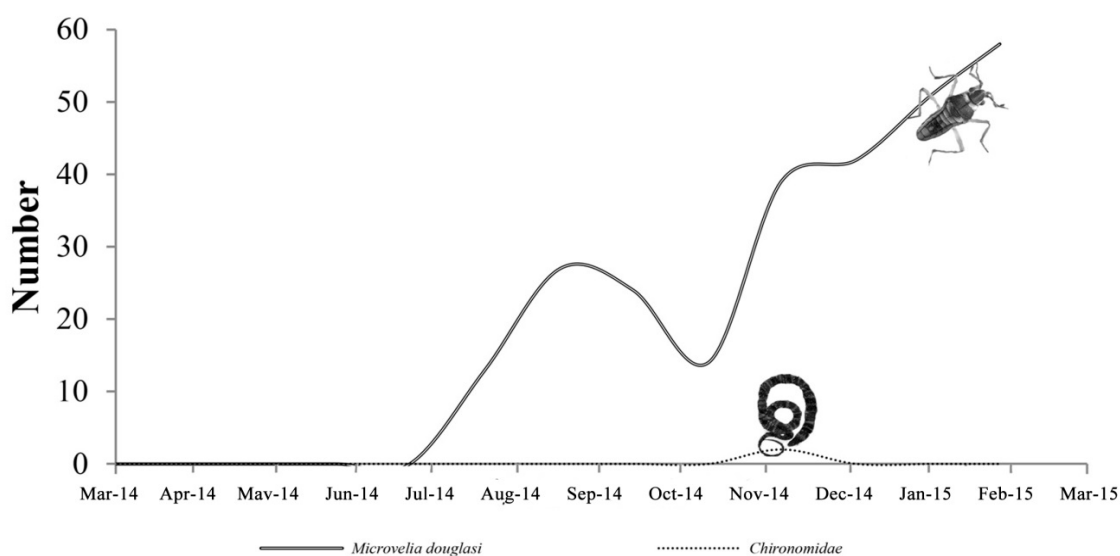


Figure 8. Number of each species for Water F (monthly).

3.4. Statistical Analysis Results

In this study, as the upper layer of Waters D and E exhibited better benefits of water quality improvement than the middle and lower layers, the upper layer is selected for statistical analysis.

The statistical analysis results of ANOVA with Scheffe's test available in SPSS Statistics showed that: (1) For samples D and F, DO ($p = 0.641$), EC ($p = 0.03$, $p < 0.05$), ORP ($p = 0.021$, $p < 0.05$), pH ($p = 0.656$), Temperature ($p = 0.969$). (2) For samples E and F, DO ($p = 1.000$), EC ($p = 0.259$), ORP ($p = 0.140$), pH ($p = 0.507$), Temperature ($p = 0.999$). This implies that only the EC and ORP for the two groups (samples D and F) have reached statistical significance. The statistical results suggest that sample D has better benefit for water quality improvement than sample E.

4. Discussion and Conclusions

This study proposed a Green Water Farm (GWF) to increase the practical application value of traditional AFIs. The outstanding feature of this study is that GWF allows for terrestrial plants to grow and carry out water purification and ecological conservation. The results showed that GWF could be used to carry out water purification and ecological conservation. In particular, the study results provided useful information for more food sources for humans and animals, and increased biodiversity. In particular, there was no obvious stratification in the GWF system (Waters D and E), meaning that the water was uniformly mixed. The statistical results suggest that sample D has better benefit of water quality improvement than sample E.

In the view of ecology, the samples with a GWF (i.e., Waters D and E) showed better ecology conservation benefits than the sample without a GWF (i.e., Water F). As shown in the previous section, four species, i.e., *Polypedates megacephalus* (Tadpole), *Tetragnatha mandibulata*, *Papilionidae* (larva), and *Caelifera*, appeared in Sample D. Moreover, six species, i.e., *Polypedates megacephalus* (Tadpole), *Tetragnatha mandibulata*, *Oxyopes macilentus*, *Papilionidae* (larva), *Statiliamaculata*, and *Polypedates megacephalus*, appeared in Sample E. However, only two saprobic index species, *Microvelia douglasi* and *Chironomidae*, appeared in Sample F throughout the entire year. According to the number of species, it can be suggested that Samples D and E have better ecological conservation benefits than Sample F. Moreover, it is worth noting that the existence of frogs can generally be used to identify whether an environment is good or bad, as frogs are also generally regarded as a keystone species in ecology. The existence of frogs (i.e., *Polypedates megacephalus*) in Sample E pointed out that Sample E is an acceptable habitat for frogs, which provides further evidence that a GWF can help ecological conservation.

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Conflicts of Interest: The authors declare no conflicts of interest.

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