JOURNAL OF
ECOLOGY AND ENVIRONMENT
http://www.jecoenv.org

Research Paper
J. Ecol. Environ. 38(4): 405-413, 2015

Analysis for the relationship of environmental factors and vegetation structure at natural streamside valley and riparian forest in South Korea

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Abstract

We classified the streamside plant community by phyto-sociological method and analyzed the relationship between environment factors and vegetation structure by using the classification and ordination method. We found that twenty one plant communities were classified according to dominant species at the natural streamside valley forest with surveying the 65 quadrats (10 m × 10 m). From the survey results, the hardwood plant communities were classified as streamside valley forest and the softwood plant communities as riparian forest according to the degree of flooding. The valley forest had a distribution of 17 plant communities which was 65% (42 quadrats) of 65 quadrats: *Maackia amurensis* community, *Betula davurica* community, *Quercus variabilis* community, *Pinus densiflora* community, *Q. serrata* community, *Prunus sargentii* community, and *Meliosma oldhamii* community etc. The riparian forest had a distribution of four plant communities which was 35% (23 quadrats) of 65 quadrats: *Salix koreensis* community, *S. rorida* community, *S. purpurea* var. *japonica* community, and *S. glandulosa* community, etc. From the two-way indicator species analysis (TWINSPAN) analysis, we found indicator species *Oplismenus undulatifolius* and *Lindera obtusiloba* for the streamside valley forest and *Humulus japonicus*, *Phragmites japonica*, and *S. koreensis* for the riparian forest. From the results of the canonical correspondence analysis (CCA), coordinates, altitude, and stream structure showed low correlation to the distribution of the plant community. Therefore, it seemed that valley forest and riparian forest were distinguished by the stream gradient and waterway width which determined by the stream water level.

Key words: CCA, hardwood forest, indicator species, softwood forest, TWINSPAN

INTRODUCTION

Generally, a stream is defined as a water mass that flows with steady waterway which has a gradient regardless of its size (Lee et al. 1996). Streams have continuity (Vannote et al. 1980, Hauer and Lamberti 1996) and they are an important element of landscape responsible for the structural and functional interaction and connection (Lee 2004). Streams have very high biological productivity and species diversity because not only do they connect hyporheic zone and the central area of the water flow but they also connect terrestrial ecosystem which includes surrounding vegetation zone (Odum 1983).

The stream ecosystem has a lot of changes in the species diversity depending on geographical characteristics and environmental variables. The physical property

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http://dx.doi.org/10.5141/ecoenv.2015.043

Received 6 April 2015, **Accepted** 1 July 2015

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pISSN: 2287-8327 eISSN: 2288-1220

such as water depth and chemical properties such as pH, salinity, and eutrophication are directly related to the change. In addition, it is said that water discharged from the streams also affects species diversity which creates a unique ecosystem (Lee et al. 2003).

The distribution pattern of the plants in the stream ecosystem is determined by the strategy and competition amongst plant species to one another if there are any physical or chemical changes in the soil due to the water flow (Hupp and Osterkamp 1996). The streamside vegetation has plant communities that are affected by regular or permanent flooding in the area close to the water and they are located in the transition zone between terrestrial and aquatic ecosystem. The vegetation of the stream ecosystem performs diverse functions such as sustaining the diversity of plant species, hydrologic control, water purification, streamside protection, and enhancement of scenic quality (Cho et al. 2001).

Furthermore, the streamside vegetation is the primary producer and it is used as an index to measure changes in water quality, stream flow discharge, and environmental factors in the basin (Lee et al. 2005). Recently, riparian vegetation was used in aquatic ecosystem health evaluation: biological quality assessment, spatio-temporal change analysis, and in assessing the effect of environmental disturbances (National Institute of Environmental Research 2014).

The plants form a community when a plant species repeatedly appear in similar site environment and likewise it is the classification of plant community which temporally and spatially determines the boundaries of a plant community (Lee et al. 2000).

The streamside forest is classified into hardwood or softwood forest depending on the level of flooding. The trees that are heavy and hard with less than 30 days of flooding period a year are classified as hardwood forest and trees that are light and soft with flooding period of 30~150 days a year are classified as softwood forest (Bittmann 1965). The hardwood forests develop mainly in the upper stream of the valley and softwood forests develop in the section below the mid-upper stream (Lee 2004).

The research on stream vegetation development was carried out in order to restore streams and flood plains in the first world countries as they recognized the importance of stream vegetation for the maintenance of healthy streams. In Germany, the streams are classified into high mountain and mountain streams, hill and plain streams, and lowland streams according to the stream classification and they suggest potential natural vegetation for the each category (Kim et al. 2008). On the contrary, we don't have streamside vegetation research results and we really need to know the type and characteristics of stream forests which are used as the basic data for the restoration of streams and flood plains.

The purpose of this research is to classify the plant community of natural streams that are not damaged or have minimal damaged by using the phytosociological classification of Braun-Blanquet and to analyze the correlation between streamside plant community and environmental factors by using classification and ordination methods. Also, we are to provide appropriate plant species for restoring river vegetation structure.

MATERIALS AND METHODS

Vegetation research

This research was firstly determined by using the aerial photographs and the research site was finalized after visiting the sites in person. Thirteen sites were selected as the research site from eight streams in total which seemed to have had minimal human contact from June to September 2009. Five quadrats were installed at each site and 65 quadrats were researched in total. The detailed information about its naturalness and artificial disturbance intensity on the research site can be referred to Han et al. (2013).

The vegetation research was performed by using phytosociological classification method (Braun-Blanquet 1964) of ZM school. The selection of a community at each research site was done in the areas which are affected or have been affected by water. The presence of influence by the water was confirmed by observing the flooding by the root of the dominant species or by checking the traces of flooding. The size of each quadrat was 10 m × 10 m. The appearing species were listed starting from the upper layer and the coverage of appearing species at each layer was measured and listed for the vegetation structure. The other environmental information of the research site (cardinal direction, stream gradient, longitude and latitude coordinates, altitude above sea level, stream width, waterway width, stream structure, and etc.) was measured using instruments such as GPS (Colorado 300; Garmin, Olathe, Kansas, USA) and inclinometer (DWL-80E; Digi-Pas, Chiyoda-ku, Tokyo, Japan). The species were identified by using the 'Coloured Flora of Korea (Lee 2003)' and species which could not be identified on the field were identified in our laboratory after collecting.

Classification and ordination methods

We used the phytosociological classification method by Braun-Blanquet which focused on the composition of plant species and two-way indicator species analysis (TWINSPAN) which was a quantitative analysis as the most typical methods for classifying the plant communities. These two vegetation classification methods were generally shown similar trends (Kim 1992, Jang et al. 1997), they were very complement each other (Lee et al. 2000), and the TWINSPAN method for the characteristic species analysis could automatically and simultaneously classify the correlation between plant species and stands (Hill 1979, Glavac 1996). We also used canonical correspondence analysis (CCA) as one of multivariate analysis and CCA generally was used to analyze the relationship between the plant community and environmental factors. CCA was the combination of correspondence analysis (CA) and multiple regression analysis which could show the relationship between the plant community and environmental factors well (Ter Braak 1986).

The analysis package PC-ORD 5.0 (MjM Software, Gleneden Beach, Oregon USA) program was used for TWINSPAN and CCA. Our vegetation data were converted to median value (5, 87.5; 4, 62.5; 3, 37.5; 2, 15; 1, 2.5; +, 0.99) of dominance scale from dominance class for the statistical analysis and only the species that were shown more than 10% appearance rate were used.

RESULTS AND DISCUSSION

Plant community

The plant communities in the 65 quadrats were classified into 21 plant communities by using dominant species as the criteria and appearing plant communities were classified into two types (Table 1).

The hardwood forest that develops mainly in the upper stream with flooding period less than 30 days a year was classified as valley forest and softwood forest that develops below mid-upper stream with flooding period of 30-150 days a year was classified as riparian forest (Bittmann 1965, Lee 2004). The valley forest was distributed around the section that has stream width of 10-170 m and waterway width of 8-120 m whereas the riparian forest was distributed around the section that has stream width of 65-230 m, waterway width of 30-150 m.

Table 1. Name of plant communities and quadrat number in studied sites

Type	Abbreviation	Community name	Quadrat No.
Valley forest	Ma	*Maackia amurensis* community	1
	Bd	*Betula davurica* community	2
	Qv	*Quercus variabilis* community	3, 31
	Pd	*Pinus densiflora* community	1, 12, 30, 33, 38, 64
	Pd-Qal	*Pinus densiflora-Quercus aliena* community	11
	Qs	*Quercus serrata* community	13, 53
	Pd-Qm	*Pinus densiflora-Quercus mongolica* community	15
	Ps	*Prunus sargentii* community	21, 55, 62
	Mo	*Meliosma oldhamii* community	22, 54
	Pj	*Pseudosasa japonica* community	23, 42, 49, 52
	Qa	*Quercus acutissima* community	24, 48, 51, 59
	Sj	*Styrax japonica* community	25
	Qa-Qal	*Quercus acutissima-Quercus aliena* community	28
	Qal	*Quercus aliena* community	29, 34, 35, 37, 40, 61, 63
	Pd-Qv	*Pinus densiflora-Quercus variabilis* community	32
	Ag	*Acer ginnala* community	36, 39, 47
	Pd-Qa	*Pinus densiflora-Quercus acutissima* community	46, 60
Riparian forest	Sk	*Salix koreensis* community	5, 6, 8, 9, 14, 16, 17, 19, 20, 26, 45, 50, 56, 57, 58, 65
	Sr	*Salix rorida* community	7, 10
	Sp	*Salix purpurea* var. *japonica* community	41, 43, 44
	Sgl	*Salix glandulosa* community	18, 27

The valley forest which falls under the classification of hardwood forest occupied 65% (42 quadrats) of 65 quadrats and it included 17 plant communities as follows: *Maackia amurensis* community, *Betula davurica* community, *Quercus variabilis* community, *Pinus densiflora* community, *Pinus densiflora-Quercus aliena* community, *Quercus serrata* community, *Pinus densiflora-Quercus mongolica* community, *Pinus sargentii* community, *Meliosma oldhamii* community, *Pseudosasa japonica* community, *Quercus acutissima* community, *Styrax japonica* community, *Quercus acutissima-Quercus aliena* community, *Quercus aliena* community, *Pinus densiflora-Quercus variabilis* community, *Acer ginnala* community, and *Pinus densiflora-Quercus acutissima* community.

Q. serrata and *P. densiflora* which belong to valley forest are distributed around dry slopes and steep hillsides (Kil et al. 2000). These plant communities generally appear in the mid-upper stream section and are usually distributed around the area with high-water level (Lee 2004). However, it was found in the recent research that *Quercus,* a high frequency species in the valley forest, is suitable for the restoration of flood plains as they are densely distributed in the tree layer of potential natural stream vegetation in Korea (Kim et al. 2008). In addition, *Quercus* could even grow over two months of flooding period due to its high flooding tolerance as shown by the result of flooding test on six species of *Quercus* (Han et al. 2009). These researches show that *Quercus*, as known as valley forest trees, can live by the streamside and be used in restoring the streams.

The riparian forest which falls under the classification of softwood forest occupied 35% (23 quadrats) of 65 quadrats and it included 4 *Salix* plant communities as follows: *S. koreensis* community, *S. rorida* community, *S. purpurea* var. *japonica* community, *S. glandulosa* community. *Salix* plants are the most typical tree around the streams and have high adaptability to stream environment (Kim et al. 2014). They are highly frequent species in the riparian forest and they are included under the paraclimax forest which is sustained by regular flooding or perpetual community (Lee 2004).

The riparian forest can have herbaceous community or woody community form not only in mid·down stream but also on the sand alluvium of the slip off slope in the upper stream (Ahn et al. 2001, Lee et al. 2003, Song 2008). However, in this research, there were no vegetations on the sand alluvium of the research sites due to their poor water-holding capacity. It appears that this is due to short germinability (1 month) of *Salix* species and because they cannot germinate on dry grounds (Lee et al. 2003).

The features of *Salix* species are high dispersion capability and germination rate, fast early-growth speed, seedlings highly resistant to flooding and they invade quickly into bare grounds of the streamside developing a community (Ishikawa 1982). *Salix* species on the streamside had stronger root anchorage and had higher capacity to regenerate cut stems than *Populus* and *Alnus* (Karrenberg et al. 2003). Therefore, *Salix* species make vegetative propagation possible having an extensive ecological scope. Also, its branches and roots grow very fast even in the barren soil (Kim and Lee 1998). These characteristics allow them to adapt to regular, irregular floodings and other disturbances.

P. japonica, *Glycine soja*, *H. japonicus*, *Phaseolus nipponensis*, *Artemisia selengensis* coexisted in high density in the herbaceous layer and they were distributed in the mid·down stream area with the altitude of 167-196 m. The average gradient was as low as 14° and even flat in some areas and there were 11 appearing species on average.

The habitat of *Salix* species is known to have mud and sand in the soil (Niiyama 1987, Ahn et al. 2001) but the soil in the research sites were mostly mud. The research of Koh and Cho (2002) also states that perennial herb community and *Salix* community are formed in the downstream as mud and sand deposits acculturate which was in agreement with this research. In South Korea, representative trees of softwood land were *Alnus japonica*, *S. koreensis*, *S. subfragilis*, *S. chaenomeloides* and *S. dependens*, and ones of hardwood land were *Fraxinus rhynchophylla*, *Zelkova serrata*, *Celtis sinensis*, *Ulmus pumila* and *U. parvifolia* in the rivers (Lee and Kim 2005). This report is consistent with our result in terms of *Salix* in the riparian forest, but different with the respects of *Quercus* and *Pinus* in the valley forest of our study.

Community type by classification method

The result of TWINSPAN which was done in five phases using all the layers in order to analyze the community type of 21 plant communities examined from 65 quadrats (Fig. 1). In the first phase, plant communities had the eigenvalue of 0.7050. It was classified into two groups by *H. japonicus*, *P. japonica*, *S. koreensis*, *O. undulatifolius*, *L. obtusiloba* which are the indicator species.

O. undulatifolius and *L. obtusiloba* appeared in high frequency in group I whereas *H. japonicus*, *P. japonica* and *S. koreensisi* appeared in high frequency in group II. According to the research of Lee et al. (2000), the forest community of Ulleung-do island were classified into different groups of species depending on the site environment in

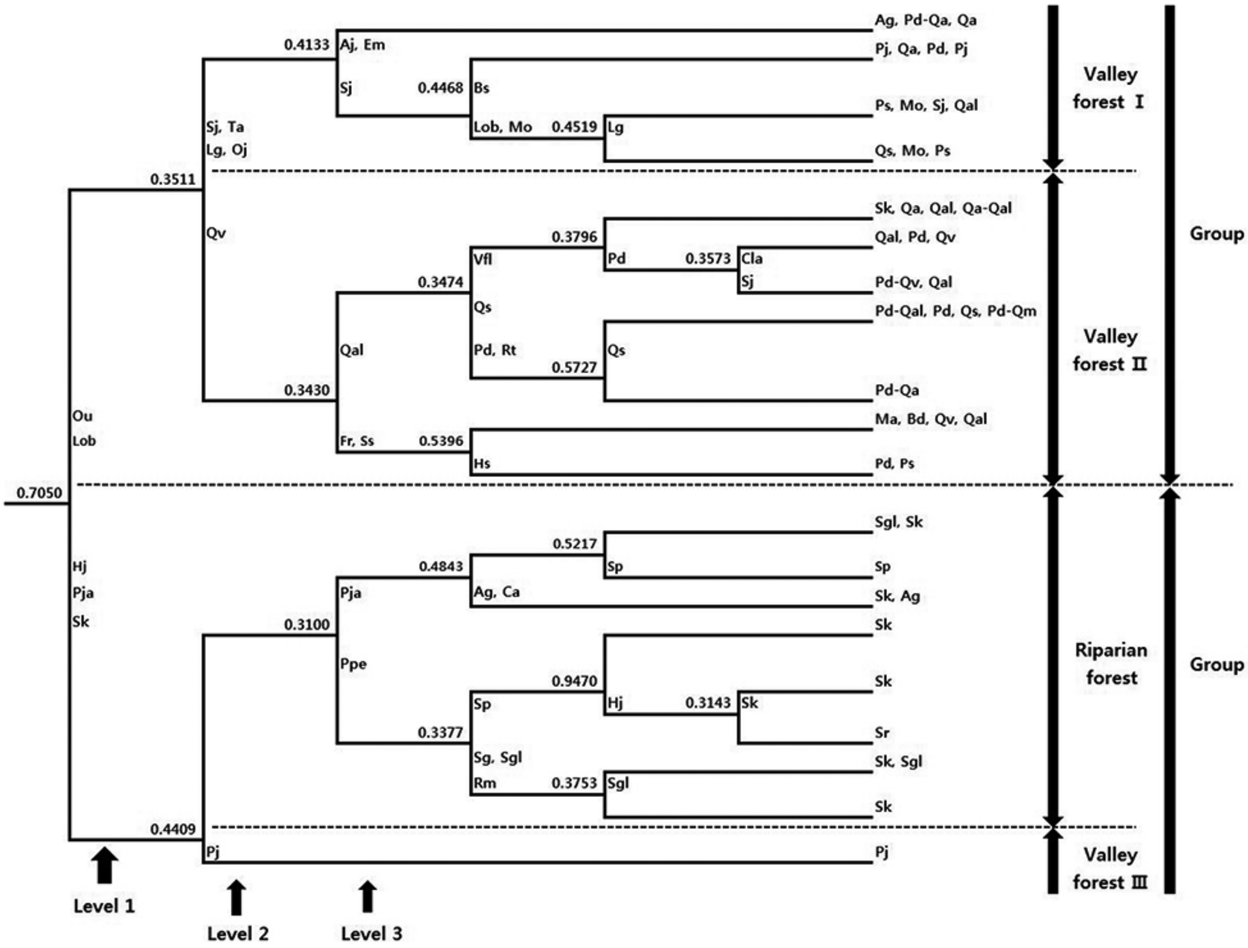

Fig. 1. Two-way indicator species analysis (TWINSPAN) of 21 plant communities (65 quadrats) using species of total layer. The numbers under the line indicate species abbreviation, the numbers on the line the eigenvalues for the division, and the numbers on right side are the plant community abbreviation. Ag, *Acer ginnala*; Aj, *Achyranthes japonica*; Bs, *Boehmeria spicata*; Bd, *Betula davurica*; Ca, *Clematis apiifolia*; Cla, *Carex lanceolata*; Em, *Elaeagnus multiflora*; Fr, *Fraxinus rhynchophylla*; Hj, *Humulus japonicus*; Hs, *Hydrangea serrata* for. *acuminata*; Lg, *Lindera glauca*; Lob, *Lindera obtusiloba*; Ma, *Maackia amurensis*; Mo, *Meliosma oldhamii*; Oj, *Ophiopogon japonicus*; Ou, *Oplismenus undulatifolius*; Pd, *Pinus densiflora*; Pj, *Pseudosasa japonica*; Pja, *Phragmites japonica*; Ppe, *Persicaria perfoliata*; Ps, *Prunus sargentii*; Qa, *Quercus acutissima*; Qal, *Quercus aliena*; Qm, *Quercus mongolica*; Qs, *Quercus serrata*; Qv, *Quercus variabilis*; Rm, *Rosa multiflora*; Rt, *Rhus trichocarpa*; Sg, *Salix gracilistyla*; Sgl, *Salix glandulosa*; Sj, *Styrax japonica*; Sk, *Salix koreensis*; Sp, *Salix purpurea* var. *japonica*; Sr, *Salix rorida*; Ss, *Smilax sieboldii*; Ta, *Trachelospermum asiaticum* var. *intermedium*; Vfl, *Vitis flexuosa*.

the TWINSPAN analysis. This research also classified the communities into valley forest and riparian forest which have different species composition.

There were 18 communities in group I as follows: *P. densiflora* community, *P. sargentii* community, *M. amurensis* community, *B. davurica* community, *Q. variabilis* community, *Q. aliena* community, *P. densiflora-Q. acutissima* community, *P. densiflora-Q. aliena* community, *Q. serrata* community, *P. densiflora-Q. mongolica* community, *P. densiflora-Q. variabilis* community, *Q. acutissima* community, *Q. acutissima-Q. aliena* community, *M. oldhamii* community, *S. japonica* community, *P. japonica* community, *A. ginnala* community and *S.koreensis* community. The dominant species of valley forest were *P. densiflora*, *Q.acutissima*, *Q. aliena* and *Lindera obtusiloba* which were found mostly in places further away from water (Kim et al. 2008, Han et al. 2013). They were dry-type natural deciduous forest that are usually found in the upper hillside and mountain ridges of relatively high altitude (Jin et al. 2002). *S. koreensis* community which falls under riparian forest was included in group I because the streamside and wetlands in the valley has perfect conditions for their growth due to high level of moisture (Niiyama 1990, Ottenbreit and Staniforth 1992).

There were six communities in group II as follows: *S. koreensis* community, *S. glandulosa* community, *S. rorida*

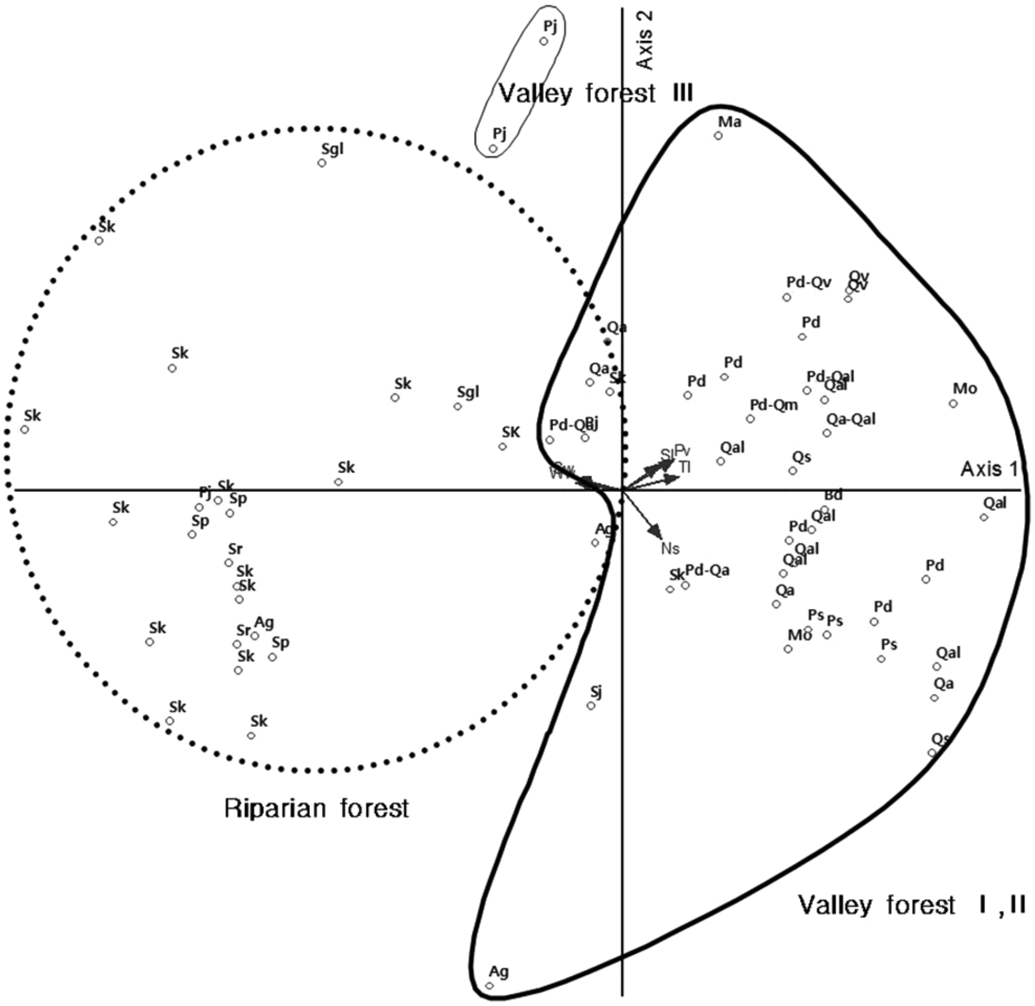

Fig. 2. Canonical correspondence analysis (CCA) ordination of 21 plant communities (65 quadrats) and environmental variables of riparian vegetation in studied sites. Al, altitude; Sl, stream gradient; Pv, percentage of vegetation cover; Tl, tree layer height; Ai, airt; Ns, number of appearance species; Ss, stream structure; Sw, stream width; Ww, waterway width.

community, *S. purpurea* var. *japonica* community, *A. ginnala* community and *P. japonica* community. However, all the communities were *Salix*, riparian forest, except *A. ginnala* community and *P. japonica* community. *Salix* plants take dominance in the transition process of riparian vegetation as they have high adaptability to stream environment if there aren't any particular disturbances (Kim et al. 2014). The dominant species of riparian forest were *P. japonica*, *Impatiens textori*, *A. princeps*, and *Carex dimorpholepis* which appear close to the water as shown in the research result of Kim et al. (2008) and Han et al. (2013). *A. ginnala* community has a characteristic of growing on mountain slopes (Kim 2008) that are less than 1,500 m above sea level, in the stream basin, and wetlands (Oh et al. 2004). It seems that *P. japonica* community was included in the second group as well because it was planted in the streamside.

In the second phase, group I with eigenvalue of 0.3511 was classified into valley forest I which had indicator species, *S. japonica*, *Trachelospermum asiaticum* var. *intermedium*, *L. glauca* and *Ophiopogon japonicus* appear in high frequency and into valley forest II which had *Q. variabilis* appear in high frequency. The group II with eigenvalue of 0.4409 was classified into riparian forest which had no appearance of indicator species, *P. japonica*, and into valley forest III which had the appearance of *P. japonica*.

In the third phase, valley forest I with eigenvalue of 0.4133 was classified into *Achyranthes japonica*, *Elaeagnus multiflora,* and *S. japonica*. The valley forest II with eigenvalue of 0.3430 was classified into *Q. aliena*, *Fraxinus rhynchophylla* and *Smilax sieboldii*. The riparian forest with eigenvalue of 0.3100 was classified into *P. japonica* and *Persicaria perfoliata*

The groups are classified up to five phases but rest of the phases were not interpreted as groups because subdividing the groups even further will lose the purpose and meaning of classification.

Correlation between plant communities and environmental factors

The group I (valley forest I, II), such as *Q. aliena* community and *P. densiflora* community, mainly appeared to the right of axis 2 and group II (riparian forest, valley forest III), such as *S. koreensis* community which is a stream tree with high flooding tolerance (Kim et al. 2014), mainly appeared on the left as shown in the ordination of plant communities by CCA (Fig. 2). The classification result of ordination method was very similar to the classification type (Fig. 1) done by using characteristic species.

The plant communities researched in the streamside was distributed according to nine environmental factors. The upper side of axis 1 seemed to be influenced by coverage of the tree layer, height of the tree layer, stream gradient, stream width, and waterway width but the lower side seemed to be influenced only by number of appearing species. It was found that the right side of the axis 2 was influenced by coverage of the tree layer, gradient, and number of appearing species but left side was influenced by stream width and waterway width (Fig. 2).

It was clear that there is a correlation between environmental factors and distribution of plant communities by looking at the correlation from axis 1 and 2 produced by CCA results and environmental factors. The forests were classified as valley forest and riparian forest depending on the site environment in this research and the environmental factors that influenced the distribution of plant communities were number of appearing species, coverage of the tree layer, height of the tree layer, gradient, stream width, and waterway width. However, coordinates, altitude, and stream structure showed low correlation to the distribution of the plant community (Table 2).

Table 2. Correlations for 9 environmental variables

Variables	Correlations	
	Axis 1	Axis 2
Altitude	0.064	0.332
Stream gradient	0.621	0.303
Percentage of vegetation coverage	0.844	0.341
Tree layer height	0.949	0.164
Airt	0.056	0.179
Number of appearing species	0.644	-0.515
Stream structure	0.314	0.369
Stream width	-0.800	0.146
Waterway width	-0.789	0.101

Generally, the ordination of stand has tendency of being controlled by the water and topographical factors such as altitude and slope (Eom et al. 2004). An important environmental factor that influenced the distribution of vegetation was topography and altitude above sea level in the research conducted by Song et al. (1992) and Yun and Hong (2000). It seems that reason for this is because the species composition differs in the forest vegetation depending on the altitude but species composition differs according to number of flooding days in the stream vegetation.

Lee and Cho (2000) stated that factors which affect spatial distribution of forest vegetation in the temperate deciduous forest are topographical factors (altitude, gradient), thickness of litter layer, soil moisture and relative luminosity. Lee et al. (2001) stated that environmental factors that affect the distribution of *Salix* are soil texture of sediments, water content, total nitrogen content, altitude, and average annual temperature. Han et al. (2013) stated that there is a significance in the fact that heterogeneity of the streamside plant community has varying moisture gradient of soil and flooding area according to the gradient. In addition, Kim et al. (2011) published in his work that *Q. serrata* takes the dominance on the site with the waterway width of less than 20 m and stated that *Salix* takes the dominance on the site with waterway width of 20-100 m and exceeding 100 m. In comparison to precedent studies mentioned above, the effect of gradient and stream width on the distribution of plant community was in congruence but altitude above sea level was not in agreement as it did not have an effect.

In conclusion, the features of natural streamside valley forests are high gradient, high coverage of tree layer, high height of tree layer, and high number of appearing species whereas the features of riparian forests are wide stream width and wide waterway width.

ACKNOWLEDGEMENTS

This work was sopported by the research grant of the Kongju National University (research number 2015-0064-01).

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