

SHORT COMMUNICATION

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Temporal and spatial variations of vegetation in a riparian zone of South Korea

Hyekyung Park¹ and Jae Geun Kim^{1,2*}

Abstract

Understanding vegetation structure and the relationship with environmental factors has been crucial for restoration and conservation of riparian zones. In this study, we conducted field survey in a riparian zone of Namhan River in South Korea both before and after flooding in order to understand temporal and spatial variations of riparian vegetation. There were significant temporal and spatial variations in species composition, and distribution patterns of vegetation were different along a gradient of elevation above the water level. At low elevation, *Zizania latifolia* was dominant throughout the field survey periods, and *Bidens frondosa* began to grow late and dominated both in post-flooding 1 and 2. Prior to flooding, *Scirpus radicans* and *Polygonum thunbergii* were widely distributed at middle elevation, while *Artemisia vulgaris*, *Phragmites australis*, and *Miscanthus sacchariflorus* were dominant at high elevation. After flooding, *P. thunbergii* was dominant at middle elevation with most other species decreasing, and more invasive or pioneer plants, including *Artemisia princeps*, *H. scandens*, and *Sicyos angulatus*, were observed at high elevation. Species composition and distribution patterns were homogeneous at low elevation, whereas dynamic variations of vegetation were observed both temporally and spatially at higher elevations. Elevation and distance from the water front were the most principal factors governing vegetation structure. Furthermore, soil physicochemical properties were also found to determine species composition and distribution patterns. These results indicate that vegetation structure in the riparian zones is formed by the combined effects of hydrological regime and soil physicochemical properties, inherent characteristics of species, and interspecific competition. Understanding of temporal and spatial variations of riparian vegetation may provide useful insights into ecological restoration and conservation of the vegetation within the riparian zones.

Keywords: Distribution pattern, Elevation, Flooding, Hydrological Gradient, Species composition

Background

Riparian zones, occurring as ecotones between terrestrial and aquatic ecosystems, are featured by unique environmental gradients. Vegetation structure of a riparian zone is a reflection of such gradients (Naiman et al. 2005). By serving as biological buffers, riparian vegetation is essential for providing habitats, reducing erosion, maintaining stream channel morphology, and improving water

quality (Knight and Bottorff 1984, Darby 1999, Tabacchi et al. 2000, Dosskey et al. 2010). It has been crucial to understand distinctive characteristics of vegetation structure and the relationship with environmental factors for restoration and conservation of riparian zones (Fail et al. 1987, Pennington et al. 2008).

Hydrological gradient is inferred as a primary factor governing riparian vegetation (Auble et al. 2005, Chen et al. 2015). In riparian zones, flooding is the most important disturbance controlling the establishment and development of vegetation (Ferreira and Stohlgren 1999, Casanova and Brock 2000). Flood pulses vary in their

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seasonal timing, frequency, duration, and magnitude. Elevation above the water level and distance from the water front reflect such characteristics of flooding thereby creating temporal and spatial gradients of hydrological regime. Plants inhabiting riparian zones either have a remarkable tolerance of flooding via physiological or morphological traits (Vandersande et al. 2001, Parolin 2002, Xiaoling et al. 2011) or avoid the effects of flooding through timing of life cycle (Blom and Voeselek 1996). Species composition and distribution patterns in riparian zones therefore reflect hydrological regime and species differences in tolerance to drought or floods (Shafroth et al. 2002, Auble et al. 2005, Capon 2005).

Besides, the gradients of soil environments are also important in determining the vegetation structure (Nilsson et al. 1989). Flooding affects soil environments including organic matter content, soil particle distribution, and nutrient availability through sedimentation and change of oxygen availability (Baldwin and Mitchell 2000, Steiger et al. 2005, Polvi et al. 2011). Hefting et al. (2004) reported that in a riparian zone, groundwater table fluctuation was a key factor of the N cycle which regulates plant productivity. Jolley et al. (2010) found out changes in plant community composition across a gradient of increasing sedimentation rates in riparian forests. That is, changes in hydrological regime alter the soil environments, and thus may lead to shifts in vegetation structure. Furthermore, flooding is expected to change the main soil physicochemical properties affecting vegetation structure.

In this study, we conducted field survey in a riparian zone of Namhan River in South Korea both before and after flooding in order to understand temporal and spatial variations of riparian vegetation. The specific objectives of our study were (1) to determine temporal and spatial variations of species composition and distribution patterns of vegetation along the elevation above the water level and (2) to elucidate the major environmental factors determining vegetation structure.

Methods

Study site and field survey

Field survey was conducted in a riparian zone of Namhan River in Yeosu City, Gyeonggi Province, South Korea (37° 26' N, 127° 30' E) (Additional file 1: Figure S1). The site was upstream of Ipo Weir, and the river width was about 300 m. The site received 936 mm of rainfall between January and October 2019, and the temperature ranged from - 6.4 to 30.5 °C with the average temperature of 14.5 °C. The climate in this area is monsoonal with high rainfall during the summer in July (total rainfall 215.1 mm) and August (total rainfall 225.6 mm), which are almost 47% of the annual precipitation. Field survey was conducted prior to flooding (pre-flooding; 4–5 June 2019) and after flooding (post-flooding 1; 26–27 August 2019 and post-

flooding 2; 7 October 2019). In pre-flooding, total monthly rainfall was only 25.5 mm, and there were almost no variations in water level, whereas there were dynamic variations in water level before post-flooding 1 and post-flooding 2 (Additional file 1: Figure S2).

In the study site, six replicate permanent line transects were established perpendicular to the river channel, and five quadrats of 2.25 m² (1.5 m × 1.5 m) were established within each line transect (total 30 quadrats). For each quadrat, distance from the water front and elevation above the water level were measured. The elevation of quadrats adjacent to the river channel was set to 0 cm, and differences of elevation were measured using a clinometer. The distance and the relative elevation of a total of 30 quadrats varied from 0 to 10.5 m and 0 to 116 cm, respectively. Quadrats were classified into three different groups (hereafter, these are referred to as low, middle, and high elevation) according to their dominant vegetation cover. Low elevation ($n = 6$), located adjacent to the river channel (0 cm to the river), was dominated by obligate wetland plants, such as *Zizania latifolia*. Middle elevation ($n = 10$), located < 26 cm above the water level and < 6.5 m from the water front, was mostly dominated by *Polygonum thunbergii*. High elevation ($n = 14$), where distinctive plants dominated according to season, located 28–116 cm above the water level and 5.5–10.5 m from the water front.

Average height, density, and coverage of every species emerged in 1.5 m × 1.5 m quadrats were surveyed. Some immature or juvenile plants were identified only to the family level. According to the literature by Choung et al. (2012), plant species were classified into five categories based on the frequency of each species in its habitats as follows: obligate upland plant (OBU), facultative upland plant (FACU), facultative plant (FAC), facultative wetland plant (FACW), and obligate wetland plant (OBW). The obligate and facultative wetland plants were classified into hydrophyte and emergent macrophytes based on the degree of wetness of their habitats (Choung et al. 2012). As soils were not homogeneous within a quadrat, three soil samples at a depth of 0–20 cm from the soil top layer were randomly collected from each quadrat, obtaining a total of 90 soil samples for each survey period.

Soil physicochemical properties

Prior to analysis, soil samples were sieved through a 2-mm mesh (standard sieve #10) to remove any plant material or gravel, mixed thoroughly, and stored at 4 °C. Each 100 g of subsample was dried at 80 °C for soil texture analysis. The soil moisture content was measured based on the weight loss of soil dried at 105 °C in an oven for over 48 h, and the organic matter content was determined by loss of ignition (LOI) at 550 °C for 4 h (Boyle 2004). The soil pH and electric conductivity (EC)

were measured in a 1:5 (w/v) soil/deionized water suspension solution using a pH meter and a conductivity meter, respectively. Soil texture was determined using the hydrometer method and the soil texture triangle of USDA (Sheldrick and Wang 2007). $\text{NO}_3\text{-N}$ and $\text{NH}_4\text{-N}$ were extracted with 2 M KCl solution, and concentrations were measured using hydrazine method (Kamphake et al. 1967) and indo-phenol method (Murphy and Riley 1962), respectively. $\text{PO}_4\text{-P}$ concentration was determined using ascorbic acid reduction method (Solorzano 1969) after extraction with Bray No. 1 solution (Bray and Kurtz 1945). Exchangeable cation concentrations (K^+ , Na^+ , Ca^{2+} , and Mg^{2+}) were measured using an atomic absorption spectrometer (model AA240FS; Varian, USA) after extraction with 1 N ammonium acetate solution (Allen et al. 1974). All results were expressed on an oven dry soil basis.

Data analysis

The response of major species along a gradient of elevation was determined using a Huisman-Olff-Fresco (HOF) model (Huisman et al. 1993). HOF model comprises a hierarchical set of predetermined models with increasing complexity, and the best model is chosen by comparing a statistical information criterion including the goodness-of-fit and model complexity (Burnham and Anderson 2002). Coverage data were square root transformed, and total 7, 8, and 6 species were selected as major species based on their frequencies (more than 3 quadrats) and total coverage (above 100%) for pre-flooding, post-flooding 1, and post-flooding 2, respectively. Community classification was conducted using TWINSpan (Two-way indicator species analysis). The cut levels were selected as 2, 5, 10, and 20. Huisman-Olff-Fresco model and TWINSpan were performed using R version 3.6.1 with package eHOF (Jansen and Oksanen 2013) and twinspanR, respectively (R Core Team 2018). The relationships between vegetation and environmental factors were examined using the CANOCO for Windows 4.5 statistical package (Ter Braak and Smilauer 2002). Since preliminary analysis using detrended correspondence analysis (DCA) suggested a linear response by the species (the length of first axes = 0.65, 0.53, and 0.47 for pre-flooding, post-flooding 1, and post-flooding 2, respectively), a linear model with redundancy analysis (RDA) was carried out in order to analyze the relationship between vegetation and environmental factors. For this analysis, rare species, which appeared at only one quadrat for each period, were excluded to reduce their influence on the ordination. The Monte Carlo permutation test with 999 permutations was applied to identify the statistical significance of canonical axes and environmental factors to explain the variance of vegetation. Significance level was 0.05 for all performed statistical tests.

Results

Species composition and distribution patterns

In this study, vegetation structure was affected by flooding, resulting in temporal and spatial variations. There was an obvious temporal variation in species composition (Fig. 1, Additional file 1: Table S1). *Zizania latifolia*, *Polygonum thunbergii*, and *Phragmites australis* were dominant throughout the field survey periods. Prior to flooding, *Scirpus radicans*, *Artemisia vulgaris*, *Galium spurium*, and *Miscanthus sacchariflorus* were dominant, while *M. sacchariflorus* was widely distributed until post-flooding 1. In post-flooding 1, *Actinostemma lobatum* and *Sicyos angulatus* were dominant. *Bidens frondosa* and *Humulus scandens* began to grow late and dominated both in post-flooding 1 and 2. In post-flooding 2, *Artemisia princeps* was dominant.

There were significant spatial variations in species composition and distribution patterns (Fig. 2, Additional file 1: Table S1). Spatial difference showed a clear relationship with the elevation above the water level. Prior to flooding, *Z. latifolia*, an obligate wetland plant, was widely distributed at low-lying areas, especially dominant at the elevation of 0 cm. *Scirpus radicans* was widely distributed below the elevation of 20 cm. *Polygonum thunbergii* and *A. vulgaris* were dominant within a range of elevations of 8–26 cm and 26–45 cm, respectively, which are periodically flooded. *Phragmites australis*, which is an obligate wetland plant, was widely distributed at elevations of 57–110 cm. *Miscanthus sacchariflorus* was observed above the elevation of 80 cm.

After flooding, species composition and distribution patterns have changed. *Zizania latifolia* and *B. frondosa* were constantly dominant at low elevation both in post-flooding 1 and 2. *Polygonum thunbergii* was dominant at middle elevation with most other species decreasing. *Phragmites australis* was widely distributed at high elevation. Invasive or pioneer plants, including *A. princeps*, *H. scandens*, and *S. angulatus*, were observed above the elevation of 28 cm. In post-flooding 2, *P. thunbergii* was still distributed over a wide range of periodically flooded areas. Obligate upland plants including *A. princeps* and *H. scandens* were widely distributed above the elevation of 19 cm, and *P. australis* was dominant above the elevation of 28 cm.

Relationship between vegetation and environmental factors

TWINSpan classified 30 quadrats of pre-flooding and post-flooding 1 and 2 into 6 (labeled A1–A6), 5 (labeled B1–B5), and 3 groups (labeled C1–C3), respectively (Fig. 3). A1 includes 6 quadrats dominated by *Z. latifolia* and was located at low elevation. Seven quadrats of A2 were dominated by *P. thunbergii* and were located at middle elevation. *Artemisia vulgaris*

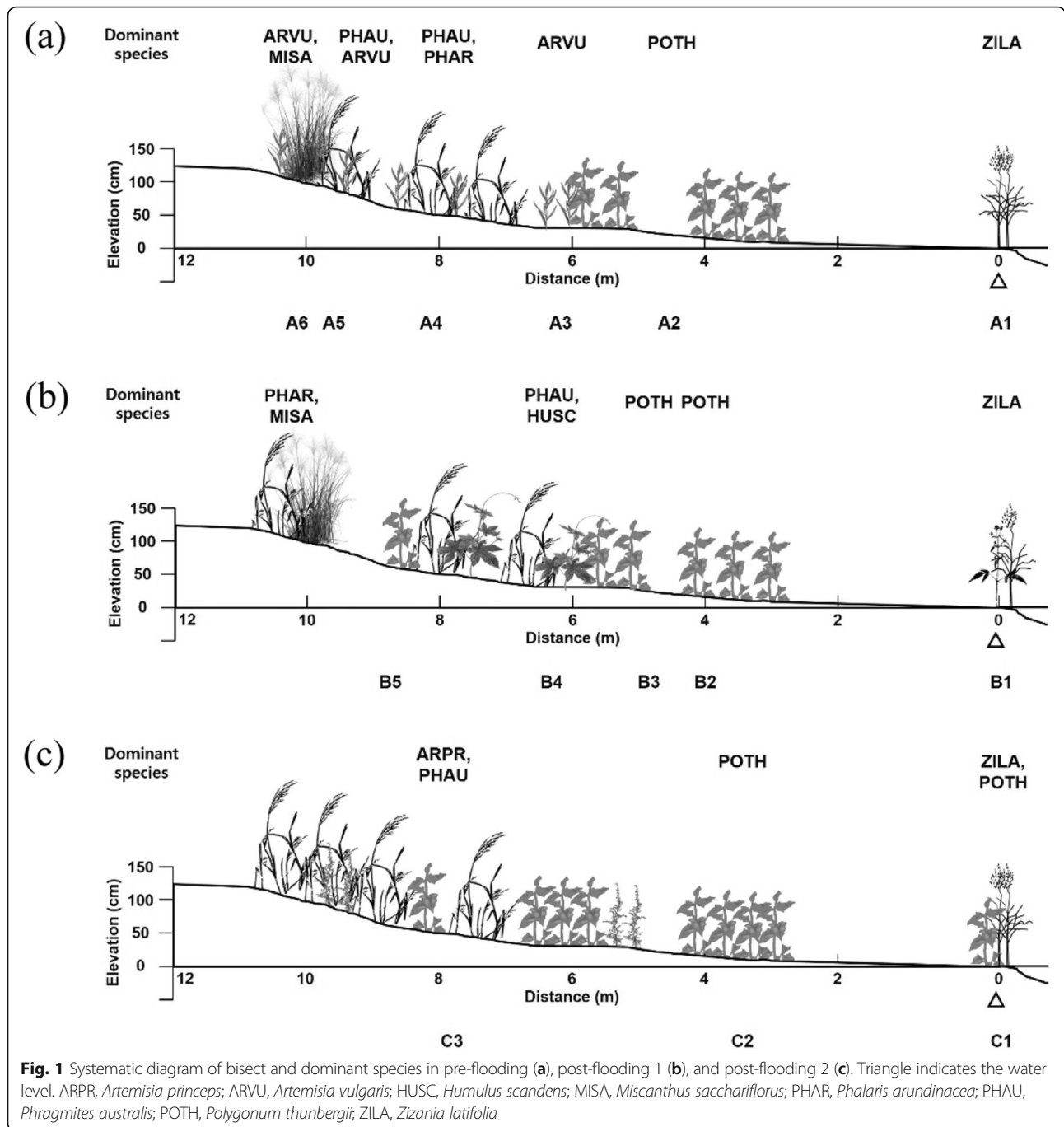


Fig. 1 Systematic diagram of bisect and dominant species in pre-flooding (a), post-flooding 1 (b), and post-flooding 2 (c). Triangle indicates the water level. ARPR, *Artemisia princeps*; ARVU, *Artemisia vulgaris*; HUSC, *Humulus scandens*; MISA, *Miscanthus sacchariflorus*; PHAR, *Phalaris arundinacea*; PHAU, *Phragmites australis*; POTH, *Polygonum thunbergii*; ZILA, *Zizania latifolia*

was a common species at A3, A4, A5, and A6, which were located at high elevation. A3 comprises 5 quadrats dominated by *A. vulgaris*. A4 includes 2 quadrats, where *P. australis*, *P. arundinacea*, and *A. vulgaris* were common species. Eight quadrats of A5 were closely related to *A. vulgaris*, *P. australis*, and *G. spurium*. A6 includes 2 quadrats, where *A. vulgaris* and *M. sacchariflorus* were common species.

After flooding, classification of vegetation changed. B1 includes 6 quadrats which were located at low elevation,

where *Z. latifolia* and *B. frondosa* were common species. B2 and B3 comprise 1 and 10 quadrats, respectively, dominated by *P. thunbergii*, and most of them were located at middle elevation. B4 includes 9 quadrats dominated by *P. australis* and *H. scandens*. Four quadrats of B5 were closely related to *P. australis* and *M. sacchariflorus*. The most common species in C1, including 8 quadrats, were *Zizania latifolia*, *B. frondosa*, and *P. thunbergii*. Eleven quadrats of C2 were dominated by *P. thunbergii*, where *H. scandens* was a common species.

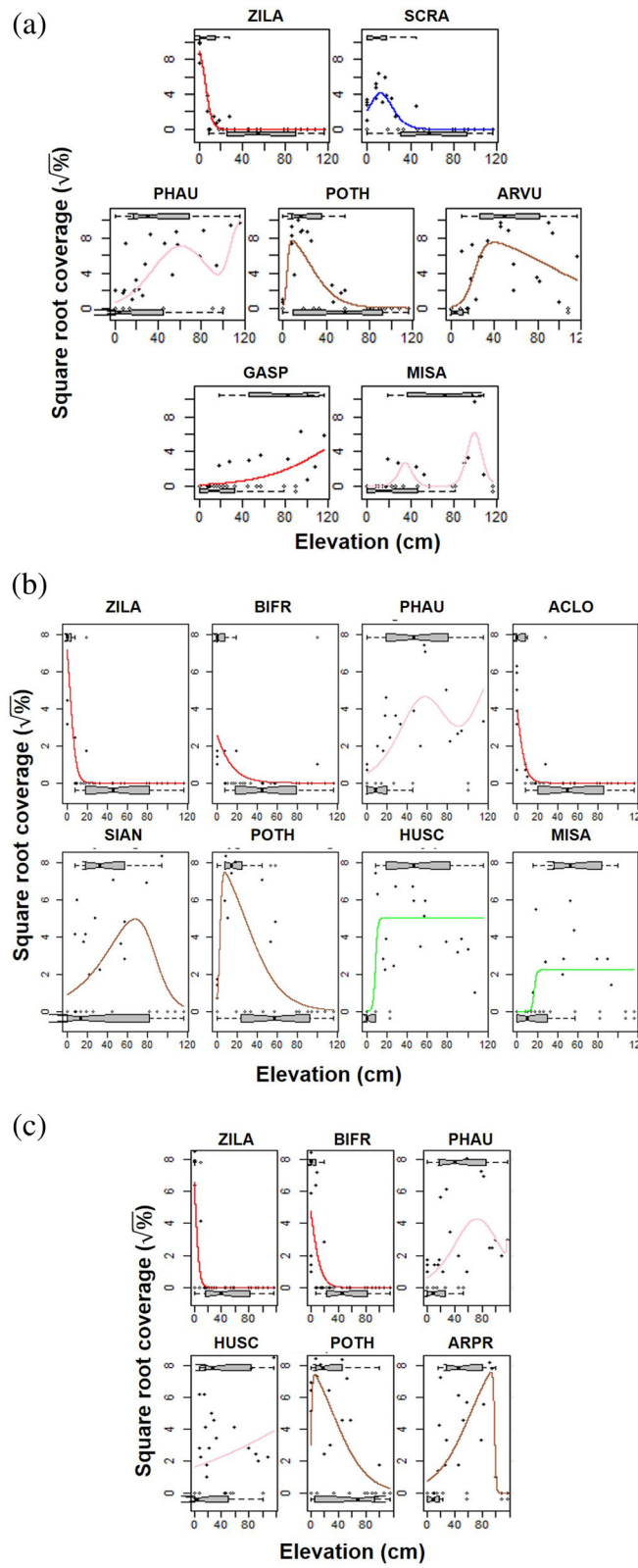


Fig. 2 (See legend on next page.)

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Fig. 2 Huisman-Olff-Fresco (HOF) analysis of species coverage data (square root transformed) of the most abundant species with respect to elevation in pre-flooding (a), post-flooding 1 (b), and post-flooding 2 (c). ACLO, *Actinostemma lobatum*; ARPR, *Artemisia princeps*; ARVU, *Artemisia vulgaris*; BIFR, *Bidens frondosa*; GASP, *Galium spurium*; HUSC, *Humulus scandens*; MISA, *Miscanthus sacchariflorus*; PHAU, *Phragmites australis*; POTH, *Polygonum thunbergii*; SIAN, *Sicyos angulatus*; ZILA, *Zizania latifolia*

C3 includes 11 quadrats, where *P. australis* and *A. princeps* were common species.

The redundancy analysis (RDA) ordination displayed scores for all of the quadrats with the arrows indicating the relative directions and strengths of the gradients of environmental factors (Fig. 4). When plotted on the RDA ordination axes, the quadrats tended to be separated into the vegetation community resulted from TWINSPAN. Furthermore, RDA showed clear separation of the quadrats according to the elevation (low, middle, and high). The first two axes explained 55.3%, 43.7%, and 42.6% of the variance in pre-flooding, post-flooding 1, and post-flooding 2, respectively. Distance and elevation were the most principal factors determining vegetation for all periods. Prior to flooding, moisture content was the most primary factors explaining 27% of the variation (Monte Carlo permutation test with 999 permutations, $F = 10.5$, $p < 0.001$), followed by distance and elevation explaining 16% ($F = 7.47$, $p < 0.001$) and 8% ($F = 4.19$, $p < 0.01$), respectively (Fig. 4a). Furthermore, organic matter content, sand content, and Na^+ concentration could explain 7% ($F = 3.95$, $p < 0.01$), 4% ($F = 2.84$, $p < 0.05$), and 4% ($F = 2.37$, $p < 0.05$) of the variation, respectively. After flooding, main factors responsible for the variation of vegetation changed. The RDA of post-flooding 1 indicated that distance and elevation were still the most primary factors explaining 20% ($F = 6.79$, $p < 0.001$) and 17% ($F = 7.43$, $p < 0.001$) of the variation, respectively (Fig. 4b). Ca^{2+} and $\text{PO}_4\text{-P}$ concentrations could explain 8% ($F = 4.06$, $p < 0.01$) and 7% ($F = 3.32$, $p < 0.01$), respectively. The RDA of post-flooding 2 revealed that organic matter content was the most principal factor explaining 25% ($F = 9.51$, $p < 0.001$) of the variation, followed by distance and elevation explaining 15% ($F = 6.38$, $p < 0.001$) and 5% ($F = 2.38$, $p < 0.05$), respectively (Fig. 4c).

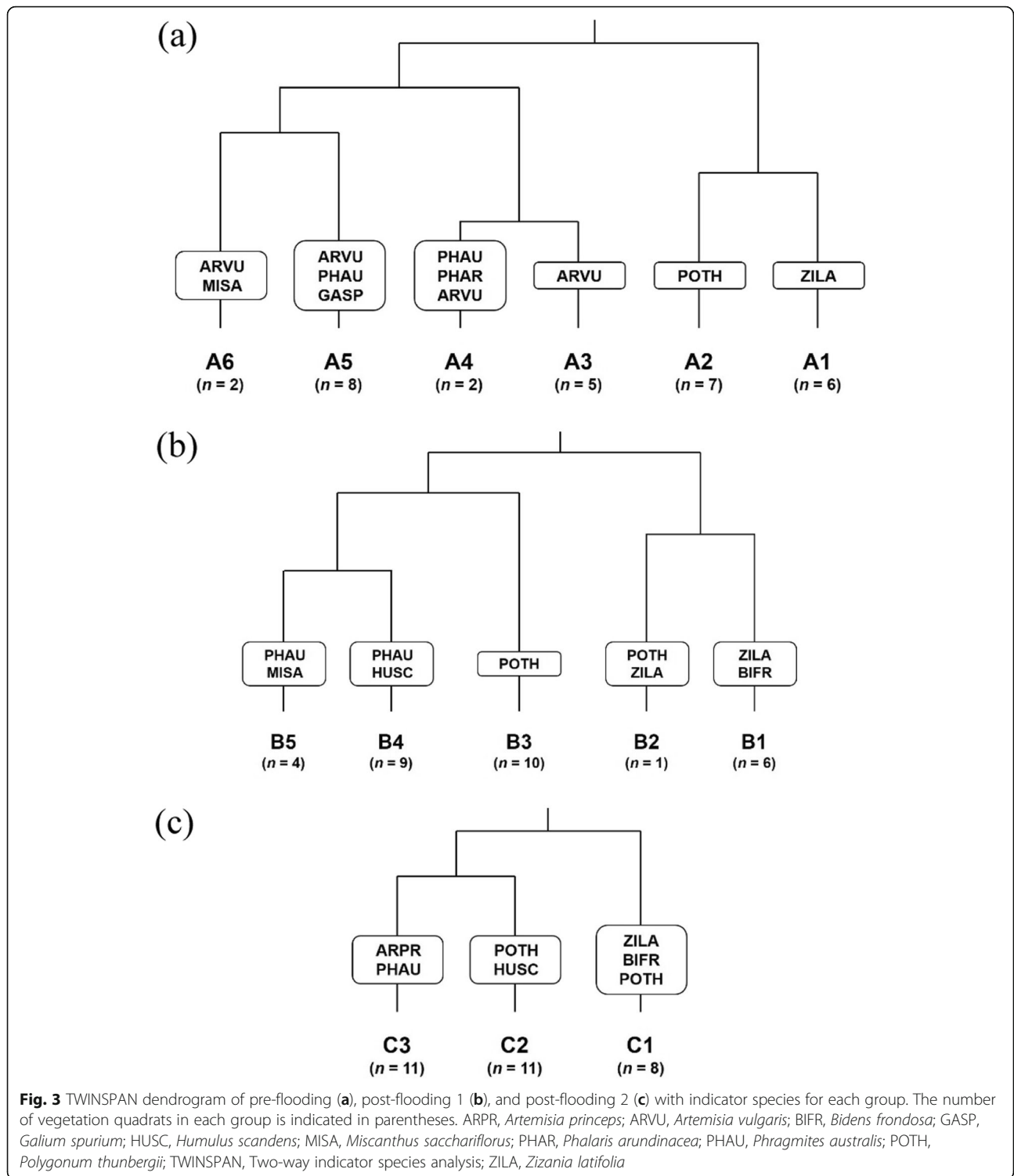
Discussion

In the riparian zone, topographic factors including elevation above the water level and distance from the water front were major factors affecting hydrological characteristics. As elevation and distance increase away from the water front, frequency, duration, and magnitude of flooding decrease. Such hydrological regime is a major determinant of species composition and distribution patterns in the riparian zone (Casanova and Brock 2000). In other words, variations in elevation and distance create spatial differences in hydrological regime, and the

hydrological gradients control the establishment and development of vegetation in the riparian zone (Ferreira and Stohlgren 1999, Casanova and Brock 2000).

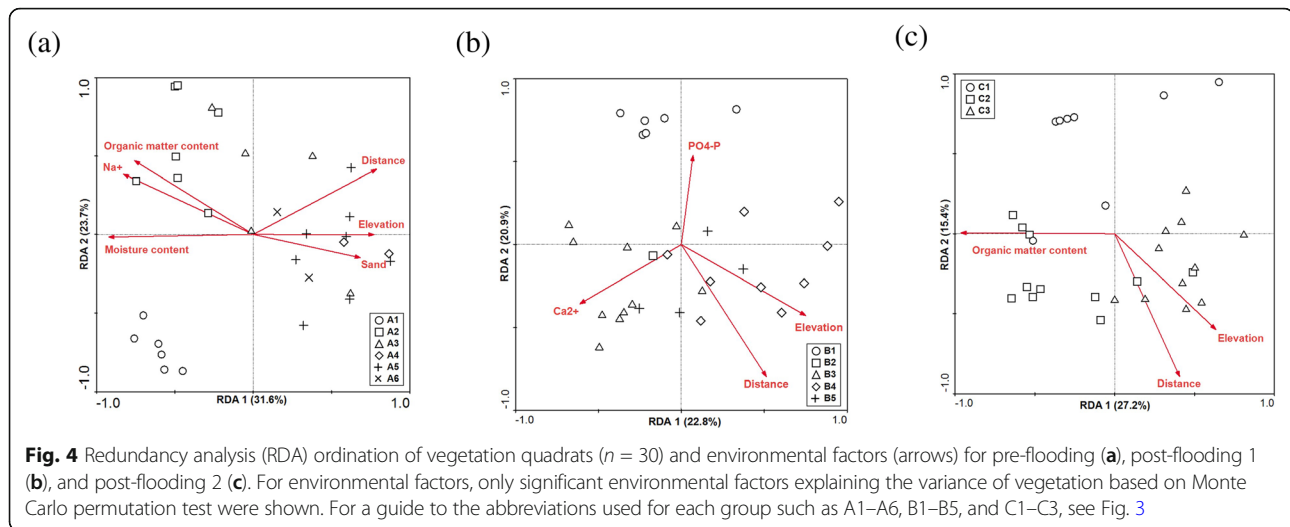
Elevation from the water level and distance from the water front were the most primary factors determining species composition and distribution patterns. The riparian vegetation exhibited a zonation pattern perpendicular to the river channel, resulting in spatial variation of vegetation along the elevation. Zonation of vegetation is determined by hydrological regime and inherent characteristics of species, especially species differences in tolerance to floods or droughts (Shafroth et al. 2002, Auble et al. 2005). Low elevation sites, which tend to be permanently or periodically flooded, were dominated by a single species tolerant to floods, such as *Z. latifolia* and *P. thunbergii*. The growth of *Z. latifolia* responded positively to high water level (Byun et al. 2017), and it could survive in deep water up to 60 cm above the soil surface and grow well in shallow water, up to 30 cm (Yamasaki and Tange 1981). *Polygonum thunbergii* could survive as creeping stems, which are parallel with the water flow and firmly fixed to the ground, making new shoots rapidly resulting in recovery of their biomass after flooding (Kim et al. 2012). Also, simple flooding during early or late vegetative growth did not affect the formation of amphicarpic seeds as well as vegetative parts (Choo et al. 2014). *Miscanthus sacchariflorus*, which is known to be a resister against flooding by standing rather than being fallen, was widely observed at high elevation both in pre-flooding and post-flooding 1 (Cho and Cho 2005). On the contrary, obligate upland plants intolerant to flooding, such as *A. princeps*, *G. max* subsp. *soja*, and *H. scandens*, were widely distributed at high elevation. Such obligate upland plants are intolerant of flooding and die following long periods of flooding (Capon 2003). Invasive species, including *H. scandens* and *S. angulatus*, were also observed at higher elevation. At lower elevation, constant flooding disturbance might have suppressed invasive species, while at middle species, in which species composition was complex and various, native species utilize limited resources more completely, thus preventing invasion (McNaughton 1983).

Species composition and distribution patterns were homogeneous at low elevation, and dominant species did not change significantly over period. In contrast, dynamic variations of vegetation were observed both temporally and spatially at higher elevations. These findings are consistent with previous studies showing the



homogeneity of vegetation at low elevation, and the wide range of variations found at higher elevation (Nakamura et al. 1997, Capon 2005, Jager et al. 2012). Since only a few species tolerant to flooding are able to dominate low-lying area, which experience high stress of flooding disturbance, there is less competition from other species

resulting in the homogeneity of vegetation. High elevation with low flooding disturbance, however, may enable various species to establish. Therefore, biotic factors, such as competition, are likely to be more important in determining species composition at high elevation (Blom et al. 1990).



In addition to the effects of hydrological gradient, soil physicochemical properties could affect riparian vegetation. Topographic factors including the elevation above the water level and the distance from the water front create heterogeneity of soil physicochemical properties which has an effect on the vegetation structure (Vivian-Smith 1997). In this study, based on RDA, moisture content, organic matter content, pH, EC, and nutrient availability were found to govern species composition and distribution patterns, and flooding altered the principal factors governing vegetation structure (Fig. 4). Moisture content was the primary factor driving vegetation patterns in a riparian zone as shown in other studies (Xu et al. 2015). Variations in soil moisture content are due to elevation above the water level and distance from the water front. Many previous studies have reported that hydrological gradient including soil moisture content and water depth along the elevation was the primary factor determining vegetation (van Coller et al. 2000, Hupp and Rinaldi 2007, Yabe and Onimaru 2009). Several other soil physicochemical properties other than soil moisture content, such as organic matter content (Eskelinen et al. 2009), pH (Asada 2002), EC (Ladenburger et al. 2006), and nutrient availability (Wassen et al. 2003) also affected species composition and distribution patterns of vegetation, which is consistent with previous studies. In other words, variations in vegetation are formed by the combined effects of hydrological gradient and variations in soil physicochemical properties.

These results suggested that a better understanding of riparian vegetation requires a synthesis of all of the environmental factors including hydrological regime and soil physicochemical properties, inherent characteristics of species, and interspecific competition.

Understanding of temporal and spatial variations in riparian vegetation would ultimately contribute to improved understanding of dynamics of riparian zones. This study may provide useful insights into ecological restoration and conservation of the vegetation within the riparian zones.

Conclusions

In this study, we conducted field survey in a riparian zone of Namhan River in South Korea both before and after flooding in order to understand temporal and spatial variations of riparian vegetation. Flooding induced variations of hydrological regime leading to variations of vegetation. There were significant temporal and spatial variations in species composition, and distribution patterns of vegetation were different along a gradient of elevation from the water level. Low elevation sites, which tend to be permanently or periodically flooded, were dominated by a single species tolerant to floods, such as *Z. latifolia* and *P. thunbergii*. On the contrary, obligate upland plants intolerant to flooding, such as *A. princeps*, *G. max* subsp. *soja*, and *H. scandens*, were widely distributed at high elevation. Invasive species including *H. scandens* and *S. angulatus* were also observed at higher elevation. Species composition and distribution patterns were homogeneous at low elevation, whereas dynamic variations of vegetation were observed both temporally and spatially at higher elevations. In addition to topography including elevation and distance, soil physicochemical properties such as moisture content, organic matter content, pH, EC, and nutrient availability were also found to determine species composition and distribution patterns. These results indicated that vegetation structure in the riparian zones is formed by the combined effects of

all of the environmental factors including hydrological regime and soil physicochemical properties, inherent characteristics of species, and interspecific competition. Understanding of temporal and spatial variations in riparian vegetation may provide useful insights into ecological restoration and conservation of the vegetation within the riparian zones.

Supplementary information

Supplementary information accompanies this paper at <https://doi.org/10.1186/s41610-020-00152-z>.

Additional file 1: Table S1. List of species observed at each elevation (low, middle, and high) in pre-flooding, post-flooding 1, and post-flooding 2 in the studied riparian zone. **Figure S1.** The map of study site and schematic diagram of field survey. **Figure S2.** Variations of water level from January to October 2019 at the study site.

Abbreviations

ACLO: *Actinostemma lobatum*; ARPR: *Artemisia princeps*; ARVU: *Artemisia vulgaris*; BIFR: *Bidens frondosa*; DCA: Detrended correspondence analysis; EC: Electric conductivity; EMER: Emergent macrophytes; FAC: Facultative plant; FACU: Facultative upland plant; FACW: Facultative wetland plant; GASP: *Galium spurium*; H: High elevation; HOF: Huisman-Olff-Fresco; HUSC: *Humulus scandens*; HYG: Hygrophyte; L: Low elevation; M: Middle elevation; MISA: *Miscanthus sacchariflorus*; OBU: Obligate upland plant; OBW: Obligate wetland plant; PHAR: *Phalaris arundinacea*; PHAU: *Phragmites australis*; POTH: *Polygonum thunbergii*; RDA: Redundancy analysis; SIAN: *Sicyos angulatus*; TWINSpan: Two-way indicator species analysis; ZILA: *Zizania latifolia*

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Authors' contributions

HP performed the field survey, analyzed experimental data, and wrote the manuscript draft. JGK conceived the research idea and edited the manuscript. The authors read and approved the final manuscript.

Availability of data and materials

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

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