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Relationship between early development of plant community and environmental condition in abandoned paddy terraces at mountainous valleys in Korea

우리나라 산지 계단식 묵논에서 식물 군집의 초기 발달과 환경 조건과의 관계

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ABSTRACT

Relationship between early development of plant community and environmental condition in abandoned paddy terraces at mountainous valleys in Korea[1]

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In Korea, many paddy fields in mountainous area have been abandoned because of their low accessibility and rice price and the abandoned paddy terraces have changed into natural lentic wetlands. To understand the relationship between characteristics of environmental conditions and early development of plant community in abandoned paddy terraces, we investigated at four well-maintained abandoned paddy terraces in 3 different climatic zones in Korea. Soil texture of abandoned paddy terraces was mostly kinds of loam or sandy loam and electric conductivity of soil was also similar range among abandoned paddy terraces. On the other hand, contents of nitrogen, phosphorus, potassium, sodium, magnesium, and calcium and in soil and water depth were relatively different

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within sites and inter-sites. Therefore, we could confirm that there was different in soil condition and water depth between locations of abandoned paddy terraces and a result of CA analysis suggested that water depth was the strongest loadings.

Although environmental conditions including climate, soil condition and water depth were different among abandoned paddy terraces, the compositions of plant communities were relatively similar in all abandoned paddy terraces. 55 dominant taxa out of 141 recorded species were commonly recorded over the sites and they were mostly perennial obligated wetland plants and facultative wetland plants. 9 taxa out of 55 dominant taxa occurred at all abandoned paddy terraces with over 10% coverage. Several site-specific species occurred at each site which was some area with deep water level or difference in environmental condition and they were showed a low coverage except some specific species. Those results indicates that early development of plant community in abandoned paddy terraces of similar water regime is similar in the entire area of Korea even though environmental conditions such as climate, biogeographic history and soil condition are different.

Keywords : hydrophytes, Korean wetlands, succession, water depth, wetland plants

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INTRODUCTION

At the regional scale, differences in climate, physical geomorphology, biogeographic history, and large-scale patterns of human land use can lead to differences in available species pools (Rickelfs 1987, Zobel 1992, Foster et al. 2003). Within the region, surrounding land uses, site isolation, and site area influence plant species composition by determining rates of propagule input (Matthews et al. 2009). Wetlands are also affected of hydrology and physico-chemical environment (Mitsch and Gosselink 2007). Hydrology regime is considered to be importance in determining characteristics of wetland plant communities (Keddy 2000, Mitsch and Gosselink 2007). Depth, duration, and frequency of flooding are major controls of seed germination and establishment (van der Valk 1981, Casanova and Brock 2000), boundaries between woody and herbaceous vegetation (Toner and Keddy 1997), plant productivity and diversity (Fennessy et al. 1994), and species composition (Weiher and Keddy 1995). It also determines the frequency and intensity of flood disturbance, which creates topographic differences and erosion (Naiman and Decamps 1997). Apart from those, other important factors of the plant composition in wetlands include fertility, salinity, and competitiveness between plants and herbivores (Keddy 2000). Soil fertility is also a determinant of plant community and diversity in wetlands (Weiher and Keddy 1995) because wetland soils are both the medium that many of the wetland chemical transformations take place and the primary storage of available chemicals for most wetland plants (Mitsch and Gosselink 2007), so that nutrient enrichment could increase growth of invasive species (Green and Galatowitsch 2002, Kercher and Zedler 2004, Rickey and Anderson 2004, Rejmankova 2011) and these environmental conditions could lead a different stage of succession.

As paddy cropping was especially important economic activity in Asia, many paddy fields and paddy terraces in mountainous valleys were developed for intensive agricultural systems (Kim et al. 2006, Park et al. 2006). Since the improvement of socio-economic conditions, there was low economic benefit due to decrease in consumption of rice, rural exodus of farmers, and government agricultural policies aiming to reduce overpopulation, and now paddy fields have been increasingly abandoned (Park et al. 2006, Byun et al. 2008). Especially, because of being located at mountainous valley, paddy terraces were inaccessible and unfavorable farming conditions such as inclining topography, small terraced plots, and levee grasses that were hard to mow, as a result they have been getting non-cropped land and they did not be cared (Fukamachi et al. 2005). Although they were the largest man-made wetland ecosystems at first, they have changed into natural wetlands after abandonment (Lee et al. 2002, Kim et al. 2006, Yamada et al. 2007). Therefore, they could provide a function of foods and protection of fowl, and habitats which could increase biodiversity (Comin et al. 2001).

Until now, abandoned paddy fields have been studied for plant succession within near-region but abandoned paddy terraces which were our study sites were distributed to several locations with mountain ranges in Korea. After abandonment, they were transformed from artificial wetlands into natural wetland by being affected by environmental condition. Diverse plant species could be established according to hydrology regime and soil condition and they could be in the different development stage of plant community. Here, we investigated physico-chemical characteristics and plant community of abandoned paddy terraces which represent three regions disconnected by the mountain ranges, which divide watersheds and climatic zones. The object of this study is to reveal the relationship between characteristics of environmental conditions and early development of plant community at abandoned paddy terraces in South Korea.

MATERIALS AND METHODS

1. Study sites

Study sites were located at mountainous valley in Ansan (site A, 37˚17′ 10.68″ N, 137˚55′ 25.96″ E, 107 m a.s.l., 6,353 m2) in Gyeonggi-do, Uljin (site B, 36˚54′ 26.43″ N, 129˚24′ 46.47″ E, 35 m a.s.l., 2,345 m2) which was located 0.33 km off the coast in Gyeongsangbuk-do, Gokseong (site C, 35˚15′ 53.38N, 127˚16′ 09.68″ E, 115 m a.s.l., 5,102 m2), and Boseong (site D, 34˚48′ 21.53″ N, 127˚04′ 55.96″ E, 158 m a.s.l., 14,020 m2) in Jeollanam-do in Korea (Fig. 1). They represent three regions distributed by the mountain ranges which determine watersheds and climatic zones. We selected study sites which were approximately abandoned between 10 and 15 years ago, composed of over five floors, and well-maintained in terms of levee structure or water regime after being uncared. Ground matrix of four study sites was granite gneiss (Korea Institute of Geoscience and Mineral Resources 2012). The main water source was surface water. Even though monsoonal climate experiences heavy rain during summer season, the water depth in these sites was kept at a constant level by slopes and dikes with excess water flowing out downhill.

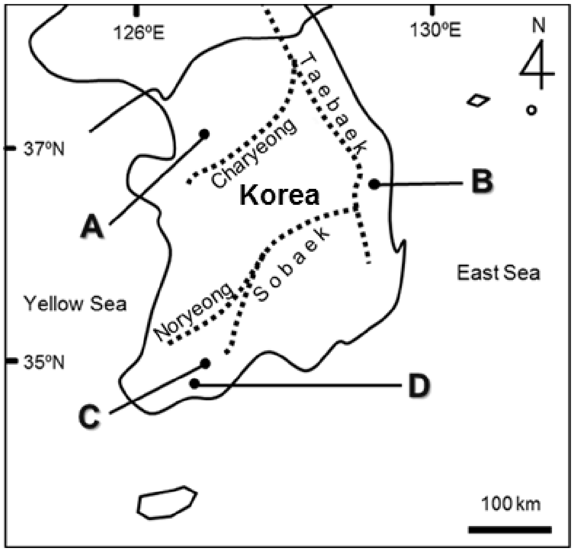

Figure 1 Locations of four study sites. A, Ansan in Gyeonggi-do; B, Uljin in Gyeongsangbuk-do; C, Gokseong in Jeollanam-do; D, Boseong in Jeollanam-do in South Korea (solid line across the map indicated the 38th Parallel and broken lines indicated mountain ranges on the map).

Mean temperature and precipitation for 30 years were quietly different among the study sites overall (Fig.2). Especially, mean precipitation of site B was lower than the other sites. Site C and D located in south showed more amount of mean precipitation and higher mean temperature than the other sites. Each floor in the same site was to be a quadrat and there was repetition at the study site.

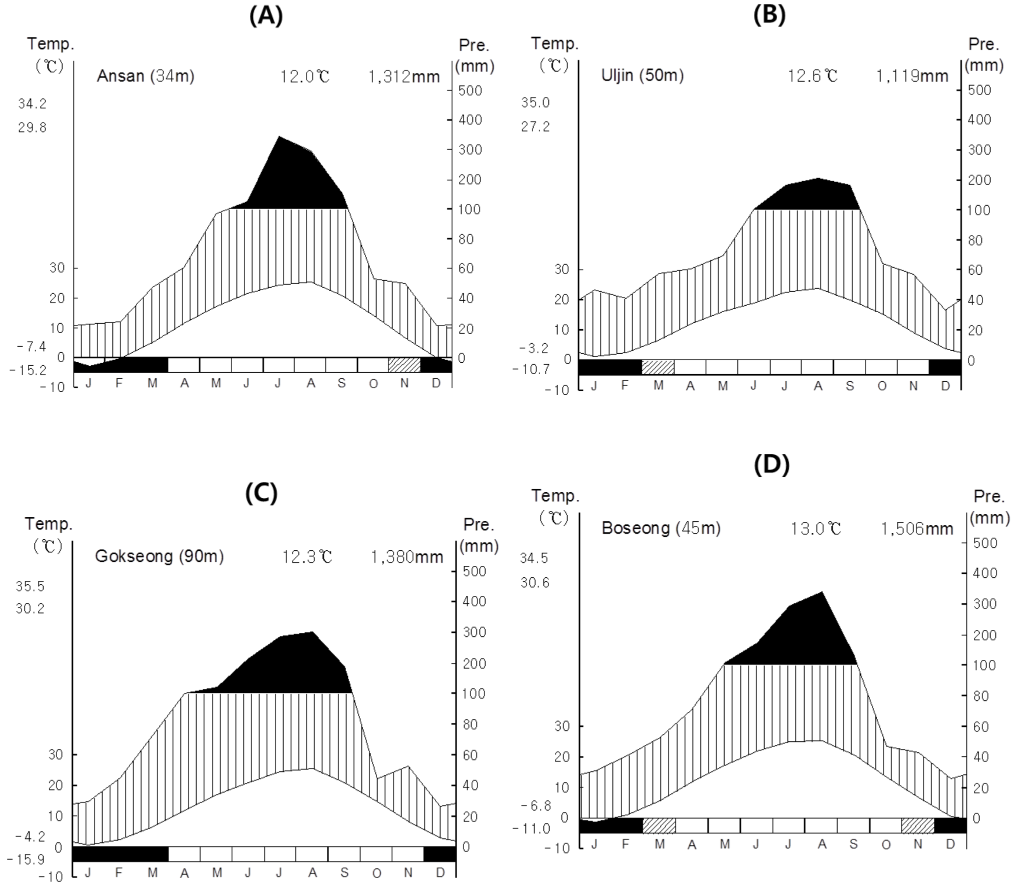

Figure 2 Climate diagrams of four study sites, Ansan (A), Uljin (B), Gokseong (C), and Boseong (D), during 1981 – 2010. Temp., temperature; Pre., precipitation.

2. Soil condition and water depth

Soil samples were randomly collected at five points in each floor with a depth of 0 ~ 5 cm from the surface by using a soil hand auger. Gravel and large organic debris were removed from samples by being passed through 2 mm sieve (standard sieve #10). Soil texture was determined using the hydrometer analysis method and the texture triangle of USDA (Carter 1993). Water content was determined after drying the samples at 105℃ in an oven for overnight (Topp 1993). Organic matter content was analyzed by the loss−on ignition method (LOI) (Boyle 2004). Soil solutions were prepared by mixing the soil samples with distilled water at a mass ratio of 1 to 5 and pH and conductivity (CON) were measured, using a pH meter (AP63; Fisher, Hampton, USA) and a conductivity meter (Model 311; Corning, Lowell, USA), respectively. NO_3−N and NH_4−N were extracted with 2 M KCl solutions (Kim et al. 2004) and measured colorimetrically using the hydrazine and indophenol methods, respectively (Murphy and Riley 1962, Kamphake et al. 1967). PO_4−P was extracted with Bray No. 1 solution (Bray and Kurtz 1945) and measured colorimetrically using the ascorbic acid reduction method (Solorzano 1969). Available K^+, Ca^{2+}, Na^+, and Mg^{2+} were extracted with 1 N ammonium acetate solution (Allen et al. 1974) and measured with an atomic absorption spectrometer (Model AA240FS, Varian, Palo Alto, CA, USA).

Water depth was repeatedly measured at five points at each floor. Water depth was measured during the early growing season before the rainy season in 2011.

3. Flora and vegetation composition

The flora list and vegetation map about dominant species were recorded at each floor during summer season in 2011. The flora was investigated by passing all over the floors. Figuring out the dominant species in the map of the vegetation composition was determined by showing over 10% at each floor. The taxonomic nomenclature designated by Lee (2003) was used to identify each plant species. Species richness was obtained by counting the number of species in the whole sites. The Shannon–Weaver diversity index (H’) was used for the vegetation data in study sites (Shannon and Weaver 1949).

$$H' = -\sum_{i=1}^{s} P_i \ln P_i,$$

where P_i= coverage of species i / total coverage

4. Data analysis

To examine and identify the similarities and/or differences in physico–chemical characteristics and plant community, correspondence analysis (CA) was conducted using the vegan–package 2.0–5 (Okasanen et al. 2012) in R program version 2.15.1. The CA ordinations based on the environment factor–site matrix table and the species–site matrix table were carried out. The specific cover data was placed into the species relative coverage.

Duncan’s post–hoc tests were conducted to identify specific differences at the 5% significance level using SPSS version 20.0 for Windows (SPSS, Inc., Chicago, IL, USA).

RESULTS

1. Soil condition and water depth

There were significant differences among abandoned paddy terraces in soil characteristics (Table 1). Soil texture was silt loam or sandy loam in most floors. Water contents and organic matter contents within and among abandoned paddy terraces were similar, but site C was slightly higher than the others. The conductivity ranged from 30 to 40 μS/cm in all abandoned paddy terraces and did not show significant difference among abandoned paddy terraces but pH ranged from 4 to 6 and showed a little difference among the abandoned paddy terraces. NO_3−N was similar in all abandoned paddy terraces but NH_4−N and PO_4−P were quite different among abandoned paddy terraces. NH_4−N was the least in site B. PO_4−P was about eight times higher in site B and D than the others. The contents of major cations were mostly higher in site B which was located near the seashore than the others. Especially, Mg^{2+} and Ca^{2+} contents were much higher than the others. The average water depth was higher in site C and D than the others, and site C particularly showed a high gradient of water level among floors.

Table 1 Soil conditions and water depth in abandoned paddy terraces (mean ± SD)

	Site A (N = 7)	Site B (N = 5)	Site C (N = 7)	Site D (N = 8)
Sand (%)	40.7 ± 20.1a	44.3 ± 2.4a	42.3 ± 2.1a	39.2 ± 4.7a
Clay (%)	6.8 ± 3.9b	5.0 ± 0.9ab	3.4 ± 1.6a	4.7 ± 1.1ab
Silt (%)	52.5 ± 16.3a	50.8 ± 2.1a	54.3 ± 2.8a	56.1 ± 4.2a
Soil texture	Silt loam or sandy loam	Silt loam or sandy loam	Silt loam	Silt loam or sandy loam
Organic matter content (%)	5.0 ± 0.8a	5.0 ± 0.6a	4.1 ± 1.5a	7.4 ± 1.6b
Water content (%)	34.8 ± 4.8a	33.2 ± 1.0a	37.7 ± 8.9a	46.9 ± 8.5b
Conductivity (μS/cm)	31.8 ± 4.5a	43.0 ± 8.4b	29.3 ± 1.3a	32.4 ± 3.8a
pH	4.7 ± 1.1a	6.3 ± 0.2b	5.4 ± 0.3a	5.2 ± 0.1a
NO_3−N (mg/Kg)	2.9 ± 0.3a	2.6 ± 0.4a	3.5 ± 0.8a	3.5 ± 1.3a
NH_4−N (mg/Kg)	10.0 ± 6.7ab	5.4 ± 1.4a	10.4 ± 4.7ab	12.2 ± 4.9b
PO_4−P (mg/Kg)	3.4 ± 2.9a	24.1 ± 16.5b	3.1 ± 1.2a	21.5 ± 13.4b
K^+ (mg/Kg)	52.6 ± 6.8a	97.5 ± 57.4b	41.2 ± 9.3a	54.3 ± 18.0a
Ca^{2+} (mg/Kg)	248.1 ± 40.7a	1520.1 ± 284.4b	397.7 ± 124.2a	430.7 ± 207.2a
Na^+ (mg/Kg)	24.6 ± 5.7a	59.4 ± 8.8c	18.0 ± 5.1a	35.4 ± 9.8b
Mg^{2+} (mg/Kg)	66.7 ± 9.9a	323.0 ± 74.5b	48.0 ± 10.8a	75.4 ± 38.1a
Water depth (cm)	6.0 ± 2.2a	7.4 ± 2.5a	33.3 ± 14.2b	28.8 ± 5.2b

Each letter denotes statistically different sub−groups by Duncan’ s test, $p<0.05$.

To identify the similarities and/or differences in physico−chemical characteristics among the floors and the sites in different location, CA ordination was carried out (Fig. 3). In CA ordination, axes 1 and 2 accounted for 66.3% (eigenvalue = 0.10) and 11.5% (eigenvalue = 0.02) of total variance, respectively. Sites with relatively strong loadings on axes 1 and 2 were water depth (score = −0.79 and 0.69, respectively). As a result, floors in the same site were completely grouped but the sites were divided into each location, and site C and D were overlapped in several floors.

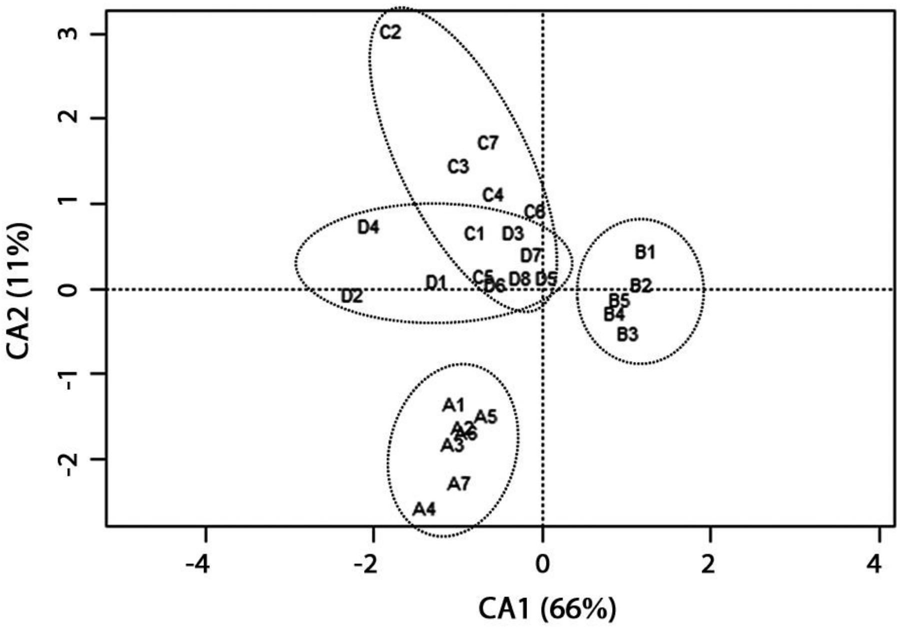

Figure 3 Correspondence analysis of the 27 floors based on physico−chemical characteristics. Labels indicate location of abandoned paddy terraces (A, Ansan; B, Uljin; C, Gokseong; D, Boseong) and floor number. Ellipses were drawn around each abandoned paddy terrace.

2. Flora and vegetation composition

A total of 141 species were recorded in four sites. According to wetlands indicator category (US Fish and Wildlife Service 1996), there was a large amount in obligated wetland plant (OBW) and facultative wetland plant (FACW), but obligated upland plant (OBU) was also counted high in our study sites (Fig. 4). Particularly, a large amount of OBW was showed in site C and D whose water level was higher than the others, and site C was especially showed the highest ratio of OBW. About life-forms of plants, perennial herbaceous plants largely took up and then annual herbaceous plants were occupied. Site C comparatively showed a high ratio of annual herbaceous. Site A showed a large coverage of shrub. Most of the plants were hygrophyte, and their habitats were mostly aquatic environment, wet meadow or meadow and shrub land. About growth-forms of plants, submerged and floating-leaved plant communities particularly occurred at high ratio in site C. Additionally, rare species *Bletilla striata* (Thunb. ex Murray) Reichb. Fil. and endangered species *Penthorum chinense* Pursh were found in site A and D, respectively. We could determine that there was similar abandoned year by measuring coverage of tree layer especially *Salix koreensis* and *S. chaenomeloides* Kimura. The coverage of tree layer was not showed all over the floors, but some floors in the site D showed about 10% coverage of *S. koreensis* and other floors in the site C showed about 10% coverage of *S. chaenomeloides* Kimura. The rest of the floors showed about from 10% to 20% of the coverage of the shrub layer, especially *S. gracilistyla* Miquel and *Amorpha* *fruticosa* L.

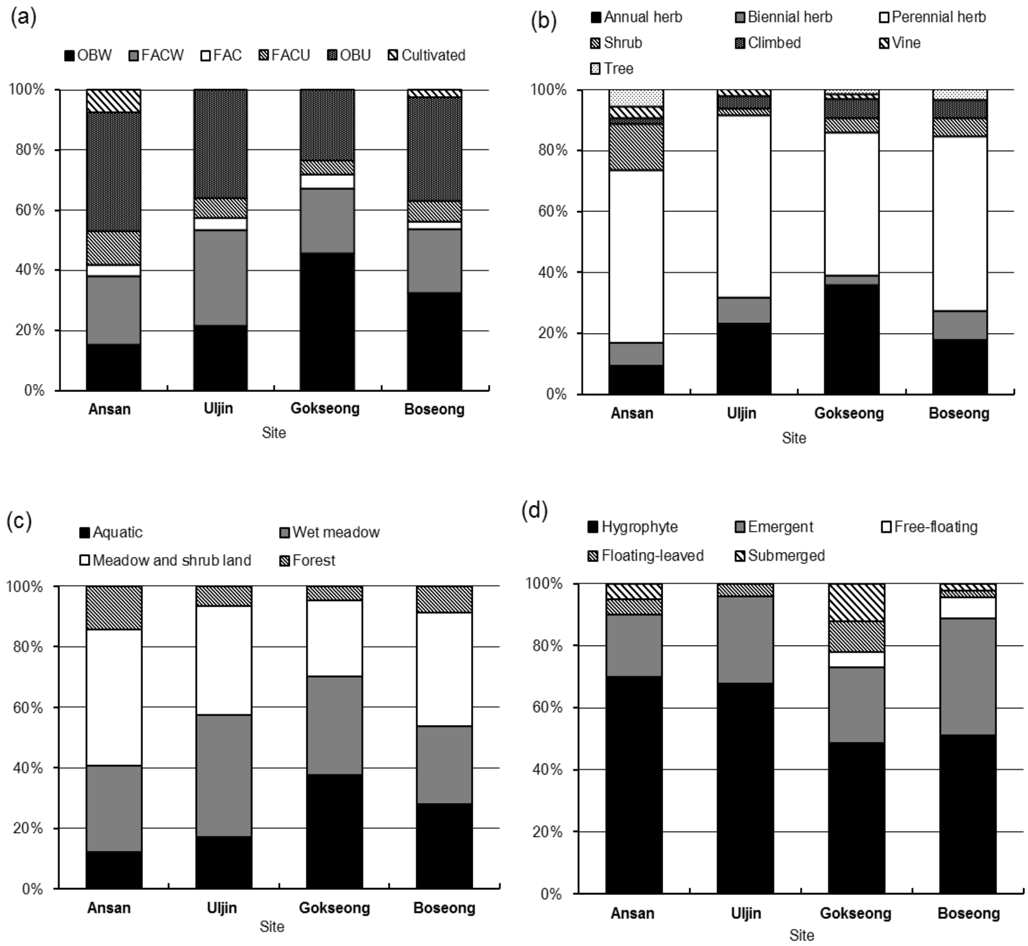

Figure 4 Characteristics of plant community identified in abandoned paddy terraces, (a) Wetland indicator, (b) Life-form, (c)Habitats, (d)Growth-form.

Mean of species richness and diversity index per floor were 22.67 ± 6.25 and 1.56 ± 0.25, respectively (Table 2). Species richness was the largest in site D and the least in site

A. However, species richness per square meter was not different between Site A and D and the highest in site B. Shannon's diversity was the largest in site A and B, but the least in site C.

Table 2 Species richness and diversity index

	Site A (N=7)	Site B (N=5)	Site C (N=7)	Site D (N=8)	Mean
Species richness	14.43 ± 4.69	23.40 ± 4.28	20.86 ± 6.89	32.00 ± 9.13	22.67 ± 6.25
Shannon's diversity index	1.77 ± 0.33	1.73 ± 0.21	1.40 ± 0.22	1.64 ± 0.21	1.56 ± 0.25

Among the 141 species, a total of 93 species occurred in all sites. A total of 55 species were recorded as dominant species by sum of the whole sites (Table 3). In order to identify the similarities and/or differences in the plant communities among the sites, CA ordination was carried out (Fig. 5). In CA ordination, axes 1 and 2 accounted for 12.1% (eigenvalue = 0.76) and 11.1% (eigenvalue = 0.70) of total variance, respectively. Relatively strong loadings on axis 1 were *S. triangulatus* (score = 3.92), *Eleocharis dulcis* (3.92), *Phragmites japonica* (2.63), *Ludwigia prostrata* (−0.91) which were recorded in specific sites, group II. On the other hand, relatively weak loadings on the axis 1 were *Persicaria thunbergii* (−0.32), *P. australis* (−0.18) and *Leersia japonica* (−0.08) which occurred at all sites, group I. Group I included major dominant plant species which were mostly FACW / OBW and perennial herbaceous plant species. Plant species in group

II were divided into three subgroups. Plant species in group II occurred at only one site as specific dominant species. Species in group II −1 occurred only in site D. Coverages of *Sium suave* and *Scirpus triangulatus* in group II−1 were high in site D, Species in Group II−2 occurred in site A and B. *Zizania latifolia* and *Artemisia princeps* were dominant species in site A and B, respectively. Species in group II−3 occurred in site C only and *Typha orientalis* was remarkably dominant species.

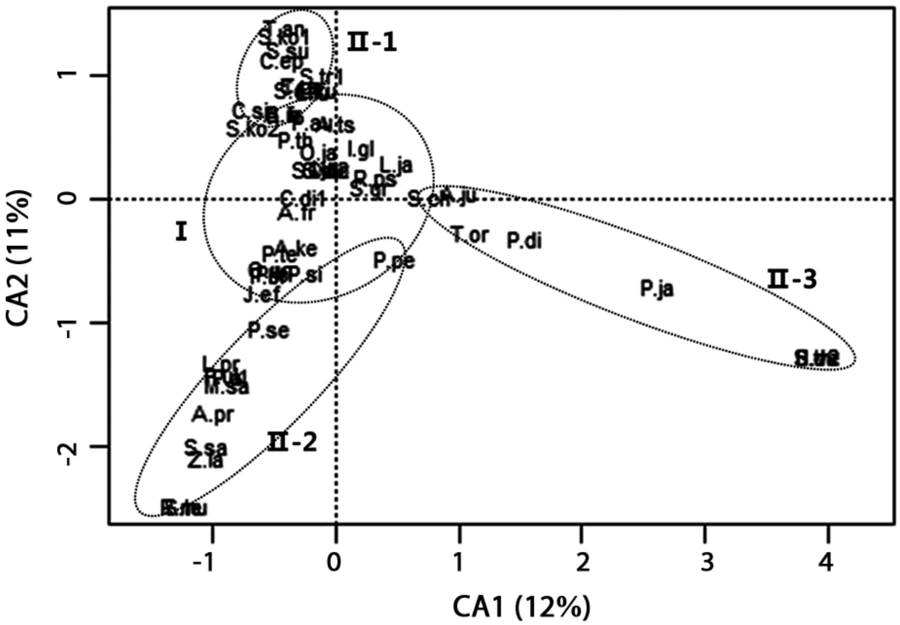

Figure 5 Correspondence analysis of the 55 dominant plant species included relative coverage in abandoned paddy terraces. Three characters indicate abbreviation of scientific name (one character is generic name and two characters are specific epithet). Ellipses were drawn around a status of each group (group Ⅰ, species occurred at several sites; group Ⅱ, species occurred at only one site).

Table 3 Dominant plant species recorded in abandoned paddy terraces

Group	Abbreviation	Species	Abbreviation	Species	Abbreviation	Species
Ⅰ	A.fr	*Amorpha fruticosa*	S.of	*Sanguisorba officinalis*	P.au	*Phragmites communis*
	A.in	*Aeschynomene indica*	S.wi	*Scirpus wichurae*	P.bi	*Panicum bisulcatum*
	A.ke	*Aneilema keisak*	T.re	*Trifolium repens*	P.lo	*Pueraria lobata*
	O.ja	*Oenanthe javanica*	P.uk	*Pseudoraphis ukishiba*	P.si	*Persicaria sieboldii*
	A.ts	*Agropyron tsukushiense*	R.ps	*Robinia pseudoacacia*	P.th	*Persicaria thunbergii*
	B.fr	*Bidens frondosa*	S.gr	*Salix gracilistyla*	I.gl	*Isachne globosa*
	C.bi	*Carex biwensis*	S.ko2	*Salix koriyanagi*	J.ef	*Juncus effusus*
	C.co	*Commelina communis*	S.mo	*Sphagnum mosses*	L.ja	*Leersia japonica*
	C.di1	*Carex dickinsii*	P.te	*Peucedanum terebinthaceum*	L.lu	*Lycopus lucidus*
	C.di2	*Carex dimorpholepis*	O.un	*Oplismenus undulatifolius*	I. ja	*Isoetes japonica*
	E.ku	*Eleocharis kuroguwai*				
Ⅱ−1	T.an	*Typha angustifolia*	S.tr1	*Scirpus triangulatus*	C.ep	*Calamagrostis epigeios*
	S.ko1	*Salix koreensis*	S.su	*Sium suave*	C.si	*Carex siderosticta*
Ⅱ−2	P.pe	*Persicaria perfoliata*	M.sa	*Miscanthus sacchariflorus*	R.mu	*Rosa multiflora*
	P.se	*Persicaria senticosa*	A.pr	*Artemisia princeps*	S.sa	*Spiraea salicifolia*
	L.pr	*Ludwigia prostrata*	Z.la	*Zizania latifolia*	S.te	*Sanguisorba tenuifolia*
	P.al	*Pennisetum alopecuroides*				
Ⅱ−3	S.ch	*Smilax china*	E.du	*Eleocharis dulcis*	H.ve	*Hydrilla verticillata*
	T.or	*Typha orientalis*	P.ja	*Phragmites japonica*	P.di	*Potamogeton distincuts*
	A.ju	*Albizia julibrissin*	S.tr2	*Scirpus triqueter*		

Among the major dominant plant species in group I, we selected species which showed over 10% coverage at a floor (Table 4). *A. keisak, L. japonica, P. sieboldii, P. australis, L. lucidus, P. thunbergii, J. effuses,* and *O. undulatifolius* were recorded in all abandoned paddy terraces, but, *C. dickinsii, S. gracilistyla,* and *P. ukishiba* were recorded only in two sites. Particularly, site C which had deep water level showed that some dominant species were submerged plant species and coverage of willows was distinguishable. Overall, Cyperaceae, Gramineae and Salicaceae were recorded relatively high in abandoned paddy terraces.

Table 4 Plant species over 10 % coverage at a site in group I

Site A	Site B	Site C and D
Aneilema keisak	*Aneilema keisak*	*Aneilema keisak*
Leersia japonica	*Leersia japonica*	*Leersia japonica*
Persicaria sieboldii	*Persicaria sieboldii*	*Persicaria sieboldii*
Phragmites australis	*Phragmites australis*	*Phragmites australis*
Lycopus lucidus	*Lycopus lucidus*	*Lycopus lucidus*
Persicaria thunbergii	*Persicaria thunbergii*	*Persicaria thunbergii*
Juncus effuses var. *decipiens*	*Juncus effuses* var. *decipiens*	*Juncus effuses* var. *decipiens*
Oplismenus undulatifolius	*Oplismenus undulatifolius*	*Oplismenus undulatifolius*
Carex dickinsii	*Carex dickinsii*	
Salix gracilistyla		*Salix gracilistyla*
	Pseudoraphis ukishiba	*Pseudoraphis ukishiba*

DISCUSSION

The study sites represent three regions distributed by the mountain ranges which divide watersheds and climatic zones. This indicates that each region might have different environmental condition. CA analysis confirmed that studied sites can be grouped into three, which was originally suggested by the relative location of the sites in South Korea. Such different climate could affect soil formation because a quantity of precipitation or a time and period of raining could be an important factor. Soil condition was a similar gradient among floors in the same abandoned paddy terraces but a quite difference among the locations. These environmental differences among the abandoned paddy terraces were confirmed by Duncan's test. Among differences in environmental factors, K^+, Ca^{2+}, Na^+, and Mg^{2+} contents were extremely high in site B. Site B was located near the east coast, so it could be affected by salt spray (Barbour and DeJong 1977) and shell crusts which were easily found in soil sample of this site. Water depth was also significantly different among the abandoned paddy terraces, not floors. In general, water level was low (less than 30 cm) and consistent through a year in all abandoned paddy terraces. However, site C showed a high physical gradient and water depth was quite different among the floors. Site C was disturbed by human activities and local government conserves this area as habitats of *Nannophya pygmaea* which is an endangered species in Korea. So, local government has managed geomorphology to have diverse water lev el.

A total of 141 species were investigated in sum of whole abandoned paddy terraces and 98 species were overlapped in all abandoned paddy terraces. 55 species were dominant plant species. CA analysis showed that all dominant species could be assigned to 4 groups. There were 9 common plant species having over 10% coverage of a floor in all abandoned paddy terraces. This indicates similar distribution pattern of dominant species despite site differences. We can expect 11 species in any between 10 and 15 year-old abandoned paddy terraces in South Korea because tree layer was lower than 10% coverage and shrub layer was lower than 20% coverage (Lee 2006). Generally, abandoned paddy terraces in mountainous valley about 10 years old would show slow growth rate of vegetation because other abandoned paddy fields could be recovered with sprout placed in there but abandoned paddy terraces might be affected by newly entering seed (Bazzazz 1968, Harrison and Werner 1982, Inouye et al 1987, Lee 1995). The coverage of *Salix* spp. was high in site A and C. *Salix* could generally germinate in low water level condition. However, water level of site C was high. This means that site C was disturbed by anthropogenic activities for the conservation of this area. The original water level at site C might be low for willow seed to germinate. High water level might make site C not dominated by *P. thunbergii* that is dominant species in other abandoned paddy fields (Byun et al. 2008). *T. orientalis* and *S. suave* occurred at all floors at site C and D, respectively. As *S. suave* is a common forb i nhabiting easily and continuously increasing in wetlands with appropriate nutrients (Green and Galatowitsch 2002). Also, *T. orientalis* was a dominant species in site C only. These species could be established by human during management activities for the conservation.

This study confirmed that water depth was the most important factor for early successional stage in abandoned paddy terraces (Weiher and Keddy 1995). Also, diverse water depth induces diverse plant species because high environmental gradient could provide diverse conditions for diverse habitats (Ackerly 2003, Pausas et al. 2003). However, consistent deep water in a lentic wetland could limit the inhabitation of plant species (Miller et al. 2003).

There was the similar early development of plant community even though the abandoned paddy terraces showed different environmental conditions through they were divided into groups according to locations. In general, ecosystem development is affected by environmental conditions. In particular, climate and physico-chemical characteristics could have a strong effect on the development of vegetation structure (Mitsch and Gosselink 2007). However, development of plant community was similar in all abandoned paddy terraces in this study. This result might come from focusing dominant species which are determined by water level.

After abandoned, paddy fields in flat ground depending on irrigation systems might be dried. However, water regime in abandoned paddy terraces was mainly affected by around mountain stream and precipitation for water resource and levee and abandoned paddy terraces maintained nearly always wet condition and water level was maintained at a consistent level because of entire levees around arable fields (Park et al. 2006). Even though monsoonal climate experienced heavy rain during summer season, water depth in abandoned paddy terraces could be kept at a constant level by slopes and levees due to flowing excessive quantity of water to downhill. Furthermore, inaccessibility to those locations could be also advantage to the disturbance by anthropogenic activities. For those reasons, abandoned paddy terraces could be showed low nutrient (conductivity of 30 to 40 μS/cm), which could relatively make interspecific competition weaken (Greulich et al. 2000). Very high nutrient levels were not to be favor of co-occurrence for species with contrasting nutrient requirements and nutrient level at abandoned paddy terraces was very low (Bornette et al. 1998). This might be accounted by diverse flora and the Red List species were recorded in abandoned paddy terraces (Uematsu et al. 2010). Thus, keeping consistent shallow water level and low nutrients condition were important characteristics to allow abandoned paddy terraces to develop similar level of plant community. It could be explained by the environmental sieve model (van der Valk 1981). Introduced species and survived species could be determined by environmental characteristics. A succession in wetlands began to open water and introduced species could be affected by characteristics of water regime. In particular, water depth was one of the important factors to decide a process of the early stage of succession (Mitsch and Gosselink 20

07). Even though seeds of some species could be distributed over the wetlands by wind, animals or another means, they might be determined whether they could germinate and settle or not by environmental factors as filters, which was assembly rules (Keddy 1992) and early settlement effect. After establishment, it seemed that what species would be developed to the dominant plant community or not could be affected by another condition which could be competition between plant species or change topography or soil condition depending on plant community

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CONCLUSION

Early development of plant community in abandoned paddy terraces in South Korea could be determined by water regime rather than climate and physico−chemical characteristics of soil. This came from the similar water regime and location of abandoned paddy terraces, which play an important role in recruiting plant species. We conclude that early development of plant community in abandoned paddy terraces is similar in Korea even though the environmental conditions are different.

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국문 초록

현재 우리나라에 위치한 산지 계단식 논들은 낮은 접근성과 쌀 소비의 저하로 인하여 방치되거나 버려지고 있으며, 버려진 논들은 자연적 정수 습지로 점차 변해가고 있다. 자연 습지로 변해가는 묵논에 정착한 식물 군집의 초기 발달 상태가 지역별 환경 조건과 관련이 있는지 알아보기 위해 우리나라의 대표 산맥으로 나뉘어 구분되는 지역에 위치하며 상대적으로 관리가 잘 되어 있는 산지 계단식 묵논 네 곳을 선정하여 조사를 실시하였다. 묵논의 토성은 대부분 미사질 양토 또는 사양토였으며 전기전도도 범위가 비슷하였다. 이와는 달리 질소, 인, 칼륨, 나트륨, 마그네슘, 칼슘 그리고 수심은 동일 조사지역 내 방형구간 또는 조사지역 간에서 상대적 편차를 보여 지역별 산지 계단식 묵논 간의 토양 환경 및 수심의 차이를 확인할 수 있었으며, CA 분석결과 수심이 가장 큰 중요요인으로 밝혀졌다.

조사지역별 계단식 묵논 간 기후와 토양 환경, 그리고 수심에 의한 환경적 조건 차이가 있음에도 불구하고, 식물 군집의 구성은 상대적으로 모든 조사지역의 계단식 묵논에서 비슷하게 발달하여 있었다. 조사한 모든 계단식 묵논에서 관찰 및 기록된 식물상은 총 141종 이었다. 이들 중 군락을 이루어 피도로 표현될 수 있는 55종의 식물군집이 모든 조사지역에서 공통으로 조사되었으며, 이들은 대부분 다년생 식물이며 절대 습지 식물(OBW)과 임의 습지 식물(FACW)로 분류되었다. 더불어 55종의 식물군집 중에서 9종의 식물군집이 지역별 모든 계단식 묵논에서 10% 이상의 피도를 차지하는 종으로 동일하게 조사되었다. 그러나 조사지역의 수심이 상대적으로 깊거나 다른 환경적 차이에 따라 각 조사지에서 특이적으로 볼 수 있는 종들 또한 발견되었으나 몇몇의 특이종을 제외하고는 매우 낮은 피도를

보였다.

위의 결과를 토대로 우리나라에 위치한 산지 계단식 묵논 습지는 기후와 생물지리적 역사, 그리고 토양에서 환경 차이가 존재하더라도 결국 비슷한 범위 내의 수심을 가지는 계단식 묵논에서 나타나는 식물 군집의 초기 발달 및 천이 단계는 비슷하다고 제안할 수 있다.

주요어 : 수생식물, 수심, 습지식물, 우리나라 습지, 천이

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