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Design Model and Management Plan of a Rice–Fish Mixed Farming Paddy for Urban Agriculture and Ecological Education

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Abstract: Imparting knowledge on agriculture and ecology is important for the preservation of nature. This study suggested the design of a rice–fish mixed farming (RFMF) paddy for urban agriculture and ecological education in Korea. This RFMF paddy supports the growth of rice as well as freshwater fish. ANOVA statistical analysis was conducted, and an RFMF paddy was necessary for urban agriculture/education and confirmed that biodiversity was high. To this aim, the design of a 10 m × 10 m RFMF paddy was suggested. Vegetation, insects, and aquatic invertebrates of the RFMF paddy constituted approximately 40 species more than a conventional paddy. The quality of an actual farm's soil and water was assessed, and techniques for the co-cultivation of rice and fish are proposed. The soil must comply with the standards of Korean paddy soil, and the water must be in the temperature range of 15 to 35 °C. In the proposed design, approximately 44.0 kg rice can be produced, and catfish can grow up to 30 cm. The study suggested many experiences using rice and freshwater fish. On the basis of our study design, a virtual model of an RFMF paddy was developed in consideration of the accessible space. The development of RFMF paddies in educational institutions can promote biodiversity in cities while providing ecological education regarding aquatic plants and insects.

Keywords: agricultural; urban; rice–fish farming; biodiversity; education; experience; museum

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1. Introduction

Since the institutionalization of the five-day workweek in the 2000s, the demand for urban agriculture, vegetable gardens, and rural tourism has been increasing due to growing interest in health, leisure, and the environment [1–5]. Learning experiences related to nature and ecology are considered important educational tools to promote environmental conservation and to understand the harmony between humans and nature by allowing people to observe and touch living organisms in the field [6–9]. Among them, ecological education and agriculture experience studies have been conducted mostly in suburban farms, fields developed on institutional campuses (i.e., urban agriculture), or vegetable gardens within cities [9–11]. These agricultural education experiences are primarily limited to field and greenhouse crops, such as lettuce, Napa cabbage, and red pepper [12–15]. Although rice is the primary source of food in Korea, conducting educational studies on rice farming throughout the year is challenging [5,16,17] owing to the difficulties with periodically conducting studies that focus on experiential education in suburban fields, such as long-distance travel and inaccessibility [18]. Urban locations, such as science museums, exhibition halls, and public-relations halls, provide an attractive alternative for hosting rice farming education and experiences [19].

The number of visitors to Korea's science museums has surpassed 4 million annually; therefore, customized education programs for visitors are considered essential [20]. However, most science museum programs focus on physics, chemistry, and astronomy [21]. Programs on natural sciences are available but are limited to Earth, earthquakes, and insect observation. Rice fields in Korea, the high ratio of cultivation land use, and the observation of the biodiversity in rice cultivation spaces may be interesting for visitors [22–24].

A rice–fish mixed farming (RFMF) paddy is a system used to add value to conventional farming and involves the culturing of catfish, loach, carp, and shrimp in paddies [25,26]. In Korea, rice farming is a 10,000-year-old tradition, and the wisdom underlying RFMF has been passed on from ancient times (206 BC) [25]. In a mixed farming paddy, a portion of the paddy is designated as a habitat for growing freshwater fish; this is traditionally called a *dumbung*, which corresponds to a pond-type wetland [27–31]. The wetland space outside a paddy has various environmental and ecological benefits [25].

The primary benefits of rice farming include the development of public interest regarding wetlands (e.g., biodiversity, flood control, and water quality protection), as well as its market value, food security, environmental conservation, employment maintenance, regional development, and social and cultural value enhancement [32–36]. Among them, organic farming can improve soil fertility, mitigate GHG and carbon, and preserve biodiversity and various ecosystem services [37–42]. For this reason, the RFMF paddy is found to have higher economic values than conventional paddy (CP) ecosystem services [43,44]. If rice paddies are developed in educational spaces, such as science museums, performing rice farming throughout the year will be possible. Additionally, these locations can be used as places to provide ecological education to visitors, enabling them to collect and observe animals and plants in this space [31].

At present, the utilization of ecological spaces to provide rice farming experiential education is possible only in suburban paddies [45]. Therefore, in this study, we propose a design plan to simultaneously offer rice agriculture education and an ecological experience through the development of an RFMF paddy where rice and freshwater fish co-exist in an easily accessible space of a science museum, a public-relations hall, or an exhibition hall. This study was conducted with the aim of contributing to the preservation of urban biodiversity, the enhancement of the environment (i.e., climate mitigation), and the provision of related education.

2. Materials and Methods

The purpose of the present study is to judge the possibility of using an RFMF paddy for ecological education for the ecological welfare of city dwellers and develop a detailed plan for its construction. This study comprises the following stages: First, we examined the ecosystem services of an RFMF paddy and conducted an expert survey to understand its value for eco-educational use (Section 2.1). Second, a field survey was conducted to identify the difference between the biodiversity of the RFMF paddy and that of the conventional paddy (Section 2.2). Third, soil and water quality was measured at a farm to determine the appropriate conditions for creating an RFMF paddy (Section 2.3), and the paddy design was developed while ensuring both that it could be built in a city and a science center and that it provides an accurate experience in terms of its contents in the space (Section 2.4). A detailed description of the materials and methods is provided below.

2.1. Evaluating the Ecosystem Service Function of the RFMF Paddy

We compared the development of public interest regarding conventional paddies, which are commonly found in Korea, with that regarding RFMF paddies, which have different structural characteristics for growing freshwater fish, based on the outcomes of a survey conducted among experts from various related domains (i.e., environmental, biology engineering, and agricultural fields). The evaluation of ecosystem services must jointly consider the opinions of experts and relevant knowledge. To design the expert survey questionnaire, we considered 17 functions based on the ecosystem services in rural areas introduced by Son et al. [28,46], who reviewed 11 previous studies related to ecosystem services and selected these 17 functions to be considered when implementing developmental projects, such as land-use changes in agricultural ecosystems. The primary functions are groundwater recharge, water storage, water purification, flood control, aquatic insect habitats, amphibian and reptile habitats, vegetation diversity, landscape creation, experience/education, avian habitats, climate regulation, air quality regulation, fishery habitats, rest areas, biological control, genetic diversity maintenance, and mammalian habitats.

The occupations of experts who responded to the questionnaire included 13 (23.6%) business officers, 18 (32.7%) institute researchers, and 19 (34.5%) university professors. Regarding educational degrees, 43 (78.2%) held a doctoral degree, and 3 (5.5%) were enrolled in doctoral courses. Furthermore, 16 experts from biological, 20 from environmental, 14 from engineering, and 6 from agricultural major fields participated in the questionnaire (see Table 1). Regarding these functions, the 56 experts were requested to score the weaknesses or required improvements in each function, using a 7-point Likert scale (+3, +2, +1, 0, −1, −2, or −3), to allow the analysis of the mean value (importance score) of each function. (+) indicates a positive value, and (−) indicates a negative value. Expert opinions on each function were obtained and analyzed. The collected data were analyzed using the SPSS software ver. 19.0 (IBM SPSS Statistics Institute, Chicago, IL, USA).

Table 1. General information of 56 expert respondents.

Category Classification (*n* = 56)		Respondence	
		Number	%
Work Fields	University Professor	19	33.9
	Institute Researcher	18	32.1
	Business Officer	13	23.2
	Public Official	4	7.1
Education Degree	Graduate Student	2	3.6
	Doctor	43	76.8
	Doctoral Course	3	5.4
	Master's Degree	6	10.7
	University Student	4	7.1
Major Fields	Environmental	20	35.7
	Biological	16	28.6
	Engineering	14	25.0
	Agricultural	6	10.7

2.2. Biodiversity of the RFMF Paddy

On the basis of the survey outcomes, the extent of biodiversity that can be improved through RFMF paddies was measured and analyzed on farms in Mundang-ri, Hongdong-myeon, Hongseong-gun, and Chungcheongnam-do, Korea. These farms implemented the RFMF method five times a year (May to September 2019). In Korea, there are very few RFMF paddies. This is because it is difficult to manage and control weeds, diseases, and pests. For this reason, organic rice paddies represent under 1.0% of all paddies in Korea [47–49]. Figure 1 shows pictures of the space created for research purposes.

The vegetation flora was examined by installing three 2×2 m^2 sub-plots per study site, according to the Braun-Blanquet method, and classification and identification were confirmed by Lee [50]. The biodiversity of insects and aquatic invertebrates was investigated by sweeping, which was conducted three times at the waterside edge. The captured individuals were identified and counted in the field using the Korean Animal Name List and the Korean Insect List [51]. Unidentified species were fixed in ethyl alcohol and transported to the laboratory for identification. The community analysis of insects and aquatic invertebrates was conducted using the dominance index (DI), the diversity index (H'), the richness index (RI), and the evenness index (J') [52–55]. Analysis of variance (ANOVA) of the data was performed using SPSS software ver. 19.0. A combined ANOVA was performed using a cultivar as a fixed variable according to [56]. Based on the level of significance calculated from the F-value of the ANOVA, Duncan's multiple range tests were applied at $p \leq 0.05$ for mean comparisons among the various treatments.

Figure 1. Survey site of RFMF paddy (**left**) and conventional rice paddy (**right**) in Hongseong, Korea.

2.3. Soil and Water Quality Analyses of the RFMF Paddy

To determine suitable conditions for developing an RFMF paddy, the soil chemistry of the farms was analyzed using soil and plant analysis methods [57], at the National Institute of Agricultural Sciences, the Rural Development Administration. The considered analysis items were pH, electrical conductivity (EC), organic matter (OM), Av.P_2O_5, potassium (K), calcium (Ca), magnesium (Mg), and Av.SiO_2. Soil pH and EC were measured using a pH/EC meter (Orion StarTM A215 pH meter, Thermo-Scientific, Calsbad, CA, USA), after extraction, by mixing the pretreated soil sample and deionized water in a ratio of 1:5. The OM content was analyzed through a dry continuous method using an elemental analyzer (VarioMAX CN, Elementar, Langenselbold, Germany). The available phosphate (Av.P_2O_5) was analyzed using the Lancaster method, namely, by measuring the absorbance at 720 nm (UV-2600, Shimadzu, Kyoto, Japan). Exchangeable cations (potassium, Ex. K; calcium, Ex. Ca; and magnesium, Ex. Mg) were extracted with 1 M NH_4OAc (pH 7.0) buffer solution and analyzed using ICP (Integra XL, GBC Scientific Equipment Ltd., Braeside, VIC, Australia). Available silicate (Av. SiO_4) was analyzed by measuring the difference in color developed by redox reaction through measuring the absorbance at 700 nm (UV-2600, Shimadzu, Kyoto, Japan).

In this study, the temperature and pH of paddy water were analyzed to determine the conditions for establishing a suitable water environment for aquatic organisms. Species commonly found in a paddy and *dumbung* were presented as collectible and observable species for experiential education. Reflecting on the structural characteristics of the real farm, we propose a design plan and provide data on the necessary soil environment characteristics for developing a functional RFMF paddy. We also present a method for future rice farming and freshwater fish management, including details for ensuring suitable water quality for paddy management.

2.4. Composition Design and Educational Use Plan of the RFMF Paddy

On the basis of the study results, a virtual model was developed using a three-dimensional design of the accessible green space in front of the Agricultural Science Museum of the Rural Development Administration, which conducts various agricultural studies in Korea.

The design that was tested incorporates two separate regions for the growth of rice and fish. The experimental area was the experimental paddy field in the National Institute of Agricultural Sciences, the Rural Development Administration. It was installed exactly according to the envisioned design, and the growth of rice and fish was observed for 1 year (Figure 2).

Figure 2. Creation ((**left**) April) and management ((**right**) June) of a rice–fish mixed farming paddy.

The educational application of the RFMF paddy was presented in terms of rice and fish farming. The experience content refers to the analysis results of Han, Son, Choi, and Yoon [58], who analyzed 3007 types of experiences in 168 rural tourism villages in Korea.

3. Results

3.1. Public Interest Regarding RFMF Paddies

On the basis of the expert evaluation results (Table 2, Appendix A), we assessed the increase in ecological and environmental as well as experience and educational functions resulting from the introduction of an RFMF paddy compared with that for a conventional paddy. The mean scores of the 17 wetland functions ranged from 0.89 to 2.39, where (+) indicates a positive value, and (−) indicates a negative value; all function scores were positive, and the mean score of the amphibian and reptile habitat function was the highest (2.39 ± 0.69). Thus, species diversity and population size can be increased with the development of a waterway-type *dumbung*, through its function in providing a habitat for amphibians and reptiles. The results also indicated that functions related to biodiversity, such as aquatic insect habitats (2.36 ± 0.66), fishery habitats (2.34 ± 0.78), vegetation diversity (2.13 ± 0.78), and avian habitats (2.05 ± 0.94), will show large improvements. The experience and education (2.29 ± 0.64) function would also increase, considering the expert opinion that the waterway-type *dumbung* can be used for ecological experiences and education, such as fishing and organism collection (Table 2). Paddies have various functions, including rice production for food [59,60]. Some other agricultural functions include food security, the maintenance of the viability of rural communities, land conservation, the sustainable management of renewable natural resources, and environmental protection (through, e.g., biodiversity conservation and aesthetic landscape development) [61]. Moreover, waterway-type *dumbungs* act as wetlands, increasing the ecological function of paddies [25,26]. Therefore, irrigation ponds and canals are important elements in rice farming [60,62]. Several studies have focused on ponds in terms of their important role in the biodiversity conservation of agricultural lands [63–65]. The combination of these aspects will increase the efficiency of environmental and ecological functions.

The outcomes resulting from the analysis of expert opinions regarding the effects of combined agriculture on ecological service enhancement indicate that all functions will be improved. Many previous studies have considered paddies as spaces that benefit various environments [66–70]. Regarding their value as habitats for amphibians and reptiles, positive opinions were obtained, considering that they can act as an ecological spawning ground and hiding place for various amphibians (i.e., Seoul pond frogs and salamanders) and reptiles, due to the greater water depth and extended open surface owing to the ecological farming method. However, it was expressed, as a negative opinion, that the movement of amphibians and reptiles will be restricted by artificial insect screens and partitions installed for fish farming. The movement patterns of amphibians can be affected by anthropogenic obstacles [71], and artificial structures limit the movement of amphibians and reptiles in agricultural ecosystems [72]. Nevertheless, positive opinions suggested that such screens can be used by aquatic insects for shelter during the midsummer drainage period and vulnerable winter season. In addition, the artificial introduction of fish could reduce the number of aquatic insects and sources, causing a disturbance. Although some experts have argued that fish species diversity will increase as a result of building a *dumbung* to grow freshwater fish, others have highlighted that fish species other than artificially introduced species cannot enter due to the blocked and isolated structure. Although small-scale fish farms have a modest impact on water quality [73], fish activity has been reported to have a negative impact [74]. In terms of vegetation diversity, many experts have suggested that waterways play a bigger role as a habitat than the conventional paddy and, as a result, the influx of plants found in wetlands, such as submerged, merged, and floating plants, will present a large increase. However, the artificial management of the habitats of freshwater fish may introduce unnecessary species, such as naturalized plants and invasive species, or decrease diversity. This is consistent with the finding that the high distribution of naturalized plants is highly influenced by the presence of humans in rural areas due to associated land-use patterns [75–77].

Table 2. Expert assessment of RFMF ecosystem services.

Function	Mean [1]
Amphibian and reptile habitat	2.39 ± 0.69 [F]
Aquatic insect habitat	2.36 ± 0.66 [F]
Fishery habitat	2.34 ± 0.78 [F]
Experience and education	2.29 ± 0.64 [F]
Vegetation diversity	2.13 ± 0.78 [F]
Avian habitat	2.05 ± 0.94 [E,F]
Groundwater recharge	1.71 ± 1.12 [D,E]
Water storage	1.68 ± 1.13 [D,E]
Maintenance of genetic diversity	1.66 ± 1.22 [D,E]
Biological control	1.59 ± 1.07 [D]
Water purification	1.46 ± 1.28 [C,D]
Mammalian habitat	1.39 ± 1.00 [B,C,D]
Creating landscape	1.32 ± 0.98 [B,C,D]
Climate regulation	1.09 ± 1.01 [A,B,C]
Rest area	1.02 ± 1.13 [A,B]
Air quality regulation	0.98 ± 0.98 [A,B]
Flood control	0.89 ± 1.20 [A]

[1] Test result is statistically significant (Duncan): $^{A} < ^{B} < ^{C} < ^{D} < ^{E} < ^{F}$.

In addition to rice farming, the fishing of freshwater fish, collection of organisms from waterways, and provision of ecological education are possible. These activities may enhance the organic safety of the produced rice in addition to diversifying income sources by expanding the freshwater fish-harvesting event into a village festival. Some studies have attempted to introduce storks through reducing the use of chemical fertilizers [78–80]. Growing rice in areas where there are Japanese and Korean storks contributes to the development of the rice brand, and tourism can also be improved, as the number of visiting tourists interested in storks will increase [79]. Such relationships among agricultural product production, brand development, education, and tourism form an essential industrial structure in rural areas [81–83].

3.2. Structural Composition Plan for the RFMF Paddy

We propose a plan for the development of an RFMF paddy, considering its various benefits, for urban students (Figure 3). The design was based on an empirical test at a farm actually implementing an RFMF paddy. The size of the RFMF paddy for rice agriculture and ecological education was 10 m × 10 m (=100 m^2 = 1 a). The bank was reinforced by digging the soil inside the paddy, and a 1.2 m *dumbung* was built around it.

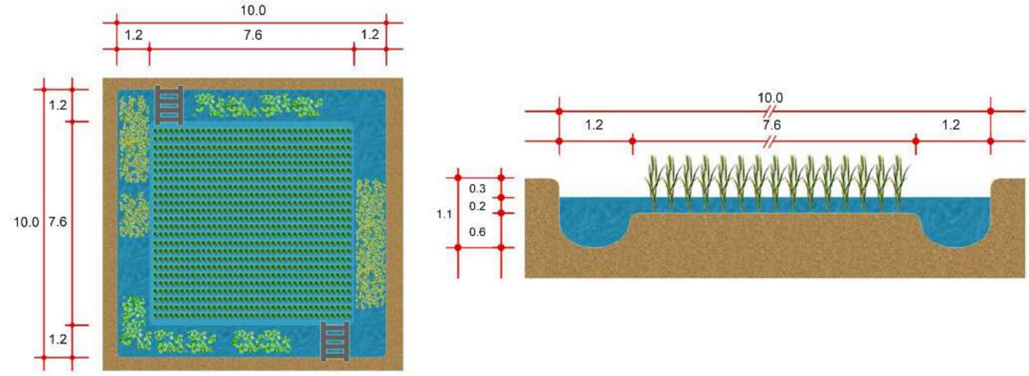

Figure 3. Proposed RFMF paddy design (unit: m).

A bridge-shaped 0.6 m wide passageway was installed to facilitate movement over the waterway to the paddy. The rainfall pattern in Korea is irregular [84,85], and temperature and water are the most important environmental factors in rice farming [86–88]. Therefore, installing an irrigation hole is necessary to periodically water the paddy, in order to counter the effects of irregular rainfall. Additionally, drainage holes must be installed to prevent flooding caused by heavy rain. Korea has historically lost large amounts of agricultural land every year to floods [89,90]. The height of a typical paddy bank is usually maintained at approximately 26 cm [91], and the depth should not exceed 80 cm to ensure the safety of the fish habitat. Moreover, a shallower water depth may be required if the space is to be used by children aged <6 years. Thus, it is recommended that the water depth should not exceed 30 cm, the threshold applied in standards for children's experience facilities [92]. Moreover, getting out of paddy soil is challenging, due to the high clay content [93]. Hence, installing safety bars is recommended when developing an experiential wetland [94].

3.3. Biodiversity of the RFMF Paddy and the Selection of Target Species

We investigated the biodiversity of the RFMF paddy. The field of investigation is vegetation flora, insects of land, and aquatic invertebrates of a hydrographic *dumbung*. Through this investigation, it was confirmed whether there was a species difference between a conventional paddy (CP) and an RFMF paddy (Table 3). In addition, it was possible to identify common species that can be used for experience and education.

The number of observed plant species (taxa) among the various paddy types was in the following order: $RFMF_A$-type (35.6 ± 8.9 species), $RFMF_B$-type (34.8 ± 6.3), and $RFMF_C$-type (34.6 ± 9.8) > CP (23.8 ± 5.3). This corresponds to approximately 10 more species found in the RFMF paddy than in the conventional paddy (CP). However, as a result of ANOVA analysis, this was not statistically verified. In general, in Korean rice paddies, there is a similar variety of plant taxa to the CP study site. Comparing the total number of taxa of the CP and RFMF sites, there is a difference of 26 compared to 32 types. The hydrographic dump is a space that develops wetland plants, which has contributed to improving plant diversity.

The results of examining the diversity of land insects are as follows: $RFMF_A$-type (27.4 ± 11.0 species), $RFMF_C$-type (34.4 ± 14.2), $RFMF_B$-type (19.8 ± 5.4), and CP (19.4 ± 11.7). The $RFMF_B$-type paddy has 15 more species than the conventional paddy (CP). However, as a result of ANOVA analysis, this has not been statistically verified. In addition, CP was found to have a low diversity index (H') and a high dominance index (DI). This means that the RFMF paddy is more diverse in terms of land insects than the CP.

Table 3. Biodiversity analysis of RFMF paddies.

Classification	$RFMF_A$	$RFMF_B$	$RFMF_C$	CP	Significance	
					F-Value	Post Hoc
Vegetation						
Total taxa	75	85	91	59	-	-
Average	35.6 ± 8.9	34.8 ± 6.3	34.6 ± 9.8	23.8 ± 5.3	2.602	N.S
Insect						
Species	27.6 ± 11.3	34.4 ± 14.2	19.8 ± 5.4	19.4 ± 11.7	2.054	N.S
Individual	57.0 ± 17.8	83.8 ± 26.8	68.4 ± 45.1	61.4 ± 43.7	0.554	N.S
H′	4.41 ± 0.66	4.61 ± 0.80	3.70 ± 0.50	3.40 ± 0.86	3.189	N.S
J′	0.94 ± 0.01	0.92 ± 0.05	0.87 ± 0.10	0.85 ± 0.05	2.410	N.S
RI	6.54 ± 2.48	7.51 ± 2.85	4.64 ± 0.84	4.41 ± 2.28	2.230	N.S
DI	0.21 ± 0.06	0.22 ± 0.12	0.34 ± 0.14	0.44 ± 0.15	4.185 *	CP > C > A, B
Aquatic invertebrates						
Species	19.4 ± 3.1	19.4 ± 3.9	20.6 ± 4.7	4.2 ± 5.8	14.882 ***	C, B, A > CP
Individual	61.8 ± 16.7	87.8 ± 13.1	95.6 ± 39.7	16.2 ± 22.4	10.146 **	C, B, A > CP
H′	3.85 ± 0.22	3.61 ± 0.81	3.83 ± 0.36	1.11 ± 1.52	11.253 ***	A, C, B > CP
J′	0.90 ± 0.01	0.84 ± 0.14	0.88 ± 0.03	0.33 ± 0.45	6.683 **	A, C, B > CP
RI	4.47 ± 0.54	4.22 ± 0.95	4.32 ± 0.70	1.02 ± 1.42	14.814 ***	A, C, B > CP
DI	0.31 ± 0.04	0.39 ± 0.18	0.34 ± 0.06	0.21 ± 0.29	0.883	N.S

* $RFMF_A$: rice + catfish; $RFMF_B$: rice + loach; $RFMF_C$: rice + shrimp; CP: conventional paddy. Test result according to Duncan's multiple range statistically significant at the $p = 0.5$ level (*), 0.01 level (**), and 0.001 level (***); NS = nonsignificant result. H′: diversity index, J′: evenness index, RI: richness index and DI: dominance index.

The number of observed aquatic invertebrate species according to type among the various paddy types was in the following order: $RFMF_A$-type (19.4 ± 3.1 species) > $RFMF_B$-type (19.4 ± 3.9) > $RFMF_C$-type (20.6 ± 4.7) > CP (4.2 ± 5.8). Approximately about 15 species were more found in the RFMF paddy than in the conventional paddy. The RFMF paddy with a hydrographic *dumbung* showed a higher number of species, and it can be concluded that the development of a *dumbung* provided expanded space for various habitats. In indices such as diversity, richness, and the evenness index, results in the RFMF paddy were greater than those of the CP. It can be concluded that the *dumbung* created for RFMF contributes to the diversity of aquatic invertebrates.

RFMF paddies are typically managed without fertilizers and pesticides and are filled with freshwater. Jungle rice (*Echinochloa colona*), water foxtail (*Alopecurus geniculatus*), clover (*Trifolium* spp.), dandelion (*Taraxacum* spp.), spiny sowthistle (*Sonchus asper*), conyza (*Erigeron canadensis*), curly dock (*Rumex crispus*), giant chickweed (*Stellaria pubera*), common groundsel (*Senecio vulgaris*), wood sorrel (*Oxalidaceae* spp.), water pepper (*Persicaria hydropiper*), violet (*Viola* spp.), mugwort (*Artemisia* spp.), water parsley (*Oenanthe javanica*), green foxtail (*Setaria viridis*), common duckweed (*Spirodela polyrhiza*), and water hyacinth (*Eichhornia crassipes*) are species that are commonly found in conventional paddies and in banks [95,96].

Weeds growing around rice fields have been used as the main ingredients for oriental medicines for a long time, and, if an educational program was established based on this content, their utilization could be highly promoted [31]. Depending on the input, Far Eastern catfish (*Silurus asotus*), loaches (*Misgurnus anguillicaudatus*), Chinese weatherfish (*Misgurnus mizolepis*), crucian carp (*Carassius carassius*), Asiatic ricefish (*Oryzias latipes*), minnow (*Zacco platypus*), and lake prawns (*Palaemon paucidens*) may inhabit the waterway; it has also been considered that black-spotted pond frog (*Rana nigromaculata*) and tree frog (*Hyla japonica*) can be introduced to the paddy habitat [28,29,97–101]. Although the diversity will increase in the waterway space along with the number of years of maintenance, various common aquatic biota, such as leeches (Hirudinea), Korean muljara (*Appasus japonicus*), water scorpions (*Laccotrephes japonensis*), water beetle (*Asellus hilgendorfii*), diving beetle (*Cybister japonicus*), dark diving beetle (*Hydrophilus acuminatus*), ranatra (*Ranatra* *chinensis*), Chinese mystery snail (*Cipangopaludina chinensis*), and Radix auricularia (*Lymnaea auricularia*), can appear and inhabit the environment [102–109].

Moreover, bees visit and collect pollen during the rice flowering period [110]. Dragonflies, mantises, grasshoppers, ladybugs, stink bugs, bees, sulfur butterflies, and cabbage butterflies are insects that commonly appear in rice fields [50,108,110–114], and exploring the contribution of the science museum RFMF paddy toward the ecosystem is possible by investigating the species that emerge after its development. Figure 4 presents an illustration of an example RFMF paddy containing various organisms that can be used in such an investigation.

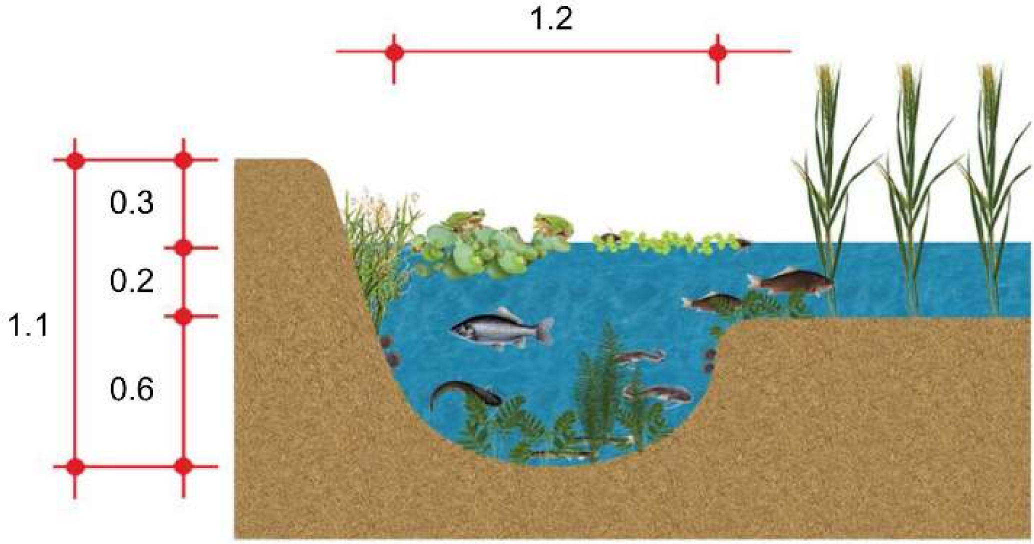

Figure 4. Illustration of an example RFMF paddy containing biological species that can be investigated (unit: m).

3.4. Soil and Water Quality Management Plan for the RFMF Paddy

The soil from a real farm with an RFMF paddy was analyzed to determine the optimal characteristics of the soil environment for developing our RFMF paddy. The soil chemistry results showed that the OM was 1.9%, the pH was 6.6, and available phosphate was 178.0 mg/kg (Table 4). These values are within the recommended chemical ranges for Korean paddy soil [115,116]. Korea's Rural Development Administration conducts soil analysis for the cultivation of rice paddies [117]. The analysis results of our study (Table 4) are similar to those of general rice paddies. However, it is necessary to add additional fertilizers according to the type of rice or the exploitation of organic materials.

Table 4. Topsoil environment of the RFMF paddy.

pH (1:5)	EC (ds/m)	OM (g/kg)	Av.P_2O_5 (mg/kg)	Ex.(cmolc/kg)			Av.SiO_2 (mg/kg)
				K	Ca	Mg	
6.6	0.4	19.0	178.0	0.1	6.3	1.7	307.0

When developing an RFMF paddy, soil with little water loss and the appropriate amount of OM should be prepared to ensure that the soil characteristics are suitable for rice farming [118–120]. When developing a wetland or paddy field within a science museum or city, collecting the topsoil from a nearby paddy and placing it at the target site can help stabilize the soil physicochemical properties for rice growth and easily and quickly establish biodiversity by introducing buried seeds and larvae. Many weed seeds have been reported to be buried in paddy soil [121,122], which are useful for rapidly developing vegetation diversity [123–125]. The introduction of soil (including many plant seeds) has provided ecological restoration in urban areas [126,127].

Tap water can be used as supply water to the paddies in a city. The temperature and quality of the paddy water affect rice growth and yield [86–88,128–131]. Several field experiments have been performed to determine the effects of irrigation conditions on paddy water temperature [132–135]. As a result, when the water temperature and quality differ from those in existing paddy fields, the growth of the rice and living organisms may be negatively affected. The examination of the characteristics of the water environment of the RFMF paddy showed that pH ranged between 7.1 and 8.0, and the water temperature ranged between 20.2 and 30.7 °C during the freshwater period (June–October) for rice production (Figure 5). In fact, the optimal water temperature for rice growth was approximately 15–35 °C, and best temperature was around 30 °C [27,62,136]. While the optimal possible pH for rice growth was 5.0–9.0, the best pH was approximately 6.5–8.5 [137–139]. The water supply for urban agriculture is bound to use public tap water. However, there may be a difference between paddy water and public tap water depending on the season. Rapid changes in pH and water temperature can affect rice production, freshwater fish, and other aquatic organisms [136,140]. Therefore, the water should be stored in a primary tank with a pH maintained between 6.5 and 8.5 before introduction into the paddy to avoid sudden changes in water temperature when irrigating for urban agriculture.

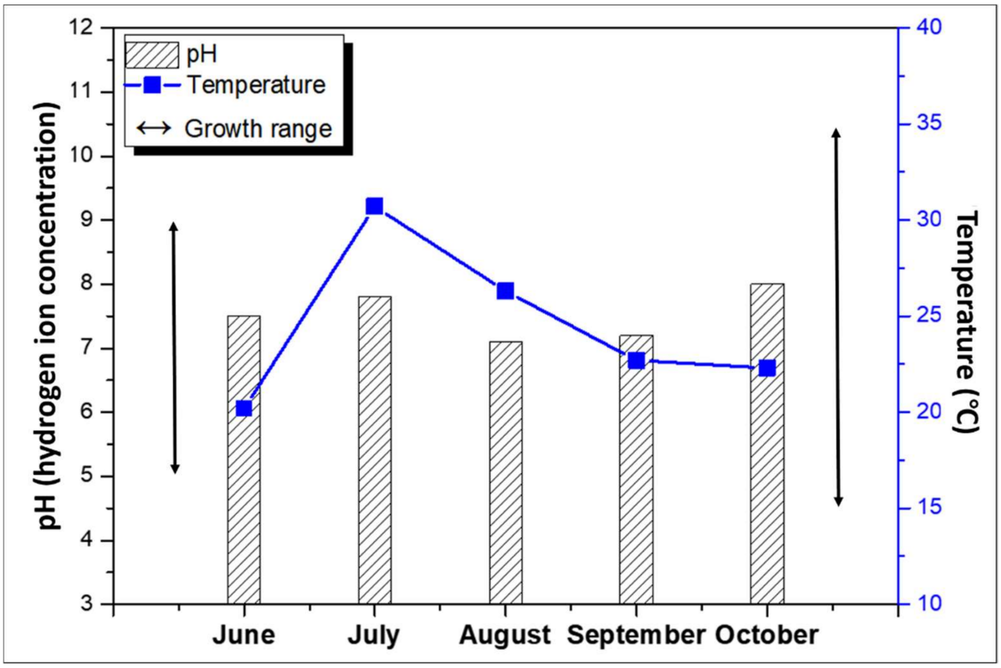

Figure 5. pH and temperature of RFMF paddy water; growth range was presented in [137–139] (pH) and [27,62,136] (temperature).

3.5. Rice and Freshwater Fish Management Methods and Related Educational Contents

Rice cultivation methods in Korea vary greatly depending on the production purpose, region, and rice variety [141–143]. Therefore, it is appropriate for operations to be conducted according to the given situation. The rice variety used in this study is 'Jopyeong'. It generally takes 6 months from sowing to produce rice in Korea [144] (Choe et al., 2003); however, 'Jopyeong' plants can produce rice in 4 months, which is faster than other varieties [145,146]. Shortening the period may be advantageous for the purpose of experience and education. Traditionally, Korea has been an agricultural country, with many rural tourism villages. The ecological experiences of rice and fish farming based on rice paddies in these villages were linked to the present study by analyzing the work of Han, Son, Choi, and Yoon [58].

For rice growth, sound rice seeds must first be selected by brining with saline water. Then, these seeds should be sterilized by soaking in hot water at 60 °C for 10 min. Afterward, they are sprouted, sown in a seedbed, and grown in a rice nursery (with the seedbed and rice nursery comprising an experience). After dividing the RFMF paddy around March, 100 kg/a of manure is applied as basic fertilizer in April, and the paddy is irrigated. The earlier it is irrigated, the more stable the paddy ecosystem, as aquatic organisms can emerge earlier in the paddy. In May, rice seedlings grown in the rice nursery are planted. After installing 30 cm × 20 cm grid lines, 3–5 seedlings are planted at a depth of 2–3 cm (comprising a rice planting experience). The water depth should be maintained between 7 and 10 cm for a week after planting, such that the roots can be quickly established. As the rice grows taller, the water depth needs to be increased. As the rice and weeds compete for nutrients and sunlight, effective weeding must be carried out to manage the weeds (comprising weeding experiences), which are managed through organic farming methods, in consideration of the freshwater fish that are present, and when the occurrence of diseases and pests are observed (based on visual inspection of the bank and inside the paddy and on organic farming education). Rice blooms from July–August and can be harvested, after approximately 40 days, in August and September (comprising rice harvesting and threshing experiences). After harvesting the rice, a new shoot—called an offshoot—emerges from the rice plant root stump. Following its harvest in August, rice is ripened from the new shoot that emerges from the stump. It is possible to recover the RFMF paddy used for rice production for a year by using the rice straw and maintaining the aquatic ecosystem through irrigation (with rope-, straw thatch-, and sandal-making experiences using rice straw). Freshwater rice cultivation is a representative agricultural tradition in East Asia [147,148]. The resulting variety of crafts is a cultural characteristic of many East Asian countries, including Korea, Japan, and China [149]. As mentioned above, various experiential learning experiences can be provided through rice and freshwater fish farming. However, caution is required to ensure measures are in place for preventing young and elderly people from falling into the freshwater fish habitat while visiting the paddy.

To inform our design, we analyzed the growth and yield of an actual RFMF paddy operating at a farm. The results indicated that a 10 a (1000 m^2) RFMF paddy can produce approximately 762.0 kg rice (Table 5). Organic fertilizer was added to Site 1, while nothing was applied to Site 2. At Site 2, the OM present in the soil and the nitrogen and phosphorus contained in the fish feed helped in the production of rice. Using eco-friendly organic products as fertilizers for paddy fields, it is possible to match the rice production yield of Site 1. According to Table 5, the rice cultivation area of 57.76 m^2 in the developed 10 m × 10 m wide RFMF paddy can produce 44.0 kg rice per year, organic fertilizer added to the paddy can produce 47.7 kg (Site 1), and adding nothing to the paddy can produce 40.3 kg (Site 2). The produced rice can be branded as being representative of the food culture of East Asia, which is associated with the traditional practices of making rice cakes and wine [150,151].

Table 5. Results of the rice yield survey of an actual RFMF paddy in a farm.

Type	Plant (cm)	Culm Length (cm)	Panicle		Yield (kg/10a)
			(cm)	(No./m^2)	
Site 1	99.1	78.5	20.6	321	826
Site 2	95.2	73.9	21.3	287	698
Average	97.2	76.2	21.0	304.0	762.0

Catfish, carp, oriental weatherfish, loaches, and shrimp have been introduced into RFMF paddies in Korea [26,152]. When a habitat is established in a paddy, the feed cost is expected to decrease, as the fish will feed on aquatic insects and pests in the water [153,154] which, in turn, positively influences rice growth [155]. This reduces the amount of pesticides needed for rice cultivation and ensures safe production. Freshwater fish were supplied by nurseries and aquafarms two weeks after planting the rice seeds, which is necessary for root establishment, and the fish were introduced to the RFMF paddy from the end of May to early June (freshwater fish introduction). Measuring the amount of dissolved oxygen, ammonia, nitrous acid, and pH of the habitat of the freshwater fish is necessary to assess the changes in water quality. The amount of feed supply is controlled with respect to the growth of fish, which is determined through measuring their length and weight (comprising freshwater fish feeding and size measurement experiences). The freshwater fish can be partially harvested by fishing or with fish traps, nets, etc., when the paddy is irrigated, or fully harvested after the completion of rice production and drainage of water in October/November using scoop and landing nets (comprising freshwater fish fishing and harvesting experiences). The total number, size (length and weight), and growth status of the harvested freshwater fish are examined, and the harvested fish can be stored in a tank over the winter, sold, or used as food (comprising a freshwater fish cooking experience). Catfish grown for approximately 4 months in the waterway-type dumbung of an RFMF paddy can grow up to 30 cm in size and be used as samples for the provision of various experiences and/or as food. The freshwater organisms grown at the study site were catfish, loaches, and shrimp, confirming the possibility of using this setup to grow these three freshwater fish species. However, if juvenile fish are used, it will be difficult to grow fish big enough to be used for food within a few months. Therefore, we suggest using older fish for the experience, as the experience of catching and raising fish in the city is considerably different to that in an aquafarming context.

Table 6 presents the experiential education contents through rice and freshwater fish co-production in the RFMF paddy. A correct interpretation must accompany the environmental education of a mixed ecology paddy—the subject of this study. The number of visitors to Korea's science museums surpasses 4 million annually and, thus, customized education for visitors is essential [20]. The purpose of this study was to implement an environment–ecology–agriculture program for science museum visitors. Understanding information correctly [156,157] and interpretation are important [158] for understanding and educating about the environment. In addition, the roles of marketers and site operators can determine the success or failure of pilot operations such as research sites [159,160]. These processes can contribute to enhancing the image of the operating institution, promoting park activities, increasing local economic value, changing visitor behaviors, and conserving resources [161].

Table 6. RFMF paddy experiential education contents.

Type	Experiential Contents (Han et al., 2015 [58])
Rice farming	Making a seedbed and growing a rice nursery; rice planting; weeding; observation of paddy (bank and inside); organic farming education; rice harvesting and threshing; and rope-making, straw-thatching, and sandal-making using rice straw
Fish farming	Freshwater fish introduction, feeding, size measurement, fishing and harvesting, and cooking

3.6. Development of an RFMF Paddy in an Urban Education Space

We developed a virtual model of an RFMF paddy using a 3-dimensional model for the Agricultural Science Museum of the Rural Development Administration to provide experiences and educational materials for agricultural and ecological education (Figure 6). This education and experience program includes rice production, rice planting, weeding in the paddy, harvesting, threshing, and crafting using rice straw. It is also possible to provide fish feeding, fishing and harvesting, and cooking experiences using freshwater fish. Ecological survey education and experience may include surveys on land and aquatic animals, plants in the paddy, bees during the rice flowering period, and the ecological food chain. The RFMF paddy model can be used as an educational and experiential space for various people, especially urban residents and children. Cities lack natural spaces [162,163] or sufficient space to practice agriculture [163–167]; therefore, several studies have considered the introduction and development of various green areas in urban cities. The RFMF paddy presented in the virtual model can serve as such a space, with great value due to its beneficial impacts on agriculture, green areas, ecology, education, and the environment.

Figure 6. Virtual model (**below**) of an RFMF paddy at the Agricultural Science Museum (**above**).

4. Discussion

The rural areas and agricultural sector of Korea have made diverse attempts to improve agricultural management. Among them, organic agricultural products have produced a higher income than conventional agriculture, and eco-friendly agricultural products are being produced nationwide using various farming methods. This study investigated a new type of complex farming that produces freshwater fish as well as organic rice for the environmental and ecological functions of rural areas. This study proposed a design plan to simultaneously provide paddy-farming education and ecological experience by developing an RFMF paddy in an educational space, such as a science museum or an experience hall.

This study analyzed expert opinions regarding the effects of complex agriculture on the enhancement of ecosystem services. The expert opinion is that the RFMF paddy can be used for ecological experiences and education (2.29 ± 0.64, first grade), such as fishing and organism collection.

This study suggested the size of an RFMF paddy for agriculture and ecological education in the Science Center of approximately 1a (10 × 10 m = 100 m^2), which is achievable during its development.

The RFMF-type with a hydrographic *dumbung* presented a high number of species. Vegetation in the RFMF-type comprised approximately 34.6~35.6 species, and the CP comprised 23.8 species. A similar result was observed for insects, the RFMF-type comprised approximately 19.8~34.4 species, and the CP, 19.4 species. Additionally, aquatic invertebrates in the RFMF-type were made up of 19.4~20.6 species, and in the CP, only 4.2 species. It can be concluded that the development of a *dumbung* provided expanded space for various habitats. In indices such as diversity, richness and the evenness index, results in the RFMF paddy were greater than those in the CP. It can be concluded that the *dumbung* created for RFMF contributes to the diversity of the species. The target plant species for the RFMF paddy were rice, water foxtail, clover, dandelion, spiny sowthistle, conyza, curly dock, giant chickweed, common groundsel, wood sorrel, water pepper, violet, mugwort, water parsley, green foxtail, common duckweed, and water hyacinth, which are commonly found in paddies and banks. The aquatic organisms found in the waterways included Far Eastern catfish; loaches; Chinese weatherfish; crucian carp; Asiatic ricefish; minnow; lake prawns; and amphibians, such as black-spotted pond frog and tree frogs. During the flowering period of rice, it will be possible to observe bees, dragonflies, mantises, grasshoppers, long-headed grasshoppers, ladybugs, sulfur butterflies, and cabbage butterflies, which are commonly observed insects in rice fields. According to the survey results, the vegetation and aquatic invertebrates of the RFMF paddy comprised 40 species more than a conventional paddy. However, this study did not identify biodiversity after the construction of the RFMF paddy in urban areas.

To develop an RFMF paddy in a green space, collecting the topsoil from a nearby paddy (Table 4) and adding it to the target site is advantageous because it can stabilize soil physicochemical properties. Caution is needed when using groundwater and tap water so as not to change the temperature (15–35 °C) of the RFMF paddy water to a large extent. Rice and freshwater fish farming is possible if the pH is maintained between 6.5 and 8.5.

In the proposed design, approximately 44.0 kg of rice can be produced, and catfish can grow up to 30 cm. If organic fertilizers are added, the production and quality of rice can be increased. The educational/experiential aspects of rice and freshwater fish production methods include rice production, rice planting, paddy weeding, rice harvesting, threshing, crafting using rice straw, feeding freshwater fish, freshwater fish fishing, harvesting, and cooking.

5. Conclusions

In this study, designs for application in urban areas, the prediction of biodiversity effects, target species selection, water and soil composition and management, rice production prediction, and experience programs were presented. The RFMF paddy proposed in this study can improve the ecosystem service function of the urban area.

During RFMF operations, care should be taken to prevent young and elderly people from falling into the deep *dumbung* during the experience. Ecological education and experience may include surveys on paddy land and aquatic animals, plants in paddy fields, bees during the rice flowering period, and the ecological food chain. However, the limitations of this study were that the study design was not actually applied and the effects of biodiversity and the environment on the surrounding areas could not be quantitively evaluated while developing an RFMF paddy. Therefore, we will install an RFMF paddy in urban areas through follow-up research. Through that, we will scientifically evaluate the biodiversity and ecosystem service function for RFMF paddies.

The results of this study can be used for agricultural–environmental–ecological education in urban areas, such as science museums, exhibition halls, and public-relations halls. The role of the science museum manager is important for creation, management, and operation. The RFMF paddy can be helpful in discovering the diverse contents of science museums and urban green designs. To date, ecological education and urban agriculture studies have been separate from biology, ecology, and agriculture. However, RFMF rice paddies can be used as an experience space for urban residents for ecological and urban agriculture education. Furthermore, in addition to the educational benefits, mixed farming paddies may contribute to the preservation of biodiversity in the urban area and improve the environment in terms of climate mitigation.

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Appendix A

Table A1. Expert assessment result according to the ecosystem function effects of rice–fish mixed farming.

Functions	Major field				Mean (n = 56)	F-Test [1]
	Environmental (n = 20)	Biological (n = 16)	Engineering (n = 14)	Agricultural (n = 6)		
Amphibian and reptile habitat	$2.50 \pm 0.59^{a,b,D}$	$2.50 \pm 0.71^{a,b,F}$	$2.00 \pm 0.76^{a,E,F}$	$2.67 \pm 0.47^{b,C}$	2.39 ± 0.69^{F}	NS
Aquatic insect habitat	$2.40 \pm 0.58^{a,b,D}$	$2.56 \pm 0.61^{b,F}$	$1.93 \pm 0.70^{a,D,E,F}$	$2.67 \pm 0.47^{b,C}$	2.36 ± 0.66^{F}	3.184 *
Fishery habitat	$2.35 \pm 0.73^{a,C,D}$	$2.31 \pm 0.85^{a,D,E,F}$	$2.21 \pm 0.86^{a,F}$	$2.67 \pm 0.47^{a,C}$	2.34 ± 0.78^{F}	NS
Experience and education	$2.20 \pm 0.60^{a,C,D}$	$2.38 \pm 0.70^{a,E,F}$	$2.21 \pm 0.67^{a,F}$	$2.50 \pm 0.50^{a,B,C}$	2.29 ± 0.64^{F}	NS
Vegetation diversity	$2.15 \pm 0.73^{a,b,C,D}$	$2.31 \pm 0.68^{a,b,D,E,F}$	$1.71 \pm 0.80^{a,B,C,D,E,F}$	$2.50 \pm 0.76^{b,B,C}$	2.13 ± 0.78^{F}	NS
Avian habitat	$2.10 \pm 0.54^{a,C,D}$	$2.25 \pm 0.90^{a,C,D,E,F}$	$1.79 \pm 1.15^{a,C,D,E,F}$	$2.00 \pm 1.41^{a,A,B,C}$	$2.05 \pm 0.94^{E,F}$	NS
Groundwater recharge	$1.70 \pm 1.10^{a,B,C}$	$1.50 \pm 1.00^{a,A,B,C,D}$	$1.64 \pm 1.34^{a,B,C,D,E,F}$	$2.50 \pm 0.50^{a,B,C}$	$1.71 \pm 1.12^{D,E}$	NS
Water storage	$1.70 \pm 1.05^{a,B,C}$	$1.44 \pm 1.12^{a,A,B,C}$	$1.50 \pm 1.24^{a,B,C,D,E,F}$	$2.67 \pm 0.47^{b,C}$	$1.68 \pm 1.13^{D,E}$	NS
Maintenance of genetic diversity	$1.35 \pm 1.28^{b,A,B}$	$1.81 \pm 1.07^{a,b,B,C,D,E,F}$	$1.57 \pm 1.35^{a,b,B,C,D,E,F}$	$2.50 \pm 0.50^{a,B,C}$	$1.66 \pm 1.22^{D,E}$	NS
Biological control	$1.45 \pm 1.02^{a,A,B}$	$1.75 \pm 1.03^{a,B,C,D,E,F}$	$1.50 \pm 1.18^{a,B,C,D,E,F}$	$1.83 \pm 1.07^{a,A,B,C}$	1.59 ± 1.07^{D}	NS
Water purification	$1.30 \pm 1.27^{a,A,B}$	$1.38 \pm 1.62^{a,A,B}$	$1.64 \pm 1.04^{a,B,C,D,E,F}$	$1.83 \pm 0.69^{a,A,B,C}$	$1.46 \pm 1.28^{C,D}$	NS

Table A1. *Cont.*

Functions	Major field				Mean (n = 56)	F-Test [1]
	Environmental (n = 20)	Biological (n = 16)	Engineering (n = 14)	Agricultural (n = 6)		
Mammalian habitat	1.25 ± 0.89 a,A,B	1.63 ± 1.11 a,B,C,D,E	1.21 ± 1.01 a,A,B,C,D,E,F	1.67 ± 0.94 a,A,B,C	1.39 ± 1.00 B,C,D	NS
Creating landscape	1.45 ± 0.80 a,A,B	1.25 ± 1.09 a,A,B	1.14 ± 1.12 a,A,B,C,D,E	1.50 ± 0.76 a,A,B	1.32 ± 0.98 B,C,D	NS
Climate regulation	1.10 ± 0.83 a,A,B	1.25 ± 1.03 a,A,B	0.86 ± 1.30 a,A,B,C	1.17 ± 0.69 a,A	1.09 ± 1.01 A,B,C	NS
Rest area	1.00 ± 1.00 a,A	1.00 ± 1.27 a,A,B	0.93 ± 1.22 a,A,B,C,D	1.33 ± 0.94 a,A	1.02 ± 1.13 A,B	NS
Air quality regulation	1.25 ± 0.94 a,A,B	0.75 ± 0.75 a,A	0.71 ± 1.28 a,A,B	1.33 ± 0.47 a,A	0.98 ± 0.98 A,B	NS
Flood control	1.20 ± 0.93 a,b,A,B	0.69 ± 1.04 a,A	0.29 ± 1.44 a,A	1.83 ± 0.90 b,A,B,C	0.90 ± 1.20 A	3.305 *
F-test [2]	5.916 ***	5.519 ***	3.053 ***	2.590 **	14.503 ***	-

* Test result is statistically significant at the p = 0.5 level (*), 0.01 level (**), and 0.001 level (***); NS = nonsignificant result. [1] Results according to the major field types; lowercase letters indicate the four major fields (Duncan): width $^a < ^b < ^c$. [2] Result according to the ecosystem service functions; uppercase letters indicate the 17 functions (Duncan): length $^A < ^B < ^C < ^D < ^E < ^F$.

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