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The influence of water characteristics on the aquatic insect and plant assemblage in small irrigation ponds in Civilian Control Zone, Korea

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민통선 둠벙의 수서곤충과 식물 군집에 대한 수환경 특성의 영향

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Abstract

A small irrigation pond for a rice paddy field is a very important refuge for aquatic insects and plants. To reveal environmental factors determining species composition of aquatic insect and plant communities, we analyzed water chemistry and connection between pond and surrounding in five types of irrigation ponds based on water source and connection in CCZ of South Korea: stagnation, exchange-stagnation, spring, stagnation-spring, and exchange-spring types. The stagnation type had the most stable water chemistry among the 16 irrigation ponds studied, and the spring type had the most variable water chemistry. Anion content was highest in the stagnation type, and cation content was highest in the exchange-stagnation type. 228 taxa including 63 wetland plants and 95 aquatic insect taxa were recorded. Six rare plant species and four rare aquatic insect species were identified. The stagnation-spring type had the highest species richness. There was no correlation between size and species richness. Multivariate analyses showed distinctive species assemblages among the irrigation pond types. This would indicate that water chemical change at annual cycle and connection influenced on the species assemblages in irrigation pond. In additional, irrigation pond contributes to regional biodiversity in agricultural areas, as irrigation pond provides heterogeneous communities for the freshwater ecosystem.

Key words : biodiversity, Civilian Control Zone, water chemical change, multivariate analysis, plant and aquatic insect assemblage, irrigation pond

요 약

본 연구에서는 둠벙의 수서곤충군집과 식물 군집에 영향을 주는 수환경 특성을 확인하고자 민통선에 존재하는 5개 유형 16개 둠벙을 선택하여 물의 화학적 특성과 둠벙과 주변 환경과의 연결 특성을 조사하였다. 둠벙의 유형으로는 괸물, 괸물-물흐름, 샘통, 괸물-샘통 그리고 물흐름-샘통형을 사용하였다. 연중 이온의 농도 변화는 괸물형 둠벙에서 가장 작았고 샘통형 둠벙에서 가장 컸다. 음이온 농도가 가장 높은 곳은 괸물형 둠벙이었으며, 양이온 농도가 가장 높은 곳은 물흐름-샘통형 둠벙이었다. 연구 장소에서 발견된 식물은 228종이었으며, 이중 습지 식물이 63종이었다. 수서곤충은 95종이 발견되었다. 확인된 희귀식물은 6종이었고, 희귀수서곤충은 4종이었다. 괸물-샘통형 둠벙에서 종풍부도가 가장 높았다. 둠벙의 크기와 종풍부도는 상관관계가 없었으며, 다변량 통계를 통해 분석한 결과 둠벙 유형별로 생물군집에서 차이가 나는 것으로 나타났다. 본 연구를 통해 둠벙에서 수환경 변화와 주변 환경과 둠벙의 연결성이 생물군집에 영향을 주는 것으로 확인되었으며, 둠벙은 담수생태계로서 이질성을 높여 농업지역의 생물다양성을 높이는데 기여함을 확인하였다.

핵심용어 : 생물다양성, 민간인 통제구역, 수환경변화, 다변량통계, 식물과 수서곤충 군집, 둠벙

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1. Introduction

The United Nations Military Armistice Commission established the Demilitarized Zone (DMZ) in 1953, with a 4 km width between North and South Korea and the 1,370 km^2 Civilian Control Zone (CCZ), which is south of the DMZ, after the Korean War. In the 1972, the central government constructed Tong-il village in CCZ, where 40 veterans family and 40 displaced people began living and farming, and agriculture activities started over all again (Park et al., 2012). Both the DMZ and the CCZ have representative topography of the Korean peninsula, which is high altitude on the eastern-side with mountains, central part with well-developed rice paddy fields, and low altitude on the western-side with well-developed estuary area and rice paddy fields. As a result, CCZ and DMZ have rich ecosystem and landscape diversity, providing a vital wildlife refuge, including several internationally endangered and vulnerable species (Kim and Cho, 2005). Especially, the highest rate of endangered species is found particularly in the western CCZ. The reason is that this area has very well developed Im-jin estuary and rice fields, which provide functional feeding and resting site and habitat for migrating birds and other wild life. After Tong-il village was open, the second village Hamaru village was established in 1990s. Until now, they still use traditional irrigation ponds which named dumbeong (Fig. 1) because modern irrigation systems are not yet settled in this area. Most other outside farms converted traditional naturally made small-sized cannels to modern man-made huge cannels and reservoirs. Since the 2008 Ramsar Convention in Korea (COP10), scientists have regarded rice paddy fields as wetlands and irrigation ponds have come to the forefront of biodiversity interests in rice paddy fields (Choe et al., 2013; Kim, 2012; Lee et al., 2010).

Many studies have shown ponds have high conservation value for biodiversity (Angélibert et al., 2004; Oertli et al., 2005; Réghino et al., 2013; Williams et al., 1997; Wood et al., 2003). Especially, the agricultural pond has ecological functions of purifying polluted water and intensive fertilization in agricultural areas (Zedler, 2003). The ponds or agricultrual ponds act as a refuge for aquatic plants, macroinvertebrates, and water birds (Collinson et al., 1995; Froneman et al., 2001; Nicolet et al., 2004; Sánchez-Zapata et al., 2005; Suurkuukka et al., 2012). The irrigation ponds also serve to refuge for aquatic plants, fish, and aquatic macroinvertebrates, which are connected to the high biodiversity in paddy fields (Lee, 2004). The pond studies have typically classified ponds as permanent or temporary (Céréghino et al., 2008; Nicolet et al., 2004; Williams et al., 2003), and the perspective of a pond is that it is more isolatied then a lake system (Hamerlík et al., 2013). Thus, pond species assemblages and biodiversity need to be studied to understand the pond system which is not just a small lake.

Water source and connection may directly affect the chemical and physical processes controlling nutrient and solid dynamics in wetlands (Mitsch and Gosselink, 2000). In particular, the pond is so small that hydrologic dynamics easily affect the body of water and slightly change water chemistry (Davis et al., 1980), which is important for establishing vegetation and macroinvertebrate assemblages. Some studies have investigated the relationships between water chemistry and species assemblages. For example, Nicolet et al. (2004) showed that the most important environmental factor influencing biotic assemblages in temporary ponds is water chemistry, particularly alkalinity and pH. Johnston and Brown (2013) reported that water chemistry is important for distinguiching lake floristic assemblages. There is, however, lack of study has investigated the relationship with biodiversity and community composition on water source and connection on the artifical pond like irrigation pond. Water fluctuation of irrigation pond was changeable by rice farming cycle. Water level in the irrigation pond is decreased rapidly in the spring

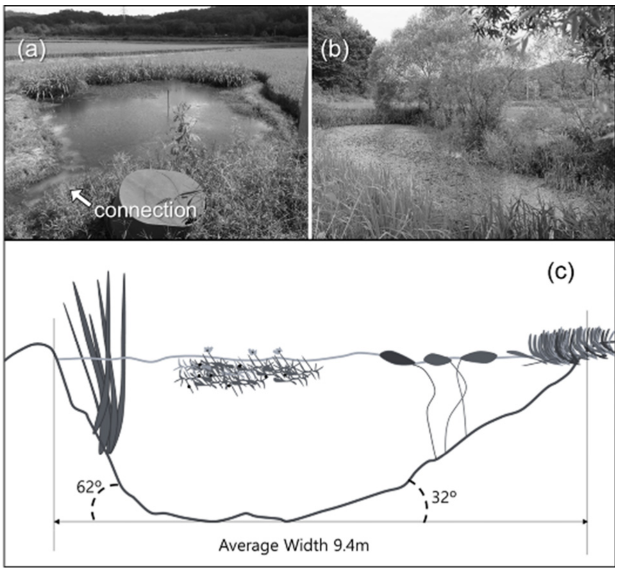

Fig. 1. Pictures of two irrigation ponds and a cross sectional profile of an irrigation pond, showing the average slope and width. (a) This irrigation pond represents Exchange type, like E-ST and E-SP, which is connected with irrigation ditch and (b) SP type irrigation pond that the externals is similar with other types. (c) The average slope and width of an irrigation pond. Every irrigation pond has different slopes; one side is steep and the other side is slight.

to irrigate paddy fields. Rice paddy fields are dried for rice harvest, and most aquatic species suffer from the lack of water during the dry phase.

Kim et al. (2011a) suggested that the irrigation ponds might be classified by water source as well as water level change such as permanent or temporal. Furthermore, Kim et al. (2011b) showed that the aquatic plant assemblage on irrigation pond would be influenced by hydrological pattern. This study showed only aquatic plant assemblage, not other species which are also important in wetland ecosystem.

The research on biodiversity and assemblages is important not only for conservation but also to understand the pond system itself (Hannigan and Kelly-Quinn, 2012). Even if the irrigation pond stand out as being more important agricultural ecosystem, but there are a few study that assemblage and hydrology to understand their own systems. In this study, we tried to 1) understand that water chemical change at annual cycle in irrigation pond and 2) the water chemical annual fluctuation influenced the relationship among species composition and diversity, based on the irrigation pond classification system of Kim et al. (2011a).

2. Materials and methods

2.1 Study area

The study area was approximately 26.81 km^2 and located in rice paddy fields at Paju in CCZ (Fig. 2). About 11% of the water was from a pumping station, and the remainder was supplied by irrigation ponds (Paju office, 2011). We selected 16 irrigation ponds which stand for 5 irrigation pond types (Fig. 2, Table 1). The climate in this area is monsoonal with high rainfall during the summer in July (mean rainfall, 558.9 mm) and August (mean rainfall, 375.4 mm), which is almost 57% of the annual precipitation (Fig. 3).

Table 1. Location and area of the 16 irrigation ponds

Type		Code	Area (m^2)
Stagnation	ST	1	925
Stagnation	ST	2	208
Spring	SP	3	466
Exchange-Spring	E-SP	4	220
Spring	SP	5	1068
Exchange-Spring	E-SP	6	144
Exchange-Stagnation	E-ST	7	708
Exchange-Stagnation	E-ST	8	99
Stagnation	ST	9	832
Exchange-Stagnation	E-ST	10	350
Spring	SP	11	239
Spring	SP	12	574
Stagnation-Spring	ST-SP	13	265
Stagnation-Spring	ST-SP	14	559
Stagnation-Spring	ST-SP	15	168
Spring	SP	16	416

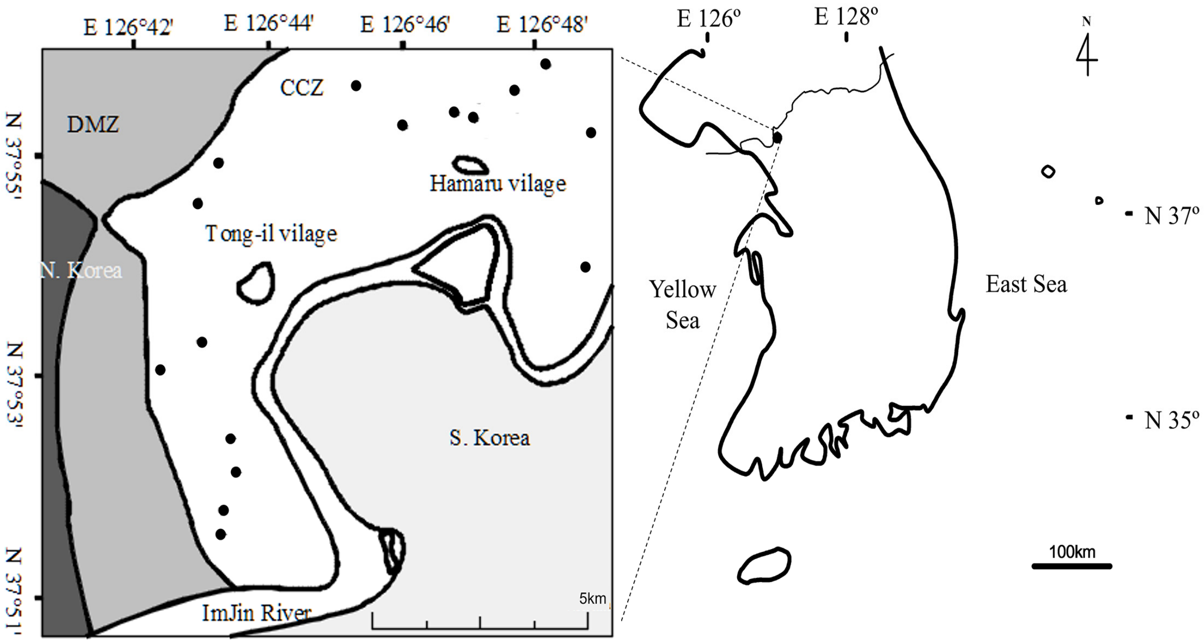

Fig. 2. Map showing the study sites. The location of samples was showed by black solid dots. DMZ : Demilitarized Zone, CCZ : Civlian Control Zone, N.Korea : North Korea, S.Korea : South Korea.

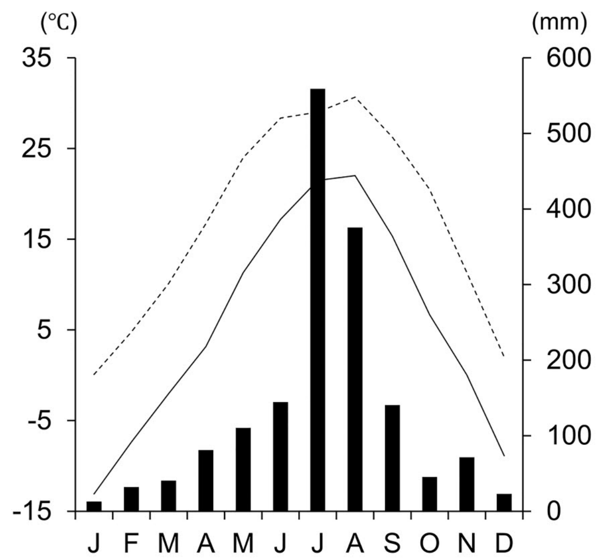

Fig. 3. The precipitation (Bar) and the average highest temperature (Solid line) and lowest temperature (Dashed line) in Paju during 2009-2013.

2.2 Data collection

Water temperature and dissolved oxygen (DO) were measured in the field with a DO meter (model PDO-520; UKAS, Taipei, Taiwan). Electric conductivity (EC) was measured with a Corning Checkmate II (model 311; Corning, Lowell, MA, USA), and pH was measured with a pH meter (model AP 63; Fisher, Pittsburgh, PA, USA). Water samples were collected from each pond and brought to the laboratory in a cool box where they were filtered with a 0.45 ㎛ membrane filter. The samples were collected on May 12-13, August 13-14, 2012, and September 18-19, 2013. NO_3-N, NH_4-N, and PO_4-P were analyzed by the hydrazine method (Kamphake et al., 1967), indo-phenol method (Murphy and Riley, 1962), and ascorbic acid reduction method (Solorzano, 1969), respectively. K^+, Ca^{2+}, Na^+, and Mg^{2+} contents were measured using an atomic absorption spectrometer (model AA240FS; Varian, Palo Alto, CA, USA). The percentage cover of wetland plants and the flora were recorded in May and August 2012 and September 2013. Vegetation coverage of each site was calculated by AutoCAD. The aquatic insects were sampled with a 1-mm mesh O-frame net. Aquatic insects were sampled in May and August 2012 and September 2013. The samples were taken in the field and sorted in the laboratory. The aquatic insects were identified to species level, except Diptera (fly) and Lepidoptera, which were sorted to the family level.

2.3 Data analysis

Detrended canonical correspondence analysis (DCCA) was used to identify the relationships between environmental factors and species assemblages using CANOCO 4.5 for Windows (Ter Braak and Smilauer, 2002). The coefficient of variations (CVs) were calculated for the environmental data, as they show annual fluctuations. We chose seven environmental factors using by estimated its independent (marginal effect). The detrending method was used a tetra order polynomial using Hill's scale. Statistical significance of the eigenvalues was tested with Monte Carlo tests based on 999 reiterations. An analysis of similarity (ANOSIM) was used to show differences between assemblage composition types. ANOSIM using the Bray-Curtis similarity index was tested with the global test using 999 permutations. The irrigation ponds types contributing to similarities within groups were investigated using similarities percentages (SIMPER). ANOSIM and SIMPER were performed using PRIMER v6 (Clarke, 1993). Species richness was defined as the number of species recorded. β-diversity among ponds of the same type was measured by Whittaker's measure re-expressed for presence/absence data (Koleff et al., 2003; Magurran, 2013; Whittaker, 1960). Tukey's HSD post-hoc test was applied after One-way ANOVA and the Game-Howell post-hoc test using SPSS statistics 21 (SPSS Inc., Chicago, IL, USA). We used Spearman's correlation analysis to consider the relationship between area and species richness.

3. Results

3.1 Water Chemical characteristics

There is no significant difference in water chemistry among irrigation pond types (Table 2). In the SP type, the CVs of PO_4-P, NO_3-N, and NH_4-N were highest; the temperature CV was lowest, and mean DO was lowest among the five types (Tables 2 and 3). In the ST type, The CVs of NO_3-N and temperature were highest; the CVs of PO_4-P, NH_4-N, K^+, Na^+, and Mg^{2+} were lowest, and mean NO_3-N and DO were highest among the five types. In the ST-SP type, the CVs of K^+ and Mg^{2+} were highest; the CVs of Ca^{2+}, DO, EC, and pH were lowest, and mean NH_4-N, K^+, Ca^{2+}, Na^+, Mg^{2+}, and EC were lowest among the five types. In the E-SP type, the CVs of Na^+, DO, and pH were highest; mean NO_3-N was lowest among the five types. In the E-ST type, the CVs of Ca^{2+} and EC were highest; mean PO_4-P, K^+, Ca^{2+}, Na^+, Mg^{2+}, and EC were highest, and mean temperature was lowest among the five types.

Table 2. Water chemical characteristics in 5 irrigation pond types. Mean (± SD)($p < 0.05$)

	SP (n=5)	ST (n=3)	ST-SP (n=3)	E-SP (n=2)	E-ST (n=3)
PO_4-P (mg/l)	0.027 (±0.014)	0.021 (±0.005)	0.026 (±0.011)	0.027 (±0.006)	0.028 (±0.009)
NO_3-N (mg/l)	0.096 (±0.111)	0.167 (±0.248)	0.103 (±0.118)	0.049 (±0.064)	0.089 (±0.095)
NH_4-N (mg/l)	0.025 (±0.027)	0.032 (±0.030)	0.022 (±0.014)	0.040 (±0.050)	0.035 (±0.045)
EC (mS/cm)	0.222 (±0.158)	0.177 (±0.173)	0.088 (±0.029)	0.202 (±0.122)	0.276 (±0.194)
K^+ (mg/l)	5.24 (±4.95)	5.36 (±3.94)	2.72 (±3.09)	4.84 (±3.63)	16.10 (±37.75)
Ca^{2+} (mg/l)	31.00 (±35.49)	29.00 (±30.35)	13.65 (±10.84)	27.59 (±27.79)	41.35 (±63.29)
Na^+ (mg/l)	7.31 (±2.45)	6.54 (±3.56)	5.09 (±2.9)	6.24 (±4.11)	9.74 (±6.19)
Mg^{2+} (mg/l)	9.91 (±10.20)	10.82 (±9.79)	4.88 (±4.71)	9.59 (±11.19)	11.44 (±10.92)
DO (mg/l)	4.9 (±3.4)	8.2 (±3.0)	5.0 (±2.5)	6.0 (±4.4)	7.7 (±3.5)
Temp (℃)	23.7 (±6.0)	20.6 (±7.6)	24.5 (±6.7)	21.4 (±8.7)	20.2 (±7.5)
pH	6.9 (±0.4)	6.7 (±0.3)	6.9 (±0.3)	7.3 (±0.8)	6.7 (±0.5)

Table 3. The mean of Coefficient of Variation (CV) of 5 irrigation pond types ($p < 0.05$, Tukey's HSD).

	SP (n=5)	ST (n=3)	ST-SP (n=3)	E-SP (n=2)	E-ST (n=3)
PO_4-P (mg/l)	0.409	0.149	0.326	0.231	0.246
NO_3-N (mg/l)	0.758^{a}	1.309^{b}	1.135^{b}	0.875^{ab}	0.817^{ab}
NH_4-N (mg/l)	0.79	0.385	0.721	0.765	0.475
EC (mS/cm)	0.559	0.565	0.327	0.521	0.784
K^+ (mg/l)	1.016^{ab}	0.660^{ab}	1.201^{b}	0.790^{a}	1.176^{ab}
Ca^{2+} (mg/l)	1.120^{ab}	0.950^{ab}	0.914^{a}	1.111^{ab}	1.252^{b}
Na^+ (mg/l)	0.34	0.309	0.548	0.652	0.549
Mg^{2+} (mg/l)	1.01^{ab}	0.760^{ab}	1.098^{b}	0.953^{a}	1.058^{ab}
DO (mg/l)	0.65	0.405	0.371	0.743	0.454
Temp (℃)	0.28	0.458	0.287	0.451	0.331
pH	0.055	0.055	0.035	0.093	0.076

Alphabets superscript indicate statistically different sub-groups by Tukey's HSD post-hoc test ($P < 0.05$)

3.2 Biodiversity of Pond

3.2.1 Plant composition and diversity

Each type showed a different relative accumulation ratio of wetland plant categories (Fig. 4). A total of 228 plant species were identified in the ponds, of which 68 were wetland indicators (classified as FAC; Facultative, FACW; Facultative wetland or OBL; Obligate wetland) (Tiner, 1991). Thirty species were classified as hygrophytes, 15 as emergent plants, three as floating-leaved plants, two as floating plants, and two as submerged plants (Fig. 4a, b). *Zizania latifolia, Leersia japonica, Persicaria thunbergii, Salix koreensis, Trapa japonica, Phragmites japonica,* and *Utricularia vulgaris* var. *japonica* were the most frequently recorded and dominant species in the ponds. The richest flora with an average of 90 taxa was recorded in the ST-SP type (Table 4). The average number of plant taxa was 58.8 in SP, 52 in ST, 47 in E-SP, and 63.3 in E-ST. No correlation was observed between pond area and the number of plant species (r^2=0.228, p=0.395). The SP type had the smallest area of open water, and the floating-leaved plant *T. japonica,* the emergent plant *L. japonica,* and the submerged plant *U. vulgaris* were dominant. The occupation ratio of floating-leaved plants in the ST-SP type such as *T. japonica* was second among the five types. ST had the largest ratio of open water area among the five types and very simple wetland plant composition, whereas the emergent plant *L. japonica* and the floating-leaved plant *T. japonica* dominated. The occupation ratio of floating-leaved plants in E-SP, such as *Potamogeton distinctus*, was highest among the five types. Although *U. vulgaris* was an E-SP indicator species, its occupation ratio was only 5%.E-ST had the second large open water area, and emergent (floating- leaved) plants such as *S. japonicum* inhabited.

Six rare species were found and were listed in the Korean Red Data Book by National Institute of Biological Resources (2012) (Table 5). *Acorus calamus* (NT: Near Threatened) was observed in the ST and E-SP types. *Aristolochia contorta* (NT) was only recorded only in the ST type. *Eleutherococcus senticosus* (NT) was found in the SP and SP-ST types. *Ottelia alismoides* (NT) was observed in the E-SP and ST-SP types.

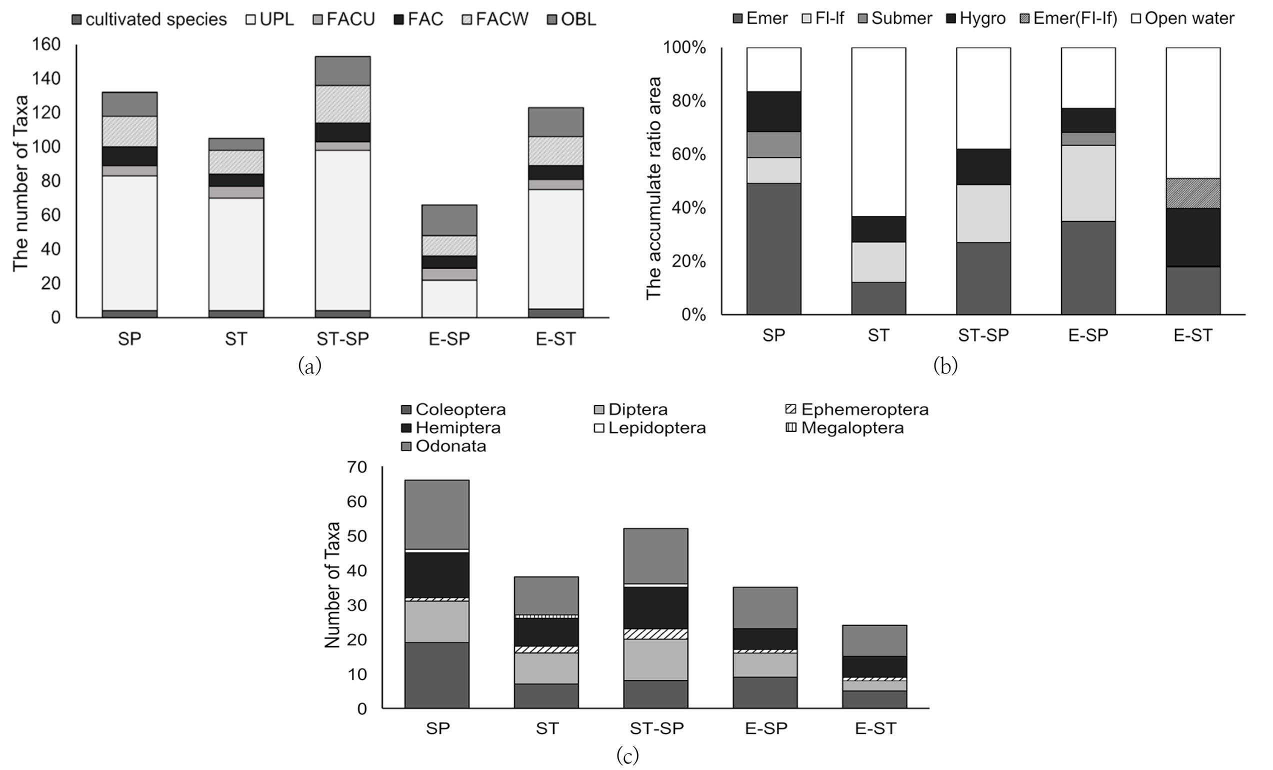

Fig. 4. Characteristics of species assemblage and environmental condition (a) the number of wetland plant indicator. (b) the accumulate ratio area of the wetland plant and openwater. Emer : Emergent plant, Fl-If : Floating-leave plant, Submer : Submersed plant, Hygro : Hygrophyte, Emer(Fl-If) : Emergent (floating-leave) plant. (c) The total number of aquatic insect taxa.

Table 4. Average species richness and beta diversity

	Species richness (mean (±SD))		Beta diversity	
	Plant	Insect	Plant	Insect
SP	58.5 (±11.5)	29 (±6.3)	0.48^{abc}	0.54^{ab}
ST	52 (±21)	16 (±11.5)	0.62^{c}	0.79^{c}
ST-SP	90 (±16)	33 (±4.5)	0.45^{ab}	0.51^{abc}
E-SP	47 (±1.4)	28 (±1.4)	0.40^{a}	0.32^{a}
E-ST	63.3 (±20.9)	14 (±1.5)	0.55^{bc}	0.65^{bc}

Alphabets superscript indicate statistically different sub-groups by Tukey's HSD post-hoc test ($P < 0.05$)

Sparganium japonicum (DD: Data Deficient) was only observed in the E-ST type. *U. vulgaris* (VU: Vulnerable) was observed in all types except ST and particularly in all SP ponds.

3.2.2 Aquatic insect composition and diversity

Each type showed a different dominant aquatic insect species (Fig. 4). Ninety-Five aquatic insect species were recorded in the 16 ponds (Fig. 4c, Table 4). The richest group was Odonata (28 species, eight families), followed by Coleoptera (26 species, eight families), Hemiptera (19 species, 11 families), Diptera (18 species, 13 families), Ephemeroptera (two species, two families), and Lepidoptera (one species), Megaloptera (one species). *Hyphydrus japonicas, Cloeon dipterum, Anax parthenope julius,* and *Ischnura asiatica* were the most frequently recorded and dominant species in the ponds. The SP type had the most richness species with 67 taxa (mean, 29 taxa). The ST type had 39 taxa (mean, 17 taxa), ST-SP had 59 taxa (mean, 33 taxa), E-SP had 37 taxa (mean, 28 taxa), and E-ST had 30 taxa (mean, 14 taxa). No correlation was detected between pond area and the number of aquatic insect species (r^2=0.050, p=0.854). Among five types, the most frequency observation of Coleoptera and Diptera was the SP type but the E-ST was the least found. That of Odonata was the SP and the ST-SP type but they the least existed in the E-ST type. Ephemeroptera was found two species in the SP and the ST-SP type and one species in E-SP and E-ST. Lepidoptera was only ascertained in SP.

Four rare aquatic insect species were identified and were listed in the Korean Red Data Book by the National Institute of Biological Resources (2013). E-ST had no rare insect species. *Cybister japonicus* (NT) and *Paracercion sieboldii* (VU) were sampled in SP and E-SP, *Copera tokyoensis* (NT) in ST, and *Lestes temporalis* (NT) in ST-SP (Table 5).

3.2.3 Species assemblages with chemical characteristics

DCCA ordination of the species (aquatic plants and insects) assemblage data (Fig. 5, Table 6) showed the assemblage groupings according to pond type (SP, ST, ST-SP, E-SP, and E-ST). The environmental variables correlated with Axis 1 were DO, NH_4-N, and EC. Axes 1 and 2 accounted for 37% and 28% of the explained variance (Table 6). A significant difference was detected in all canonical axes ($p < 0.01$). SP type community was associated with high fluctuation of DO, NH_4 and P. ST type community was linkup with high changed temperature and EC. ST-SP type community was affiliated with high fluctuation of K^+ and Mg^{2+}. E-SP type community was associated with high fluctuation temperature. E-ST type community was confederation with EC. The global ANOSIM test showed significant differences (R = 0.46, $p < 0.003$) in assemblage composition among pond types. SIMPER test results showed that average similarity was 68.8% in SP, 58.9% in ST, 67.9 % in ST-SP, 60% in E-SP, and 65.9% in E-ST. Plant β-diversity was significantly higher in the ST than that in the E-ST type ($F_{4,16}$=5.68, $p < 0.05$). Average aquatic insect β-diversity was highest (0.79) in the ST type and lowest (0.32) in the E-SP type ($F_{4,16}$=5.14, $p < 0.05$) (Table 4).

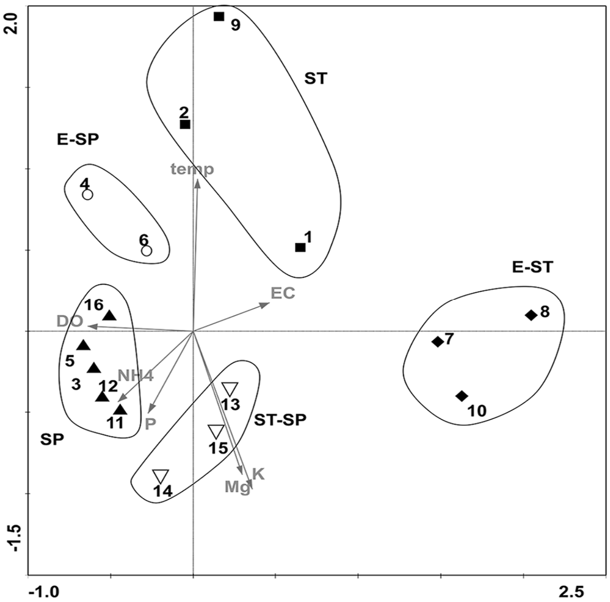

Fig. 5. Detrended Canonical Correspondence Analysis of the aquatic plant and insect species assemblages.

Table 6. Summary statistics of the DCCA for the aquatic plant and insect species assemblages.

Axes	1	2
Eigenvalues :	0.372	0.282
Species-environment correlations :	0.996	0.977
Cumulative percentage variance		
of species data :	9.4	16.6
of species-environment relation:	19.1	33.6
Correlation		
PO_4-P (P)	-0.1798	-0.3525
NH_4-N (NH_4)	-0.3025	-0.3062
K^+ (K)	0.2379	**-0.6778**
Mg^{2+} (Mg)	0.1982	-0.6181
Dissolved Oxygen (DO)	**-0.4231**	0.0194
temp	0.0191	0.6555
EC	0.3069	0.1207

4. Discussions

4.1 The fluctuation of water chemical of the irrigation ponds surveyed and their influence on assemblage composition.

The water level in irrigation ponds fluctuates annually because it is used as a water supply and is influenced by the farming cycle, which cause annual fluctuations in chemical concentrations and would influence on plant and aquatic insect assemblages (Davies et al., 2008). DO was the major factor influencing species distribution and was conspicuously low in September and high annual fluctuation at the SP and E-SP types. Low DO can occur when emerged plants and floating-leaved plants start to die (Frodge et al., 1990) or submerged plants decline in abundance (Kaenel et al., 2000; Miranda and Hodges, 2000). The SP and E-SP types had a high abundance of submerged and floating plants, and the open-water area was small. DO decreased rapidly in September when these plants declined in abundance.

In many studies showed that EC can be used to discriminate wetland plant community types (Johnston and Brown, 2013; Rolon and Maltchik, 2006; Sass et al., 2010) and as an indicator of the wetland water source because it tends to be greater in groundwater and run-off water than in precipitation (Davis et al., 1980; Green, 1970). In our study, EC value in most ponds, particularly the E-ST type, was high in August, which may have originated from fertilizer in rain water from surrounding farm land (Fig. 3).

The water temperature was low in the SP, E-SP, and ST-SP types where the main water source was groundwater. The annual change of nutrient were large but their means were low (Table 2). These might indicate the presence of spring water. The difference in summer and winter water temperatures was lower in spring type than other types. Drexler and Bedford (2002) and Craft et al (2007) showed that species richness declines when NH_4-N increases. The ST-SP type had the lowest NH_4-N concentration, which might be associated with the highest number of plant and insect species. Furthermore, these characteristics would influence the abundance of aquatic plants (Kibriya and Iwan Jones, 2007; Pip, 1989). *U. vulgaris* occupied water surface in all SP irrigation ponds and thick beds of this species might be used as habitats by aquatic insects and rare species. *C. japonicas* (NT, NIOBR (2013)) and *P. sieboldii* (VU, NIOBR (2013)) were observed only in the spring type also. Undoubtedly, plants provide insects hiding places from predators as well as oviposition sites (Gioria et al., 2010). As a result, we suggested that *U. vulgaris* may be an indicator species of the spring type of irrigation ponds. Moreover, we conclude that the number of species was influenced by the water source.

Overall, the important environmental factor which is influenced on assemblage composition of irrigation ponds would be water chemical change and connection.

4.2 Diversity of irrigation ponds

The size and shape of the irrigation ponds were not related to species richness, as their shapes were very similar and did not affect species richness (Williams et al., 1997). In general, large areas have larger species richness than that of smaller areas (Jeffries, 1998; Møller and Rørdam, 1985). Our result, however, that was a very weak correlation with area and species richness for a number of plant and invertebrates. Oertli et al. (2002) showed that a set of ponds of small size had more species than a single large pond. Moreover we suggest that the species richness was dealing with the dramatic annual change in water level due to the use of water for rice farming.

Previous study showed ponds play an important role in freshwater ecosystem biodiversity although ponds occupy relatively small areas on a local scale (Hamerlík et al., 2013). β-diversity was high in the ST than other types. A number of studies have highlighted that ponds can have very different physico-chemical conditions which can drive high beta diversity even when they are in close proximity (Scheffer et al., 2006; Williams et al., 2003), which means that environmental heterogeneity was related to hydrological heterogeneity of the pond in the studied area. We suggest that the irrigation ponds improve the heterogeneity on monoculture area, and contribute to regional biodiversity in agricultural areas (Benton et al., 2003).

Notably, species of Odonata in the pond was 28, which is 22.7% of Odonata species abundance in South Korea (Jung, 2007). Dragonflies (Odonata) have an important top predator role in freshwater ecosystems (Corbet 1962) and are umbrella species for biodiversity conservation (Lambeck, 1997; Schindler et al., 2003). It is highly probable that the pond in this area has highly conservation value, and important role in CCZ. In addition, Flora and aquatic insect fauna of ponds in the studied area were 61% and 594% of those in the Ungok wetland, which is a Ramsar lacustrine-inland wetland site in Korea, most similar to a pond, and a very well-known wetland with high biodiversity (NIER and NWC, 2013).

In addition, the pond was a momentous habitat not only plant and invertebrate but also birds (Froneman et al., 2001; Sánchez-Zapata et al., 2005). We found nesting sites for mandarin duck (Least Concerned Species: IUCN, 2001) in the pond every year. We also observed grey herons, egrets, and red-crowned cranes (Endangered Species: IUCN, 2001). The CCZ is a well-known area for migrating birds (DMZ ERI, 2013; Lee, 2013) and the rice paddy fields in CCZ were very important to them. Moreover, our results showed that the irrigation pond can improve habitat heterogeneity in farmland areas and provide refugee or nesting sites for water birds in agricultural areas (Benton et al., 2003; Galbraith, 1988). Therefore, the irrigation ponds in the agriculture ecosystem are very important for wildlife.

5. Conclusions

The goal of this study was to investigate whether biodiversity and species assemblages were associated with water chemical annual fluctuation. Our results show that water chemical annual fluctuation might influenced on plant and aquatic insect communities in ponds. In addition, the ponds are a rich and valuable source for biodiversity. Moreover, ponds improve habitat heterogeneity in agricultural areas and this benefits wildlife by providing breeding, resting, and refugee sites. Proceeding from what has been said above, it should be concluded that the pond which is controlled by water source and connection is the major axis of supported the CCZ biodiversity.

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