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Vegetation and Water Characteristics of an Eco-technological Water Purifying Biotope in Yongin

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용인시에 위치한 생태공학적 수질정화 비오톱의 식생 및 수환경 특성

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Abstract

Vegetation and water characteristics of an eco-technological water purifying biotope were investigated at five years after the wetland construction. A total of 91 vascular plant species in 36 families were recorded. Initially planted emergent macrophytes such as *Phragmites australis*, *P. japonicus*, *Zizania latifolia*, *Typha latifolia*, and *T. angustifolia* mainly comprised the vegetational components of the wetland. The effect of water purification was observed markedly in most indicators such as electric conductivity ($P < 0.01$), NO_3-N ($P < 0.05$), NH_4-N ($P < 0.001$), K^+ ($P < 0.05$), Na^+ ($P < 0.01$), and Mg^{2+} ($P < 0.01$). In particular, NO_3-N and NH_4-N concentrations decreased to about 60% and 30%, respectively, via the purification process of the wetland. Separativeness and curvature from the meandering structure of 15 units (multi-cell wetland system) seemed likely to make the wetland continuously play a role as an eco-technological water purifying biotope. We recommend that eco-technological design factors should be included in wetland constructions for efficient and continuous functioning, thus enhancing ecological values of wetlands.

Key words : curvature, eco-technological water purifying biotope, multi-cell wetland system, separativeness, wetland construction

요 약

조성 후 5년이 경과한 생태공학적 수질정화 비오톱을 대상으로 식생 및 수환경 분석을 수행하였다. 그 결과, 총 36과에 속하는 91종의 유관속식물종이 확인되었으며 갈대, 달뿌리풀, 줄, 큰잎부들 그리고 애기부들 등 초기 식재된 대형정수식물들이 주된 식생 요소로 확인되었다. 또한, 전기전도도($P < 0.01$)를 포함하여 질산태($P < 0.05$) 및 암모니움태 질소($P < 0.001$)와 칼륨($P < 0.05$), 나트륨($P < 0.01$) 및 마그네슘($P < 0.01$) 등에서 수질정화 효과가 확인되었다. 그 중에서도 질산태 및 암모니움태 질소의 경우 인공습지를 경유하는 과정을 통해 각각 약 60% 및 30% 수준으로 감소하는 수질 개선 효과를 나타내었다. 15개의 단위습지(다중셀습지)가 곡류형 하천과 같은 형태로 조성됨에 따른 '분리성'과 '곡률'은 본 인공습지가 온전한 생태공학적 수질정화 비오톱으로서 지속적으로 기능할 수 있도록 기여한 것으로 판단된다. 인공습지 조성에 있어, 습지로 하여금 다양한 기능들을 안정적으로 수행할 수 있도록 함으로써 습지의 생태적 가치를 제고하는 생태공학적 디자인 요소 반영을 적극 제안하는 바이다.

핵심용어 : 곡률, 다중셀습지, 분리성, 생태공학적 수질정화 비오톱, 인공습지 조성

1. Introduction

Wetland ecosystems, which are referred to the kidneys of the earth, perform many functions such as water purification, food and habitat supply, flood control, and landscape enhancement (Gren et al., 1994; Kim et al., 2015). The need for wetland constructions has increased as public recognition on the values of wetland ecosystems has increased (Hong and Kim, 2013a; Hong et al., 2014a; Hong et al., 2016). Constructed wetland for reducing water pollution is a representative example of the wetland constructions in Korea (Kim et al., 2006; Kang et al., 2011; Kim et al., 2011). For example, artificial floating marshes

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(islands), which are artificial floating platforms vegetated with wetland plants such as *Phragmites australis* (Cav.) Trin. ex Steud., *Zizania latifolia* (Griseb.) Turcz. ex Stapf, and *Typha angustifolia* L., play an important role as a water purifier in the areas of water source (Choi et al., 2007; Kim et al., 2010).

Although most cases of established artificial wetland have mainly been constructed for the purpose of water purification, recent cases of constructed wetland have been created for some specialized-functions or multi-functions (Choi et al., 2007; Hong and Kim, 2013a; Hong et al., 2014a). In particular, there has been an increase in the number of constructed wetlands with multi-functions including water purification, food and habitat supply (biotope), and waterfront area supply, possibly leading to more valuable wetland ecosystems (Byeon, 2006; Lee et al., 2011; Kang and Song, 2014).

Multi-functioning artificial wetlands are usually constructed based on eco-technological designs, which enable the wetlands to function continuously and stably (Kang and Song, 2014; Jeong and Byun, 2016; Noh et al., 2017). For instance, in a report by Chovanec (1994), a created wetland in urban recreational areas was constructed with consideration of the proportion of environmental components including littoral zone, shoreline, and open water as design factors. In a report by Byeon (2006), a sustainable structured wetland biotope (SSB) was also created based on the structure of multi-cell system as an eco-technological design to meet the conditions as a multi-functioning sustainable wetland.

In the present study, we tried to focus on an eco-technological water purifying biotope in Yongin, Korea. The biotope is considered as a representative case of artificial wetland that was recently constructed and based on eco-technological design factors. To examine whether or not the wetland plays a role as a water purifying biotope, we surveyed the vegetation, which is a primary ecological component determining biodiversity of wetland ecosystems, and analyzed water characteristics including NO_3-N, NH_4-N, and PO_4-P as major nutrients at five years after the wetland construction. Via our investigation, we also tried to demonstrate the effect of eco-technological designs on continuous performance of a multi-functioning constructed wetland.

2. Materials and Methods

2.1 Study site

The water purifying biotope (37° 11'N, 127° 15'E) in Yongin was located in a floodplain area used as paddy fields within the upper stream of Gyeongancheon, which is one of the major water sources of Paldang Dam supplying water for the residents inhabiting Seoul metropolitan region (**Fig. 1a**). The water purifying biotope was designed as a part of the campaign for water quality improvement in Gyeongancheon stream. For that reason, the water purifying biotope adjacent to Gyeongancheon had been planned to utilize the discharge water from the terminal disposal plant of sewage in Yongin so that the discharge water could flow directly into Gyeongancheon via the water purifying biotope. In particular, the water purifying biotope was designed to act as an water purifying biotope and to prevent Gyeongancheon from water level drawdown in the dry season.

The water purifying biotope was constructed by LS

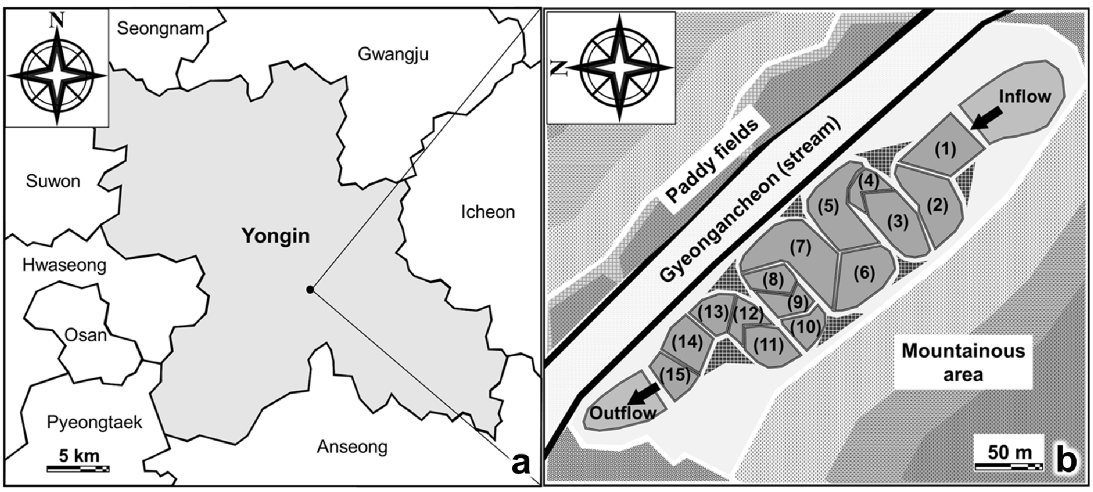

Fig. 1. Maps and information of the eco-technological water purifying biotope in Yongin. Consecutive numbers (1 ~ 15) on the biotope (b) indicate individual wetland units of the biotope as a multi-cell wetland system.

Ecological and Environmental Restoration Co., Ltd. as a wetland form of multi-cell system (19,443 m^2) not only to play a role as an effective water purifier but also to meet the conditions as a biotope for a variety of plants and animal species based on an eco-technological design concept, sustainable structured wetland biotope (SSB; Byeon, 2010). A total of 15 wetland units of different areas formed a long meandering-shape wetland structure with high curvature (**Fig. 1b**). The altitude (above sea level) difference between highest (#1, 137 m) and lowest wetland unit (#15, 127 m) was about 10 meters. Several macrophytes were planted as initial vegetational components such as *P. australis*, *T. angustifolia*, *Z. latifolia*, *Iris pseudacorus* L., and *Nymphoides peltata* (S. G. Gmel.) Kuntze (Appendix 1).

2.2 Vegetation survey

The vegetation survey on the wetland was performed in the summer growing season in 2017. The taxonomic nomenclature designated by Lee (2003) and the Korean plant names index (KPNI, http://www.nature.go.kr) were used to identify vascular plant species of the wetland. All plant species with the vegetation cover of over 1 m^2 in canopy area were included into the vegetational components of the wetland. In addition to the vegetational cover, the area of open water was also measured to make an entire map of the wetland. The area covered with free-floating or floating-leaved wetland plant was included into the vegetation cover, whereas the area only filled with submerged plant was recorded as the area of open water.

To understand the dominant species of the wetland, relative frequency (*R.F.*), relative coverage (*R.C.*), and importance value (*I.V.*) of the major vegetational components were determined. Density values were excluded in determining *I.V.* with consideration of different types of vegetational components. The values were calculated as follows:

(1) *R.F.* = (frequency of a species/frequency sum of all species) × 100

(2) *R.C.* = (coverage of a species/coverage sum of all species) × 100

(3) *I.V.* = *R.C.* + *R.F.*

2.3 Analyses on water characteristics

Physical (water depth and electric conductivity, EC) and chemical (NO_3-N, NH_4-N, PO_4-P, and cations) water characteristics were analyzed. Water depth of each wetland unit was measured around water sampling points repeatedly (n = 10) within each wetland unit by using a wood-stick ruler. EC was also measured at each sampling point by using a portable EC meter (Corning Checkmate model 311; Corning, USA). Water samples (n = 73; five samples per wetland unit except wetland unit #1 & #3 with four samples) were carried to the laboratory in Seoul national university and were filtered by using nitrocellulose membrane filter (0.45 μm) for chemical analyses.

Instead of TN and TP as chemical environments of water, NO_3-N, NH_4-N, and PO_4-P were analyzed because those forms of nitrogen and phosphorus not only present the water quality of wetland ecosystems but also indicate the concentrations of available macro nutrients for wetland plants. Macro nutrients (NO_3-N, NH_4-N, and PO_4-P) were analyzed by the hydrazine method (Kamphake et al., 1967), indo-phenol method (Solorzano, 1969), and ascorbic acid reduction method (Murphy and Riley, 1962), respectively. Cations (K^+, Ca^{2+}, Na^+, and Mg^{2+}) as micro nutrients were measured by using an atomic absorption spectrometer (Model AA240FS; Varian, USA).

2.3 Statistical analyses

Duncan's post hoc test (differences in water depth between wetlands units) and t-test (differences in water quality between wetland unit #1 and #15) were performed by using SPSS ver. 20 for Windows (SPSS, Inc., Chicago, IL, USA). Trend lines on water chemicals and the relationship between wetland area and number of plant species were also determined by using SPSS.

3. Results

3.1 Vegetation

A total of 91 vascular plant species in 36 families were recorded and 15 species were classified as the vegetational components of the wetland via our field survey (**Fig. 2**). Wetland units were composed of a variety of vegetational components of different areas and combinations with mosaic forms. Wetland unit #13 was comprised of only four vegetational pieces of three species, whereas unit #5 was made up of a total of 20 vegetational pieces of nine species (**Fig. 2**).

According to *I.V.* values of each species, emergent macrophytes such as *T. angustifolia* (25.8), *P. australis* (24.6), *P. japonicus* (24.3), *Z. latifolia* (23.4), and *T. latifolia* (19.2) comprised the major vegetation components of the wetland. Floating-leaved macrophytes such as *Nymphaea tetragona* Georgi (15.9) and *N. peltata* (13.5) also covered wide areas of the wetland (**Table 1**). In addition to the major vegetational components, *I. pseudacorus* (8.5), *Alisma*

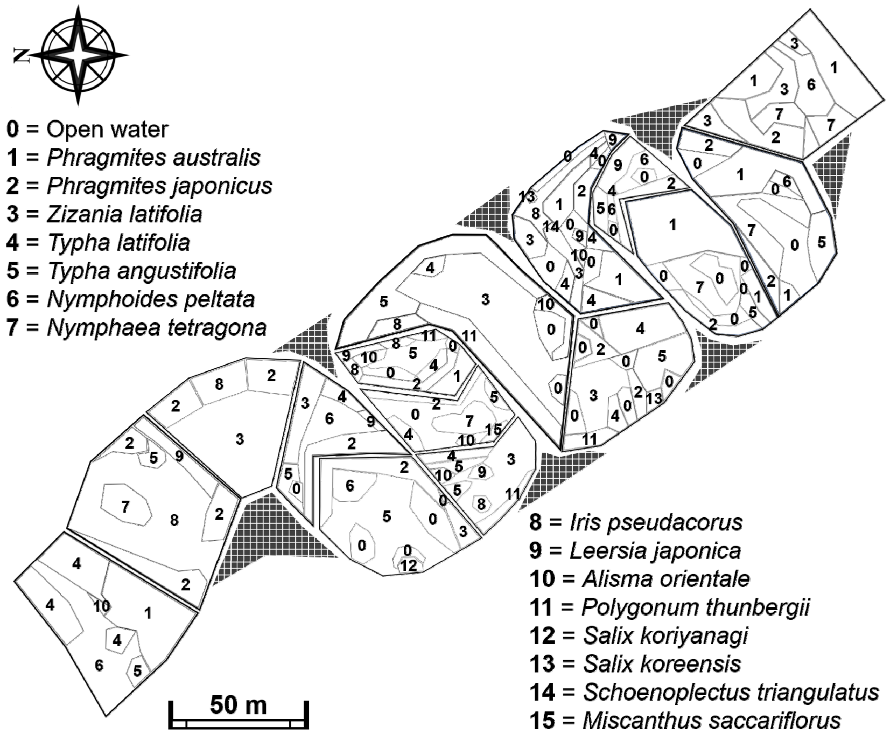

Fig. 2. Vegetation map of the eco-technological water purifying biotope.

Table 1. Results of the vegetation survey on the study site. All vegetational components of over 1 m^2 in coverage area were included in the survey.

Coverage area (m^2)	Wetland unit															R.F.	R.C.	I.V.
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15			
T. angustifolia	0	149.8	47.6	47.8	146.4	229.5	327.4	134.7	25.8	64.2	361.9	27.9	0	0	25.2	13.4	12.4	25.8
P. australis	326.8	287.0	606.4	0	439.2	0	0	85.3	0	0	0	0	0	181.2	131.0	8.5	16.1	24.6
P. japonicus	214.1	137.3	107.0	91.5	73.2	108.7	0	80.8	51.6	0	118.4	95.5	129.7	23.6	0	14.6	9.6	24.3
Z. latifolia	0	0	0	0	0	265.8	896.0	0	0	417.3	39.5	75.6	366.6	0	0	7.3	16.1	23.4
T. latifolia	202.9	0	0	8.0	131.8	265.8	34.5	35.9	34.4	51.4	0	27.9	0	0	105.8	12.2	7.0	19.2
N. tetragona	202.9	224.6	202.1	0	0	0	0	0	98.9	0	0	0	0	520.1	0	6.1	9.8	15.9
N. peltata	180.3	37.4	0	131.3	0	0	0	0	0	0	0	147.3	0	63.0	231.8	7.3	6.2	13.5
I. pseudacorus	0	0	0	0	146.4	0	51.7	26.9	0	19.3	0	0	67.7	0	0	6.1	2.4	8.5
A. orientale	0	0	0	0	29.3	0	51.7	13.5	8.6	19.3	0	0	0	0	10.1	7.3	1.0	8.4
P. thunbergii	0	0	0	0	0	60.4	292.9	13.5	0	51.4	0	0	0	0	0	4.9	3.3	8.1
L. japonica	0	0	0	75.6	58.6	0	0	18	0	19.3	0	11.9	0	0	0	6.1	1.4	7.5
S. koreensis	0	0	0	0	14.6	36.2	0	0	0	0	0	0	0	0	0	2.4	0.4	2.8
S. koriyanagi	0	0	0	0	0	0	0	0	0	0	19.7	0	0	0	0	1.2	0.2	1.4
M. saccariflorus	0	0	0	0	0	0	0	0	17.2	0	0	0	0	0	0	1.2	0.1	1.4
S. triangulatus	0	0	0	0	14.6	0	0	0	0	0	0	0	0	0	0	1.2	0.1	1.3
Open water (m^2)	0	411.8	225.9	43.8	409.9	241.6	68.9	40.4	193.5	0	118.4	11.9	0	0	0	-	-	-
Sum	1127	1248	1189	398	1464	1208	1723	449	430	642	658	398	564	788	504	100	100	200

R.F. = relative frequency, R.C. = relative coverage, I.V. = importance value.

orientale (Sam.) Juz. (8.4), *Polygonum thunbergii* (Siebold & Zucc.) H. Gross (8.1), and *Leersia japonica* (Makino ex Honda) Honda (7.5) constituted the minor vegetational components of the wetland. *Salix koreensis* Andersson (2.8), *S. koriyanagi* Kimura ex Goerz (1.4), *Miscanthus sacchariflorus* (Maxim.) Hack. (1.4), and *Schoenoplectiella triangulata* (Roxb.) J. Jung & H. K. Choi (1.3) were also included into the vegetational components of the wetland (**Table 1**).

In addition, all of the major vegetational components including two floating-leaved species were initially planted species.

3.2 Water characteristics

The wetland of 15 units showed a variety of water depth condition. Water depth of wetland units ranged from 11.9 ± 2.2 cm (#13) to 88.2 ± 5.8 cm (#2) with the average of 50.7 ± 21.6 cm. Water depth of all adjoining wetland units were statistically different ($P < 0.05$) except two neighboring units, #11 (42.7 ± 7.9 cm) and #12 (45.2 ± 6.7 cm). According to the post hoc test (Duncan's test), water depth of wetland units were classified into five groups: (a) #10 (16.2 ± 4.4 cm) and #13 (11.9 ± 2.2 cm); (b) #1 (41.4 ± 4.9 cm), #5 (42.1 ± 4.4 cm), #7 (45.2 ± 7.9 cm), #9 (41.8 ± 7.7 cm), #11 (42.7 ± 7.9 cm), and #12 (45.2 ± 6.7 cm); (c) #3 (58.9 ± 6.8 cm), #8 (53.3 ± 8.7 cm), and #15 (53.2 ± 8.7 cm); (d) #4 (65.3 ± 6.4 cm) and #6 (70.6 ± 7.7 cm); (e) #2 (88.2 ± 5.8 cm) and #14 (84.6 ± 8.4 cm) (**Fig. 3**).

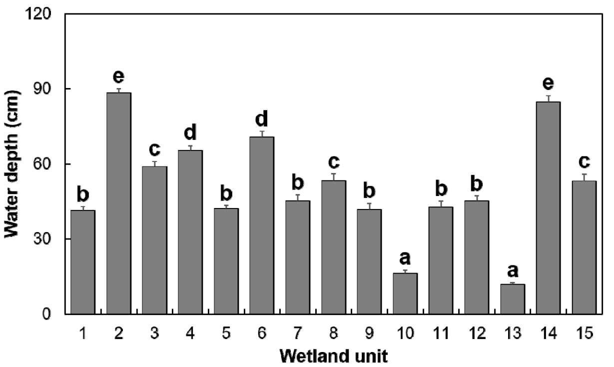

Fig. 3. Water depth of individual wetland unit (n = 15) of the study site. Error bars indicate standard error (n = 10). Different alphabets indicate statistically different sub-groups by Duncan's post hoc test ($P < 0.05$).

Electric conductivity significantly decreased via the wetland (y = −0.3514x + 569.7; y = EC, x = distance from the inflow; R^2 = 0.4976, $P < 0.01$). The difference in EC between unit #1 (573.0 ± 8.3 μS/cm) and #15 (547.4 ± 5.9 μS/cm) was also marked ($P < 0.01$). NO_3-N concentration (y = −0.0413x + 6.0; y = the concentration of NO_3-N, x = distance from the inflow; R^2 = 0.4279, $P < 0.01$) and NH_4-N concentration (y = −0.083x + 9.0; y = the concentration of NH_4-N, x = distance from the inflow; R^2 = 0.6114, $P < 0.01$) showed similar significant patterns of a linear decrease (**Fig. 4**). Statistical differences in concentration between unit #1 and #15 were also confirmed in NO_3-N (#1 = 4.2 ± 0.3 ppm, #15 = 2.7

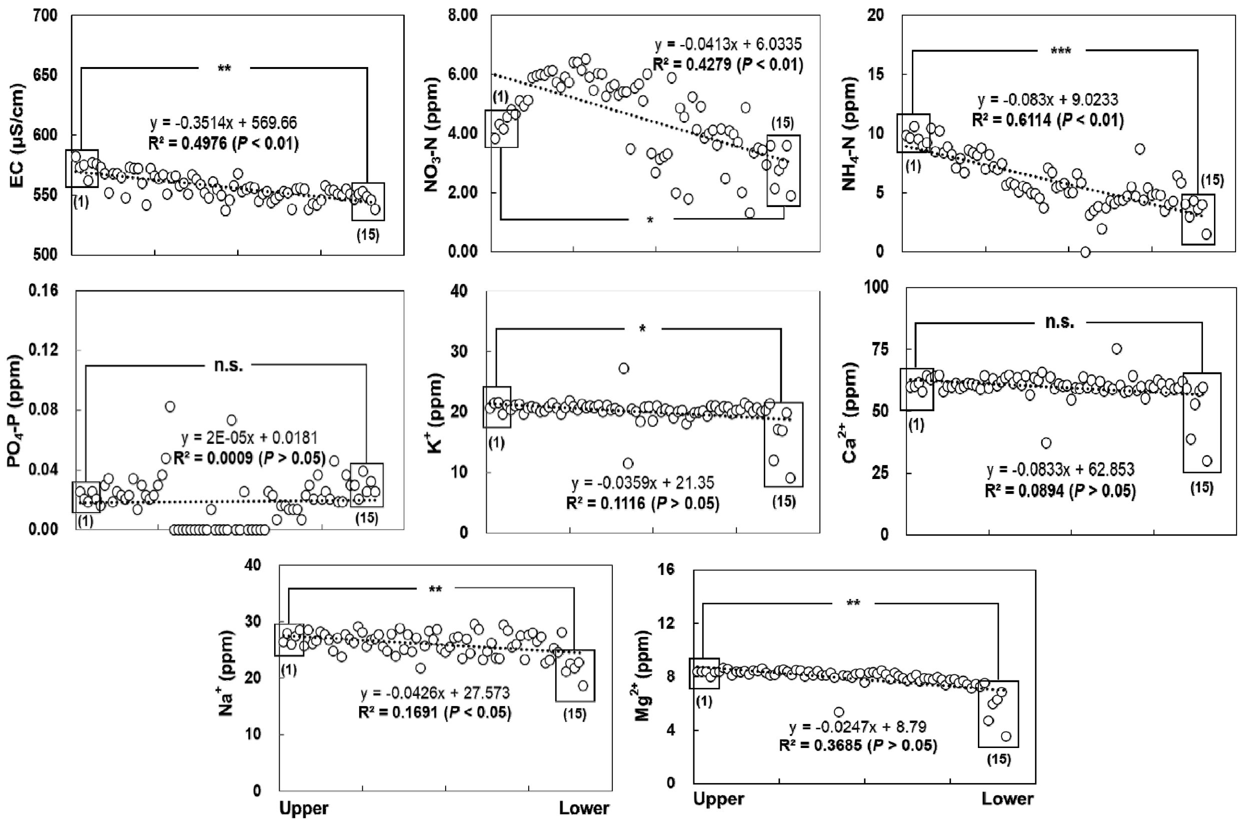

Fig. 4. Water characteristics of the eco-technological water purifying biotope (a total of 15 wetland units, n = 73). Samples from the 1st wetland unit (next to the inflow, n = 4) were statistically compared with those from the 15th wetland unit (before the outflow, n = 5). n.s. = 'not significant ($P \geq 0.05$)', * = '$P < 0.05$', ** = '$P < 0.01$', *** = '$P < 0.001$'.

± 0.7 ppm; $P < 0.05$) and NH_4-N (#1 = 9.9 ± 0.5 ppm, #15 = 3.3 ± 1.1 ppm; $P < 0.001$). In contrast, PO_4-P did not show any significant tendency.

Although K^+ concentration did not show any significant tendency with the distance from the inflow, there was statistical difference ($P < 0.05$) in K^+ concentrations between unit #1 (20.8 ± 0.9 ppm) and #15 (15.0 ± 4.4 ppm). By contrast, Ca^{2+} did not show any significant tendency (**Fig. 4**). Na^+ concentration significantly decreased via the wetland (y = −0.0426x + 27.6; y = Na^+ concentration, x = distance from the inflow; R^2 = 0.1691, $P < 0.05$). The difference in Na^+ concentrations between unit #1 (26.9 ± 0.9 ppm) and #15 (21.4 ± 1.7 ppm) was also marked ($P < 0.01$). In the case of Mg^{2+} concentration, there was only statistical difference ($P < 0.01$) between unit #1 (8.3 ± 0.2 ppm) and #15 (5.5 ± 1.3 ppm).

4. Discussion

4.1 Vegetation

In wetland ecosystems, water depth (or level) is the most important environment in determining vegetational components (Kim et al., 2013a; Nam et al., 2014; Hong and Kim, 2016). The pattern of zonation by wetland vegetation in littoral zones is a representative example indicating the effect of water depth on determining wetland vegetation. In addition, heterogeneous water depth as a micro-environment is considered to contribute to high biodiversity in wetland ecosystems (Hong and Kim, 2013b; Park et al., 2013). In the present study, the wetland of 15 units showed not only a wide range of water depth (from about 10 cm to 90 cm) but also high heterogeneity in water depth particularly between adjoining wetland units, possible explaining high plant species richness of the study site (Moser et al., 2007). Complicated mosaic forms of numerous vegetational components seemed likely to be a result of heterogeneous water level in our study site.

In addition, most wetland units of the study site showed the water depth of around 50 cm (50.7 ± 21.6 cm) not only enabling the co-existence of various types of wetland species such as emergent, submerged, free-floating, and floating-leaved plants (Hong et al., 2012; Park et al., 2013; Nam et al., 2014) but also inhibiting possible introduction and expansion of terrestrial invasive species such as *Ambrosia artemisiifolia* L., and *Sicyos angulatus* L. (Hong et al., 2012; Nam et al., 2015; Byun et al., 2017). Although a few species designated as invasive macrophytes in the inside and outside of the country such as *Ambrosia trifida* L., *Bidens frondosa* L., and *Phalaris arundinacea* L. were included in the flora list of the wetland, those species occupied only the wetland margin in a small area.

It has been reported that the structure of multi-cell wetland system may contribute to not only high efficiency of water purification but also high diversity of wetland ecosystems (Moser et al., 2007; Wiegleb et al., 2017). Physically divided structures of wetland could hinder the expansion of wetland invaders with vigorous asexual reproductive organ and subsequent monotypic occupation (Hong et al., 2012; Hong and Kim, 2013b) explaining high plant diversity in abandoned paddy terraces, which are usually composed of several wetland units physically divided (Hong and Kim, 2013b; Park et al., 2013). In the current study, although strong competitors such as *P. australis*, *T. angustifolia*, and *Z. latifolia* exhibited high competitiveness throughout the wetland, the distributional patterns of those species seemed to be restrained within wetland units.

4.2 Water characteristics

Most indicators of water quality including EC, NO_3-N, NH_4-N, and cations such as K^+, Na^+, and Mg^{2+} remarkably presented the purifying effect of the wetland. In particular, NO_3-N and NH_4-N, which frequently cause eutrophication and algal-blooming (Jeon et al., 2015; Hong et al., 2017), markedly decreased to 60% and 30%, respectively, via the wetland. The structure of multi-cell wetland system could contribute to high efficiency of water purification in the study site (Moser et al., 2007; Wiegleb et al., 2017).

In addition, high efficiency of water purification also appeared to attribute to vigorous growth performances of emergent macrophytes that were initially planted in the wetland such as *P. australis*, *P. japonicus*, *T. angustifolia*, and *Z. latifolia*. Those emergent macrophytes are well-known for effective materials in nutrient uptake (Hong and Kim, 2013a; Hong et al., 2014a; 2014b). In particular, *P. japonicus* is also considered as an effective water purifier that can be utilized even under lotic conditions (Choe and Kim, 1999; Hong et al., 2012).

4.3 Eco-technological water purifying biotope

From our investigation, the wetland seemed to play roles as not only a biotope but also a water purifier at five years after the wetland construction. Although the wetland exhibited high efficiency in water purification by several vigorous emergent macrophytes such as cattails and common reed, the wetland showed high plant species richness of over 90 vascular plant species including various types of wetland plants such as emergent, free-floating, floating-leaved, and submerged plants. Even considering of the area

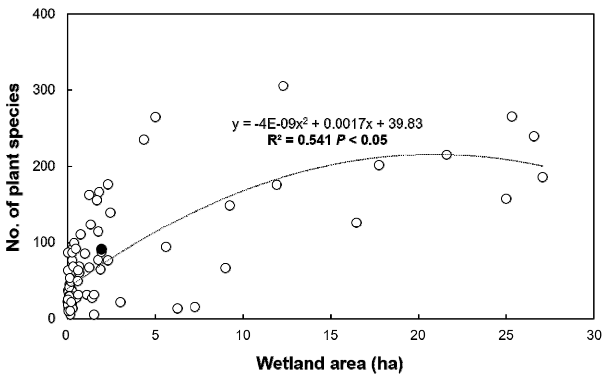

Fig. 5. Relationship between wetland area (ha) and number of plant species based on the dataset derived from the studies on natural and artificial wetlands in Korea (n = 100). Black (n = 1) and white circles (n = 99) indicates the study site and the cases of comparative wetland, respectively. Detail information of the comparative cases is presented in Appendix 2.

of the study site, the wetland appeared to be a valuable biotope ensuring the co-existence of numerous plant species when compared to other natural or artificial wetlands (Fig. 5).

It seemed likely that the eco-technological design factor (SSB) applied in the wetland of multi-cell system contains two primary components: 1) separativeness (Son et al., 2012; Lee et al., 2014) and 2) curvature (Byeon, 2014). Many separative units formed a long meandering shape of the wetland. Separativeness and curvature seemed likely to contribute to high efficiency in water purification process by enabling the effluent to stay in the wetland for a long time. Separativeness and curvature also appeared to contribute to numerous plant species composition in the wetland by physically dividing the wetland into many wetland units as frequently seen in abandoned paddy terraces of high plant species diversity (Hong and Kim, 2013b; Park et al. 2013). Furthermore, separativeness and curvature seemed likely to make the wetland to function as a more valuable wetland ecosystem. The well-functioning water purifying biotope appeared to provide aesthetic value as a waterfront area for local residents by guaranteeing diverse vegetation and clean water condition.

Increasing awareness on the importance of wetland ecosystems have contributed to increasing number of artificial wetlands in Korea (Hong and Kim, 2013a; Hong et al., 2014a). Recently, artificial wetlands have been constructed with benchmarking successful overseas cases. Multi-functioning artificial wetland based on eco-technological design factors is a representative case of those wetlands (Byeon, 2010; Wiegleb et al., 2017). Nevertheless, a number of artificial wetlands are still being constructed without applying eco-technological designs possibly deteriorating the values of wetland ecosystems. Wetlands without design factors may be turned into useless and even obnoxious facilities by monotypic occupation with alien plant species, unintended flooding or drawdown, and algal-blooming (Kim and Cho, 1999; Kim and Myung, 2008; Kim et al., 2011; Son et al., 2015a). Therefore, we suggest that eco-technological design factors such as separativeness and curvature should be applied in constructing artificial wetlands for efficient and continuous functioning in various ways.

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Appendix 1. Flora of the eco-technological water purifying biotope

Family name	Species name (Korean name)	Planted species	*Exotic species
Alismataceae	*Alisma orientale* (Sam.) Juz. (질경이택사)		
Asclepiadaceae	*Metaplexis japonica* (Thunb.) Makino (박주가리)		
Balsaminaceae	*Impatiens textori* Miq. (물봉선)		
Boraginaceae	*Trigonotis peduncularis* (Trevis.) Benth. ex Baker & S. Moore (꽃마리)		
Brassicaceae	*Lepidium apetalum* Willd. (다닥냉이)		
	Lepidium virginicum L. (콩다닥냉이)		
Cannabaceae	*Humulus japonicus* Siebold & Zucc. (환삼덩굴)		
Caryophyllaceae	*Cerastium holosteoides* var. *hallaisanense* (Nakai) M. Mizush. (점나도나물)		
	Stellaria aquatica (L.) Scop. (쇠별꽃)		
Celastraceae	*Celastrus orbiculatus* Thunb. (노박덩굴)		
Chenopodiaceae	*Chenopodium album* var. *centrorubrum* Makino (명아주)		
Commelinaceae	*Commelina communis* L. (닭의장풀)		
	Murdannia keisak (Hassk.) Hand.-Mazz. (사마귀풀)		
Compositae	*Ambrosia trifida* L. (단풍잎돼지풀)		○
	Artemisia princeps Pamp. (쑥)		
	Bidens frondosa L. (미국가막사리)		○
	Cirsium japonicum var. *ussuriense* (Regel) Kitam. (엉겅퀴)		
	Crepidiastrum sonchifolium (Bunge) J. H. Pak & Kawano (고들빼기)		
	Erigeron annuus (L.) Pers. (개망초)		○
	Hemistepta lyrata Bunge (지칭개)		
	Lactuca serriola L. (가시상추)		○
	Taraxacum officinale F. H. Wigg. (서양민들레)		○
	Youngia japonica (L.) DC. (뽀리뱅이)		
Convolvulaceae	*Calystegia sepium* var. *japonica* (Thunb.) Makino (메꽃)		
Cyperaceae	*Carex dimorpholepis* Steud. (이삭사초)		
	Carex dispalata Boott ex A. Gray (삿갓사초)		
	Carex neurocarpa Maxim. (괭이사초)		
	Eleocharis acicularis f. *longiseta* (Svenson) T. Koyama (쇠털골)		
	Schoenoplectiella hotarui (Ohwi) J. Jung & H. K. Choi (좀올챙이골)		
	Schoenoplectiella juncoides (Roxb.) Lye (올챙이고랭이)		
	Schoenoplectiella triangulata (Roxb.) J. Jung & H. K. Choi (송이고랭이)		
	Scirpus tabernaemontani C. C. Gmel. (큰고랭이)		
Equisetaceae	*Equisetum arvense* L. (쇠뜨기)		
Fabaceae	*Albizia julibrissin* Durazz. (자귀나무)	○	
	Amorpha fruticosa L. (족제비싸리)		
	Glycine soja Siebold & Zucc. (돌콩)		
	Pueraria lobata (Willd.) Ohwi (칡)		
	Robinia pseudoacacia L. (아까시나무)		
	Trifolium pratense L. (붉은토끼풀)		○
	Trifolium repens L. (토끼풀)		○
	Vicia tetrasperma (L.) Schreb. (얼치기완두)		
Hydrocharitaceae	*Hydrilla verticillata* (L. f.) Royle (검정말)		
Iridaceae	*Iris pseudacorus* L. (노랑꽃창포)	○	
Juncaceae	*Juncus effusus* var. *decipiens* Buchenau (골풀)		
	Juncus tenuis Willd. (길골풀)		
Lemnaceae	*Lemna perpusilla* Torr. (좀개구리밥)		
	Spirodela polyrhiza (L.) Schleid. (개구리밥)		

Family name	Species name (Korean name)	Planted species	*Exotic species
Lentibulariaceae	*Utricularia japonica* Makino (통발)		
Menyanthaceae	*Nymphoides peltata* (S. G. Gmel.) Kuntze (노랑어리연꽃)	○	
Nymphaeaceae	*Nymphaea tetragona* Georgi (수련)	○	
Onagraceae	*Oenothera odorata* Jacq. (달맞이꽃)		○
Oxalidaceae	*Oxalis corniculata* L. (괭이밥)		
Papaveraceae	*Chelidonium majus* var. *asiaticum* (H. Hara) Ohwi (애기똥풀)		
Plantaginaceae	*Plantago asiatica* L. (질경이)		
Poaceae	*Agropyron ciliare* (Trin.) Franch. (속털개밀)		
	Alopecurus aequalis Sobol. (뚝새풀)		
	Beckmannia syzigachne (Steud.) Fernald (개피)		
	Bromus japonicus Thunb. (참새귀리)		
	Echinochloa crus-galli (L.) P. Beauv. (피)		
	Isachne globosa (Thunb.) Kuntze (기장대풀)		
	Leersia japonica (Makino & Honda) Honda (나도겨풀)		
	Lolium perenne L. (호밀풀)		○
	Miscanthus sacchariflorus (Maxim.) Hack. (물억새)	○	
	Oplismenus undulatifolius (Ard.) Roem. & Schult. (주름조개풀)		
	Phalaris arundinacea L. (갈풀)		○
	Phragmites australis (Cav.) Trin. ex Steud. (갈대)	○	
	Phragmites japonicus Steud. (달뿌리풀)	○	
	Poa pratensis L. (왕포아풀)		
	Setaria viridis (L.) P. Beauv. (강아지풀)		
	Zizania latifolia (Griseb.) Turcz. ex Stapf (줄)	○	
Polygonaceae	*Polygonum hydropiper* L. (여뀌)		
	Polygonum maackianum Regel (나도미꾸리낚시)		
	Polygonum perfoliatum (L.) L. (며느리배꼽)		
	Polygonum senticosum (Meisn.) Franch. & Sav. (며느리밑씻개)		
	Polygonum thunbergii Siebold & Zucc. (고마리)		
	Rumex acetosa L. (수영)		
	Rumex acetosella L. (애기수영)		○
	Rumex crispus L. (소리쟁이)		○
Potamogetonaceae	*Potamogeton distinctus* A. Benn. (가래)		
Primulaceae	*Lysimachia davurica* Ledeb. (좁쌀풀)		
Ranunculaceae	*Ranunculus sceleratus* L. (개구리자리)		
Rosaceae	*Duchesnea chrysantha* (Zoll. & Moritzi) Miq. (뱀딸기)		
	Spiraea salicifolia L. (꼬리조팝나무)	○	
Salicaceae	*Salix caprea* L. (호랑버들)	○	
	Salix gracilistyla Miq. (갯버들)	○	
	Salix koreensis Andersson (버드나무)	○	
	Salix koriyanagi Kimura ex Goerz (키버들)	○	
Scrophulariaceae	*Veronica arvensis* L. (선개불알풀)		○
Typhaceae	*Typha angustifolia* L. (애기부들)	○	
	Typha latifolia L. (큰잎부들)	○	
Urticaceae	*Boehmeria tricuspis* (Hance) Makino (거북꼬리)		
No. of species	91	15	13

*Exotic species includes both alien species and naturalized species.

Appendix 2. Detail information of the comparative wetland cases in Fig. 5.

No.	Wetland type	Wetland area (m^2)	No. of plant species	Reference
1	Salt marsh	270,480	186	Oh et al., 2014
2	Reservoir (pond)	265,724	240	Song and Park, 2013
3	Back marsh	253,162	266	Kim et al., 2000
4	Salt marsh	250,000	158	Kim, 2007
5	Marsh	216,000	216	Lee et al., 2005
6	Back marsh	177,416	202	You et al., 2008
7	Abandoned paddy field (marsh)	164,489	127	Moun et al., 2017
8	Reservoir (pond)	123,000	306	Kim et al., 2011
9	Reservoir (pond)	119,000	176	Kim et al., 2011
10	High moor (fen)	92,500	149	Park et al., 2011
11	Marsh	90,000	67	Song et al., 2006
12	Reservoir (pond)	72,600	16	Chun, 2008
13	Reservoir (pond)	62,500	14	Chun, 2008
14	Reservoir (pond)	56,067	95	Lee et al., 2003
15	Marsh	50,000	265	Park et al., 2000
16	Marsh	43,602	236	Ko et al., 2014
17	Forested swamp	30,000	22	Chun, 2008
18	High moor (fen)	24,500	140	Son et al., 2015b
19	Abandoned paddy field (marsh)	23,000	77	Han and Park, 2014
20	Constructed wetland (marsh)	23,000	177	Kim and Myeong, 2008
21	High moor (fen)	19,300	88	Son et al., 2015b
22	Abandoned paddy field (marsh)	18,719	65	Lee et al., 2003
23	Reservoir (pond)	18,000	167	Kim et al., 2011
24	High moor (fen)	17,500	115	Son et al., 2015b
25	Floating marsh	17,400	78	Kim et al., 2013b
26	Reservoir (pond)	16,500	156	Lee et al., 2013
27	Abandoned paddy field (marsh)	15,000	32	Chun, 2008
28	Reservoir (pond)	15,000	6	Chun, 2008
29	Abandoned paddy field (marsh)	14,000	28	Chun, 2008
30	Marsh	13,228	124	You and Kwon, 2018
31	High moor (fen)	12,341	163	Park and Kim, 2012
32	Pond	12,300	68	Han and Park, 2014
33	Pond	11,000	32	Oh et al., 2009
34	High moor (fen)	9,900	86	Son et al., 2015b
35	High moor (fen)	7,500	111	Son et al., 2015b
36	Reservoir (pond)	6,700	61	Han and Park, 2014
37	Abandoned paddy field (marsh)	6,561	69	Hong and Kim, 2013a
38	Abandoned paddy field (marsh)	6,041	64	Park et al., 2013
39	Abandoned paddy field (marsh)	6,000	32	Chun, 2008
40	Abandoned paddy field (marsh)	5,782	50	Park et al., 2013
41	Pond	5,000	28	Oh et al., 2009
42	Abandoned paddy field (marsh)	4,652	92	Park et al., 2013
43	Marsh	3,824	100	You and Kwon, 2018
44	High moor (fen)	3,305	34	Choi et al., 2003
45	Abandoned paddy field (marsh)	3,219	69	Hong and Kim, 2013b
46	Constructed wetland (marsh)	3,000	93	Son et al., 2015a
47	Reservoir (pond)	2,800	14	Chun, 2008
48	Reservoir (pond)	2,700	77	Han and Park, 2014
49	Pond	2,700	14	Oh et al., 2009
50	Pond	2,500	37	Oh et al., 2009

No.	Wetland type	Wetland area (m^2)	No. of plant species	Reference
51	Pond	2,500	30	Oh et al., 2009
52	Abandoned paddy field (marsh)	2,500	51	Chun, 2008
53	Marsh	2,500	87	You and Kwon, 2018
54	Forested swamp	2,400	20	Chun, 2008
55	Pond	2,300	35	Oh et al., 2009
56	Constructed wetland (marsh)	2,192	22	Kim et al., 1999
57	Abandoned paddy field (marsh)	2,095	49	Hong and Kim, 2013b
58	Pond	2,000	20	Oh et al., 2009
59	Pond	2,000	40	Oh et al., 2009
60	Pond	1,900	26	Oh et al., 2009
61	Pond	1,600	6	Oh et al., 2009
62	Pond	1,500	21	Oh et al., 2009
63	Pond	1,500	31	Oh et al., 2009
64	Pond	1,500	28	Oh et al., 2009
65	Abandoned paddy field (marsh)	1,500	54	Chun, 2008
66	Riverine marsh	1,500	45	Chun, 2008
67	Reservoir (pond)	1,500	11	Chun, 2008
68	Pond	1,300	15	Oh et al., 2009
69	Pond	1,300	23	Oh et al., 2009
70	Forested swamp	1,200	21	Chun, 2008
71	Abandoned paddy field (marsh)	1,168	54	Hong and Kim, 2013b
72	Back marsh	1,016	46	Han and Park, 2014
73	Riverine marsh	1,000	23	Oh et al., 2009
74	Forested swamp	1,000	20	Chun, 2008
75	Riverine marsh	1,000	42	Chun, 2008
76	Pond	980	25	Oh et al., 2009
77	Riverine marsh	900	30	Chun, 2008
78	Pond	800	27	Oh et al., 2009
79	Riverine marsh	800	31	Chun, 2008
80	Pond	750	13	Oh et al., 2009
81	Forested swamp	750	19	Chun, 2008
82	Forested swamp	750	30	Chun, 2008
83	Pond	700	22	Oh et al., 2009
84	Pond	700	19	Oh et al., 2009
85	Pond	600	36	Oh et al., 2009
86	Reservoir (pond)	600	10	Chun, 2008
87	Pond	550	12	Oh et al., 2009
88	Pond	500	23	Oh et al., 2009
89	Forested swamp	500	27	Chun, 2008
90	Pond	450	16	Oh et al., 2009
91	Forested swamp	450	22	Chun, 2008
92	Pond	300	26	Oh et al., 2009
93	Pond	250	38	Oh et al., 2009
94	Pond	208	87	Han and Park, 2014
95	Reservoir (pond)	200	26	Chun, 2008
96	Pond	168	64	Han and Park, 2014
97	Reservoir (pond)	140	18	Chun, 2008
98	Forested swamp	100	21	Chun, 2008
99	Forested swamp	50	23	Chun, 2008